Across the first frontier: The behavioural ecology of the Sydney region aborigines

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Across the First Frontier:
The Behavioural Ecology of the Sydney Region Aborigines

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ABSTRACT

This study represents a contribution in support of the use of optimality theory in human adaptational research. Optimal foraging theory is used to construct a model of the behaviour that an efficient human predator might be expected to have displayed in the Sydney region prior to 1788 and the arrival of the Europeans. This model is tested against the locational characteristics of archaeological and art sites which are assumed to be analogues of the distribution of two separate areas of Aboriginal behaviour. The results of this comparative study and subsequent statistical analysis (based solely upon archaeological data) clearly demonstrate that the Aboriginal population of the Sydney region tended to behave optimally with regard to the cost/benefit ranking of patches. Information about Aboriginal behaviour from the records of the First Fleet (1788) is used as an independent test of the degree of fit between the behavioural model and the archaeological data. Conclusions drawn from this test support the results of the statistical analysis in general, but also reveal some of the limitations of the use of models derived from animal ecology in the study of man.

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I must end these acknowledgements with four notes of debt.

Firstly, the title of this thesis 'Across the First Frontier' is a wholly appropriate amalgamation of the titles of two admirable books which have viewed the frontier from different perspectives - Henry Reynold's "The Other Side of the Frontier" and T.M. Perry's "The First Frontier".

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To these three I dedicate this thesis.

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1 CHAPTER ONE:

MAN, LAND, ADAPTATION AND AUSTRALIA

In this chapter the bases and characteristics of the whole thesis are introduced in four parts. The first concerns the history of the study of man-land relationships in anthropology and charts the course of the development of an explanatory human ecology - a method of understanding man as an interacting part of nature. This discussion emphasizes: a) the superior explanatory qualities of optimality principles derived from evolutionary ecology in the study of human adaptation; b) the central role of hunter-gatherers in that study and c) the value of optimality theory in the explanation of past human behaviour. In the second part, the limitations of optimality theory are examined, both in general and specifically with regard to the archaeological record. In the third part, the reasons for believing that Australia, and particularly the Sydney region, are suitable testing grounds for assessing the usefulness of optimality theory in human adaptational research are introduced. Finally, the specific aims and the organization of the thesis are described.

1.1 ANTHROPOLOGY AND THE DEVELOPMENT OF HUMAN ECOLOGY

1.1.1 Introduction

The relationships between man and his 'environment' have been the subject of comment and philosophy since the days of Aristotle. Yet it was not until the works of Charles Darwin and Ernst Haeckel were published that the problems involved in these observed relationships became evident and the subject of intense research. This research sought to answer the question - if man does not hold a special place within nature, how should his relationship with the environment be considered; and throughout the development of the study, a corollary has been - can the observation of the behaviour of other animals help us to understand ourselves?

These questions eventually led to the development of a 'human ecology' - the study of man as part of the environment, but the initial response of anthropologists was in the tradition of the Ancients: to seek explanatory schemes for observed human behaviour of a mechanistic form (man as the product of his environment). As a consequence of this response, physical and social anthropology (and archaeology) were greatly influenced in their formative years by 'environmental determinism'.

Essentially, the determinist framework was concerned with uni-directional causation which could be determined through positivistic and statistical empiricism (see Ellen 1982). The subtlety with which environmental variables interact with social phenomena, at what we would understand today as a 'micro-ecological' level, could not be recognized - the environment was fragmented into coarse constituent variables which, it was hoped, might explain all (or almost all) observed cultural variation. In essence, the relationship between man and environment was perceived not as one of interaction but as one of conflict - 'culture' versus 'environment'. As a consequence of the use of such gross conceptual and physical characteristics the results of analyses tended to produce gross and unhelpful answers (Geertz 1963:1; Vayda 1965:3).

In addition, it became increasingly clear that man could not be viewed as simply a product of his environment, for much of that environment was clearly of his making. Indeed, the conceptual difficulties of incorporating such anthropogenic factors into the environmentalist framework were a principal factor in its demise and a principal cause of the somewhat reactionary form (from the perspective of an explanatory human ecology) of the succeeding possibilist framework. For, particularly through the work of Wissler (1929), the study of man-land relationships increasingly developed towards the notion of environment as a passive limiting agency ('environmental possibilism').

The possibilism of Boas, Kroeber and Lowie was one in which the organic was constant and culture - the superorganic (Kroeber 1917) - was a thing _sui generis_. Cultures, environments and histories were thought of as so variable that any generalization concerning their relationship would be at best hazardous (Ellen 1982:24). As a result, the ecological component of anthropological study became largely neglected in ethnography - it became a footnote, an appendix or an introductory chapter presented _in vacuo_. From the point of view of the development of an explanatory human ecology, the only value of possibilism and the closely associated 'culture area approach' of Wissler (1926), Kroeber (1939) and Forde (1934), with its conception of broad constraints upon culture, lay in the development of an understanding of the dangers of seeking simple environmental controls.

The genesis of the modern study of man-environment relationships within a truly ecological framework is particularly associated with the work of Julian Steward (1955, 1977), which was subsequently developed into 'cultural ecology' (Vayda 1969; Rappaport 1967). Steward sought systematic ways of studying the man-land relationship through intervening variables - technology, material culture and economic transactions. Essentially, this approach avoided the superficiality of determinism and the general poverty of the possibilist approach as explanatory methods in the study of the relationship.

The new research paid both careful attention to empirical details, and also to causal links with the 'cognized environment' (though Steward did not use the term; see Moran 1984b:8). Through these parts of environment and parts of culture, man could be seen to <u>interact</u> with his environment. However, attempts to utilize Steward's research strategy, which had been formulated using inadequate ethnographic literature (Ellen 1982:63), led to large scale modifications (including the 'cultural materialism' of Marvin Harris (1968)); and in practice, Steward's concept of the 'culture core' was shown to underestimate the scope, complexity, variability and subtlety of both environmental and social systems (Geertz 1963; Moran 1984b). In addition, the comparison of societies across time and space, in search of causal explanations, could be shown to be flawed (Rappaport 1968).

The major consequence for the anthropological discipline of this discovery (and a concurrent increase in the influence of European sociologists) was that it led social anthropologists toward the view that human behaviour owed little to 'environmental factors' (Harris 1968). Ironically, one of the major faults of the Stewardian approach was that while he emphasized the ecological formulation, he actually considered human culture as being superorganic (and consequently not subject to the same selective pressures as other components of the natural system) - much in the manner of the environmentalists and possibilists. Subsequent developments in cultural anthropology entailed the rejection of this notion and a tendency towards a more clearly biological viewpoint (man as part of the environment) or 'ecological anthropology'.

Methodology and theory derived from the wider field of systems ecology (see Golley 1984), and particularly the ecosystem concept, have been widely used in pursuit of this anthropological sub-discipline - for example, by Geertz (1963), Vayda (1969) and Rappaport (1963) (see Moran (1984a) for examples of recent formulations). The ecosystem approach has been seen as singularly useful because "it expresses nature in physical mechanical terms, deemphasizes the biological-evolutionary aspect and links directly to computer science and information theory" (Golley 1984:43). Yet, despite the value of this approach as a rejection of the treatment of culture and environment as quite different spheres, there are inherent flaws within the technique, principally concerning the necessity of being able to close the ecosystem; and the level of naivety required of the investigator in order to form a system from what are usually severely limited data.

In a recent paper, Eric Smith (1984a) has made a more fundamental criticism of the ecosystem concept and its theoretical and methodological basis. He sees the ecosystem approach as making but "a limited contribution to anthropology" (and hence to an explanatory human ecology; op.cit:51), because it imposes a scale of analysis inappropriate for explaining man's behaviour; and because much of the recent use of the concept has been of a teleological nature, imputing behavioural strategies at the level of the ecosystem - a notion which is incompatible with our present state of knowledge concerning evolutionary mechanisms. As a consequence, Smith considers that the systems ecology framework, as a whole, offers little <u>explanatory</u> utility for anthropology as a basis for the understanding of behavioural diversity within or between human societies (op.cit:56).

However, in the same paper, Smith charts the course of a second branch of general ecology which has been largely ignored by anthropologists until relatively recently - <u>evolutionary ecology</u>. This is a body of theory based upon neo-Darwinian premises (see Smith 1984b; Foley 1985; Smith & Winterhalder 1981), which has a far greater explanatory potential for anthropology than any of the preceding intellectual frameworks. For all the aspects of ecology in anthropology introduced above - 'cultural ecology' (Steward 1955, 1977; Netting 1971) and 'ecological anthropology' (Rappaport 1971) - have in common the presentation of normative descriptions of common-sense ecological features - the environment is presented as a static background characterized by averaging statistics (Winterhalder 1980b:136). Evolutionary ecology, in contrast, produces heuristic models incorporating environmental variables couched in terms of spatial pattern, temporal fluctuation and quantity. The key concept within evolutionary ecology is adaptive strategy and the theory's major assumption is that organisms attempt to achieve time and energetic efficiency in exploiting resources. Unlike cultural ecology, which assumes long-term equilibrium through negative feedback between a human population and the environment, evolutionary ecology recognizes that humans often change environments through exploitation. In addition, because it assumes that goals and purposes reside only in individuals, it does not confuse levels or involve teleology.

This introduction to the history of ideas concerning the man-land relationship has demonstrated that the development of a theoretical background in anthropology suitable for the formation of an explanatory human ecology has taken a long time. Early attempts at establishing such a background were dogged by the notion of culture as superorganic - above and beyond the forces of nature - and it was only with the introduction into anthropology of methods derived from general ecology that the process really began. Systems ecology and the ecosystem concept - a method of expressing the idea that 'everything is related to everything else' (Golley 1984:43) - provided cultural ecology with an empirical methodology of dubious value, but more importantly provides little in the way of explanatory utility to the study of human adaptations. However, evolutionary ecology (or socioecology (Winterhalder and Smith 1981)), escapes the pitfalls of the cultural ecology approach (see Peoples

1984:408) through its basis in neo-Darwinian principles, its focus upon the individual and its consequent avoidance of the misguiding influences of teleology and assertions of equilibrium.

The potential of optimality principles in the forming of an explanatory human ecology have been most clearly established in relation to a sub-set of principles referred to as <u>optimal foraging theory</u> (MacArthur and Pianka 1966; see also Pyke et al.(1977), Pianka (1978) & Krebs and Davies (1981) concerning later developments of the initial formulation). This thesis forms a contribution to this body of supportive material, for it also employs optimal foraging theory in order to better understand the behaviour of a hunter-gatherer group - the Aborigines of the Sydney region. However, while optimal foraging theory has been tested, for the most part, upon extant hunter-gatherer groups (see Winterhalder & Smith 1981), here the theory is applied to a group represented only by archaeological sites and early contact history (for other archaeological applications see, in particular, Yesner 1981; Perlman 1976, 1980).

This thesis (like most of these recent human optimal foraging studies) fits into a long history of the use of hunter-gatherer populations to test theories in anthropology. As a consequence of this emphasis, in the next section the reasons why these peoples have been the centre of research, and the differences in the characteristics of extant and extinct hunter-gatherer groups are examined.

1.1.2 The role of extant and extinct hunter-gatherers in the development of human ecology

When Steward constructed the basis of cultural ecology, he applied it to hunter-gatherers. For then, as now, a fundamental assumption in anthropology was that among hunter-gatherer cultures, environment and subsistence adaptation are inextricably linked (Service 1962, 1966; Steward 1938); and that almost every aspect of hunter-gatherer culture must be studied in full knowledge of the technological/environmental context (Willey & Sabloff 1974).[1]

However, owing to the lack of a general unifying theory, research in cultural ecology (and other analyses utilizing systems ecology) has been based simply upon the assumption that hunter-gatherers adapt to their environments and that this process is constrained and directed sufficiently to produce an optimal solution under any given circumstance. From this perspective, the anthropologist's task is to infer and describe behaviour and then offer explanations as to how this behaviour accomplishes its presumed adaptive functions (Bettinger 1980:194). (As a closely related point, Bettinger (op.cit:195) suggests that, one of the reasons that much of the more advanced archaeological analyses of prehistoric hunter-gatherers have taken place in areas historically

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[1] The great number of ecological studies of extant hunter-gatherers from many different parts of the world bear witness to the generally accepted utility of hunter-gatherer studies in techno-environmental analyses, particularly in archaeological applications - see for example, in America: Balikci, 1970; In Africa: Lee 1968, 1969, 1972; Silberbauer 1981; Tanaka 1976; In Australia: Gould 1969; Peterson 1973; O'Connell and Hayden 1976. See Hayden (1981) for an overview.

inhabited by hunter-gatherers (for example Gould 1977; Thomas 1973; Jennings 1957) is because ethnographic models make it unnecessary to develop theoretical expectations of hunter-gatherer behaviour.)

The principal danger of this approach lies in the fact that one can never be certain that a specific behavioural trait is properly explained by a need it is thought to fulfil, since it is always possible that some other trait is fulfilling that need (Bettinger 1980:195; Orans 1975). It requires a greater degree of detail concerning the behaviour and a more general understanding of the relationship between the need and the behaviour than systems ecology can provide, to undertake the sort of cross-cultural comparison that might remove this ambiguity.

To move beyond merely plausible hypotheses requires general explanatory models and, because it is firmly based upon neo-Darwinian principles, optimal foraging theory is capable of providing them. The theory has been used extensively in recent years (see for example Winterhalder and Smith (1981)) in association with hunter-gatherer data (because the connection with extant ecological models derived from the study of non-human animals is the most direct (Smith 1984a)). The results of these studies suggest that optimality models provide a viable framework for the analysis of human adaptation and the appreciation of the relative values of alternative behaviours.

Thus in this thesis, despite the fact that early historical documentation concerning the behaviour of the Sydney region Aborigines is available, this does not form the basis of model construction. The behavioural model is based solely upon ecological principles and is tested using only the material remnants of behaviour (the archaeological record). Ethno-historical data is used only to examine aspects of the fit between the ecological model and the archaeological data.

The behaviour of the Sydney region Aborigines is of particular interest from the viewpoint of explanatory human ecology, for as hunter-gatherers living in close proximity to coastal areas, they represent an example of an extinct human condition - the maritime life - which was once a principal human niche.

1.1.3 Hunter-gatherers and the life near the ocean wave

The combination of archaeological data and optimality theory is used in this thesis as a method for understanding the adaptive strategies of maritime hunter-gatherers (that is, those groups for which aquatic resources form the major part of dietary protein or calories (Yesner 1980)), and as a consequence it is necessary to consider the problems the study involves and, above all, the essential characteristics and qualities of the life.

The behavioural characteristics of maritime hunter-gatherers are known to have been very different from those of extant tropical hunter-gatherer groups. These latter, for the most part, live in environments which contain no coastal or estuarine (and in some cases few freshwater) resources - they live in environments that have a much lower gross and net productivity than environments which contain these components (Odum 1971; Whittaker 1975). Such marginal resource zones are not typical of those which have been available to hominids during 99% of human history (see Binford 1983) - although in a sense they may be the fundamental 'hunter-gatherer' niches (as opposed, perhaps, to 'hunter-fisher': see Hayden 1981:353; Renouf 1984).

Recent studies, particularly of the high arctic Inuit, south African San and Australian Aborigines have tended to give rise to a false sense of cultural homogeneity among hunter-gatherers (Wobst 1978; Bender 1985). However, it is known that maritime hunter-gatherers possessed characteristics beyond those associated with extant tropical groups; particularly with regard to tendencies toward greater sedentism, higher population density, larger group size and non-band organization (Lawrence 1969; Rohner & Rohner 1970; see also Yesner 1980). As a relevant example, we may note that Birdsell (1968) has calculated that coastal Australian Aborigines were characterized by population densities forty times greater than those of interior groups.

The utilization of marine foods by hunter-gatherers first becomes visible c. 400000BP (Yesner 1980), but it is not until the late Pleistocene that it becomes a widespread visible phenomenon within the archaeological record (Osborn 1977). The principal evidence for human use of marine resources in the past - the shell midden - makes its appearance during the upper Palaeolithic in Europe, North Africa and Japan and slightly later (c. 10000-8000BP) in the North Pacific and Oceania. (It is important to note, in passing, that while shell middens are the most visible evidence of marine adaptation through time, they have tended to misguide the understanding of that adaptation. Shellfish are unlikely ever to have dominated the diet of any human group. In the ethnographic present, Meehan (1977, 1982), for example, has shown that shellfish represent only 15-20% of the Anbarra diet. For this reason, middens are not generally helpful in determining the extent to which a hunter-gatherer group should be considered to be 'maritime hunter-gatherers' (sensu Yesner 1980:728; see also Bailey 1979).)

Concerning the origin of the maritime life, Cohen (1977) has suggested a behavioural model which is readily interpretable within the context of optimal foraging theory. He suggests that, in general, hunter-gatherers first entered the maritime environment principally in search of large game (ranked highly with regard to cost/benefit ratios). As the population grew and as large animals became scarce (resource depression), secondary resources (lower rank/increased cost) such as aquatic products and vegetable starches became important; and as the population continued to grow, tertiary resources such as roots, tubers and grains might have been included in the diet. Significantly, he views shell-fishing as having always been a strategy of necessity rather than choice.

As an example of this development and its generality, in a more recent paper, Cohen (1981) has compared the sequence of foraging activity in Japan and western North America over the past ten thousand years (see also

Aikens 1981). During this period, both areas were characterized by forested mountains, coastal rivers and estuaries and a stable climatic environment. Both hunter-gatherer populations also shared characteristics of 1) a high population density; 2) a high degree of sedentism; 3) an elaboration of material culture; and 4) an elaboration of sociocultural organization.

Cohen's interpretation of the data from California is shown in Table 1.1. The pattern clearly follows that of his earlier assessment; and (although the material is less fully understood) the same processes seem to have occurred in Japan - particularly indicated by an intensification of nut use and, in the late Jomon period, root use. In addition, there was a general intensification in aquatic and vegetation resource use - associated with a steady increase in population - until about 4000BP. This general trend continued until the end of the Jomon period (c.1000BP), when wet rice cultivation was introduced and was adopted in Japan. The pattern through time in these two areas, then, appears to be consistent with behaviour expected through the use of optimal foraging theory, whereby long-term population growth and resource depression necessitates the re-direction of foraging behaviour to less 'valuable' (in terms of cost/benefit ratios) resource types.

However, the trend towards maritime adaptation may not be as clear-cut as Cohen's model implies. Coastal, and particularly estuarine, resources can often possess return rates (i.e. kcal/hr) which are higher than those of terrestrial prey (see Yesner 1980; Perlman 1980). Indeed, several

Period	Activity
11000-8000BP	Hunting period
8000-5000BP	Transition from hunting to seed gathering.
5000BP + (especially 3000BP +)	Seed processing gives way to two regional patterns: a) Acorn processing, riverine fishing and hunting in central valleys and mountainous areas b) Marine exploitation on the coast and offshore islands

Table 1.1: Changes in foraging activity in California over time. (Source: Cohen 1981:281-282).

features of coastal environments increase the likelihood that if hunter-gatherers tend to utilize food resources according to optimality principles, coastal resources are likely to be very highly ranked (in terms of cost/benefit ratios). In addition, the same features offer at least a partial explanation of those behavioural characteristics which are associated with maritime hunter-gatherers, particularly the greater degree of sedentism and higher population density than inland groups. These factors are principally a function of greater productivity; and the nature and distribution of resource 'patches' (q.v.). For example:

1. The linear (as opposed to planar) nature of resource patches, the higher degree of species-packing (MacArthur 1970), and the ecotonal qualities of the coastline (Clarke 1978; Rhoades 1974, 1978; Perlman 1980) promote a compression of predator populations into linearity. Highly productive resource 'patches' along this linear distribution are likely to promote foraging from a central place (Orians & Pearson 1977).
2. Maritime systems tend to display less seasonality than terrestrial systems and, as a consequence, aquatic patches tend to be less ephemeral than terrestrial patches.
3. In maritime systems, and particularly in estuaries, there are likely to be available a number of 'unearned' resources (Birdsell 1957), i.e. migratory species which can be exploited extensively with a high maximum sustained yield.
4. Maritime systems also tend to have a much lower risk of capture failure than terrestrial systems (Perlman 1980). When such events

occur, 'buffer foods' such as shellfish, provide a measure of safety not usually found in terrestrial systems (Perlman 1980:282).

In addition, as has been noted above, it is likely that fishing is generally more productive than hunting per unit time, though data concerning the relative costs of coastal resource exploitation (in terms of required time and energy investments per unit of nutritional yield) are very limited (Yesner 1980:733). Perlman (1976) (quoted in Yesner (1980)) suggests that fishing appears to produce the higher yield - up to 5000kcal/hr compared with c. 4000kcal/hr for terrestrial mammal hunting. However, if protein rather than calorific yields are considered then the efficiency of fishing (in term of kcal investment per g of protein yield) is higher than that of intensive agriculture (Yesner 1980). In addition, the generally minimal technology required for the extraction of many maritime resources eases the cost element of the cost/benefit ratio.

Perlman (1980:283) particularly emphasizes the importance of estuarine environments and their associated high-value patches of earned and unearned resources, because they provide a subsistence base which allows the minimization of movement and the maintenance of relatively high density populations.

Overall, if it can be assumed that the maritime hunter-gatherer adaptation is consistent with patch choice models based upon cost/benefit ratios, estuarine and inshore coastal environments are likely to be disproportionately utilized. For only under circumstance of resource depression (brought about, primarily, by the migration of potential prey) should hunter-gatherers redirect effort to other resource areas. Of these, it is likely that other aquatic areas, such as wetlands and 'old-age' rivers (highly productive because of high levels of nutrients held in suspension) are likely to be of the next greatest importance (see Lourandos 1977, 1980 for an example of this influence in the Australian context). In comparison with these areas, terrestrial resource zones are likely to be of lowly importance.

However, the subtleties and advantages of the maritime adaptation cannot really be appreciated without a few examples.

1.1.4 Cropping the sea - aspects of three hunter-gatherer groups

What, then, are the essential characteristics of hunter-gatherers who crop the sea?

A great deal of information is available concerning the behaviour of many ethnographically and archaeologically known hunter-gatherer groups who utilized marine resources, particularly from the north-west of America (see Hayden 1981:345 & map). In this section, three less well-known hunter-gatherer groups are described. Two of these groups possess characteristics which are of direct relevance to the present study and the third displays an extreme form of marine adaptation among hunter-gatherers.

The Ainu

The Ainu of Sakhalin (Takakura 1960; Watanabe 1964, 1968; Ohnuki-Tierney 1974) displayed seasonality in their settlement patterns consistent with the harshness of their environment. Summer settlements were close to the sea and winter settlements lay further inland - though still relatively close to the sea. During the winter (which was severely cold) hunting and trapping of land and sea mammals and ice fishing sustained the population. Martens, bears, musk deer, reindeer, foxes, otters, hares and squirrel were taken - mostly by trapping, trap bows or by bow and arrow. Animal meat was particularly favoured in autumn - "when it was tasty and rich with fat" (Ohnuki-Tierney 1974:19). Bears, reindeer and musk ox were good sources of fat, which was stored and used to supplement dried fish in winter. Sea mammals and beached whales were used in the same way. In summer, near-shore waters, rivers and lakes were utilized, particularly for herring in May and trout in July. Herring oil was treasured and was stored for winter. Bulbs and tubers were dried and also stored for winter.

The Ainu represent an adaptation which is indicative of the complexity of using principles derived from animal studies in the human context. For the relationship between individual behaviour and resources was affected by two important factors: the use of untended facilities in trapping (see Oswalt 1976); and the use of storage technology to offset winter shortage. The importance of untended facilities with regard to cost-benefit analyses lies in the fact that after the initial effort - the construction of the facility - benefits accrue without the necessity of the presence of the maker, who can, as a consequence, turn his attention and effort elsewhere. In addition, the deflexion of hardship through the use of storage technology places an obvious difficulty in the path of behavioural models derived from animal ecology. (The use of storage technology by the Ainu is consistent with Binford's (1980) comment that food storage tends to increase with latitude, though this is not necessarily true of all maritime hunter-gatherers even at high latitudes (Yesner 1980:729).)

Both the use of facilities and storage technology are likely to be instrumental in the maintenance of high population densities, protected in the winter (the season of greatest ecological stress) through the use of stored unearned resources of high return (herring, trout, seals, whales); stored high-return resources (particularly animal fats); and stored 'buffer' foods (bulbs, tubers) to supplement the diet when the major potential prey is high-risk and low-density.

In general, then, the ecology of the Ainu illustrates how man, through the use of techniques not widely distributed among other animals, may offset the direct relationship between seasonal food availability and food acquisition. As has been noted, these techniques are most often associated with hunter-gatherer populations in high latitude environments, where there is a great degree of seasonality: in temperate regions this association (and its corollary of deflexion in the relationship between availability and behaviour) becomes less apparent. In the temperate Sydney region, for example, there is little evidence to suggest that the relationship between Aborigines and seasonal availability was influenced by the use of either untended facilities or storage technology.

Archaeological studies in Cape Province, South Africa

The climatic regimes of the Cape Province are, at least in part, similar to those of the Sydney region. Much of the area possesses a warm climate with uniform rainfall and a long, mild summer (Koppen Cfb; cf. Dick 1975). (Other climatic regimes represented in the area are associated with dry hot (Csa) and dry mild summers (Csb).) The vegetation (coastal and montane fynbos) is dominated by similar sclerophyllous shrubs (some taxa of which it shares with the shrubs of Australia), and is subject to similar patterns of recurrent firing. In addition, as in the Sydney region, soils are generally sandy and (at least in the mountain areas) are very low in nitrogen and phosphorus (Kruger 1979).

It appears that the shrub elements of the Cape Province flora emerged during early Holocene environmental changes. These were accompanied in the archaeological record, by the advent of a 'small tool tradition' - the Wilton - circa 8000-7000BP (Deacon 1976:162), similar to that which occurred throughout Australia at much the same time. (The development of archaeological patterns during this environmental change has been examined particularly by Parkington at Eland's Bay Cave (1981).) The contents of Wilton strata seem to indicate a greater specialization with regard to marine resources. At Nelson Bay, for example, bones of fish and marine birds increase many fold relative to those of mammals (Klein 1974:273).

Historical data from the region suggests that the bushmen moved seasonally between the coast and the interior (Deacon 1969) and oxygen isotope analysis of shell midden material has lent support to this suggested pattern of movement, by indicating that shellfishing was principally a winter occupation (Klein 1974; cf. Bigalke 1973). The archaeological data also indicate that during periods of inland occupation, there appears to have been an emphasis upon the hunting of small terrestrial animals, which is in marked contrast to the evidence for hunting from the (pre-Wilton) Albany period. This development probably reflects the reduction of grazing over much of the South Cape as the vegetation changed (Klein 1974:276; 1977).

The floral evidence from Melkhoutboom (Deacon 1976) suggests that despite 'the extraordinarily rich' shrub flora (a description used frequently to describe the rather similar Sydney flora), only a relatively small number of species, dominated by the <u>Watsonia</u> corm and relatives in the Iris family - collectable for all but two months of the year - were consistently used. A form of 'natural agriculture' - the use of fire - to stimulate the growth of these species was also evident (op. cit:105). On the basis of these data, Deacon (loc.cit.)

suggests that corms, bulbs, rootstocks and small non-migratory animals made up most of the inland diet.

As we shall see in succeeding chapters, the South African data closely parallels the information available from the Sydney region during periods of environmental change and the concurrent genesis of a 'small tool tradition'. In both areas the effect of the spread of shrub vegetation was to depress the availability of mammal resources. This depression appears to have had the effect of directing foraging behaviour towards maritime resources at least upon a seasonal basis. It should be noted also that this depression (in both cases) is likely to have been largely independent of the action of man, (discounting, for the moment, the possible anthropogenic factor in the vegetation change), being rather a function of climatic change (cf. Cohen 1977).

In terms of the relationship between seasonal availability and expectations of hunter-gatherer behaviour, in the Cape Province, location upon the coast in winter would take advantage of the ecological richness within a compressed area. In addition to fish resources, the value of high-return cetacean populations as seasonal 'unearned resources' may well have been an influential factor in this usage, for Smith & Kinahan (1984) suggest that, "while whale stranding could not be predicted closely, the probability of there being access to cetaceans increased from August to December and would encourage coastal exploitation at this time" (op.cit:95).

It is also important to note that the populations of the Cape Province utilized two distinct groups of 'buffer foods' (temporally and spatially stable dietary elements of low risk) one of which was associated with inland, the other with coastal, activities. Clearly, from the archaeological evidence, shellfish are very likely to have had this function on the coast; but more importantly, the Watsonia corm is likely to have held this position inland - it is available for most the year, grows in dense patches and its location is entirely predictable.

It was noted above that buffer foods are on the whole rarer in the terrestrial environment than in the marine. However, in shrub-dominated areas, there is usually a high underground biomass in the form of roots, tubers and corms - which are of low nutritional value but also low in risk - which can serve this function. This is further emphasized by the fact that the Cape Province archaeological record indicates that the development of corm usage was concurrent with the reduction in faunal abundance and a number of components of the edible flora (the two are, of course, likely to be related). During this period of environmental change, hunting, in particular, would have become an increasingly high-risk occupation. This risk could be reduced by the emergency use of underground resources of high areal density and reliability.

The information from South Africa, which is associated with an environment (at least in part) similar in its development and characteristic 'natural' flora to that of the Sydney region, should alert us to the likelihood of possible similarities in hunter-gatherer behavioural response. In particular, the same depressing influences of sclerophyllous vegetation upon the distribution and density of high-value edible production, and the incidence of 'buffer foods' in the form of specialized root forms, might be thought of as most likely to affect hunter-gatherer decisions in the Sydney region in much the same way as the evidence suggests that those decisions were influenced in the Cape Province.

The Aborigines of New England, New South Wales

A number of important ethnohistorical and archaeological studies have been undertaken within the New England region of New South Wales (see for example McBryde 1974, 1978; Belshaw 1978; Coleman 1978, 1982). This region, to the north of the study area, is of particular interest because of the Aboriginal association with a temperate estuarine environment similar to that of the Sydney region.

McBryde (1974:17, 226) used ethnohistorical and archaeological evidence to suggest seasonal population movements - to the coast in spring and summer and a dispersal of people along the Clarence valley and the coastal hinterland in winter. However, subsequent analyses (particularly by Pierce (1971), Belshaw (1978) and Coleman (1982)) have suggested that, on the contrary, coastal (and particularly estuarine) tribal territories were small, focussed upon aquatic resources and densely populated (approximately 6 people per km.sq. (Belshaw 1978:72-73)). The mobile, scattered and small family groups which had been considered to be the norm within the region and the basis of archaeological research (McBryde 1974), have proved through the study of ethnohistorical sources, to be an artefact of European interference. The earliest contact reports reveal high-density "semi-sedentary local populations on the coast, with a highly sophisticated organic material culture, which vanished overnight with European contact" (Coleman op.cit:7).

The ethnohistorical records suggest that all Aboriginal activity ran parallel to the coast (Coleman 1982:4) and that this activity was closely associated with shell middens (Coleman 1982; Sullivan 1982). Coleman (1982) has gone so far as to suggest that the Aboriginal populations of the north coast were near-sedentary, living in 'villages' and using 'fish-traps' rather than ranging widely in response to seasonal food availability. (However, Sullivan (1982) has pointed out that the fish traps, at least, may well be post-contact features.)

Contrary to the first appraisal of the Aboriginal behaviour within the region, then, it is clear that the Aborigines of the estuaries and coast of New England, conformed to a general pattern of compression into the linear dispersion that would be expected on ecological grounds - in close proximity to high-value earned and unearned marine resources. There is also evidence of 'central place foraging' from semi-permanent 'villages' (though the validity of these 'villages' has also been questioned by Sullivan (1982)).

The general ecological similarities between the New England and the Sydney regions suggest that it might be expected that compression of the population along the estuarine and marine margin and central place foraging would also be features of the behaviour of Sydney region Aborigines.

In these three cases the role of marine resources is understandable in terms of the potential of the sea and estuaries to provide high returns for low cost and less risk (particularly in terms of seasonality) than is true in the associated hinterlands. (Though, the relationships between those resources and human behaviour, can be exceedingly complex, as in the case of the Ainu and their storage of marine-related high value foods.) The material from New England suggests a number of linking factors between human and animal behaviour which are predictable upon ecological grounds (in particular, the compression of the population into linearity, central place foraging and the use of shellfish as buffer foods). While the archaeological material from Cape Province indicates the value of having an emergency food inland.

These three hunter-gatherer populations, each known from a different source - ethnography, archaeology and ethnohistory - tell us something of the subtlety and complexity of the maritime adaptation and indicate that optimality principles, and particularly optimal foraging theory, are likely to be able to help us understand the relationships between man and the coastal environment.

However, we must first determine what we mean by 'adaptation' and, as important, the limitations of the way we seek to determine the nature of that adaptation.

1.2 ADAPTATION AND THE LIMITATIONS OF OPTIMALITY THEORY

'Adaptation' is one of the key concepts in current anthropology yet it remains ill-defined. The word has become almost magical - "a concept that is either protean in meaning or else is really several different concepts travelling under the same semantic label" (Smith 1979:55). Rappaport (1979:145) considers that this vagueness in definition is in itself adaptive; while others have considered that the term is so misused that it should be abandoned altogether (Bargatzky 1984). In the context of evolutionary ecology, however, the neo-Darwinian concept of adaptation is central to the analysis, and precision is required because of the different emphases appropriate in the analysis of the behaviour of non-human animals and that of man.

The concept of adaptation, in essence so elegant - literally the 'fitting' of an organism to an environment - has become confounded within biology by a number of overlapping alternative definitions (for example, Lewontin 1957; Dobzhansky 1968:5; Stern 1970:40f). The term 'adaptation' has, in fact, been used in three main senses by biologists:

1. In reference to a structure - a fin is an adaptation for swimming.
2. As a state of being - 'fitness' in a particular environment.
3. As a process of change - modification to achieve a better fit between organism and environment.

Although the second definition has been prominent in anthropology - culture as an adaptation (e.g. Cohen 1968) - the third definition, is the most valuable in understanding the fundamental relationship that exists between adaptation, evolution and ecology which is the basis of evolutionary ecology. This relationship is based upon variability and the differential fitness of organisms under the selection pressures of the environment. Adaptation as a process operates in a specific environment, the stability and heterogeneity of which are of utmost importance in determining selection pressure.

Gould and Lewontin (1979:592-593) have suggested that there are three levels at which this adaptation can occur: firstly, the genetic level, with Darwinian adaptation arising from selection acting upon genetic variation; secondly, the phenotypic level, where phenotypic plasticity permits organisms to mould their forms to the circumstances prevailing during ontogeny; and, thirdly, the sociocultural level - " a 'heritable' form of non-Darwinian adaptation in humans (and, in a few other advanced social species)" (op.cit:155-156).

In man, particularly, adaptation at the genetic level has given rise to another powerful form of adaptation - brought about through learned transmitted behaviour. Yet, this form is far from being divorced from environmental challenges and, indeed, it has become man's primary means of interacting with his ecological setting - as Clarke (1968:660) has said, "Once initiated the sociocultural system will adaptively explore the changing environment and constantly update the information condensed in cultural traits".

However, this is not to suggest that 'cultures' adapt. Socio-cultural adaptation is likely to operate at the level of the individual no less than do genetic and phenotypic adaptation. Both Richerson (1977) and Peoples (1982) have argued that selection for cultural traits takes place largely at the individual (and not the group) level - individuals choose from the cultural pool on the basis of cost and benefit. They choose from alternative social relations, technology, and subsistence strategies on a daily basis. As conditions change in the natural and cultural environments, individual selection based on perceived individual benefits direct change (Earle 1984:406).

The combination of these genetic, phenotypic and sociocultural factors produces whole individual adaptations and, as Goldschmidt (1971:303) has said, as a consequence "It is reasonable to see ecological adaptation as a generalized statement of the process of individual adaptive acts". In an analogous pathway to the retention or loss of genetic characteristics in all natural systems, <u>adaptive</u> behaviour is retained or fixed in this cultural pool while behaviour which works against adaptedness will be selected against and dropped from the repertoire of learned behaviour patterns. The distinction between these latter 'maladaptive' behaviours and 'non-adaptive' or 'adaptively neutral' behaviours is important. Much of human behaviour does not confer any detectable selective value to the population. Owing to this factor, in this thesis we are concerned only with those aspects of behaviour which possess a detectable selective value, and their relationship to the characteristics of ecological populations, that is, groups of interacting individuals who:

1. are confronted with the same set of environmental challenges.
2. regularly transmit and share adaptive information among themselves.
3. share the same pattern of behavioural responses to the environment.

How, then, may we distinguish between adaptive and maladaptive behaviour?

To some extent, this is an intractable problem - particularly with regard to archaeological data, because we can not know the exact characteristics of the behaviour which leaves the material remnants that form the record. It has been noted above that a major fault in hunter-gatherer investigations based upon systems ecology has been the assumption that the majority, if not all, behaviour is adaptive in some measure. Optimal foraging theory, in contrast, allows the production of models which test the adaptiveness of observed alternative behaviours.

A large part of this thesis is concerned with establishing a model of optimal resource-use based upon ecological data for the Sydney region, and then testing the degree of adaptedness displayed by the observed Aboriginal behaviour (or rather, in this case, those material aspects of behaviour which entered the archaeological record). In fact, a dichotomy in the data (between Aboriginal archaeological and art sites) is readily apparent; and this division can be used to serve a basic purpose - for it allows the development of a hypothesis concerning the adaptiveness of the two behaviours which these two site populations represent: if the Aborigines of the Sydney region located their behaviour optimally with regard to the temporal and spatial distribution of high-value resources, then the archaeological site data should display less variation with regard to those environmental factors which influence the distribution of those resources, than is evident among art sites.

It should be stressed that this is not to suggest that art sites represent maladaptive or even (necessarily) neutral behaviour; only that, because of the greater likelihood that archaeological sites are more closely linked with the food-quest, evidence for optimal behaviour should be more readily apparent in this population than in the art population.

In fact, the question of the degree to which these tendencies toward optimality may be apparent in a human population at all, is a complex one. Foley (1985) has recently addressed the general problem of the extent to which optimality principles may contribute to the understanding of human ecology. Principal among a number of points which he makes concerning the general theory as it concerns all organisms, are that many factors inhibit perfection of adaptation or optimality (see also Dawkins 1982) and, consequently, that analysis of behavioural traits within a specific environment can only be expected to demonstrate a <u>tendency</u> towards optimality.

The main inhibitors of optimal responses between organisms and resources are:

1. The time-lag between changes in environmental conditions and the action of natural selection.
2. The limiting effects of the degree of genetic variation present, and the phylogenetic inertia of the organism, upon the modifying power of natural selection.
3. The influence upon an organism of an array of selective agencies that affect reproductive success - many of which will conflict with each other - so that the organism as a whole may tend toward optimality only through a balance of adaptations to specific environmental challenges, which ensures that the organism survives the overall challenge.
4. That, in an environment which is inherently unpredictable, optimality is an impossible goal.

Foley proceeds to consider the value of this tendency towards optimality for anthropology and to identify hominid characteristics which suggest that optimality principles may influence behaviour. For example, hominid omnivory depends directly upon the degree of heterogeneity within the environment and the costs and benefits involved in food extraction, and consequently optimization principles are likely to be influential. In addition, as a K-selected organism (that is, an organism selected for the ability to compete for finite resources; see Pianka 1970, 1978), man's efficient use of those resources is an expected trait. Hence optimization of behavioural elements such as foraging behaviour and spatial organization are highly probable.

Although optimal foraging theory was developed through the study of non-human species in which optimizing influence could be seen as a product of selection processes upon genetic variation, this does not necessarily diminish their value in the study of man. For, peculiarly hominid characteristics which are largely independent of genetic influence, such as technology and language, can also be viewed as ways of cutting costs in the ratio of costs to benefits which is a critical element in optimization theory. Similarly, the symbolic element in human territoriality (Cashdan 1983) reduces the costs of defence in relation to the benefits of exclusive ownership, in a way that is unavailable to non-human animals, but which can nevertheless be understood in terms of optimality theory. Leading to a broadly similar conclusion, Torrence's (1983) analysis of technology suggests that hunter-gatherers invest in technology to maximize benefits in relation to units of time, to a degree beyond the capabilities of other species.[2]

However, it is also possible to identify hominid characteristics which inhibit the tendency toward optimization beyond those limiting factors identified above as operating upon optimization in all organisms. These additional constraints are derived directly from the status of hominids as 'culture-bearing organisms' - able to process information other than that derived via Mendelian inheritance, and to acquire and modify novel behavioural strategies at a rate and on a scale unknown in other species. The accelerating rate of change associated with human history exacerbates the time-lag between environmental change and the influence of natural selection - an extension of the time-lag constraint identifiable in all organisms.

Time-lag may be particularly influential in highly variable environments and in situations of rapid colonization - which place a premium upon opportunism and, consequently, high variability. In addition, group-based activities which are characteristic of hominid behaviour may obscure optimizing strategies, which are assumed (because of the genesis of the basic principles within neo-Darwinism) to operate at the level of the individual. Through co-operation (or coercion) individual freedom may be curtailed and, as a consequence, some behaviour may be maladaptive at the level of the individual, yet tend toward optimality for a larger part of the population. Finally, the very

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[2] Note that Torrence uses a different 'currency' (time) to that which is usual in cost-benefit analyses (energy) (see Winterhalder 1981a:20 for a discussion of the merits of various currencies).

rapidity with which humans change their adaptive strategies may be a cause of instability in their environment, influencing optimizing behaviour through the alteration of the frequency of occurrence and value of resources.

In summary, as highly complex animals, flexible in behaviour and capable of rapid adjustment to environmental change, hominids represent a fascinating challenge to concepts derived from evolutionary ecology. This challenge is greatest in the sub-discipline of archaeology, but so - in terms of illustrating human evolution and, in particular, aiding the explanation of the diversity of human response to environmental challenge through time - are the potential rewards.

1.2.1 Archaeology and optimal behaviour

Only behaviour and environment leave material traces in the archaeological record - the way in which a past population perceived its environment (cognition) must, of necessity, be reduced to the status of a large and impenetrable 'black box' (Clarke 1968). However, all observable patterns of behaviour, reflect the cognition process and are directly subject to natural selection (Kirch 1980). The privilege of archaeology is a database exhibiting the material products of adaptive change over the fullness of time, rather than the 'short time perspective' of ethnography (cf. Lee 1976:95).

The connections between behaviour and the archaeological record (and the analysis of modifications to those material remnants of behaviour after deposition) have been studied, principally in relation to hunter-gatherer populations, as part of the sub-discipline of ethnoarchaeology (see Gould 1978, 1980; Kramer 1979; Binford 1978b, 1979, 1983; for general principles see Schiffer 1976, 1983). However, those archaeologists who have attempted to understand what causes the behaviour - essentially an ecological question - have of necessity relied heavily upon ethnographic analogy and consequently fallen into the same functionalist trap as cultural ecologists (Smith & Winterhalder 1981). The consequence has been a growing dissatisfaction with the guidance offered by both ethnography (Wobst 1978) and cultural ecology (Butzer 1975, 1978).

At a time when prehistorians are increasingly able to identify features of diet and behaviour through time and space (Isaac 1976, 1978, 1981; Walker et al. 1978) and palaeoecologists are generating detailed information concerning environmental variables (Butzer 1977, 1978, 1982), principles derived from evolutionary ecology are in the unique position of having been expressly formulated in order to study the relationship between behavioural and environmental variability (Smith & Winterhalder 1981:6). It is therefore unsurprising that the majority of optimal foraging studies undertaken to date have been pursued because of their potential value to archaeology (Winterhalder & Smith 1981; Hawkes et al. 1982).

However, Foley (1985) has stressed in relation to the archaeological usage of optimality theory, that the theory is essentially a static one, providing a model of how an organism should behave under one peculiar set of circumstances and cannot as a consequence account for change. Thus, while archaeological data provide a picture of past exploitational strategies coupled with a limited amount of information concerning past environments; in order to operationalize optimality models, independent environmental data must also be sought from materials not greatly affected by human activity (e.g. geomorphology and climatology; see Yesner 1981). In essence, the establishment of a sufficiently detailed knowledge of the environmental context requires that ecological congruence between past and present can be demonstrated (op.cit:149).

This requirement of stasis in the environment has two primary effects:

1. It restricts the time depth of the utility of optimality models to recency (because as time depth increases so does uncertainty about congruence between past and present environments) and,
2. It requires that all the archaeological evidence for past exploitational strategies is contemporaneous and recent.

In the case of stratified sites, wherein the information of each level might be thought of as indicating different evidence of past exploitational strategies, only the uppermost level can be directly associated with an environment known in detail (and only then provided that it can be demonstrated that: a) taphonomic events have not confused the evidence and b) this level is recent). In addition, because optimal foraging theory is based upon principles of spatial heterogeneity, testing the theory requires of the archaeological record an identifiable regional pattern.

This form of archaeological data - recently occupied sites upon a regional scale - is well-known in Australia (see Sullivan & Bowdler 1984), and, indeed, studies of regional man-land relationships from both the archaeological and the ethnographic perspective in Australia have made a major contribution to our knowledge of hunter-gatherer behaviour.

1.3 MAN AND LAND IN AUSTRALIA

1.3.1 The study of man-land relationships in Australia

The study of man-land relationships in Australia has centred on a number of different paradigms which undoubtedly reflect the development of the archaeological community and Australian society as a whole (Rowland 1983; see Kuhn 1971, concerning this general phenomenon in science).

For the majority of the period since 1788, the Aborigines have been viewed as 'unchanging, in an unchanging environment' - fitting models of past human development (see Mulvaney 1975). However, The 'Man the Hunter' symposium of 1966 (Lee & Devore 1968) was highly influential in placing all hunter-gatherers within the niche of the 'original affluent society' (Sahlins 1972) - ecologically aware and in harmony with the environment -

notions which appealed in a time of increasing awareness of 'ecological issues'. (This idealistic view of hunter-gatherer society has since been challenged, for example by Colson 1979; see also Altman (1984a) for a recent re-assessment of Sahlins' original affluence hypothesis in Arnhem Land).

More recently Aborigines have been seen as the dominant agent of change in the Australian environment - 'Man the destroyer' (Merrilees 1968), and the 'fire-stick farmer' (Jones 1969). Interestingly, Horton (1982:248) suggests that this image stems from an unconscious notion of hunter-gatherers as second-class citizens in comparison with farmers, which produces a tendency to present Aborigines as 'farmer-like' (Rowland 1983). Horton's own position - that the Aborigines adapted to change rather than being a principal cause of it - suggests that the role of humans as agents of change in the Australian environment is overstressed at the expense of the influence of environmental changes which are independent of human action (1980, 1982). More specifically, Lourandos (1983) has recently noted a general tendency to understate the influence of Holocene climatic fluctuations because they were of a lower magnitude than those of the Pleistocene. His analysis of archaeological sequences in Tasmania suggests that climatic change may explain the timing of intensification of usage of marginal rainforest and wet sclerophyll areas in contrast to the indefinable periods of cultural adaptation proposed by Jones (1977) and Bowdler (1979). He also stresses that these environmental factors would not determine culture change but merely provide an incentive for it.

Optimality principles have had a limited influence upon Aboriginal research to date. Principal among attempts to apply optimal foraging theory is O'Connell and Hawkes (1981) analysis of Alyawara plant use in central Australia. The authors were able to show that the exploitation of grass and tree seeds was dependent upon the cost/benefit ratio in comparison with other food resources - only when the returns of higher ranked foods decreased in abundance were seeds included in the diet, because at other times handling and processing costs far outweighed any potential benefit. In addition, O'Connell & Hawkes have displayed something of the explanatory potential of optimal foraging theory for human ecology, in their contribution (op.cit:114-115) to a long-standing debate in Australian archaeology concerning the colonization of the continent.

In order to appreciate their contribution, it is necessary to briefly review the history of the debate. Birdsell's radiation model (1957), in which the Aboriginal population expanded rapidly in all directions and occupied all areas of the continent in 1350-2200 years, has been challenged by Bowdler (1977) on both environmental and archaeological grounds. Her coastal colonization model suggests that the occupation of Australia was entirely coastal and riverine until c.12000BP when the interior began to be settled. At present, however, there are too few sites known or excavated in the interior to either support or refute her hypothesis. More recently, Horton (1981) has added to the debate by suggesting something of a hybrid of the two previous models mixed with his interests in megafaunal extinction and climatic variation. He suggests that the Aboriginal population radiated out from the initial migration points and penetrated all but the arid core by 25000BP (see also Tindale 1981), then as climatic conditions became more arid and the megafauna became extinct, the Aborigines retreated to the coast, only entering the interior again when the climate ameliorated c.12000BP. Horton's model, like Bowdler's, is based upon the absence of data rather than its presence and relies heavily on associations with megafauna which are, at present and at best, not proven.

To this argument, then, O'Connell and Hawkes have brought optimal foraging theory to bear and have produced an eminently reasonable and testable model, which suggests that on landing:

> "..... the order in which habitats or habitat types were occupied should have varied directly with the net energy gained from exploiting them and inversely with their distance from the original landing-point(s). Habitats in which energy returns were comparatively low should have remained unoccupied until returns in "better" habitats fell to the same level" (op.cit:115).

Only when population increase or climatic change reduced returns in a habitat should another have been occupied. In general, this would tend to support Bowdler's hypothesis of coastal and riverine occupation but does not assume a "preadaptation" to aquatic resources. It is also highly probable that under these conditions the interior was not occupied until fairly late; O'Connell and Hawkes see the onset of arid conditions between 18000-17000BP as a critical period of resource depression in high-ranking habitats, which saw the advent of occupation of interior areas of formerly lesser value (loc.cit.).

O'Connell and Hawkes' model should be capable, as we begin to understand more about Australian palaeoenvironmental development (see for example Jones 1982; Hope 1984), of producing a number of alternative hypotheses which will bring us nearer to the resolution of this long-standing debate.

It is interesting to note that all these researchers refer to 'habitats' as essentially regional areas rather than as local microecological elements in the landscape. In fact, this regional emphasis is a consistent characteristic of nearly all areas of Aboriginal research in Australia.

1.3.2 The development of regional analysis in Australia

Owing to the fact that Australia was at the time of contact an enormous continent of hunter-gatherers (and because of the late recognition of Aboriginal society as something other than an unchanging remnant of a stage in past human development) it was inevitable that the analysis of many Aboriginal characteristics would be undertaken upon a regional scale. These large-scale analyses reflect the continent-wide variation in Aboriginal behaviour in relation to the great diversity of habitats. Regional ethnographic differences have been proposed by Elkin (1964), Berndt and Berndt (1977; see also Peterson (1976a)) and a map of tribal boundaries has been produced (Tindale 1974). Linguistic maps have also been constructed by Oats and Oats (1970) and Wurm (1972).

Regional assessment of broad ecological influences upon Aboriginal distribution stem largely from Birdsell's (1953) well-known and influential rainfall correlation (cf. Hiatt 1968), of which Peterson's (1976b) regional division of Aboriginal populations on the basis of drainage systems - the fundamental units of geomorphology - is the best known. In addition, Sullivan and Hughes (1984) have emphasized the importance of structural and climatic environmental elements in regional archaeological research (see also Anderson 1984; Sullivan 1976, 1980).

Regional differences in the archaeological record have until recently been limited to assessments of the distribution of certain tool types (Mulvaney 1975). Witter (1984), however, has recently proposed a division of Australia utilizing environmental boundaries which have "cultural implications" (op.cit: 48). Broadly, these 'cultural adaptive areas' are consistent with the tribal, linguistic and drainage basin divisions of the recent past. The time depth of this approach is consequently limited to the past 6000 years, the period for which Australian climatic regimes have been relatively stable (loc. cit.).

1.3.3 Contemporary adaptation research and environmental perspective

Studies concerning the economic and ecological activities of contemporary hunter-gatherers have of necessity centred upon desert (for example Gould 1969, 1973, 1980; O'Connell and Hawkes 1981) and tropical populations (Jones 1980ab; Meehan 1976, 1977, 1982; Altman 1984ab; see also Harris' (1978) historical work concerning tropical rainforest populations).

While desert adaptations are inherently interesting from an ecological viewpoint, and are fixed in the popular mind as being fundamentally 'Aboriginal', they are likely to have been relatively late developments in the colonization of the continent (Bowdler 1977; O'Connell & Hawkes 1981), and - if population density is considered for a moment as a measure of some abstract 'Aboriginal state' - virtually insignificant in comparison to coastal adaptations. Studies of adaptation among contemporary, coastal Aborigines have necessarily been limited to relatively high-density populations in the tropical north, although it is generally accepted that population densities were as great, if not greater, in more temperate latitudes (see Tindale 1974; Smith 1981; Heathcote 1975) - a belief which accords well with Binford's (1983:208) recently expressed opinion that it is in the temperate zone that man is reproductively most efficient.

These northern studies have had a tendency to develop a pan-Australian relevance, particularly in archaeological research concerning areas in which the Aboriginal population was decimated early in the course of the European invasion - principally in temperate latitudes (for example, Poiner 1971; Sullivan 1982; Hughes & Sullivan 1981). Little account has been taken of the great ecological differences between the two areas. The observed adaptations in the tropics occur within savanna environments characterized by a high degree of seasonality (Harris 1980b; Jones 1980a;

Calaby 1980); while over much of coastal temperate latitudes in Australia (and particularly on the south-eastern coast) the land is dominated by the presence of '*sklerophyllen* flora' (*sensu* Specht 1979b) and low seasonality.

1.3.4 The sklerophyllen environment in south-east Australia

An appreciation of the differences between 'savanna' and 'sklerophyllen' environments is important to the understanding of the differences in environmental challenge between the tropics and the temperate zone and the prediction of adaptational strategies.

For just as the term 'savanna' may imply vegetational associations from "pure grassland to dense woodland, with the presence of a more or less continuous ground layer of grasses beneath or between the trees as the one common denominator" (Harris 1980b:5); so 'sklerophyllen' implies vegetation structures from open heath to open woodland with the presence of a more or less continuous ground cover of shrubs in the same positions. In neither case is it the trees (in Australia usually the ubiquitous *Eucalyptus* or *Acacia* spp.) which define the essential characteristic of the flora. The taller species are invariably evergreen and sclerophyllous whatever the ground cover, and these characteristics do not appear to be edaphically controlled (Specht 1979b:4).

In general, sclerophylly is almost certainly an evolutionary response to low levels of mineral nutrient content in soils (Beadle 1968). As 'savanna' is best defined in climatic terms (Harris 1980b:3); so 'sklerophyllen' communities are best defined with reference to edaphic factors - exceptionally low soil nutrient status is the common factor controlling the location of these ecosystem types (Specht 1979b).

Nowhere in Australia is this 'sklerophyllen' influence stronger than in the Sydney region of the south-east, wherein the shrubland elements of the endemic flora reach their greatest diversity and areal extent (Beadle 1981). In fact, as we shall see, nutrient deficiencies (particularly in phosphorus) have fundamental implications for the ecosystem as a whole, principally upon flora but also directly and indirectly upon fauna.

This thesis, then, is devoted to the understanding of the environmental challenges facing the individual hunter-gatherer in this temperate, shrub-dominated environment, not through ethnographic analogy but through ecological models and the material remnants of behaviour.

1.4 THE AIMS OF THIS THESIS

By April 1789, barely a year after the arrival of the First Fleet, perhaps fifty to seventy percent of the Aboriginal population of the Sydney region were dead. Apart from a remnant population, they left behind, in the accounts of the First Fleet observers, a notion of their culture, and a wealth of archaeological data which represents the material component of that cultural activity. The principal aim of this thesis is to test the utility of optimal foraging theory in the study of past human adaptations and coincidentally to attempt to illuminate the behavioural patterns of the Sydney region Aboriginal population prior to the arrival of the Europeans in 1788, through an understanding of their environment and through the use of archaeological behavioural markers.

Yesner (1981), one of the principal proponents of the use of optimality principles in the exploration of past human adaptations, has assumed that in order to test the principles of optimality in an archaeological context the record must contain an abundance of faunal and floral remains. This notion necessitates a naive viewpoint concerning taphonomic processes, and this thesis attempts to test these principles, not with regard to the contents of sites but using the locational characteristics of sites upon a regional scale and with due regard for taphonomic processes.

In this study, then, the locational characteristics of individual Aboriginal sites are analysed, much in the manner that a population geneticist might apply analytical techniques to data gathered from individuals in order to better understand the adaptational characteristics of a whole population. It is not concerned directly with the relationship between sites which is a particular interest of archaeologists (see for example, Hodder and Orton (1976)) but with the relationships between individual sites and ecologically productive areas aggregatively considered.

1.5 THE ORGANIZATION OF THIS THESIS

The remainder of this thesis is formed by nine chapters.

In Chapter Two, a broad overview of the dimensions and macro-scale characteristics of the Sydney region is presented in order to familiarize the reader with a base upon which small-scale and dynamic characteristics are built in subsequent chapters.

In Chapter Three, the recent palaeoenvironment of the Sydney region is discussed with reference to the ways in which the environment has developed over time. An attempt is made to estimate the stability of the present environment of the Sydney region with a view to establishing the extent to which it can be said to be representative of the recent past (i.e. the last thousand years). Here too, of necessity, the effects of the European invasion are also discussed in order to ascertain the dimensions of this cataclysmic event for the native fauna and flora, and the ways in which it may alter our perception of the recent palaeoenvironment.

In Chapter Four, optimal foraging theory is introduced and its principles are used to establish the essential characteristics of the Sydney region from the viewpoint of an efficient human forager. On the basis of these characteristics a locational model of expected behaviour is established and a division of the 'landscape' into component variables capable of testing the model is presented.

In Chapter Five, the sources of data and methods of analysis are presented; while in Chapter Six the limitations of the archaeological data are discussed in order to determine the extent to which the fundamental unit of the investigation - the site - can be taken as representative of Aboriginal behaviour which is likely to have been influenced by considerations of optimality. Essentially, this chapter emphasizes the importance of the recognition of formation processes and proceeds to establish the degree of site contemporaneity and temporal congruence with the recent environment which are the two principal prerequisites of the use of optimality principles in the past.

In Chapter Seven, the behavioural model and landscape variables are used to produce predictions concerning the locational characteristics of Aboriginal sites under the assumption that the population was behaving optimally with regard to the distribution of high-value resources. These predictions are assessed through the use of elementary statistical comparisons. Then multivariate statistical techniques are used to assess the extent of support for the behavioural model.

In Chapter Eight, an attempt is made, through the analysis of archaeological and ecological data from a small area within the region, to determine the likelihood of local small-scale ecological influences having affected Aboriginal locational decisions in ways which are not necessarily apparent from the regional perspective.

In Chapter Nine, ethnohistorical data from the same small area are introduced in order to independently test the observed relationship between the behavioural model and Aboriginal location as it is expressed by the archaeological record.

Finally, in Chapter Ten, the conclusions of the study and some suggestions for the further development of the results are presented.

2 CHAPTER TWO:

THE SYDNEY REGION

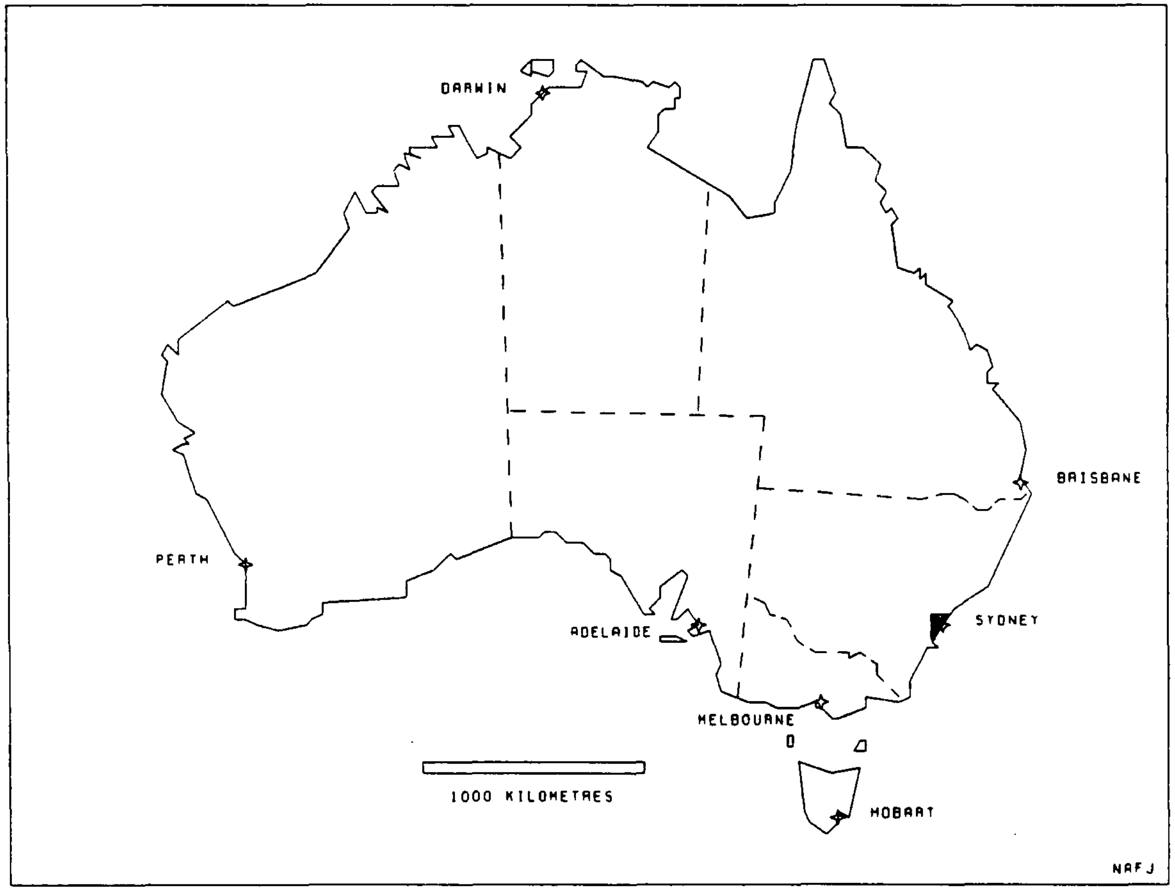
In subsequent chapters, details of the physical and climatic structure of the Sydney region are used as data in the analysis of the relationship between Aboriginal behaviour and zones within the landscape of high return for the hunter-gatherer. In order to place these details into context, this chapter takes the form of a broad overview of the major features of the landscape.

2.1 THE DIMENSIONS OF THE SYDNEY REGION

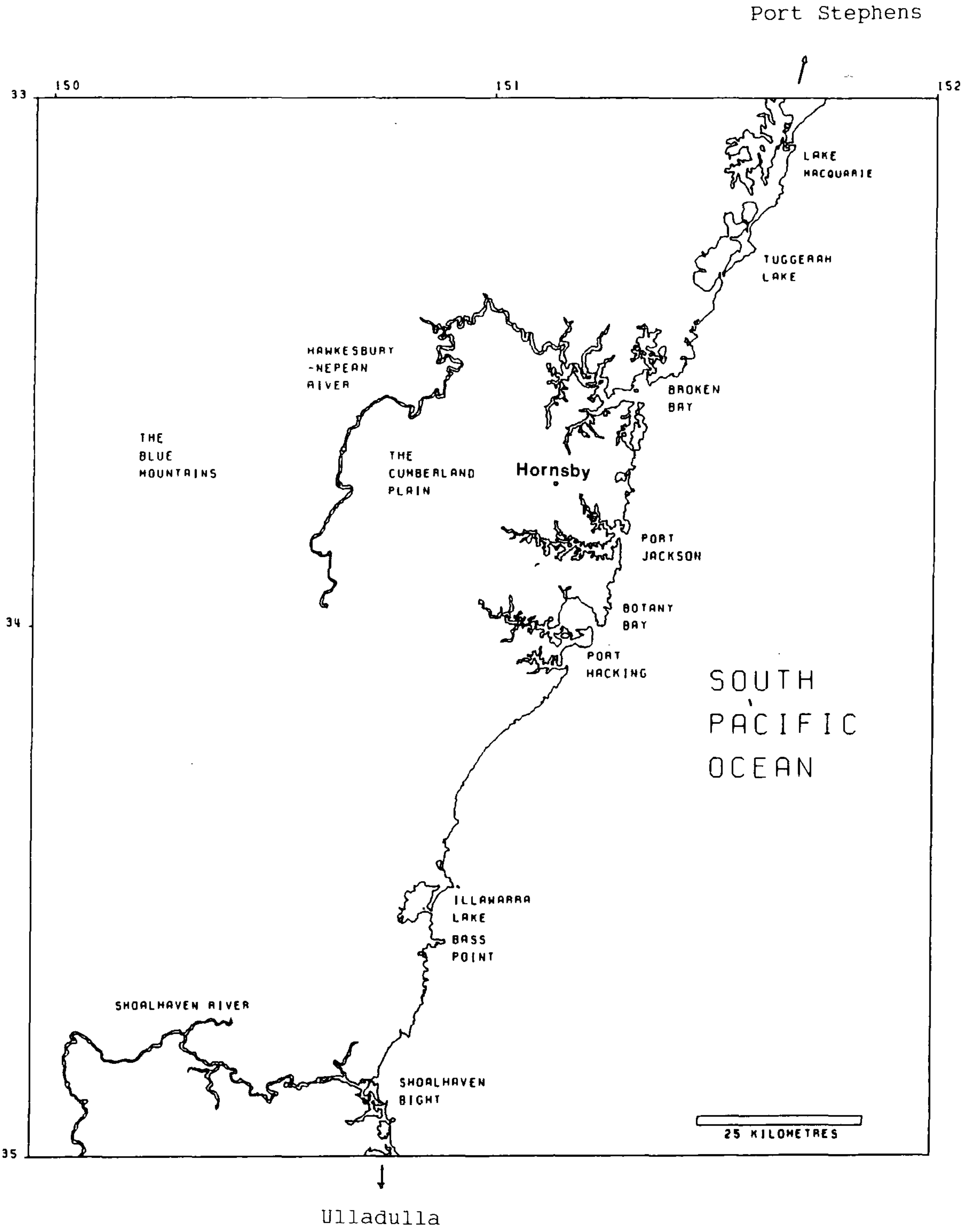
The Sydney region is defined by latitude 33 degrees to 35 degrees south and by longitude 150 degrees east and eastward to the coast (Maps 2.1 & 2.2); and is coterminous with the area covered by the Sydney and Wollongong 1:250000 topographic and geological maps (Sl 56-5 and Sl 56-9). The total land area of the region is approximately 22000 square kilometres.

2.2 STRUCTURE AND TERRAIN

The Sydney region is part of the Sydney-Bowen basin - a broad geosyncline which has been gradually filled with near-shore marine or terrestrial deposits (Packham 1969). It is predominantly capped by Triassic sandstones and shales which overlie Permian sandstones, shales and coal measures. This structural basin extends from Port Stephens in



Map 2.1: The location of the Sydney region.



Map 2.2: The major features of the Sydney region.

the north to Ulladulla on the south coast - the axial plane running NNW and the basin as a whole 'plunging' towards the Tasman Sea (Nashar 1967; Browne 1969). The majority of the Triassic sandstones are assigned to the Hawkesbury series, which are overlain by shales of the Wianamatta series (Heally 1973; Herbert 1980). Other Triassic rocks, particularly the Narrabeen series of sandstones, conglomerates and shales, which were laid down before the Hawkesbury series, outcrop only in certain areas - particularly on the north shore of Broken Bay (Ward 1972).

During the late Tertiary, while folding occurred elsewhere (the Kosciusco orogeny) a number of small basins and folds developed (e.g. the Cumberland and Botany basins) and the Hawkesbury and Narrabeen sediments to the west of the basin were uplifted by a monoclinal flexure. At the same time upon the eastern margin of the basin, the Hawkesbury sandstone was uplifted to produce the Hornsby Plateau (to the north of the present city of Sydney); and the north-westward tilting Woronora Plateau (to the south of Sydney). In between these zones of activity the Wianamatta shale area remained as a relative downwarp (the Cumberland Plain). The principal result of this activity is that there is now little relationship between age and depth among the rock types of the region. For example, the youngest series (Wianamatta) has its main distribution west of Sydney close to sea-level, and older rock layers rise to the north, south and west to form plateaux up to 1000 metres above sea-level (Figure 2.1).

The overall effects of these geomorphological processes upon the structure of the region are best seen in relation to three sub-areas:

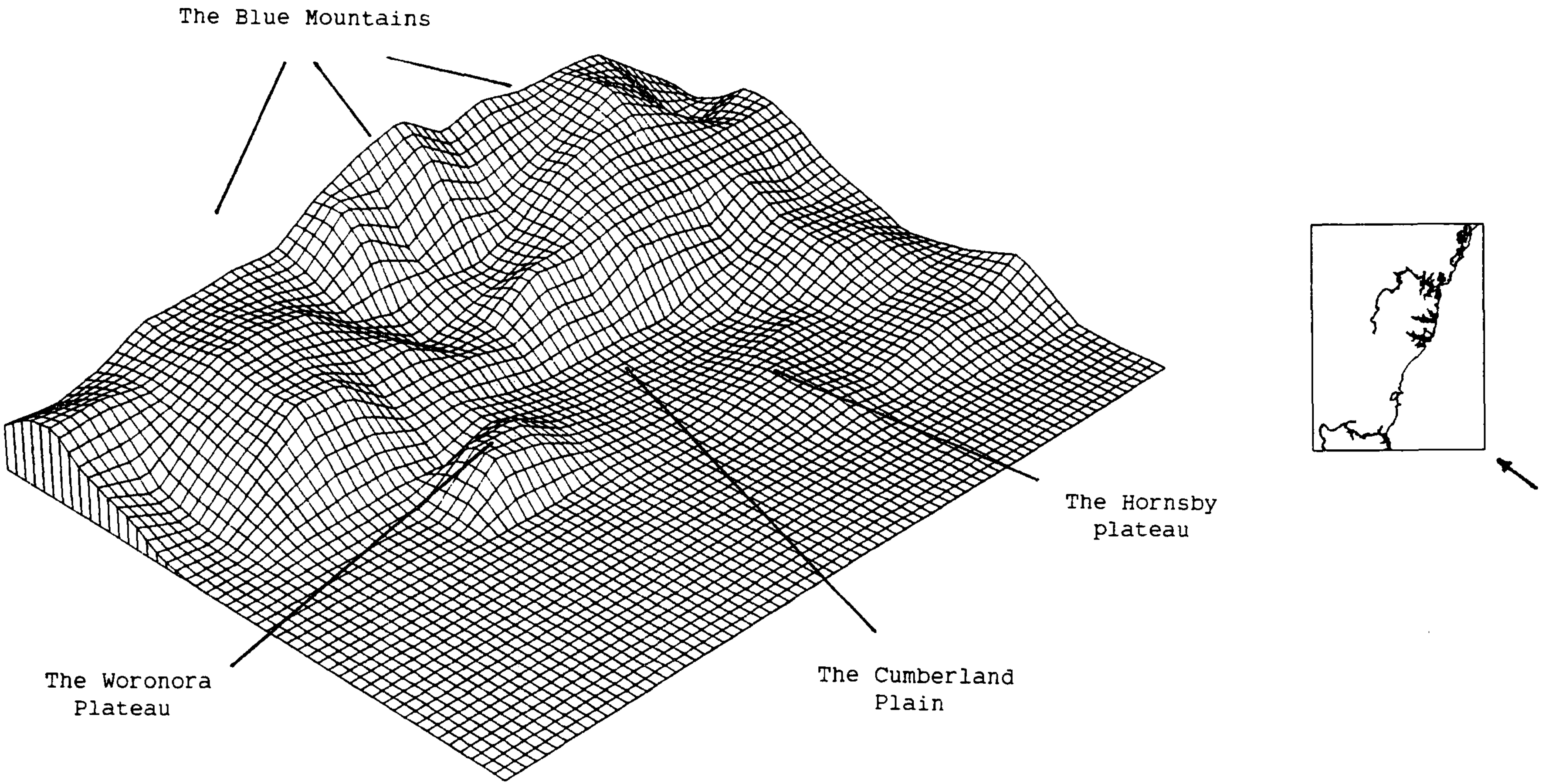


Figure 2.1: The topographic characteristics of the Sydney region.

2.2.1 The coast and estuaries

There is no coastal plain within the Sydney region. Instead the coastline is characterized by a series of cliffed headlands of Hawkesbury sandstone separated by sandy beaches and barriers (Taylor 1970). At the centre of the coastal border of the basin, the outline of Botany Bay has been structurally imposed by the differential warping of the Hawkesbury and Wianamatta series. However, the majority of coastal landforms within the region are depositional in origin, particularly barriers, beaches, dunes and floodplains. Other features (such as bays) are partly depositional and partly erosional in origin; while wholly erosional rock shorelines make up only a small proportion of the coastal landscape.

The structure of most of the estuaries within the study area has been principally determined by the nature and warping of the bedrock, particularly the ria-like estuaries (Broken Bay, Port Jackson, Georges river and Port Hacking) and the bay estuary (Botany Bay) which were created during the Holocene marine transgression. Other estuaries are more directly related to depositional factors, particularly the floodplain estuary (Shoalhaven river) and estuarine lakes or lagoons (Tuggerah Lake and Lake Illawarra) (Langford-Smith & Thom 1969; Sullivan 1982; Bayley 1975; Bird 1967ab; Dunstan 1979).

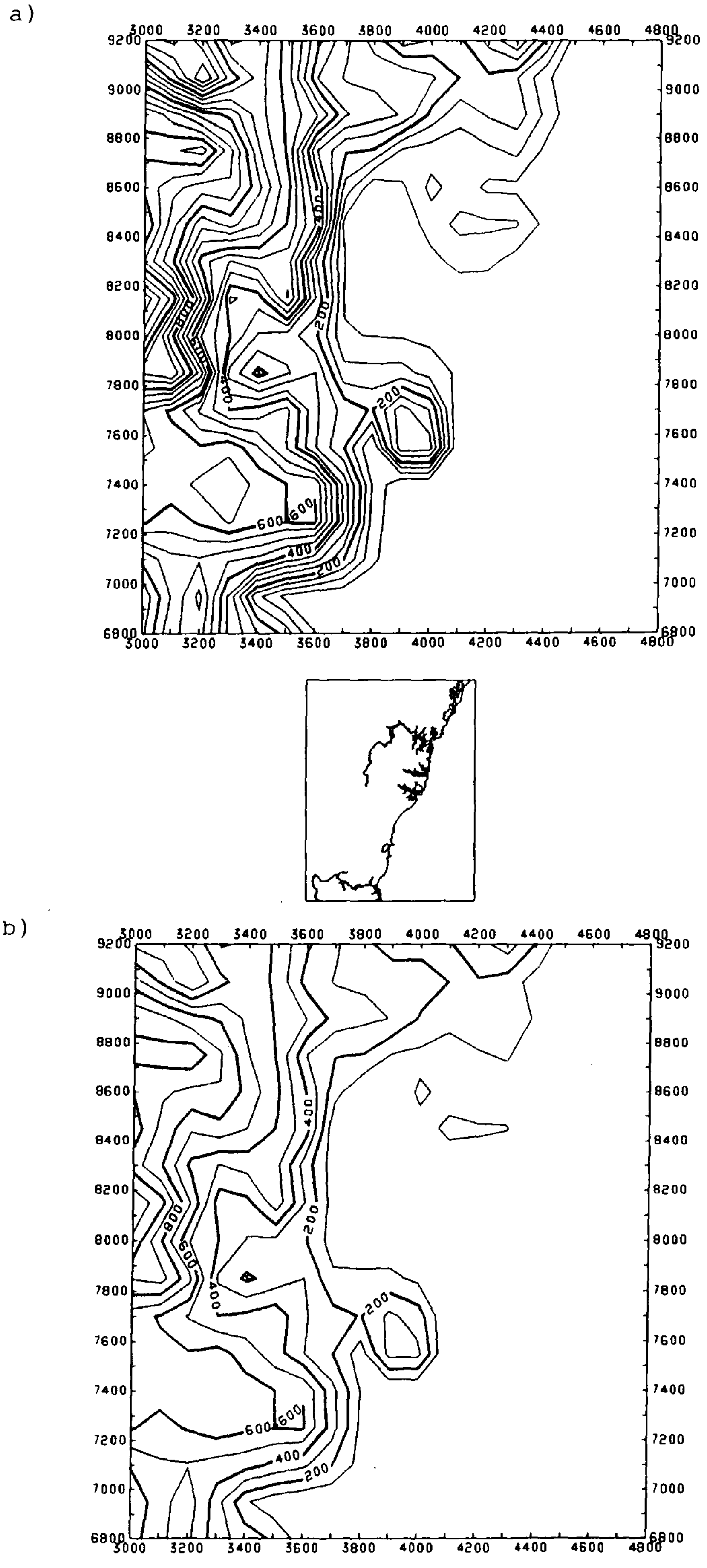
2.2.2 The Cumberland Plain

The Cumberland Plain, bounded to the west and north by the Hawkesbury-Nepean river, is an undulating low-lying area underlain by shale and surrounded by sandstone plateaux of a younger series. Close to the river, Tertiary gravel, sand, silt and clay - the products of ancestral river systems - are widespread. The existence of the plain is solely attributable to the warping of the rock strata in such a way that the Wianamatta series lies below the surrounding and younger Hawkesbury series.

2.2.3 The sandstone plateaux and the Blue Mountains

Surrounding the Cumberland Plain, the near-horizontal beds of Hawkesbury sandstone form plateaux generally 20-50 metres high around Sydney rising to 1000 metres in the Blue Mountains (Map 2.3).

As a result of the late Tertiary uplifting on the periphery of the Cumberland Plain, the major rivers of the region (Hawkesbury, Nepean, Parramatta, Georges) were rejuvenated, resulting in deeply-incised gorges cutting into the former peneplain. As a consequence, valley slopes in the gorges tend to be near vertical. In addition, as the sandstone is highly-jointed, it tends to erode into blocks leaving vertical cliffs which may range at their highest from 50 metres at the coast to a few hundred metres in the Blue Mountains. Narrow valleys and waterfalls are also very common and these features, together with others related to the



Map 2.3: Height above sea-level in the Sydney region.
a) contour interval = 50 metres. b) contour interval = 100 metres.

jointing of the rocks, give rise to very few areas of extensive flat. The term 'dissected plateaux', suggesting that dissections are more frequent and more extensive in the area than intervening flats, is most appropriate.

2.3 CLIMATE AND RELATED FACTORS

The Sydney region possesses a climate which can be classified using the Koppen system as a Cfa climate with a trend towards a Cfb climate in the Blue Mountains and the Woronora Plateau (Dick 1975; Table 2.1).

2.3.1 Rainfall and related factors

Although rainfall occurs in all months there is generally an increase during the summer, particularly in inland parts (a reflection of the influence of prevalent thunderstorm rainfall in areas of high relief); and an increase in autumn at the coast (Bureau of Meteorology 1979:11; Table 2.2). At the other extreme, spring tends to be the driest season over most of the region. However, in all seasons the average rainfall exceeds the effective rainfall and as a consequence the growing season is probably continuous over most of the area.

Rain falls on about 40% of days and the average annual rainfall ranges from 750mm on the Cumberland Plain to over 1250mm along the coast between Port Jackson and Broken Bay extending inland across the uplands to Hornsby (see Bureau of Meteorology, 1979:9). Along the coast from a point south

C	Warm climate (at least one month below 18C)
f	Uniform rainfall
a	Hot summer (hottest month above 22C)
b	Long, mild summer (hottest month below 22C and at least 4 months above 10C)

Table 2.1: The Koppen classification of the Sydney region climates. (Source: Dick 1975).

	Summer	Autumn	Winter	Spring	Year
Richmond (inland)	259	213	154	168	794
Sydney (Coast)	288	383	317	227	1215

Table 2.2: The mean values of seasonal rainfall (mm). (Source: Fitzpatrick & Armstrong 1973).

	January	July
Cumberland Plain	>29	3-4
Sydney and coast	<26	7-8

Table 2.3: The influence of coastal proximity upon seasonal temperature (C) (Source: Fitzpatrick & Armstrong 1973:12).

of Port Hacking, annual average rainfall is in excess of 1500mm, reflecting the stronger orographic effect. This orographic influence can also be seen in the Blue Mountains to the west of the Cumberland Plain, where rainfall rises to 1250mm.

However, the effective influence of rainfall can also be affected by other topographic factors. The rugged topography of the sandstone plateaux ensures that run-off is considerable and, particularly where the underlying rocks are exposed, dry environments are produced. Conversely, run-on into valleys produces almost permanently wet environments. The overall effect of these two processes is the occurrence of a variety of habitats from 'arid' rocky outcrops to 'ever-wet' ravines, and in between, a gradient of moisture regimes which is reflected in a gradient of flora.

2.3.2 Temperature

Temperatures within the region vary depending upon season, aspect, altitude and distance from the sea. The latter influence is particularly prominent in respect to maximum temperature in summer and minimum temperature in winter: the influence of coastal proximity is markedly less in the case of summer minimum temperature and winter maximum temperature (Table 2.3).

Throughout the region, temperatures are mostly within or not far removed from levels generally accepted for human comfort (Fitzpatrick & Armstrong 1973:13). They are likely, however, to have a greater affect upon the distribution of flora (and hence upon the fauna), particularly with regard to altitudinal influences. However, the altitudinal range to the east of the Blue Mountains is too small for there to be any major difference between relatively higher areas (such as the Hornsby plateau) and the rest of that part of the region, even in winter. Yet, the influences of aspect and slope, and in particular the effect of cold air drainage into valleys at night, may be considerable in areas of dissected terrain.

2.3.3 Wind and aspect

Undoubtedly, the influence of winds tends to be greatest at the coast. West winds blow onto the region from May to September and east winds prevail during the rest of the year (Linacre and Hobbs 1977). Winds which bring rain are mainly from the south and east; while storm winds generally come from the south-east. North-east winds are, in contrast, very stable because they bring warm air; while north-west winds are usually stable in winter, but may become unstable in summer when they often carry dust from the interior.

Aspect effects are mostly observable in valleys - the north-facing slopes tend to be drier. A consequence of this is that these slopes tend to have a more xeromorphic (q.v.) vegetation than south-facing slopes.

2.3.4 The influence of urbanization on climate

On the basis of climatic averages there is no evidence that urbanization has a conspicuous effect on the climate of the Sydney area, principally because of its proximity to the coast (Fitzpatrick & Armstrong 1973:17). In particular, it would appear that the proximity of water-bodies and the comparatively large areas of parkland and open-space within the Sydney urban area serve to reduce greatly the intensity of heat-island development (op. cit:18).

2.4 SOILS AND VEGETATION

Of the five major factors generally thought to be involved in the formation of soils - climate, parent material, landforms, vegetation and time - parent material appears to have had the greatest influence within the study area (Corbett 1973). Climate for example, plays relatively little part in differentiating soils because the climatic gradients are less marked than the changes in parent material (op. cit:43). In fact, climatic influence is essentially limited to the promotion of podzolization in the majority of soils.

The fact that markedly different soil types are found in close proximity is attributable to the juxtaposition of shale and sandstone beds and the minor outcropping of other rock types. Loamy lithosols, red and yellow podzolics are characteristic of areas of non-calcareous grey shale or shaley alluvium, particularly upon the Cumberland Plain (op. cit:48;

Stace et al. 1968); while sandy lithosols, yellow podzolics and acid peats are characteristic of sandstone areas, particularly the dissected plateaux (Corbett 1973:49). Minor soil groups represent minor areas of different parent material; sand podzols among dunes; krasnozems, prairie soils and black earths upon outcrops of Tertiary basic rocks and basic alluvium; red podzolics derived from Pleistocene alluvium; and minimum prairie soils from recent alluvium (Table 2.4; op. cit:50-54; Walker 1961; Stace et al. 1968).

The native vegetation within the area is much more of a dependent variable than an important element in the formation of soils (Burrell 1973). A number of factors - low nutrient content; low and erratic moisture supply; and the long isolation of the continent - have resulted in a flora which has little effect on soils through nutrient recycling and litter return (op. cit:45). Though most of the soils within the area are low in nutrients (considered in their natural state to be agriculturally useless), those that have developed from the Wianamatta and Narrabeen series are considered to be richer than those derived from Hawkesbury sandstone. In general, the sandstone areas are dominated by Open Scrub and Low Woodland; and the areas of the Wianamatta and Narrabeen series by Woodland, Open Forest and Tall Open Forest. The dominant overstorey species are Eucalyptus, while the dominant understorey species are mainly shrubs, though grasses (particularly Themeda spp.) make an appearance in areas of greater fertility (see Pidgeon 1937, 1938, 1940, 1941). Within the area as a whole the various xeromorphic assemblages become richer from north to south, and reach their maximum development upon the sandstone

Geology	soil types	Extent	pH
Wianamatta Shale, shale alluvium & Narrabeen shale & sandstone	loamy lithosols red podzolics yellow podzolics	small great small	5 - 4.5 5 - 4 6.5 - 4.5
Hawkesbury Sandstone	Sandy lithosols yellow podzolics acid peats	great great great	5.5 - 5 5.5 - 5 4.5 - 5
Sand dunes	sand podzols acid peats	great small	5 - 4 5.5 - 5

Table 2.4: The soils of the Sydney region according to parent material. (Source: Corbett 1973).

plateaux around Sydney (Beadle 1981).

Agricultural expansion away from the urban sprawl of Sydney and Wollongong has tended to occur in areas of relatively greater fertility (see Perry 1963), that is: a) areas of soils derived from the Narrabeen series which formerly supported Tall Open Forest; b) areas of alluvial deposit along the Hawkesbury-Nepean river; and c) areas of soils derived from Wianamatta shale. In contrast, the Hawkesbury sandstone plateaux has been little disturbed except in some of the comparatively rich valley bottoms.

2.5 THE NATIVE FAUNA

The agricultural exploitation of parts of the Sydney region has led to the depletion of the vertebrate fauna as the nature and density of the native flora has been changed - yet the region retains an extraordinarily rich indigenous fauna. It is not possible to say exactly what changes have been brought about since the beginning of the European invasion, though relative abundances within species are likely to have changed (Calaby 1971). This change need not necessarily have been one of decline in all species. It is known for example, that some kangaroo populations in other areas of Australia have grown at a great rate because of the disturbance of the pre-European environment and because of the reduction of predation by the dingo (Caughley et al. 1980).

	Fish	Amphibians	Reptiles	Birds	Mammals
Indigenous	c. 300	35	50	386	25-28
Introduced	5	1	0	15	7

Table 2.5: A comparison of the numbers of indigenous and introduced species within the Sydney region.
(Source: Recher 1973).

In fact, it is likely that few species which occurred in the Sydney region prior to the European invasion are now extinct (Recher 1973). This is principally because of the existence of large areas of bushland to the west, south and north of the city. In addition, introduced species have not displaced the native fauna from their niches (Table 2.5); of the fifteen species of introduced birds, for example, all are restricted to the vicinity of human habitation or to agricultural areas.

The reason for the evident abundance of fish species within the Sydney region lies in the fact that the 'edge' of northern warm and southern cold waters occurs here. The result is that many tropical fish species (especially juveniles) are present in summer and many cold-water forms appear in winter. Similar temperate influences and the wide range of habitats available also help to explain why the resident avifauna contains so many species.

2.6 SUMMARY

In terms of structure, the Sydney region is remarkably uniform in its characteristics, the differentiation of sub-regions being effectively determined by the relative dominance of Hawkesbury sandstone or Wianamatta shale or by the deposition of material along the coast. This variation is reflected by the distribution of plants within the area which appears to be little influenced, for the most part, by the coarser influences of climate or altitude - though, at a local level, the water regime or aspect differences may cause minor fluctuations in the vegetation pattern. Owing to the survival of many large areas of native vegetation because of the low nutrient characteristics of many of the soils, the indigenous fauna is unlikely to be depleted in terms of species.

Overall, despite the utilization of much of the region for agricultural or settlement purposes, large areas remain which appear to be representative of the essential characteristics of the pre-European environment. The extent to which this appearance is likely to be real will be assessed in the next chapter.

3 CHAPTER THREE:

THE SYDNEY PALAEOENVIRONMENT

In this chapter the principal developmental processes which have led to the present environment of the Sydney region are examined, in order to establish its fundamental characteristics. Two of these characteristics are particularly emphasized: 1) the predominant influence of nutrient distribution upon the distribution of flora and fauna; and 2) the stability of the Sydney environment for at least the past thousand years. The former characteristic establishes a unifying current beneath the locational characteristics of edible biota; and the latter establishes the environmental stability which is the prerequisite of the analysis of optimal foraging strategies.

The study of the recent palaeoenvironment of the region can best be understood with reference to the development of four sub-sections of the information: a) structure; b) climate; c) vegetation patterns; and d) faunal patterns.

3.1 STRUCTURAL DEVELOPMENT

The marine transgressions which affected so many parts of the world during the Quaternary, ended in south-eastern Australia between four and six thousand years ago (according to local rates of isostatic adjustment) (Thom & Wasson 1982). Within New South Wales, standstill occurred between 3500 and 5000B.P. (Hails 1968), and during the Holocene the coastline of the region appears to have been tectonically stable (Thom et al. 1971).

The depositional features now associated with the coastline - sandy barriers, beaches and lagoons - have developed during the past seven thousand years (Bird 1967a; Hails 1968; Langford-Smith and Thom 1969); while the major areas of erosional landforms - rock platforms and, to a certain extent, ria formations - were rapidly modified to their present form after the sea reached its present level (Bird 1967b; Lampert and Hughes 1974). After this time the marine and estuarine faunal patterns seen at present are likely to have become established (cf. Wise & Schopf 1981).

However, coastal environments are dynamic systems and as such can be expected to be seldom truly 'stable' (though the magnitude of fluctuations may be small) and recent studies (reviewed by Rowland (1983)) have suggested that local variations in sea-level occurred after this time (Thom & Wasson 1982). In fact, it is likely that minor adjustments occur continuously between land and sea which might have significant effects upon the distributional characteristics of both land and marine biotic communities, particularly through alterations in the water table, sedimentation regimes and coastal morphology (Rowland op.cit:70). On a smaller scale still, single events can influence the resource potential of an area (see Lees and Bates 1984; and Meehan's (1977:368-369) description of the destruction of shell beds by unusual events).

These latter events are small in magnitude (in comparison to major eustatic adjustments that may occur on a global basis) but are important at a local level. With reference to their relevance to the environmental stasis required by optimality models, it can be said that as the theory tests behaviour against spatial heterogeneity of resources over a regional scale, although we may recognize the existence of these localized dynamic agents of change, at any given time they are unlikely to produce sufficient variation in the pattern of the whole region to have a major effect upon results.

The inland areas of the region, of course, have been undergoing erosion for much greater periods of time. The primary process involved is one of pene-planation acting upon the Triassic series which were formed as an adjunct of the vertical movement associated with the creation of the eastern uplands (Mabbutt 1970). The present-day incised plateaux are the result of the differential erosion of these resistant but deeply faulted cap-rocks.

Overall, while dynamic processes are still important with regard to structural development there is no evidence that they are a major source of environmental instability.

3.2 CLIMATIC DEVELOPMENT

The study of past climates can not be divōrced from the study of the evolution of vegetation patterns - for the latter represent the principal data for understanding the former.

By the end of the Tertiary period the various landmasses which later became Australasia had drifted to their present position (Coleman & Packham 1976) and since that time (circa 1.8 million years BP) the present broad categories of Australian vegetation and fauna have been established.

In south-eastern Australia the extinction of Nothofagus brassii rainforest is taken to mark the transition between the late Tertiary (Pliocene) and the early Pleistocene (Hope 1984). This extinction is symptomatic of the late Tertiary processes whereby the closed forests became restricted to high rainfall areas and were replaced by open eucalypt forests in south-eastern Australia (and by the spread of arid communities and the appearance of grassland, shrub steppe and, probably, sclerophyll-dominated woodlands throughout the continent as a whole).

During the early to mid-Pleistocene, closed forest and sclerophyll assemblages appear to have contracted and expanded at the expense of each other. The closed forest assemblages were comprised of gymnosperms such as members of the Araucariaceae, Microcachrys, Podocarpus, Phyllocladus and Dacrydium which grew together with Myrtaceous genera and Casuarina. The sclerophyll assemblages which replaced the closed forest consisted mainly of Myrtaceae but also contained Acacia, Proteaceae, Graminae, Compositae and Chenopodiaceae (Singh 1982:96). These periods of sclerophyll or closed forest community dominance are thought to represent vegetational responses to dry and wet climatic periods which occurred during the Plio-Pleistocene. Singh (1980) suggests that these patterns also reflect a sequence of warmer periods being associated with higher rainfall and cooler periods associated with drier climates.

In particular, since the beginning of the Brunhes period of the earth's polarity (0.7 m.y. BP) there have been nine regular closely-spaced and well-marked glacial/interglacial intervals (Shackleton and Opdyke 1973), and despite the fact that at no time in Australasian history have ice sheets formed within the region, the growth and decay of these to the south has been an important influence upon south-eastern Australian climates. In fact, temperatures close to those of the present day have only occurred for 10% of the period since 0.7 m.y. BP - relatively cooler conditions have been the norm; and as a consequence, the closed forest flora has had only short warm/wet periods in which to recover from periods of aridity.

Climatic patterns in the more recent past are best assessed from detailed studies such as that which has been undertaken at Lake George (A.C.T.) to the south-west of the Sydney region.

Palaeo-climatic evidence from Lake George (A.C.T)

At Lake George, four major fluctuations have been recorded over the last 350000 years (Singh, Kershaw and Clark 1981). The inter-glacials were dominated by forests or woodlands and the glacials by openland vegetation consisting mainly of grassland. During the first two interglacials, rainforest taxa were in evidence, fire frequency was low and there were few fire-adapted taxa. However, at the start of the last interglacial circa 128000BP, a marked change in vegetation and fire activity occurred. *Eucalyptus* and associated Myrtaceous shrubs increased in the record at the expense of *Casuarina* and a range of other fire-sensitive taxa, which underwent a simultaneous decline. It has been suggested that this change in favour of fire-adapted vegetation was initiated by man (Singh et al. 1981). However, given that this activity would antedate the archaeological visibility of man's presence by many tens of millennia, it is probably more economical to seek an explanation of these events in climatic terms, and particularly in terms of the prevailing dry conditions (Rowland 1983). For recent research tends to suggest that climatic influences are the most important in the development of fire-dependent vegetation, though man may have some influence upon *rates* of development (see Clark 1983).

However, it is generally held to be true that during the ascendancy of *Eucalyptus* associations, closed forest contracted in southern temperate latitudes into small, especially favourable patches, presumably as a result of increased fire frequency and/or intensity. Its place was taken by a variety of grades of wet and dry sclerophyll forest and woodland.

Recent environments in south-eastern Australia

The oscillations in climate recorded since 10000BP have suggested to Bowler et al. (1976) that climatic variations were both smaller in magnitude and shorter in duration than those of earlier times. The evidence suggests that while the period between 7500 & 5000BP may have been wetter than at present, since 10000BP the climate and associated soils and vegetation of the south-east appear to have been generally similar to those of the present.

Costin (1971) suggests (on the basis of data from the Snowy Mountains) that there may have been colder periods, between 4000 to 3000BP and between 3000 to 1500BP, of low magnitude and effect, and limited to higher elevations. A limited degree of corroboration of these events comes from archaeological data from the Blue Mountains, for Stockton and Holland (1974) have proposed (on the basis of breaks in the stratigraphic sequence) a gap in occupation between 6050 and 3360 BP - but not during the period between 3000 to 1500BP suggested for the second cold period (op. cit:46).

As a point of particular relevance to the Sydney region, Costin suggests that, in coastal and coastal-montane areas which were subject to oceanic influences, the temperature changes noted for the Snowy Mountain region during this period may not have occurred. Indeed, many of the present-day communities may have existed in their present range throughout the oceanic areas. More generally, he has stated that "almost certainly none of the changes in south-eastern Australia during the last 10000 years, except perhaps for the 'little ice age' (3000 - 4000BP) effects at higher elevation would have caused much inconvenience to the Aborigines" (Costin 1971:36).

However, Costin's statement is symptomatic of a general trend among researchers to understate the influence of climatic oscillations in the Holocene. Though these dynamic trends in climate were smaller in scale than those of the Plio-Pleistocene (see Frank 1975; Figure 3.1), they are, none the less, likely to have exerted an influence upon biotic communities. For example, a general periodic cyclicity in climatic events has been demonstrated in Holocene Australia (Rognon & Williams 1977) and, in addition, it can be demonstrated that such events as eighty year trends in sunspot activity can have a profound influence upon wind and rainfall patterns and thus, indirectly upon geomorphological characteristics and vegetation (Ward & Russell 1980).

From the point of view of the present regional analysis the available climatic data are not of sufficient fine-scale to be able to determine such minor dynamic trends or indeed to determine the local influence of weather characteristics. Although it is recognized that these processes occur and are likely to be influential upon a local scale, it is assumed (of necessity) that the climate of the recent past is adequately represented in all its major regional characteristics by climatic statistics based upon

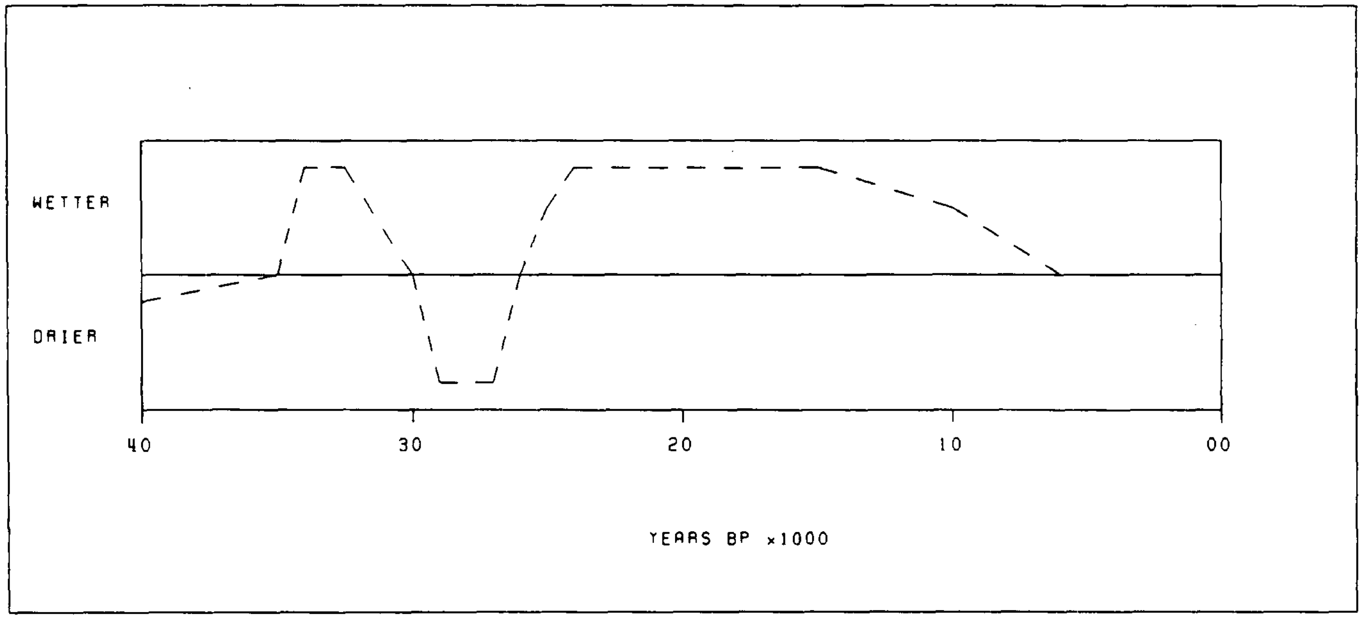


Figure 3.1: Large-scale Quaternary climate changes in eastern New South Wales. (After Frank 1975).

data collected over the past 70 years, and that, to all intents and purposes, the climatic environment has been stable for at least the past thousand years.

3.3 VEGETATION PATTERNS

Two hundred years of agricultural and urban expansion within the Sydney region might reasonably be expected to have destroyed the pre-settlement vegetation entirely. That it has not, is essentially due to the characteristics of the region's soils. For the most part, they are useless for agriculture, partly because of the extensive areas where bare rock breaks the surface and the general shallowness of the soil; but mostly because of their exceptionally low chemical fertility (Beadle 1981).

In a recent survey within the Sydney city limits, Burrell (1973:75) found that only 200ha of the area had soils with more than 480ppm phosphorus which is considered to be the threshold for agriculture in Australia today. Exotic species do not fare well in competition with the 'native'[1] vegetation in these low nutrient environments, and have become abundant "only in those areas where nutrients have been added locally to the soils, notably along roads and railway lines and near habitation" (Beadle 1981:251).

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[1] The terms 'native' and 'natural' used in this context and later in the context of fauna, are not intended to imply that these communities have not been influenced by the actions of Aboriginal man - the implication is only that these communities are representative of vegetational and faunal associations before the arrival of European settlers in 1788.

As a consequence of these factors, since 1788, agricultural expansion has been limited to fairly small areas: pockets of soil derived from the Narrabeen series; much of the Cumberland Plain and other areas which possess relatively fertile soils derived from Wianamatta shales; and, most importantly, the alluvial terraces and plains of the Windsor-Richmond area near to the Hawkesbury-Nepean river. All other areas (effectively, the Hawkesbury sandstone plateaux and the more inaccessible areas of the other series) have been little disturbed, and are now (for the most part) designated as National Parks. The overall result of this differential preservation has been that the natural vegetation of the sandstone plateaux persists on approximately two-thirds to three-quarters of its original area; while that of the Cumberland Plain has been reduced to less than one-sixth of its original extent (Burrell 1973:73).

To a greater extent than can be said to be true of any other part of Australia (with the possible exception of the area around Perth), the vegetation of the Sydney region can be described as uniquely Australian, for it is within this area that the greatest development of endemic genera and species occurs (Beadle 1981). Most of these species are xeromorphic and sclerophyllous, that is to say, they have morphological characteristics which are related to drought resistance and are leathery-leaved and woody. Below the ubiquitous (except in coastal heathlands) Eucalyptus spp. overstorey, small evergreen shrubs with extensive root systems predominate.

Using Specht's (1970) classification of vegetation structure based upon the life form and projective foliage cover of the predominant stratum (Table 3.1), the communities of the Sydney region can be seen to range from open heathland to small communities of closed forest in a continuum of overstorey from zero (Heathland), sparse (Woodland, Low Woodland), mid-dense (Open Forest with heathy understorey) to dense (Tall Open Forest, Closed Forest). These communities have been described in full elsewhere (Pidgeon 1937, 1938, 1940, 1941; Siddiqi et al. 1972; Davis 1936, 1941a, 1941b; Clarke and Hannon 1967, 1969, 1970, 1971; Beadle 1981; see also Chapter 8 of the present volume), and the descriptions below are but a brief summary:

1. *Heath and coastal scrub*.

   Open heath vegetation is found on all three of the major rock types (Hawkesbury sandstone, Wianamatta shale and Narrabeen sandstone) in coastal situations exposed to wind and spray. Common shrub species are *Banksia ericifolia*, *Casuarina distyla* and *Hakea teretifolia*, though local species composition depends on soil depth and drainage.

   Coastal Open to Closed Scrub occurs mainly on aeolian sand dunes. Common shrubs are *Banksia integrifolia*, *Leptospernum laevigatum*, *Acacia longifolia* and *Banksia serratifolia*.

2. *Estuarine complex*.

   The estuarine complex is found on alluvial mudflats and consists of a series of zones from the water's edge:

Life-form and height of predominant strata	Projective foliage cover of predominant stratum			
	70 - 100%	30 - 70%	10 - 30%	10%
Trees 30m+	Tall closed Forest	TALL OPEN FOREST	Tall woodland	---
Trees 10-30m	CLOSED FOREST	OPEN FOREST	WOODLAND	OPEN WOODLAND
Trees 6-10m	Low closed forest	Low open forest	LOW WOODLAND	Low open woodland
Shrubs 2-8m	CLOSED SCRUB	OPEN SCRUB	Tall shrubland	Tall open shrubland
Shrubs 1-2m	Closed heath	OPEN HEATH	Low shrubland	Low open shrubland
Hummock grasses	---	---	Hummock grassland	Open hummock grassland
Herbaceous plants	Closed herbland	Herbland	Open herbland	Sparse herbland

Table 3.1: The classification of vegetation structures by life-form of the predominant strata & projective foliage cover.
(Note: Upper case denotes vegetation structures found within the Sydney region).
(Source: Specht 1970).

a). Open scrub of mangroves (*Avicennia marina* var. *australasica* and *Aegiceras corniculatum*) which receives daily inundation.

b). Saltmarsh of succulent-stemmed *Sarcocornia quinqueflora* and *Suaeda australis*.

c). Rushland with *Juncus krausii* and *Sporobolus virginicus*.

d). Swamp forest with *Casuarina glauca* or *Eucalyptus robusta*.

Where sandstone slopes meet the water's edge directly and there is no build-up of alluvium, the zonation is limited to a line of mangroves and a few *Casuarina glauca*.

3. *Low Woodland*.

Low Woodland is found on ridges and plateaux of Hawkesbury sandstone often with *Eucalyptus haemastoma* and *E. racemosa*. These dry, exposed communities have a rich shrub understorey with species of Proteaceae, Fabaceae, Epacridaceae and Myrtaceae.

Low Woodland is also found on sandy soils of Tertiary alluvium where *Eucalyptus sclerophylla* and *Angophora bakeri* are the most common species. The understorey is of shrubs, though some grasses (e.g *Themeda australis*) may occur.

4. Woodland.

Woodland is principally associated with the Wianamatta series and is dominated by Eucalyptus moluccana and E. tereticornis. Ground cover is generally grassy with patches of Bursaria spinosa. The common native grasses are Themeda australis, Eragrostis leptostachya and Aristida spp.

Woodland also occurs on sheltered hillsides and gullies of Hawkesbury sandstone where it may grade into Open Forest. The trees are principally Eucalyptus gummifera, E. oblonga and E. capitellata or E. piperita or Angophora costata. The understorey is dominated by a series of shrubs of the families Proteaceae, Fabaceae and Myrtaceae. Along creeks there is a distinctive flora containing Tristania laurina, Backhousia myrtifolia , Ceratopetalum apetalum and Callicoma serratifolia.

5. Open Forest.

Open Forests are principally associated with bedrocks of the Narrabeen series, where Eucalyptus maculata, E. paniculata, Syncarpia glomulifera, Casuarina torulosa and E. gummifera predominate in the overstorey. The rich soils derived from this series have allowed rain-forest type species to become established in sheltered areas - the principal species being: Diospyros australis, Synoum glandulosum, Glochidion ferdinandi, Ficus coronata, and Livistona australis. In more exposed areas these may be replaced by more shrubby species.

In hilly areas of Wianamatta shale, Open Forest of *E. maculata* and *E. moluccana*; or *E. crebra* and *E. fibrosa*; or *E. fibrosa* and *E. moluccana* predominate. The understorey is mainly composed of shrub species with some grass patches (e.g. *Aristida vagans* and *Themeda australis*).

In very deep, sheltered gullies upon Hawkesbury sandstone, Open Forests may occur in small patches dominated by *Eucalyptus saligna* with a limited development of ferns and rainforest-type species in the understorey.

6. Tall Open Forest.

Tall Open Forest may be found on volcanic basalt outcrops in the lower Blue Mountains. It is usually dominated by *E. amplifolia* and possesses a grassy understorey.

Tall Open Forest is also associated with recent alluvium, where *E. benthamii* or *Angophora subvelutina*, *E. amplifolia* and *E. teretifolia* predominate, with an understorey of tall shrubs (e.g. *Acacia glaucescens* and *A. floribunda*), and smaller shrubs such as *Breynia oblongifolia* and *Hymenanthera dentata* . This vegetation structure may also be found in areas of Wianamatta shale and high rainfall >1100mm p.a. (*E. pilularis* and *E. saligna* predominate). Shrubs up to two metres high are common and often form a dense cover, while on moister sites these shrubs are replaced by ferns.

7. *Swamps and sedges*.

Freshwater swamps generally consist of a series of concentric zones related to the depth, period and frequency of inundation.

a). Reedland of *Eleocharis sphacelata*

b). Rushland of *Juncus* spp.

c). Tall shrubland of *Melaleuca linariifolia*, *M. styphelioides* or *Casuarina glauca* which may grade into *Eucalyptus* woodland.

Sedgelands are found in poorly-drained sites and may also contain some shrubs such as *Baeckea imbricata* or *Melaleuca thymifolia*.

8. *Closed Forest*.

Closed Forest is limited to small areas of (at the most) a few hectares. There are extant communities on highly fertile Narrabeen series shales in the Bulli district to the south of Sydney, and in the past there were small patches to be found within the estuaries of Broken Bay and Port Jackson upon recent alluvium.

These forests have a high mineral requirement in comparison to *Eucalyptus* forests and heaths (Beadle 1981:136), and tend to be sharply delimited. *Ceratopetalum apetalum* generally occurs but is not necessarily dominant. *Toona australis*, *Livistona australis* and *Diploglottis australis* are also present. Other significant occurrences are *Ficus* spp., *Dendrocnide excelsa*, the large liana (*Piper novae-hollandiae*) and epiphytic ferns (*Asplenium nidus* and *Platycerium bifurcatum*). The understorey consists mainly of the ferns

Blechnum patersonii, Dennstaedtia davallioides, Histiopteris incisa and Pellaea falcata.

3.3.1 The vital importance of nutrients and the distribution of edible vegetation

The distribution of nutrients is the primary influence upon the characteristics of the Sydney region flora, and more importantly the edible component of that flora. For this reason, nutrient distribution can be used as a predictive tool to estimate (in broad terms) the amount of edible vegetation available to both herbivorous animals and omnivorous man within a given area. The characteristics of the nutrient cycle of phosphorus, in particular, and its vital influence upon vegetation structure must be illustrated in some detail, if this predictive function is to be fully understood.

In a series of papers, Beadle (1953, 1954, 1962, 1966, 1968; see also Groves 1979ab) has shown that the distribution of the structural associations described above is to a great extent determined by the level of phosphorus in the soil. Phosphorus is important in the energy transformations of all living things (Colinvaux 1973:206), and it is generally held to be true that the greater the level of phosphorus: the greater the productivity of the land. Thus soil fertility can be taken to imply productivity. (Here 'productivity' is assumed to mean 'edible productivity' - that part which is of direct use to man and herbivores.)

There are, in fact, few natural sources of phosphorus in any system, but the principal ones within the Sydney region are:

1. Parent material. This is the primary source. Beadle found that the phosphorus contents of parent materials varied considerably. Least phosphorus enters the Sydney regional system from the Hawkesbury series: the most from the Narrabeen series (Table 3.2).

2. Rainfall. The input is always very low - often too low to be measured. However, Allen et al. (1969) measured a range of 0.002 to 0.009 kg/ha/cm (of rain) in a broadly similar environment.

3. The soil reserve. The phosphorus content of the soil follows the general pattern of that of the parent material, but the levels are lower because of the many sources of loss (see below). Table 3.3 illustrates the levels of phosphorus in soils derived from the three principal geological series within the Sydney region - the pattern closely matches that of the contribution of parent materials.

4. Movement of animals. The addition of animal dung may enrich limited areas of the landscape. The low density of animals overall, and the lack of herding animals in the Australian context make it unlikely that this is an important source of phosphorus.

Thus, principally from parent materials, phosphorus is gained by the system at a more or less steady rate. However, large amounts of soil

Parent material	Mean value P (ppm)	Extremes
Hawkesbury sandstone	32	12-55
Wianamatta shale	630	107-1950
Narrabeen sandstone	2230	1200-3100

Table 3.2: The phosphorus content of geological parent materials within the Sydney region.
(Source: Beadle 1962).

Parent material	Mean value P (ppm)	Extremes
Hawkesbury sandstone (ridge)	37	23-53
Hawkesbury sandstone (valley)	98	65-163
Wianamatta shale	139	74-266
Narrabeen sandstone	430	230-720

Table 3.3: The phosphorus content of soils associated with the principal geological parent materials within the Sydney region.
(Source: Beadle 1962).

phosphorus may be lost from the system at far greater rates. The principal causes of loss are:

1. Erosion and deep drainage. Large amounts of phosphorus are lost on steeply-sloping surfaces, although this tends to collect elsewhere (see for example the difference between the levels of phosphorus in the dissected plateaux region of Hawkesbury sandstone upon the ridges and in the valleys). In addition, deep drainage may cause an annual loss of phosphorus from podzolized soils (Leeper 1957).

2. Fire. Loss of phosphorus is generally small relative to the amounts of other nutrients lost, but considerable in amount relative to the input of phosphorus. Table 3.4 presents data concerning the amount of phosphorus lost during a fire in a forest area of the Florentine valley in Tasmania. In a fire some of the phosphorus is lost as smoke (about 10-20%), but most becomes part of the ash, and may be retained in the surface soil in an insoluble form; added by rapid leaching to the soil solution where it becomes available to plants; leached out of the root zone completely; or lost through wind or rain action.

3. Herbivory. A variety of nutrient retaining mechanisms which shrub plant formations possess, make it unlikely that herbivory is a major source of phosphorus loss (see below).

In addition to the effects of these losses, phosphorus may not be available to plants for other reasons. In particular, the structural

	Before fire	After fire
Leaves	1.9	----
Bark	0.2	----
Twigs	16.0	----
Wood	18.0	4.1
Logs	34.6	27.7
Man fern	4.4	2.2
Litter	21.3	5.8
	96.4	39.8
Ash		46.6
		86.4

Table 3.4: The phosphorus loss associated with burning. Florentine Valley, Tasmania.
(Note: Loss to atmosphere = 10 kg/ha).
(Source: Harwood & Jackson 1975).

characteristics of the flora may slow down the phosphorus cycle. Within the Sydney region, for example, plants most often store phosphorus in modifications of the root system, scarcely any is stored above ground - a fact which has important consequences for the distribution of phosphorus - for little of the flux occurs in the form of litter decomposition. Indeed, many species mobilize and translocate phosphorus compounds out of the senescing tissue prior to leaf fall (Gill (1981b:165) suggests that this withdrawal may be as high as 70-80% of the phosphorus). In addition, other parts of the flora (particularly Banksia spp. (Proteaceae) and Xanthorroea spp. (Xanthorrhoeaceae)) lose phosphorus through fruit or dead leaves, and this phosphorus is effectively removed from the system until the next firing because decomposition of litter may take between 1.5 to 2.5 years - owing to the depauperate status of the litter fauna (Specht 1979b; Edmonds & Specht 1979).

Corroborative evidence for the fundamental role of phosphorus in the distribution of vegetation comes from Hannon's (1956, 1958, 1961) analysis of the distribution of nitrogen in the Hawkesbury sandstone areas (see also Burrough et al. 1977). The nitrogen deficiency is a reflection of the lack of phosphorus, for nitrogen is a ubiquitous element, whose presence is only limited by the degree of energy transference determined by the levels of presence of other nutrients. Figure 3.2 indicates the general relationship between understorey species and phosphorus and nitrogen levels (Stace et al. 1968) - the phosphorus content of all areas of shrubland is small compared with areas of herbaceous understorey. As soils increase in phosphorus content heath/shrub flora diminish and grass

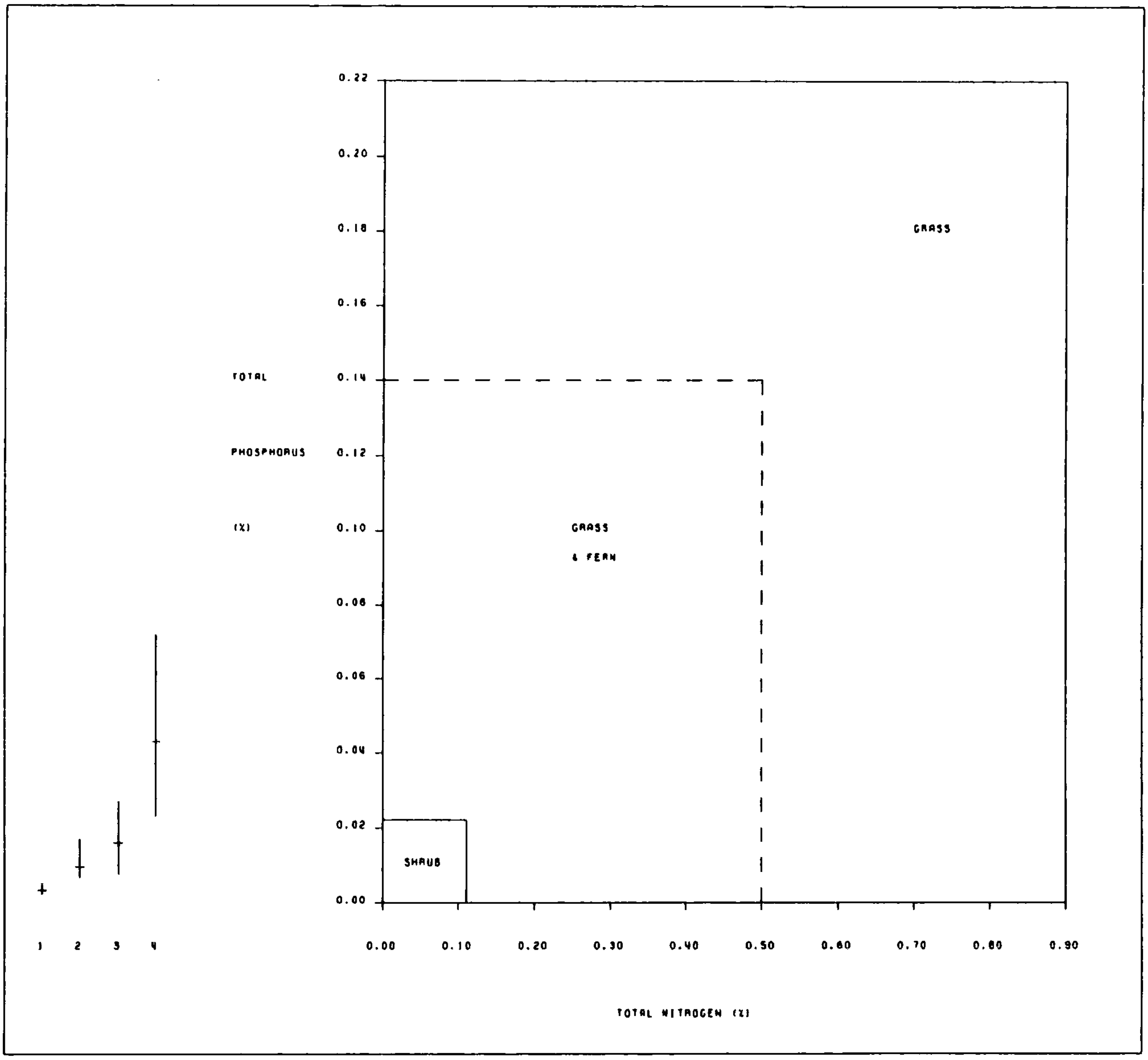

Figure 3.2: Edaphic relationships (based upon phosphorus and nitrogen levels in surface soils) of scrub, grass/fern and grass communities and a comparison with the phosphorus contents of Sydney region soils.
(Note: No data concerning nitrogen contents is available.
1 = Hawkesbury sandstone (ridge)
2 = Hawkesbury sandstone (valley)
3 = Wianamatta shale
4 = Narrabeen sandstone
Mean values of phosphorus are marked.)
(Data: Stace et al. 1968 & Beadle 1962).

dominated flora increase (Specht 1981:272). Table 3.5 presents data which illustrate this pattern.

The vital importance of phosphorus lies in its relationship to edible productivity - as the phosphorus level increases so does the component of the flora available to herbivores and omnivores. Owing to the fact that the principal sources of phosphorus within the Sydney region are the geological parent materials, it is possible to broadly predict the occurrence of edible production upon the basis of geological distribution. Thus, least edible production is likely to be available in Hawkesbury sandstone areas; and most in Narrabeen sandstone areas. This effect on the distribution of edible production may also be amplified by topographic influences - points of nutrient accretion (such as valley bottoms and wetlands) are likely to possess a more abundant edible flora than points of nutrient loss (such as ridge tops). It should be noted that as phosphorus is essentially available only from parent materials, and the cycle of this nutrient is severely limited; any tendency toward increased loss, for example through the increased frequency of fire, is likely to reduce the edible component of the flora (a point which is expanded below with regard to Aboriginal fire-use).

The complexity of the phosphorus cycle within the Sydney Region, then, has fundamental consequences concerning the distribution of edible flora. This in its turn has important influences upon the distribution of fauna.

	Scrub	Herb
Phosphorus (%P)	0.007 ± 0.0009	0.026 ± 0.0041
Nitrogen (%N)	0.074 ± 0.0104	0.127 ± 0.0123

Table 3.5: The phosphorus and nitrogen contents of soils supporting scrub or herbaceous understoreys in South Australia.
(Source: Specht 1979b).

3.4 PRE-SETTLEMENT FAUNA

The extant vertebrate fauna within the region numbers as many as seven hundred and ninety six species - 25 mammal, 50 reptile, 35 amphibian, 300 fish and 386 bird (Recher, 1973). However, few of these species are resident in the shrub-dominated areas of the region (Figure 3.3). Most utilize such areas opportunistically - according to the asynchronous flowering rhythms.

In the following section, the development and associations of the Sydney fauna are reviewed and the environmental constraints acting upon them are introduced. The data can conveniently be divided into six major categories: mammals, reptiles, amphibians, fish, birds and invertebrates.

MAMMALS

Most species recorded in the region are principally associated with areas which possess an understorey which is not dominated by shrubs. These latter areas are of marginal importance in terms of food. Exceptions to this general rule are small species with a small range; and species which have a close association with shrubland as part of their range because of the proximity of wetlands or patches of abundant pollen and nectar.

The abundance of mammals in shrub-dominated landscapes is thought to be highly correlated with nutrient distribution (Kikkawa et al. 1979; Dwyer et al. 1979ab; see also Brown 1967) and (more locally)

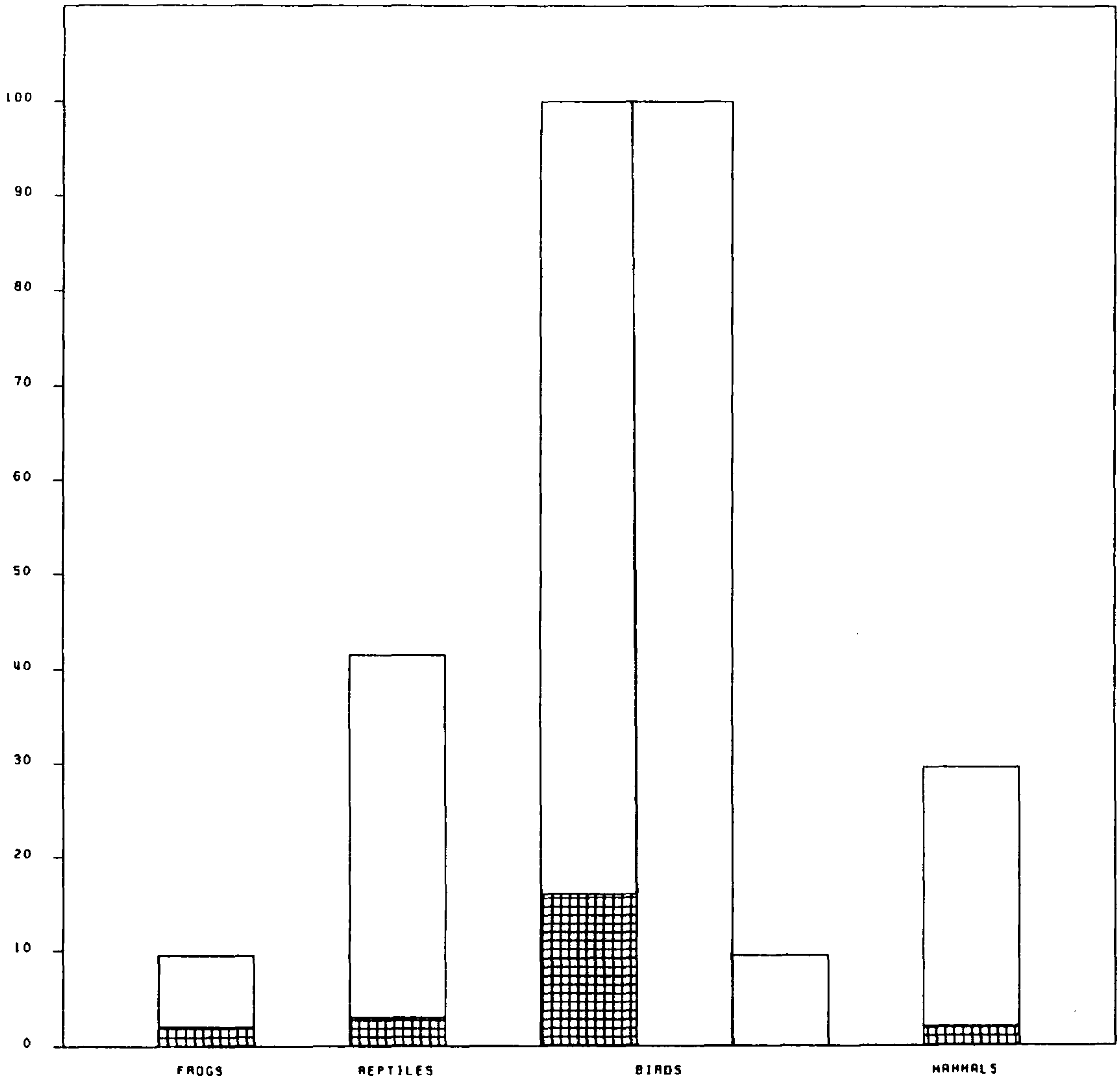

Figure 3.3: The number of faunal species represented within the Sydney region by vertebrate class.
(Note: Shading indicates the number of species in each class displaying a special relationship with shrub-dominated areas.)
(Source: Kikkawa et al. 1979; Modified by the extraction of introduced species.)

with the degree of lateral cover (Caughley 1964; Taylor 1980). Only one species, the rock wallaby (Petrogale penicillata), is known to have a close relationship with any other environmental characteristic - it is closely associated with rocky substrates (Kikkawa et al. 1979).

Table 3.6 lists the mammal fauna of the Sydney region, and illustrates broad habitat preferences of species (based particularly upon the works of Marlow (1958, 1962), Troughton (1965) and Ride (1970)).

REPTILES

There are eight reptile families represented in the Sydney region (Chelidae (1 species), Gekkonidae (4), Pygopodidae (2), Agamidae (4), Varanidae (2), Scincidae (16), Typhlopidae (1) and Elapidae (10)). Of these only two species are restricted to the shrub-dominated areas associated with Hawkesbury sandstone - Hoplocephalus bungaroides (Elapidae) and Phyllurus platurus (Gekkonidae).

Storr (1964) has suggested that the distribution of reptiles is influenced more by substrate than by vegetation, and indeed, the associations of the Gekkonidae within the region is most frequently with rocky outcrops. None of the other species, however, seems to display any similar preferences in this regard. Table 3.7 lists those species present in the Sydney region.

Species	Common name	Status	Habitat
MACROPODIDAE (Herbivorous, mainly nocturnal but larger species partly diurnal).			
Macropus giganteus	Grey kangaroo	extant	TOF, OF, WOOD
M. robustus	Euro	extant	OF
M. rufogriseus	Red-necked wallaby	extant	CF, TOF, OF, WOOD, CS, OS
Petrogale penicillata	Rock wallaby	extant	OF
Potorous tridactylus	Potoroo	extant	CF, TOF, OF
Protemnodon parma	Parma wallaby	extant	CF, TOF
Thylogale thetis	Red-necked pademelon	extant	CF, TOF
T. stigmatica	red-legged pademelon	extant	CF, TOF
Wallabia bicolor	Swamp wallaby	extant	CF, TOF, OF
PHALANGERIDAE PETAURIDAE BURRAMYDIAE PHASCOLARCTIDAE (Nocturnal, arboreal, omnivorous to vegetarian. Some species have gliding membrane)			
Trichosurus vulpecula	Brush-tailed possum	extant	CF, TOF, OF
Petaurus australis	Yellow-bellied glider	extant	CF, TOF, OF
P. breviceps	Sugar glider	extant	CF, TOF, OF, WOOD
P. norfolcensis	Squirrel glider	extant	CF, TOF, OF, WOOD
Pseudocheirus peregrinus	Ring-tailed possum	extant	CF, TOF, OF, WOOD
Schoinobates volans	Great glider	extant	CF, TOF, OF, WOOD
Acrobates pygmaeus	Pygmy glider	extant	CF, TOF, OF, WOOD
Cercatetus nanus	Pygmy possum	extant	CF, TOF, OF, WOOD
Phascolarctus cinereus	Koala	extant	OF, WOOD

Table 3.6: The mammals of the Sydney region, their status and principal vegetational associations.
(Note: CF = Closed Forest; TOF = Tall Open Forest; OF= Open Forest; WOOD = Woodand; WET = Wetland; RIVER = Riverine. 'Special' indicates those species which possess a special association with shrub-dominated areas.)
(Sources: Marlow 1958, 1962; Troughton 1965; Kikkawa et al. 1979; Aplin 1981; Attenbrow 1976)

VOMBATIDAE (Nocturnal, omnivorous)			
Vombatus ursinus	Common wombat	extant	CF, TOF, OF
V. hirsutus	Hairy-nosed wombat	extant	CF, TOF, OF
PERAMELIDAE (Nocturnal, terrestrial & omnivorous)			
Isoodon macrourus	Short-nosed bandicoot	extant	TOF, OF, WOOD
Parameles nasuta	Long-nosed bandicoot	extant	CF, TOF, OF
DASYURIDAE (Nocturnal, terrestrial insectivorous to carnivorous)			
Antechinus flavipes	Yellow-tailed antechinus	extant	CF, TOF, OF
A. maculatus	Pigmy marsupial mouse	extant	CF, TOF, OF
A. stuartii	Brown marsupial mouse	extant	CF, TOF, OF, WOOD
A. Swainsonii	Dusky marsupial mouse	extant	CF, TOF, OF, WOOD
Dasyurus maculatus	Tiger cat	extant	CF, TOF, OF, WOOD
D. viverrinus	Quoll	extant	TOF, OF
Phascogale tapoatafa	Brush tailed phascogale	extant	CF, TOF, OF
Sminthopsis leucopis	White footed marsupial mouse	special	TOF, OF
S. murina	Common dunnart	extant	TOF, OF, WOOD
MURIDAE (terrestrial, omnivorous)			
Hydromys chrysogaster	Eastern water rat	extant	WET
Pseudomys gracilicaudatus	Queensland thetomys	special	OF, WOOD
P. novaehollandiae	Eastern pseudo-rat	special	OF, WOOD
Rattus fuscipes	Southern bush rat	extant	CF, TOF, OF, WOOD
Rattus lutreolus	Eastern swamp rat	extant	WET

Table 3.6: The mammals of the Sydney region (continued).

TACHYGLOSSIDAE (Terrestrial, nocturnal)			
Tachyglossus aculeatus	Echidna	extant	CF, TOF, OF, WOOD
ORNITHORHYNIDAE (Aquatic)			
Ornithorhynchus anatinus	Duck-billed platypus	extant	RIVER
VESPERTILIONIDAE RHINOLOPHIDAE PTEROPODIDAE (Bats, nocturnal & insectiverous)			
Chlalinolobus gouldii	Gould's wattled bat	extant	CF, TOF, OF, WOOD
Eptescius pumilis	Little brown bat	extant	CF, TOF, OF, WOOD
Miniopterus schreibersii	Bent-winged bat	extant	CF, TOF, OF, WOOD
Myotis australis	Long-eared bat	extant	CF, TOF, OF, WOOD
Nycticeius greyii	Long-eared bat	extant	CF, TOF, OF, WOOD
N. rueppelii		extant	CF, TOF, OF, WOOD
N. timorensis	Greater long-nosed bat	extant	CF, TOF, OF, WOOD
Rhinolophus megaphylus	Eastern Horseshoe bat	extant	CF, TOF, OF, WOOD
Pteropus poliocephalus	Grey-headed fruit bat	extant	CF, TOF, OF, WOOD
P. scapulatus	Red flying fox	extant	CF, TOF, OF, WOOD
CANIDAE (terrestrial, carnivorous)			
Canis familiaris dingo	Dingo	extant	CF, TOF, OF, WOOD

Table 3.6: The mammals of the Sydney region (continued).

SEA MAMMALS (seasonal, winter & spring)			
Balaena glacialis australis	Southern right Whale	extant	offshore/ stranded
Megaptera novaeangliae	Humpback Whale	extant	offshore/ stranded
Orcinus orca	Killer whale	extant	offshore/ stranded
Globicephala melaena edwardii (uncommon)	Pilot whale	extant	offshore/ stranded
Physeter catadon (uncommon)	Sperm whale	extant	offshore/ stranded
SEALS (seasonal, winter & spring uncommon)			
Arctocethalus pusillus doriferus	Australian fur seal	extant	Island, beach
Hydrurga leptonyx	Leopard seal	extant	Inshore/ (rare) beach
Mirounga leonina	Southern elephant seal	extant	Inshore/ (rare) beach

Table 3.6: The mammals of the Sydney region (continued).

Species	Common name	Species	Common name
CHELIDAE		GEKKONIDAE	
Chelodina longicollis	Long-necked tortoise	Diplodactylus vittatus	Wood gecko
		Oedura lessueurii	Lessueur's gecko
		Phyllurus platurus (special)	Southern Leaf-tailed gecko
		Underwoodisaurus millii	Thick-tailed gecko
PYGOPODIDAE		AGAMIDAE	
Lialis burtonis	Burton's snake-lizard	Amphibolurus barbatus	Bearded dragon
Pygopus lepidopodus	Common scaly-foot	A. diemensis	Mountain dragon
		A. muricatus	Jacky lizard
		Physignathus lesueurii	Eastern water dragon
VARANIDAE		TYPHLOPIDAE	
Varanus gouldii	Sand monitor	Ramphotyphlops australis	Unnamed (burrowing lizard)
V. varuius	Lace monitor		
BOIDAE		COLUBRIDAE	
Morelia spilota	Diamond python	Boiga irreularis	Brown tree snake
		Dendrelaphis punctulatus	Common tree snake

Table 3.7: The reptiles of the Sydney region.
(Note: 'special' indicates those species which possess a special association with shrub-dominated areas. Asterix (*) indicates those species which are thought to be 'highly dangerous'.)
(Sources: Cogger 1975; Kikkawa et al. 1979)

ELAPIDAE		SCINCIDAE	
Acanthopsis antarcticus	Common death adder*	Anomalopus spp. (special)	Unnamed limbless skink
Cacophis squamulosus	Golden crowned snake	Carlia amax	Unnamed skink
Cryptophis nigrescens	Eastern small-eyed snake*	Ctenotus rubustus	Unnamed skink
Demansia psammophis	Yellow-faced whip snake	C. taeniolatus	Copper-tailed skink
Furina diadema	Red-naped snake	Egernia cunninghamia	Cunningham's skink
Hemiaspis signata	Black-bellied swamp snake	E. whitii	White's snake
Hoplocephalus bungaroides (special)	Broad-headed snake	Lampropholis delicata	Unnamed
Notechis scutatus	Eastern tiger snake*	L. guichenoti	Unnamed
Pseudechis porphyriacus	Red-bellied black snake	L. mustelina	Weasel skink
Pseudonaja textilis	Eastern brown snake*	Leiolopisma platynota	Red-throated skink
		L. trilineata	Unnamed
		Omolepida casuarinae	Unnamed
		Saiphos equalis	Unnamed
		Sphenomorphus quoyii	Eastern water skink
		S. spp.	Unnamed
		Tiliqua scincoides	Eastern blue-tongued lizard

Table 3.7: The reptiles of the Sydney region (continued).

AMPHIBIANS

Of the four families which constitute the amphibian fauna of Australia (Myobatrachidae, Hylidae, Microhylidae and Ranidae), only the Myobatrachids (6 species) and the Hylidae (3 species) contribute to the resident fauna of the region. Of these only Pseudophryne australis (Myobatrachidae) displays a special association with areas possessing a predominantly shrub understorey (Table 3.8).

FISH

Nearly three hundred species of fish have been collected from Sydney waters and it has been suggested that all 700 species occurring on the New South Wales coast should sooner or later be found here (Recher 1973). Table 3.9 lists the species which form seasonal shoals.

BIRDS

The species of birds which utilize the Sydney region are far too numerous to list here (72 families: 386 species). In general, their association with shrub-dominated areas is opportunistic and they are, for the most part, non-exclusive in their usage. A few species of small birds do show a special association with flowering shrubs - particularly nectivorous birds of the Ephthianuridae (1 species) and Artamidae (3 species). Table 3.10 lists the larger birds and their preferred habitats.

It should be noted that (in addition to the 386 resident species) a number of migrant seabird species may also make use of the region's

Species	common name	Species	common name
MYOBATRACHIDAE		HYLIDAE	
Heleioporus australiacus	Giant burrowing frog	Litoria caerulea	Green tree frog
Limnodynastes ornatus	Ornate burrowing frog	L. jervisiensis	Jervis Bay tree frog
L. peronii (special)	Brown-striped frog	L. peronii	Peron's tree frog
Pseudophryne australis (special)	Red-crowned toadlet		
Ranidella signifera	Common eastern froglet		

Table 3.8: The amphibians of the Sydney region.
(Note: 'special' indicates those species which have a special association with shrub-dominated areas.)
(Source: Cogger 1975)

Species	Common name	Coast	Estuary
Acanthropagrus australis	Yellowfin bream	*	*
Argyrosomus hololepidotus	Mulloway	*	*
Arripis trutta	Australian salmon	*	
Chrysophrys auratus	Snapper	*	*
Girella tricuspidata	Luderick	*	*
Liza argentea	Flat-tailed mullet	*	*
Monocanthus chinensis & Meuschenia trachylepis	Leatherjacket	*	*
Mugil cephalus	Sea mullet	*	*
Platycephalus fuscus	Dusky flathead		*
Pomatomus soltatrix	Tailor	*	*
Sillago ciliata	Sand whiting		*

Table 3.9: The shoaling fish of the Sydney region and their principal habitats. (Source: New South Wales Fisheries 1982)

Species	Common name	Habitat
DROMAIIDAE		
Dromaius novaehollandiae	Emu	OF, WOOD
ANATIDAE		
Anas castaneae	Chestnut teal	WET
A. gibberifrons	Grey teal	WET
A. rhynchotis	Shoveller	WET
A. superciliosa	Black duck	WET
Aythya australis	Hardhead	WET
Biziura lobata	Musk duck	WET
Chenonetta jubata	Wood duck	WET
Cygnus atratus	Black swan	WET
Malalacorhynchus membranaceus	Pink-eared duck (rare)	WET
Tadora tadornoides	Mountain duck	WET

Table 3.10: The larger birds of the Sydney region and their principal habitats.
(Note: OF = Open Forest; WOOD = Woodland; WET = Wetland)
(Sources: Kikkawa et al. 1979; Frith 1967)

Species	Common name	Coast	Estuary
Anadara trapezia	Sydney cockle		*
Cellana spp.	Limpet	*	
Crassostrea commercialis	Sydney rock oyster	*	*
Mytilus planulatus	Edible mussel	*	*
Ostrea angasi	Mud oyster		*
Patellanax patelloides	Limpet	*	
Plebidonax deltoides	Pipi	*	
Pyrazus ebeninus	Mud whelk		*
Trichomya hirsutus	Hairy mussel		*

Table 3.11: The principal shellfish species of the Sydney region. (Source: Sullivan 1982)

coastline during the winter and early spring (see Gaughwin 1978).

INVERTEBRATES

A large number of both estuarine and marine species of shellfish are represented in the region. The freshwater mussel (Velesunio spp.) is also widespread but seldom numerous. Table 3.11 is limited to those species which are both common and are found in dense communities.

The number of insect species within the Sydney region is probably very great, although populations are likely to be more limited in shrub-dominated environments because of the lack of nutrients in the litter (Edmonds & Specht 1979).

3.4.1 Influences upon the diversity, abundance & distribution of terrestrial fauna

As has been suggested above, despite the high floristic diversity of the region (Beadle 1981), available productivity is low as a consequence of the low nutrient status of the substrate. The energy available to animals in shrub-dominated environments can thus be seen to be a severely limiting factor in comparison to habitats such as grasslands which have a similar primary biomass (Kikkawa et al. 1979). In fact, low abundance and diversity have been reported in shrub-dominated areas for: foliage insects and litter fauna (Edmonds and Specht 1979); birds (Bell 1966; Recher 1969; see also Dwyer 1972); and mammals (Dwyer et al. 1979ab).

A particular characteristic of shrub vegetation is that the flora's 'requirement' of efficient nutrient retention has resulted in adaptations which make herbivory hazardous. Janzen (1974), for example, has suggested that the exceptionally high concentrations of tannins and other phenols in shrub-dominated areas would have a debilitating effect on closely associated animal communities; and it is very likely that the poor representation of large herbivorous animals within the Sydney region should be understood in this context (Kikkawa et al. 1979). (There is, however, some evidence that at least a few mammals are able to detoxify these chemicals - particularly, Macropus fuliginosus, Trichosurus vulpecula and Rattus fuscipes (Oliver et al. 1977).)

Additional nutrient constraints upon herbivory occur as a more direct consequence of nutrient deficiencies within the Sydney environment: particularly those related to the distribution of dietary phosphorus and copper at the coast, and sodium in more montane habitats (Kikkawa et al. 1979; Coaldrake 1961).

As a consequence of these direct and indirect influences of nutrient distribution, food chains tend to be reduced and simplified, and most of the vertebrates which utilize shrublands do so opportunistically. For the most part, they occupy the most consistently productive habitats and only occupy others in response to particularly productive phases of the local vegetation. In terms of optimal foraging theory, herbivores tend to utilize patches of higher rank than are associated with shrub-dominated areas for most of the time. Only when the potential returns of 'shrub patches' rise above the average for the environment as a whole, would herbivores be expected to make use of them (cf. Lee & Cockburn 1985). In fact, insectivory and nectivory are the only major feeding strategies available to vertebrates in shrub-dominated environments. The generally low densities of primary consumers and decomposers constrains the former strategy: the asynchronous flowering regimes of plants, the latter.

The specific effects of all these nutrient effects upon faunal distribution in a landscape constructed of areas of different natural fertility have been examined by Dwyer et al. (1979ab) in the Cooloola and Beerwah region of coastal south-east Queensland (a broadly similar environment to that of the Sydney region). The results of their analysis clearly demonstrate that as nutrient levels increase so does the abundance of fauna. Dwyer et al. (op.cit.) explain this greater degree of association with areas of higher natural fertility within their study area in the following ways:

1. The vegetation contains lower concentrations of toxins and consequently permits a greater degree of herbivory.
2. The vegetation is of a higher nutritive value because productivity rates and hence turnover, are higher and/or
3. There is a shift in floristics.

Newsome and Catling (1979) have drawn similar conclusions from their study in the Nadgee National Park in southern New South Wales, where they observed a trend in the abundance of small mammals from coastal heathland to swamps (number of animals trapped 21 vs 260), while tracks of larger mammals, followed the same pattern, being least common in heathland and most numerous in sclerophyll forest. For both small and large mammals, it is reasonable to assume that faunal abundances in this area - as in the Cooloola and Beerwah region - followed the pattern of nutrient availability (broadly, from heathland to forest to wetland).

On the basis of both general principles and the results of these field studies, it is reasonable to suggest that the abundance of the native fauna in the Sydney region is likely to follow a general trend from low density associated with soils derived from Hawkesbury sandstone, to relatively higher density in areas of soils derived from the Narrabeen series; and in wetlands. In addition, other points of nutrient accretion (such as valley bottoms) are likely to possess a relatively higher density of fauna than points at which nutrients are lost (such as ridge tops).

3.4.2 Fire history and the development of the fauna

While the relationship between faunal abundance and nutrient distribution is probably a fundamental characteristic of the Sydney region, an underlying limitation upon the diversity and abundance of fauna is likely to have also been imposed by elements of fire history. The present vegetation of the Sydney region is principally composed of fire-tolerant and fire-dependent species. Indeed, it is true to say that fire is endemic within the region.

Catling & Newsome (1981) have considered how fire may have influenced the Australian fauna over time, and propose eight characteristics which might be expected of a fire-influenced fauna. These characteristics and the information which these authors use to indicate the validity of the propositions are summarized below:

1. <u>Archaic forms would survive in the least fire-prone habitats</u>.

   There is considerable evidence which suggests that 'primitive' forms of birds (for example, bowerbirds) and mammals (echidna) are limited in their distribution to wet environments. Forms which are seen as more 'advanced' live in the drier, fire-prone eucalypt forests, woodlands and xeric habitats (op.cit:277). Among the marsupials, the Dasyuridae are considered to be the primitive form, and such species as the Tasmanian devil and wolf, <u>Antechinus</u> spp., and the bandicoot are (or were) principally associated with rainforest areas (op.cit:279).

2. <u>Species diversity overall would be low</u>.

   The Australian mammalian fauna is usually regarded as depauperate (op.cit:279). This may, to some extent, be attributable to changes brought about in the vegetation by fire. Catling and Newsome (op.cit:280) suggest that there may have been insufficient time for an evolutionary response to the increased incidence of fire and as a consequence it is only the survivors of that impact which we see today.

3. There would be 'fire specialists'.

There is some suggestion that fire specialists do occur among the Australian fauna. (A 'fire specialist' is an animal whose existence depends upon fire.) For example, the ability of the reptile *Amphibolurus fordi* to lapse into a state of dormancy and cease to grow in dry summers may be viewed as an adaptive response to a predictable increase in fire frequency, while the ground parrot *Pezoporus wallicus* also appears to be adapted to heath fire regimes - the population size grows after a fire until the heath vegetation reaches about knee height, when the population falls again (op.cit:281); though this and other associations noted in bird species may represent opportunistic behaviour rather than a particular fire specialism.

After fires a number of mammals, from small *Antechinus* spp. to large macropods, have been observed to increase in population size. As in the case of avifaunal behaviour, these responses may simply be opportunism rather than fire specialism *per se*. However, The rat kangaroo (*Bettongia penicillata*) possesses behavioural characteristics which are the closest to those that might reasonably be expected of a fire specialist. The species prefers the shelter afforded by *Casuarina* and this particular habitat requires fire every seven years or so in order to be maintained (op.cit:283). More generally, similar dependence has been suggested for the quokka, the western hare wallaby and some murid rodents.

4. The seral response would be truncated.

Due to the high frequency of fire within the Australian environment it might be expected that the associated fauna would be adapted to short seral responses or be able to withstand fire altogether. Catling & Newsome suggest, from their data concerning the major fire at Nadgee Nature Reserve (and fires elsewhere), that although major changes in abundance occur after a fire there is no evidence of a long seral response (op.cit:289). Data concerning native rodents suggests a quick regeneration time of around 3 to 5 years and a need for fire every decade or so for further regeneration. However, information about macropod response to fire suggests that numbers decline after a fire, and remain low while most other species are increasing, until approximately three years after the fire (op.cit:293).

5. Species diversity would be highest in the least fire-prone habitats.

In fact the greatest species diversity occurs in eucalypt forest, not in the least fire-prone (rainforest). Catling & Newsome suggest that this is consistent with the suggestion that the fauna have evolved in close association with *Eucalyptus* forests. When these forests are divided into their wet and dry components the proposition is supported, in that the greater species diversity is to be found in the former forests.

6. Reproductive patterns would be modified.

Higher rates of reproduction might be expected in the most fire-prone environments. Catling and Newsome present data concerning the reproductive potential of three possums, *Schoinobates volans* (great gilder: wet sclerophyll forest: upper canopy), *Trichosurus vulpecula* (brush-tailed possum: dry sclerophyll forest: middle and lower canopy) and (*Pseudocheirus peregrinus* (ring-tailed possum: dry sclerophyll forest: lower canopy). Of the three species, the glider (which is closely associated with wet sclerophyll forest) has the lowest reproductive potential (0.6, 1.4, 1.7 young p.a. respectively); the lowest mortality in the first year (0.2, 0.5-0.8, 0.7 respectively); and has the best defined and shortest breeding season.

In addition, many macropods are known to breed opportunistically which circumvents reduction or complete loss of reproductive effort in any year through the action of fire (op.cit:300).

7. There would be a prevalence of ecological generalists.

Where fire is frequent, species may be selected for their ability to adapt to a wide range of conditions: in forests infrequently fired there could be more time for specialization to occur (op.cit:300).

The expectation would be that in fire prone environments a few common species broadly adapted to the environment, rather than many specialised specialists, would occur. A comparison between the specialist glider (Schoinobates volans) and the closely related (but more widely distributed) ring-tailed possum (Pseudocheirus peregrinus) suggests this is so. The large predator, Dingo (Canis familiaris dingo), is known to adopt a generalist strategy with regard to diet, after a fire - and appears to be the least affected of all mammals.

8. There would be few forms in the lowest strata of vegetation.

In areas with shrub understoreys (but also, to a lesser extent, in areas with grass understoreys) it is expected that few species would inhabit the bottom layers because of the frequent disruption caused by fire. Recher (1969) has been able to show that the lowest species diversity occurs in the lowermost 1.5m of both dry and wet sclerophyll forest within the Sydney region and that the number of species in heath habitats was lower than the forest. Only one mammal, the honey possum (Tarsipes spencerae), exploits the shrub layer for food (nectar and pollen) and possesses highly specialized anatomical features to this end.

The evidence supplied by Catling and Newsome clearly suggests that the influence of fire history is likely to be an underlying factor in the abundance and diversity of vertebrate fauna within the Sydney region. However, the principal influences are likely to be so closely associated with the characteristics attributable to nutrient distribution that the two are likely to be indivisible (and, indeed, the two influences are likely to be interrelated). The tendency toward greater faunal abundance as the vegetational structure tends toward Tall Open Forest and lower fire frequency, for example, closely parallels the expected pattern associated with nutrient distribution.

3.4.3 Limiting factors, terrestrial faunal distribution and prediction - a summary

The preceding discussion has attempted to demonstrate that two fundamental and closely-related constraints of predictive significance, are likely to have influenced the abundance, diversity and distribution of faunal populations within the Sydney region. Firstly, the distribution of essential nutrients influences the fauna both directly through dietary deficiencies and indirectly through an association with degrees of sclerophylly, and hence with amounts of edible production and levels of toxicity. Secondly, the extant faunal community is closely associated with a flora which is adapted to frequent fire - some floral elements depending upon it for reproduction and some adapted to encouraging it (for example, through the production of volatile oils). The extant species of fauna associated with the eucalypt forests are likely to be those which during the period since the Tertiary, have been able to adapt to changes occurring in the vegetation toward fire-dependence and tolerance. (There are, in fact, some indications that faunal adaptations may have lagged behind vegetative change (for example, this may be the reason for the depauperate status of the fauna).)

The combined effect of these two fundamental influences permits the prediction of the relative abundance of faunal species within the variety of vegetational structures which characterize the Sydney region. Faunal abundance should be greatest in areas which support Tall Open Forest and wetlands (because these are associated with high natural fertility or nutrient accretion and relatively low fire frequency) and lowest in those areas which support Low Woodland and Heath (because they are associated with areas of low fertility, nutrient loss and high fire frequency). Owing to the fundamental role of phosphorus in the development of the vegetation structures of the Sydney areas, the relative abundance of the fauna is likely to be very closely associated with the distribution of parent materials.

3.5 THE SYDNEY BIOTA, FIRE AND THE ABORIGINES

The role of fire in the development of the biotic community is, as has been indicated, an important one for Australia as a whole, and for the Sydney region in particular. Natural fires occur with greater frequency in shrub-dominated environments than in any other vegetational zone, and as a consequence tendencies toward fire-related adaptations tend to be pronounced. In Chapter One, it was indicated that the suggestion that the Aborigines were the principal cause of widespread vegetational change through policies of deliberate firing (Tindale (1959), Jones (1968, 1969, 1975) Hallam (1975) and Hughes & Sullivan (1981)) has been maintained among archaeologists, at the expense of seeing causation in comparatively subtle climatic changes with the role of man limited to possible influences in the rate of change (Horton, 1982; Clark 1983; Rowland 1983; see Nicholson 1981 for a review of Aboriginal fire use). While 'fire-stick farming' (Jones 1969) may yet be productive behaviour in savanna environments (Jones 1980b), a case can be made for not viewing Aboriginal fire-use as adaptive behaviour either in the long- or (for the most part) short-term in shrub-dominated environments.

In general, however, it is important to note that concepts of succession and climax have changed greatly in recent years (Wright & Heinselman 1973). The idea of fire disturbing the equilibrium of vegetation and returning it to an earlier successional stage, which is central to much of the argument for the influence of Aboriginal firing through time is probably unfounded (Noble & Slayter 1981; see also Horn 1974). Studies of successional change in Australia have shown that all species present before a fire regenerate soon afterwards (Purdie & Slayter 1976). Particularly in shrubland areas like the Sydney region, the majority of the species quickly re-establish themselves from lignotubers, rhizomes, corms and bulbs - this regeneration is rapid in all seasons because shoot growth can occur throughout the year (Specht 1979b:143; 1981:257).

In the light of this information it can be seen that, within the Sydney region, persistent burning would certainly not be adaptive behaviour - no obvious benefits would accrue. Indeed, the principal effect of firing in excess of the high rate of natural fire occurrence is likely to have been an increase in the loss of the already limited and limiting supply of nutrients (particularly phosphorus; see above), and a concomitant increase in the sclerophyllous nature of the flora. This latter effect would reduce the amount of food available to all members of higher trophic levels.

In addition, the effects of persistent and extensive Aboriginal firing of the vegetation would be likely to influence the fauna in other deleterious ways:

1. It would cause further depletion in abundance in all sizes of vertebrates (Newsome et al. 1975), which are already low in abundance within the area because of nutrient constraints. After the fire the population of small mammals would decline most markedly, but all animals would take a considerable time to reach their pre-fire densities. In addition, extensive firing would decimate the insect populations and decomposers and thus slow down the (already limited) redistribution of nutrients.

2. It would reduce food and shelter for the survivors until shrubs sprouted from their underground parts. The loss of shelter might be particularly damaging to the faunal population in that animals would be exposed to the full rigours of summer heat or winter cold.

3. In addition, there is evidence to suggest that there would be an

increase in competition between humans and dingoes after a fire - Newsome et al. (1975) report that dingoes switch their prey from small mammals to wallabies and kangaroos.

4. On a purely practical level, fire would destroy the runways of small and large animals through the dense shrub undergrowth, thus reducing their predictability.

However, the effects of small burns may exert less drastic influences upon the shrub-dominated environment, yet their influence over time may be significant enough to indicate that even this may be maladaptive behaviour. For example, small burns are known to attract the grey kangaroo (Macropus major) to new shoot growth (Dwyer et al. 1979b) - yet, the benefits of this attractive property to a predator, may be largely offset by the macropods requirement of dense cover nearby and their increased wariness. In addition, the increased grazing pressure upon these small areas of good feed surrounded by areas of low nutritional value, would prevent the regeneration of palatable species, which could have a significant impact upon edible production over time.

The relationship between the biota and frequent or infrequent burning is summarized in Table 3.12 (Main 1979). Overall, it is clear from the available data concerning shrubland-dominated environments that frequent or infrequent small burns would favour unpalatable species (cf. Dewitt & Derby 1955); while large burns destroy the faunal populations and shelter available to recolonizing herbivores. Dwyer et al. (1979a) at the end of

	Shelter for herbivores	Grazing by herbivores	Regeneration of palatable species	Source of reinvasion by invertebrates
Small burn	Adjacent	Intense	Severely affected by grazing	Close
Large burn	Distant	May be absent	unaffected by grazing	Distant

	Frequency of fire		Nutrient loss	Nutrient gain
	Frequent	infrequent		
Small burn	Favours fast reproducing unpalatable species	Favours unpalatable species	Limited	Accumulated in shelter areas
Large burn	Favours fast reproducing weedy species	Maintains plant diversity	Great	Nutrients may not be shifted

Table 3.12: The effects of small and large burns within shrub-dominated environments.
(Source: Main 1979)

their study of the ecology of a shrub-dominated region on the south-eastern Queensland coast, concluded that the nutritional rewards to be reaped by the Aboriginal use of fire in such an environment would be scant, and it is reasonable to assume that (at least) the same would be true in the Sydney region.

However, it is possible to identify some situations and locations in the Sydney region where the use of fire may have been of adaptive advantage to the Aboriginal population. For example:

1. Within areas underlain by Wianamatta shale and Narrabeen sandstone, where nutrients are relatively abundant and where native grasses abound, in order to attract herbivores to new growth.

2. Within wetlands to encourage the growth of succulent sprouts suitable for browsing by waterfowl.

3. In small areas to promote the development of specific plants (for example, _Macrozamia_ _communis_ (see Harris 1977; Beaton 1982), or _Microseris_ _scapigera_ (see Gott 1982, 1983).

In addition, fire may also have been used for driving game in the more fertile areas. It is also possible that such a technique might be used in shrub areas to flush out game for short-term benefit despite the long-term damage to the area burnt. However, Hayden (1981:368-9) suggests that hunter-gatherers (in general) only use such large amounts of labour and time as are necessary to organize communal fire-drives out of absolute survival necessity. In such a case, short-term benefits might outweigh long-term effects.

There is a tiny amount of historical material which tends to support these contentions. Aboriginal use of fire is mainly reported in the early journals as a hunting technique whereby individual trees were burned in order to smoke out small animals. Other fires mentioned by the first settlers were most probably small burns of the trickle type and were of sufficiently low intensity and areal extent to cause little disturbance to the early settlement (Burrell 1973).

Two other pieces of information also suggest that the widespread use of fire, particularly in the shrub-dominated areas, was not in evidence. Firstly, the well-developed and impenetrable nature of the shrub understorey is mentioned by all authors (for example, Worgan 1978:9; Tench 1979:65; Phillip 1982:122). Secondly, when travelling through shrubland areas it is clear that the Aborigines used well-defined pathways ("well trodden" is the term used by Hunter 1968:157; "Beaten" by Phillip (1982:136) see also Bradley 1969:116) through the dense understorey. These paths were used in both coastal and inland situations. Tench, for example, reports that as the first expedition along the Hawkesbury-Nepean was making its way along the banks of the river, an old man saw them stumbling along and "came out of his canoe, and took the lead, and he soon brought them to a path made by the natives. Where it was very good walking and which ran along the river" (op.cit:520). In addition, the Aborigines had a clear tendency to prefer canoes as a mode of transport both on the coast and upon the Hawkesbury river. The density of the shrubland in some areas may also be suggested by an apparent aversion on the part of the Aborigines for "a thick brush, which (they) don't like to get into" (Bradley 1969:97); an aversion clearly shared by kangaroos in the course of pursuit by dingoes, as they "kept to paths of their own choosing" (Tench op.cit:270).

Although none of this historical evidence is conclusive, it is certainly suggestive of the fact that shrubland areas were not extensively burned by the Aborigines.

3.5.1 The role of Aboriginal firing - a summary

In recent years, ecosystems have come to be understood less as large scale environments subject to successional stages of 'embryonic' development toward the Climax, but rather as mosaics of successional stages - "a blurred successional patchwork" (Horn 1974:30) - with localized successional sequences initiated repeatedly by disturbances that are more or less unpredictable, frequent, and often endemic; which establish a mosaic or spatially heterogeneous pattern of vegetation. Such is certainly the case within the Sydney region, wherein the most important endemic disturbance is fire.

While Aborigines may have increased fire frequency in a limited number of mosaic elements (principally associated with areas of relatively high natural fertility) in order to facilitate the extraction of resources, interference with the frequency of fire within the majority of the area would almost certainly not have been to the long-term advantage of the Aborigines.

In summary, while large scale use of techniques of 'fire-stick farming' might be adaptive behaviour in the extensive landscapes of the savanna environment, there is at least a suggestion that the same might not be true of shrublands. To assume that such activities were pan-Australian (for example Hughes & Sullivan 1981) risks missing the subtlety of local adaptation to local environment.

3.6 POST-SETTLEMENT ENVIRONMENTAL DISRUPTION

The arrival of the Europeans in Sydney in 1788 was a disastrous event in the history of Australia biota. Over the following decades the Aboriginal people were all but destroyed (itself a fundamental alteration in the ecological system), an event which was swiftly followed by the impact of grazing, cultivation, urban development and mining. The European invasion was a watershed beyond which Australian ecosystems were permanently changed (Adamson & Fox 1982:110).

In a recent paper, Adamson and Fox (op.cit.) have considered the effects of European settlement upon Australian vegetation. Their analysis can be summarized in the following way:

1. The displacement of the Aborigines. Hunting, gathering and burning adaptations were removed from the ecosystem.

2. Cultivation. Vegetation was cleared and huge numbers of plant species were introduced - cultivation was limited only by topography, rainfall and (to a lesser extent) soil fertility. Among a number of insidious changes, irrigation altered the pattern of water-related features of the vegetation by increasing salinities and changing the nature of river discharges.

3. Grazing. Vegetation was cleared and a number of animal species were introduced, which through their behaviour, effected changes in the ecosystem; for example, soils were affected by the trampling of hard-hoofed animals. Owing to the grazing habits of the new species, soil erosion became widespread.

   The influence of grazing upon the native fauna was also important. Some native grazing animals increased in population density, at least in part, because of the development of watering places, and the practice of widespread firing in order to produce palatable feed for introduced livestock.

4. Forestry and introduced species. Management to produce uniform-age stands includes the elimination of old trees which remove animal

breeding sites. Relict rainforests have been opened up for weed invasion, while, more generally, pine plantations replace former forests.

In addition, a very large number of plants have been introduced - about 10% of the extant Australian flora has been introduced since 1788 (Amor & Piggin 1977).

Many animals, other than those associated with grazing, have also been introduced: as draught animals (horses, donkeys and camels); for hunting (rabbit, hare, fox deer); as pets (dog, cat); accidentally (mouse, rat); or as food (pig, goat, buffalo) - as a consequence a new Australian fauna has been assembled.

5. Urban, industrial and mining development. Urban development removes vegetation, alters hydrology and produces waste which completely changes the former ecosystem. Relict vegetation in an urban setting is subject to intense impact. Effects of mining are also intense at a local level.

In fact, however, the Sydney region is one of the few areas in Australia which display a low degree of European impact - a characteristic mainly attributable to the rugged and dissected landscape, nutrient-poor soils, lack of grazing and uneconomic trees (Adamson & Fox 1982:115). The impact of exotic species in these bushland areas is thought to be slight (Recher 1973; Beadle 1981; Adamson & Buchanan 1974; Adamson & Myerscough

1981), and as such the natural zones have shown a remarkable degree of 'resiliance' (Hollings (1973)) - in that they have tended to absorb and survive the impacts of the European invasion - though changes in animal species abundance may have contributed an unstable element. Even within the urban area only about a fifth of the total flora is introduced (Amor & Piggin 1977)). This lack of success on the part of exotic species in these areas is primarily attributable to the low nutrient status of the soils.

The areas in which the original environment has been wholly or partially destroyed are those which were suited for agriculture or those that have been overrun by urban sprawl. The present agricultural areas formerly possessed an understorey in which grasses such as Themeda australis predominated. These were destroyed through their sensitivity to grazing and have been largely replaced by introduced species. In other less productive areas (such as coastal heaths) destruction has been brought about by nutrient-enrichment and other influences which are the product of proximity to European populations. In general, the zones of contact between the Sydney urban area and the vegetated undeveloped land appears sharp (the most arresting example is the division along the banks of the Hawkesbury, where on the east bank the cultivated Cumberland Plain stretches out toward the city in the distance, while the beginnings of the Lapstone monocline (on the west bank) sweep steeply upwards in thickly-forested slopes). However, there is usually a broad irregular zone where the effects of urban proximity are detectable (including roads through these areas).

Yet, to a great extent, the urban bushlands of Sydney represent a remarkable survivor of a cataclysmic event which began in 1788. It is, however, naive to see these areas as the elusive 'native' vegetation of the region - changes in fire regimes and the minor but conceivably influential incursions by exotic species - make this unlikely. Indeed, given that the development of the flora was (and is) a dynamic process it is unlikely that there has ever been such a stable entity. However, the resiliance of these areas to the impact of the European invasion, which is a function of both topography and poor nutrient status suggests that these areas are, to a large degree, representative of pre-European vegetation associations.

3.7 SUMMARY

In this chapter the major biotic and abiotic elements of the Sydney environment have been introduced in an developmental context. Change through time is a characteristic that links all elements of the Sydney environment. Yet, the emphasis has been to show that changes of great magnitude ended sufficiently long ago that we are in a position to speak of a 'stable environment' (while recognizing small-scale dynamic processes), which can be described in sufficient detail to be utilized as a basis for studying the degree of optimality displayed by the behaviour of the extinct Aboriginal population. In general, the available evidence suggests that this is a tenable position - structure, climate and (admittedly to a much lesser extent) biotic communities have been much as they are for millennia. Even when enormous change has been brought about comparatively recently, as through the effects of the European invasion, the catastrophe can be shown to have been limited to a greater degree than can be said of many other areas of Australia. Overall, by taking a regional viewpoint removed from the local, it is possible to observe a steady state about which very small-scale fluctuations occur, which will serve as the 'stable' environment, which is a prerequisite of optimality theory and the study of adaptive responses.

Another purpose in the preceding chapter has been to establish the position of two important connecting threads - from the abiotic elements through the flora and on to the fauna - the abundance and distribution of nutrients, and the role of fire. These two factors exert a major influence upon vegetation structure - through the adaptations of the flora to prevent nutrient loss and take maximum advantage of (or even to promote the influence of) fire - and upon the faunal population. The flora has produced adaptations over time which have meant that fire-effect can be considered minimal in terms of the opportunity it provides for the establishment of new species and major changes in the relative population structures of the native flora - all species present before a fire tend to be found after it. These adaptations are principally related to the development of epicormic buds, roots, tubers and rhizomes. To a lesser extent the same characteristics can be said to be true of the fauna - though there is some evidence of time-lag behind the development of the flora.

Thus, it is probable that factors related to the distribution and availability of nutrients (factors closely associated with the distribution of geological parent materials) are likely to be the most accessible aspect of the relationship described here between the abiotic and biotic environmental elements in the contemporary 'stable' environment.

4 CHAPTER FOUR:

OPTIMAL FORAGING IN THE SYDNEY REGION

In this chapter those principles of optimal foraging theory which are relevant to the study of past human adaptations are introduced and are used to establish a model of optimal behaviour for a hunter-gatherer population. This model is based upon relevant parts of our knowledge concerning the distributional and behavioural characteristics of plant and animal species; and takes into account the peculiar characteristics of the Sydney region with regard to nutrient distribution.

To obtain the model, the region is first divided into broad areas of energy availability which are subsequently refined in order to establish the probable location of high-value patches. In the final section of this chapter, the concept of 'landscape' is introduced in order to demonstrate how the fit between the theoretical model and Aboriginal behaviour may be tested.

4.1 OPTIMAL FORAGING THEORY AND AN ARCHAEOLOGICAL PERSPECTIVE

Optimal foraging theory is concerned with the differences in feeding between individuals and how this influences reproductive fitness - it assumes that selection will favour those individuals who acquire food at the maximal possible rate. The original model was produced by MacArthur & Pianka (1966), and has become an increasingly sophisticated tool in evolutionary ecology (see for example, Charnov 1976; Pyke et al. 1977;

Pianka 1978; Krebs & Davies 1981; Hixon 1982; McNair 1982; Sih 1982; Krebs et al. 1983).

A number of recent anthropological studies have utilized these principles among extant hunter-gatherer populations (see Winterhalder and Smith 1981; Keene 1981; Perlman 1980; Hames & Vickers 1982; Hawkes et al. 1982, 1985; Smith 1985; see also Martin 1983; Smith 1984b), with the clear intention of using the derived information in the consideration of the archaeological record (Winterhalder 1981). The utility of the theory in a specifically archaeological context has been tested by Yesner (1981, 1984) and recently the theory has been examined in order to establish its value to the study of early hominid evolution (Kurland & Beckerman 1985).

Yesner (1981:150) considers that information concerning the locational characteristics of archaeological sites is of the same order as information derived from studies of patch selection and time allocation in other animals. In effect, this notion largely frees us from the constraint of considering the 'emotional' component of habitat selection and allows us to consider the variation in hunter-gatherer behaviour solely in relation to ecological variability. In reality, of course, there are likely to be many influences upon the behavioural patterns which relate to locational strategies in a hunter-gatherer group. We should expect only a tendency towards optimality with regard to foraging behaviour -just as other behaviours related to other goals (such as mate acquisition) may display a similar tendency towards optimality. It is the whole behaviour, with its many goals and many strategies which is reflected in the locational characteristics of the archaeological record. In addition, few people would realistically doubt that emotion does play a part in all human behaviour - acting as a deflector of decisions based upon biological necessities.

Among human populations however, the degree of behavioural deflexion brought about by the demands of goals other than the acquisition of food (or by emotion) is likely to be at its least in hunter-gatherer groups. For despite their (more apparent than real) 'affluence' (Sahlins 1972; cf. Altman 1984a), the modal characteristics of extant hunter-gatherers - mobility, low population density, small groups and fluid social organization - are closely related to biological requirements and influences. The end goal is survival, and foraging strategy most clearly influences the 'inclusive fitness' of the individual - the proper focus of evolutionary studies. In the course of foraging, then, each individual must strive to acquire adequate supplies of resources which are necessary for survival - 'limiting factors' (Odum 1971; for example, water, energy, and nutrients), and must adjust to environmental stresses (Yesner 1981:148).[1]

As has been noted above, optimal foraging theory predicts that these resources will be gathered as efficiently as possible (and with as little conflict with other goals as possible). This efficiency of resource usage, in both archaeological and ethnographic contexts, is normally

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[1] Note, however, that, particularly in human societies, while the unit of selection is the individual; the individual is not necessarily the foraging unit.

studied utilizing energy as a currency (see Winterhalder 1981:20-22), because a group which optimizes ratios of energy consumption to energy expenditure can be shown to be more likely to survive through time (Slobodkin 1962), and hence enter the archaeological record.

However, a number of researchers have criticized the use of energy as a currency because of its general abundance in most environments (which suggests that it is seldom a limiting factor). As a consequence, alternative currencies have been suggested, including protein (Speth & Spielman 1983), time (Torrence 1983), risk (Jochim 1981) and security (Binford 1983). In addition, nutrients have been shown to be an important currency among extant human groups (Harpending & Davis 1977; Meehan 1977) and although the influence of nutrient constraints has been considered by Pulliam (1975) in the wider theoretical context of evolutionary ecology, it has received little attention by the proponents of optimal foraging theory in anthropology (for exceptions see Keene 1979, 1980, 1981).

However, it is clear that at our present state of knowledge, energy (because it is the most accessible) is the currency which is most likely to help us to understand human behaviour in the archaeological context - though in some cases nutrient constraints may be identifiable. In this study, for example, while the model is essentially based upon energy distribution, it is argued (see below) that because of the readily apparent direct and indirect influences of nutrient deficiencies upon the Sydney region biota, an optimal foraging model must take the distribution of nutrients into account. With this in mind we may turn to a consideration of the ways in which an efficient forager is most likely to attempt to harness energy in a heterogeneous environment.

4.1.1 Diet, patch and grain - key concepts in optimal foraging theory

As a general principle, the harvesting of any resource involves the expenditure of effort and a varying degree of risk, and it is in order to minimize both of these elements within the food quest that most human groups choose a smaller number of foods from an array of potential resources. These resources are unlikely to be uniformly distributed in space or time, but are likely to be distributed in 'patches' (Wiens 1976).

Wiens defines a 'patch' as an area "distinguished by discontinuities in environmental character-states from (its) surroundings" (1976:83); while Levin and Paine describe it as "a 'hole', a bounded, connected discontinuity in a homogeneous reference background" (1974: 2744). Both definitions are deliberately vague because the boundary conditions of a 'patch' (in space and time) are those which have an adaptive significance for a particular organism - that is, they are "organism defined" (Wiens 1976:83) - and the definition may depend upon what characteristic of the environment is being considered. For example, patches relating to foraging behaviour are likely to be different from patches related to climatic adaptation.

From the point of view of efficient foraging, patches which exert a discernible influence upon behaviour are likely to be those within which effort and risk are minimized in relation to the energy returned. Under most circumstances, those patches which best meet this criterion will always be exploited by an organism in preference to those in which effort or risk are relatively greater (MacArthur & Pianka 1966; MacArthur 1972; Pianka 1978).

Two principal models within optimal foraging theory have been used to study the relationship between organisms and the distribution of high-value (i.e. high benefit/low cost) resources: a) the optimal diet breadth model; and b) the optimal patch choice model.

4.1.2 Optimal diet breadth

In an optimal diet breadth study, each potential prey[2] is allocated a food value measured in calories (or other unit depending upon the orientation of the study) and a handling (processing) time. Food types are then ranked according to their food value to handling time ratio. In addition, of course, time must also be spent searching for the food item (search time). By estimating the relationship between handling times, food values, and search time, the net rate of food gain can be calculated for any possible diet.

The optimal diet is determined by ranking the ratios of food-value to handling and search time until the point is reached where the result for a

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[2] Note that both here and subsequently the term 'prey' is used in a general sense, to mean food species - animal and plant. In addition, such terms as 'ranking' and 'choice' possess no implicit connotation of conscious decision.

food item is less than the net rate of food intake for the diet without the addition. The optimal diet tends to display two important characteristics: firstly, as the abundance of a preferred food-type increases, the number of less preferred food-types included in the optimal diet will decrease (i.e. increased food abundance should lead to greater specialization); and secondly, as any given food item is either included or excluded from the optimal diet (if it is included it should be eaten whenever it is encountered) there should be no 'partial preferences'. However, if dietary constraints or random variations in food abundances intervene, the theory may be extended so that partial preferences can be anticipated.

In general, the model has been supported by animal field studies. In particular, it can be shown that greater food abundance leads to greater food specialization (Charnov 1976; Emlen & Emlen 1975) and that animals select prey of high profitability (Pyke, Pulliam and Charnov 1977).

4.1.3 Optimal patch choice

The extent to which patches are utilized by an organism depends principally upon how their quality changes through time. For example, patches may:

1. stay constant in quality.
2. change in quality as a result of the predator's activity (i.e. depletion or 'resource depression' (Charnov et al. 1976)) or

3. change over short periods of time independently of the predators activity (e.g. migratory species).

The first state is rare in nature; but the second occurs widely (Krebs 1978:40). The consequence for the predator is that the profitability of the patch declines with time and it must choose the point on a curve of diminishing returns at which it will seek a new patch - i.e. when its rate of intake declines to a level equal to the average for the habitat as a whole ('the marginal value'; Charnov 1976).

The availability of prey may, of course, be reduced by changes independent of the action of a predator, as in the case of seasonal migration of a prey species (point three above). The effect upon a predator would be similar to a rapid form of resource depression; occasioning an equally rapid approach to the marginal value, which would necessitate a switching of attention to the next most productive patch (or patches - as specialization decreases).

The apparent assumption that a predator possesses the knowledge of where to go when the marginal value is reached, may appear to imply that an organism must visit all possible patch types in order to rank them in terms of cost/benefit. However, if an animal can learn the location and types of patch in an area (and particularly if it can reference them with regard to time) a patch can be rejected or accepted before it is encountered. The resulting adjustment in encounter rates within various patch types may, in fact, allow a great deal of specialization. For, in some situations, it may also be advantageous to move from one patch of the best type to another - this would almost certainly be the case if travel costs were small and if the animal knew all the best patches (Pyke, Pulliam and Charnov 1977). Man, of course, has a great faculty for the diffusion of such information (see Moore 1981) which is likely to ensure that the best patches are known to all.

However, while the theoretical implication of patch-ranking may be that an animal should only occupy one patch type (the most profitable) at any time, there is evidence that this does not always happen in real animal systems. Through a study of titmice, Smith and Dawkins (1971) and Smith and Sweatman (1974) have suggested that, in fact, effort is distributed throughout most patches - though the greatest time is allocated to the patches of highest food abundance, and progressively less time to progressively worse patches. This apparent contradiction of optimal patch choice models is resolved by viewing this behaviour as a long-term adaptation to fluctuating patch quality, rather than a short-term one. This resolution is supported by the fact that the rate of response to changes in patch quality decreased among the titmice in rank order, so that change was slowest when the worst patch became the best, and fastest when the second best patch became the best. The titmice clearly tracked change in their environment by continual sampling, and in human populations tracking of this type is likely to occur (see for example Blurton Jones & Konner 1976). The results are transmitted through the information network, in the light of past experience and with the minimum wastage of energy.

Whatever the cause, If food within one patch type becomes scarce (through migration or depletion), an organism will move to the next most profitable patch type, and so on down the ranking. Each step down implies an increase in mean hunting time (the ranking is after all a construct based on minimizing effort or maximizing prey calories caught per unit time). In addition, where energy becomes more generally scarce owing to a rapid process such as the seasonal migration of a high energy-yield food, mean hunting time is likely to increase sharply (particularly because more patches of scarce food are likely to be introduced into usage owing to the reduction of the average return for the whole habitat (cf. Charnov 1976)). In this case, it is likely that all patches will be utilized provided that the resulting gain in time spent per unit food exceeds the loss (MacArthur and Pianka 1966).

4.1.4 Grain and heterogeneous environments

The concept of 'grain' or the 'grain response' (Wiens 1976:84) is closely related to that of patch. The distinction between 'coarse-grained' and 'fine-grained' was originally used to describe the relationships between the sizes of environmental patches and individual mobility (Hutchinson and MacArthur 1959) or the differences in the ways organisms responded to heterogeneous resource mixtures (MacArthur & Levins 1964). The confusion between these two orientations attests to the difficulty of separating these aspects of patch definition. Wiens, however, states the relationship between patchiness and grain in the following way:

> "The concept of grain is best interpreted as a behavioural response to an environmental mosaic. Organisms may thus be characterized as coarse- or fine-grained only in reference to utilization of the resources associated with a particular life-history function, and categorization of species as fine-grained or coarse-grained without specifying the context is inappropriate. If "grain" refers to the nature of a behavioral response or utilization pattern, "patch" applies to the physical environments or resource units upon which the grain response is expressed" (Wiens op.cit:85).

Thus, given an environmental resource mosaic, a fine-grained response would be to use the units of the mosaic (the 'patches') in direct proportion to their frequency of occurrence. Conversely, a coarse-grained response utilizes patches non-randomly i.e. an animal exhibits patch 'preference'. A fine-grained response may be produced if there is no perceptual differentiation between mosaic units or if a difference is discerned but the information is not acted upon. A coarse-grained response implies patch selection either through active choice or passively as a result of some external agent.

Humans, as large predators, tend to exploit patches in the proportions in which they occur (Oaten 1977; Krebs et al. 1974), i.e. in relation to their actual biomass. Not all food items will be harvested, but those that are should be harvested in proportion to their natural occurrence provided that no nutrient or other constraint intervenes.

4.1.5 Archaeology and the value of the patch model

From the available ethnographic material (see for example, Winterhalder & Smith 1981), hunter-gatherers are thought to effectively establish two ranks of resource-value based on the heterogeneous distribution of food in the environment: firstly, of resource patches; and secondly, of individual resources which are to be exploited whenever they are encountered. Whether a hunter-gatherer will exploit only certain types of patch, selecting only a finite number of resources; or selects a finite number of resources and searches for them regardless of patch distribution, depends both upon the 'grain' of the environment and of their behavioural strategy (see Pianka 1978:263-266).

Of the two principal models within optimal foraging theory, the diet breadth model is extremely difficult to use in an archaeological context, because it requires a detailed knowledge of the environment, and also an extraordinarily well-preserved faunal and floral assemblage which can be assessed in relation to that environment. In addition, handling and search times would be difficult to estimate without recourse to ethnographic analogy which (in the given archaeological context) may be wholly erroneous. Further, the detailed requirements of the diet breadth model and the differential preservation of archaeological material, diminish the possibility of using optimal foraging theory as a powerful comparative tool (which is one of its major attractions). In contrast, the use of the optimal patch choice model and the locational characteristics of archaeological sites upon a regional scale are far more likely to allow the identification of underlying trends in the relationship between human behaviour and environmental heterogeneity, and as a consequence patch location is emphasized in the remainder of this chapter and forms the basis of the behavioural model presented in its latter pages.

4.2 PATTERNS OF ENERGY DISTRIBUTION IN THE SYDNEY REGION

Although our interest lies in resource patches and their ranking according to cost/benefit ratios, in this section the Sydney region is broken down into broad regions (assessed by assumed primary productivity) in order to illustrate the existence of distinct areas of energy potential upon which the patch distribution is likely to be based. For this reason, emphasis is laid upon the distributional characteristics of the available production.

It should be noted, however, that the distinction between areas of high available productivity and high-value patches is an important one. While the former represents a generalized characteristic in space with little regard to changes through time; the latter is specific in character and finely-tuned with regard to aspects of space, time and ease of acquisition.

The following rank-order of areas based upon estimated primary production averages for specific environments (Whittaker 1975) can be determined:

1. Wetlands (mean value = 2000g/m.sq/yr)
2. Estuaries and the inter-tidal zone (mean value = 800g/m.sq/yr)
3. Temperate forest (mean value = 1250g/m.sq/yr)
4. Woodland and scrubland (mean value = 700g/m.sq/yr)
5. River, stream and open lake (mean value = 500g/m.sq/yr)
6. Continental shelf (mean value = 360g/m.sq/yr)
7. Open ocean (mean value = 125g/m.sq/yr)

This general ranking of resource areas can be modified in the light of specific information from the region, to produce a rough assessment of the nature of available production.

4.2.1 Wetlands

'Wetlands' are areas of swamp, shallow water or water-logged land (Goodrick 1970; Briggs 1981). In general, their productivity is equal to that of the most productive vegetational zone on earth - tropical rain-forest (mean value = 2000g/m.sq/yr). In terms of available production, their value lies primarily in their role as refuges for wildlife and fish (which tend to congregate in these areas of high nutrient levels).

Goodrick (1970) distinguishes several types of wetland within the Sydney region and particularly emphasizes their importance as refuges for waterfowl (see also Frith 1967). (Table 4.1 illustrates the relative importance of these wetland types as waterfowl habitats and indicates the difference between their present and former extent.) In addition,

WETLAND TYPES	HABITAT VALUE	ORIGINAL AREA (Ha)	1969 AREA (Ha)
Fresh meadows & Seasonal fresh swamps	High	1457	162 567
Semi-permanent fresh swamps	High	81	81
Open fresh water	High	486	445
Teatree swamps	Medium	81	81
Salt meadows	Medium	607	405
Reed swamp	Medium	162	81
Salt flats	Medium	607	567
Mangrove swamps	Medium	2590	2185
Shallow estuarine waters	Medium	No data	No data
Sheoak swamps	Low	No data	No data

Table 4.1: Types of wetland within the Sydney region (ranked according to their value as waterfowl refuges) with an estimate of their present (1969) and past extent.
(Note: Converted from acres to hectares)
(Source: Goodrick 1970)

wetlands within the Sydney region tend to be important sources of fish. In particular, the highly nutritious eel (Anguilla spp.) is to be found in the majority of these areas within the region.

Mangrove swamps, though only of medium value as wildfowl habitats, are highly productive in terms of fish and shellfish, principally because of high levels of nutrients held in suspension (Bell et al. 1984; Odum & Heald 1972). Though many of them have been destroyed (6400 acres originally to 5400 acres in 1969 (Goodrick 1970)), there are still isolated pockets of mangrove within Broken Bay, Port Jackson, Georges River, Port Hacking and Botany Bay (Blacker 1977; Clarke and Hannon 1967, 1969, 1970, 1971; Goulter & Allaway 1979).

4.2.2 Estuaries and the inter-tidal zone

The estuaries and inter-tidal zone of the Sydney region are highly productive. Indeed, the primary production of this zone could be expected to be ten times that of the coastal zone and a hundred times that of the open ocean (Odum 1971; Lieth & Whittaker 1975). (These figures do not account for the total availability of resources in the estuarine environment, for the average productivity figures do not take account of the presence of 'unearned' resources - migratory species which do not necessarily utilize the energy of the system in which they appear.) The estuarine macrofauna is comprised of two distinct groups: those species permanently resident; and those species entering estuaries at high or low tide, principally to feed (i.e. fish and birds respectively).

Sydney region estuaries are exceedingly rich in resident fish, shellfish and avifaunal species. For example, Table 4.2 presents modern data for catches of estuarine fish which at least give some idea of the order of their availability - as much as 83% of the total catch of commercial fisheries within New South Wales comes from the major estuaries (Urquhart 1978). In addition, large numbers of shellfish take advantage of the stable substrates provided by mangrove swamps, while others occupy areas of mud-flat which are rich in detritus. Since the amount of detritus varies with the particle size of the substratum, the biomass of these consumers tends to be irregularly distributed (Bassingdale & Clark 1960).

The shellfish of the inter-tidal zone are subject to greater fluctuations in population than estuarine species, because of the higher energy-stress (particularly through the action of waves). Rocky-front and sandy-beach systems contain few species (Odum & Copeland 1974:36) - though on rock platforms they can reach great densities. In general, shellfish populations along the coast of the region tend to reach their greatest density near the mouths of estuaries because of the concentrations of detritus which has been lost from the estuaries (see Barnes 1974).

The emphasis upon the difference between a generalized notion of productivity and the actual presence (in space and time) of patches, is nowhere better displayed than in the estuaries. For estuarine fish patches possess a tendency to be largely temporal phenomena associated

Species	common name	Average catch (tonnes)	10 year range	comment
Mugil cephalus	Sea mullet	2560	1800-3270	
Arripis trutta	Australian salmon	620	180-1380	Catches were greater in the past.
Girella tricuspidata	Luderick	540	320-890	
Acanthopagrus australis	Yellowfin bream	340	230-520	
Liza argenta	Flat-tailed mullet	230	80-360	
Sardinops neopilchardus	Pilchard	190	110-270	Requires sophisticated netting techniques
Platycephalus fuscus	Dusky Flathead	180	130-340	
Pomatomus saltatrix	Tailor	150	100-200	
Sillago ciliata	Sand whiting	120	90-190	
Monocanthus chinensis & Meuschenia trachylesis	Leatherjacket	220	70-490	
Agyrosomus hololepidotus	Mulloway	80	50-150	Mostly juveniles Main catch off-shore waters
MINOR SPECIES				
Anquilla australis & Anquilla reinhardtii	Eels	20	10-80	Mainly A. australis
Chrysophrys auratus	Snapper	10	0-20	

Table 4.2: The principal inshore and estuarine fish species and modern catches (Source: New South Wales Fisheries 1982)

with the presence of unearned migrant species, and constant loss of production to the sea.

4.2.3 Temperate forest, woodland and scrub

The difference between productivity and available productivity is most evident with regard to the vegetational characteristics of the region. The influence of nutrient distribution upon flora and fauna is such a fundamental characteristic of the region that is has, of necessity, been fully described in Chapter Three.

In general, the increase in the extent of an overstorey and a concomitant decrease in the presence of a shrub understorey is associated with more abundant available productivity.

4.2.4 Streams and rivers

A substantial portion of the energy within stream and river systems is provided by dead organic matter - allocthonous input - and this can be contrasted with the internal production by photosynthesis - autocthonous input (Odum 1956).

Within the region, most streams receive an allocthonous input as they pass through the forested catchment areas, but because of the low nutrient status of the environment and the nutrient-retaining mechanisms of the flora, this is likely to be small. The shade provided by the trees also precludes any significant growth by algae and macrophytes in the upper reaches of the streams. However, as the streams widen the shading effect becomes restricted to the margins and autotrophic production should increase until depth or turbidity reach the extent that light does not reach the bottom, and growth will be restricted to the margins (Townsend 1980).

As a consequence of these factors, the streams within the region are characterized by low production - in the upper reaches of rivers and in all streams, only a small but fairly constant fish population can survive. Toward the estuary, rivers tend to be richer in species and abundance but the fish populations are more susceptible to the influence of low temperature and saline transgressions. Note however that the fringes of rivers where macrophytes emerge are usually highly productive though linear and narrow. Here, productivity is likely to be of the order of other 'wetland' areas.

4.2.5 The continental shelf and the open ocean

The productivity of the continental shelf is approximately a tenth of that of the estuaries: the productivity of the open ocean - a hundredth (New South Wales State Fisheries 1979; Rhyther 1969; Bunt 1975).

The New South Wales continental shelf is approximately 40 kilometres wide and is swept by rather infertile currents (Bird 1971; N.S.W. State Fisheries 1982). Yet many sea mammals, fish and birds directly depend upon this system, principally because food chains tend to be shorter in these areas than in the open sea (where zooplankton forms an additional trophic level). The highest levels of primary production occur close to areas of estuarine output (as high as 100gC/m2/yr; Barnes 1974). In addition to earned production, many species migrate through the coastal zone in winter without depending upon local primary production (e.g. the sea-perch (Australian salmon) _Arripis trutta_).

In general, the continental shelf shows greater stability in terms of the amplitude of resource fluctuations than corresponding terrestrial ecosystems (Dunbar 1960). However the frequency of oscillations can be greater. In addition, because the food chains tend to be shorter, resources within the continental shelf area tend to be less stable than those of the open sea. In contrast to both these areas, the productivity of the open ocean is consistently low and resources are widely spaced.

It should be noted that some few species which pass through the oceanic system may form an unearned addition to terrestrial available production, either deliberately (seals beaching in summer) or accidentally (beached whales or sea-birds after a storm).

4.3 RESOURCE FLUCTUATIONS AND NUTRITIONAL INFLUENCES UPON OPTIMAL FORAGING IN THE SYDNEY REGION

It is clear that wetlands, estuaries and inter-tidal zones are the areas most likely (on the basis of the distribution of available productivity) to produce high-value patches; the forest and shrubland, and the open seas are the least so; while river margins and the continental shelf hold an intermediate position.

However, the recognition and ranking of high-value patches (i.e. those areas of available production defined by a hunter-gatherer as potential food) is likely, in the Sydney region, to be a function of two particular temporal and spatial characteristics of animal and plant species: 1) seasonality and superabundance and 2) the distribution of dietary nutrients.

4.3.1 Seasonality and superabundance

Although, for the most part, the terrestrial environment does not experience classic seasons (shoot growth can occur throughout the year), seasonality impinges upon the regional environment through changes in the distributional characteristics of aquatic resources. At certain times of the year, various aquatic resources become superabundant in discrete and mobile aggregations (for example, fish shoals (e.g. mullet and eels) for the purposes of reproduction; and waterfowl for the purposes of reproduction and drought avoidance).

Optimal foraging theory predicts that as the abundance of food types increase the number of lower ranked food types should become smaller (i.e. increased food abundance should lead to greater specialization). Shoaling or flocking increases the profitability of the prey item by reducing handling and search time per item and should mean that the prey would be specially selected by a predator (Pyke, Pulliam and Charnov 1977). Nevertheless, fish shoals are associated with an environment - water - which is essentially alien to the terrestrial forager, and if shoals are difficult to find, overall search time may become prohibitive. In general, however, shoals in estuaries tend to be related to specific boundaries (for example, the mouth of estuaries prior to spawning runs).

In comparison, the location of waterfowl flocks is more predictable, in that their likely distribution at a given time of the year (particularly in relation to the dryness of the weather) is calculable. (Note that in either case the transmission of information through the human network would have a significant effect in reducing overall search times.)

Such seasonal superabundances are followed by rapid resource depletion through migration or redistribution, either removing the patch components altogether or increasing their areal extent until the patch is broken (for example, in the case of migratory fish and drought-avoiding birds respectively). The effect would be to necessitate a rapid expansion of diet breadth and/or relocation of patch use.

4.3.2 Diet and nutritional requirements

To this point, we have considered in the broadest terms the energy potentially available to foragers. In the present context the availability of energy is too crude a measure to be generally useful, for it is abundant within a system which (because of its marine boundaries) cannot be closed. Principally because of the direct and indirect influence of nutrient distribution upon faunal and floral patterns within the region, nutrients are likely to provide a more generally useful currency (cf. Speth & Spielman 1983).

A number of factors related to the distribution of dietary nutrients, influence the locational characteristics of mammals within the region. We know, for example, that the faunal communities are likely to be limited by nutrient deficiencies, particularly in relation to the poor representation of phosphorus and copper (cf. Kikkawa et al. 1979). Such nutrient deficiencies are as likely to affect man as they are to affect any other mammal. (It should be noted, however, that while phosphorus deficiency is a well-known phenomenon amongst non-human mammals, it has not been described in humans (Mottram pers. comm.).)

Phosphorus, for example, is found in the molecules of the nucleic acids that transmit inheritance and build proteins, and is intimately concerned with energy transfer and storage. Dietary deficiency would clearly have far-reaching influences upon the distributional characteristics of any organism. In terms of human nutritional requirements, however, there is a general consensus that "if we look after the calcium in our diet, the phosphorus will look after itself" (Mottram 1979:89). (The converse, however, is not true - too much phosphorus prevents the absorption of calcium.) All foods contain phosphorus as phosphate but fish and meat contain most, followed by whole grain cereals.

The effect of dietary deficiency in copper, in comparison, is well understood in man. Copper is a component of many enzymes and is also necessary for the mobilization of iron from its store as ferritin (op. cit.:85). Inadequate supplies can have important effects in humans, including anaemia and scorbutic bone changes (Golden & Golden 1981). The principal sources of dietary copper are green vegetables, fish and liver.

How, then, may such nutrient constraints have affected a hunter-gatherers' recognition of patches within the Sydney region?

Pulliam (1975) has shown that where there are no nutrient constraints, a predator should take a prey whenever it is encountered i.e. it will utilize patches in a descending order of profitable prey. However, where there <u>are</u> nutrient constraints, a predator may show preferences towards prey which contain more of the given nutrient (for the mathematical basis see Pulliam (1975)). This would tend to suggest that an optimal forager in the Sydney environment might tend to favour patches associated with fish, meat, liver and green vegetables.

However, as we have seen, wider nutritional factors interpose within the Sydney region - the floral components of the biota are, for the most part, sclerophyllous and possess a number of adaptations for the retention of nutrients. The tendency towards herbivory is likely to have been as potentially hazardous for man in the Sydney environment as it is thought to have been among non-human mammals, principally because of the prevalence of toxins; but also because many of the possible sources of dietary carbohydrate (in the form of roots, tubers and rhizomes) tend to be in the form of non-digestible compounds such as inulin (Jennie Brand, pers. comm.).

In essence the effect of these factors would be that an efficient forager, in order to maintain his energy and nutrient requirements, would have to rely heavily upon dietary protein; yet animal protein is also limited within the Sydney environment. Marine protein, however, is not.

Yet, a reliance upon fish protein would bring more nutritional factors into play, principally because of the low fat content of fish and their very low calorific value. (There is more water and less fat in fish than in meat and as a consequence the calorific value of fish is considerably less per unit weight.) In general, it is likely that where fish protein is predominant in the diet, it is essential that other nutritional sources (including a source of fat) are also utilized. In her analysis of faunal remains around Veracruz, Wing (1978), for example, has suggested that one of the reasons why the domestic dog was introduced to the area was in order to provide such an additional food source.

Fats, in particular, would be likely to assume great importance under these conditions. Jochim (1981:81), Hayden (1981:349-398) and Speth & Spielman (1983) have all stressed the 'fat hypothesis': that hunter-gatherers often rank animals according to their lipid content, (amongst vegetable foods the importance of some nuts may also reflect a preference for 'fatty' plant foods). In general, as Hayden says (1981:418) there is sufficient "..... circumstantial evidence to suggest that limited fat availability is a serious and widespread nutritional bottleneck for hunter-gatherers."

The primary importance of dietary lipids lie in the fact that, in general, they supply twice as much energy per unit weight (38kJ/g = 9kcal/g) compared with proteins (17kJ/g = 4kcal/g) or carbohydrate (16kJ/g = 3.8kcal/g) (Gurr 1984); but other characteristics, summarized by Hayden (1981:394), also contribute to their importance:

1. Lipids act as an energy substitute for sugars and starch in human metabolic processes.
2. In order to metabolize a given quantity of meat protein, a given amount of lipid (or carbohydrate) is necessary.
3. Lipids are necessary for synthesizing lipoproteins, lack of which results in malnutrition, ataxia and retinal degeneration.
4. Lipids are essential for the absorption of many fat-soluble nutrients especially vitamin A and carotenes.
5. Certain lipids are known to be essential nutrients for children.
6. Lipids are important in regulating oxygen absorption in biological

systems, with deficiencies possibly leading to cystic fibrosis.

The nutritional and nutrient aspects clearly make lipids an essential part of the diet, but in addition, fats have the important function (as does carbohydrate) of allowing more efficient absorption of protein. This function has important consequences for a population whose diet is mostly composed of low-fat fish protein. Without a source of additional lipid, 'protein starvation' (in which the greater part of the ingested protein passes through the body) might be unavoidable.

The lipid content of fish, largely stored as triacylglyserols in the liver (Gurr 1984), would probably be sufficient to prevent the full weight of protein starvation (illustrated by Speth and Spielman (1983)) provided:

1. sufficient fish could be caught and eaten to counteract the loss of protein through excretion.
2. that the fish was not gutted (i.e the lipid stores removed).

The role of fat is likely to have been so vital that we may state that in the event of seasonal resource fluctuation bringing into being a 'patch' of high-fat prey which could be harvested at relatively low cost, it would inevitably be ranked very highly in the optimal diet. This is the implication behind Smith & Kinahan's (1984) recent statement concerning the presence of cetacean populations in the broadly similar environment of South Africa: "Any attempt to produce an archaeological optimal exploitation model based on energy input and output for coastal populations will have to take location and predictability of whale strandings into account" (op.cit:96).

There is sufficient evidence to suggest, then, that protein, fat and nutrient distributions are likely to be among the most influential factors in the recognition of patches by hunter-gatherers within the Sydney region.

4.4 SYDNEY REGION PATCHES - FOOD IN SPACE AND TIME

In this section an attempt is made to define the principal patches within the Sydney region palaeoenvironment, from the point of view of an optimal forager constrained by nutritional factors. These patches are considered in terms of location and also in terms of time; for patches are, generally, as much temporal phenomena as spatial ones.

4.4.1 Vegetation patches

Vegetation patches are essentially a spatial rather than a temporal phenomenon within the Sydney region. Shoot growth occurs throughout the year and there is little evident seasonal differentiation.

As has been noted above, herbivory in much of the Sydney region is likely to have been as potentially hazardous for man as for other mammals. Yet plant foods are essential to provide vitamins, fibre and carbohydrates (both as an energy source and as an efficient protein-sparer). The general principle that the amount of edible vegetation available to man is likely to be dependent upon nutrient levels, can be broadly examined in terms of the number of species known to have been utilized by Aboriginal peoples and their association with the principal vegetation structures.

There is a considerable body of data concerning the plant species utilized by the Aboriginal peoples of south-eastern Australia (Maiden 1889, 1900; Cribb and Cribb 1974; Attenbrow 1976) and their association with vegetation structural divisions (Attenbrow 1976; Benson pers. comm.; Kohen pers. comm.). When these data are compared with the plant census for the central coast of New South Wales (Jacobs & Pickard 1981), a general idea of the total number of food species conceivably available in each vegetation structure can be obtained. (This is, of course, only an extremely broad and general guide to availability, because it takes into account only diversity of food species not the relative abundance of individual food items.)

Figures 4.1 and 4.2 present the data concerning food species availability for the structural associations from Tall Open Forest to Open Scrub, based on all food groups (Figure 4.1) and for the groups of seeds/nuts, roots and fruits alone (Figure 4.2). (The division of species into broad categories - fruits, roots, leaves, pith, nectar, manna, seeds/nuts - follows that used by Attenbrow (1976).) It is clear that the number of conceivably available edible species falls with the structural gradient from Tall Open and Open Forest to Open Scrub, particularly if

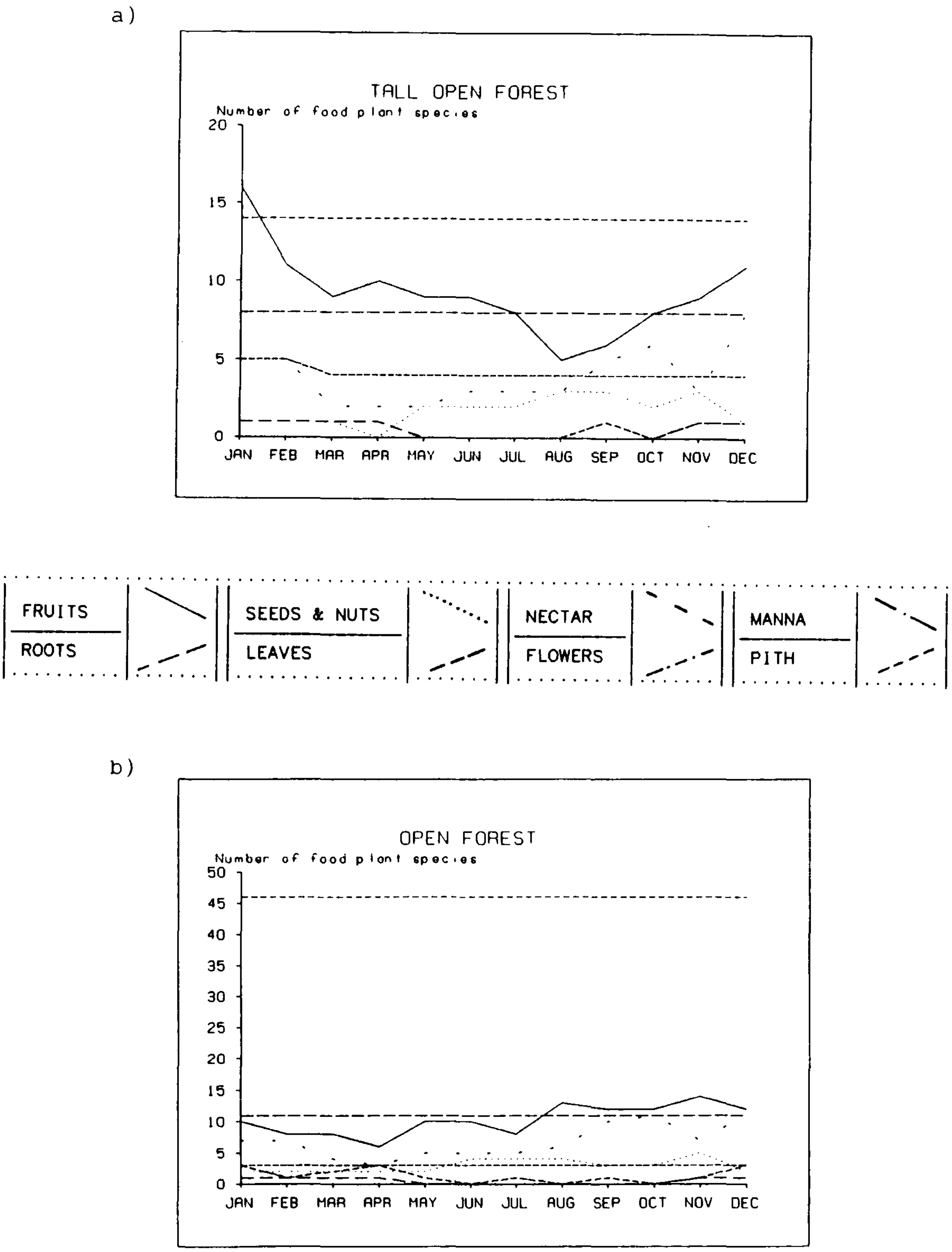

Figure 4.1: The probable number of plant species yielding Aboriginal foods in a) Tall Open Forest; b) Open Forest; c) Open Woodland; and d) Open Scrub; illustrating the decline in available production as sclerophylly increases. (Sources: Cribb & Cribb 1974; Attenbrow 1976; Maiden 1889, 1900; checked against Jacobs & Pickard 1981.)

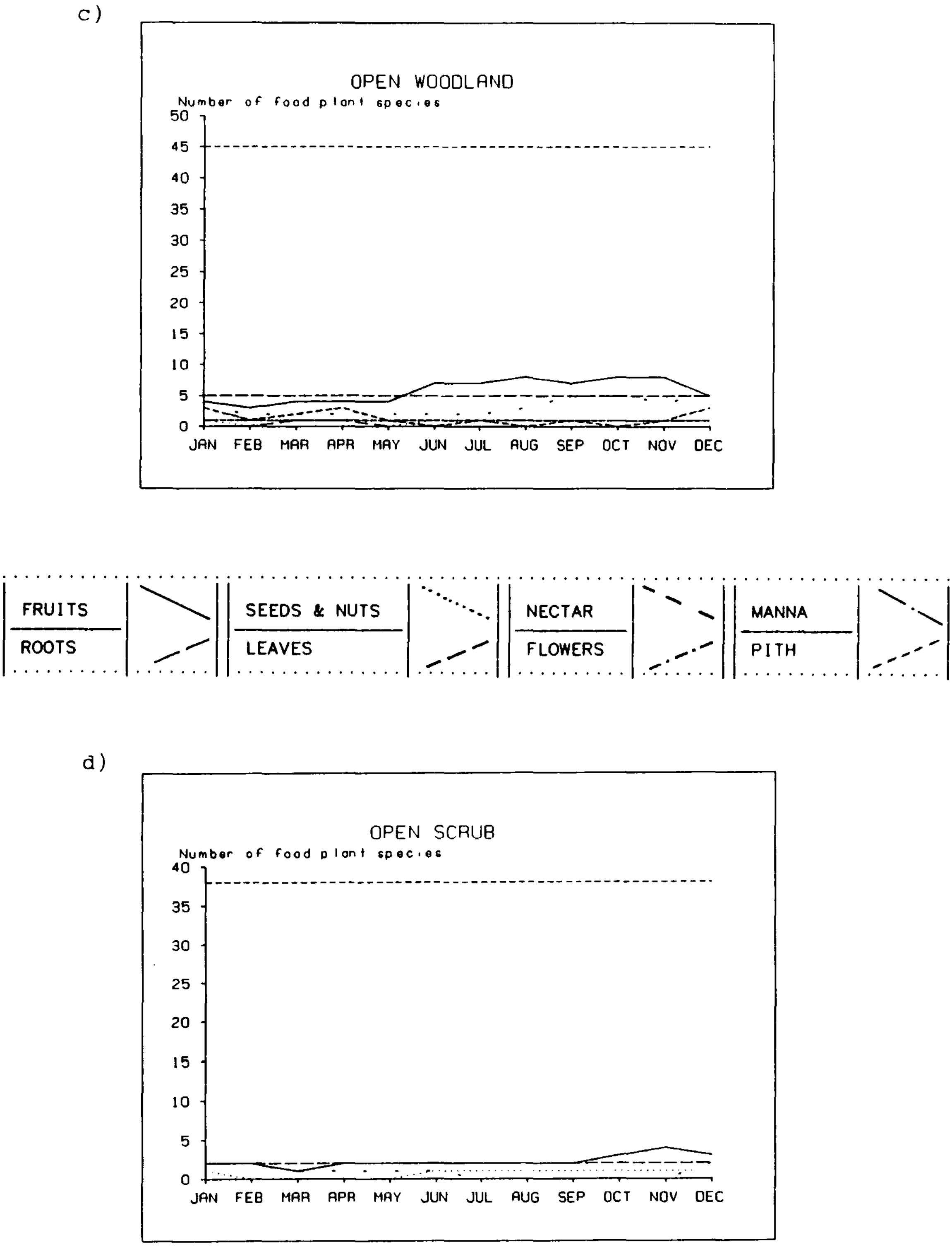

Figure 4.1: The probable number of plant species yielding Aboriginal foods (continued)

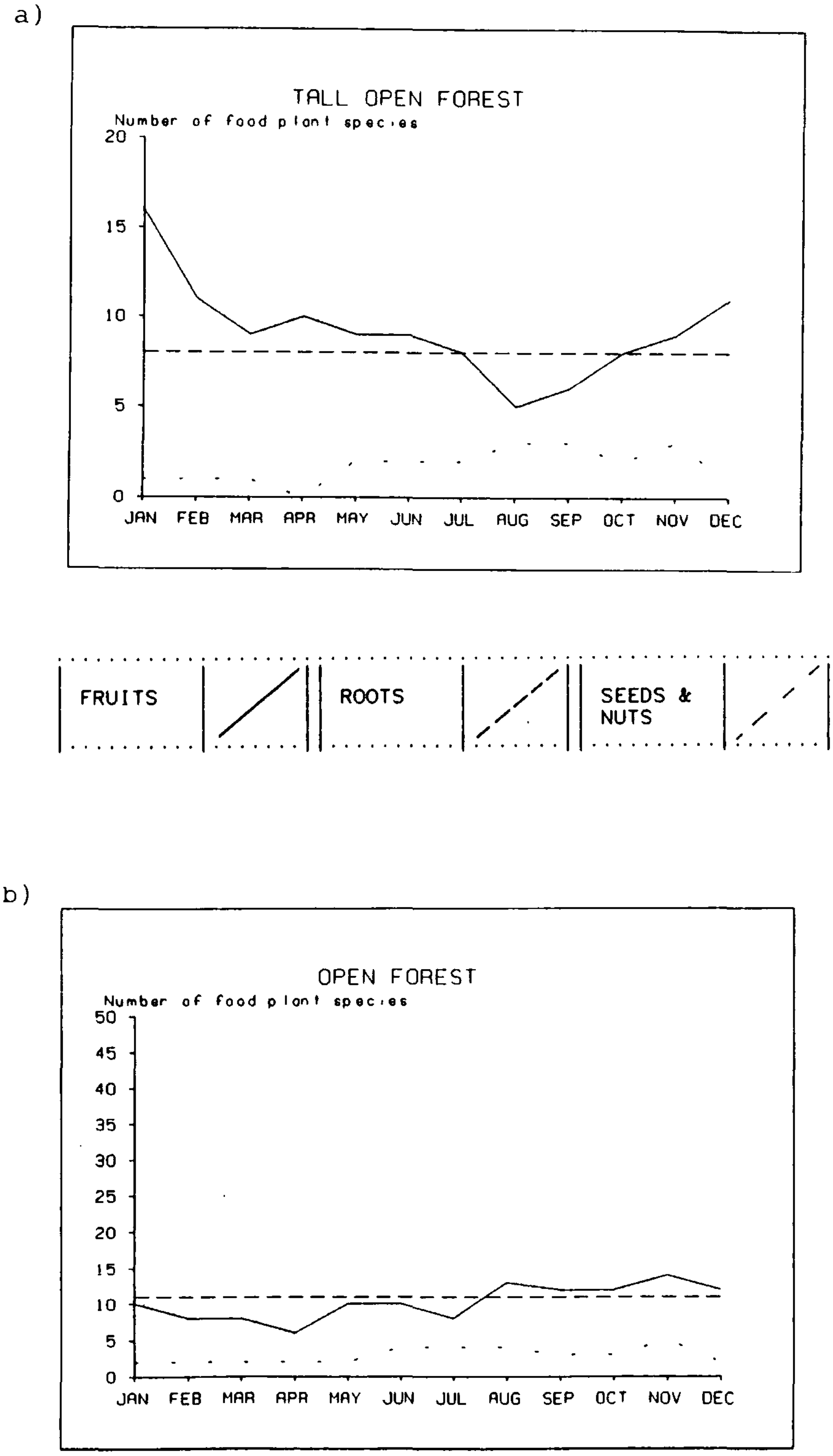

Figure 4.2: The probable number of plant species yielding Aboriginal foods (seeds/nuts, fruits & roots) in a) Tall Open Forest; b) Open Forest; c) Open Woodland; and d) Open Scrub; illustrating the decline in available production as sclerophylly increases.
(Sources: Cribb & Cribb 1974; Attenbrow 1976; Maiden 1889, 1900; checked against Jacobs & Pickard 1981.)

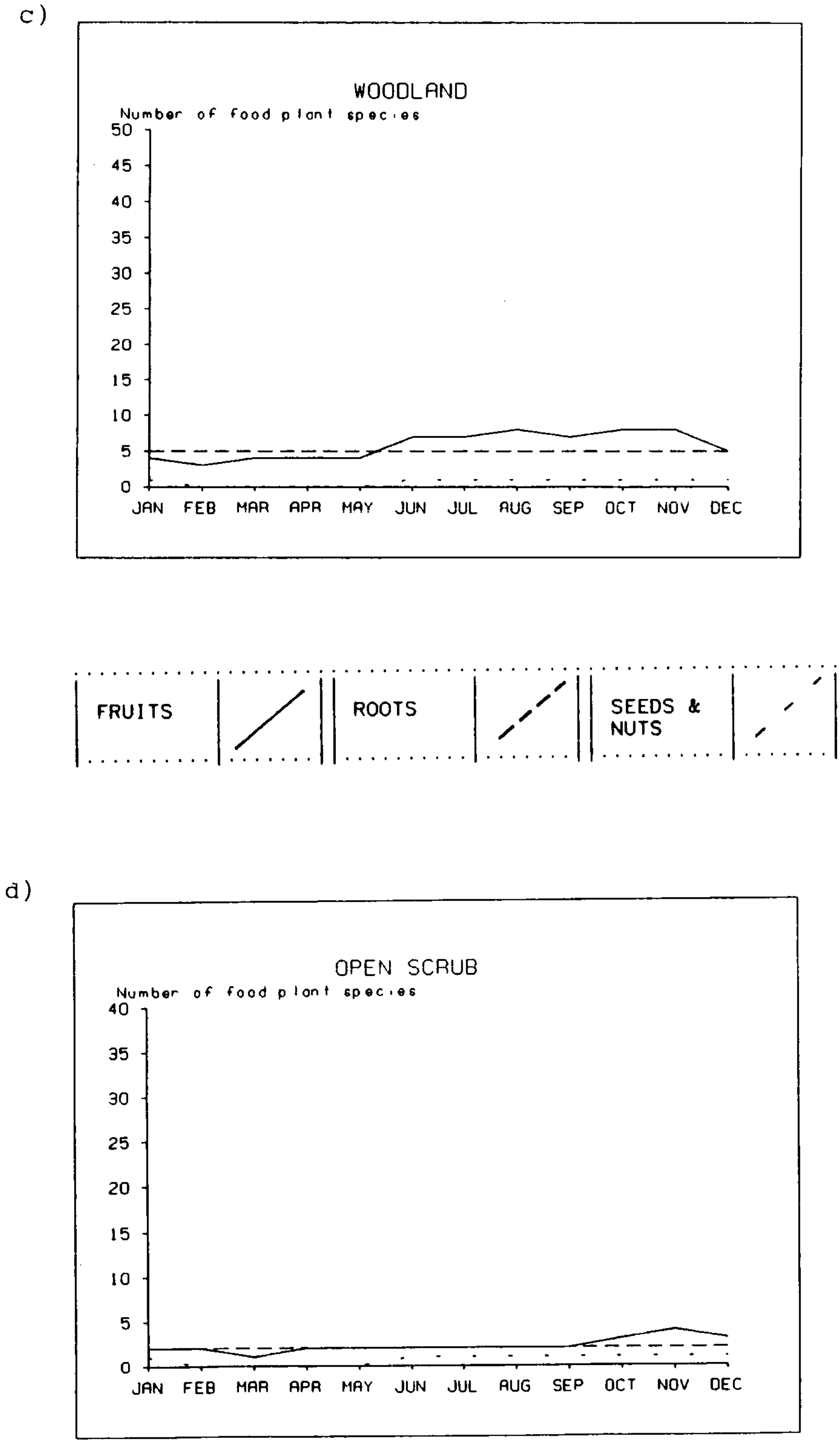

Figure 4.2: The probable number of plant species yielding Aboriginal foods (seeds/nuts, fruits & roots) (continued).

leaves (utilized, most often, by infusion) were to be removed from the data.

Note that two other vegetation characteristics are emphasized in these figures: firstly, the general lack of evident seasonality due to the asynchronous reproductive activity of the plants and the length of the growing season and; secondly, the consistency of root and tuber availability.

As to this latter point, below-ground resources are likely, from a foragers' point of view, to be an important element in the formation of vegetation patches, particularly because of the predominance of plant species which store nutrients below ground as an adaptation to nutrient shortages and high frequency fire regimes. It has been shown in similar areas that, under these circumstances below-ground productivity can often far exceed that above ground. For example, Noy-Meir (1973) has shown that an average range in semi-arid shrubland may be 100-600 g/m.sq/yr above ground, and 250-1000 g/m.sq/yr below ground. Below-ground biomass is particularly high in wetlands (Piecgynska 1975), where it can constitute 60% of the standing crop (Hatley & Kappelman 1980:373). This plant material tends to develop horizontal creeping axes of rhizomes, often of great size and rich in starch (Hutchinson 1975).

Wetlands and wetland margins are consequently likely to have been recognized as areas of consistent and temporally stable patches, because of the general tendency for these plants to be clumped, subject to a low degree of seasonality and low in cost.

The ecology of Aboriginal root-use, in general, has been examined in South Australia by Gott (1982). Owing to the lack of seasonality exhibited by roots, she has stressed their claim to be 'staple' (i.e. dependable) foods (Gott 1982:64, 1983; see also Bowdler 1981). In fact, Gott identifies _two_ broad categories of Aboriginal root use: wetland and dryland. The succulent shoots and fibrous rhizomes of _Typha_ spp. and rhizomes of _Scirpus_ spp. and _Triglochlin procera_ appear to have been predominant in the diet obtained from the wetland; while Orchidaceae, liliaceous plants, and rhizomes of ferns (but particularly _Microseris scapigera_ roots (Gott 1983) and _Pteridium esculentum_ rhizomes) seem to have dominated the diet obtained from dryland areas. All these species occur within the Sydney region (though _Blechnum_ ferns tend to more abundant than _Pteridium_).

Gott appears to assume generally high nutritive quality (particularly in starch) in these roots and rhizomes, yet a more detailed analysis of their nutritional value is particularly instructive in the present context:

1. _Microseris scapigera_. (Yam-daisy). The standard nutritional values for the yam-daisy are illustrated in Table 4.3 (Jennie Brand & Vic

Edible portion %	Energy kJ	Water g	Protein g	Fat g	Carbo-hydrate g	Fibre	Ash
100	264	73.1	1.5	0.7	13.3	11.1	1.0

e 4.3: The nutritional composition of the yam-daisy (*Microseris scapigera*)
(Source: Jennie Brand, Commonwealth Institute of Health, pers. comm.)

Edible portion %	Energy kJ	Water g	Protein g	Fat g	Carbo-hydrate g	Fibre g	Ash g
100	169	70.4	0.6	0.3	9.2	18.7	0.8

e 4.4: The nutritional composition of the fern - *Pteridium esculentum*.
(Source: Vic Cherikoff, Commonwealth Institute of Health, pers. comm.)

Cherikoff pers. comm.).[3]

At first glance the data in Table 4.3 might suggest that the yam-daisy is a good source of energy in the form of carbohydrate. However, much of this carbohydrate is in the form of inulin (Jennie Brand, pers. comm.), a non-digestible substance which also occurs in Jerusalem artichoke (Paul & Southgate 1978).

In fact, the advantages of Microseris scapigera lie only in:

a) Its stability through the year.

b) Its growth in dense stands which can be harvested at minimal search and handling costs.

c) Its good response to extraction methods. (Cropping of dense stands reduces competition for light and nutrients, improving the growth of the remaining plants; spreading may occur through the discarding of plants in the turned-over soil; while digging (which aerates and loosens the soil) would allow the penetration of new roots.)

2. Pteridium esculentum and Blechnum spp. The nutritional values of Pteridium esculentum are presented below (Table 4.4; figures for Blechnum spp. are not available but are likely to be of the same order (Vic Cherikoff, pers. comm.)). Although the rhizomes and young fronds

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[3] In this case and in all subsequent presentations of nutritional data, the information should be thought of only as a guideline, individual samples can vary to a great degree. All estimates are based on 100g samples unless otherwise stated.

contain much starch and mucilage, older plants contain tough fibres and less starch. These ferns also have a high tannin content which would tend to make over-use hazardous. The principal advantages in the utilization of these plants are broadly the same as those noted for *Microseris scapigera* above.

These two examples indicate the difficulties involved in the acquisition of an adequate supply of vegetable starches within the Sydney region. Yet more specifically indicative of the general toxicity of the vegetable component of the Sydney landscape, is the observed Aboriginal behaviour related to the detoxification of *Macrozamia communis* kernels - which are associated especially with the Blue Mountains (and have been found there at Capertee 3 (McCarthy 1964) and at Noola rockshelter (Tindale 1961) both in a recent context (Bowdler 1981:103)). The complex process of detoxification and preparation has been outlined by Beaton (1982:55) in the following way: a) collect ripe seeds; b) remove and discard fleshy husk and inner seed coat; c) dissect seeds; d) leach seeds for several days in water; e) dry seeds; f) recombine seed parts; g) roast.

On the basis of the limited archaeological evidence, Bowdler (1981) suggests that in the recent past *Macrozamia* was an important source of food in the Blue Mountains, not simply a 'communion food' - an item utilized to allow large gathering - as it appears to have been used elsewhere (Beaton 1977).

Macrozamia stands in the Sydney region are smaller than those associated with other (particularly northern) Australian areas; but its productivity can be stimulated by fire (cf. Harris 1977) and synchronized (cf. Beaton 1982) in the same ways. Even so, the handling costs are likely to be very large considering its rather mediocre nutritional value in this region (Table 4.5; the samples were from the Sydney region).

It is possible, however, that at least part of the value of Macrozamia in this region lies outside the range of standard nutritional data. The copper content of Macrozamia has been estimated as 4.7mg per 100g portion. This is more than double the next figure for copper content in any other bush food for which data are available (see for example Brand et al. 1983). (Illustrative data drawn from a variety of food types is presented in Table 4.6.) The role of this source of relative abundance of dietary copper in an area away from the coast (where fish, in particular, would fulfil this role) is particularly interesting in an environment in which copper is thought to be a limiting factor with regard to mammal populations.

In human populations, children are thought to require 0.05 mg/kg body weight/day and adults 0.2 mg/day (Mottram 1979). The earliest reference from the Sydney region thought to refer to the use of Macrozamia, states that the kernel was prepared "to give to their children ..... (although) I have seen them eat it themselves" (Bradley 1969:192). In the light of this piece of information, the role of the kernel as a source of dietary copper becomes extremely appealing.

Edible portion %	Energy kJ	Water g	Protein g	Fat g	Carbo-hydrate g	Fibre g	Ash g
69	362	57.2	7.3	0.2	14.4	19.7	1.2

Table 4.5: The nutritional composition of <u>Macrozamia</u> <u>communis</u> after treatment to remove the toxin 'macrozamin'.
(Data: Jennie Brand, Commonwealth Institute of Health, pers. comm.)

Species	Copper mg
VEGETABLE	
Macrozamia communis (treated for eating)	4.7
Caessia vittata (raw)	2.4
Dionella laevis (raw)	1.6
Acaucaria budwillii 'nut' (raw)	0.2
Castanospermum australe 'nut'	0.3
Microseris scapigera	0.2
Nymphaea macrosperm	0.4
ANIMAL	
Plebidonax deltoides (boiled) 'shellfish'	0.2
Trichosurus spp. (possum) (cooked)	0.7

Table 4.6: The copper contents of a selection of bush foods.
(Data: Brand et al. 1983; Brand & Cherikoff n.d.; Brand pers. comm.)

It is suggested then, that Macrozamia may have acted as a copper source in the interior, in the way that fish may have done upon the coast. This relationship, if it does exist, would tend to validate the argument that the fulfilling of nutrient requirements would be a major element in the optimal foragers' definition of patches within the region. In addition, The difference here between human and non-human behaviour is instructive. This dietary copper would not have been available to the fauna of the region, but through technological introduction or possibly innovation[4] it would be available to man and would permit the utilization of areas in which nutrient deficiencies may formerly have prevented it.

Though the evidence is not clear, Bowdler (1982) has suggested a connection between the exploitation of Macrozamia and the beginning of occupation in the Blue Mountains. The possibility that the partial reduction of nutrient constraint, brought about by the knowledge of the use of the kernel, may have aided population expansion into hitherto unused or under-used areas in the environment is fascinating, but beyond the scope of the present study.

Finally, it should be noted that in the small areas of relative fertility associated with wetlands and Closed Forest, a number of species of higher nutritional value do occur (Table 4.7). It should be stressed that the presence of these resources tends to be very limited within the Sydney region (with the possible exception of Typha in wetlands).

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[4] It is more likely to be introduction for as Beaton (1977:202) has said, owing to the toxicity "there is no such thing as people ..... who are just learning to prepare them".

Species (common name)	Edible portion %	Energy kJ	Water g	Protein g	Fat g	Carbo-hydrate g	Fibre g	Ash g
Auraucaria bidwillii (Bunya pine)								
Fresh	100	906	42.7	9.1	1.9	42.6	2.6	1.1
Old	100	796	44.2	20.4	0.5	26.9	7.0	1.0
Castanospermum australe (Moreton Bay chestnut)								
Cooked	100	293	79.0	3.2	0.7	13.3	0.5	3.3
Santalum acuminatum ('Quandong')								
Raw	75	352	76.7	1.7	0.2	19.3	—	2.1
Dioscorea transversa (Long yam)								
Cooked	90	490	68.0	3.2	0.3	26.5	—	2.0
Raw	67	578	62.3	1.6	0.4	33.5		2.2
Nymphaea macrosperm (Waterlily root)								
Cooked	100	575	33.6	9.6	1.0	23.4	—	30.0
(Waterlily pods)								
Raw	100	350	69.7	2.8	0.4	18.0	8.3	0.8
Cooked	100	513	59.4	2.9	0.5	27.8	8.3	1.1

Table 4.7: The nutritional composition of some vegetable species associated with areas of Closed Forest and with Wetlands. (Data: Brand et al. 1983; Brand & Cherikoff n.d.)

Vegetation patches in space and time

In summary, vegetation patches defined by optimal foragers in the Sydney region are not likely to have been constrained by time. The underlying characteristic of these patches is likely to have been a ranking which echoed the pattern of nutrient distribution from wetlands, closed forests and tall open forests down to heathland, where potential returns may have been so low that patches may not have been recognized at all.

At the higher end of this continuum not only is the edible flora less toxic, but the ratio of edible to inedible compounds is likely to increase. Yet overall, the carbohydrate available to the efficient forager is likely to have been low - though techniques not available to non-human animals (principally firing) may have helped to stimulate the development of some species which were already recognized as comprising a patch.

4.4.2 Mammalian patches

Before proceeding to consider the essential characteristics of faunal patches in the Sydney region it should be noted that there is an important distinction between the nature of vegetational and faunal patches: vegetational patches are static; while faunal patches are mobile. The distributional characteristics of these latter potential patch components can be classified in three ways: a) randomly dispersed; b) clumped or aggregated; or c) regularly or uniformly spaced (see Brown & Orians 1970:239; Wiens 1976:83). In general, the abundance of mammals is likely to be low; hence in the discussion below, it is aggregations of mammals which are assumed to form potential patches.

The available evidence suggests that as nutrient levels increase so does faunal abundance, so that the likelihood is that mammal patches would have been ranked in terms of vegetational structure associations upon a continuum from wetlands, closed forest and tall-open forests to heathland. However, from the point of view of an optimal forager, nutritional factors are also likely to have influenced faunal patch recognition.

From a purely nutritional point of view, all the mammals within the Sydney region are reasonably good sources of protein. However, with the exception of bats (and the cetaceans) they are extremely poor sources of fat. It was suggested earlier in this chapter that fat is likely to have been a very important commodity within the region because of the necessity of relying heavily upon protein in the diet.

The amount of dissectable fat among the larger marsupials is very small and occurs principally as subcutaneous tail fat (Tribe & Peel 1963). Tables 4.8 and 4.9 present data which illustrate this low fat content through the carcass composition for different weight ranges in the larger kangaroos (Hopwood et al. 1976) and data for fat percentages in other game species from elsewhere (Speth & Spielman 1983). Note that the fat content in the game species drops in winter; presumably such fluctuations occur in

Empty body weight (kg)	Carcass weight (kg)	Bone %	Muscle %	Fat %	Water %
20	12.69	14.7	78.6	0.8	5.9
30	19.29	14.6	79.0	0.6	5.8
40	25.89	14.5	79.1	0.5	5.9

Table 4.8: The body composition of the red kangaroo.
(Note: These data are based upon gutted weight. Hayden (1981:397) warns that intestinal fat can be important. However, these data do include tail fat).
(Source: Hopwood et al. 1976)

Animal	part	% fat	season
Antelope (Antilocapra americana)	ham	4.5	Summer
	ham	1.2	Winter
	loin	6.0	Summer
		1.1	Winter
Deer (Odocoileus hemionus)	(male)		
	whole body	16.9±7	Summer
	whole body	5.4±2	Winter
	(female)		
	whole body	12.5±3	Fall
	whole body	6.9±3	Spring

Table 4.9: The fat composition of some comparable game species.
(Source: Speth & Spielman 1983)

kangaroo populations - though there is evidence that this is not the case among some smaller Australian mammals.

Generally, small marsupials tend to have a greater lipid content per 100g sample that larger marsupials. Brand et al. (1983) have analysed cooked samples of the possum *Trichosurus arnhemensis* (Table 4.10), their results indicate that the lipid content of viscera could be significant - though overall they consider the possum to be very low in fat (1983:298).

However, in some small mammals the lipid content is known to nearly double *in winter*. This phenomenon is best known in *Rattus fuscipes* (Stewart & Barnett 1983), but is also known in other small mammals such as *Rattus lutreolus* (Lunney 1978) and *Peromyscus microtus* (Stewart and Barnett op. cit.; see also Bamford 1970; Table 4.11). The function of the extra lipid is uncertain - it could provide insulation or, more probably, it is a source of energy.

The seasonal increase in lipid content in these small mammals is a good example of how a patch can be purely temporal, in that during the winter, the returns involved in small mammal hunting would be greater (both in terms of energy from the fat and also through the role of fat in increasing the efficiency of protein absorption) though the costs of hunting these animals would not be any higher than at any other time of the year. Thus, during the winter 'small mammal patches' would be likely to be more highly ranked (in cost/benefit terms) than at any other time.

Edible portion %	Energy kJ	Water g	Protein g	Fat g	Carbo-hydrate g	Ash g
Flesh cooked 100	700	61.3	33.6	3.5	0	1.6
Liver cooked 100	704	64.7	26.5	6.8	0.1	1.8
Kidney cooked 100	713	62.2	28.7	5.7	0.9	2.4

Table 4.10: The nutritional composition of the possum - *Trichosurus arnhemensis*.
(Source: Brand et al. 1983)

	Summer	Winter
Body weight (g)	109.7	99.2
Carcass (wet) (g)	42.9	37.5
Carcass lipid (g)	1.62	2.84

Table 4.11: The winter increase in carcass lipid in *Rattus fuscipes*
(Source: Stewart & Barnett 1983)

Mammal patches in space and time

Owing to the constraints placed upon the abundance of terrestrial mammals by nutrient deficiencies within the landscape, the recognition of patches is likely to have followed the pattern of nutrient distribution in much the same manner as has been suggested for vegetation patches.

Over much of the region, particularly along the coast and upon the plateau, the low abundance of mammal fauna is likely to have meant that mammal patches (if recognized at all) were likely to have been of low rank, particularly because of the high search time (cost) involved. The generally low fat content of the mammal fauna would also have been likely to have influenced the ranking. (Hayden 1981:421 gives an interesting factual example of this influence, in the context of the Australian desert, for he has seen the Aborigines "..... kill a kangaroo, examine the intestines for fat, and abandon the carcass where it lay because it was too lean.....(and Hayden notes that)..... Upon making a kill, Aboriginal hunters always open the intestinal cavity and check the fat content".)

Where nutrients become greater in abundance, particularly in areas associated with wetlands, Closed Forest and Tall Open Forest the highest ranking mammal patches are to be expected, though the general lack of fat may still prevent the patch from being defined. However, the fact that the best vegetation patches and the best mammal patches are likely to have been discerned within the same area in the landscape, may have tended to raise the ranking of both.

Physiological changes is some small mammals associated with winter, would have had a tendency to increase the probability of these being discerned as a patch. Particularly during a period of the year when other patches may have been depressed. Animals in which this trend has been detected are most abundant in the areas of high nutrient content, and particularly wetlands.

That one group of mammals - bats - may under exceptional circumstances have been likely to be recognized as a patch of great value (particularly in terms of lipids) is indicated by the presence of the flying fox on one historical occasion reported in the First Fleet sources, in a camp of 20000 at Rose Hill (Hunter 1968). Such phenomena particularly illustrate the value of efficient information networks.

Another group of mammals - the cetaceans - may also have been defined as patches under exceptional circumstances; but because our viewpoint is that of the terrestrial predator, a discussion of the recognition of these patches is attached to the next broad category - aquatic patches.

4.4.3 Aquatic patches

The two major groups of aquatic fauna within the Sydney area - fish and shellfish - have to be considered separately, because the one resource is highly mobile and not clearly associated with landscape features; while the other is for the most part static and tied to specific landform structures.

a) Fish

Fish are a resource of great abundance and diversity within the Sydney region. They are potentially available in large quantities throughout the year. As a general principle, fish are only likely to be defined as patches by a terrestrial forager when they shoal. Some species within the region shoal throughout the year, and the period of shoaling of others may not be limited to any particular time period.

In general, however, estuarine fish have a tendency to shoal at the mouth of estuaries or in the surf zone beyond in winter to take advantage of the warmer waters as the sea grass (*Zostera* spp.) dies back and primary productivity is reduced (see Figure 4.3). As a consequence, fish are at their lowest abundance in the upper estuary during these months.

Table 4.12 illustrates the seasonal availability of shoals of fish ('fish patches') in the three areas of the coast, estuary mouth and estuary. (As our perspective is that of the terrestrial forager, the species noted for the coast are limited to those which are available from rocks or from the surf zone and excludes many abundant offshore migratory species.)

While the majority of fish are to be found at the estuary mouths during winter, yellowfin and black bream and flat-tailed mullet are available throughout the year provided the patches can be discerned (for example, bream tend to shoal in the early night in shallow water in order to feed,

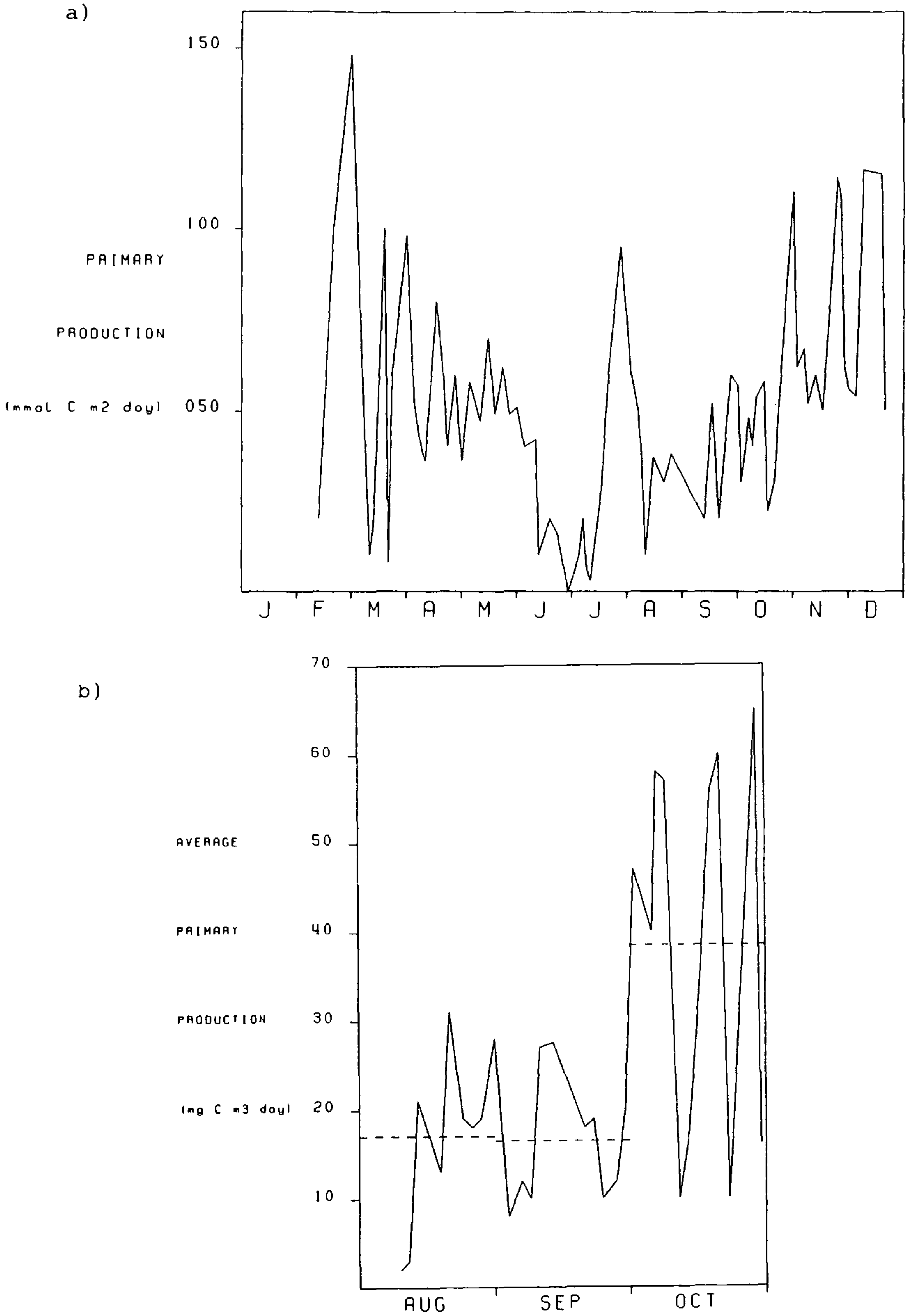


Figure 4.3: Primary production at two points on the Sydney coast, illustrating the tendency for production to: a) fall during winter and; b) rise sharply in spring.
(Sources: a) Port Hacking. Scott 1978.
b) Cronulla Bay. Carpenter & Carpenter 1976)

	Dec - Feb summer	Mar - May autumn	June - Aug winter	Sep - Nov spring
COAST	John dory Tailor	Mulloway Sea mullet Salmon Tailor John dory Leatherjacket	Mulloway Sea mullet Salmon Tailor Yellowfin bream Tarwhine Luderick	Salmon Snapper
ESTUARY MOUTH	Sand whiting	Mulloway Sea garfish	Yellowfin bream Sea garfish Luderick	Sand whiting
ESTUARY	Mulloway Flat-tailed mullet Most abundant period	Flat-tailed mullet Dusky flathead River garfish Eel *	Low period in main estuary (see text) Hairtail +	Fish return to estuaries

Table 4.12: Shoaling fish and their annual distribution. (Note: all these species are known from an archaeological context at some point upon the New South Wales coast except (+) hairtail and (*) eel which is known only from the artistic record.) (Sources: New South Wales Fisheries 1982; Sullivan 1982)

while flat-tailed mullet shoal to feed in the early morning (Gregory's 1982). In addition the mangrove swamp areas serve as refuges throughout the winter period for a wide variety of fish (Bell et al. 1984).

Other winter-shoaling species include a number of migratory and other fish which utilize the surf zone. Principal among these are the sea perch (Arripis trutta - the 'Australian Salmon'), Snapper (Chrysophrys auratus), and the sea mullet (Mugil cephalus).

Arripis trutta spend winter and spring along the inshore coast of New South Wales prior to migrating southwards in summer (NSW State Fisheries 1982:17). The population is thought to have been far greater in the past than at present owing to the depletion of the species caused by over-fishing. Snapper occur all year round near rocky environments while sea mullet congregate in winter and run in large shoals along sea beaches.

Earlier in this chapter, Table 4.2 was presented in order to demonstrate the importance of these shoaling species to the present-day fishing industry and to provided a rough guide to their potential availability. However, the recognition of fish patches is, in fact, a very complicated business, and must almost certainly depend upon an efficient information network. Unlike terrestrial fauna, fish shoals are not necessarily predictable in their location, nor are they necessarily visible from any distance. Modern fishing fleets are energy and capital intensive and provide little guide as to how such an information network could be formed or how it would be likely to operate. Amateur fishermen provide a better guide, particularly because the technological (i.e. extractive) aids are broadly comparable (i.e. hook and line) and hence handling and search-time costs are comparable to those likely to be associated with hunter-gatherers. (It should be noted, however, that the discrepancy between amateur and commercial potential catches need not necessarily be great, for example at Tuggerah Lake (1978-1979) the total amateur catch of luderick was 85% by weight of the commercial catch (NSW State Fisheries 1982).)

The following account of where, when and how modern amateur fishermen define fish patches is based on the popular handbook "Gregory's fishing guide". The complexity of patch definition and the value of the information system are self evident. (It is assumed that the basic aquatic structure is much the same in the present day as it was in the past. A seemingly reasonable assumption, in that pollution, for example, is not thought to have had a major effect within the Sydney region upon fish populations (Recher 1973)).

1. <u>Tidal lakes and rivers</u> are fished for bream, whiting, luderick, and dusky flathead (which are resident) and for tailor, mulloway and salmon (which are not). Anglers line the beach around the entrance to catch fish as they feed near the outlet to the sea. Small tidal lakes that become blocked are fished for the abundant young fish, prawns and squid which accumulate. Bream in particular are caught in great numbers throughout the year by the more experienced fisherman but very few by the unskilled (Gregory's 1982: 118) - they are most easily

caught during the early night.

2. Estuaries and bays. Anglers who habitually fish the estuaries and bays go out in boats at daylight and fish in a favoured spot on the incoming tide, or drift with the wind or current across sandbanks for flathead. Luderick fishers get out early to a favourite spot and fish all day: bream fishermen will fish the channels, deeper holes and flats.

At night they fish near mangrove banks, near oyster beds or near weed beds. Principal species are bream, flat-tailed mullet throughout the year, luderick (particularly during April to July when they "bite freely") and juvenile snapper.

3. Beaches. The main fishes are sand whiting, bream, dusky flathead, and tailor, salmon and sea mullet in season. The surf fisherman is very much at the mercy of the elements as well as the vagaries of fish movement. Onshore winds flatten out the beaches and eliminate holes and gutters. Rougher weather provides deeper features which can be used by the fish. "The visible formations of the surf beach usually determine whether a visiting party will stay to fish or not" (Gregory's 1982:101).

Tailor are most abundant between May and July and are best caught at dawn and dusk. Salmon (August to October) are found on beaches and around rocks in "a biting mood much more than any other sporting fish during the middle of the day", but the salmon also "..... has great merit as a sporting fish because it stays in the surf longer than most, and will bite day or night". Sea mullet are principally found from March to July, they travel close to rocks and surf.

4. Rock fishing. The main fish taken are bream, luderick, snapper and sea mullet. As in beach fishing, rock fishing is dependent upon moderate seas and can be dangerous. Great quantities of snapper are taken in May, June, July and August (i.e. winter) particularly in the early morning. Sea mullet are caught as on beaches. Luderick are at their most abundant from April to July.

The evidence supplied by the behaviour of amateur fisherman clearly suggests that, provided the information network is good enough, fish patches can be recognized throughout the year within the Sydney region. For despite the fact that estuarine fish are less abundant in winter, shoaling fish are available and largely predictable in their behaviour upon the coast during that period.

Of all areas in winter, the mouths of estuaries and closely associated inshore coastal areas represent the zone in which fish patches are likely to be most predictable. Generally, these fish patches are probably more predictable than 'beach and rock' migratory species because they are spatially limited and because there is a greater degree of shelter from the influence of weather than in the majority of places along the coast.

In contrast to many estuarine species, riverine fish possess the most stable population structure in the region - provided that floods do not wash out the fish to the estuary (as happens occasionally along the Hawkesbury-Nepean). There are few species to be found and those are at low density (cf. Sloane 1984abc), principally because of the low nutrient input from the landscape. Thus fish patches associated with rivers are likely to be lowly-ranked unless severe resource depression affects more highly-ranked patches. The principal species are mullet and bream which can be caught throughout the year. Average fish size tends to be smaller in winter because the larger fish - having reached sexual maturity - join spawning runs in the estuaries, hence handling costs (in particular) are likely to increase.

The standard nutritional values of the (essentially) estuarine species, bream, and the sea mullet are given in Table 4.13: the figures for cod and the fat-rich Atlantic salmon are also given as a broad comparative guide. Although most of the composition of the Australian fish is water they have a relatively high protein, but low fat content. Note also that the phosphorus content is high (there are no data available concerning copper, but fish in general are considered to be a major source of dietary copper (see above).

Within the Sydney region, other fish of potentially great nutritional value are likely to be defined as very high-ranking patches at particular times of the year. In particular the eels - Anguilla australis and A. reinhardtii - which reach their greatest biomass in south west Victoria

Edible portion %	Energy kJ	Water g	Protein g	Fat g	Carbo-hydrate g	Phosphorus mg
BREAM steamed 100	414	77.1	17.8	3.0	0	238
MULLET raw 100	550	72.7	20.6	5.4	0	238
COD raw 100	304	81.6	17.0	0.4	0	194
SALMON atlantic raw 100	842	65.5	19.9	13.6	0	266

Table 4.13: The nutritional composition of two Australian and two Atlantic fish species - a standard chart with phosphorus levels.
(Note: converted to kJ using Atwater factors (see Brand et al. 1983).)
(Source: Thomas & Corden 1970)

Edible portion %	Energy kcal	Water g	Protein g	Fat g	Carbo-hydrate g	Phosphorus mg
66	233	64.6	15.9	18.3	0	233

Table 4.14: The nutritional composition of the eel - Anguila australis. A standard chart with phosphorus level.
(Source: Thomas & Corden 1970)

(Usui 1974; Tesch 1977; see Lourandos (1977, 1980) concerning their influence upon Aboriginal populations), are also abundant in the Sydney Region. The ecology of eels has recently been studied by Sloane (1984abc) in the Douglas River, Tasmania. In general, the biomass of these species declines with distance from the sea. Though *A. australis* tends to be found further inland probably because of the predation upon it by *A. reinhardtii* (Sloane 1984a:327).

Eels spend the greater part of their lifecycle in freshwater rivers, creeks, and swamps at low density. However, when they mature (about 6-12 years) they congregate and move out to sea. Spawning occurs in the open sea, and after three years the elvers move back into the estuary and thence to the rivers, creeks and swamps (Williams 1979:71-2). Eel congregations occur in autumn within the Sydney Region. The importance of the event is that it represents a trend from the dispersion of a fatty resource to an aggregation. The composition of the eel is presented in Table 4.14, The high fat content of the fish is clearly confirmed, as is a high phosphorus content.

b) Shellfish.

Although shellfish occur inland (particularly *Velesunio* spp.) they are nowhere abundant, and are only likely to have been discerned as patches under conditions of extreme resource depression. However, on the coast and in the estuaries they are a major feature of the environment. In these areas, they tend to form static and stable populations, which are more closely connected to the landscape than are fish. Owing to the very low handling costs associated with them it is highly probable that an optimal forager would recognise them as patches.

Broadly, shellfish species which form dense populations can be divided into three groups (Table 4.15):

1. Species found on rocks and sand along the coast.
2. Species found on rocks, sand and mud in estuaries.
3. Species found in both environments.

These species are either immobile or are limited in their mobility once they begin to mature. In addition, those species within the estuary are less liable to large-scale fluctuations in the population, which among coastal populations may be brought about by the action of storm forces and other factors.

The individual characteristics of some of the species reveals their essential dependability as patches of low risk food, despite the fact that some of the species tend to shift their position from year to year.

The Sydney rock oyster (<u>Crassostrea</u> <u>commercialis</u>) for example, shows a marked preference for rocky or mangrove surfaces settled on by previous generations, and consequently endures in particular locations. The oyster can tolerate higher proportions of fresh water than most other shellfish and may also be found in fully coastal habitats.

Coastal	Estuarine	Coastal/ Estuarine
ROCK	ROCK & MANGROVE	ROCK
Crassostrea commercialis (Sydney rock oyster)	C. commercialis	C. commercialis
	ROCK	
Mytilus planulatus (edible mussel)	M. planulatus	M. planulatus
Trichomya hirsutus (hairy mussel)	MUDFLAT Anadara trapezia (Sydney cockle)	
Patellanax spp Cellana spp (limpet)	Pyrazus ebeninus (whelk)	
SAND	SANDY MUD	
Plebidonax deltoides (pipi)	Ostrea angasi (mud oyster)	

Table 4.15: The principal shellfish species of the Sydney region and their substrates.
(Source: Sullivan 1982)

The Sydney cockle (Anadara trapezia) is limited to the estuaries. Although their preference is for salinities approaching those of sea water (30-35 parts per thousand: seawater=36ppt), they can tolerate salinities down to 15ppt (but at this level changes in the amount of fresh water flowing through the beds can destroy them). Cockle beds shift from year to year because of environmental changes (particularly smothering) associated with their substrate (Sullivan 1982). Though in sheltered areas they have been known to have been stable for several generations.

The ecology of the mussels Mytilus planulatus and Trichomya hirsuta is very similar to that of the oyster. Mussels are capable of movement however, and may sometimes compete with oysters upon the rocky substrate. There are marked fluctuations in settlement intensity from year to year and populations have a rapid turnover. However in favourable conditions they reach maturity more quickly than other species (in about a year).

Nutritional data for some shellfish species is presented in Table 4.16. It is evident that the principal nutritional component is protein and the fat content is low. However, they represent a stable, abundant and low-cost (in terms of handling and search time) resource and these factors are likely to combine to ensure that at least parts of the shellfish population would be defined as a patch.

In addition to the foregoing, there are a number of aquatic resource which would be likely to be recognized as high value patches should the

Edible portion %	Energy kJ	Water g	Protein g	Fat g	Carbo-hydrate g	Phosphorus mg
Crassostrea commercialis (Sydney rock oyster) 100	269	83.8	8.7	1.5	4.1	149
Mytilus spp. (Mussel) 100	199	87.9	7.6	1.2	1.6	not known
Hemidonax donaciforme (sand cockle) 100	323	79.2	16.8	1.0	0	not known
Plebidonax deltoides (pipi) (boiled) 100	379	78.0	14.3	1.8	4.3	not known

Table 4.16: The nutritional composition of some shellfish species from the Sydney region - a standard chart with a phosphorus level for *Crassostrea commercialis*.
(Note: Data for the sand cockle (*Hemidonax* spp.) are likely to be of the same order as those for the Sydney cockle (*Anadara trapezia*) (Cherikoff pers. comm.) and are used here in the absence of data concerning the latter species.)
(Sources: Thomas & Corden 1970; Cherikoff pers.comm.)

appropriate phenomena occur. Leopard seals, for example, which may haul out on to beaches in winter, have a composition of approximately 41% fat by bodyweight. More importantly, a number of whale species migrate past the Sydney coast during the winter and spring. Although not directly accessible, through accidental strandings large quantities of the precious commodity - fat - would be made available.

There are little data concerning the migratory habits of the whales in Sydney waters because of the early predation upon these populations by Europeans, and the consequent near-extinction of species. However, in a recent paper, Smith & Kinahan (1984) have examined a broadly comparable situation on the west coast of South Africa. They estimate that between 7.3 and 10.7 cetaceans become stranded each year upon this coast, even in these times of depressed cetacean abundance. Such a resource, perhaps a sperm whale of 25 tons, a humpback of 40 tons or a right of 60 tons, or indeed, smaller cetaceans such as the common porpoise (41kg) with their comparatively higher fat composition could not fail but to be ranked highly upon a cost/benefit appraisal, and defined as a high-value patch.

In addition, as beaching is associated with gently sloping sandy beaches, the structural landscape features of the coast of the study region (in the form of the gently shelving continental shelf) would make almost any part of the coast, (with the exception, clearly, of rock headlands and clifflines) a potential source of this rich resource.

Aquatic patches in space and time

Most aquatic patches are very difficult for a terrestrial forager to discern because they are remote from most of the features of the landscape, and their distribution may be unrelated to patterns of production in the whole system (as in the case of migratory fish). However, they are also the most productive resource within the region in terms of calories and protein. From the point of view of an optimal forager, the highest ranking aquatic patches would be recognized within the estuaries (a fact demonstrated, incidentally, by the observed high density of aquatic predators (e.g. sharks) within these landscape features.)

Despite their cryptic characteristics, the occurrence of fish patches could be predicted within broad limits, because of the characteristic shoaling behaviour of species. Premier amongst these predictable movements is that of a number of fish species to the mouth of the estuaries and the immediate inshore coastal areas, and the passing of migratory species in the inshore zone in winter and early spring.

Throughout the year, high-return fish patches could be recognized, then, despite the fact that their spatial and temporal characteristics (as well as their species composition) might alter. In the period from spring to autumn, patches would be estuarine and associated with Zostera beds, mangrove swamps and other areas of high productivity. In winter, as these sources of nutrients were reduced, potential patches would have moved through the system to the mouth of the estuary and coastal inshore areas.

None the less, the characteristics of aquatic patches (excluding shellfish) are such that it is likely that search times for a terrestrial predator without access to an information network, would be prohibitive. The importance of such a system in patch assessment is particularly illustrated in the case of cetacean populations, for the location and frequency of occurrence of these patches cannot be known in advance. Yet as potential (or, indeed, highly probable) patches, they would be likely to influence patch-ranking particularly in winter, when other resources are likely to be depressed. One of the best examples of the action of such an information system comes from the Sydney region - for during the winter in 1788 a number of beach strandings are reported, even within the limited area known to the Europeans at this time. Each stranding was accompanied by the aggregation at such points on the landscape of two or three hundred Aborigines - implying the rapid spread of information concerning the phenomenon.

An element of risk in the use of aquatic resources still remains - what happens on those days when a predator cannot identify high-return aquatic patches?

The answer - if only the aquatic resource area is considered - must be that the efficient forager must turn to shellfish. That is to say, the event of effective resource depression, must cause the predator to seek resources from lower down the ranking of patch types than would be the case if those more 'valuable' patch types were present. Shellfish are dependable low return but low cost resources of extensive range. In this respect they are true 'buffer foods' (see below).

4.4.4 Avifaunal patches

The avifauna contribute far more species to the Sydney region than any other vertebrate group, yet they are only a little less opportunistic in their association with particular vegetational structures than mammals (a greater number of species do have a special association with shrublands, however).

The principal strategies available to the avifauna are nectivory and insectivory. The asynchronous flowering regime constrains the former and the poor representation of insects the latter. As a consequence of these factors, from the point of view of the optimal forager, those species which rely on these strategies are high cost resources and would be unlikely ever to be recognized as patches.

In essence, only three groups of medium to large bird could be considered as likely to form potential patches: the emu (_Dromaius novaehollandae_); the representatives of the quails (Phasianidae and Turnicidae); and the representatives of the waterfowl (Anatidae).

Virtually nothing is known about the ecology of either of the first two groups in the region, but the emu population was probably no less constrained by nutrient distributions than the mammal population. Its principal food within the region appears to have been grass and flowers (Blandfordia spp.) (Tench 1979) which would have limited it to areas of grassy understorey (principally areas on the Cumberland Plain) and to wetlands. Similarly the quail are known to be associated with the more fertile areas of the Cumberland Plain, particularly along the river bank, which suggests that the same patterns of constraint are likely to have affected them.

However, from the point of view of an optimal forager, the principal component of the avifauna would be the waterfowl. (The principal species associated with the Sydney region and their mean weights are presented in Table 4.17.) The potential of the waterfowl to be recognized as patches would have been influenced both by their mobility and by their periodic aggregation.

Unlike the waterfowl of the northern hemisphere, Australian waterfowl seldom embark on mass migrations (when they do occur they are erratic in both direction and timing). Some species are relatively sedentary, others are arealy limited, but most are nomadic (Frith 1967:5). They disperse from their feeding or breeding place whenever it becomes unsuitable and do not necessarily return there again. The driest period in an area tends to see waterfowl aggregating upon wetlands near the coast.

Although there are differences in the predominant form of the diet between species (black duck, grey teal, chestnut teal, hardhead and

Species	Common name	mean weight (g) male	 female
Cygnus atratus	Black swan	6270	5100
Tadora tadonoides	Mountain duck	1559	1291
Anas superciliosa	Black duck	1114	1025
Anas gibberifrons	Grey teal	507	210
Anas castanea	Chestnut teal	486	235
Anas rynchotis	Shoveller	667	665
Aythea australis	Hardhead	902	838
Chenonetta jubata	Wood duck	815	800
Bizuir lobata *	Musk duck	2398	1551

Table 4.17: The waterfowl of the Sydney region and their mean weights (Note: the musk duck (*) is considered to be inedible because of its very powerful scent.)
(Source: Frith 1967)

mountain duck are predominantly vegetarian; shoveller and musk duck - insectivorous; and black swan and wood duck - vegetarian) there is no evidence that within these diet groups, any waterfowl selectively feeds. The composition of the food eaten closely parallels the abundance and availability of the food items in the chosen feeding habitat and waterfowl will stay until they have 'exhausted' the habitat (or more probably, until the marginal value is reached) and then move on. Indeed, "food is the major factor which controls the movement of birds" (Frith 1967).

The principal unpredictable element in the formation of waterfowl patches, from a human predators point of view, lies in the birds' ability to detach themselves from the mobility constraints of the land surface (which constrain the predator's behaviour). This gives them the ability to rapidly redistribute themselves in relation to the availability of food or the incidence of predation. In consequence, small numbers of waterfowl would represent a very high harvesting costs and are not likely to have been defined as patches by an efficient forager - the potential for high returns and low costs lies only in the aggregation of these birds.

The tendency for these birds to aggregate and other features related to their potential as patches are summarized below:

1. Black swans are abundant within the Sydney region as a whole, but for most of the year they are widely dispersed. Overall, this species is considered to be the most adaptable of the waterbirds and occupies the widest range of habitats. Although there is usually a small resident

population in their preferred habitats - fresh and brackish lakes, inland billabongs, lagoons and coastal rivers - the majority of the population is nomadic and moves erratically. Consequently, there is a rapid turnover in the population. Table 4.18 illustrates this characteristic using data from Lake Brewster, N.S.W. Frith estimates that the total number of birds to pass through the system may have been as many as ten thousand (op. cit:95). The swan congregates to breed upon the major wetlands in winter (April to August).

2. The mountain duck is not common within the Sydney region, but when it is found. it usually occurs in flocks of more than a thousand birds. During the day they rest usually in or at the edge of water, particularly in lakes and estuaries but also in freshwater lakes and billabongs. The principal concentrations occur in summer and the bird tends to disperse in winter to breed.

3. The black duck inhabits permanent swamps within the region. During the winter and spring they congregate in coastal districts to breed.

4. Grey teal are found in any fresh, brackish or salt water habitats at any time, but are far less abundant in salt-water bays and estuaries. They congregate in lagoons and billabongs of inland rivers to breed in winter and spring.

5. Chestnut teal are to be found in brackish coastal lagoons, salt water estuaries, mangrove and other swamps. They breed (usually more than

Total number of birds	Number of marked birds
1200	381
After three months	
1800	20

Table 4.18: The number of marked black swans in relation to the total population: an experiment at Lake Brewster, N.S.W. (Source: Frith 1967)

one clutch) in summer and are usually only found in small groups or pairs.

6. Shoveller are found in widely dispersed groups or pairs in permanent swamps. After the breeding season (August - December) they are found in lagoons and billabongs. This species is thought to have been much more abundant in the past when wetlands were more widespread.

7. Small flocks of hardhead are common, and large flocks not unknown. They favour deep water and are to be found in lagoons, large coastal swamps, permanent swamps and billabongs, and breed in summer.

8. Wood duck favour the edge of swamps and lightly-timbered river margins. After breeding they gather in flocks of about a hundred. Each flock has a traditional camp, but during the spring, the flocks disperse into pairs for breeding.

9. Musk duck are completely aquatic - each bird maintains a distance between itself and other. They favour deep permanent water with dense vegetation. They breed in summer; and in autumn and winter they move to larger swamps and deep lakes.

The behavioural characteristics of the majority of these species is such that during the winter and early spring, aggregations of individuals and species are associated with coastal lagoons, coastal rivers, and wetlands. However, this does not automatically ensure that an optimal forager would recognize such aggregations as patches. For the birds are not limited to the terrestrial plane and may escape in directions that the human predator cannot follow (i.e. up!), and in addition, waterfowl concentrations are known to disperse rapidly and widely after the first shot has been fired (or, presumably, the first spear thrown) (Maher 1982). Such complications are likely to greatly increase extraction costs, possibly to the extent where they far outweigh potential benefits. However, the costs incurred through the predation responses of individual waterfowl species are not equal, and these inequalities are likely to exert most influence upon the optimal forager's recognition of patches.

In his classic book on Australian waterfowl, Frith (1967) distributes throughout his account, hints as to the behaviour of the waterfowl in relation to predation (he is, of course, referring to the predation by modern hunters armed with shotguns or rifles, but broadly the two predator behaviours are the same; particularly because the density of the habitat of these species normally precludes long-distance shooting). The variety of the responses which he notes, suggest that some species may possess a greater potential for patch formation than others:

Black swan

> Black swan are usually scattered over large bodies of water but often come ashore and walk clumsily. When disturbed they rise with difficulty, taking forty to fifty yards before they are airborne. Among timber and rough water they cannot rise and in the thick vegetation at the fringe of their habitats they can be caught from

boats or on foot (op.cit: 91), for they seldom use water areas that are more than three feet deep, because at greater depths they cannot reach food.

In addition, it is known that black swans, which breed along the coast and rivers in winter/early spring, moult after laying and are entirely flightless until the new feathers have grown. In addition, the cygnets (which may weigh between 4000-5000gms) are unable to fly for 180 days.

Mountain duck

Mountain duck are found at the edge of the water. They are very wary, alert and difficult to approach. When disturbed the whole flock rises.

Black duck

The small groups of black duck are found in swamps with heavy vegetation. They are wary and alert and difficult to approach. When disturbed they fly swiftly and straight. The bird often leaves the water to feed on land (15% of its food may come from the land).

Grey teal

Grey teal are to be found in the water, on mud banks and clustered on fallen trees. They are easy to approach, except when they have already been disturbed, when they are very wary and fly in a compact flock.

Chestnut teal

These birds seldom leave the water, though they can be found on rocky islands and mud banks. They are always wary and swift flying.

Shoveller

Shoveller prefer densely vegetated swamps. They are very wary and swift flying.

Hardhead

These birds are found on water; seldom on shore. They favour deep water and are very difficult to approach. When disturbed they rise almost vertically and swiftly. They are difficult to hit and hard to kill - when wounded they dive and swim; and are hard to recover.

Wood duck

Wood duck favour the lightly timbered edge of swamps and river margins. They are extremely wary and shy. When they sense danger they remain motionless and silent, making them very hard to detect.

Musk duck

Musk duck are considered to be inedible because of the pungent scent of the meat. Their response when detected is to sink slowly or dive and swim away.

Of all these species, the black swan, because of its high density during winter when other resources may be depressed; its size and slow reaction; and its inability to escape under certain conditions, must surely have been recognized by an efficient forager as a a potential high return/low cost patch, independent of the potential returns of the other waterfowl which are to be found in the same locations. Hunting of this species would not easily deplete the resource at any single locus, because of the rapid turnover of local populations. In fact, there is some evidence that the black swan can sustain relatively high predation pressure, because a large percentage of the population may not be required in order to maintain the population structure. At Lake George, N.S.W., Frith found that from a population of two to three thousand birds only four hundred clutches were started, leaving a large number of birds which were either immature or unable to breed because of a shortage of nest sites.

It should be noted that the potential for patch formation in relation to aggregations of breeding birds, does not only lie with the birds themselves but also with their eggs; which are likely to be more accessible to the forager. Table 4.19 summarizes the data concerning the nest sites and clutch data for the principal species. The ground nests of the black swan tend to be found only on islands; elsewhere they nest amidst shallow swamp vegetation. Note also that a number of birds use holes in trees as their principal nesting sites, where the eggs would be readily accessible.

It should also be noted that, the human predator can, to some slight extent, manipulate the spatial distribution of waterfowl. The primarily

Species	Preferred nesting area					clutch		Incubation
	swamp	open	raised	concealed	tree	range	average	(days)
Black swan	2	1				4-10	5.5	39-41
Black duck		2			1	8-10	9.1	26-28
Grey teal		2	2	2	1	6-14	—	24-26
Chestnut teal			2		1	7-15	—	28+/-
Shoveller		1	2			9-11	—	24+/-
Hardhead	1					9-12	—	25+/-
Wooduck					1	9-11	—	28+/-
Mountain duck				2	1	10-14	—	30-35
Musk duck	1					1-3	2.8	——

Table 4.19: The preferred nesting areas of Sydney region waterfowl and data concerning clutch sizes and incubation periods, indicating the availability of eggs to a predator.
(Note: The preferred nesting sites are divided into: a) swamp vegetation; b) open nest upon land; c) open nest on a raised site; d) concealed nest under rocks; e) nests in tree holes. '1' indicates principal preferred sites; '2' represents less preferred sites.)
(Source: Frith 1967)

vegetarian waterfowl, for example, are partial to young shoots of Typha spp. (The two principal components of the black swan's diet, for example, are algae (20%) and Typha (19%).) The burning of the Typha borders of wetlands would have the affect of increasing the representation of the nomadic waterfowl population as they feed upon the new, succulent shoots; and improve the likelihood of aggregation to a level wherein high-value patches could be discerned.

The nutritional compositions of the various waterfowl species of the region are not known and as a consequence Table 4.20 presents the data for duck (non-specific) from the tables of Australian Foods by Thomas and Corden (1970). It is highly probable that the figures for the waterfowl of the region are of this order. Clearly, the fat content of the birds is high; and, even allowing for a greater percentage of inedible material, the nutritional qualities of the average 6270gm male black swan would be considerable.

Similarly, there are no data available concerning the nutritional composition of duck eggs. Table 4.21 presents the data for chicken eggs and those of the Australian goose (Anseranas semipalmata). Clearly neither is satisfactory, but it is highly probable that the waterfowl eggs lie somewhere within this range probably nearer to the data given for goose than those for chicken. Despite the absence of data, it appears reasonable to say that the fat and protein contents of waterfowl eggs within the region are likely to be high (see Gurr 1984; Mottram 1979:52).

Edible portion %	Energy kJ	Water g	Protein g	Fat g	Carbo-hydrate g
(raw) 61	1349	53.7	16.0	29.1	0

Table 4.20: The nutritional composition of duck (non-specific).
(Note: converted from original to kJ using Atwater factors)
(Source: Thomas & Corden 1970)

Edible portion %	Energy kJ	Water g	Protein g	Fat g	Carbo-hydrate g
chicken raw 88	653	73.8	12.5	11.6	0.7
goose cooked 87	839	71.9	13.2	16.6	0.0

Table 4.21: The nutritional composition of the eggs of the domestic chicken and the Australian goose (<u>Anseras semipalmata</u>), indicating the range within which Sydney waterfowl eggs are likely to fit.
(Sources: Thomas & Corden 1970; Brand et al. 1983)

Avifauna patches in space and time

Avifauna are little constrained in their mobility by features of the landscape, other than the distribution of wetlands. All the avifauna within the region use available resources opportunistically, their patterns of aggregation and dispersion reflecting the overall distribution of appropriate foods.

While the small-bodied nectivorous and insectivorous avifauna would be unlikely to be defined as patches; both quail and emu, because they are associated with areas of relatively great fertility - wetlands and areas of grassy understorey - may have been recognized as patches when other resources were depressed. Waterfowl, by contrast, represent a nomadic resource of great potential as high-ranking patches - particularly, in winter and early spring; and especially because of their high fat content.

The behavioural characteristics of some of these waterfowl species make them more liable to be formed into patches than others - the black swan, in particular, is likely to have been discerned as a high-ranking patch.

4.4.5 Amphibian and reptile patches

The little information available, would suggest that amphibians are unlikely to have been discerned as patches because of their low density - the returns are never likely to have approached the costs. The same is likely to be true of the reptiles represented in the region, under most circumstances. The majority of reptiles are ground-living insectivores, while the remainder predate upon insects, other reptiles, nestling birds and carrion. The distribution and density of these prey species is thought to increase as the level of nutrients rise; and reptile abundance is likely to follow suit, though it is known that many of the reptiles are more specific in their environmental associations, preferring rocky substrates.

For these reasons, the overall abundance of reptiles is probably low. Only is areas such as wetlands (and other areas of higher fertility and moisture) are reptiles likely to have been discerned as patches.

To some extent, reptile patches are more likely to have been discerned, if they were recognized at all, during periods of cold weather (and early mornings!) when most reptiles are torpid and are easily caught. However, only under exceptional circumstances would an optimal forager consider that benefits would outweigh risks with regard to the front-fanged and venomous Elapidae and Boidae.

There is no available nutritional data concerning reptiles, but it is known that the goanna (Varanus spp.) is noted elsewhere for its high fat content (Jones 1980a). The potential of the Varanidae, of all reptiles, to be recognized as a patch lies in this potential as a fat source; and in the fact that both their daily and seasonal activities are restricted by their ectothermy. For example, the sand goanna's (Varanus gouldii) daily activity areas are known to become smaller in winter (Green & King 1978).

In addition, during this cold season, many goannas spend long periods basking outside their burrows, and are likely to be slower to react to the action of a predator; other sub-species remain underground throughout the winter where they are readily accessible to a predator provided with the relevant information for their detection. There may also be a tendency for goannas to move away from more exposed areas in winter towards better drained areas such as sandy slopes, or to areas where there is more ground cover (Green & King 1978:422).

Amphibian and reptile patches in space and time

It is unlikely that amphibian patches existed for the human forager in the Sydney region, because the costs are always likely to have exceeded returns. The same is likely to be true of the majority of reptiles. However, in the case of the Varanidae, the fat content may have tended to increase the probability of patch formation, particularly in winter when handling and search times would be reduced; and other resources are likely to be depressed.

4.4.6 Insect and miscellaneous patches

Fat wood-boring larvae ('witchetty grubs'; for example, Cremoplates edulis) are well-known in the Australian context, but ants and termites can also provide significant sources of fat. There are probably many thousands of species of edible insects within the region, but their general abundance is likely to be constrained by nutrient distribution.

Ants and termites are available in dense communities throughout the year. Some ants (e.g. 'bulldog') can give an extremely painful bite (or bites - personal experience!), and presumably could not be used as food unless their high formic acid content was removed or neutralized. The only nutritional data available for ants comes from another context but may give a vague idea of nutritional values (Table 4.22; Brand et al. 1983) The existence of high-value insect patches is best known with regard to the seasonally aggregating 'Bogong' moth. The implications of its presence for the Aborigines are well-known from Flood's study (1976, 1980), but the species is not thought to have entered the Sydney region.

By-products of insect activity may have acted as minor energy sources or food adjuncts. In particular, 'honey bag' - the nests of wild bees - provides high carbohydrate in the honey and high fat and protein in the grubs; and the nests of termites or ants may provide some sustenance in the same way. In addition, the presence of insects may be indirectly influential in providing minor foods, for example, flowers which produce excessive amounts of nectar or pollen.

The role of insects and the by-products of their behaviour are likely to be those of adjuncts to the diet. Their nutritional value on their own is unlikely to make them major food sources or improve the likelihood of their forming high-ranking patches.

Edible portion %	Energy kJ	Water g	Protein g	Fat g	Carbo-hydrate g
100	1272	52.4	1.8	25.0	19.8

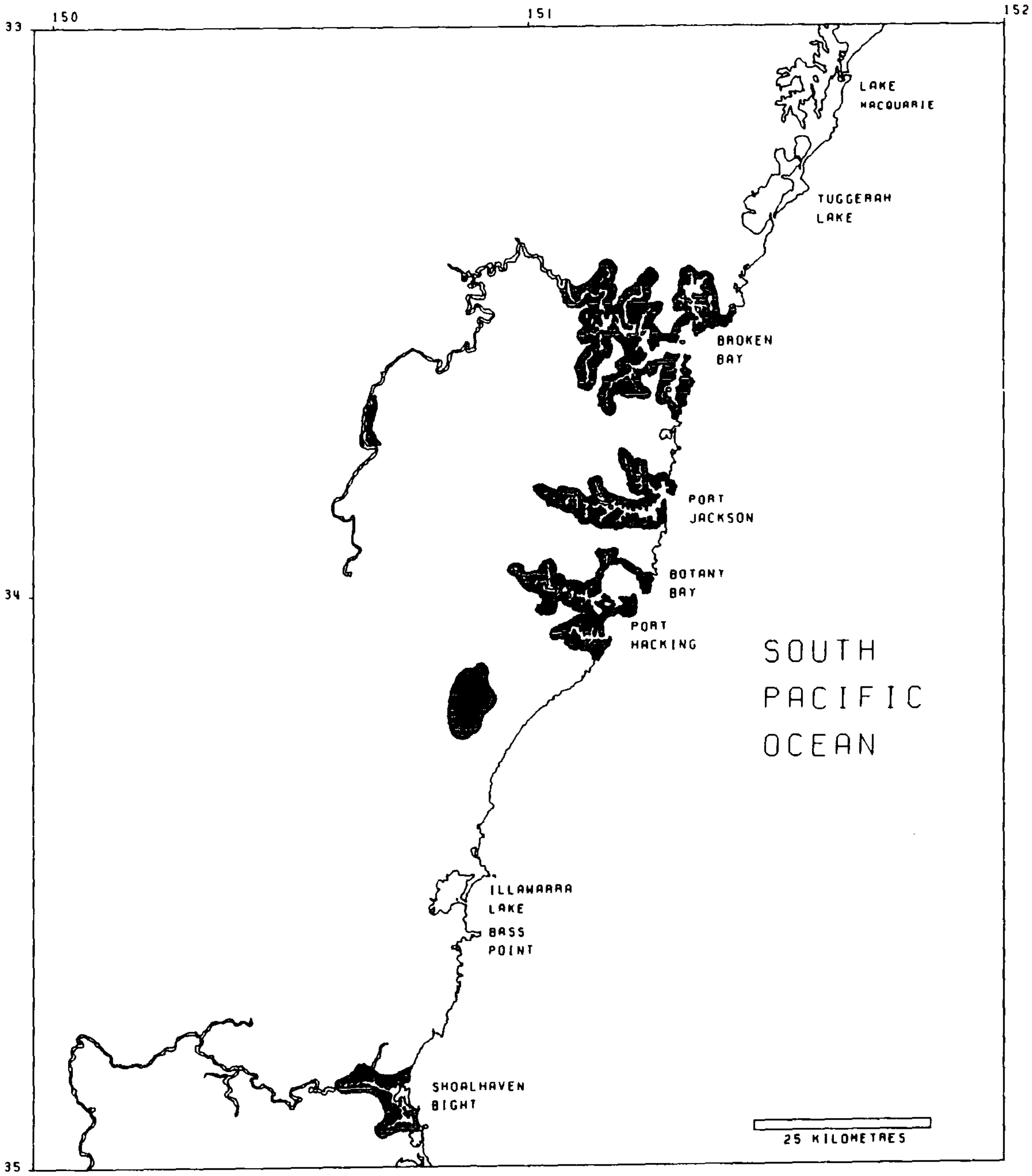
able 4.22: The nutritional composition of the green ant (Oecophylla smaradgina)
(Source: Brand et al. 1983)

4.5 THE LOCATION OF HIGH-VALUE PATCHES IN THE SYDNEY LANDSCAPE

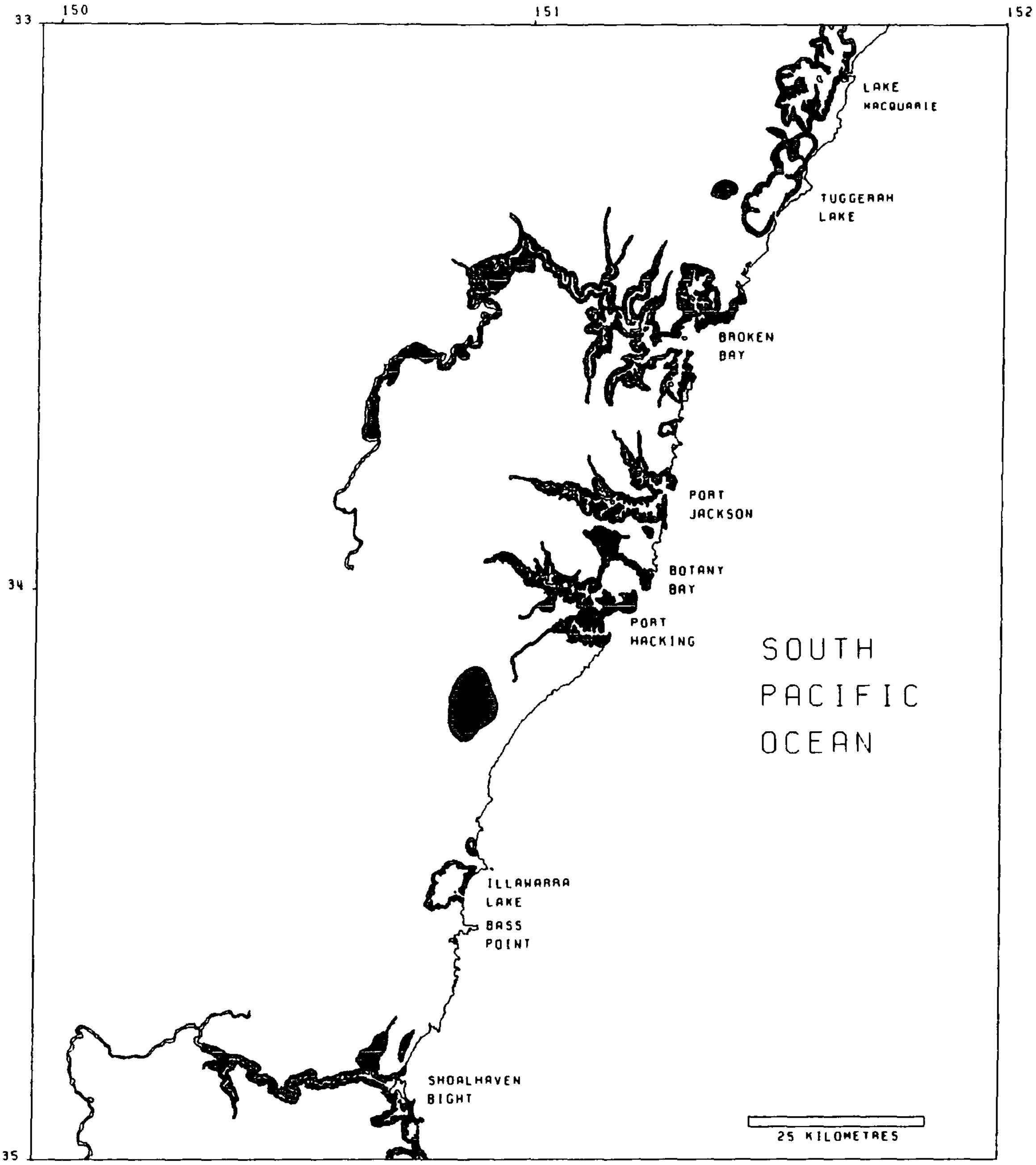
In the preceding section a number of potential 'patches' that would be ranked highly on a scale of cost/benefit by an optimal forager have been identified, taking into account nutrient constraints. When all these patches are placed in time and in relation to the regional landscape, we are provided with a guide to the locational characteristics which would be expected of efficient human foragers throughout the year.

Broadly, it appears reasonable to assume that an optimal forager in the Sydney region would recognize the greatest variety of high-ranking patches in the summer. These patches would be distributed within the estuaries and wetlands, and lower ranking patches, particularly inland, would be associated with vegetation structures upon soils of relatively high natural fertility. The areas associated with the highest-value patches are illustrated in Map 4.1. Note that, because they are unlikely to be as nearly highly ranked as those loci marked, such areas as the Cumberland Plain, the valley of the Mangrove Creek and the Narrabeen regions of the Blue Mountains are not emphasized despite the fact that such areas would be more highly-ranked than the surrounding plateaux (These medium-ranked areas are shown in Map 4.5).

These same areas are likely to delimit high-ranking patches in autumn (Map 4.2), but patches associated with wetlands would be most important (particularly toward the coast as eels congregated).



Map 4.1: The location of the highest value patches in summer



Map 4.2: The location of the highest value patches in autumn

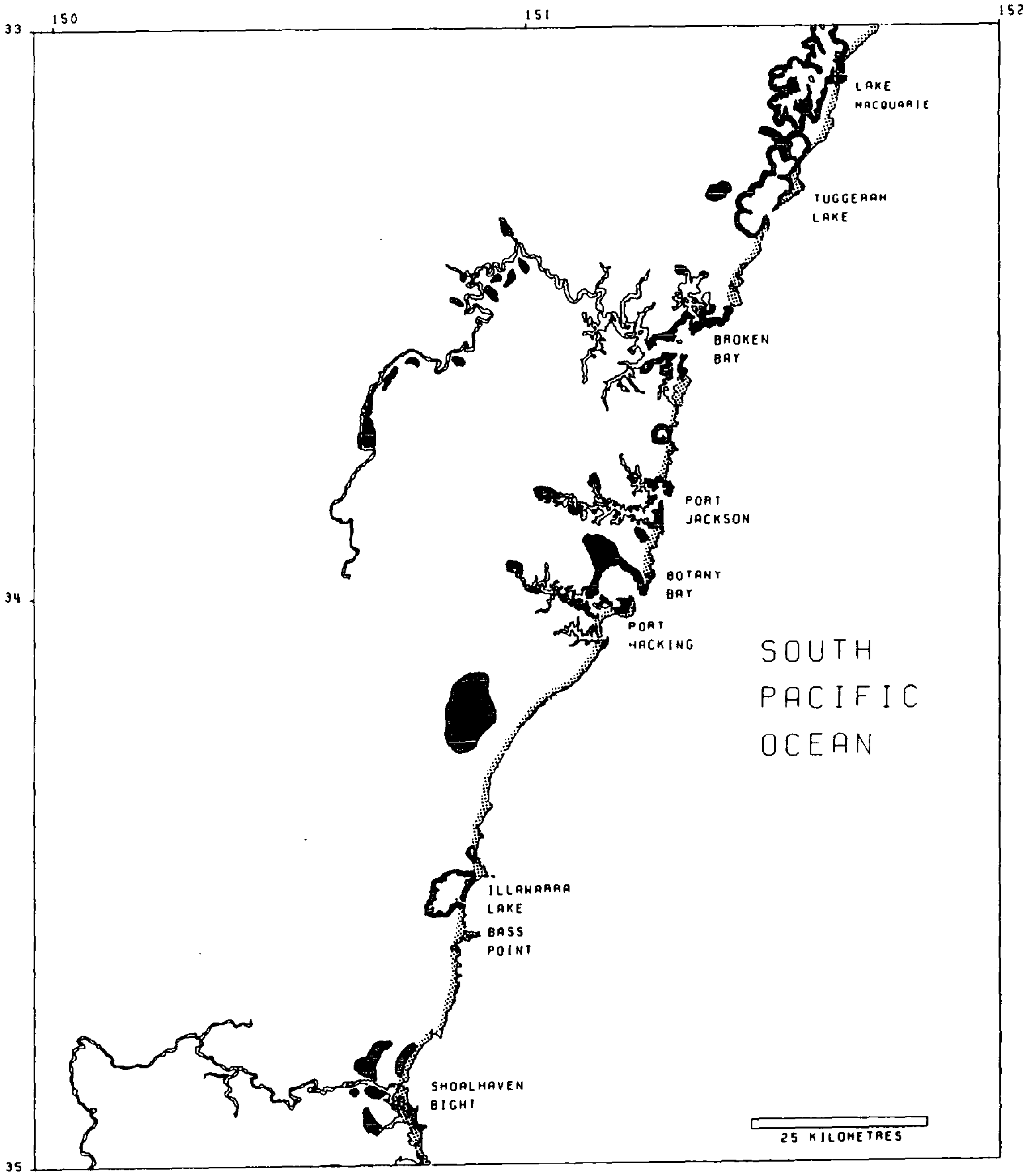
The lowest variety of high-ranking patches is likely to be associated with winter and early spring (Map 4.3) when a number of resources would have been likely to have been depressed. However, within the Sydney region a number of high-value patches - principally of "unearned resources" - would be discerned during this period. These patches would have been principally associated with the mouths of estuaries, the inshore coast (migratory fish (and cetaceans?)), wetlands (avifauna) and, lower in the ranking, areas of vegetation structure upon soils of high nutrient contents (small mammals).

Late spring (Map 4.4) would see the return of the fish to the estuaries and the dispersion of waterfowl from the wetlands and as a consequence the pattern of patch distribution would begin to resemble that of the summer period.

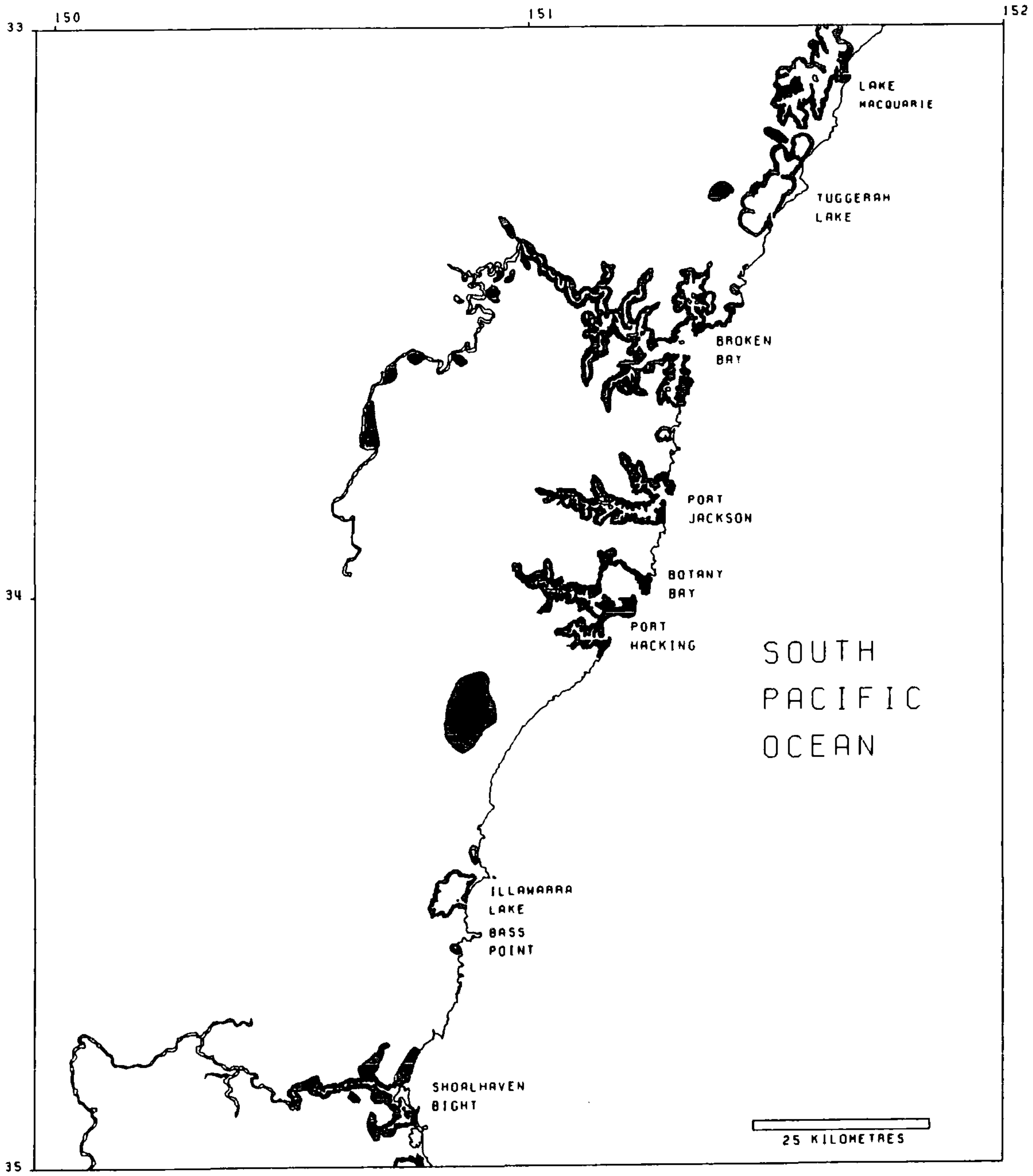
It is readily apparent that in this temperate landscape the differences in patch quality between winter and summer tends to be small (though they are not the same patches). The major difference between the two periods concerns the greater degree of mobility inherent in winter patches and the consequent relative increase in risk and search time.

4.5.1 Risk and the importance of buffer foods

The majority of the high value patches outlined for the year, and emphasized for the period of winter and early spring above, are of mobile aquatic, avian or terrestrial fauna. These patches assume their high



Map 4.3: The location of the highest value patches in winter and early spring (Note: Light shading upon the coastal fringe indicates the probable but largely unpredictable presence of unearned resources including cetaceans.)



Map 4.4: The location of the highest value patches in late spring

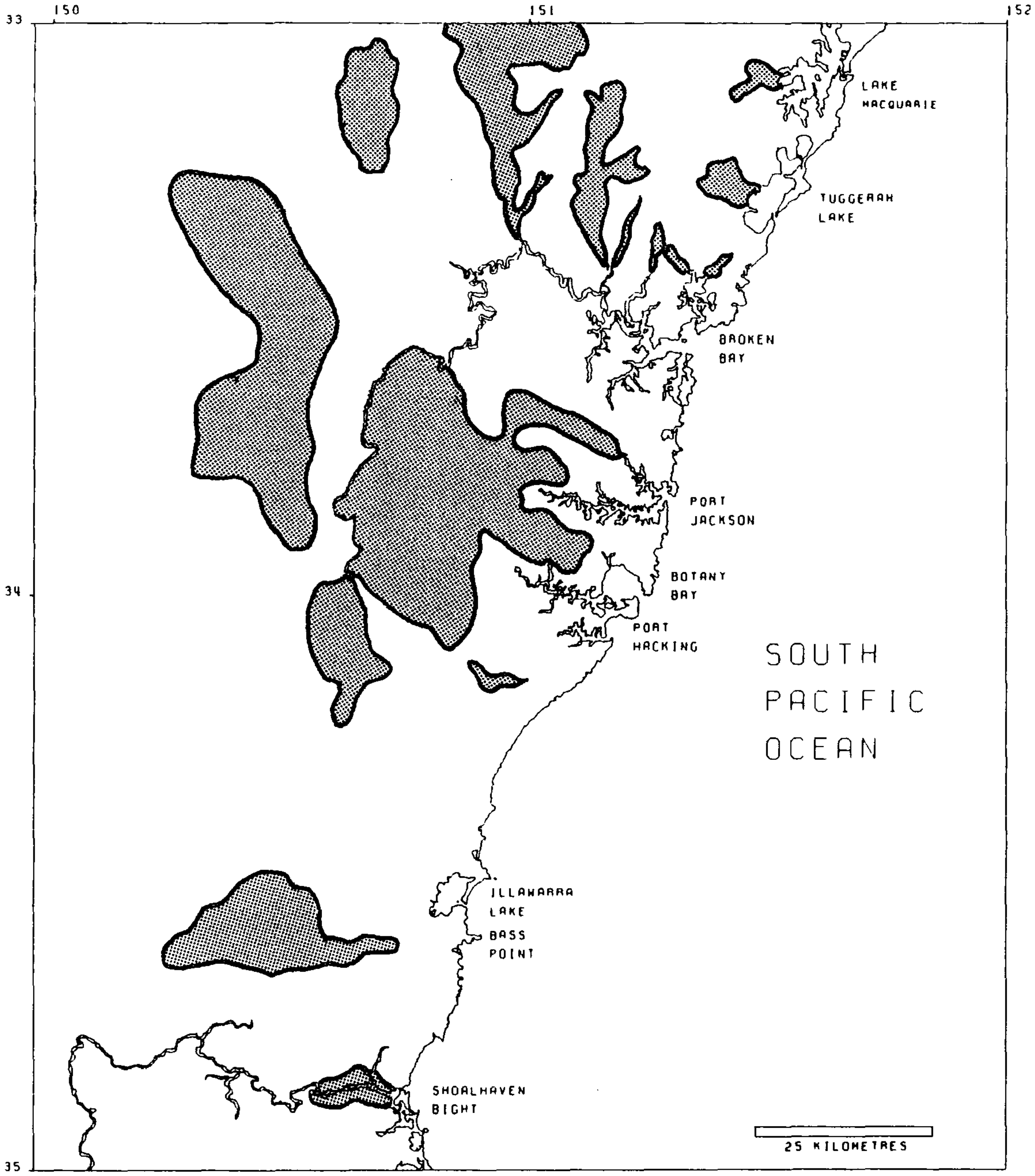
ranking against a background of immobile and largely perennial vegetation structures of low edible production and high toxicity - patches of, with but few exceptions, consistent low value in a cost/benefit ranking.

Yet there is always an element of risk attached to the pursuit of game - the risk of failure. Risks of this kind can occur at any time of the year, but it is in winter, when the principal patches are all mobile, that it becomes imperative (not just comforting, as it may be for the rest of the year), that a forager has access to 'buffer foods' - resources which are completely dependable and low in costs.

The Sydney region possesses two principal forms of such food. Firstly, shellfish which are available throughout the year on the coast and in the estuaries; and secondly, roots, rhizomes and tubers available throughout the year both on the coast and inland. This latter group of foods is present in many small areas within the Sydney region, but fern-roots and the yam-daisy (which probably represent the major components of this group) are particularly associated with areas of natural fertility and especially with wetlands (Map 4.5).

4.5.2 A landscape division based upon the distribution of high value patches

Within the group of high-value patches identified above there is a division which is best expressed in terms of spatial characteristics. One side of the division is easily identifiable and obvious - that is, that aquatic or avifaunal high-value patches are present upon the coast and



Map 4.5: The location of medium-ranked patches associated with areas of greater natural fertility.
(Note: Buffer foods may be found in any of these areas and in small concentrations elsewhere. However, they tend to be most extensive in the estuaries (particularly shellfish) and along the river banks and weland borders (particularly roots, tubers and rhizomes).

within estuaries throughout the year, and that the spatial shift evident in patch distribution is small over that period (i.e. estuary - wetland - coast).

However, the other side of the division is not so easily identifiable or so obvious, but relates to the same spatial characteristics of patches. It is possible to identify an inland landscape wherein patches of high value are also available throughout the year - areas of relative nutrient fertility are principally an inland phenomenon (for example the Cumberland Plain) and wetlands (including river margins) are not limited to the coast. The inland area, principally because of the lack of 'unearned resources' passing through it, would not possess the same level of energy or protein abundance as the coastal area and as a consequence would not be able to support the same densities of human foraging population as these former areas. In addition, the inland area would be likely to contain a higher inherent risk factor (particularly in winter and early spring). However, the presence of a variety of buffer foods in the form of roots and rhizomes, would substantially reduce this risk and allow the occupation of the area throughout the year.

4.6 HUMAN FORAGERS IN THE SYDNEY LANDSCAPE - A BEHAVIOURAL MODEL

The analysis of probable patch location suggests that there would have been the potential to support two ecological populations within the Sydney region: a coastal and estuarine population; and an inland population associated with fertile areas and wetlands (including rivers).

The spatial characteristics of these two efficient populations during an annual cycle (on the basis of patch distribution) would be:

1. The coastal and estuarine population. The population of the coast and estuary would be concentrated within the estuaries during the summer because of the absence of high-value patches upon the sandstone plateaux and in the wholly marine environment. Autumn would see an element of dispersion to wetlands as eels were recognized as patches. However, contact with the estuaries is still likely to have been maintained as fish began to form very large shoals prior to breeding, and were discerned as high-value patches. Winter and early spring would see a dispersion of the efficient foraging population along the whole estuarine and coastal fringe as unearned resources (migratory fish and (probably) cetaceans) were discerned as high-value patches. A concentration of the population would occur at the estuary mouth to take into account other high-ranking fish patches associated with species which move to this area and the immediate coastline. The wetlands would be recognized as areas associated with high-value resources (waterfowl). The spring return of high-value fish patches to the estuaries would see a return of the population to that estuarine fringe, particularly as waterfowl and unearned patches dispersed to the extent that they could no longer be recognized. Throughout this year, shellfish, roots and tubers would have formed an underlying resource of low rank but high reliability.

2. The inland population. In summer the inland optimal foraging population would be distributed in relation to the spatial characteristics of relatively nutrient-rich areas (which are far more extensive than upon the coast). High-value patches would be associated particularly with wetlands, but also with: a) areas of Closed and Tall Open Forest (principally associated with soils derived from Narrabeen sandstone); b) areas of Open Forest (associated with soil derived from Wianamatta shale); and (possibly) c) the ecotones between these communities and flora associated with soils derived from Hawkesbury sandstone. In autumn there would be a tendency for populations to be more closely associated with wetlands (as eel congregations were discerned as patches). In winter and early spring the population would be concentrated upon the rivers and associated wetlands in order to exploit the patches associated with waterfowl. This would be the period of maximum stress upon the population, and communal effort to capture the dispersed but relatively more profitable (i.e. increased lipid content) small mammals and birds might occur. (As Hayden (1981:368) suggests, communal hunting occurs predominantly when meat is an absolute survival necessity, for ".....groups will hunt individually when they can and communally when they have to, in resource-poor areas".) Throughout this year roots and tubers would have been discerned as a patch of low-risk but dependable foods.

4.7 LANDSCAPE AS ENVIRONMENTAL VARIABLES

In order to be in a position to test the fit between this optimal behavioural model and the location of Aboriginal behaviour within the Sydney region, it is necessary that high-value patch locations are broken down into their basic attributes.

The essential concept required to achieve this is 'landscape'. The term refers to the fundamental qualities which define patchiness for an organism (Winterhalder 1980), and includes landform, soil, vegetation and climatic characteristics. As Winterhalder has said:

> "Features of landscape combine with animal distributions to give a locality a particular adaptive quality related both to the resources and hazards found there, and to the impediments that landscape structure places between the organism, its resources and its predators and conspecifics" (op. cit:153).

It should be noted that animal distributions are not generally considered to be features of the landscape, but within the Sydney region, because of the effects of nutrient distribution, they are likely to be very closely tied to the landscape features which determine the distribution of vegetational patterns.

Landscape in the Sydney region can be broken down into a number of independent variables broadly classified into three groups: a) terrestrial structure; b) aquatic structure; and c) climatic structure.

4.7.1 Terrestrial structure

The terrestrial components of landscape structure within the Sydney region are geological parent material, topography and height:

Geological parent material

As has been emphasized throughout this study, geological parent material has a fundamental influence upon the distribution of floral and faunal patches through its role as principal source of important nutrients (particularly phosphorus).

Topography

Topographic features have an influence upon an organism's ability to define patch types (for example in dissected and rugged areas), as well as a direct influence upon faunal and floral patch distribution principally through differences in aspect and steepness of slope. In addition, topography may also be associated with high-value patch location through the tendency for nutrients to be associated with low-lying and water-related landforms.

Height

Closely associated with the other two structural variables, height may have a direct influence upon the ability of a human forager to detect patches (as well as upon faunal and floral patch distribution), through altitude effects and through the tendency for nutrient-rich areas to be low-altitude phenomena.

4.7.2 Aquatic structure

Here, aquatic structure refers to any water-dominated areas. The perspective of the human forager is always from the land, and as a consequence the variables must be categorized as measures of distance from: a) estuaries; b) the coast; c) wetlands; and d) freshwater.

Estuarine distance

Distance to estuaries within the landscape is an important variable because these areas are consistently associated with high-return patches (in comparison with the terrestrial point from which this distance is determined).

Coastal distance

Distance to coast has broadly the same characteristics with regard to patch distribution as estuarine distance (though because the association with consistently high-value patches is lower: so the degree of association is likely to be). However, coastal distance may also influence faunal and floral patch distribution in other ways, particularly as proximity tends to be associated with higher minimum temperatures (see below).

Wetland distance

Distance to wetland is not closely related to the other two aquatic variables. However, it is important, in that it is a measure of proximity to areas within the terrestrial structure associated with the greatest accumulation of nutrients, and consistently high-value patches.

Freshwater distance

Freshwater distance is also not closely associated with the other aquatic variables. The proximity of freshwater is likely to have an influence upon faunal and floral patch distributions independent of factors related to nutrient levels.

4.7.3 Climatic structure

Climatic structure is associated with a complex set of landscape variables which share in common, dynamics which the preceding variables do not. The principal problems involved in dealing with these dynamic variables are the choice of a suitable temporal scale; and the scale of climatological definition which is accessible.

Throughout this study, while long-term dynamics and phenomenal occurrences have been discussed, the year has been considered to be an appropriate unit. However, the year may or may not be an appropriate landscape division with regard to climatic variable and their influence upon patch distribution. The important influence may be upon a shorter scale and as a consequence, in this study, climatic variables are considered both upon a yearly and upon a seasonal basis (i.e. climatic data for mid-summer, mid-autumn, mid-winter and mid-spring). (Further division (e.g. to the month) would be largely profitless in this study region, for the degree of seasonality is very small.)

More problematic is the question of the accessibility of an adequate level of definition. Yoshino (1975) defines four broad climatic phenomena by spatial scale: a) microclimate (e.g. greenhouse effect); b) local climate (e.g. thermal belt on a slope); c) mesoclimate (e.g. the climate of a drainage basin); and d) macroclimate (a climatic zone). Clearly, the identification of the subtle influence of micro-climatic variation upon floral and faunal distribution as it relates to patch formation, would be most useful.

However, in practice, extrapolation to the local level from mesoclimatic data (i.e. by contouring data from weather stations), is the nearest we may approach the micro-climate. As a consequence, climatic variables tend towards a greater degree of crudity than would be acceptable in the measurements of other groups of structural variables.

The climatic and related variables considered here as being part of the landscape are rainfall, temperature and aspect.

Rainfall

Although rainfall occurs in adequate amounts throughout the year, there is a tendency toward greater rainfall in the summer and least rainfall in spring. In addition, rainfall tends to be orographically distributed over the region. Both these factors may tend to influence the location of potential floral and faunal patches either directly or indirectly.

Temperature

Temperature is a complex landscape variable with two major components - minimum and maximum - which may influence the likelihood of floral and faunal patch formation. In general, the influence of minimum temperature is likely to be greater than the influence of maximum temperature (particularly in winter); though maximum temperature may be relatively more important in summer. In addition, that temperatures are influenced over the whole region by topography and proximity to the coast, may also affect the distribution of potential patches.

Aspect

The least complex of this set of variables, aspect may be particularly important in the development of floral patches (because of the association of north-facing slopes with increased xeromorphy).

These, then, are the variables which summarize the environmental influences which are likely to affect the probability of high-value patch distribution. Their individual characteristics will permit us to test the extent to which the Sydney region Aborigines behaved optimally with regard to food acquisition.

5 CHAPTER FIVE:

SOURCES AND METHODS

Three sources of data were used in the course of this research - archaeological, ecological and ethnohistorical. The archaeological and ecological data were in a form which was readily transferable into computer-readable databases; the ethnohistorical data were not.

This chapter and the next, form necessary preliminaries to the analysis which begins in Chapter Seven. The complexities involved in the use of archaeological data to test a behavioural model deserve a separate chapter (Chapter Six). Here, the sources of the ecological and archaeological databases are introduced and a broad overview of techniques is presented.

5.1 THE ARCHAEOLOGICAL DATABASE

The theoretical basis of this study - optimal foraging theory - seeks to understand aspects of foraging behaviour in relation to the spatial heterogeneity of resources. In the case of the Sydney region, the majority of the information concerning the behaviour of the Aborigines in relation to the landscape is held within the archaeological record.

The New South Wales National Parks and Wildlife Service (NPWS) in Sydney were approached because they have had systems for recording the location and details of Aboriginal sites for some decades. In fact, the Aboriginal sites register contains information not only concerning the large number of extant sites, but also about a large number of sites which have been destroyed by development or disturbed by other factors. The site register has been compiled both from systematic surveying in areas at risk, and from purely fortuitous recording. As a consequence, there is considerable variation in the quality of entries. However, there is good information concerning the larger proportion of the sites and the quality of the material as a base for a locational study was considered to be adequate.

The information from the register was supplemented by measurements derived from topographic (1:250000, 1,100000 & 1:50000), geological (1:250000) and vegetation maps (1:100000). Aerial photographs (Cumberland series) kept by the resources division of the NPWS and the major climatic survey (Bureau of Meteorology 1979) were also used in the description of site environments. The recording method was particularly designed to facilitate the use of statistical packages held at the Computer Centre of Durham University. All characteristics were reduced to numerical codes and were originally entered onto standard data-punching forms. The sites were not recorded in a systematic geographical sequence but were sorted later by eastings and, within that, by northings, for the sake of convenience.

The description below follows the order in which the information was recorded onto the data sheets: site type and site location; site characteristics; and the locational characteristics of the site.

5.1.1 Site type and site location

(columns 1 - 10)

Although site type was originally recorded using the thirty-four overlapping divisions used by the NPWS, this was considered to be too unwieldy during the analysis. Consequently, a more satisfactory division of sites was derived.

This resulted in five major site groups:

1. Open archaeological sites.
2. Shelter archaeological sites.
3. Open art sites and sites of 'mythological' or 'ceremonial' importance.
4. Shelter art sites.
5. Sites which contained evidence of both art and archaeology.

The original NPWS divisions were retained only in order to aid the extraction of certain site types (shell middens and axe grinding grooves) which was necessary during the course of subsequent analysis.

An eight figure grid reference was always recorded for each site within the site register and was used to locate the sites on the 1:250000 topographic and geological maps.

5.1.2 Site characteristics

(columns 11 - 78)

A record was made if the site had been excavated and the survey type (e.g. intensive, cursory or literature search) was noted where this information was available.

Where additional information concerning the sites was recorded within the register or in survey reports, this was also coded. In particular, archaeological characteristics and art characteristics were noted. The archaeological data were coded on the basis of the presence or absence of certain broad artefact categories (e.g. flakes, cores, edge-ground axes); the presence of charcoal or hearths; and the presence of dietary evidence (e.g. bone or shell). Very little data were available concerning lithic raw material types and consequently they were not included.

The little evidence that does exist, however, suggests that the raw materials were nearly always acquired locally and that exotic stone was infrequently used. Two exceptions to this general rule are likely to have been the movement of silcrete around the Shoalhaven area (Hughes et al. 1973) and the movement of high-quality axe blanks from the Blue Mountains and the headwaters of the Hawkesbury-Nepean (see McBryde 1984 for an example of the extent of this form of trade in another region). The art characteristics coded were simply a record of vertebrate subjects to be found among the shelter painting and rock engravings (the full subject categories have been assessed by McMah (later Maynard) (1965; Maynard 1976). Although many of the groupings (birds, fish, small marsupials etc.) had been subdivided into smaller groups or even ascribed to species, these divisions are thought to be unreliable (Sue O'Connor, NPWS, pers. comm.), owing at least as much to imagination as to reality.

Shellfish species recorded for middens were ranked according to their apparent dominance at the surface of the site. The most frequent species within the assemblage was scored as '4', secondary species '3', tertiary '2' and presence at a lower level '1'. However, this information was not used in the analysis because Sullivan (1982) has analysed many of the characteristics of the middens along the New South Wales Coast, including the availability and regional importance of species.

Finally, site dimensions were recorded where these were available. Length, breadth and depth of sites were seldom all recorded, but for sites where length and breadth were both recorded site area was entered as a separate variable.

5.1.3 Locational characteristics

(columns 79 - 152)

The landform characteristics of the site location were assessed using topographic maps and aerial photographs of the region and a representative description was coded (e.g. plateau top, river valley bottom, creek valley side, rock platform).

The surface *geology* was noted from the 1:250000 geological series maps and the *matrix* of the site was noted where this was recorded in the register or in the detailed reports.

The present *vegetation type* of the area was assessed from the 1:100000 vegetation maps of Benson (1980, 1981a, 1981b, 1982) or Hayden (1971).

In addition, a number of measurements were taken from the appropriate maps either directly or through the use of a map-measurer (made by Eshenbach optik, Nurnburg). *Height above sea-level*, for example, was estimated directly using the contours of the topographic maps while *distance to fresh water* was estimated using the map-measurer and estimating the distance between the site and the nearest marked water source.

A number of longer measures were also taken from the position of the site to coastal, wetland (swamps, lake margins etc.) and estuarine resources (*coast distance*, *wetland distance* and *estuarine distance*) in a straight line. A second set of measures were taken from the site to these areas allowing for the influence of topography and vegetation density (for example, in calculating *coastal best distance*, *wetland best distance and estuarine best distance*, ridge tops were favoured because they offer less dense vegetation than the wetter valleys).

Distance to major thoroughfare was also measured in order to provide an index of the relationship between the European usage of the area and the discovery of Aboriginal sites.

Estimates of climatic factors at each site were also made from the climatic survey of the Sydney region (Bureau of Meteorology 1979). Although the broad climatic features of the area within which the site lay could be recorded, microclimates, which may have been important in the selection of the site location could not be determined. However, in a region noted for being frost-free and among sites for which aspect and height had been recorded it was considered that the following climatic factors should be noted: average maximum annual temperature, average maximum summer temperature (January), average maximum autumn temperature (April), average maximum winter temperature (July), average maximum spring temperature (October), average minimum annual temperature, average minimum summer temperature (January), average minimum autumn temperature (April), average minimum winter temperature (July), average minimum spring temperature (October), average annual rainfall, average summer rainfall (December - February), average autumn rainfall (March - May), average winter rainfall (June - August) and average spring rainfall (September - November).

5.2 THE ECOLOGICAL DATABASE

In order to produce information upon a sufficiently fine-scale to be able to detect local ecological influences it was necessary to define a small sub-area of the region.

The area bounded by latitude 33 degrees 30 minutes to 34 degrees south and longitude 150 degrees 30 minutes east and eastward to the sea (which is coterminous with the area covered by the Sydney and Penrith 1:100000 maps (sheets 9130 & 9030)) was selected principally because of the availability of detailed information concerning vegetation patterns (see Chapter Eight).

The area was divided into one kilometre square cells and the characteristics of each cell were entered onto coding forms in the manner described for the archaeological data above. The information was derived from topographic, geological and vegetation maps at a scale of 1:100000.

The description below follows the order in which the information was recorded onto the data sheets: cell location and environment; detailed environmental characteristics; and present and past vegetation structure.

5.2.1 Cell location and environment

(columns 1 - 21)

The area was divided into 55 rows and 87 columns - a total of 4785 cells - and the broad environmental characteristics were recorded.

The average height above sea-level and the surface geology were assessed from the appropriate maps. The primary geology (based on greatest areal extent), secondary geology and tertiary geology were noted and the existence of a geological boundary within the cell was recorded as a separate variable. In practice, this threefold division was found to be adequate for all cells - no more than three geological series outcropped in any one cell.

A similar threefold division was used to determine the landform characteristics of the area (primary landforms (greatest areal extent), secondary landforms and tertiary landforms).

5.2.2 Detailed environmental characteristics

(columns 22 - 39)

The presence of land within the cell was noted (as opposed to those cells which contained only open estuarine or open marine water); and those cells which contained the borders between land and estuarine or marine water were identified (*estuarine land* and *marine land*).

The number of *creek valleys* and *creek confluences* were noted and the probability of seasonal absence of water assessed (*seasonal water*). The presence of *fresh*, *fresh/marine* and *marine* water and evidence of *seasonal inundation* were also recorded. A number of other water-related features were also recorded: *rivers*, *swamps*, *lake margins*, *ponds*, *lagoons* and *mangrove swamps*. Two modern land-use characteristics were also included within this section: the presence of *oyster leases* and the presence of *urbanization*.

5.2.3 *Present and past vegetation structure*

(columns 40 - 58)

The extant vegetation structure of the sub-area has been mapped by Benson (1980, 1981a) and, in addition, within this section the results of an attempt to reconstruct the natural vegetation of the area were recorded.

The present vegetation was classified as *primary vegetation* (greatest areal extent), *secondary vegetation* and *tertiary vegetation* (including the category 'cleared' for those areas under agriculture or urban sprawl).

The categories were based on the structural divisions of Specht (1970). Benson's extension of this classification to the specific associations of the area identifies the main canopy and understorey species, the limits of occurrence, the predominant life-form and the height of the predominant strata.

On the basis of the information derived from Benson (1980, 1981a and pers. comm.), Pidgeon (1937, 1938, 1940, 1941), Davis (1936, 1941ab), Siddiqi et al. (1972) and the evidence of the first settlers and explorers reports (Tench 1979; Hunter 1968), an attempt was made to reconstruct the past vegetation of the sub-region. This was recorded as <u>past primary vegetation</u>, <u>past secondary vegetation</u> and <u>past tertiary vegetation</u>.

Finally, the broad vegetation formation of the cell (e.g. Tall Open Forest, Closed Scrub, Open Woodland) was classified following the divisions of Specht (1970) - (<u>primary formation</u>, <u>secondary formation and tertiary formation</u>); and the presence of <u>vegetation boundaries</u> was noted as a separate variable.

5.3 <u>METHODOLOGICAL ASPECTS</u>

Of the 4680 recorded Aboriginal sites within the Sydney Region, 1998 (43%) contain no traces of archaeological deposit or any evidence of activity likely to be related to foraging behaviour. They are sites which contain paintings or engravings; or they are sites which are thought to have been of cultural significance to the local population.

The dichotomy between these two types of site (technology/work vs art/ceremonial) is important. As von Bertalanffy has noted (1968:191) a great deal of human behaviour, such as play, exploratory behaviour and "any form of creativity", is spontaneous and not necessarily a response to environmental stimuli, i.e. there is much behaviour that does not confer any selective advantage to the population - it is neutral with regard to the processes of adaptation.

Dunnell (1978) has stressed this fundamental dichotomy in terms of '<u>Style</u>' and '<u>Function</u>' - "Style denotes those forms that do not have detectable selection values. Function is manifest as those forms that directly affect the Darwinian fitness of the population in which they occur" (Dunnell 1978:199).

5.4 THE CHARACTERISTICS OF FUNCTION AND STYLE SITES

Figure 5.1a illustrates the composition of the archaeological data within the Sydney region according to the Function/Style dichotomy. 536 (11%) of the data fall into both categories and have been treated separately in the analysis as 'Function/Style' sites. The two principal parts of the Aboriginal site data display completely different components.

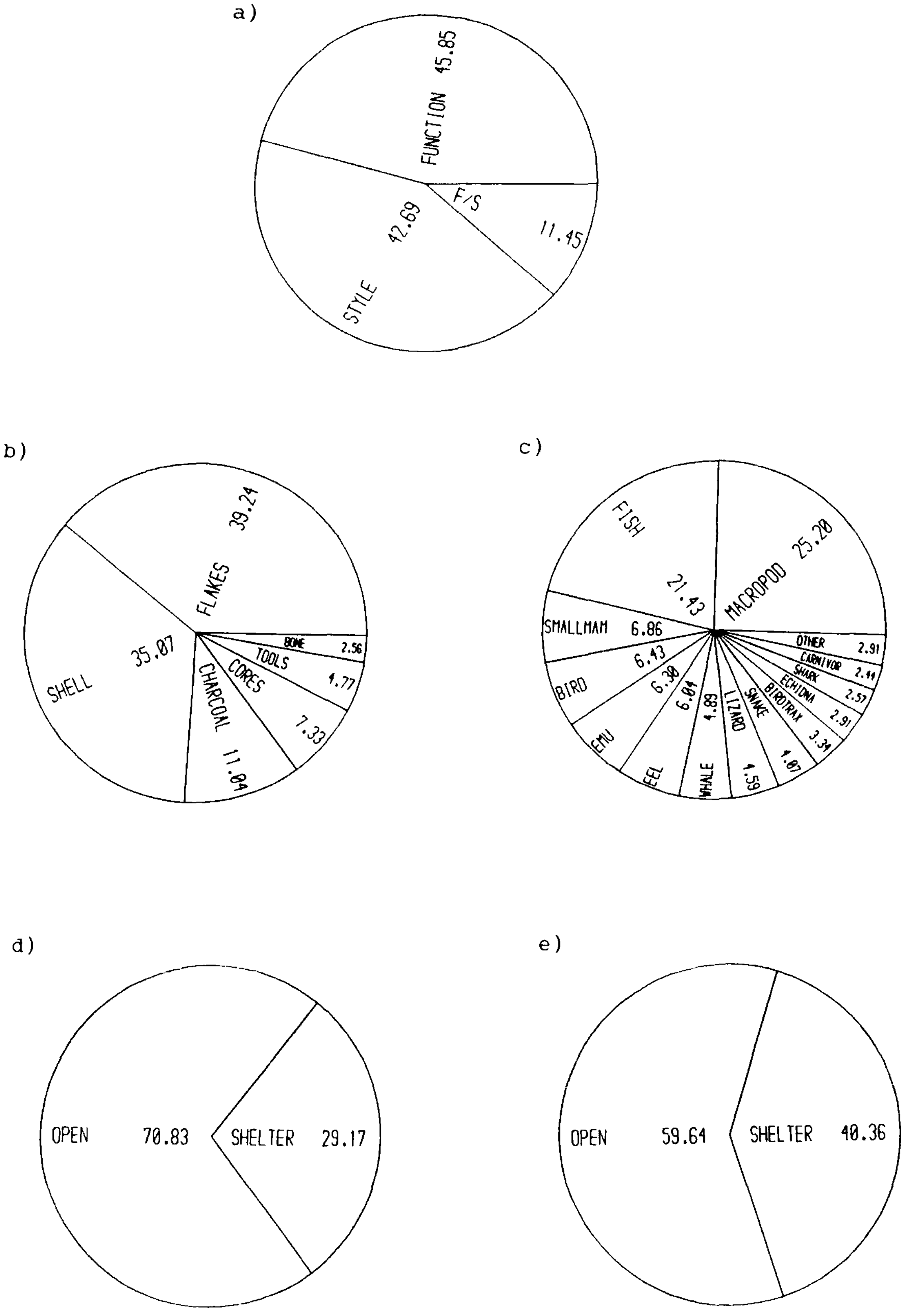


Figure 5.1: The characteristics of the Aboriginal site data in the Sydney region: a) the percentage of sites in each category; b) the characteristics of Function sites; c) the characteristics of Style sites; d) the percentage of shelter and open sites in the Function population; e) the percentage of shelter and open sites in the Style population.

5.4.1 Function sites

Figure 5.1b indicates the components of Function sites within the Sydney region, based upon the presence of six broad archaeological characteristics - flakes, shell, charcoal, cores, tools (e.g. fish-hooks, edge-ground axes) and bone. The absence of evidence for food items, apart from shells, is self-evident - vegetable materials and bones do not often survive in the highly-acidic environments of the region (see Chapter Six). In contrast, the massive presence of shell material dominates the archaeological record of food materials.

Included within the Function category, but excluded from the components of the archaeological record described above, are the sites known as 'axe grinding grooves'. These sites take the form of grooves cut into outcrops of rock by the process of grinding edge-ground axes (see Dickson 1981). They are separated from the other archaeological characteristics throughout the analysis, because they are clearly more closely related to maintenance activities than they are (directly) with food acquisition.

5.4.2 Style sites

Although artists were still active for some years after the arrival of the First Fleet, by the time anyone enquired into the significance of the engravings and painting which surround Sydney, they had gone. We know only that the sites were sacred, or more precisely, that they were places where "too much dibble-dibble walk about" (quotation in Maynard 1979).

Figure 5.1c shows the percentage of different vertebrates represented in the artistic record. We can not know the significance of this apparent ranking. However, by analogy with other regions of Australia and elsewhere we can suggest that the pre-occupation with fauna - particularly large fauna - appears to be a fairly general characteristic among hunter-gatherers.

Hunting is often one of the means by which a man may achieve prominence in the community (see Sackett (1979) for a modern Australian example). The predominance of the Macropodidae within the artistic record of the region should most probably be seen as a function of this attention. (Compare the position of the eland in Vinnicombe's South African study (1976) and the red kangaroo in Newsome's study (1980); see also McCarthy 1963, 1965).

Even less is known about the significance of the supposed 'natural mythological sites', 'initiation sites' and burial sites (i.e. mythological and ceremonial sites). From an ecological viewpoint it can be suggested, however, that aggregations of people for ceremonies would have been most likely to occur when a particular resource (or several resources) were seasonally abundant; densely distributed within a circumscribed area; and required little effort in extraction (see, for example, Flood 1980).

5.5 OPEN OR SHELTER - AN INTERNAL DIVISION

Within the Function/Style dichotomy, there exists an internal division between sites which are to be found in the open and those which are to be found in rock shelters. This dichotomy is a function of the geological structure of the area - at the exposed end of the Hawkesbury sandstone beds (in particular), the rock erodes to form cavernous holes which were used extensively by the Aboriginal people. The importance of maintaining a division between open and shelter lies in the fact that the characteristics of particular shelters may have influenced the behaviour of foragers, in that short detours may have been made during the food-quest to make use of a shelter that was, for example, close to water or provided shade. The location of open sites, in contrast, is less likely to be so clearly influenced by the structure of the landscape and more likely to be influenced by resource distribution. (Figure 5.4d and 5.4e indicate the relative percentage of open sites to shelter sites for Function and Style sites within the Sydney Region).

The most important factor involved in this structural dichotomy is that Function Shelter and Style Shelter sites are likely to be derived from the same potential population (i.e. of naturally occurring overhangs). Therefore any significant difference between the two sub-populations is likely to possess some importance.

In summary, this wealth of data places us in the position of being able to ask whether there is evidence that some specific types of Aboriginal sites reflect (in their locational characteristics) a closer relationship with certain environmental characteristics than do other sites.

5.6 THE DISTRIBUTION OF DATA - REGION AND SUB-REGION

The distributions of the separate site groups utilized in the analysis are illustrated in Appendix A, while the distribution of Aboriginal sites as a whole is illustrated in Figure 5.2 and Map 5.1. The coastal and estuarine bias of the data is clear. As a consequence of this bias, and in order to understand better the relationship between the archaeological evidence for past behaviour and the environment over the whole region; six sub-regional areas, wherein intensive surveys have been undertaken (under the auspices of the National Parks and Wildlife Service), have been extracted from the data (Map 5.2).

Three of these sub-regions are marine/estuarine areas - Gosford-Wyong, Royal National Park and Cataract Dam - and the remainder are distributed in the hinterland - Upper Mangrove Creek, Cumberland Plain and the Blue Mountains (The distribution of site types in these sub-regions is illustrated in Appendix B). Each sub-region possesses unique characteristics which are summarized below:

Gosford-Wyong

The Gosford-Wyong sub-region is formed by an extrusion of the Hawkesbury sandstone plateau into the Broken Bay estuary. Approximately 90% of the area is underlain by Hawkesbury sandstone.

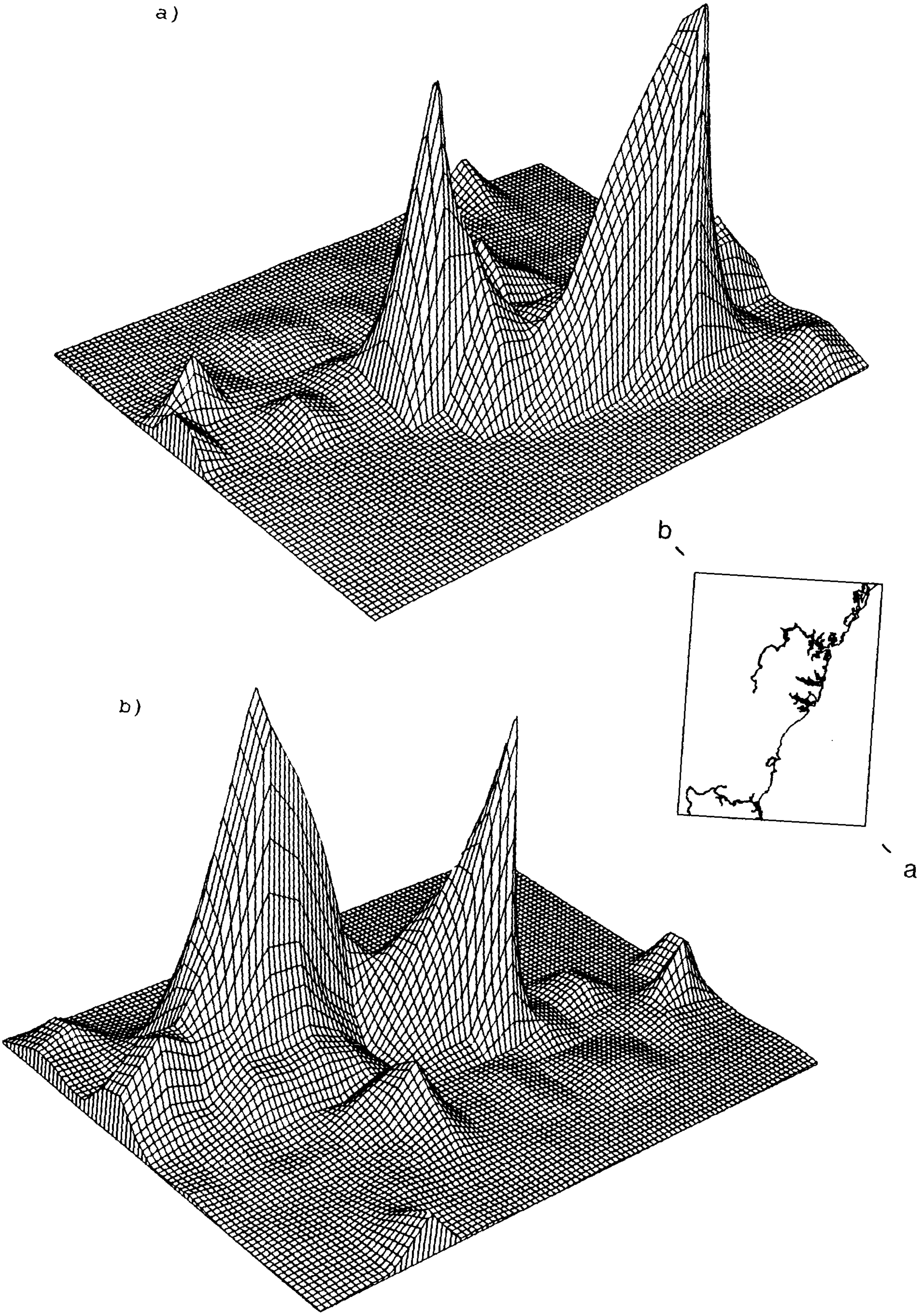
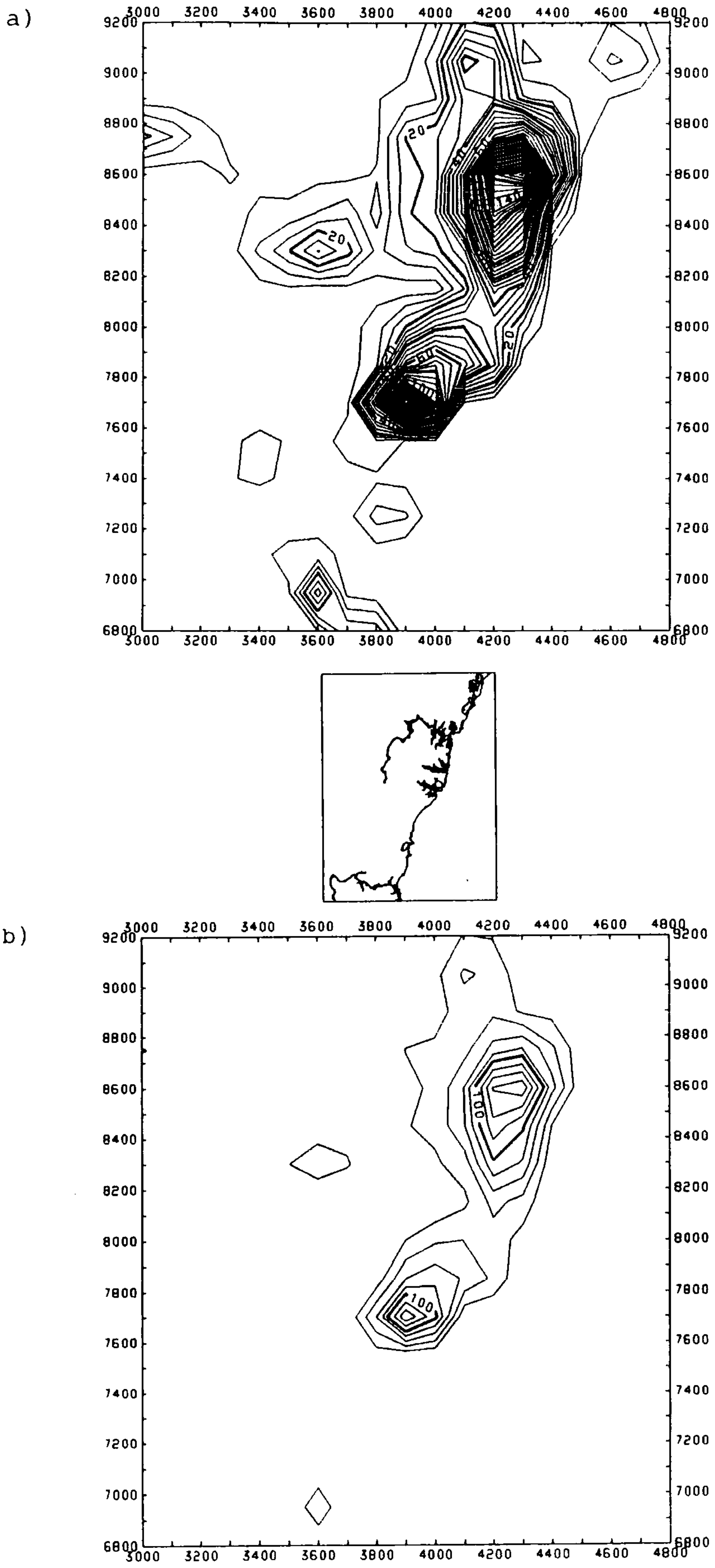
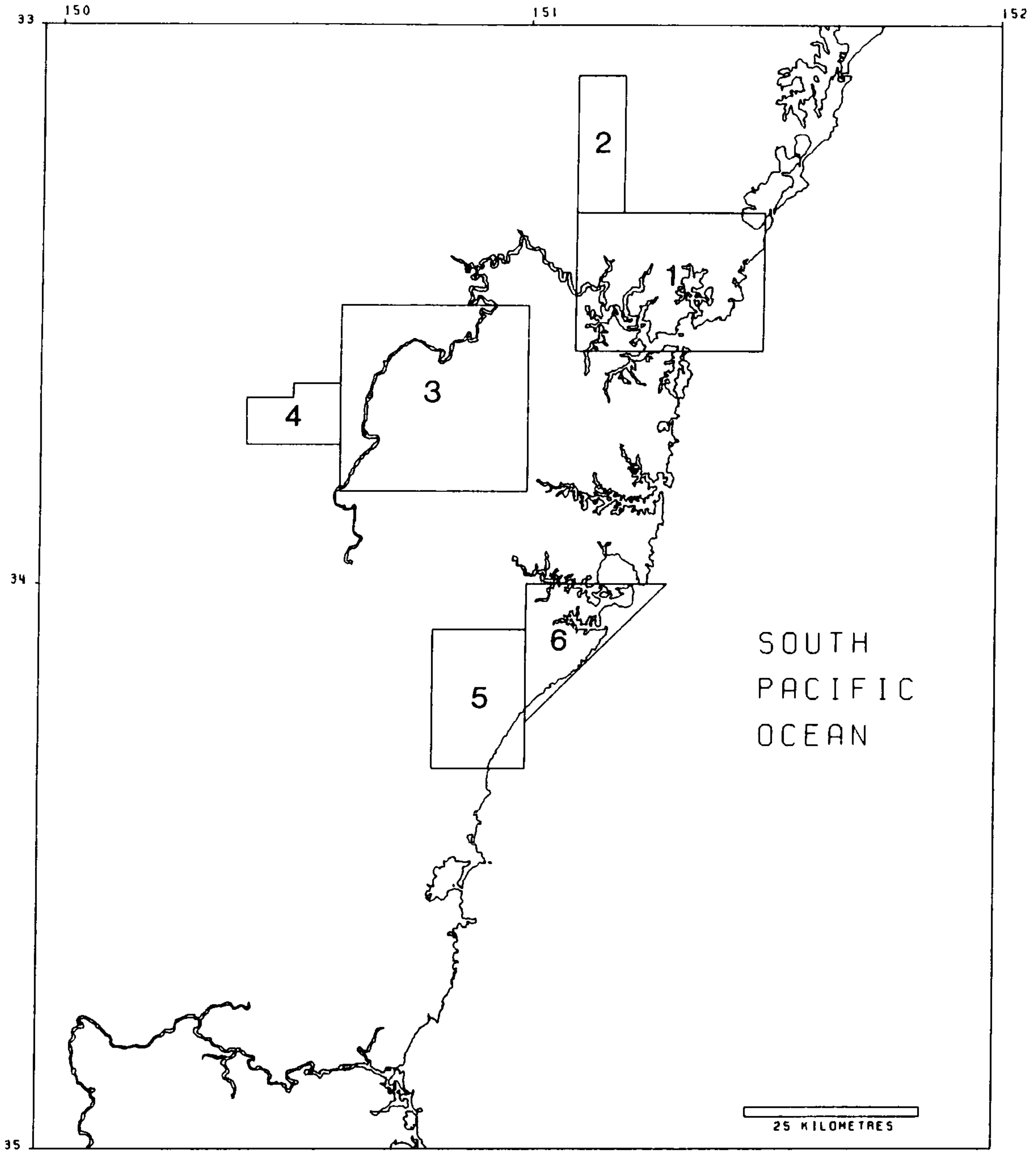


Figure 5.2: The distribution of Aboriginal sites within the Sydney region illustrating the coastal bias in the data.



Map 5.1: The distribution of Aboriginal sites in the Sydney region.
a) contour interval = 5; to illustrate the inland distribution.
b) contour interval = 20; to illustrate the coastal distribution.



ap 5.2: The location of sub-regions.
(Note: 1 = Gosford-Wyong; 2 = Upper Mangrove Creek; 3 = Cumberland Plain; 4 = Blue Mountains; 5 = Cataract Dam; 6 = Royal National Park)

To the east of the sub-region, Quaternary sand predominates; while Narrabeen sandstone is limited to the eroded fringes and valleys of the plateau and represents only about 2-3% of the area.

Upper Mangrove Creek

The Upper Mangrove Creek sub-region is dominated by Hawkesbury sandstone (60% of the region). The Mangrove Creek and its tributaries cut down to the Narrabeen series, so that about 35% of the region is of this type (this represents one of the very few extensive areas of this series within the region); Quaternary alluvium deposits make up the remainder of the sub-region.

The Cumberland Plain

The Cumberland Plain sub-region is the only one of the selected sub-regions which has been largely cleared and settled. It is a gently undulating plain surrounded by Hawkesbury sandstone plateaux to the north, south, west and (at least in part) east. The Hawkesbury-Nepean river runs along the west and north borders of the sub-region - separating plain from plateau. 55% of the sub-region is underlain by Wianamatta shale, 30% by clays and gravel, 10% by alluvium and 5% by Hawkesbury sandstone.

The Blue Mountains

The Blue Mountains sub-region is the only area within the Blue mountains were a substantial number of sites has been found (Stockton & Holland 1974). The area is characterized by Narrabeen sandstone ridges, with Hawkesbury sandstone to the east of the area (where the Narrabeen dips under the Hawkesbury series). Approximately 50% of the area is underlain by Hawkesbury Sandstone; 45% by Narrabeen sandstone (another of the few extensive areas); 4% by Wianamatta shale and 1% by basalt.

Cataract Dam

The Cataract and Woronora dam sub-region is formed by part of the Woronora Plateau - 90% of the sub-region is plateau top. To the east-south-east a steep, scarp slope falls to the ocean. Several valleys cut down through the Hawkesbury sandstone to rich Narrabeen shales which support the only extant area (and then only a few hectares) of Closed Forest within the Sydney region. Narrabeen shales, however, underlie only about 2% of the region. The Hawkesbury sandstone plateau represents the remaining 98% of the sub-region.

The Royal National Park

The Royal National Park is the most eastward extension of the Woronora plateau. To the north it borders the estuary of the Hacking river and, to the south-east, the ocean. Approximately 98% of the region is underlain by Hawkesbury sandstone, while Quaternary sand and tiny outcrops of Narrabeen sandstone compose the remainder.

5.7 METHODS AND LEVELS OF ANALYSIS

The statistical analysis of the relationships between Aboriginal behaviour and the Sydney palaeoenvironment (Chapter Seven) was divided into two major parts:

1. The extent to which the location of Style and Function sites differ in their relationships to a number of landscape (q.v.) characteristics was determined, in order to establish the validity of the principle that Aboriginal behaviour related to food acquisition was influenced by the location of patches.

   In order to maximize the information derived from the analysis of the locational characteristics of the Aboriginal sites, a number of site sub-populations were used. The definitions of these sub-populations and the abbreviations use to refer to them in the remainder of this thesis are presented in Table 5.1 (the influence upon regional and sub-regional sample sizes of this reducing technique is indicated in Appendix C).

   The sub-populations were constructed by the exclusion of shell middens (which, bias the data towards coastal characteristics) and/or axe grinding grooves (which because they are related to behaviour not closely associated with food-acquisition were considered to be likely to bias the data away from those locational characteristics which would indicate a relationship between sites and high-value patches).

Abbreviation	Definition
F	All sites with archaeological deposits or grinding grooves.
S	All art sites and 'ceremonial' and 'natural mythological' sites
F/S	Sites containing archaeological deposits and art.
FO	As for F but only open sites
FS	As for F but only shelter sites
SO	As for S but only open sites
SS	As for S but only shelter sites
FOXM	As for FO but excluding middens
FOXGG	As for FO but excluding axe grinding grooves
FSXM	As for FS but excluding middens
FSXGG	As for FS but excluding axe grinding grooves
FOXMGG	As for FO but excluding both middens and grinding grooves
FSXMGG	As for FS but excluding both middens and grinding grooves

Table 5.1: Abbreviations and definitions of Aboriginal site sub-populations used in the analysis.

In addition, it was considered that the structural dichotomy between open and shelter sites necessitated the separate analysis of these sites types. Shelter sites are bound to certain geological and topographic associations, while open sites (at least in theory) could be located anywhere within the landscape.

Two non-parametric statistics were used at this stage of the analysis. The Mann-Whitney 'U' statistic was used to test the significance between sets of metrical data and the Chi-squared statistic was employed to test the significance of categorical data. The former statistic was obtained through the use of the Michigan Interactive Data Analysis System (MIDAS); while the latter was obtained by hand throughout (principally because of the necessity of maintaining the rule of the test that no more than 20% of the expected values should fall below five). A general significance level of 0.01 was used at the regional level (except in the case of aspect data - because of the low number of cases involved) in order to minimize the influence of large sample size. At the sub-regional level the significance level was lowered to 0.05.

2. After this comparative analysis, two multivariate analysis techniques were applied to the Function data in order to determine a) the degree of inter-relationship between ecological influences upon Aboriginal locational choice; and b) the relative importance of individual and group influences upon Aboriginal locational decisions.

Firstly, multi-dimensional scaling, a series of techniques for representing the relatedness of variables, was undertaken using the MDSX program MINISSA and contours derived from cluster analysis (CLUSTAN), in order to establish the identity of a) groups of variables which are likely to have represented a general influence upon locational choice; and b) individual variables which are likely to have had an independent influence upon that choice. Secondly, factor analysis techniques (derived from the recently updated SPSS package - SPSSX) were utilized in order to determine the extent to which the relative importance of ecological influences upon Aboriginal choice fitted expectations based upon the behavioural model.

These latter techniques were applied only to those areas which are archaeologically well-known (the sub-regions identified above); for these areas have been extensively surveyed and, as a consequence, observed relationships between the location of sites and the location of high-value patches are likely to possess a greater validity than those which exist in the whole region - the majority of which is only superficially known.

However, an amalgamation of these sub-regions into two larger categories - one coastal, the other inland - was effected. Within these areas, factors were extracted independently for open and shelter sites, because of the likelihood that shelter sites (which are tied to specific geological and topographic characteristics) would display a greater degree of deflexion of Aboriginal behaviour with regard to patch distribution.

Finally, because of the artificiality and potential sources of error inherent in these divisions of the data into open/shelter and coastal/inland, factors were extracted from the amalgamated pool of sub-regional data in order to determine which ecological characteristics of the Sydney palaeoenvironment are likely to have influenced Aboriginal locational decisions upon a regional scale. This was achieved through the extraction of factor scores by case. The top and bottom 10% of these scores were plotted using the CARTOGRAPH program within the MIDAS package in order to identify the location of Aboriginal sites which contribute most highly to the positive and negative loadings of these regional factors, and to determine the extent to which the patterns which were discernible within the coastal/inland divisions were observable as patterns in the region as a whole.

5.8 PAST ENVIRONMENTS AND PAST BEHAVIOUR: A SELECTED AREA

A comparatively small section of the region was used in an attempt to identify ecological influences upon Aboriginal locational choice of a smaller scale than were identifiable within the region as a whole (Chapter Eight). This area - 'the Sydney area' - was divided into one kilometre cells - a technique that has been used in archaeological studies elsewhere (Thomas 1975; Bettinger 1977). The archaeological data were plotted (using the MIDAS program CARTOGRAPH) and contoured (SURFACE II) in order to establish the distributional characteristics of the data: firstly, without grinding grooves; and secondly, without grinding grooves or middens. These distributions were compared with the terrestrial and aquatic structural characteristics, and with a proposed reconstruction of the pre-European vegetation structure, in order to suggest the ways in which local ecological influences may have influenced Aboriginal locational decisions.

Finally, the ethnohistorical observations of First Fleet writers, who travelled extensively within the bounds of this special area, were examined for evidence of local patterns of Aboriginal distributional and behavioural characteristics, which either lent support to or were at variance with the proposed degree of fit between the behavioural model and the archaeological evidence for Aboriginal activities (Chapter Nine).

5.9 CONCLUSION

The extensive and well-known archaeological material within the Sydney region provides an almost unique opportunity to assess (through the use of comparative inferential statistics and multivariate statistical techniques) the extent to which an extinct hunter-gatherer population may have had a tendency to optimize in its response to environmental spatial and temporal heterogeneity.

However, this is not to suggest that the archaeological record is a faultless and readily interpretable record of past human behaviour - for it is not. In the next chapter, the limitations of the data will be discussed and the identification of those parts of it which are relevant to the present investigation will be undertaken.

6 CHAPTER SIX:

DISCARD, DESTRUCTION AND DISCOVERY

In order to utilize optimality models upon the remnants of behaviour that constitute archaeological sites, it is necessary to establish both contemporaneity between sites and also that the sites are sufficiently recent that they can be safely associated with the contemporary environment - the only environment which we can know in sufficient detail. Consequently, in this chapter the evidence for suggesting that Aboriginal sites in the Sydney region are recent and contemporaneous is reviewed. In addition, the theoretical and ethnoarchaeological grounds upon which the notion of the likelihood that these hunter-gatherer sites reflect, in their locational characteristics, a close association with the objectives of the food quest, are discussed. Finally, the limitations of the data, and in particular the influence of post-depositional taphonomic factors, are introduced both at a general level and for the specifics of the Sydney region.

6.1 INTRODUCTION

There is insufficient room here to discuss even the major features of recent Australian archaeological research - our attention is directed solely toward south-eastern Australia. However, the reader is referred to the recent major reviews of the field undertaken by Mulvaney (1975), White & O'Connell (1982) and Flood (1983).

As a form of introduction, however, it should be noted that although available dates go back no further that about 35000BP there is reason to suppose that the colonization of Australia began at least c.50000BP (White & O'Connell 1982:42). The earliest dates for human activity (for example, 30780±520BP, at Lake Mungo) are to be found in the southern half of the continent and it is reasonable to assume that earlier sites must have existed to the north - presumably most of these were destroyed during subsequent marine transgressions. By 20000BP all the coast had been settled, as had the hinterland up to the margins of the desert core; and by 10000BP all the major environmental zones were occupied (Jones 1979).

6.1.1 Sydney sites and the poverty of the internal record

Post-depositional processes within the Sydney region have taken a severe toll upon the archaeological record. The structure of sites has been greatly influenced particularly by the acidity of the soil; and probably by many other more mechanical factors (see Walters (1984) for an interesting Australian study of the probable influence of dingoes on site structure). Only minute quantities of organic materials (other than shells) have survived (see for example, the faunal material recovered from excavations in Megaw (1974) - Table 6.1; see also Sullivan (1982) concerning the shellfish species within Aboriginal middens; and Urquhart (1978) concerning fish remains).

However, the tiny amount of information which does exist suggests that upon the coast, marine resources (shellfish, fish) predominated in the

Fauna	Common name	Sites
FISH		
	Snapper	Wattamolla
	Blue groper	Wattamolla, Curracurrang
	Wrasse	Wattamolla
	Leatherjacket	Wattamolla, Curracurrang
	Bream	Curracurrang
	Parrotfish	Curracurrang
	'fish'	Yowie Bay
MAMMALS		
	Bandicoot	Wattamolla
	Dingo	Wattamolla, Yowie Bay
	Seal	Wattamolla, Curracurrang
	'macropod'	Wattamolla, Curracurrang, Yowie Bay.
	'small marsupial'	Curracurrang, Yowie Bay
BIRDS		
	Mutton bird	Wattamolla, Curracurrang
	Petrel	Wattamolla
REPTILES		
	'Lizard'	Curracurrang

Table 6.1: Faunal representation in coastal sites within the Sydney region. (Source: Megaw 1974)

diet (though some land species are also represented in the record); while a similar diet is suggested by evidence from the estuarine environment - shellfish and fish predominate though some land animals are present (Clegg 1979).

In the hinterland the archaeological record suggests that land animals predominated in the diet. In particular, Attenbrow (1981) and Aplin (1981) have undertaken a systematic survey of faunal remains within the Upper Mangrove Creek catchment area (note that Aplin (1981) considers that available evidence from the Blue Mountains supports the pattern of diet discerned in this area). Table 6.2 presents the faunal record for Loggers Shelter and Mussel Shelter. The majority of the represented fauna are small mammals; and particularly those associated with Tall Open Forest, Open Forest and Woodland. (Table 6.3 also presents the data concerning the number of identifiable bones (not MNI) from Loggers Shelter, Upper Mangrove Creek, and confirms the predominance of small mammals in the record (Aplin 1981).)

There is even less information preserved in the archaeological record concerning vegetable foods, essentially these data are limited to the occasional occurrence of <u>Macrozamia</u> kernels (for example at Noola rock-shelter (Tindale 1961)). Overall, then, the faunal and floral components of the Sydney region archaeological record provide the minimum of information concerning the relationship between man and the environment.

Species	Common name	Loggers Shelter	Mussel shelter
LARGE MACROPODIDAE		41	17
Macropus robustus	Euro	3	6
M. rufogriseus	Red-necked wallaby	3	6
Wallabia bicolor	Swamp wallaby	8	16
MEDIUM MACROPODIDAE		107	33
Petrogale pencillata	Rock Wallaby	4	3
Thylogale spp.	Pademelon	3	1
SMALL MACROPODIDAE		150	112
Potorous sp.	Potoroo	3	-
Potoroidae	Potoroo	17	5
Trichosurus vulpecula	Brush-tailed possum	12	2
Pseudocheirus peregrinus	Ring-tailed possum	1	-
Petaurus sp.	Glider	1	-
Isoodon sp.	Bandicoot	2	-
Schoinobates volans	Great glider	-	1
Peramelidae	Bandicoot	10	1
Vombatus ursinus	Common wombat	1	-
Vombatus hirsutus	Hairy-nosed wombat	-	1
Phascolarctos cinereus	Koala	-	1
Pteropus scapulatus	Red flying fox	1	-
MURIDAE	Murid rodent	-	1
Rattus sp.	Rat		1
REPTILIA	Reptiles		1
Boidae	Python	5	-
Ophidia sp.	(Lizard)	8	-
Agamadae	Dragon	8	-
Egernia sp.	Skink	1	-
OTHER			
?Dromaius novaehollandiae	Emu	1	-
Teleost fish		8	1

Table 6.2: Faunal representation at Loggers Shelter and Mussel Shelter, Upper Mangrove Creek (identifiable bones).
(Source: Aplin 1981)

Fauna	%
Large mammals	12.03
Medium mammals	24.94
Small mammals	56.33
Reptiles	4.30
Fish	2.00
Birds	0.30

Table 6.3: Percentage faunal composition, Loggers Shelter, Upper Mangrove Creek. (Source: Aplin 1981)

Site	Date ± SE
COASTAL	
Bass Point	571 ± 150
The Landing Place	360 ± 110
Curracurrang 1	200 modern
Curracurrang 7	1050 ± 100
Durras North	480 ± 80
Wattamolla	560 ± 130
INLAND	
Loggers cave	780 ± 80
Dingo and horned Anthropomorph	581 ± 120
Lyre Bell Dell	530 ± 80
Kings Table	980 ± 70
Springwood Creek	615 ± 80

Table 6.4: Some radiocarbon dates indicating recency of occupation from sites within the Sydney region.
(Sources: Bowdler 1970; Megaw 1974; Lampert 1966; Attenbrow 1981; Stockton & Holland 1974)

There is, however, an abundance of stones within the record. Yet even these, from the viewpoint of the study of patterns in the location of Aboriginal behaviour, are virtually valueless entities - for there is little evidence that raw materials were anything other than local - both Hawkesbury and Narrabeen sandstone contain conglomerate beds of siliceous pebbles (quartz, chert and jasper in the Narrabeen series; chert and quartz in Hawkesbury sandstone). For example, Sullivan (1982) in a study of sites along the coast of New South Wales observed "a gradual change along the coast in the raw materials ..... which correlates broadly with locally available sources of fine-grained siliceous rocks suitable for flaking" (op. cit: 198). The only exception to this general pattern of local stone usage concerns the edge-ground axe, which was usually made of igneous rock (basalt or diorite and sometimes quartzite) for which the principal sources would have been on the upper Hawkesbury or in the Blue Mountains (see Dickson 1981).

Overall, there is little information in the Sydney region archaeological record which might be utilized to determine aspects of food acquisition or movement over the landscape. From this perspective, the value of archaeological sites lies only in the fact that they represent the foci of Aboriginal activities.

6.2 THE EASTERN REGIONAL SEQUENCE AND EVIDENCE OF RECENCY

In order to establish the recency and contemporaneity of Aboriginal sites it is necessary to establish some measure by which this may be judged. The archaeological sequence contains little material that is inherently useful in establishing the recent occupation of sites. Material such as charcoal, which is ideal for establishing age through the radiocarbon dating method is abundant; but archaeologists within the region have been more interested in establishing antiquity of occupation than recency; and, in any case, the method is not generally useful in establishing contemporaneity for standard errors associated with recent materials tend to be as large as they are for antique samples (Foley pers. comm.; see, however, Table 6.4 for some recent C14 dates from the region). Thus the typology and assemblage structure of the lithic material provide the principal evidence that can be used in order to establish contemporaneity and recency.

Fortunately, despite the fact that terminology and dating of phases differ between researchers, there is (more or less) a consensus concerning those characteristics of the artefact record which are likely to be markers of recent occupation.

In 1948 McCarthy proposed a tripartite sequence (on the basis of materials excavated within the Sydney Region) for the assemblages of eastern New South Wales, which is referred to as 'The Eastern Regional Sequence'. His three divisions - Capertian, Bondaian and Eloueran - were characterized by particular assemblage structures and particular stone implement types.

Subsequently, some archaeologists have objected for various reasons to the continued use of these terms for the archaeological assemblages (see Mulvaney 1975:123); and later researchers have tended to use a pan-Australian terminology: an early "core tool and scraper tradition" and a later "Australian small tool tradition" (see Mulvaney 1975:174, 212). The earliest phase of the Eastern Regional Sequence (Capertian) broadly equates with the Core Tool and Scraper Tradition and the latter two phases (Bondaian and Eloueran) with the Small Tool Tradition.

However, McCarthy's phases (with some modification) still provide a viable and more sensitive framework for the establishment of the recency of stone artefact assemblages in the Sydney Region, and hence they are retained here.

Based upon evidence from Lapstone Creek and Capertee 3, McCarthy (1948:22; 1964:234-9; 1976:96-7) described the three divisions thus:

Capertian

> The earliest phase; this contained pebble tools, dentated saws, a basic series of chert flakes and blade implements (scrapers), core tools, cores and a few hammerstones. Burins and fabricators were rare. Large primary flakes and blades were more abundant than in the succeeding Bondaian assemblage.

Bondaian

The features of the Capertian were retained but new implements were introduced: backed implements - bondi pōints, eloueras and geometrics - as well as ground-edge axes. Burins and fabricators increased slightly in number and the average size of artefact decreased. The percentage of chert artefacts was greater than in the Capertian and Eloueran assemblages.

Eloueran

This period was characterized by fabricators, eloueras and edge-ground axes. The number of these artefacts had increased in proportion to other implement types. Bondi points were not present. Quartz was used to a much greater extent than in the Bondaian.

Similar sequences to these have been found at other sites within the Sydney region (for example upon the south coast: Burrill Lake (Lampert 1971), Curracurrang (Megaw 1965); and in the Blue Mountains: Walls Cave and Springwood Creek (Stockton & Holland 1974)). However, variations upon this theme are known elsewhere within the region.

As a consequence of this variation, Lampert (1971:127) has said that, in fact, the Bondaian is "the only universal and distinctive industry ..... it is well distributed and easily recognizable"; and because of these characteristics, the term has continued to be widely used. However, alternatives have been proposed for both the earlier and later phases.

Lampert has been principally responsible for modifying the definition of the Capertian. He suggests that the presence of dentated saws at Burrill Lake, Capertee and Curracurrang - and not at sites of similar age further afield - indicates a broad division within this period (Lampert 1971:65). There is some confusion in the terminology associated with this period, for Lampert prefers the term 'pre-Bondaian' or 'Phase I' to Capertian, while Stockton & Holland (1974) retain the term Capertian, but indicate that assemblages do not always include the larger components such as pebble tools and horsehoof cores.

Adding to the debate, Stockton & Holland have suggested that McCarthy's Capertian should not strictly be classified as part of the Core Tool and Scraper tradition, but as a transitional assemblage between this and the Small Tool tradition. This transitional tradition appears to have occurred between 12000 and 6000BP (Stockton and Holland 1974:53). The assemblage which occurs before 12000BP is referred to by Stockton & Holland as 'Archaic' (op. cit:53) and is properly considered to be of the Core Tool and Scraper tradition.

Of more particular interest here, however, are the modifications which the definition of the Eloueran has undergone. The term, in fact, is not now generally used for the latest phase in south-eastern prehistory, principally because in sites excavated since Lapstone Creek, layers overlying Bondaian assemblages have not been found to be dominated by eloueras. Indeed, at some sites eloueras are not present at all and Bondi points are often present.

As to this latter point, there appears to be a geographical dichotomy. Bondi points are often found in the Blue Mountains, New England and the upper Hunter Valley, but in coastal sites they have not been found on the surface or in surface levels. This may be due to taphonomic processes whereby treadage and scuffage have brought Bondi points to the surface in the hinterland (Lampert & Hughes 1977); or it may indicate that Aborigines in the ranges were utilizing the implement type much later than Aborigines on the coast; or were utilizing it for different purposes (or some other factor as yet undetermined).

In general, both Stockton & Holland (1974) and Lampert (1971:68) see the final phase (McCarthy's Eloueran) as part of the Bondaian. Lampert proposes the term 'Phase III', Stockton & Holland prefer the term 'late Bondaian' (they see the post-Capertian as a continuum - early, middle and late Bondaian).

Radiocarbon dates have, of course, contributed greatly to this debate. The introduction of backed pieces - the beginning of the Bondaian phase (or small tool tradition) - is dated to about 5500-5000BP at many sites (McCarthy 1976:76) though some researchers propose a later date circa 4000BP (Johnson 1979). The beginning of the final phase (late Bondaian) is dated to about 2000-1000BP (McCarthy 1976:96). Table 6.5 presents the terminology of the various authors and approximate dates of the broad sequences.

Pan-Australian	McCarthy	Lampert	Stockton & Holland	C14 dates
Australian core tool and scraper tradition	Capertian	Phase 1	Archaic Capertian	To 5500-5000 BP
Australian small tool tradition	Bondaian	Phase 2	Early Bondaian Mid Bondaian	To 2000-1000 BP
	Eloueran	Phase 3	Late Bondaian	To 1788

Table 6.5: The Eastern Regional Sequence, alternative terminologies and approximate dates.
(Sources: McCarthy 1976; Lampert 1971; Stockton & Holland 1974; Mulvaney 1975)

In practice, the division between the early Bondaian and the mid-Bondaian is unclear and it is not often possible to say which Bondaian phase an assemblage belongs to unless at least two of the phases are present so that relative proportions can be compared, but they can be broadly outlined in the following way (Stockton & Holland 1974):

Early Bondaian

5500 - ?BP. The features of the Capertian continue but a series of fine-worked backed implements are present (e.g. Bondi points). Fine-grained siliceous stone materials were predominant.

Mid Bondaian

? - c.1200BP. The number of Bondi points increased relative to the early Bondaian. The number of bipolar pieces also increased but not to the level of Bondi points. The amount of quartz used also increased.

Late Bondaian

c.1200BP - 1788AD. Bondi points were not present or had decreased in number. Eloueras and bi-polar pieces increased in numbers. Implements were generally smaller in size and average weight. The number of edge-ground implements increased. The amount of quartz used continued to increase and became the predominant stone used.

It is important to note that all these assemblage divisions are imposed by archaeologists upon the continuum of the data. As Poiner (1976:194) has said: "It is difficult to know whether new artefact appearances are instances of functional replacement or additions to the subsistence tool kit", for no reliable or consistent relationship exists between the archaeologists' classification of such implements based, as it is, upon visible and measurable attributes of the artefacts themselves, and the Aboriginal way of classifying them (though see below concerning ethnoarchaeological research). However, the characteristics of the late Bondaian, as it is presently understood, are likely to provide the best guide to the recency and contemporaneity of sites.

6.3 HOLOCENE POPULATIONS AND THE INCIDENCE OF THE LATE BONDAIAN

On the basis of the lithic sequences it is an inescapable conclusion that the vast majority of sites within the Sydney region belong to the recent past and are approximately contemporaneous.

It has in fact, been known for some time that during the Holocene, and particularly the late Holocene, the coast of New South Wales saw an increase in population (i.e. from the archaeologists' point of view, - an increase in the number of sites used; see Megaw 1974; Lampert & Hughes 1974; Poiner 1976; Bowdler 1977; Callaghan 1980). Recent papers by Hughes and Lampert (1982), Hughes and Sullivan (1979) and Attenbrow (1981, 1982) have examined the whole basis of the incidence of new sites and the intensity of site occupation, both in the coastal zone and in the hinterlands of the Sydney region, using isotopic and geomorphological data.

Hughes and Lampert (op.cit.), in particular, conclude concerning coastal sites within the study area that:

1. Up until about 8000BP very few sites show evidence of having been occupied. Between 8-6000BP occupation becomes archaeologically visible for the first time at several sites, reflecting the arrival of the sea at its present level, and the concomitant arrival of man.

2. Over the last 5000 years the increase in the number of site showing evidence of occupation is roughly two or threefold (op. cit:20) and the increase in intensity of occupation of those sites already visible six to tenfold.

Hughes and Lampert stress that this increase (Figure 6.1) does not simply reflect the destruction of sites or the establishment of sites on newly-formed sandy landforms (op. cit:20) and they conclude their analysis by the refutation of the following alternative hypotheses to Holocene population growth as a cause of the phenomenon:

1. The location of sites changed to situations where they are more likely to be visible today. There is no evidence to suggest this, in an archaeologically well-known area, and because it involves putative hidden data Hughes and Lampert consider this hypothesis unattractive (op. cit:24).

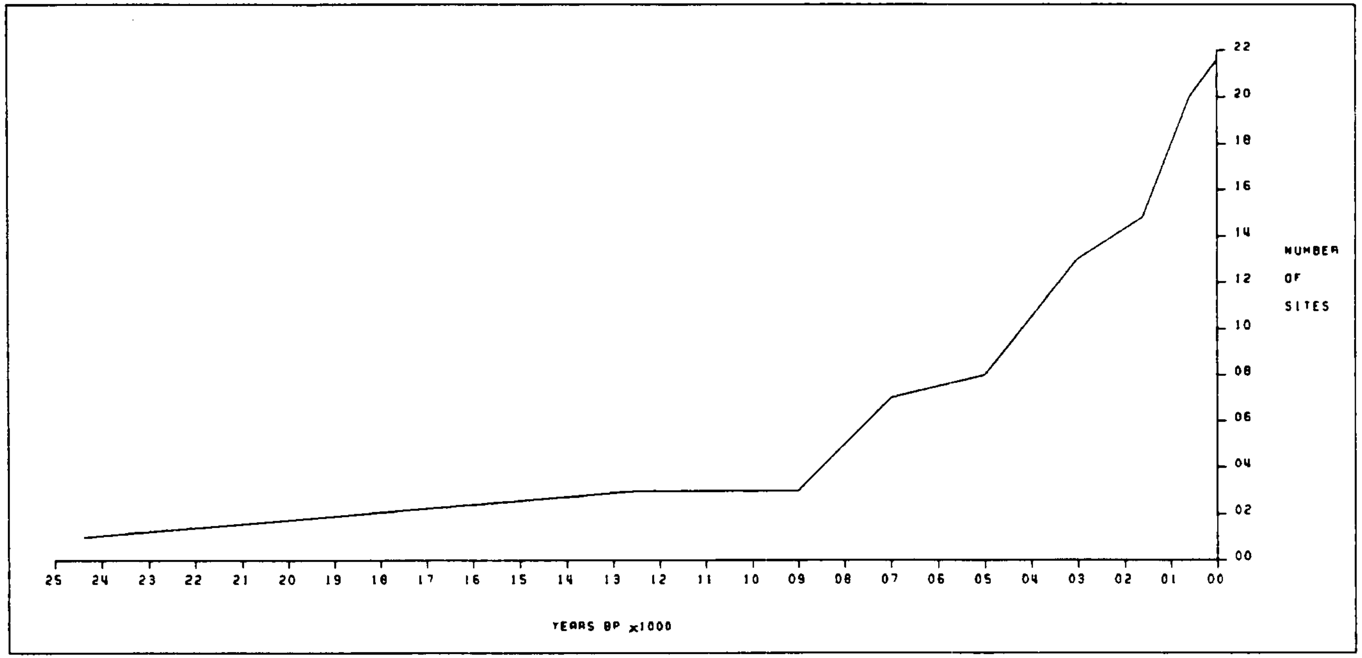


Figure 6.1: The rise in the number of sites occupied upon the coast of the Sydney region during the Holocene.
(Adapted from Hughes & Lampert 1982)

2. *There was a decreasing rate of site destruction, due to less erosion associated with climatic or other environmental change*. There is no evidence for any environmental change that would have so greatly altered the decay rate of the sites.

3. *More stone tools were used per head of population*. Intensity of occupation does appear to rise after the advent of small tools in the region. However, analysis of the numbers of large 'maintenance' tools at Burrill Lake and Currarong 1 suggest that the population was not using more of these implements than before the advent of the tradition.

4. *The coast has always had a higher population density than most inland regions. The increase in intensity of occupation can be attributed to the retreat of coastal people to the present shoreline as the sea level rose*. This hypothesis is unlikely to be true because the intensity of occupation continued to increase after the sea stabilized around 6000BP. This increase was also synchronous at hinterland sites (for example, Sassafras - 35km from the coast and in the Upper Mangrove Creek area).

Hughes & Lampert are left with the hypothesis that only a rise in population could account for this increased intensity of site usage and site creation (see also Lourandos (1985); and for comparable developments across the highlands, Allen (1974)).

It is interesting to note that the rise in population posited by Hughes & Lampert after the sea-level stabilized, may be due to three principal factors of ecological and evolutionary significance:

1. The stabilization of the sea-level would have allowed the population growth of marine and estuarine species which require a stable substrate (in particular, shellfish and highly important plant species (in terms of both productivity and habitat) such as sea grass (<u>Zostera</u> spp.) and mangrove (<u>Avicennia</u> spp.) which influence the population dynamics of local species as well as providing resources for migratory species).

2. The observed increase in occupation over time may represent the time-lag between the development of an environment of higher inherent productivity (which also attracts unearned resources), and the process of human adaptation to it.

3. The rapid rise in population continuing to the ethnographic present may a consequence of the tendency of populations to continuously outgrow their resource base (see Cohen 1977).

This latter point is likely to explain the considerable evidence that the rise in population occurred inland as well (Attenbrow 1981, 1982), probably through the (essentially) coastal population overspilling into these areas. Very few shelters were occupied in the Upper Mangrove region before 5000BP, for example, but subsequent increases occurred up to the ethnographic present (Figure 6.2). More generally, in her overview of the data, Bowdler (1981:108) has argued that in the eastern Australian highlands, Aboriginal occupation of any intensity can only be dated to within the last 5000 years.

The foregoing, then, establishes that the vast majority of sites within the Sydney region are likely to have been established within the last 5000 years, and that the greater part of that number have been established only since the most recent periods within that era.

In fact, the recency of the archaeological data and its contemporaneity within the Sydney region can be established to a much finer degree. For the excavated material suggests that once occupation had begun *both coastal and inland sites continued to be occupied until the ethnographic present* (Attenbrow 1982:75; Hughes and Lampert 1982:20). Only one site - Yowie Bay - appears to have been an exception, having been used only between 3000 and 2000BP (Poiner 1974). In addition, survey work undertaken within the Sydney region tends to confirm the presence of this overwhelming tendency in unexcavated sites within the region (in Gosford-Wyong (Vinnicombe 1980); Upper Mangrove Creek (Attenbrow 1981); and the Cumberland Plain (Haglund n.d.; Kohen pers. comm.)).

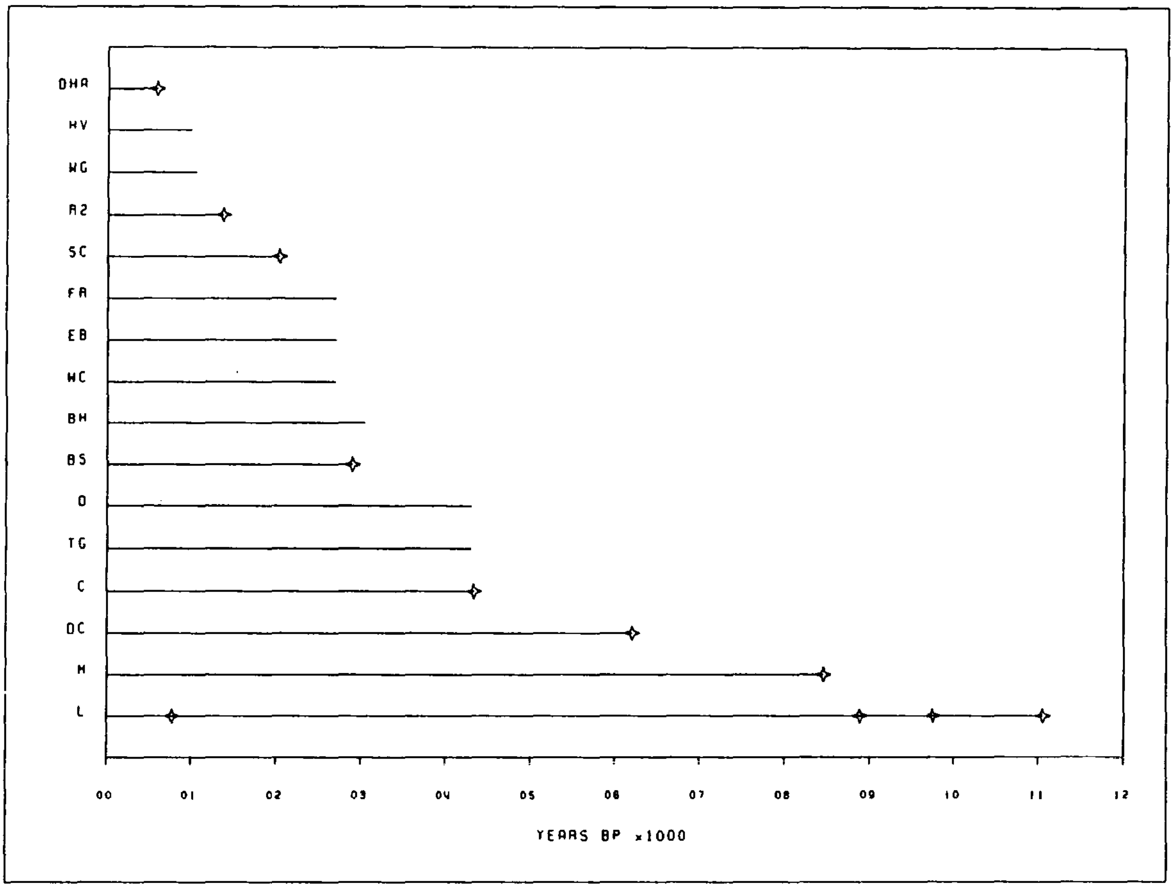


Figure 6.2: Duration of occupation among excavated sites within the Upper Mangrove Creek area of the Sydney region, illustrating the rise in occupation rates in inland areas during the late Holocene and continuity of usage from the time of first occupation until 1788.
(Note: These data were based upon typology alone except where C14 dates (marked) were available. The site represented here are Dingo & Horned Anthropomorph (DHA); Homestead View (HV); White Gum (WG); Rainforest2 (R2); Sandy Cave (SC); Fallen Rock (FR); Echidna-Bucketty (EB); Wattle Creek (WC); Black Hands (BH); Bracken Shelter (BS); Dendrobium (D); Three Gullies (TG); Campsite (C); Deep Creek (DC); Mussel (M); Loggers (L).
(Adapted from Attenbrow 1982)

6.3.1 Recency and contemporaneity in the Sydney region

As has been stressed throughout this chapter, recency and contemporaneity must be characteristics of the archaeological data if it is to be used in the study of Aboriginal behaviour using the present environment. Fortunately, owing to the history of detailed study of typological sequences within the Sydney region, it is an inescapable conclusion that the archaeological data fulfil this criterion. From the analysis undertaken by Lampert and Hughes upon the coast and by Attenbrow and Stockton and Holland within the hinterland, concerning excavated sites within the region (as well as opinions expressed by those concerned with surveys within the area), it can be confidently stated that the overwhelming majority of sites used as the basis of this study (including these excavated and surveyed sites) are likely to have <u>at their surface</u> an assemblage which:

1. at least post-dates the establishment of the present environmental regime (c.3000BP).

2. most probably belongs to the past 1000 years.

3. is likely to have been deposited at a time very close to that of the arrival of the Europeans in 1788.

Having established that the archaeological sites are, at least at surface, recent and contemporaneous, we must proceed to problems of equal importance. We must establish the nature of the relationship between Aboriginal food acquisition and these groups of battered stones; and we must establish the extent to which the information concerning that behaviour may have been modified by natural processes of destruction and obscuration.

6.4 DISCARD AND DEPOSITION

Archaeologists have become increasingly concerned with the ways in which the stratigraphic record is formed and the processes by which that record is modified from the time of discard to the point of retrieval (see Schiffer 1983 for a review).

The study of tool use and discard behaviour has been the subject of much ethnoarchaeological research (see for example Binford 1978ab, 1982, 1983; Gould 1980; Hayden 1979). This research suggests that the relationship between artefacts and food acquisition is unlikely to be a simple one, for other behaviour will also be recorded in the artefacts. The principal studies of patterns in the accumulation of the material remnants of food acquisition and other behaviours in the Australian context, are those of Gould (1980) and Hayden (1979).

6.4.1 The Aborigines and lithic usage

In concluding his study of the technological abilities and memories of informants from the Western Desert, Hayden (1979:11) states that the function of lithic technology was, firstly, the working and procuring of wood; and secondly, the butchering of animals. Stones were not used in the working of hides nor in the procuring or processing of plant foods. It is clear, then, that in this case, there is a deflexion in the relationship between Aboriginal behaviour, lithic usage and food acquisition - stone tools make wood tools which are used to obtain food.

This conclusion, is supported in a similar study of Western Desert Aborigines undertaken by Gould (1980). Gould estimated the number of flakes and 'chopper planes' required for wood working, replacing ceremonial paraphernalia and for the cutting of carcasses in a year (Table 6.6; Gould 1980:128-130), and was able to confirm that woodworking and animal butchering were the primary uses of lithics. In addition, Gould estimated the total lithic use by weight/man/year of non-quarried material (stone utilized as instant tools and discarded at or near where the material was found) and quarried stone (which by contrast was transported from the locus of collection to a habitation base camp where it is further shaped and used (Gould 1980:133; Table 6.7). His results indicate that approximately 18.9 times more stone picked up at the locus of an activity was used, than stone derived from a quarry site; and 99.95% of the total lithic material was used at task specific locations rather than in the context of habitation.

Usages	No. of times per year	Average no. of flakes	Average no. of 'chopper-planes'
WOODWORKING			
Spearthrower	0.5	0.5	0.5
Wooden club	0.5	0.25	0.5
Spearshaft	17.3	8.7	17.3
Speartip (resharpening)	182.5	9.1	----
Digging bowl	2.0	1.0	----
Throwing stick	1.0	0.5	1.0
Finishing bowls (women)	----	c.20.0	
sub-total usage	203.8	40.05	19.3
REPLACING PARAPHENALIA		3.0	2.0
BUTCHERING		20.0	---
TOTAL USAGE	203.8	63.05	21.3

Table 6.6: Lithic usage in the Western Desert.
(Source: Gould 1980)

Artefact class	Total amount (g)
NON-QUARRIED	
Chopper-planes -scrapers	17237
Flake knives	800
QUARRIED	
Adze flakes and equivalent scrapers	945

Table 6.7: The weight of stone used per man per year in the Western Desert
(Source: Gould 1980)

However, this does not necessarily imply that these task-specific sites would form a major part of the archaeological record. The discard produced by an individual or small group at any point within the range is likely to be lost, unless many individuals utilize the same point many times. This process of aggregation of material which results from the behaviour of a number of individuals, increases the likelihood of the preservation of habitation sites - the 0.05% of material is accumulated in spatially circumscribed loci.

6.4.2 The patterns of discard

Developments in the field of discard studies together with his own theoretical and practical work (1981c) have led Foley (1981a) to propose a model of regional archaeological structure based upon differential artefact discard. Starting from the assumptions that patterns of artefact discard reflect, though not necessarily directly, the behaviour of the population and that most artefact use and discard is related to subsistence activities (op. cit:3), Foley has suggested that, within the framework of home-range, five spatial components occur which account for virtually all discard (Table 6.8). The greatest amount of discard occurs in spatial components 'A' and 'B', and progressively less in components 'C', 'D' and 'X'.

The difficulty of using these divisions in an archaeological context lies in the problems of their recognition. In the Sydney region, for example, partly because of the poverty of the faunal and floral record,

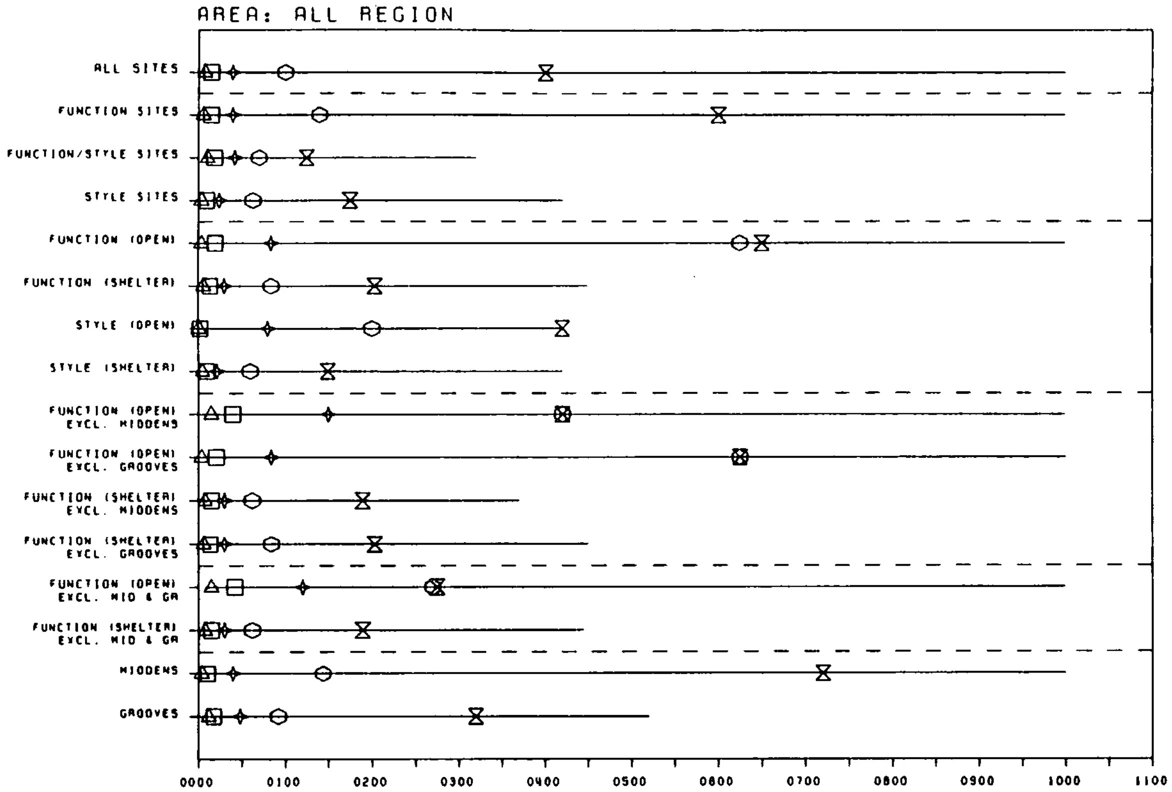
Spatial component	Name	definition
A	Home base	The primary focus for behaviour and discard: of variable permanency
B	Home base periphery	A focus for many activities & discard
C	Secondary home range foci	Repeatedly visited points in the landscape where specific activity related discard takes place
D	Occasional home range foci	Occasionally visited (or passed) points where discard occurs during subsistence activity
X	Extra home range foci	Total range discard beyond the bounds of home range

Table 6.8: The spatial components of artefact discard.
(After Foley 1982)

but mostly because of the generality of the record at its most modern (the only part that concerns us), there are few criteria upon which to base divisions of the site data.

The analysis of the size of sites may provide some criterion. It is tempting to suggest that large area sites represent Foley's category 'A', and that progressively smaller sites represent Foley's categories 'B' to 'D'. However, while such a division may, on the whole, possess a broad validity, it also requires a high level of naivety.

Figure 6.3 illustrates the site area data for archaeological site in the Sydney region (the areas of art sites are also included for comparison). In general, the majority of archaeological sites tend to be small (< 50 sq.m.) which is suggestive of the preponderance of Foley's categories 'B' to 'D' types within the area; yet behind this general characteristic there is a high degree of variation. In particular, there is a wide difference between the sizes of open and shelter archaeological sites - the two are not comparable. Shelter sites are likely to be constricted in their maximum dimensions to a greater degree than open sites (there is, of course, a minimum size of shelter which can be utilized as well). Open sites can be of any size (from a metre to a kilometre as in the case of a small isolated group of flakes; or middens, extensive areas of axe grinding grooves or artefact scatters, respectively). It would be wrong, in this case, to assume that open sites represent category 'A' sites and shelters the remaining categories.



Key	
△	10%
□	25%
✧	50%
○	75%
⧖	90%

Figure 6.3: The site-areas of archaeological and art sites and all sub-populations of the data within the Sydney region (sq.m.).

The problems of size as a criterion are compounded, as has often been recognized (see for example Bailey 1977), by the dimensions of shell middens. These sites are generally large, yet their is little evidence to suggest that they necessarily represent sites equivalent to Foley's category 'A', rather than the accumulation at the same location of many category 'D' sites (comparable to Meehan's (1982) 'dinner-time camps').

In short, then, although the idea that small size suggests an activity on the periphery of the home base or further afield in the home-range and large size suggests home-bases may have an underlying validity, the actual relationships between Aboriginal behaviour and site size are likely to be far more complex.

Owing to the lack of material suitable for the adequate differentiation of spatial categories, two of Foley's other suggestions concerning the patterns of discard over the landscape assume a greater value in the present context:

1. Gross artefact density should correlate with those places where benefits are high in relation to costs. (Foley (pers. comm.) has modified his (1981a) position concerning the close relationship between productivity and behaviour to one more clearly based upon optimality principles (i.e. high return/low cost).)

2. Discard patterns are likely to be clumped and discontinuous when the

habitat is irregular in resource abundance (i.e. spatially heterogeneous).

The value of Foley's regional scheme to the present study, then, lies in the suggested relationships between the amount of deposition over the landscape and the spatial heterogeneity of resources. If his assumptions can be shown to be correct, then the spatial distribution of archaeological material (in the present case archaeological sites) will possess a proportional spatial relationship with a ranking of 'patches' according to cost/benefit values.

This relationship need not necessarily be direct, indeed, the principles of optimality would suggest only that there would be a tendency towards optimal behaviour with regard to highly ranked 'patches' evident in foraging behaviour (or in the present case in the archaeological evidence for foraging behaviour), for this behaviour is only a part of the total behaviour of man; each component having its own demands upon the time and effort of the individual.

In addition, the archaeological record, at least at the level of the site in Foley's categories 'A', 'B' and 'C', is not likely to be a record of an <u>individual's</u> tendencies towards optimal behaviour, but rather the remains of many individual strategies aggregated in a single location. Indeed, individual tendencies towards optimal behaviour may be constrained by membership of a group. However, a constant throughout all the possible goal conflicts of individuals, multiplied by the number of individuals, is that food acquisition is a primary goal with regard to survival (i.e. inclusive fitness), for all individuals. Thus the tendency for a site to be located optimally with regard to areas of high benefit/cost ratio food resources, is likely to be greater than the influence of any tendency related to other goals aggregatively considered.

On theoretical grounds, then, we can assume that the archaeological sites in the Sydney region are likely to reflect in their location and density (at a given time) a tendency to be distributed in relation to areas of high benefit/cost ratios. As cost approaches benefit the density of sites should begin to approach zero.

6.4.3 Further aspects of the articulation between sites and patches

In recent years, archaeologists have tended to assume that the articulation between sites and environment usually takes the form of an association through a generalized catchment area (Higgs 1972, 1974; Dennell 1980; see also Lee 1969).

However, Wobst (1978) while accepting that humans articulate strongly with spatially-circumscribed local variability, warns against an over-reliance upon this concept. A generality of hunter-gatherer behaviour is that under the extremes of variation in the environment, they rapidly redefine their catchment areas or shift resources, thus redefining the food supply. This theoretical development within archaeology - from the generality of the concept of broad catchment areas surrounding sites to a concept of sites articulating with what are in effect high-value patches - has lead Wood to create an interesting theoretical framework for describing the ways in which sites are located optimally with regard to resources in terms of 'settlement space' (Wood 1978).

The framework concedes that people act in terms of a simplified model of their environment - a cognized model consisting of knowledge and beliefs (as opposed to the operational model of the ecologist (see Rappaport 1971)). This cognized model employed in settlement location defines settlement space:

> "Settlement space is a simplified model of the environment as reflected in the outcome of locational choices. It is the spatial representation of the fundamental niche and it is a model of the mapping of environmental variety and constraint into the settlement system" (Wood 1978:259).

Wood makes several propositions for the location of sites based upon the concept of settlement space:

Proposition 1

Limited activity sites (Foley's spatial component 'C') will be located so that the distance between a site and the resource indicated by the activity is minimal.

Proposition 2

Multiple activity sites (Foley's Spatial components 'A' and 'B') with dominant sub-sets of activities will be located so that the distance between a site and the matching resources indicated by the dominant subsets are minimal.

Proposition 3

Multiple activity sites will be located so that the average distance to all the 'critical resources' is minimal.

If Wood is correct, then, it can be assumed that in terms of cost/benefit ratios, the location of a site is likely to show a tendency towards one (or a small group) of very highly ranked resource(s). Goals other than food acquisition are also likely to influence the location but the tendency towards optimal location in relation to these areas should be identifiable.

In fact, some support for these suggestions is found in the real world - for example, Binford (1980, 1982) has been able to confirm, from ethnoarchaeological material, that campsite locations are generally chosen for their proximity to high-value resources[1].

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[1] It is worth remarking that the ethnoarchaeological evidence also suggests that activities unrelated to food-acquisition (such as maintaining equipment) often take place away from the home-base at places such as hunting-blinds (see Binford 1978a, 1983) or 'dinner-time' camps' (Meehan 1982). Such activities would alter the artefact structure of a site (Binford 1978a). They would not, however, alter the spatial relationship between that site and resource 'patches'. Indeed, by adding to the deposit at that locus it would make it more likely that such a transitory phenomenon as a hunting stand would survive to become part of the archaeological record.

6.5 DISCARD, FOOD ACQUISITION AND LOCATION IN THE SYDNEY REGION

The theoretical work discussed above suggests that provided it can be shown that Aboriginal discard behaviour within the Sydney region was associated with food acquisition, then information concerning Aboriginal site location is an appropriate source of data for the testing of the behavioural model based upon optimality principles and ecological data. In order to assess this it is necessary to understand what parts of technology-related behaviour are likely to be detectable in the archaeological record.

Fortunately, the first settlers recorded many aspects of the technological inventory. The natural components of the technology of the Sydney region Aborigines are noted in Table 6.9. There is no reason to think that this list is exhaustive, but it is clear that the majority of the recorded material is wooden (including bark), and that, at the coast, shell was sometimes substituted for stone (see for example, Tench (1789:87).

In terms of discard this would suggest as in Gould's (1980) study, that much of stone usage was concerned with the making and maintenance of wooden implements - a stage removed from food acquisition. However, within the Sydney region, this viewpoint can in part be modified in the light of our knowledge of the Aboriginal use of edge-ground axes, rather than chipped-stone axes, for wood-working.

Item	Vegetable (fibre etc.)	Shell	Bone	Wood	Stone	Comment
SUBSISTENCE						
Multi-pronged fishing spear	*	*	*			Xanthorroea stalk barbed with bone or shell
Single point fishing spear	*	*	*			(ditto)
Hunting spear						Oyster shell barbs. Inland spears barbed with stone
(coast)	*	*				
(inland)	*				*	
Spear thrower (Throwing aid digging tool cutting tool Butchering tool, shell-fish opener)	*	*		*	*	Stone or shell mounted in distal end.
Fish hook +		*				(+Bird talons)
hook file					*	Made by women.
+ line	*					Bark or palm fibre.
Throwing stick (Wamareen)				*		
Canoe &	*					Casuarina bark
paddles				*		
Hafted stone axe or adze	*			*	*	
Net bag	*					
Bark trough	*					
Palm baskets	*					
Hoop net	*			*		
Snare	*					
Digging stick				*		

Table 6.9: The natural components of the technology of the Sydney region Aborigines.
(Data: First Fleet (1788) records - Bradley (1969); Collins (1971); Phillip (1982); Tench (1979); White (1961); Worgan (1978))

Item	Vegetable (fibre etc.)	Shell	Bone	Wood	Stone	Comment
<u>MAINTENANCE</u>						
Choppers					*	
Mallet				*		
Blades		*			*	Oyster shell used to sharpen spears on occassion
<u>OTHER</u>						
Fighting spear				*		Hardwood point
Club				*		
'Sword'				*		
Parrying stick				*		
Shield	*			*		
Bark dish	*					Bark
Drinking vessel						
Fish poison	*					
Possum-skin coats						Mainly inland but seen in Broken Bay
<u>STRUCTURES AND FACILITIES</u>						
Shelters	*			*		Bough frame covered in bark
Hides	*			*		(ditto)
Drive trap(?)	*			*		
Eel trap				*		hollow log

Table 6.9 (cont.): The natural components of the technology of the Sydney region Aborigines.

Using limited data, Hayden (1979) has estimated that edge-ground hafted axes are at least as (if not more) efficient as chipped stone chopping implements in wood work. The principal advantages in the use of these edge-ground tools are: an increase in mechanical efficiency, comfort and longevity; while the principal disadvantages are that they take a long time to make and they must be carried about on camp moves (109-110). Hayden emphasizes that in the Australian context there is probably a threshold of wood-use which determines whether ground or chipped stone axes will be used. Where there is extensive use of wooden items in the material repetoire it would seem reasonable to maintain a specialist implement, especially as it confers working advantages (op. cit:14-15). The value of the edge-ground axe to Aborigines using a lot of wood, has been well described by Brough-Smyth (1878:1: 379; quoted in Dickson 1981):

> "With the stone axe he ..... cuts off sheets of bark for his miam or for his canoes and shapes wood into shields or clubs or spears .... its uses are so many and various that one cannot enumerate them".

It is clear from the accounts of the First Fleet that the edge-ground axe rather than flake technology was used in the Sydney region for the sort of wood-working activities which Gould describes as requiring the largest component of flake production. For example, White (1975:196) reports that the only tools necessary for the construction of canoes and huts were "the stone hatchet and the shell-stick" (i.e. the spearthrower with a shell instead of a stone mounted on the distal end). Worgan (1978:17-18) gives a description of the making of a canoe which illustrates the lack of flakes required in the making of complex pieces of wood technology, and the utility of the edge-ground axe:

> "After having made a circular incision through the bark, beginning 3 or 4 feet from the bottom of the tree, they, by the help of notches, climb as high up as they mean the length of the canoe shall be, where, they cut ye bark through as at the bottom. After this is done, they divide it in a straight line from the top incision to the bottom, and they contrive that this longitudinal division of ye bark shall run through the middle of the notches which they had cut to climb up by, so that they prove no detriment to the bark for the purpose that it is intended. It being cut through to the body of the tree, they thrust in sticks between it and the bark, by way of wedges to separate it from the tree. They then leave them in this manner 'till the bark will strip off without using any violence that might split it. Having got it off they pucker up the ends and tie them with a tough stringy kind of bark, and in order to stretch it open we suppose that they place sticks across, and keep them there till the bark takes the form of a canoe".

The versatile edge-ground axe was also be used as a hunting tool, to cut notches in trees in order to facilitate the hunting of small arboreal marsupials.

Clearly, then, the edge-ground axe was utilized by the Aborigines of the Sydney region in many cases where flakes would have been used in the Western Desert, particularly in the creation and maintenance of wooden implements. This would suggest that a higher proportion of flakes in the Sydney region archaeological record are likely to have been derived from activities more closely related to foraging behaviour than would be true of the archaeological record created by the activities of the Aborigines in Gould's study.

A single piece of information from the First Fleet writers suggests that the use of sharp edges was closely associated with extraction of resources; and, more particularly, that such edges were used at the place of extraction. Governor Phillip notes that skinned animals were seen at the bottom of trees which had been burnt in order to smoke them out (Phillip 1982:104). Although not much weight can be put upon such a small piece of information, it is indicative of a pattern of lithic usage which appears reasonable.

Owing to the presence of the edge-ground axe as a specialized wood-working tool, then, it is highly probable that a higher proportion of stone flakes (which constitute the major component of the archaeological record) were used in a more direct role in relation to foraging behaviour than would be expected of a record associated with a group not possessing that tool. In addition, it is also highly probable that the bulk of flake production occurred in an opportunistic manner described by Gould and Hayden utilizing nearby flakes as and when the need arose. In the light of the propositions of Foley (1981a) and Wood (1978), these probabilities suggest that the association between discard and food acquisition is likely to be strong within the Sydney region.

6.6 THE DESTRUCTION OF DATA

The above discussion has concentrated upon lithic materials because stone has a much greater tendency to survive through time than wood or other organic material. Yet stone material is equally subject to influences which affect its distribution within the landscape or site. The organizational patterns sought by archaeologists can be disturbed and new patterns created by diverse patterns of human and natural influences. The problem of what happens to artefacts after they are discarded lies in the realm of formation processes (see Schiffer 1976, 1983:676; Foley 1981b). Ethnoarchaeological studies, in particular, have shown how processes occurring after site abandonment can influence the distribution of artefacts (Robbins 1973; Lange & Rydberg 1972; Stanislawski 1969; Stevenson 1985); while vertebrate taphonomic studies have shown how the faunal record can become biased (Brain 1981; Behrensmeyer and Hill 1980; Walters 1984).

The archaeological record is always a transformed and distorted view of artefacts as they once participated in a behavioural system. Regardless of how much material there may be, the archaeologist cannot read behaviour and organization directly from the patterns discovered in the archaeological record (Schiffer 1983:677). However, the distortion caused by formation processes can, to some extent, be rectified at a regional level by a knowledge of the local processes and our knowledge of the laws governing them (op.cit:677-8).

6.6.1 Formation processes in the Sydney region

Foley (1981b) has developed a generalized model to show how geomorphological influences could influence the distribution of artefacts in idealized environments. In broad terms, depositional influences tend to obscure archaeological information, while erosional influences tend to either cause the destruction of data or may cause the juxtaposition of originally distinct, stratified archaeological material. The influences upon the deposits of the Sydney region are principally erosional (cf. Witter 1984) and can best be described with reference to the three major geomorphological divisions of the region - the sandstone plateau, the Cumberland Plain and the coast.

The sandstone plateau.

The principal geomorphological process of this area - erosion - has a direct influence upon the nature of the record concerning all Aboriginal sites (including art sites). The dominant site type is the rock shelter - the result of the weathering of naturally-occurring excavations within the sandstone which form abundant caverns and overhangs of varying sizes and aspects - though open sites (both engravings and archaeological deposits) are also known.

1. Rock shelters. Hughes (1977) has demonstrated that the rate of weathering within rock shelters is greatly accelerated by human occupation; and this and other natural processes make it unlikely that

any shelter deposit or art within the plateau area is of any great antiquity. The direction of weathering within shelters is upwards and inwards (away from the drier conditions outside), which results in the formation of floors that slope downwards and outwards. These floors shed deposit very quickly and as a consequence it is likely that any deposit remaining within the shelter is of recent origin (Hughes, 1977; Attenbrow 1981). Unfortunately, because of this process and the obscuring of in-shelter deposits by other products of weathering, the number of shelter sites is probably greatly underestimated.

2. Open archaeological deposits. The products of the weathering of the whole landscape have probably obscured many sites in valley bottoms. Those which have survived these processes are likely to be of recent origin (Hughes and Sullivan 1979).

3. Engraving. The survival of rock engravings in this erosional landscape is determined by the quality of the rock and the initial depth of the incision. This variability makes it difficult to assess the age-range of these sites.

The Cumberland Plain.

Unlike the sandstone plateau, the processes which have influenced the archaeological record upon the Cumberland Plain are as much related to changes in post-settlement land-use as to natural processes. There are no rock shelters upon the Wianamatta shale - the dominant site types are open. As a consequence, the sites which have survived the agricultural development of the plain tend to be palimpsests of material. In addition, two geomorphological processes have tended to eliminate or obscure archaeological data: the continuous deposition of aeolian sand upon the eastern plain; and the frequent and extensive deposition of alluvium upon the flood-plain of the Hawkesbury-Nepean river. Both of these processes have buried evidence of Aboriginal activity (Kohen 1980; Haglund n.d.). As a consequence of all these factors, there is no evidence of any surface material being any older than 1000 years (Kohen 1979 & pers. comm.; see also Kohen et al. 1980, 1984). The suggestion of recency for sites upon the Cumberland Plain is amplified by the frequency of artefacts made from bottle-glass and other European material found in association with lithic materials; and by the fact that the area was still used by Aboriginal people as late as the 1830's (Darwin 1968 (1845)).

The coastal and estuarine fringe.

Shell middens dominate the fringe of the region and are subject to the same processes which influence the geomorphology of the whole - deposition and erosion. The development and movement of dune systems tends to obscure Aboriginal material; while the processes of erosion may act directly upon middens through the action of storm waves (Hughes & Sullivan 1974); or other processes. As a consequence, there is no evidence that any of the midden material within the region is older than 1000 years (Sullivan 1982:14).

During the course of the growth of Sydney, many hundreds of sites within these areas have been destroyed. In 1788 Governor Phillip (after ordering the first archaeological excavation in Australia) ordered that midden material should be spread over the fields as fertiliser. Shells were also used as the only source of lime available to the colony (see Ceci (1984) concerning the destruction of middens). Other sites were undoubtedly destroyed as the urban area grew (though at least some of these were recorded in the site register).

Overall, geomorphological and related post-depositional processes, and urban and agricultural expansion are likely to have influenced the record of Aboriginal behaviour in the Sydney region in two specific ways: one is detrimental to our understanding of that behaviour; the other, beneficial. Firstly, the destruction of data in each of the three broad structural divisions of the Sydney region is likely to be detrimental to our understanding of the spatial distribution of Aboriginal behaviour. To some extent this may be offset by the regional perspective and large sample size, but it remains a largely insuperable problem (as it does throughout archaeology) - we are forced, in the absence of information to the contrary, to assume that the sample we possess is a representative one. Fortunately, the second influence of these processes is beneficial to our present cause - the processes of erosion and deposition associated with the region are likely to limit the vast majority of archaeological material (at the surface) to within the past thousand years.

6.6.2 The discovery of sites

To some extent the Sydney region is still frontier archaeological country, the nature of the terrain and vegetation within the bushlands make it difficult to find sites. Many are still found by accident by bushwalkers (though systematic surveys have been undertaken in most areas of the region by the NPWS and it is the data from these which are stressed in the analysis). This has meant that there has been a tendency for the majority of sites to be found close to European settlement. This fact is not as easy to interpret as it might appear - the whole region is well-known archaeologically and all the major concentrations of sites are likely to have been discovered.

In general, it is likely that there is a close association between those areas which have been used by Europeans since 1788 and those which were likely to have been used by the Aborigines prior to that date. This is, perhaps, intuitively obvious with regard to estuarine and coastal locations, but is also likely to be true of the hinterland. For example, it has been noted in an earlier chapter that the development of the city of Sydney followed closely the pattern of fertility of soils within the region - onto the Cumberland Plain and across to the alluvial banks of the Hawkesbury-Nepean and eschewing the Hawkesbury sandstone plateau - patterns of Aboriginal occupation are likely to have displayed the same characteristics. This pattern may even be extended to the association of Aboriginal sites with modern roads, for many of these follow the lines of

Aboriginal tracks through the region (for example across the Blue Mountains).

However, this association with modern thoroughfares can be used to test the degree of distinguishable difference in the patterns of discovery of archaeological ('Function') and art ('Style') sites. The distances of sets and sub-sets of the Aboriginal site data from major thoroughfares are illustrated in Figure 6.4. The overwhelming characteristic of the data is the proximity of all sites to thoroughfares. However, in order to test whether there is any difference between the degree of this proximity with regard to the Function and Style site populations, the Mann-Whitney 'U' statistic was applied to the data and a significance level of 0.01 was chosen because of the large sample size (4680 sites). Table 6.10 shows the results of the test, which suggest that there is little evidence to support the view that art sites are found more frequently at a greater distance from European settlement that archaeological sites.

6.7 THE ARCHAEOLOGICAL DATA IN PERSPECTIVE

A fine balance must be struck concerning the value of the archaeological data in the Sydney Region. There is little doubt that the region is one of the best-known in Australia. However, the reason why it is one of the best-known, stems from the fact that it is also one of the most densely-populated; and people inevitably destroy sites. Yet in very large areas of the region the land remains undisturbed and represents all the major structural elements of the region. It is unlikely that we know

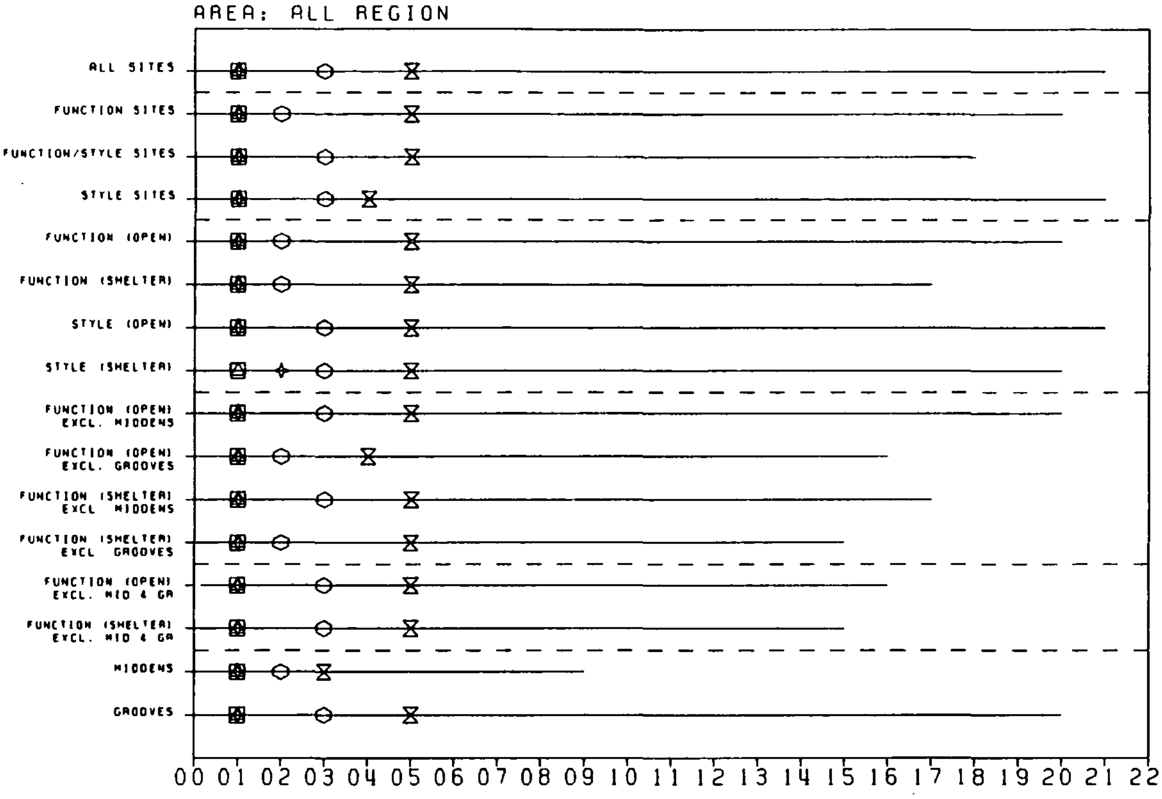

Figure 6.4: Aboriginal sites and distance to major thoroughfares (km).

Test populations	U statistic	Attained Significance	Significant at chosen level (0.01)
Archaeological versus Art	7884.0	0.0195	No
Open Arch. vs Open Art	6445.0	0.1332	No
Shelter Arch. vs Shelter Art	5068.0	0.2296	No

Table 6.10: The relationship between Aboriginal sites and the thoroughfares of the Sydney region.

of all the sites within these areas, but it is almost certain that we know of all the concentrations of sites.

The quality of the data within each site is poor (in comparison, say, with sites in a broadly similar environment in South Africa (see, for example Deacon (1976) and Parkington (1981)). In the Sydney region there is no way in which the archaeologist can establish the difference between sites (for example, between home-base and task-specific site; or winter and summer sites). The archaeological record of the Sydney region is constructed of points upon a landscape: loci of indistinguishable behaviour (with the (probably misleading) exception of shell middens).

This chapter has been concerned with establishing two major points concerning the spatial characteristic of the archaeological data: firstly, that the great majority of sites can be shown to be of recent origin at their surface and therefore can be safely assumed to have been formed during the period in which conditions very close to those of the present-day have existed; and secondly, that archaeological sites are likely, even given that many other factors may also exert an influence, to show in their locational characteristics a tendency to be associated with areas of the landscape that can provide the greatest benefit (in terms of food) for the least cost.

The work of Lampert & Hughes (1982), Attenbrow (1982) and others have established that once occupied, sites both on the coast and in the hinterland were used repeatedly up to the arrival of the Europeans, thereby establishing the recent nature of the surface of the sites and their approximate contemporaneity. In addition, the theoretical work of Foley (1981a) and Wood (1978) and the ethnoarchaeological work of Binford (1980, 1982) have established that a key determinant of the location of any archaeological site will be the location of 'critical resources'. This relationship is likely to be most clear amongst task-specific sites away from the home-base; but as Wobst (1978) has shown, because of the ease with which hunter-gatherers relocate themselves within an environment the relationship is likely to be characteristic of homebases as well. In addition, there is some evidence to suggest that the principal component of the archaeological record in the Sydney region, the stone flake, may have been more closely connected with foraging behaviour than can be said for the same artefact in contemporary Aboriginal communities.

In Chapters Three and Four, it has been established that the environment of the Sydney region has been relatively stable for at least the past thousand years and that the spatial heterogeneity of that environment can be determined. In this chapter it has been established that there is a body of archaeological evidence of Aboriginal behaviour which is likely to be closely associated in its locational characteristics with food acquisition; and which is thought to have been formed within the regime of the present environment. These are the prerequisites for testing optimal foraging theory.

7 CHAPTER SEVEN:

ABORIGINAL LOCATION AND LANDSCAPE - TESTS OF THE BEHAVIOURAL MODEL

7.1 THE ARCHAEOLOGICAL RECORD OF BEHAVIOUR AND LANDSCAPE VARIABLES

In the last chapter it was suggested that the archaeological sites of the Sydney region would display (in their locational characteristics) a tendency toward spatially discontinuous areas which would provide the maximum return for the minimum cost. That is, sites would display a tendency toward being located optimally with regard to high-value 'patches'.

In the recent archaeological context of the Sydney region, this tendency can be understood through the study of the relationship between landscape characteristics (which are likely to influence the probability of patch formation) and sites. These landscape characteristics can be divided into three major groups:

1. Terrestrial structure. The relationships between sites and the terrestrial features of landscape are likely to be one of the most clear witnesses of the operation of optimality principles in site location, because of the relationships which exist between nutrient distribution, floral structure and faunal densities.

2. Aquatic structure. Aquatic structure is associated with areas of nutrient accretion and unearned resources. The influence of its

components upon Aboriginal locational decisions must be considered as a function of the distance between the aquatic area and adjacent points in the terrestrial landscape (because the patches are defined from the viewpoint of a terrestrial forager).

3. Climatic factors. The complexity of climatic factors; their inter-relatedness with other variables (e.g. height and proximity to the coast); and the problem of scale factors make the formation of expectations difficult. Despite the low degree of seasonality within the region as a whole, topographic and coastal influences are likely to produce climatic characteristics which might influence the distribution of terrestrial resources in more subtle ways than the edaphic characteristics of the land.

7.1.1 Landscape, sites and multifactorial influence

It is highly probable that most of the individual landscape variables considered here would, through their effect upon the potential for patch formation, have influenced Aboriginal locational decisions to a greater or lesser extent. No single variable is likely to be able to explain the variation apparent in the evidence of behaviour. Yet in order to approach a position wherein this multifactorial influence can be successfully analysed, it is necessary to understand the relationships between Aboriginal behaviour and these individual influences.

As a consequence, the analysis of these data proceeds in three stages:

Stage One

The individual landscape characteristics are introduced and the tendency for the behaviour represented by Function sites to be closely related to those characteristics which can be seen as potentially influencing the distribution of high-value patches is considered. In order to achieve this, a comparison is made between the relationship of Function sites and Style sites with regard to these variables, the expectation being that, if the Aborigines located their sites in a manner consistent with optimality principles, then Function sites (which represent activity which would have affected the Darwinian fitness of the population) should display characteristics of lower variability than those displayed by Style sites.

The act of removing the grinding groove and/or midden sub-populations (in order to excise the influence of a behaviour pattern not closely associated with the food quest in the former case; and too closely associated with the coast in the latter), requires that a number of statistical tests be performed between Function and Style sites. This series of tests has a supplementary advantage, in that by testing the relationships between a reducing Function and a Style population, the consistency of a statistically significant independence can be examined - for the likelihood of significant results due only to large sample size is reduced.

Further, in order to counteract the influence of the uneven distribution of data, and to better understand the ways in which the relationship between Function sites and landscape may change over the region, six sub-regions are examined. These sub-regions have been intensively surveyed and each has different characteristics from the rest.

For the convenience of the reader the statistical tables and diagrams which are an essential part of this section are provided separately in Appendix D, so as to prevent unnecessary breaks in the text.

Stage Two

Landscape variables are likely to be interconnected in their influence upon the potential for patch formation, and hence upon the locational characteristics of Function sites. In this part of the analysis the hidden structure of landscape variables represented in site location is examined through the use of multi-dimensional scaling techniques and cluster analysis. The identification of major groups of variables and independent variables leads to:

Stage Three

a) Through the use of factor analysis an attempt is made to identify those landscape variables which most influenced Aboriginal locational decisions; and to demonstrate their association with the behavioural model. At this stage the data are divided into an inland and a coastal part.

b) Through the use of factor scores derived from a factor analysis of the total site population represented by the sub-regions, the geographical location of those sites which weight heavily upon the principal factors are identified and mapped, and their relationship to the behavioural model is considered.

7.2 LANDSCAPE CHARACTERISTICS - FUNCTION VERSUS STYLE

In this section the characteristics of Function and Style sites in relation to landscape variables are assessed. A broad division is maintained between a) terrestrial structure; b) aquatic structure; and c) climatic structure.

7.3 TERRESTRIAL STRUCTURE

7.3.1 Geology

If the Aboriginal population tended to behave optimally, Function sites should be located in closer proximity to geological parent materials of relatively high natural fertility than Style sites. Operationally, this should mean that the Aborigines tended to avoid areas of Hawkesbury sandstone and were attracted to areas of Narrabeen and Wianamatta series rocks.

The results of the analysis (Appendix D.1.1) clearly show that geological structure was, indeed, an influence upon Aboriginal locational decisions within the region as a whole and in the individual sub-regions:

1. All region. The strong attraction of rock types other than Hawkesbury sandstone displayed by the Function population is emphasized by three important characteristics: firstly, despite the fact that they are likely to be derived from the same potential population of naturally weathered excavations, Function and Style Shelters differ from each other - the former group of sites are clearly more closely associated with rock types other than the Hawkesbury series. Secondly, when middens and grooves are removed from the analysis, Open Function sites (which may, in theory, be distributed anywhere within the landscape), show the clearest degree of attraction to rock types other than the Hawkesbury series. Thirdly, Narrabeen series rocks, which produce the most nutrient-rich soils, underlie the Function population to a far greater extent than their actual distribution would suggest as appropriate.
2. Gosford-Wyong. Those characteristics which are likely to indicate an influence upon the choice of site location in the region as a whole, are also clearly evident in this sub-region. Particularly, the differences between the two shelter populations and the apparent attraction of the Narrabeen series are clear.

3. <u>Upper Mangrove Creek</u>. This sub-region has the unusual characteristic of being underlain by extensive areas of Narrabeen sandstone. This may account for its divergence from the regional pattern - there is no discernible difference between the shelter populations. However, it is evident that the behaviour represented by Function Open sites was much more influenced by the presence of Narrabeen sandstone than that represented by any other site population.
4. <u>The Cumberland Plain</u>. In this sub-region, Hawkesbury sandstone is a relatively minor geological unit. Yet the evidence suggests that rock types influenced the choice of site locations in this sub-region as in the region as a whole. For the Function population (including shelter sites) are more closely associated with the Wianamatta shale areas than are the Style sites.
5. <u>The Blue Mountains</u>. In the absence of sufficient data for many valid statistical tests, it can only be said that appearances suggest that the data support the general pattern established for the region. The relationship between Aboriginal site location and fertility is, perhaps, emphasized by the association of Function Open sites with the tiny outcrops of basalt (though this may also be interpreted as an association with quarrying activities).
6. <u>Cataract Dam</u>. The majority of sites are distributed upon Hawkesbury sandstone - to such an extent that only one valid statistical assessment can be made. This suggests that rock type was not significant in influencing Aboriginal locational decisions within this sub-region.
7. <u>Royal National Park</u>. There is little evidence to suggest that

geological parent material was a major factor in the location of sites in this sub-region. However, while the shelter populations do not differ, Function Open sites have a clear association with rock-types other than Hawkesbury sandstone.

The results of the analysis concerning the relationship between Aboriginal sites and geological parent material suggest that the Sydney Aborigines, in general, utilized areas of the greatest natural fertility and avoided areas of low fertility - a pattern which is consistent with expectations based upon the probable location of high-value patches. The consistent differences between Function and Style populations with regard to this landscape characteristic lend clear support to this view. For those sites which represent behaviour which most probably affected the Darwinian fitness of the population display this tendency to the greatest extent.

Function sites display this characteristic most evidently where rock types other than Hawkesbury sandstone are a relatively minor component, and less so where other more fertile rock types are a major part of the landscape (as in the Upper Mangrove Creek and Blue Mountains sub-regions). The Cataract Dam sub-region represents something of an anomaly within this pattern for the tendency towards rocks of series other than the Hawkesbury is not particularly evident. A possible explanation for this apparent divergence may be found in the characteristics of the vegetation structure supported by the Narrabeen series within this sub-region - small areas of Closed Forest - which may influence the archaeological record by obscuring data (see Bowdler 1983) and/or may be better exploited from its periphery (because of its density).

7.3.2 Topography

The influence of topography upon patch distribution lies particularly in relation to slope and its influence upon nutrient distribution, and in the probable importance of landforms related to aquatic resource distribution (at least in part, the same influence). This means that Aboriginal behaviour should be linked with landforms of low relief and water-association. In terms of the present data, the part of Aboriginal behaviour represented by Function sites should be distributed in closer association with these landform characteristics than that part represented by Style sites.

In general, the results of the analysis (Appendix D.1.2) indicate that these landform characteristics did influence Aboriginal locational decisions:

1. All region. That the association between Aboriginal behaviour and landform characteristics is consistent with the general model of patch distribution is emphasized here by the tendency of both Function populations to be distributed upon lower landforms than Style populations. A particularly important result is that, despite the fact that they are derived from the same potential population, Function and Style Shelter sites differ. The former population is

clearly located upon lower landscape features and more closely associated with water-related landforms.

2. Gosford-Wyong. The analysis of data from this sub-region supports the conclusions derived from the region as a whole. Both Function populations differ from Style sites in being associated with low landforms; and with landforms specifically associated with estuaries, bays and creeks.
3. Upper Mangrove Creek. There is little variation in landform types within the catchment area of Mangrove Creek. Nonetheless both Function Open and Shelter sites can be seen to be more closely associated with low, water-related landforms, along the creek valley.
4. Cumberland Plain. Unsurprisingly, there is little variation in landform characteristics related to height upon the Plain. However, both Function sub-populations display a closer association with water-related landforms (particularly the Hawkesbury-Nepean river) than do Style sites.
5. Blue Mountains. There is little variation in the landform types associated with sites in the Blue Mountains - certainly too little to form the basis of accurate statistical assessment. In fact, there is no apparent evidence to suggest that topography influenced Aboriginal locational decisions.
6. Cataract Dam. In this sub-region, also, there is little variation in landform types and no evidence to suggest that landform characteristics played a part in decisions concerning location.
7. Royal National Park. All sites in the Royal National Park tend to be associated with marine and estuarine landforms. However, Function

Open sites tend to be more closely associated with these landforms than the other site populations.

The consistent differences between the Function and Style populations suggest that the Sydney region Aborigines tended to locate their non-art activities upon low-lying landforms. More particularly, this behaviour was associated with water-related characteristics - freshwater in the case of inland sub-regions, salt and brackish among the coastal sub-regions (though these tendencies are less clear in those sub-regions within which landform variation is low). This general pattern is best illustrated by the influence of landforms related to position in creek valleys (Upper Mangrove Creek), estuarine headlands and bays (Gosford-Wyong and Royal National Park) or to the more substantial freshwater characteristics (Cumberland Plain). In all these cases, the results indicate a close association with landscape characteristics which would have increased the probability of patch formation.

7.3.3 Height above sea-level

Height is likely to have influenced the probability of floral and faunal patch formation through altitudinal differences (e.g. in temperature) but also through the tendency of nutrients to be transported to the low points in the landscape, leaving the highest areas in states of nutrient poverty. If optimality principles operated, therefore, Sydney region Aborigines should have located their activities at low height and avoided high areas; and this tendency should be more evident in the

Function than in the Style population.

The results of the analysis (Appendix D.1.3), tend to support these expectations:

1. All region. All Aboriginal sites tend towards the lower end of the range in heights. Yet it is evident that both Function populations are consistently lower than Style sites. This tendency is most remarkable in the Function and Style Shelter sites, because both populations are likely to be drawn from the same potential population of naturally weathered excavations. Overall, the evidence suggests that low height influenced Aboriginal locational decisions as they are made manifest in the Function population.
2. Gosford-Wyong. In general the results of the analysis support those for the region as a whole. All Aboriginal sites tend to be located in low areas. However, it is evident that middens are to a large degree responsible for the differences in height between Function and Style sites, and that when these are removed from the analysis this relationship is weakened.
3. Upper Mangrove Creek. The results within the Upper Mangrove Creek sub-region are wholly consistent with those derived from the region as a whole. Both Function Open and Shelter sites tend to be located at lower altitudes than their Style counterparts.
4. Cumberland Plain. There is only a small degree of variation in height upon the Plain, and as a consequence, it is not surprising that there appears to be no evidence to support the suggest that height

influenced Aboriginal locational decisions.

5. Blue Mountains. Despite the absence of sufficient data to form valid statistical tests, there appears to be a tendency for Function sites to be located at lower heights than Style sites.
6. Cataract Dam. There is no evidence to suggest that height was a factor in the location of sites in the Cataract Dam sub-region. All sites display a tendency to be located upon the top of the Woronora Plateau.
7. Royal National Park. The results of analysis suggest that height influenced the location of Aboriginal behaviour in this sub-region much in the manner which appears to be true for the region as a whole. Both Function populations tend to be associated with lower heights than Style sites.

Overall, the results of the analysis suggests that the Sydney region Aborigines tended to utilize areas of lower height and avoided higher areas. The consistent tendency of Function sites (which represent behaviour which would have affected the Darwinian fitness of the population) to diverge from Style sites, supports the view that this differential utilization is of adaptive significance and related to the increased probability of patch formation. The difference is, unsurprisingly, least apparent where variation in actual height is small (as in the Cumberland Plain and the Cataract Dam sub-regions).

7.3.4 Terrestrial structure - an assessment

The examination of the relationships between Aboriginal behaviour (as represented by site locations) and the three terrestrial structure variables - geology, topography and height - reveals a clear and consistent pattern. It is evident that Function sites, are closely associated with those characteristics of these variables which would indicate a tendency toward optimal behaviour with regard to the probable location of high-value patches (i.e. toward rock types other than Hawkesbury sandstone, low-lying and water-related landforms and low height).

This tendency is most evident in Function Open sites - which could theoretically be placed anywhere in the landscape - but is most significant among the Function Shelter sites, which are potentially derived from the same population as Style Shelter sites (i.e. naturally weathered overhangs). Despite this, Function Shelter sites possess (although not with the same intensity) all the associations of Function Open sites.

Divergence from these patterns is particularly associated with those sub-regions which are relatively uniform with regard to a particular variable (e.g. topography and height in the Cumberland Plain sub-region); or where the expected important element of the environment approaches co-dominance with another element, rather than being spatially constricted and consequently more likely to be associated with a distinct tendency (e.g. geology in the Upper Mangrove Creek and Blue Mountains sub-regions).

7.4 AQUATIC STRUCTURE

The relationship between Aboriginal behaviour and aquatic structure has to be considered as a function of the distances of constituent parts to points in the terrestrial landscape, because the patches are defined from the viewpoint of a terrestrial forager.

7.4.1 Estuarine distance

Estuarine distance measures the proximity of a forager to abundant high-value patches of both earned and unearned resources. The behaviour of the Sydney Region Aborigines, if they tended to behave optimally, should display a tendency towards minimizing this distance; and this tendency should be most clearly evident among Function sites.

The pattern which emerges from the analysis of the regional and sub-regional data possesses a number of important characteristics (Appendix D.2.1):

1. All region. The distance to estuarine resources was not a clear influence upon the location of Aboriginal behaviour, though the majority of sites tend to be distributed near estuaries. There is an apparent difference between Function Shelter and Function Open sites in regard to this variable - for while the former population display a

tendency to be more closely associated with estuaries than Style Shelter sites; the latter group are (equally clearly) less closely associated with these areas than Style Open sites. An explanation of this characteristic may lie in the general eastward emphasis of the Style Open sites in comparison to the more widely distributed Function Open sites, and particularly, the association of this latter group with inland areas such as the Cumberland Plain (where there are few Style sites).

2. Gosford-Wyong. Analysis of the site data from this estuarine/coastal sub-region indicates the bias inherent in the regional distribution concerning Aboriginal locational characteristics. There is a clear tendency for both Function Open and Shelter sites to be located in closer proximity to the Broken Bay estuary than Style sites - approximately 75% of Function Shelter sites and 50% of Function Open sites lie within one kilometre of the estuary.
3. Upper Mangrove Creek. In the Upper Mangrove Creek sub-region the distance to the Broken Bay estuary had little influence upon Aboriginal locational decisions. In fact, Style sites are consistently closer to the Broken Bay estuary than Function sites, emphasizing the lack of influence of this landscape characteristic upon adaptive behaviour (as represented by this latter population).
4. Cumberland Plain. There is little evidence to suggest that distance to estuarine resources influenced Aboriginal locational decisions in this sub-region - the sites as a whole do not display any discernible tendency toward proximity to estuaries. It is clear, however, that Function Shelter sites tend to be closer to estuaries than Style

Shelter sites, both these populations being distributed principally upon the eastern borders of the plain. However, there is no corresponding tendency in Function Open sites, which represents the greater part of the Function population.

5. Blue Mountains. There is no evidence to suggest that distance to estuaries influenced Aboriginal locational decisions behaviour within the Blue Mountains, neither Function nor Style sites display any tendency towards these landscape features.
6. Cataract Dam. Estuary distance possessed only a slight influence upon locational decisions within this sub-region. There is an apparent tendency for Function Shelter sites to be located in closer proximity to estuaries than Style Shelters, but this characteristic is not evident in the relationship between Function and Style Open sites.
7. Royal National Park. It is clear that all sites in the Royal National Park are closely associated with the estuaries. Yet, Function Shelter sites, in particular, can be seen to be in much closer proximity to this landscape characteristic than the other site populations.

Estuarine patches are a feature of the most easterly part of the region, and this factor is emphasized by the locational characteristics of the evidence for Aboriginal behaviour. When the region as a whole is considered, any relationship between behaviour and estuarine resources may be obscured by distance factors (this appears to be particularly true of Function Open sites). That this is the case, is suggested by the results derived from the sub-regions, for here the evidence suggests that a broad division can be made between the three coastal sub-regions - which display a clear tendency towards estuarine areas (though this is only partial in the case of the Cataract Dam sub-region) - and the three inland areas (wherein there is either a tendency towards the reversal of the expected relationship or no evidence of a tendency in either direction). This inland/coastal difference is particularly emphasized by the data from the Upper Mangrove Creek sub-region which has its southern boundary less than 10km from the Broken Bay estuary, yet displays a clear tendency toward the reversal of the expected relationship.

The inference to be drawn is clear: while estuarine patches are likely to have influenced Aboriginal locational decisions in the coastal sub-regions, the influence diminished rapidly as distance increased (i.e. estuarine patches do not appear to possess an attraction over long distances - inland locational decisions appears to have been independent of their influence).

7.4.2 Coastal distance

Coastal distance is a measure of the relationship between Aboriginal behaviour and high-value (but seasonal) patches. In addition, it may have a more general influence upon the probability of floral and faunal patch formation (in ways unrelated to the distribution of nutrients); particularly with regard to climatic variation (e.g. temperature and rainfall). If optimality principles are appropriate, The Sydney region Aborigines should have behaved in such a way as to minimize distances from the coast; and this should be most evident in the Function population (Appendix D.2.2).

1. All region. All evidence for Aboriginal behaviour tends to be distributed in close proximity to the coast. Yet, as was the case with regard to estuary distances, there is a clear dichotomy in the relationships between Function Shelter and Open sites and potential coastal patches. Function Shelters are consistently closer to these areas than Style Shelters; while Style Open are closer than Function Open sites. Again, a probable explanation lies in distance factors and the more widespread distribution of Function Open sites upon such inland features as the Cumberland Plain, whereupon Style Open sites are absent.
2. Gosford-Wyong. In this estuarine/coastal sub-region there is clear evidence that coastal distance was a factor in the location of sites. Both Function Shelter and Open sites tend to be found in closer proximity to the coast than their Style counterparts.
3. Upper Mangrove Creek. As was the case with regard to estuary distance, Style sites tend to be consistently closer to the coast than Function sites. This suggests that distance to the coast was not an influence upon Aboriginal locational decisions with regard to that part of behaviour which would have most clearly influenced the Darwinian fitness of the population.
4. Cumberland Plain. The results of the analysis of site location accord with those described in relation to estuarine distance. There is little evidence to suggest that coastal distance influenced

locational decisions. Though Function Shelter sites, which are principally associated with the eastern fringe of the Plain, do display a tendency towards minimizing coastal distance which is not displayed by the Style Shelter sites. As before this tendency is not shared by Function Open sites which constitute the major part of the Function population.

5. Blue Mountains. There is no evidence to suggest that coastal distance was an influence upon Aboriginal locational decisions in the Blue Mountains, for there is no apparent evidence of a difference between Function and Style sites.
6. Cataract Dam. In this coastal sub-region, the results of analysis clearly show that Aboriginal locational decisions were influenced by coastal proximity. Function sites are located in much closer association with the coast than their Style counterparts.
7. Royal National Park. All sites are to be found in close proximity to the coast, yet, there is no evident tendency for Function sites to be located in closer association.

In a broadly analogous pattern to that observable with regard to estuary distances, there is a clear division between coastal and inland behaviour (as represented by the sub-regions). Inland there is little evidence to suggest coastal distance influenced Aboriginal behaviour, while among the coastal sub-regions this distance is clearly a factor in the distribution of behaviour which is likely to have influenced the Darwinian fitness of the population. An exception within this latter group is the coastal/estuarine sub-region of the Royal National Park, wherein there is little evidence to suggest that coastal distance was a factor in Aboriginal location. This is in marked contrast to the relationship that obtains between sites and estuary distance, and is, perhaps, indicative of the relative ranking of the two landscape characteristics within this sub-region.

7.4.3 Wetland distance

Wetland distance is likely to have had the greatest influence upon Aboriginal locational decisions of the three major elements of aquatic structure, because of their intermediate status as part of the aquatic structure within the terrestrial sphere; and because of their characteristic as the most highly nutrient-rich and spatially circumscribed features in the landscape. If optimality principles are applicable, the Sydney region Aborigines should have located their behaviour in close proximity to these landscape features, and in addition, Function sites should be more closely associated with them than Style sites (Appendix D.2.3).

1. <u>All region</u>. There is a clear tendency for all Aboriginal site types to be located in very close proximity to wetlands. It is particularly significant that Function Shelter sites are consistently different from Style Shelter sites in this regard, despite the fact that both groups are derived from the same potential population. Function Open sites, however, do not display this same characteristic with regard to Style Open sites. This lack of differentiation may in part be due to

scale factors, for in both sub-populations 50% of sites occur within two kilometres of wetlands.

2. Gosford-Wyong. All site types tend to be located in close proximity to wetlands - 50% of all the data occurs within three kilometres of these potential sources of high-value patches. However, there is no evident difference between Function and Style with regard to this proximity.
3. Upper Mangrove Creek. Proximity to wetlands was not an influence upon Aboriginal locational decisions within this sub-region. While Shelter sites do not differ with regard to this landscape characteristic, Style Open are clearly closer to wetlands than Function Open sites.
4. Cumberland Plain. Upon the Cumberland Plain, the evidence suggests that all sites tend toward proximity to wetlands. Function Open sites are consistently closer to these landform characteristics than the other site populations, a fact which is consistent with the peripheral status of the other three site sub-populations and the concentration of Function Open sites in close association with the Hawkesbury-Nepean river.
5. Blue Mountains. The results of locational analysis in the Blue Mountains suggests that all sites tend toward proximity to wetlands (90% of all data lies within 6km of wetlands). There is however no evidence to suggest that Function sites possess a tendency toward greater proximity to these areas than is displayed by Style sites.
6. Cataract Dam. In this sub-region, all evidence of Aboriginal behaviour lies within very close proximity to wetlands (90% of all

sites lie within 3km of these areas). In addition, it is clear that Function sites are consistently closer to wetlands than are Style sites. This suggests that proximity to wetlands influenced locational decisions with regard to that part of Aboriginal behaviour which is likely to have influenced Darwinian fitness.

7. <u>Royal National Park</u>. The results of the analysis suggest that all Aboriginal activity was closely related to wetlands. However, there is no evident difference between Function and Style sites with regard to this landscape characteristic.

Overall, the results of the analysis indicate that all Aboriginal activities were located in close proximity to wetlands (except in the Upper Mangrove Creek sub-region). However, the distribution of Function sites in inland areas (except, again, in the Upper Mangrove Creek sub-region), appears to indicate that distance to wetlands influenced Aboriginal locational decisions with regard to subsistence activities. However, this factor is most clearly evident in the coastal Cataract Dam sub-region, wherein all Aboriginal sites lie in close proximity to wetlands, and yet Function sites are consistently closer to these areas of abundant high-value patches (90% of Function sites are within two kilometres of these areas).

7.4.4 Freshwater distance

Distance to freshwater is largely unrelated to other features of aquatic structure in the region - it is a ubiquitous commodity. Nonetheless, there is likely to be a general tendency for the distribution of floral and faunal patches to be influenced by the presence of water, particularly with regard to the direct and indirect affects of reduced xeromorphy upon a gatherer and hunter. However, the relationship between a forager and water is likely to be more direct than simply the relationship to patch formation, in that water is an independent resource of importance (although not one which is readily ascribable to patch definition based upon energy availability). On the basis of these characteristics, the Sydney region Aborigines, if optimality principles are applicable, should have located their behaviour in such a way as to minimize the distance to freshwater, and this should be most evident among Function sites.

A summary of the results of analysis (Appendix D.2.4) suggests that freshwater distance was, in general, an influence upon Aboriginal locational decisions:

1. <u>All region</u>. All Aboriginal activities occurred in close proximity to freshwater. There is no difference between Function and Style Shelters with regard to this landscape characteristic, presumably reflecting the influence of the broad geological and topographic similarities of these two site sub-populations. However, Function

Open sites (which could be distributed anywhere in the landscape) display a clear and consistent pattern in being closer to freshwater than any other site group.

2. <u>Gosford-Wyong</u>. The locational characteristics of Aboriginal activities in the Gosford-Wyong sub-region conform to the pattern evident for the region as a whole. Function Shelter sites are indistinguishable from Style shelter sites in this regard, while Function Open sites are most closely associated with freshwater.
3. <u>Upper Mangrove Creek</u>. In this inland sub-region the results of the analysis clearly attest to the significance of freshwater proximity in Aboriginal locational decisions. Both Function Shelter and Open sites are closer to freshwater than are their Style counterparts.
4. <u>Cumberland Plain</u>. All sites upon the Cumberland Plain are very closely associated with freshwater. However there is no observable difference between Function and Style sites in this regard. A possible explanation for this lack of differentiation lies in the ubiquitous nature and regular spacing of water upon the Plain.
5. <u>Blue Mountains</u>. Despite the absence of sufficient data to form a consistent series of statistical tests, it is evident that Function sites do tend to be more closely associated with freshwater than are Style sites.
6. <u>Cataract Dam</u>. In this sub-region it is clear that all evidence of Aboriginal activities tends toward close proximity to freshwater. However, there is evidence that proximity to water was an influence upon Aboriginal locational decisions, in that Function Shelter sites tend to be closer to freshwater than Style shelters. That Function

Open sites do not share this same tendency with regard to Style Open sites may be explained, in part, by scale factors; for both populations lie very close to freshwater.

7. <u>Royal National Park</u>. The results of the analysis suggest that freshwater proximity was not an influence upon Aboriginal locational decisions in this sub-region - no sites display a particularly strong association with this landscape characteristic. In addition, there is no evident difference between Function and Style sites in this regard. A partial explanation of this general lack of association, may lie in the fact that there are relatively few natural water sources in this Hawkesbury sandstone-dominated sub-region - the Aborigines are known to have used so-called 'Aboriginal rock-wells' (rock-cut rainwater troughs) in this area.

As freshwater is (more or less) a ubiquitous commodity within the region, the close association between Aboriginal behaviour and this landscape feature is not surprising. That same ubiquity may also account for the general lack of significant difference between the Function and Style populations (except in the Upper Mangrove Creek sub-region). Overall, there is little to suggest that freshwater proximity was a major influence upon Aboriginal locational decisions which would have influenced the Darwinian fitness of the population.

7.4.5 Aquatic structure - an assessment

Aquatic areas tend to produce patches associated with nutrient concentrations and the presence of unearned resources. In broad terms, the three principal aquatic landscape variables, may be ranked according to the cost/benefit value of probable patches - 1) wetland, 2) estuary and 3) coast. In reality the temporal element of patch distribution makes this ranking less absolute than it may appear - for in winter, coastal patches are likely to equal, if not surpass, estuarine patches in the ranking. However, the Aborigines might be expected to have located their behaviour in rough accordance with the broad ranking.

Owing to the consistent unit of measurement used in the consideration of the relationship between Aboriginal behaviour and the principal elements of aquatic structure, it is possible to form some idea of the relative ranking of these elements in the region as a whole and in each sub-region. Figure 7.1 illustrates the relative proximity of various sub-sections of the Function population in relation to wetland, estuarine and marine distances (cut off at 90% of the data - in order to remove extreme values - and at the median) for (1) the region as a whole and (2 - 7) for each of the sub-regions.

At the 90% level (Figure 7.1a), Aboriginal behaviour (or rather that part of it which is likely to have influenced the Darwinian fitness of the population) over the whole region, can be seen to be closely associated with wetland areas. At least in part, this is indicative of the wider

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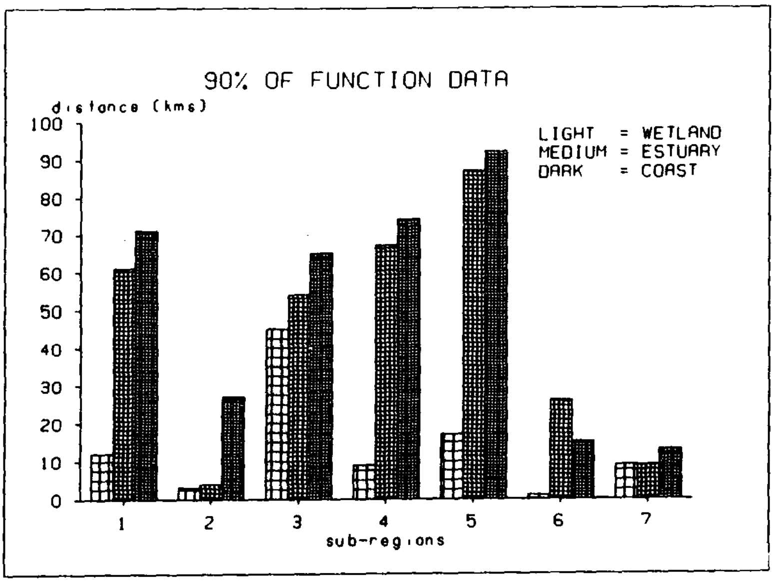

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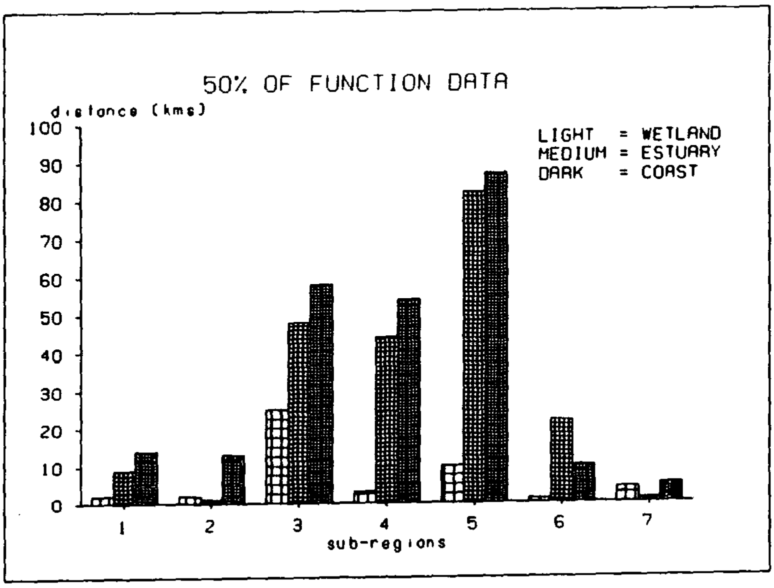


gure 7.1: The relationship between Aboriginal Function sites and the three principal components of the aquatic structure (wetlands, estuaries and the coast) of the Sydney region at the a) 90% and b) 50% levels in (1) the the region as a whole, and in (2) the Gosford-Wyong; (3) Upper Mangrove Creek; (4) Cumberland Plain; (5) Blue Mountains; (6) Cataract Dam and (7) Royal National Park sub-regions.

geographical spread of these landscape elements in comparison with estuaries and the coast, but it does not wholly explain the distribution. The 50% level (Figure 7.1b) also reveals the general coastal bias in all the data but still emphasizes proximity to wetlands.

This pattern is maintained, in general, by all the sub-regions. However, some interesting points arise from the relationships within these areas:

1. The relative importance of proximity to wetland areas, rather than the coast, in the Cataract Dam sub-region is consistent with the proposed differences in the ranking of these aquatic landscape features.
2. In the Gosford-Wyong sub-region, there is clearly an approximate balance between the distance to the estuary and the distance to wetlands, but no evidence of a particularly strong association with areas of marine resources.
3. In the Royal National Park the influences of the three landscape components appear to form little pattern which suggests ranking. However, 90% of all Function data lie within approximately 10km of all three elements.
4. Within the inland sub-regions there is little evidence of a force exerted upon Aboriginal locational decisions by estuarine or coastal proximity (this characteristic is exemplified by the Cumberland Plain and Upper Mangrove Creek sub-regions which possess boundaries in close proximity to estuarine areas). In comparison, the influence of wetlands is particularly evident in the Cumberland Plain - but is also clear in the Blue Mountains. However, the Upper Mangrove Creek area

differs from the other sub-regions in not displaying the same degree of close association with wetland areas, which may indicate that aquatic landscape characteristics (apart from freshwater) were not influential at all within this sub-region. It is tempting to speculate that the high representation of Narrabeen series rocks in the principal valley and tributaries (with its corollary of comparatively richer vegetative and faunal patches) may be sufficient explanation of the usage of the area in itself.

The single unit of measure used to assess the association between Aboriginal behaviour and aquatic structure also allows us to gain some impression of the degree of behavioural deflexion inherent in the use of rock shelters. It has been suggested above that Function Open sites may (in theory) be located anywhere in the landscape, but Function Shelter sites, by definition, only occur where natural processes have eroded the rock. However, owing to the great number of such natural excavations within the Sydney region, this did not necessarily curtail Aboriginal choice; nor does it necessarily suggest a great degree of deflexion in the level of proximity to probable patch distribution. Function Shelter sites may occur in any of the shelters within the region, which are large enough to allow a human activity (Vinnicombe's (1980) 'Potential Habitation Shelters') and may still display a close association with landscape elements.

In Figures 7.2 and 7.3 the 90% and 50% levels for the two sub-groups are displayed (excluding grinding grooves, which are unlikely to have had

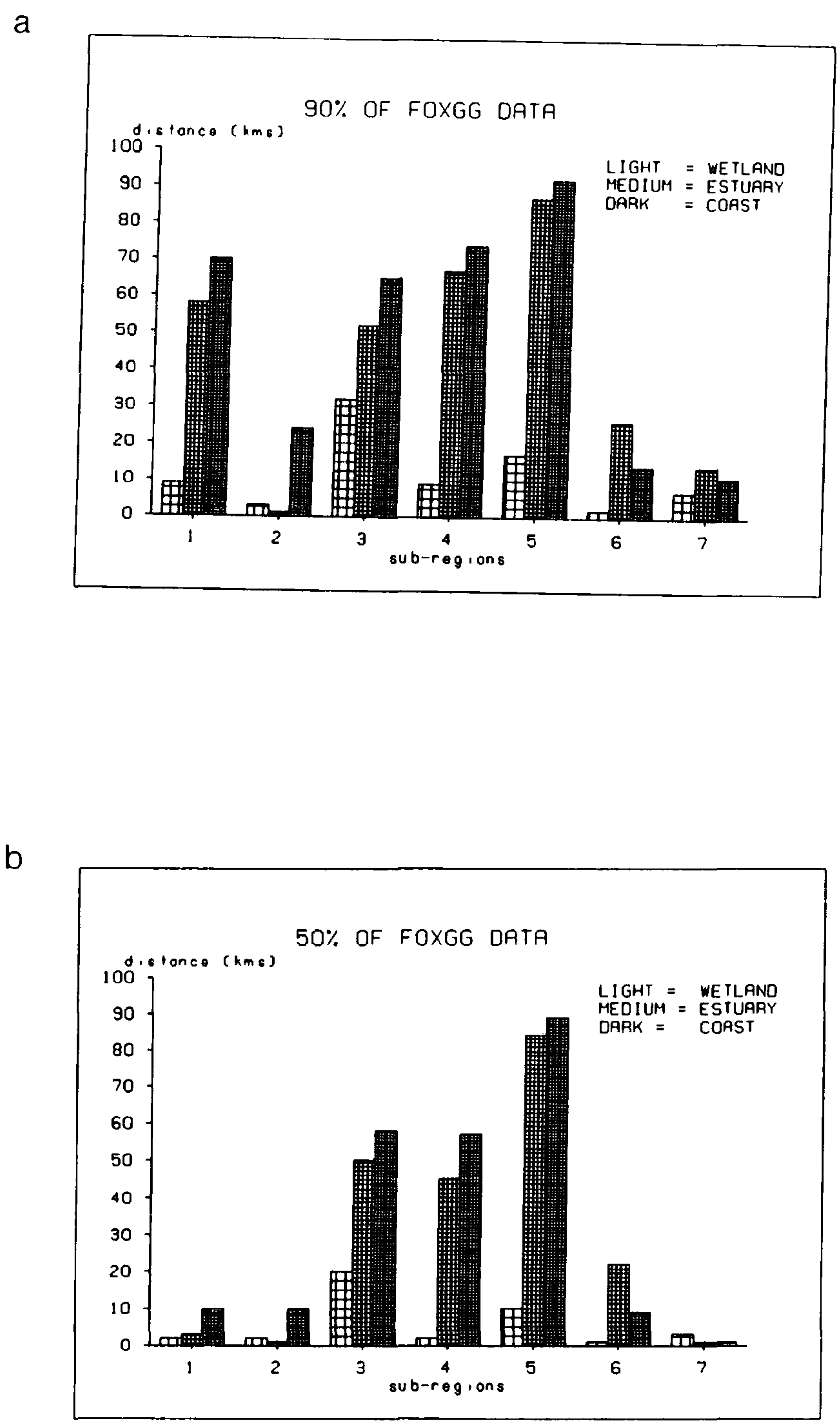
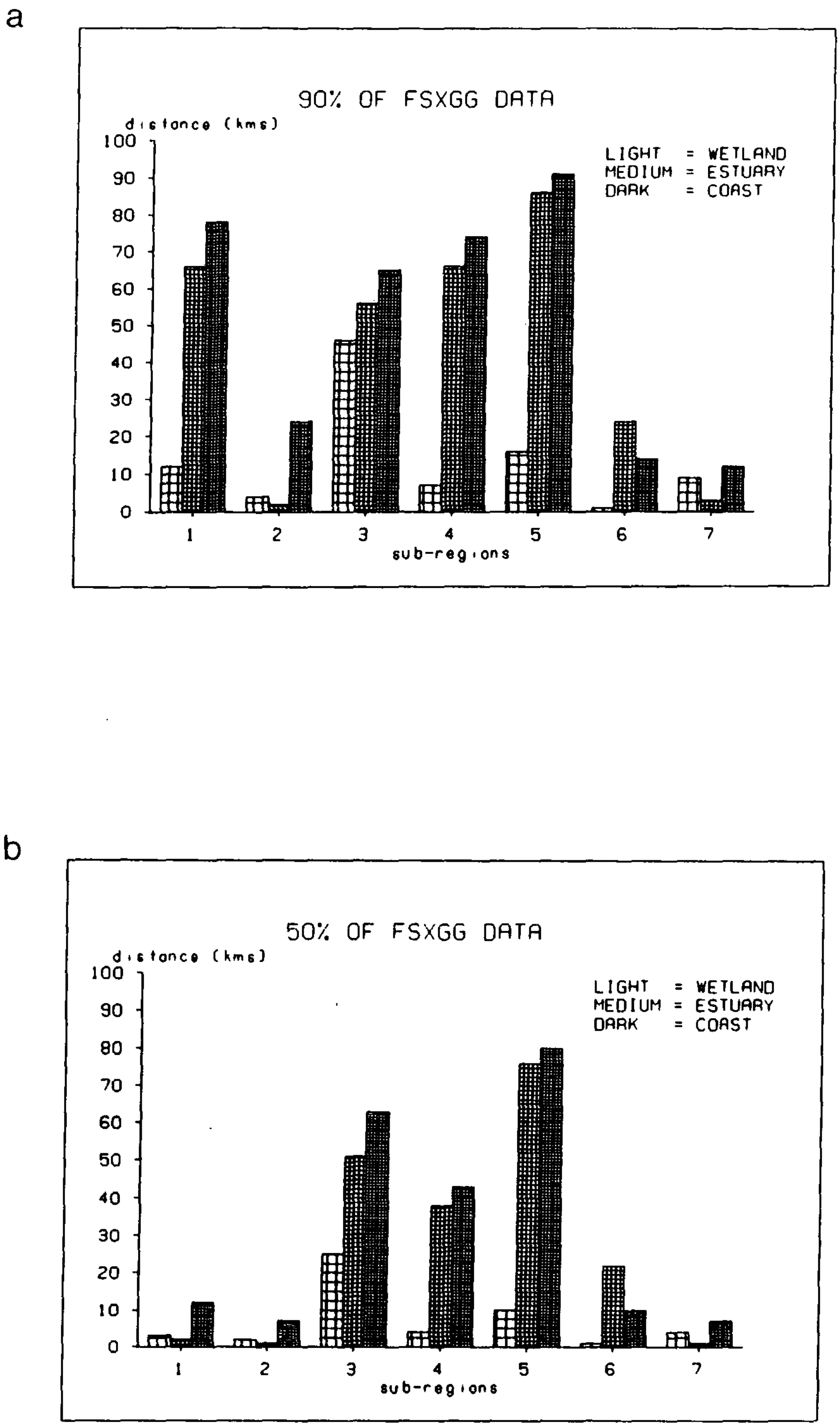


Figure 7.2: The relationship between Aboriginal Function Open sites (excluding grinding grooves) and the three principal components of the aquatic structure (wetlands, estuaries and the coast) of the Sydney region at the a) 90% and b) 50% levels in (1) the region as a whole, and in (2) the Gosford-Wyong; (3) Upper Mangrove Creek; (4) Cumberland Plain; (5) Blue Mountains; (6) Cataract Dam; and (7) Royal National Park sub-regions.



gure 7.3: The relationship between Aboriginal Function Shelter sites (excluding grinding grooves) and the principal components of the aquatic structure (wetlands, estuaries and the coast) of the Sydney region at the a) 90% and b) 50% levels in (1) the region as a whole, and in (2) the Gosford-Wyong; (3) Upper Mangrove Creek; (4) Cumberland Plain; (5) Blue Mountains; (6) Cataract Dam; and (7) Royal National Park sub-regions.

a close association with food acquisition). An inspection of the graphs confirms that the pattern outlined above for the whole region, is broadly substantiated. Yet Function Shelter and Open sites diverge in some characteristics.

The principal evidence for a degree of behavioural deflexion in inland areas lies in the relationship with wetlands. That 90% of all Function Open data lies within 9km of wetland areas (50% within 2km): and 90% of Function Shelter data lies within 11km (50% within 3km) of these sources of probable high-value patches, is indicative of the subtlety in the degree of behavioural deflexion which separates these two sub-populations.

In the coastal sub-regions there is little evidence of a great degree of differentiation between the two Function sub-populations which might be seen as suggestive of behavioural deflexion - with the exception of the closer association of Function Shelter sites and estuarine resources in the Royal National Park. That shell middens are the principal site component contributing to the evident high degree of coastal and estuarine proximity among all Function sites is indicated when these sites are removed. However the degree of evident deflexion (and the relationships between these site groups and the elements of aquatic structure) can be seen to be of approximately the same order even without these sites (Figures 7.4 & 7.5).

Middens themselves display some interesting associations with the principal elements of aquatic structure (Figure 7.6) which tend to support

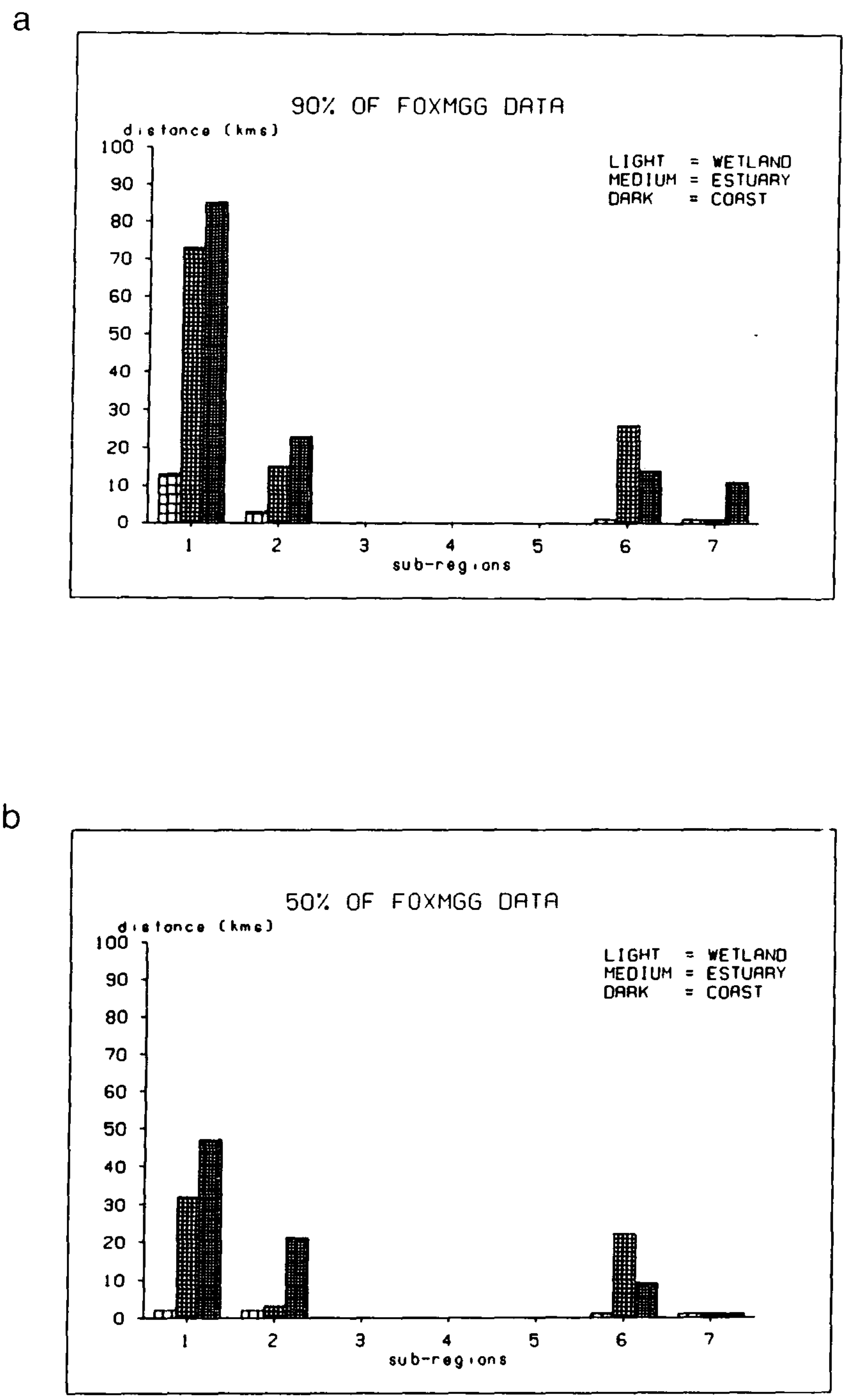
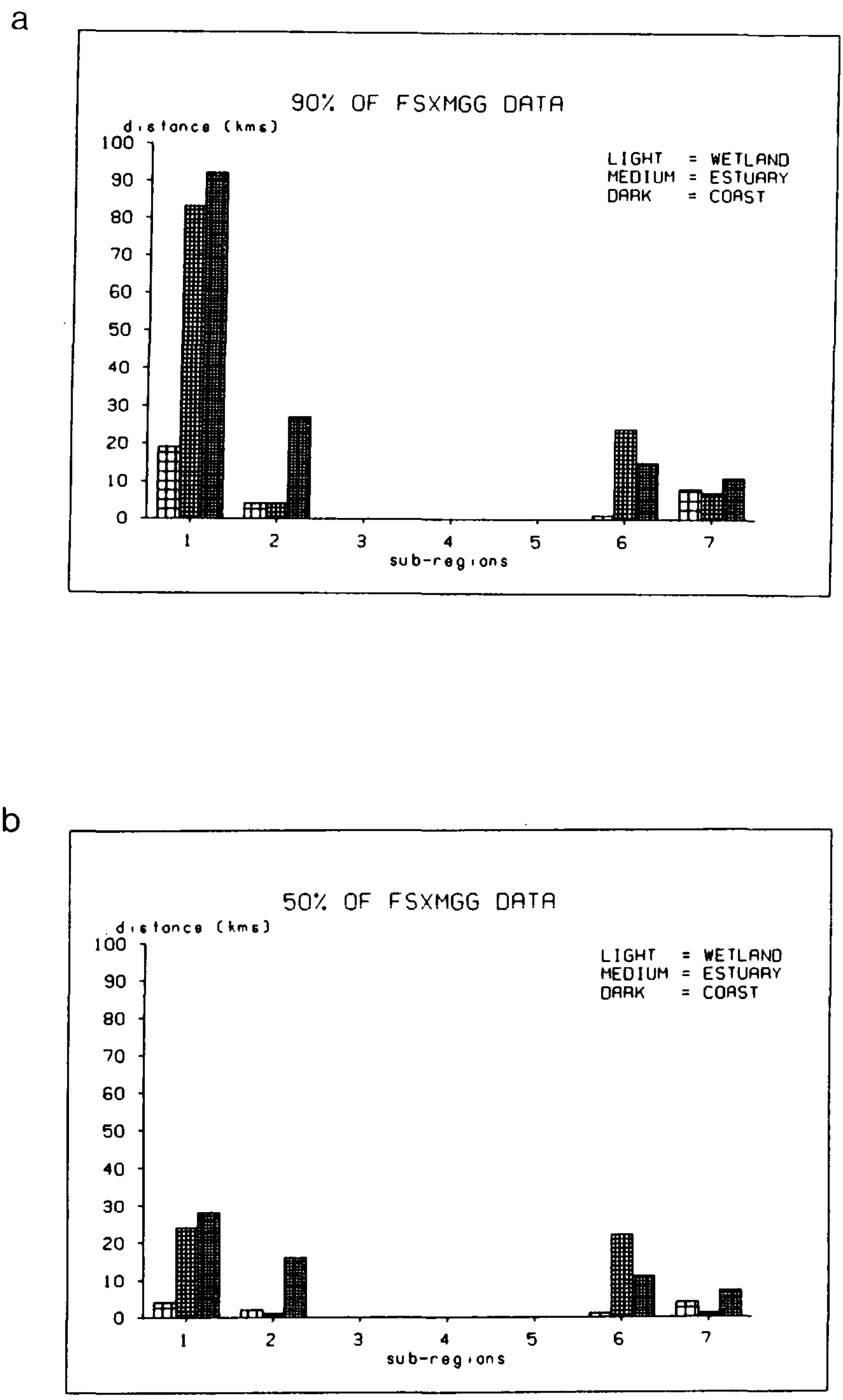


Figure 7.4: The relationship between Aboriginal Function Open sites (excluding grinding grooves and middens) and the principal components of the aquatic structure (wetlands, estuaries and the coast) of the Sydney region at the a) 90% and b) 50% levels in (1) the region as a whole, and (2) the Gosford-Wyong; (6) Cataract Dam; and (7) Royal National Park sub-regions.



igure 7.5: The relationship between Aboriginal Function Shelter sites (excluding grinding grooves and middens) and the principal components of the aquatic structure (wetlands, estuaries and the coast) of the Sydney region at the a) 90% and b) 50% levels in (1) the region as a whole, and (2) the Gosford-Wyong; (6) Cataract Dam; and (7) Royal National Park sub-regions.

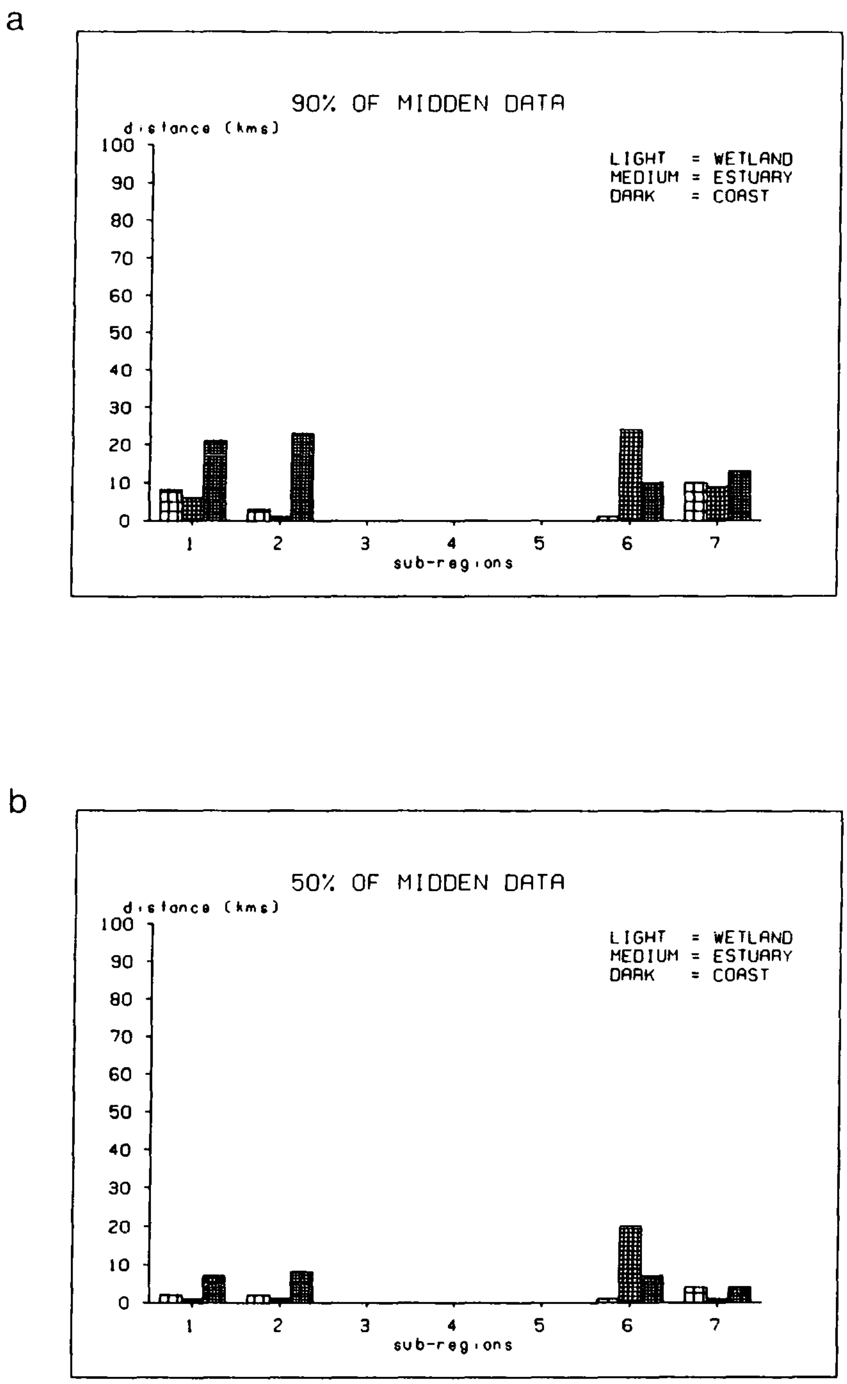


Figure 7.6: The relationship between Aboriginal shell midden sites and the principal components of the aquatic structure (wetlands, estuaries and the coast) of the Sydney region at the a) 90% and b) 50% levels in (1) the region as a whole, and (2) the Gosford-Wyong; (6) Cataract Dam; and (7) Royal National Park sub-regions.

the expected pattern of ranking. All middens within the region display the closest association with estuaries, but they are also clearly located in proximity to wetlands. This general pattern is maintained in Gosford-Wyong and the Royal National Park; but, in the Cataract Dam sub-region, it is clear that middens are more closely associated with wetlands than they are with the coastal source of their principal archaeological component.

In general, then, in terms of the behaviour of the Aborigines of the Sydney region and its relationship to the optimal model, there is clear evidence that where all (or two) of the aquatic structure elements were present, the degree of their influence upon Aboriginal locational decisions is likely to have been proportional to their value based upon their properties as sources of potential patches (wetland - estuary - coast). This is evident particularly of that segment of the total Aboriginal behaviour which is most likely to have influenced the Darwinian fitness of the population - the Function sites. Although the behavioural associations are to some extent deflected in this latter population (because of the structural ties implicit in the use of rock shelters) this degree of deflexion does not appear to be a major factor (though it is clearly a source of increased variation). The evidence concerning aquatic structure variables suggests that shelters appear to have been used provided that they were in (almost) as close association with high-value patches as open sites were.

7.5 CLIMATIC STRUCTURE

The complexity of the patterns of probable inter-relatedness with other variables (e.g. height and coastal proximity); and the problems associated with scale factors make the formation of expectations with regard to climatic structure difficult. Despite the low degree of seasonality within the region as a whole, topographic and coastal influences are likely to produce climatic characteristics which may influence the distribution of floral and faunal patches in more subtle ways than the edaphic characteristics of terrestrial structure.

7.5.1 Rainfall

The distribution of rainfall is influenced both by topography and proximity to the coast, and this is likely to have affected the distribution of floral and faunal patches. In addition, rainfall may also influence patch distribution through differences in absolute amounts of rain throughout the year - levels of annual rainfall may be influential: seasonal rainfall differences are likely to be more so. Further, because rainfall is orographic in its influence - increasing, more or less, with height - the relationship between Aboriginal locational decisions and rainfall distribution is likely to be even more complex - for (as we have noted) as height increases so nutrients decrease. If proximity to areas of greater rainfall was an influence upon Aboriginal locational decisions as they are reflected in the Function population, this influence should be finely balanced with regard to that of nutrient distribution.

In general, though, if the Aborigines tended to behave optimally in their foraging behaviour, sites should be located in close proximity to to a) areas of higher annual rainfall; b) areas of higher rainfall in summer (i.e. when evaporation is greatest); and c) areas of higher rainfall in winter (i.e. when resources are likely to be most depressed). Function sites should be more closely associated with these characteristics than Style sites.

<u>Average Annual Rainfall</u>.

The results of the analysis of site location suggest that the influence of rainfall was a complex one upon Aboriginal locational decisions. Though at least part of this evident complexity may be due to the coarseness of the measure and the consequent small degree of variation evident in the sub-regions (Appendix D.3.1):

1. <u>All region</u>. There is no general trend toward the higher end of the regional rainfall pattern observable in the distribution of Aboriginal sites. However both Function Open and Shelter sites display a consistent tendency to be located in areas of higher rainfall than Style sites. That (despite the fact that the measure of rainfall is unavoidably coarse) Function and Style Shelter sites should consistently differ in this regard, appears to be the more significant result (though it is clear that the presence of middens is a major source of this difference).

Upon the regional scale, then, it appears that the distribution of rainfall influenced Aboriginal locational decisions which are likely to have affected the Darwinian fitness of the population.

2. Gosford-Wyong. All evidence of Aboriginal activity appears to be located toward the wetter end of the range, but there is little difference between Function and Style sites in this regard. That Style Open sites tend to be located in wetter areas than the other site sub-populations, tends to indicate that rainfall was not an influence upon Aboriginal locational decisions.
3. Upper Mangrove Creek. In this sub-region there is no evident tendency for sites to be located in close proximity to areas of greater rainfall. The tendency for Style Open sites to be located in areas of higher annual rainfall suggests that this was not an important influence upon Aboriginal locational decisions.
4. Cumberland Plain. All Aboriginal site groups tend toward the higher end of the range of rainfall upon the Cumberland Plain. Function Open sites, which represent the major Function component in this sub region, display a clearer tendency towards wetter areas than is evident for any of the other site populations. This suggests that rainfall was an influence upon Aboriginal locational decisions with regard to that part of behaviour which would have most clearly influenced the Darwinian fitness of the population. That nutrient distribution is less likely to have been a major influence in this extensive area of soils derived from Wianamatta shale (in comparison to surrounding areas wherein nutrient distribution is likely to be a major influence - because of its restricted nature), may be an

explanation of this association.

5. Blue Mountains. In the Blue Mountains all evidence of Aboriginal activity suggests an avoidance of wetter (and higher) areas. There is no evident difference between Function and Style in this regard, which suggests that annual rainfall did not influence those Aboriginal locational decisions which would have been most closely associated with the Darwinian fitness of the population.
6. Cataract Dam. All Aboriginal sites in the Cataract Dam sub-region display a tendency toward the wetter end of the range. Yet, Function Shelter sites differ significantly from all other site groups in being located in wetter areas. There is some indication therefore that Aboriginal locational decisions were influenced by annual rainfall, particularly because it is the two shelter populations which differ, despite the fact that they are derived from the same potential population.
7. Royal National Park. The results of analysis in this sub-region suggest that annual rainfall was not an influence upon Aboriginal locational decisions. All sites tend towards the lower end of the range, and there is no discernible difference between the Function and Style populations.

In summary, there is some indication that annual average rainfall did influence Aboriginal locational decisions within the Sydney region. The evidence is most persuasive at the regional level, which, because of the enforced coarseness of the measure of this variable, may be the only level at which analysis is really appropriate. In the sub-regions, despite the fact that there appears to have been a general tendency for Aboriginal behaviour to be located in areas of higher rainfall than modal characteristics would suggest would be likely, there is little evidence that Function sites differ from Style sites (though this may in part reflect the coarseness of the scale necessarily imposed).

However, the evidence from the Cataract Dam and the Cumberland Plain sub-regions differs from this general pattern. In the former case, Function Shelters differ from all other site types in being located in wetter areas. That these sites should diverge from their Style counterparts and from Function Open sites is suggestive of an important difference in the locational decisions associated with the use of shelters. Upon the Cumberland Plain an explanation of the observable influence of annual rainfall upon Aboriginal locational decisions may lie in the fact that nutrient distribution is less likely to be a major influence upon decisions (because of the extensive nature of soils derived from Wianamatta shale).

Average summer rainfall

The analysis of the relationships between the evidence of Aboriginal behaviour and the distribution of summer rainfall suggests, to some small extent, that this was an influence upon Aboriginal locational decisions. However, the relationship appears to have been, by no means, a general one (Appendix D.3.2).

1. All region. There is no evidence to suggest that, on the regional scale, summer rainfall was important in the location of Aboriginal behaviour. All sites tend to be distributed around the middle of the range. In addition, Function sites do not display any characteristics which suggest closer proximity to areas of greater summer rainfall. In fact, Style Open sites are clearly located in areas of higher rainfall than Function Open sites - presumably as a function of their greater coastal bias.
2. Gosford-Wyong. In this sub-region, there is evidence which suggests that all Aboriginal activities tended to occur in areas of higher summer rainfall. In addition, Function Open sites tend to be found in wetter areas than the other site groups, which suggests that this factor may have influenced Aboriginal locational decisions concerning that part of behaviour which is likely to have affected the Darwinian fitness of the population.
3. Upper Mangrove Creek. There is little support for the proposition that Aboriginal locational decisions were influenced by summer rainfall in this sub-region, for both Style sub-populations tend to be located in wetter areas than Function sites - presumably as a function of their greater height and the orographic distribution of the rainfall.
4. Cumberland Plain. Upon the Cumberland Plain all sites tend to occur at the higher end of the range. However there is no discernible difference between Function and Style sites in this regard.
5. Blue Mountains. There is no evidence to suggest that summer rainfall influenced Aboriginal locational decisions in the Blue Mountains - all

sites tend to be distributed around the middle of the range. However, in the absence of sufficient data to form statistical tests, it could be suggested that Function Open sites tend to be located in areas of lower rainfall than Style Open sites.

6. Cataract Dam. In the Cataract Dam sub-region, all sites tend to be located at the higher end of the range. However, the results of analysis suggest that Function Shelter sites tend to be located in wetter areas than any of the other sub-populations, which suggests that summer rainfall may have influenced Aboriginal locational decisions.
7. Royal National Park. There is no evidence to suggest that summer rainfall was a general factor in the location of Aboriginal behaviour. This is also suggested by the fact that Function Shelter sites tend to be in drier areas than the other three site sub-populations.

Despite an observable tendency for evidence of Aboriginal activity to occur in areas of greater summer rainfall, no clear pattern of differentiation is apparent between the behaviour represented by Function and Style sites. This lack of differentiation is likely to be due, at least in part, to the coarseness of the measure of this variable (particularly in the case of the relationships between the two shelter sub-populations). However, among the inland sub-regions where a difference does occur, it is usually an element of the Style population which diverges from the remaining groups into wetter (and higher?) areas, a fact which indicates the lack of influence of this factor upon locational decisions which would have been likely to influence the

Darwinian fitness of the population. Among coastal sub-regions, by contrast, an element of the Function population tends to diverge from the remaining sub-populations, suggesting that here summer rainfall may have been rather more of an influence upon locational decisions than inland.

Average winter rainfall.

The results of the analysis concerning the relationship between Aboriginal behaviour and average winter rainfall, suggest that this landscape variable may have had some influence upon locational decisions (Appendix D.3.3):

1. All region. All Aboriginal activities appear to have been located in areas at the lower end of the winter rainfall range. The differences between Function and Style in this respect do not form a consistent pattern: Function Shelter sites are clearly associated with wetter areas than Style Shelter sites; while Function Open are clearly associated with drier areas than Style Open sites. That the Shelter population should be differentiated in this way, despite the fact that both groups are derived from the same potential population, is probably the more important result; for the effects of the distribution of Function Open sites upon the Cumberland Plain and other inland areas are likely to account for the differences in the two open populations.

2. Gosford-Wyong. All Aboriginal behaviour within this sub-region appears to have been located in wetter areas. Yet, Function sites display a consistent tendency to be located in areas with a higher winter rainfall than their Style counterparts. This suggests that winter rainfall did influence Aboriginal locational decisions particularly in regard to that part of behaviour which would have influenced the Darwinian fitness of the population.
3. Upper Mangrove Creek. In this sub-region all Aboriginal activity seems to have been located in areas at the wetter end of the range. In addition, both Function Open and Shelter sites are to be found in areas with a greater winter rainfall than their Style counterparts. This would suggest that winter rainfall was an influence upon Aboriginal locational decisions as they are represented by the Function population.
4. Cumberland Plain. There is no evidence to suggest that winter rainfall influenced Aboriginal locational decisions upon the Cumberland Plain, except that both Function Open and Style Open sites tend to be located in drier areas than Shelter sites. This difference, however, is likely to reflect the peripheral status and height of shelter sites and the orographic nature of the rainfall.
5. Blue Mountains. In the absence of statistical inference, it might be suggested that Function Shelter sites tend to be located in wetter areas than the other site sub-populations. However, there is little evidence to suggest that winter rainfall was an influence upon Aboriginal locational decisions.
6. Cataract Dam. All sites appear to be located in areas which receive

a greater measure of winter rainfall than is modal for the area. However, there is little evidence to suggest that this variable influenced the Aboriginal locational decisions concerning Function sites, though Function Shelter sites do tend to be distributed in drier areas than the other site sub-populations.

7. Royal National Park. There is no evidence to suggest that Aboriginal activities were generally influenced by the distribution of winter rainfall. However, because Function Shelter sites are consistently located in wetter areas than Style sites, it can be suggested that this climatic factor is likely to have influenced locational decisions concerning that behaviour which would probably have affected the Darwinian fitness of the population.

There is considerable evidence that winter rainfall distribution influenced Aboriginal locational decisions, to a greater degree than can be said to be true of annual or summer rainfall. Both in inland and coastal sub-regions an element of the Function population tends to diverge from its Style counterpart into wetter areas. In this regard, it is particularly significant that Function Shelter sites should diverge so consistently from Style shelters (in the region as a whole, and in the Gosford-Wyong, Upper Mangrove Creek, Blue Mountains and Royal National Park sub-regions) despite the fact that they are derived from the same potential population and the degree of definition of this variable is unavoidably coarse.

7.5.2 Temperature

The difficulties in forming predictions concerning the relationship between Aboriginal behaviour and temperature variables are broadly the same as those outlined for rainfall above. In general, provided that optimality principles are applicable, Aboriginal locational decisions are likely to have been influenced by areas which possessed the following characteristics (in approximate order of importance): a) a high minimum temperature in winter (which may particularly influence mobile prey because of the incidence of cold, but also may restrict the growing season of flora); b) low maximum temperature in summer (which may influence floral growth and the distribution of fauna (in search of cooling). c) a high minimum annual temperature (which may have a general influence on the flora); d) high maximum temperature in winter (which may influence the growing season of flora and the location of fauna in search of warmth) and; e) low minimum temperature in summer (which might influence mobile prey in search of cooling); f) high maximum annual temperature (which may influence the distribution of flora and fauna (for example, ectothermic fauna)). Function sites should display a greater tendency toward these areas than Style sites. The difference between the two populations is most likely to be clear with regard to annual and winter minimum, and summer maximum temperatures, because these climatic factors would have affected the probability of patch formation to the greatest degree.

In the following section, minimum and maximum temperatures are considered, firstly, on the annual scale; secondly, for the summer; and thirdly, for the winter:

Average Annual Maximum Temperature

There is only a little evidence to suggest that this variable influenced Aboriginal locational decisions which are likely to have affected the the Darwinian fitness of the population (D.3.4):

1. All region. All Aboriginal activity appears to have tended toward areas at the warmer end of the range. However, while Function Shelter do not differ from Style Shelter sites with regard to this climatic variable, Function Open sites are found in consistently cooler places than Style Open sites, which suggests that annual maximum temperature may have influenced Aboriginal locational decisions, as they are reflected by the Function Open sub-population.
2. Gosford-Wyong. There is no evidence to suggest that annual maximum temperature influenced Aboriginal locational decisions in this sub-region; all sites occur in areas which are associated with temperatures at or close to the modal value.
3. Upper Mangrove Creek. There is no reason to suppose that locational decisions were influenced by this climatic factor, all sites occur close to the modal value and there is no discernible difference between Function and Style.
4. Cumberland Plain. The variation in the levels of this climatic characteristic is so small upon the Cumberland Plain, that there is

too little to allow valid statistical analysis - we are forced to assume, therefore, that annual maximum temperature did not influence Aboriginal locational decisions.

5. Blue Mountains. In the Blue Mountains, there is no evidence to suggest that average annual maximum temperature influenced locational decisions. Sites do not tend to be distributed in areas associated with temperatures other than the modal value for the area and there is no significant difference between Function and Style populations.
6. Cataract Dam. In this sub-region, there is some evidence that annual maximum temperature may have had an influence upon locational decisions, for Function Shelter sites tend to be distributed in consistently cooler places than the other sub-populations.
7. Royal National Park. The results suggest that average annual maximum temperature may have influenced Aboriginal locational decisions in the Royal National Park. All sites tend to be located at the warmer end of the range, above the modal value, but Function Shelter sites diverge from the other site sub-populations in being located in noticeably warmer areas.

In general there appears to have been a tendency for Aboriginal activities to have been located toward the warmer end of the range, which is likely to be a function of the principally coastal distribution of sites. This is particularly indicated by the lack of influence upon Aboriginal decision evident in the inland sub-regions. In contrast, in the coastal sub-regions there is a clear tendency for Function Shelter sites to diverge from the other sub-populations.

Average Annual Minimum Temperature

There is considerably more evidence that average annual minimum temperature influenced Aboriginal locational decisions (Appendix D.3.4):

1. All region. All Aboriginal sites tend to be located toward the higher end of the range. However, there is a clear pattern of differentiation - despite the fact that the two populations are derived from the same potential one - between Function and Style shelters; wherein Function Shelters tend to be located in areas with a higher minimum temperature than their Style counterparts. However, Function Open sites differ from Style Open sites in being distributed in consistently cooler areas - presumably as a function of the greater degree of coastal orientation exhibited by the latter group.
2. Gosford-Wyong. In this sub-region all evidence of Aboriginal activity tends to be located towards the warmer end of the range. In addition, because both Function sub-populations tend to be located in areas possessing a higher average minimum temperature, it is likely that this climatic characteristic influenced locational decisions involving that part of behaviour which would have affected the Darwinian fitness of the Aborigines.
3. Upper Mangrove Creek. There is no evidence to suggest that annual minimum temperature influenced Aboriginal locational decisions - there is little discernible difference between Function and Style and no evident tendency for sites to be distributed away from the modal characteristic of the area.

4. Cumberland Plain. Upon the Cumberland Plain there is no evidence to suggest that sites tend to be distributed away from the modal value of the area, or that the Function population diverges from the Style.
5. Blue Mountains. The results of analysis suggest that all sites tend to be distributed below the modal value for the sub-region. In addition, there is no evidence to suggest that Function sites are different from Style sites, and consequently no reason to suggest that this climatic variable influenced locational decisions within this sub-region.
6. Cataract Dam. All Aboriginal sites tend to be located in areas with a higher average annual minimum temperature than that which is modal for the area. Yet there is a clear tendency for both Function sub-populations to be located in areas with a higher minimum temperature than their Style counterparts. For this reason, it is likely that this climatic characteristic did influence Aboriginal locational decisions.
7. Royal National Park. In the Royal National Park, there is little evidence to suggest that any site sub-population tends to be distributed away from the modal value for the area, nor is there any consistent pattern of difference between Function and Style. Overall, there is no evidence here to suggest that annual minimum temperature was an influence upon locational decisions.

The relationships between evidence of Aboriginal behaviour and average annual minimum temperature, suggest that this climatic characteristic might have influenced Aboriginal locational decisions to some degree. The consistent pattern of difference between the Function and Style populations in the region as a whole and in the Gosford-Wyong and Cataract Dam sub-regions indicates that proximity to generally warmer areas may have been an influence with regard to that part of Aboriginal behaviour which would have been most likely to have affected the Darwinian fitness of the population at the coast. However, there is no evidence to suggest that this climatic factor influenced Aboriginal locational decisions inland.

Average Maximum Temperature - summer

There is some evidence that maximum summer temperature influenced Aboriginal locational decisions (Appendix D.3.5):

1. All region. The results of the analysis of Aboriginal behaviour for the whole region suggests that maximum summer temperature might have influenced locational decisions. Both Function sub-populations tend to be distributed in areas possessing a lower summer maximum temperature than their Style counterparts.
2. Gosford-Wyong. All evidence of Aboriginal activity tends to be associated with maximum summer temperatures below the level which is modal for the sub-region. In addition, that both Function sub-populations tend to be distributed in areas which are cooler than those associated with Style sites, suggests that this climatic characteristic influenced Aboriginal locational decisions, as they are represented by the former group.

3. Upper Mangrove Creek. The results of the analysis suggest that there was no general tendency for Aboriginal behaviour to be located in arêas other than those associated with temperatures which are modal for the area. In addition there is no evident difference between the Function and Style populations in regard to this climatic characteristic, which suggests that it was not an influence upon Aboriginal locational decisions.
4. Cumberland Plain. Upon the Cumberland Plain, Aboriginal sites display little tendency to occur in areas other than those which possess the modal characteristic. In addition, there is no evident pattern of differentiation between Function and Style sites, which suggests that this climatic variable did not influence Aboriginal locational decisions.
5. Blue Mountains. Despite the absence of sufficient data to form valid statistical tests, there is some evidence that maximum summer temperature influenced Aboriginal locational decisions. Both Function Shelter and Open sites have the appearance of being distributed in areas which are consistently cooler than those associated with their Style counterparts.
6. Cataract Dam. There is some evidence to suggest that maximum summer temperature may have influenced Aboriginal locational decisions in this sub-region. In particular, Function Shelter sites tend to be located in areas with a lower maximum summer temperature than any of the other site groups.
7. Royal National Park. There is no evident variation in average maximum summer temperature in this sub-region.

Overall, there is clear evidence that Aboriginal sites tend to be located at the lower end of the range in maximum summer temperature - both in the region as a whole and in most of the sub-regions. It is also clear that this climatic factor may have influenced Aboriginal locational decisions. For the results indicate that in the region as a whole and in two of the coastal sub-regions (Gosford-Wyong and Cataract Dam) and also (possibly) in the Blue Mountains, Function sites tended to be located in cooler locations than Style sites.

Average Minimum Temperature - summer.

Analysis of the locational characteristics of Aboriginal activities suggests that this climatic variable had little influence upon Aboriginal locational decisions (Appendix D.3.6):

1. All region. The results of the analysis suggest that minimum summer temperature may have possessed some influence upon locational decisions. All sites tend to be located towards the warmer end of the range; but, it is evident that Function Shelters diverge from Style shelters in being in consistently warmer places. However, Function Open sites tend to be located in cooler positions than Style Open sites.
2. Gosford-Wyong. There is little evidence that sites tend to be distributed away from those areas wherein the modal temperature predominates. However, there is a consistent tendency for both Function sub-populations to be located in areas possessing a higher

summer minimum temperature than their Style counterparts. Which suggests that this climatic variable may have influenced Aboriginal locational decisions.

3. Upper Mangrove Creek. In this sub-region there is little evidence to suggest that this climatic variable may have influenced locational decisions. While all sites tend to be distributed in areas associated with the modal value. Style Open sites diverge from the other groups into warmer locations.
4. Cumberland Plain. There is no evidence to suggest that minimum summer temperature influenced locational decisions upon the Cumberland Plain. Sites display very little tendency to diverge from the modal characteristic and there is no evident difference between Function and Style sites.
5. Blue Mountains. The analysis suggests that there is no evidence that locational decisions were influenced by this climatic variable. All sites tend to be distributed at the warmer end of the range, but there is no discernible difference between Function and Style sites.
6. Cataract Dam. All sites tend to be distributed in areas of higher minimum summer temperature than is modal for the sub-region. There is some evidence that this climatic characteristic may have influenced Aboriginal locational decisions, in that Function Shelter sites tend to be located in areas of higher minimum summer temperature than the other site groups.
7. Royal National Park. All sites tend to be located in areas which possess the modal temperature for the sub-region. However, Function open sites display a consistent tendency to be located in cooler

places than the other site groups, which suggests that this climatic characteristic might have possessed some influence upon Aboriginal locational decisions.

In the region as a whole, and in most of the sub-regions, Aboriginal behaviour tends to be located in areas of higher minimum summer temperature than is modal for these respective areas. However, there is little evidence of differences, with regard to this variable, between that part of Aboriginal behaviour represented by the Function population and that part represented by Style sites. Yet upon the coast there is evidence that at least one of the Function sub-populations tends to be located in areas with a higher minimum summer temperature than is associated with Style sites. Inland, by contrast, Function sites show little tendency to be located in areas which are cooler or warmer than those associated with the Style population.

Average Maximum Temperature - winter

There is a little evidence that average maximum winter temperature influenced the Aboriginal locational decisions as they are represented by the Function population (Appendix D.3.7):

1. All region. There is a clear tendency for all sites to be distributed in warmer places. However, there is a tendency for Function sites to be distributed in different areas from their Style counterparts. That Function Open sites tend to be located in areas with a lower maximum

winter temperature than Style Open sites is likely, at least in part, to be a function of the greater degree of coastal proximity evident in the latter population. It is more remarkable, given that both groups are derived from the same potential population, that Function and Style shelter sites should consistently differ - the former population being in warmer areas than the latter.

2. Gosford-Wyong. Although evidence of Aboriginal behaviour tends to be located in areas associated with the modal temperature for the sub-region, there is a significant difference between Style and Function Shelters, wherein the latter group are found in areas with a higher maximum winter temperature. This suggests that this climatic variable may have influenced Aboriginal locational decisions.
3. Upper Mangrove Creek. There is little evidence to suggest that maximum winter temperature influenced locational decisions with regard to Function sites in this sub-region. All sites tend to be distributed in areas which possess temperatures at or close to that which is modal for the area. However, Style Open sites tend to be found in warmer areas than the other site groups.
4. Cumberland Plain. Upon the Cumberland Plain all sites tend to be located towards the higher end of the range (above the level which is modal for the area). However, because there is little difference between the Function and Style populations, there is little evidence to support the suggestion that this variable influenced Aboriginal locational decisions with regard to that part of behaviour which is most likely to have influenced the Darwinian fitness of the population.

5. Blue Mountains. There is a tendency displayed by the evidence for Aboriginal activity toward the warmer end of the maximum winter temperature range. However, there is little evidence to suggest that Function and Style populations differ in their relationship to this climatic variable.
6. Cataract Dam. In the Cataract Dam sub-region there is little evidence to suggest that this variable was influential in the location of Aboriginal behaviour. All sites tend to be located in areas which are characterized by temperatures which are modal for the area and there is no evident difference between Function and Style.
7. Royal National Park. The results of the analysis suggest that maximum winter temperature may have influenced Aboriginal locational decisions in this sub-region, for, Function Shelter sites differ from the other site groups, including Style Shelters in being located in areas of higher maximum winter temperature.

There appears to be a tendency for all Aboriginal sites to be located in warmer areas, which is particularly evident in the region as a whole and in two of the inland sub-regions (Cumberland Plain and the Blue Mountains). In the coastal sub-regions there is a clear tendency for one of the Function sub-populations to be located in warmer areas than Style sites (e.g. Gosford-Wyong and the Royal National Park). Inland, by contrast, in both the Upper Mangrove Creek and (possibly) in the Blue Mountains sub-region, there is a clear tendency for the expected tendency to be reversed - both Function sub-populations tend to be located in areas with a lower maximum winter temperature. Overall, there is evidence that this climatic factor did influence Aboriginal locational decisions but only upon the coast does this relationship appear to have coincided with the expected one.

Average Minimum Temperature - Winter

There is considerable evidence to suggest that Aboriginal locational decisions were influenced by this climatic variable (Appendix D.3.8):

1. All region. The results of the analysis suggest that all Aboriginal sites tended to be located in areas characterized by higher minimum winter temperatures. In addition, there is evidence that this climatic factor was an influence upon Aboriginal locational decisions which would have been likely to affect the Darwinian fitness of the population. Both Function sub-populations are distributed in areas which are consistently warmer than those occupied by their Style counterparts.
2. Gosford-Wyong. In this coastal sub-region there is evidence that this variable was an influence upon Aboriginal locational decisions. Function sites tend to be distributed in areas with a higher minimum winter temperature than Style sites.
3. Upper Mangrove Creek. All sites tend to be distributed toward the warmer end of the range (above the modal value). The evidence suggests that this climatic characteristic influenced locational decisions because both Function sub-populations tend to be distributed in areas which are warmer than those occupied by Style sites.

4. Cumberland Plain. The results of analysis suggest that upon the Cumberland Plain, minimum winter temperature did not influence Aboriginal locational decisions. Function and Style Shelters do not differ, but Function Open sites tend to be in cooler positions than the other sub-populations. Presumably this relationship reflects the peripheral status of the other site groups and their greater degree of coastal proximity.
5. Blue Mountains. In the Blue Mountains all sites tend to be distributed around the lower end of the range, below the modal value for the area, and there is no consistent difference between Function and Style; though in the absence of sufficient data to allow statistical testing, there is some evidence that Function Open sites may have tended to be located in slightly warmer areas than the other site groups.
6. Cataract Dam. All evidence of Aboriginal activity tends to be distributed towards the warmer end of the range (above the modal value). Function Shelter sites tend to differ from all other sites (including Style Shelters) in being associated with warmer areas. That it is the shelter populations which displays a difference would appear to indicate that this climatic variable influenced Aboriginal locational decisions which were likely to have affected the Darwinian fitness of the Aboriginal population.
7. Royal National Park. There is no evident variation with regard to minimum winter temperature in this sub-region and therefore no basis to suppose that this variable influenced Aboriginal locational decisions.

There is an apparent tendency for all evidence of Aboriginal activity to be located in areas which are characterized by a relatively high minimum winter temperature (in the region as a whole, and in the Gosford-Wyong, Upper Mangrove Creek, and Cataract Dam sub-regions). In addition, in those same areas, there is a clear tendency for one (usually Function Shelters) or both of the Function population to diverge from the other sub-populations in being located in areas with a higher minimum winter temperature than can be said to be true of Style sites. This tendency clearly suggests that minimum temperature in winter was an influence upon Aboriginal locational decisions as they are represented by Function sites.

7.5.3 Aspect

The loosely associated variable - aspect - is likely to have influenced the potential for floral and faunal patch formation in several ways. Principally, aspect influences local characteristics of flora (and as a consequence may influence fauna); for example, areas in the shade (i.e. facing south) tend to produce a less xeromorphic vegetation. In addition, areas facing east to south-east may tend to show the influence of oceanic winds in the structure of their vegetation (for example through a greater complement of heath-type plants), particularly if the area is in close proximity to the coast. In general, then, we might suggest that if optimality principles are appropriate, the Sydney region Aborigines should have located their sites in areas which faced south or west to north-west.

However, it should be noted that the aspect of a site, which is the basis of the analysis here, is at least as likely to be influenced by the comfort requirements of the forager; that is, aspect considerations may represent adaptations associated with goals other than efficient food acquisition. These two potential adaptive characteristics - comfort and food acquisition - are likely to be inseparable in the consideration of aspect.

Nonetheless, there is some evidence to suggest that aspect considerations may have influenced Aboriginal locational decisions in such a way as to suggest a connection with patch distribution:

1. All region. There is a clear tendency for all site groups to shelter away from the south-easterly storm winds. However, Function Open sites display a strong southerly component (i.e. in the shade and associated with a less xeromorphic vegetation). That Function Shelter sites tend to face north to a greater degree than Style sites, may be viewed either as a refutation of the expectation based upon optimality principles (except that faunal populations and particularly ectothermic fauna may be influenced by such an aspect) or as an adaptation to comfort (the warmth of the sun). Overall, however, this would tend to suggest that aspect was an influence upon Aboriginal locational decisions.
2. Gosford-Wyong. The results of the analysis of evidence for Aboriginal activity reveal the same general pattern of reluctance to face the direction of the principal storm winds. The characteristics of the

Function population are the same as those for the region as a whole - Function Open sites tend to face south and Function Shelter sites tend to face north, to a greater degree than is evident in their Style counterparts.

3. Upper Mangrove Creek. In the inland Upper Mangrove Creek sub-region, all sites again tend to face away from the south-east. However, the preferred aspects of the Function sites - north-east and north-west should perhaps, be considered as likely to be mainly comfort-related, because they face towards warm stable winds; though it is not unlikely that faunal populations might also have been influenced by such considerations.
4. Cumberland Plain. Few sites upon the Cumberland Plain itself can be said to possess an aspect and, as a consequence, there is too little data to produce valid statistical tests.
5. Blue Mountains. Similarly, in this sub-region there are too few data available to allow valid statistical tests.
6. Cataract Dam. The results of the analysis indicate that Function Shelter sites have a significant tendency to face southward (in the shade and associated with a less xeromorphic flora), while Function Open sites display a tendency (on the basis of a small amount of data) towards the north. Of these two results the first is most significant because the data are more numerous. This result suggests that this factor may have influenced Aboriginal locational decisions which may have affected the Darwinian fitness of the population.
7. Royal National Park. In this coastal sub-region all sites tend to face away from the south-east, the principal direction of storm winds.

In the absence of sufficient data to carry out valid statistical tests, it can be suggested that Function Style sites tend to display a greater association with northerly aspects, which suggests that any adaptive significance may be largely attributable to comfort factors.

The majority of the aspect data is derived from shelter sites which, ultimately, are limited in their aspect by the quirks of nature. The actual choice of a site, with regard to aspect, may be the result of a number of conflicting influences: convenience; comfort; outlook; and/or some expression of the proximity of easily gathered resources (which would be of interest here).

The most evident characteristic of aspect data is the reluctance exhibited by the Aborigines to choose sites which faced south-east into the principal storm winds. The reasons for this reluctance are probably mostly attributable to comfort factors, though the influence of these winds upon the probability of floral patch formation may be a subsidiary factor.

In contrast, the association of Function Open sites (all region and Gosford-Wyong) and Function Shelter sites (Cataract Dam) with south facing slopes is equally interpretable in terms of the likelihood of the proximity of less xeromorphic floral assemblages. It is also possible that the tendency to face north-east was associated with vegetation unaffected by most coastal winds (Gosford-Wyong and Royal National Park).

7.5.4 Climatic structure - an assessment

The relationships between the location of Aboriginal behaviour and climatic influences are evidently complex. Yet, in general, it can be said that all those variables which were expected to influence Aboriginal locational decisions, because of their relationship to the distribution of high-value patches, do so (if only to a small degree). It is clear, however, that none of these influences was a general factor over the whole region.

Overall, however, the consistent tendency of the Function population (at least in part) to differ from the Style population emphasizes the likelihood that these factors did influence the locational characteristics of that part of the total behaviour which would have been most likely to affect the Darwinian fitness of the Aboriginal population. Remarkably, despite the difficulties imposed by scale factors, it is often Function Shelter sites which display the expected tendency, though such sites are derived from the same potential population (of naturally-weathered excavations in the rock) as their Style counterparts.

It is also evident that the consistency of differences between Function and Style with regard to these climatic variables largely depends upon time-scale factors - the annual averages may not provide a measure of sufficiently fine temporal scale to allow the detection of substantial and significant differences. For example, it is evident that consistent and significant differences occur between these two populations in relation to winter rainfall and maximum summer and minimum winter temperatures.

Generally, of all the climate variables, rainfall possesses the clearest pattern of association with Aboriginal locational decisions. Below the clear associations at the annual level, the distribution of rainfall in winter is likely to have influenced Aboriginal locational decisions. This is evident among inland sites in general, but particularly of Function Shelter sites both inland and upon the coast.

While the general pattern of average maximum temperature reflects the coastal bias of Aboriginal behaviour, sub-regional variation suggests that Function sites, particularly inland, tend to be found in areas of lower annual average maximum temperature than Style sites. This is also reflected in the patterns observable with regard to summer maxima - Function sites display a clear tendency towards cooler areas. In winter, this relationship is to some extent reversed, for Function sites (and particularly Function Shelters) tend to be associated with areas of higher maximum winter temperature than can be said to be true of Style sites.

With regard to minimum temperatures there is, more or less, a general tendency for sites to be located at the higher end of both regional and sub-regional ranges. Inland Function sites, in particular, appears to have diverged most frequently toward higher annual minimum temperatures. With regard to differences based upon the seasonal scale, the influences of summer minimum temperature are less clear than the influences of winter minima, which indicate clearly the tendency for this latter climatic variable to influence locational decisions (particularly in Function Shelter sites) toward warmer areas - especially upon the coast.

The relationships between Function and Style populations and aspect are most enigmatic. Certainly, even with the limited data available, it is clear that Function sites differ significantly from Style sites - but it is the reason for this difference which is problematic. The characteristics observed are undoubtedly the results of a number of influences - only one of which is likely to be the relationship with landscape characteristics which would have influenced the probability of patch formation.

Overall, there is considerable evidence that climatic factors did influence Aboriginal locational decisions in such a way as to suggest that the connection is likely to be related to the effect of climate upon the distribution of patches. The results of the analysis suggest that climatic extremes which were likely to affect floral growth periods, viz. winter rainfall, maximum summer temperature and minimum winter temperature, were most influential.

7.5.5 Function versus Style - some general comments

The analysis of the location characteristics of all Aboriginal behaviour indicates that the part which was most likely to have been influenced by optimality principles (the Function population) was distributed in such a way as to support the general patch model.

The most clear and consistent patterns of difference between the Aboriginal behaviours represented by Function and Style sites are those associated with the terrestrial structure. In each case - geology, topography and height - the expected differences are, almost without exception, observable. In general, the same can be said to be true of the aquatic structure variables and to a lesser extent the climatic structure.

However, particularly among the aquatic and climatic variables the regional scale of analysis tends to possess the disadvantage of promoting the influences associated with the coastal bias of the whole database. The use of sub-regional areas in the analysis indicates that there are broad differences between those landscape variables which are likely to have influenced Aboriginal locational decisions upon the the coast and those which are most likely to have influenced them inland.

Table 7.1 indicates the location of significant differences between the Function and Style sites and indicates where these differences fall in with expectations and where the result is unexpected. (Note that this table is based solely upon the difference between Function and Style groups and does not take into account those occasions when both populations can be shown to be responding to a landscape variable in a particular fashion - such as displaying a tendency to be distributed above the modal value.)

The principal group of unexpected results occurs in the sections concerning distances to the coast and estuaries. There is clear evidence

	GEOLOGY		TOPOGRAPHY		HEIGHT	
	FO	FS	FO	FS	FO	FS
A	+	+	+	+	+	+
G	+	+	+	+	+	+
U	+		+	+	+	+
C	+	+	+	+		
B	+?	+?			+?	+?
D						
R			+		+	+

	ESTUARY		COAST		WETLAND		FRESH	
	FO	FS	FO	FS	FO	FS	FO	FS
A	-	+	-	+	-	+	+	
G	+	+	+	+	+		+	
U	-	-	-	-	-		+	+
C				+	+			
B			-	-			+?	+?
D		+	+	+	+	+		+
R		+	-	-				

	ANN. RAIN		RAIN SUM		RAIN WINT	
	FO	FS	FO	FS	FO	FS
A	+	+	+		-	+
G	-		+		+	+
U	-		-	-	+	+
C	+					
B						
D		+		+		-
R		-		-		+

	MAX ANN. TEMP		MAX SUM. TEMP		MAX WINT. TEMP	
	FO	FS	FO	FS	FO	FS
A	+		-		-	+
G			+	+		-
U					+	
C						
B			+	+		
D		+		+		
R		+				+

	MIN ANN. TEMP		MIN SUM. TEMP		MIN WINT. TEMP	
	FO	FS	FO	FS	FO	FS
A	-	+	-	+	+	+
G	+	+	+	+	+	+
U					+	
C					-	
B						
D	+	+		+	+	
R			-			

	ASPECT	
	FO	FS
A	+?	+?
G	+?	
U		+?
C		+?
B		
D		+?
R		

e 7.1: The relationship between the Function population and landscape variables, illustrating the extent to which Function sites display the characteristics which would suggest that Aboriginal locational decisions were influenced by the distribution of high-value patches.

(Note: (+) denotes those results which suggest that the Function population diverges from the Style population in the expected way. (-) denotes those results which suggest that the Function population diverges from the Style population in the opposite direction to that expected. A blank indicates a lack of statistically significant difference.

A = All region; G = Gosford-Wyong; U = Upper Mangrove Creek; C = Cumberland Plain; B = Blue Mountains; D = Cataract Dam; R = Royal National Park.)

here of a dichotomy between a 'coastal' and an 'inland' response, wherein the majority of inland sites can be seen to possess no tendency toward association with the coast or estuaries, despite the fact that (as in the case of the Upper Mangrove Creek and Cumberland Plain sub-regions) estuarine resources may lie only a few kilometres away. A similar pattern clearly divides coastal and inland Aboriginal behaviour with regard to minimum temperatures. The coastal sub-regions display differences between Function and Style (at least in part because of the presence of middens) with regard to these variables: the inland sub-regions, on the whole, do not. Overall, these differences are suggestive of a broad coastal/inland dichotomy which lends support to the likelihood of two ecological populations being present in the Sydney region.

However, it is equally evident that there are internal differences in the relationship between that part of Aboriginal behaviour represented by Function sites and the influence of landscape variables upon locational decisions. For Open and Shelter Function sites clearly differ in the incidence of statistically significant differences with regard to their Style counterparts. In general, the fundamental geological and topographic strictures upon Function Shelter location ensure that there is a greater incidence of difference between Function Open and Style Open sites than there is between Function and Style shelters. Function Shelter sites are derived from the same potential population of naturally weathered caverns as Style Shelter sites. This has the dual effect of making the discovery of significant differences difficult (particularly where only coarse data are available - as in the case of climatic variables); but also, as a corollary, increases the likely importance of any observable significant difference.

However, these inconsistencies in the relationships between Function and Style sites might (from an extreme viewpoint) tend to suggest that all apparent associations between Function population and factors associated with patch distribution are fortuitous. In fact, there is clear, consistent and internal evidence that Aboriginal Function behaviour was influenced in its locational properties by landscape characteristics in directions which can be associated with probable patch distribution. For grinding grooves, which are the least likely sub-population among Function sites to be closely related to the food-quest (and hence least likely to display locational characteristics consistent with expectations based upon the relationship between landscape variables and high-value patches) can be shown, almost without exception, to operate as a spoiling variable. These sites tend to alter the characteristics of the whole Function population in the opposite direction to the expected one, either inland or upon the coast (see for example Appendix D.1.1 to D.1.3). Only when these sites are removed from the analysis do the expected tendencies (now associated with sites which are likely to be closely related to the food quest) become evident. (Additional support comes from the relationship of those sites with intermediate characteristics (Function/Style sites) and landscape variables - these sites apparently confirm their ambiguous status by being frequently more closely associated with the characteristics of Style sites than with those of Function sites.)

In general, the results derived from the analysis of differences between Function and Style sites suggests that while no one landscape variable characterizes the relationships between Aboriginal behaviour and high-value patches, most variables can be seen to support, in some measure, the idea that Aboriginal behaviour (as represented by Function sites) tended to be located optimally with regard to potential high-value patches.

However, this does not allow us to state which variables influenced Aboriginal locational decisions to the greatest degree, which is a prerequisite of testing many of the facets of the behavioural model. In order to achieve this we must first know how the variables are related to each other - that is, we must determine the hidden structure of the data.

7.6 MULTI-DIMENSIONAL SCALING AND THE HIDDEN STRUCTURE OF THE DATA

Multi-dimensional scaling is a statistical technique through which the hidden relationships between variables may be examined. The technique examines internal similarities within data (in this case a two-way symmetric matrix of correlations) and by means of a Euclidian distance model establishes groups in n-dimensional space (see Kruskal and Wish 1978). The proximate input concerning the Function data was derived from a Spearman rank-order correlation because of the difficulty of including the nominal variables - geology and topography. Accordingly, these two variables were raised to an ordinal scale by amalgamating the categories into rank order by the fertility of the soil produced by the parent materials in the former case; and by broad slope categories (e.g. low flat, low slope, medium slope, high slope) in the latter. (Note that the direction of correlation is not used in this technique, for the proximate data is derived only from the strength of relationship.)

In practice, three dimensions were found to be a good compromise between the operational demands of the test and the requirements of clarity - stress levels were sufficiently lower than those based upon random data to indicate that the derived solutions were viable; and the comparative ease with which three dimensions can be conceptualized - in contrast to a greater number - suggested the utility of this compromise.

In addition to multi-dimensional scaling derived from the MDS (X) programme MINISSA (Roskam 1975), the cluster analysis package CLUSTAN (Wishart 1978) provided the basis for contouring within the groups established by the former technique. (Multiple-link clustering was used as the basis of contouring rather than single link because (broadly) the former technique establishes the relationship between the similarity of a variable to the preceding <u>group</u> rather than in the latter technique, the similarity between variables. Single link clusters, which were also derived from the data, invariably confirmed the pattern observed in the more immediately useful multiple-link clusters.)

In the following discussion the landscape variables are considered for the Sydney region as a whole, but the division between open and shelter sites is maintained in order to maximize the information derived by avoiding the obscuring influence of the geological and topographic ties of Function Shelter sites.

In Figure 7.7 the results of multi-dimensional scaling using all Function Open data are displayed. It is readily apparent that the influences upon Aboriginal locational decisions of rainfall, minimum temperature and maximum temperature are likely to have acted as coherent wholes; though there is some evidence that, (with regard to maximum temperature) autumn/winter and spring/summer temperatures are likely to have displayed a degree of independence from each other. In addition, it is evident that both summer rainfall and summer maximum temperature may have exerted a degree of separate influence upon locational decisions beyond that of other variables in the appropriate groupings.

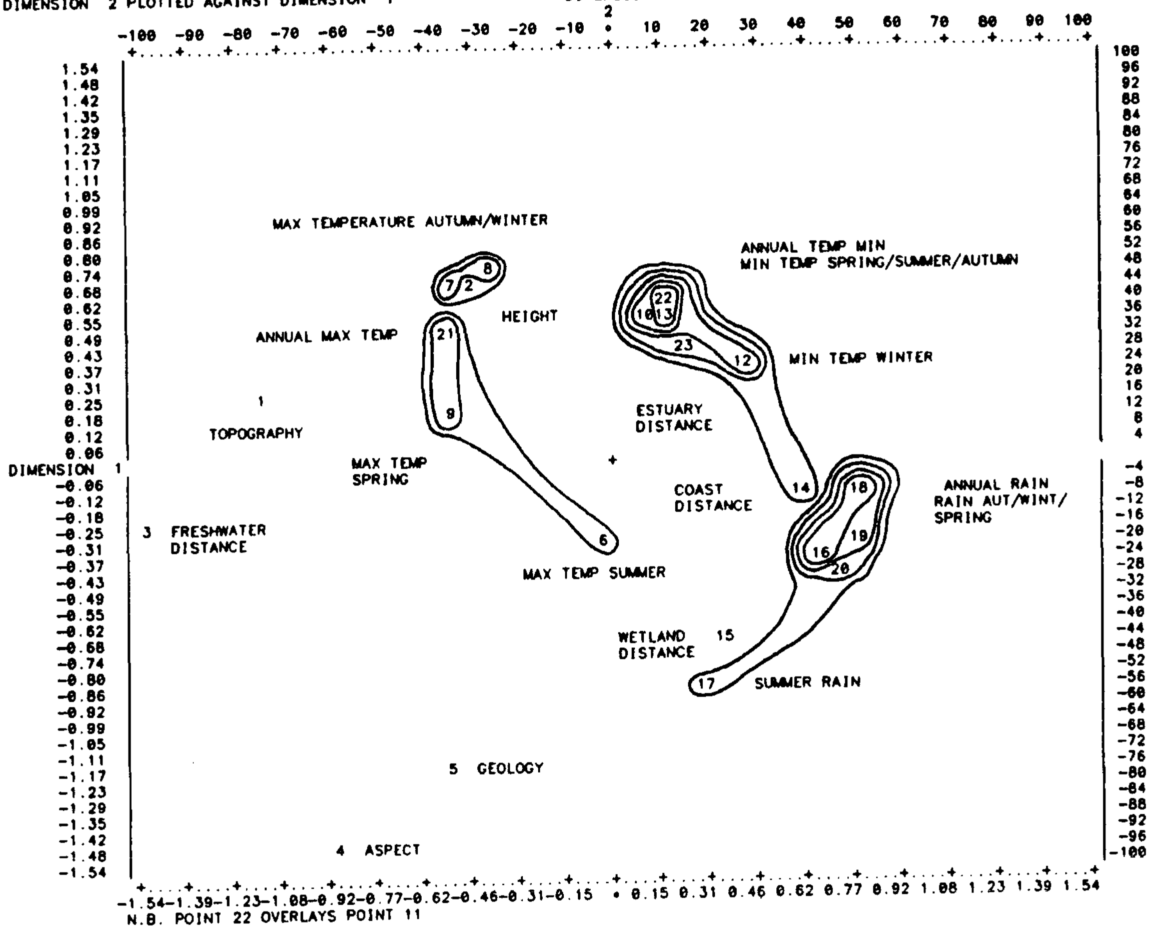
How, then, did aquatic and terrestrial structure influences interact with these clearly distinguishable climatic groupings and with each other?

The influences upon Aboriginal locational decisions of two of the terrestrial variables - geology and topography (and the climate-related variable - aspect) are likely to have been largely independent of the influences of other variables. In contrast the influence of height is clearly associated with that of average maximum temperatures in winter and autumn: indeed more so than those two variables are with the other maximum temperature variables. With regard to the influence of aquatic structure, both freshwater and wetland distance display a large measure of independence from all other variables. However, the influences upon

KEY TO MULTI-DIMENSIONAL SCALING PLOTS.

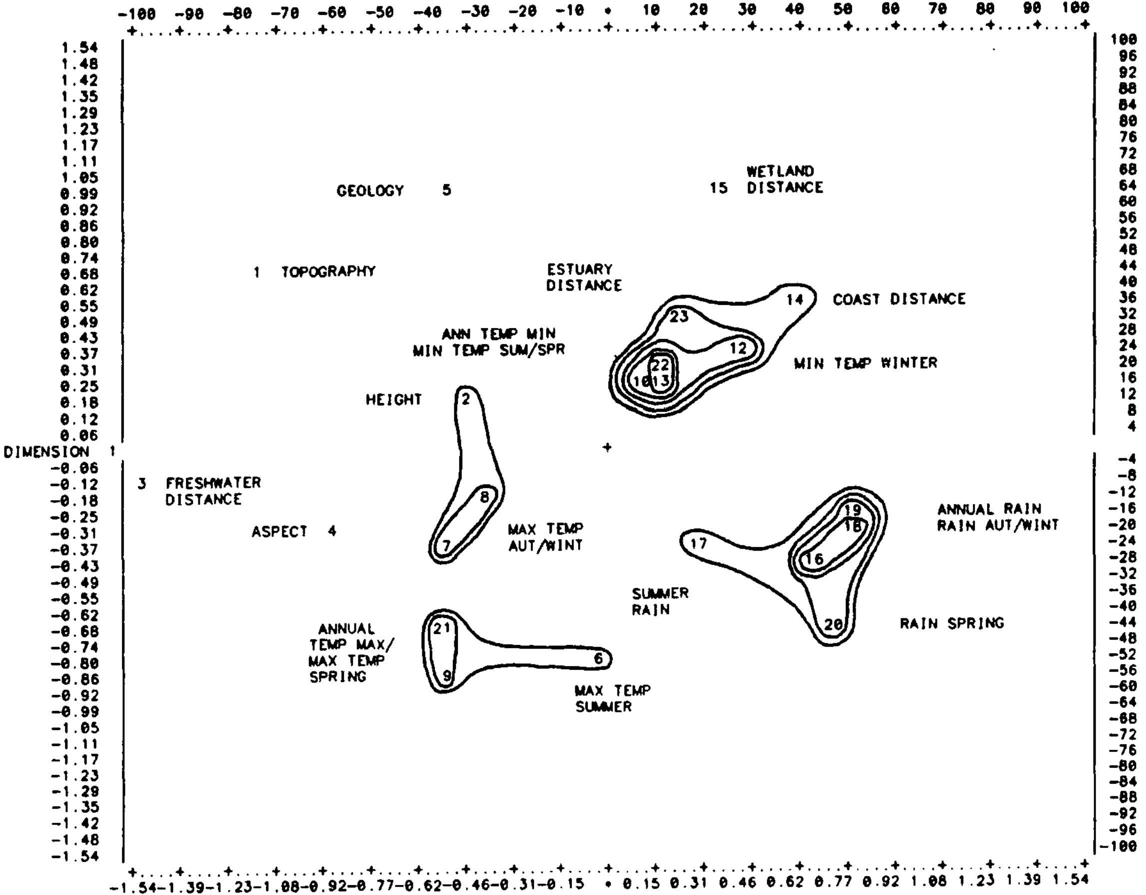
1 Topography
2 Height
3 Freshwater Distance
4 Aspect
5 Geology
6 Maximum Temperature Summer (January)
7 Maximum Temperature Autumn (April)
8 Maximum Temperature Winter (July)
9 Maximum Temperature Spring (October)
10 Minimum Temperature Summer (January)
11 Minimum Temperature Autumn (April)
12 Minimum Temperature Winter (July)
13 Minimum Temperature Spring (October)
14 Coast Distance
15 Wetland Distance
16 Annual Rainfall
17 Rain - Summer
18 Rain - Autumn
19 Rain - Winter
20 Rain - Spring
21 Annual Average Temperature (Max)
22 Annual Average Temperature (Min)
23 Estuary Distance

SOLUTION IN 3 DIMENSIONS:
STRESS DHAT = 0.126157 STRESS BASED ON APPROXIMATION TO RANDOM DATA = 0.238487
DIMENSION 2 PLOTTED AGAINST DIMENSION 1



N.B. POINT 22 OVERLAYS POINT 11

DIMENSION 3 PLOTTED AGAINST DIMENSION 1



N.B. POINT 13 OVERLAYS POINT 11

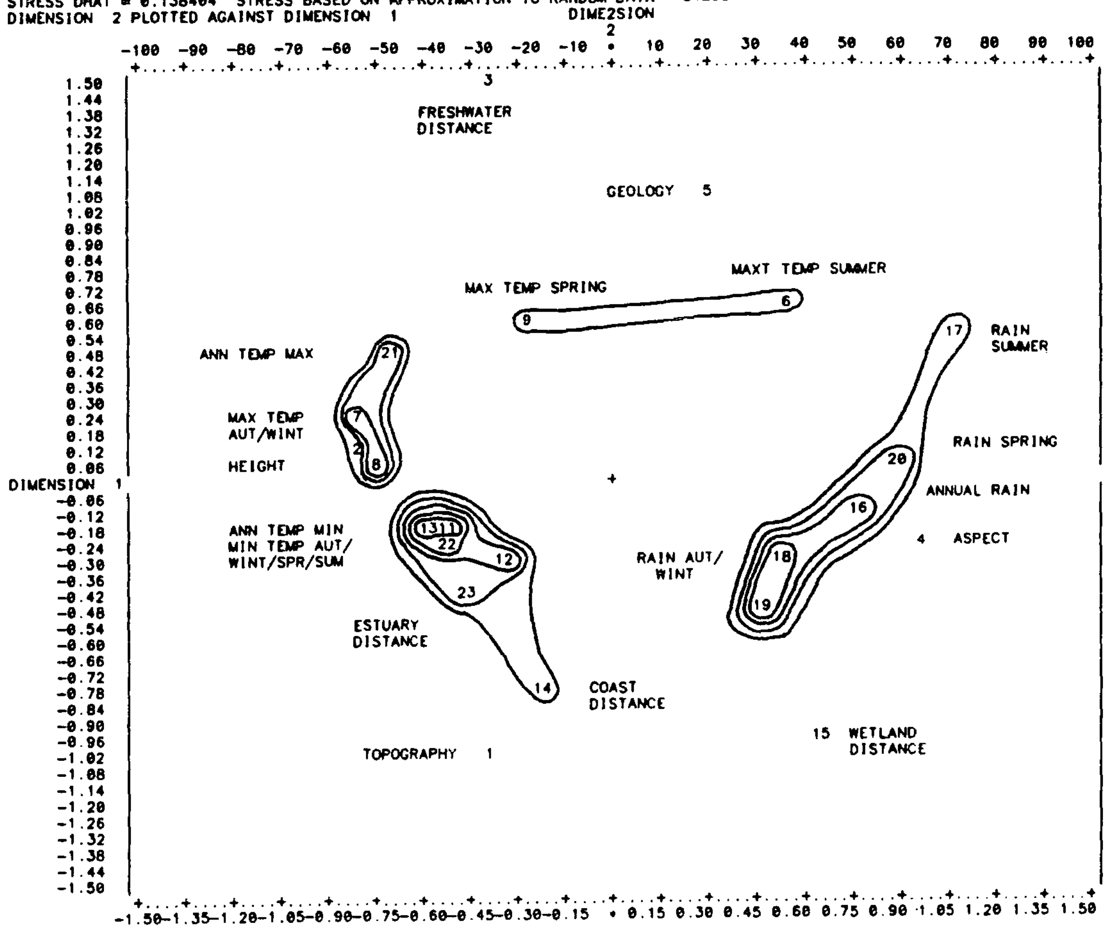
Figure 7.7: The identities of probable independent and multivariate influences upon Aboriginal locational decisions (Function Open sites).

locational decisions of both estuarine and coastal distances are likely to be conjoined with minimum temperature, and particularly with winter minimum temperature (which is itself likely to have possessed a degree of influence independent of the other minimum temperature variables).

The apparent distribution of individual, independent influences upon Aboriginal locational decisions as they are made manifest in Function Shelter sites (Figure 7.8) is similar to that associated with Function Open sites - those variables which were observed to be independent in Function Open sites are independent here (and, in addition, the same major group are observable). However, the strength of all apparent influences is weaker (i.e. the contours are more widely spaced). This is particularly evident in the maximum temperature grouping (in which maximum spring and summer temperatures are not only independent of the other variables but are also not closely related to each other), but also in the wide spacing between variables. This looseness in comparison with Function Open sites is likely to be associated with the greater influence of fundamental geological and topographic ties which has been stressed throughout this chapter as a source of major difference between the two Function sub-groups.

When grinding grooves are removed from the analysis of Function Open sites (and hence we begin to assess that portion of Aboriginal behaviour which is most likely to have been influenced by optimality principles; Figure 7.9), while the close association of climatic variables is largely maintained, maximum summer and spring temperature appear to have formed an

```
SOLUTION IN  3 DIMENSIONS:
STRESS DHAT = 0.138404  STRESS BASED ON APPROXIMATION TO RANDOM DATA = 0.238487
DIMENSION  2 PLOTTED AGAINST DIMENSION  1
```



N.B. POINT 13 OVERLAYS POINT 10

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DIMENSION  3 PLOTTED AGAINST DIMENSION  1
```

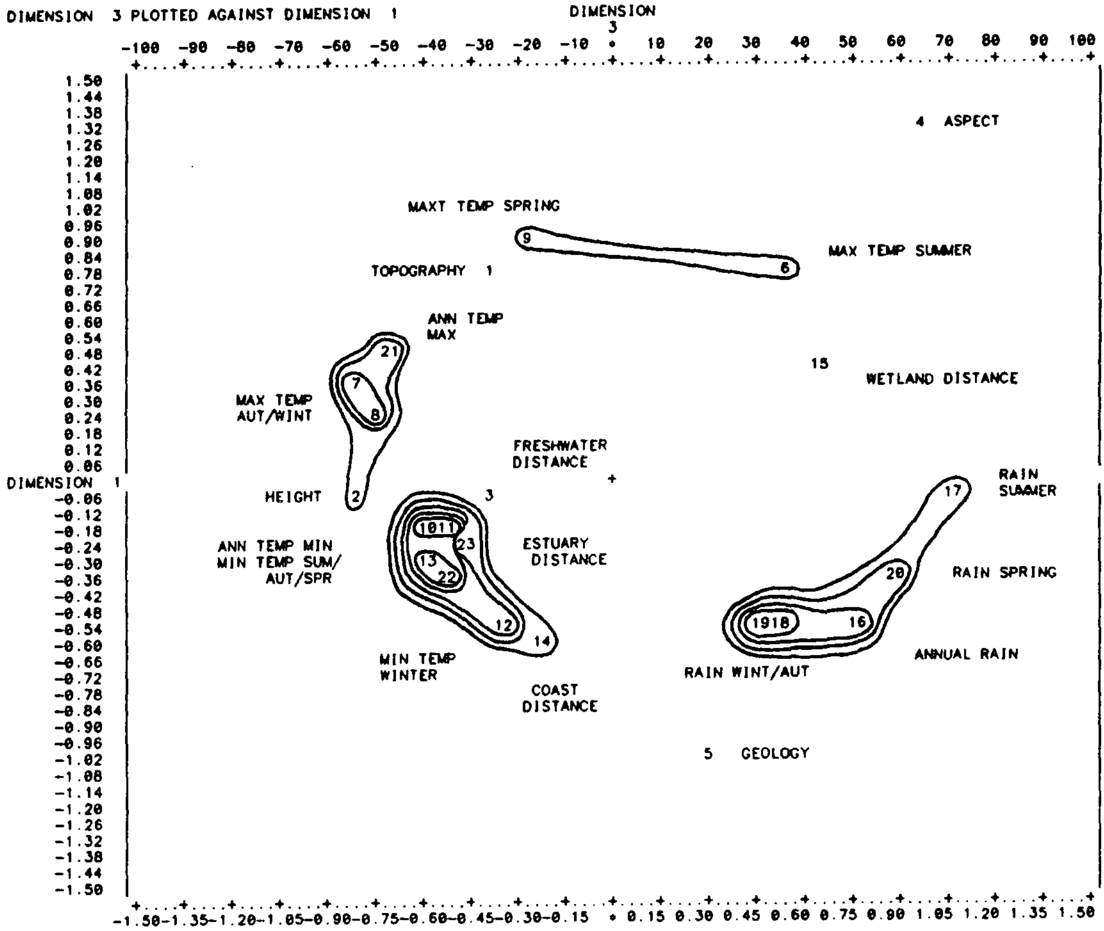
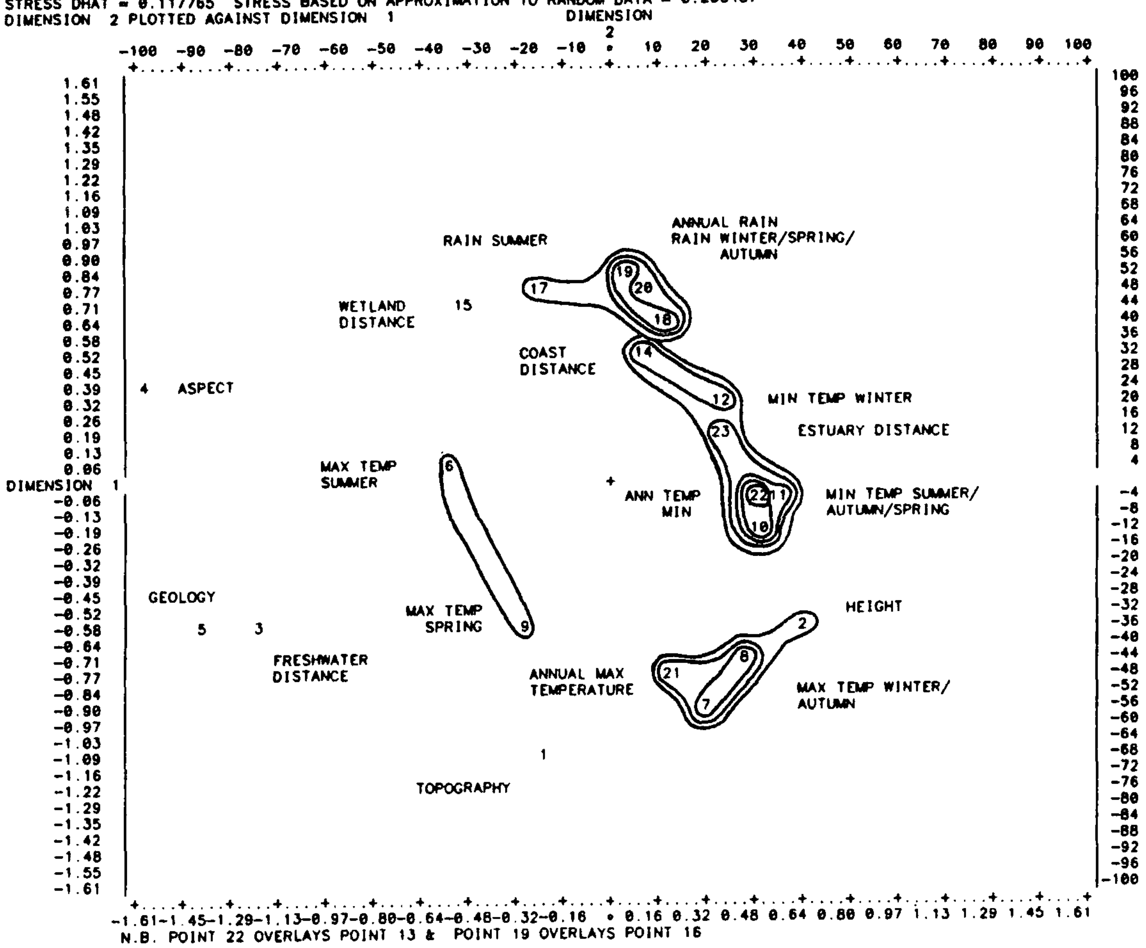


Figure 7.8: The identities of probable independent and multivariable influences upon Aboriginal locational decisions (Function Shelter sites).

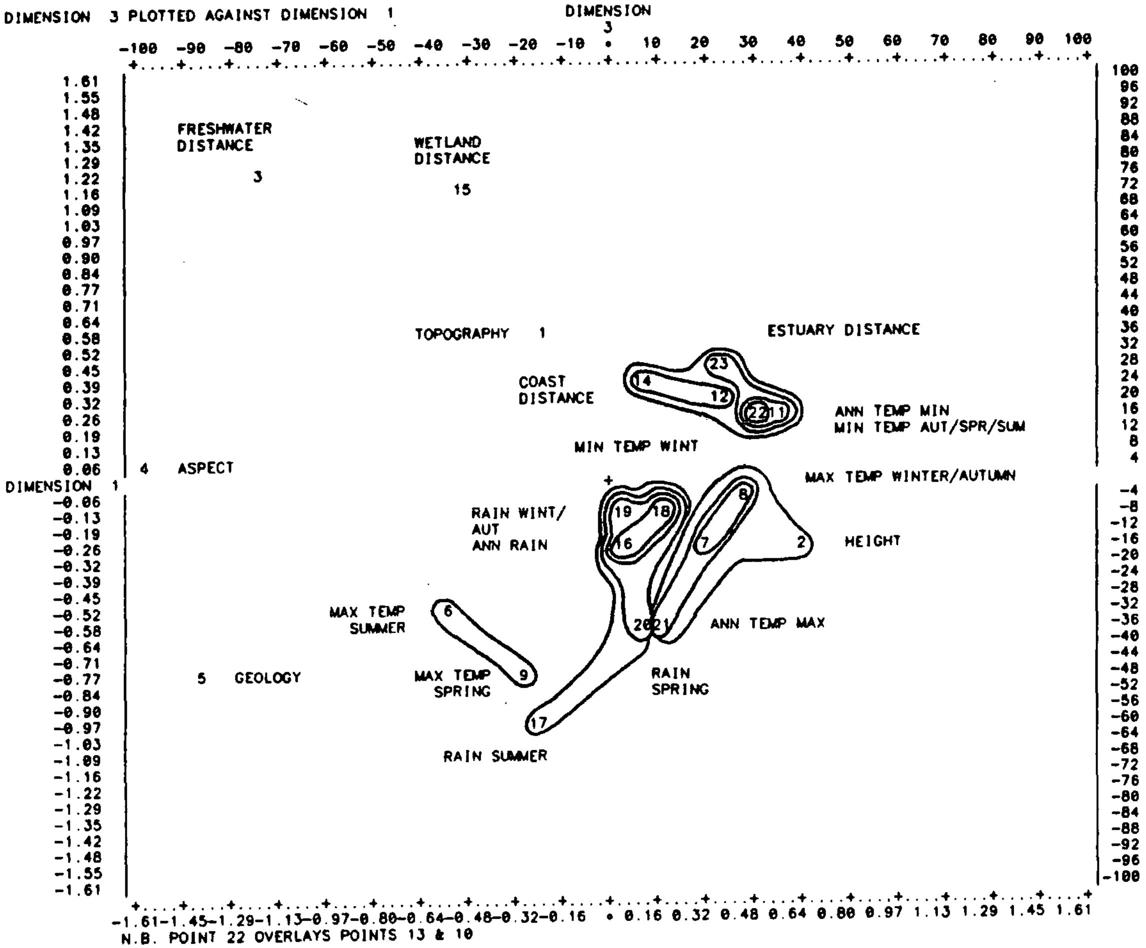
SOLUTION IN 3 DIMENSIONS:
STRESS DHAT = 0.117765 STRESS BASED ON APPROXIMATION TO RANDOM DATA = 0.238487

DIMENSION 2 PLOTTED AGAINST DIMENSION 1



N.B. POINT 22 OVERLAYS POINT 13 & POINT 19 OVERLAYS POINT 16

DIMENSION 3 PLOTTED AGAINST DIMENSION 1



N.B. POINT 22 OVERLAYS POINTS 13 & 10

Figure 7.9: The identities of probable independent and multivariate influences upon Aboriginal locational decisions (Function Open sites excluding grinding grooves).

independent influence upon Aboriginal locational decisions. In addition, coastal distance forms an almost independent group with minimum winter temperature. Similarly, among Function Shelter sites (Figure 7.10) the tendency to looseness of association continues to an extent wherein summer rainfall is likely to have been an independent influence upon Aboriginal locational decisions.

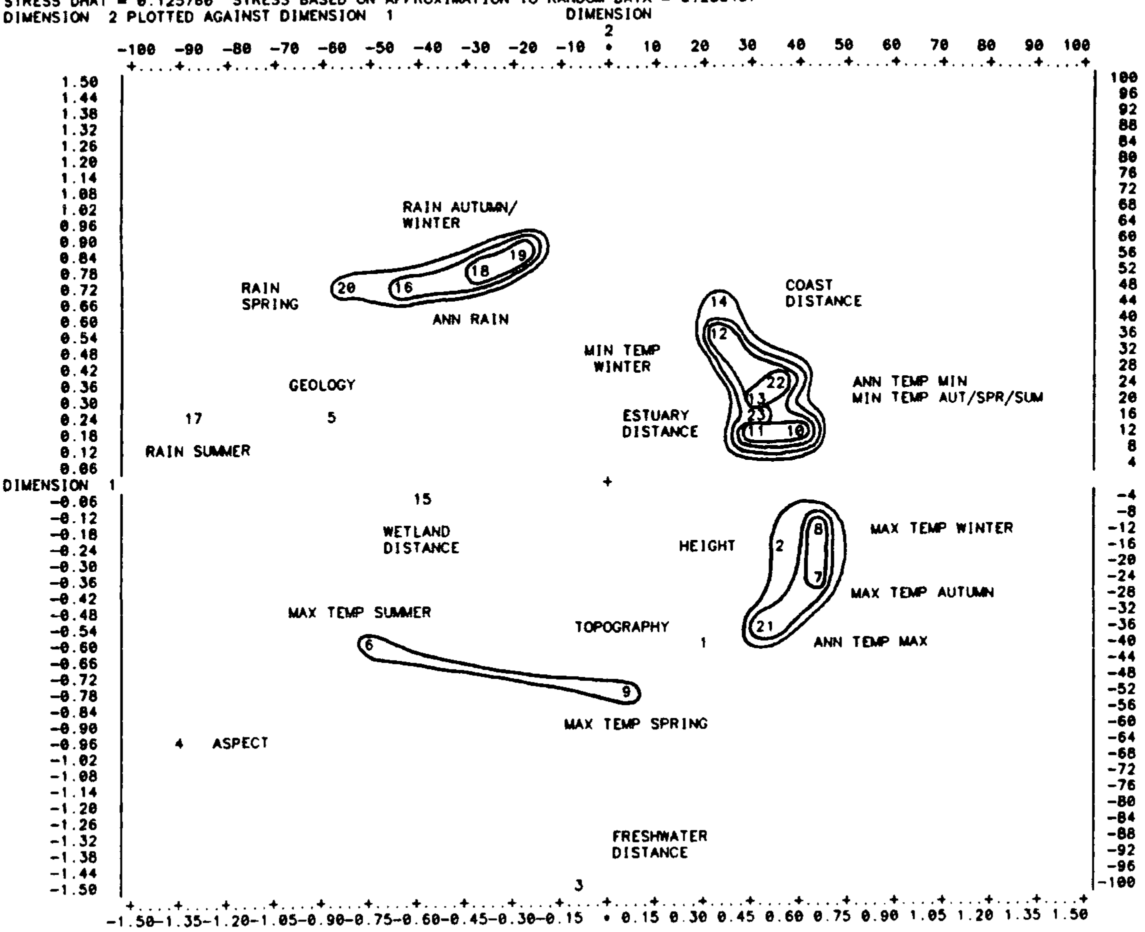
When middens (which possess, of course, the most pronounced coastal bias) are also removed from the analysis - coastal distance becomes an apparently independent influence upon locational decisions with regard to Function Open Sites (Figure 7.11). In addition, maximum temperature becomes a more widely dispersed group, with maximum temperature in summer but loosely associated - indicating the likelihood of the independence of the influence of this variable upon locational decisions. Broadly the same associations hold true for Function Shelter sites (Figure 7.12), but here summer maximum temperature becomes an independent variable.

7.6.1 The hidden structure

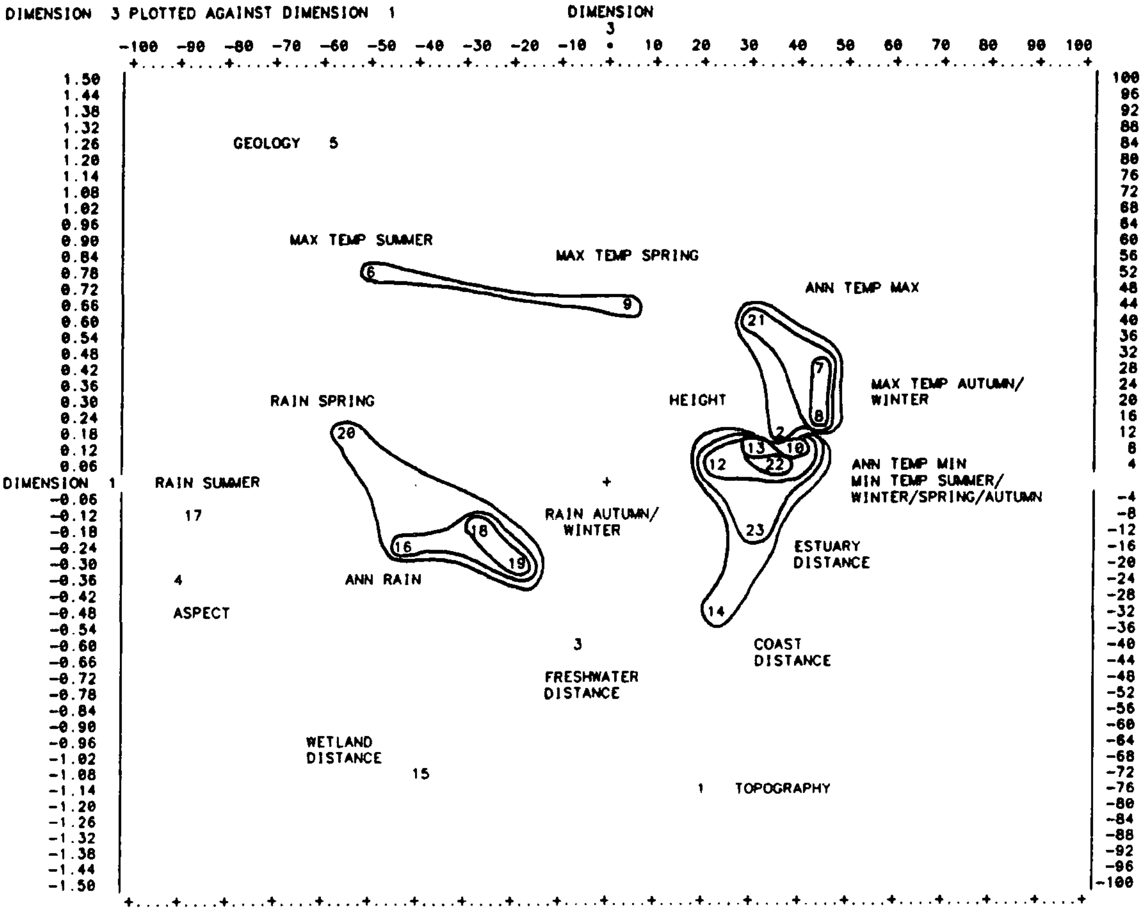
The application of multi-dimensional scaling techniques identifies those landscape variables which are likely to have influenced Aboriginal locational decisions as a group, and those which are likely to have influenced them independently of other variables. It does not, however, tell us anything about the nature of these associations (for example, while we may assume that winter minimum temperature and coastal distance, which show a close association throughout, are strongly and negatively

```
SOLUTION IN  3 DIMENSIONS:
STRESS DHAT = 0.125760  STRESS BASED ON APPROXIMATION TO RANDOM DATA = 0.238487
```

DIMENSION 2 PLOTTED AGAINST DIMENSION 1



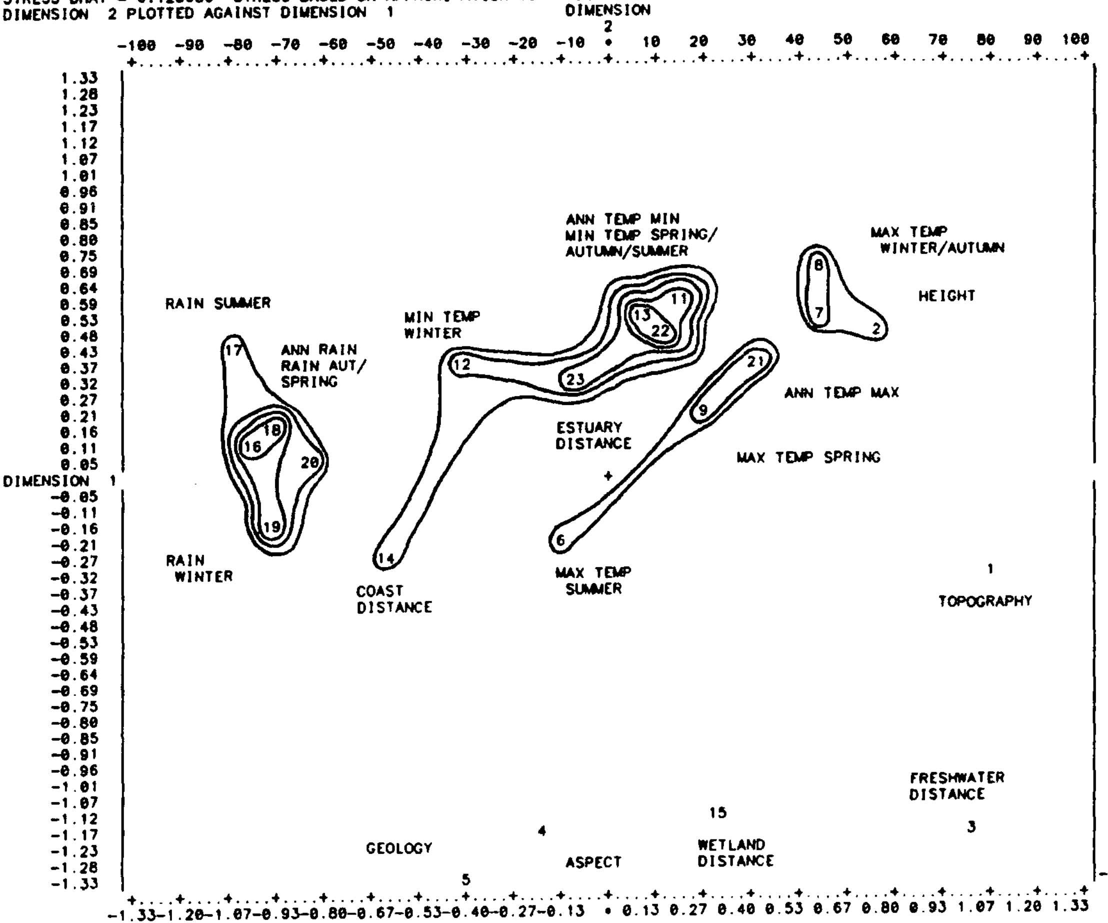
DIMENSION 3 PLOTTED AGAINST DIMENSION 1



N.B. POINT 13 OVERLAYS POINT 11

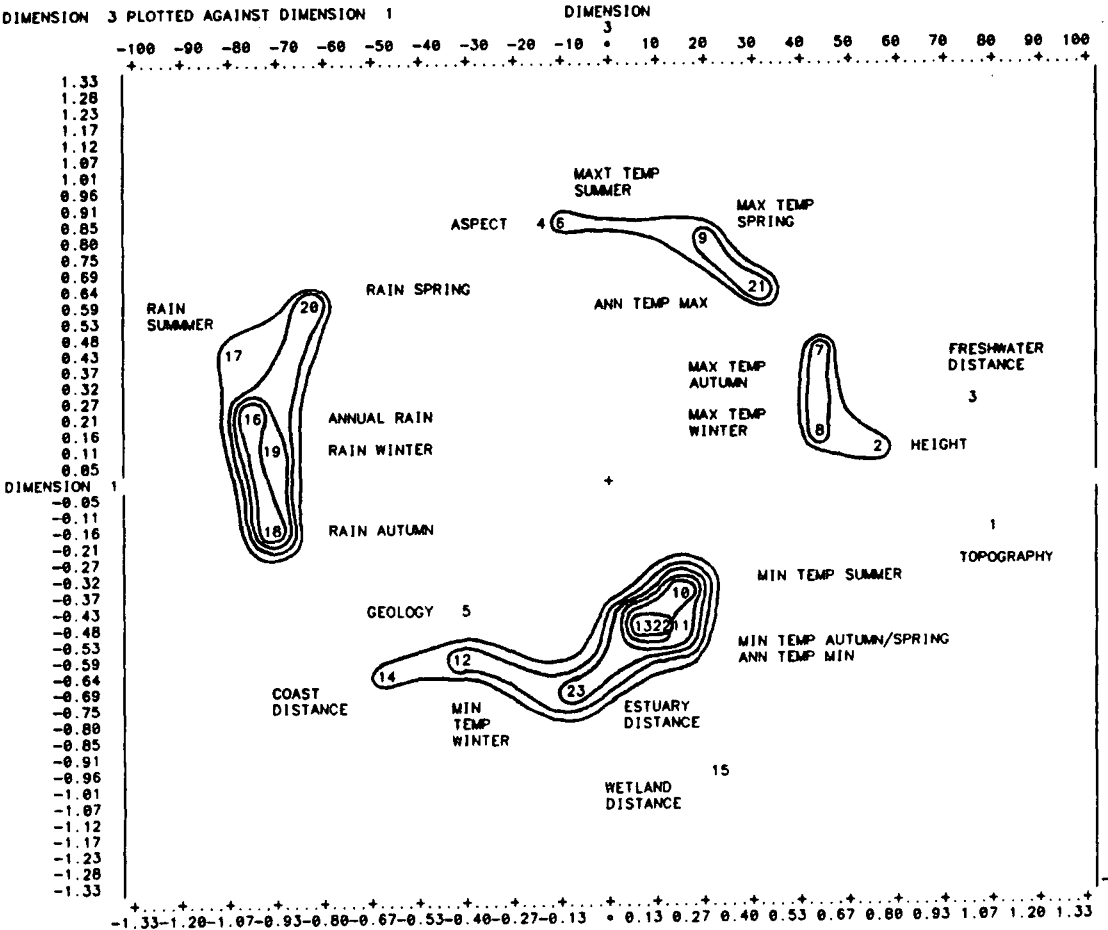
Figure 7.10: The identities of probable independent and multivariate influences upon Aboriginal locational decisions (Function Shelter sites excluding grinding grooves).

```
SOLUTION IN  3 DIMENSIONS:
STRESS DHAT = 0.123686  STRESS BASED ON APPROXIMATION TO RANDOM DATA = 0.238487
DIMENSION  2 PLOTTED AGAINST DIMENSION  1
```



N.B. POINT 11 OVERLAYS POINT 10

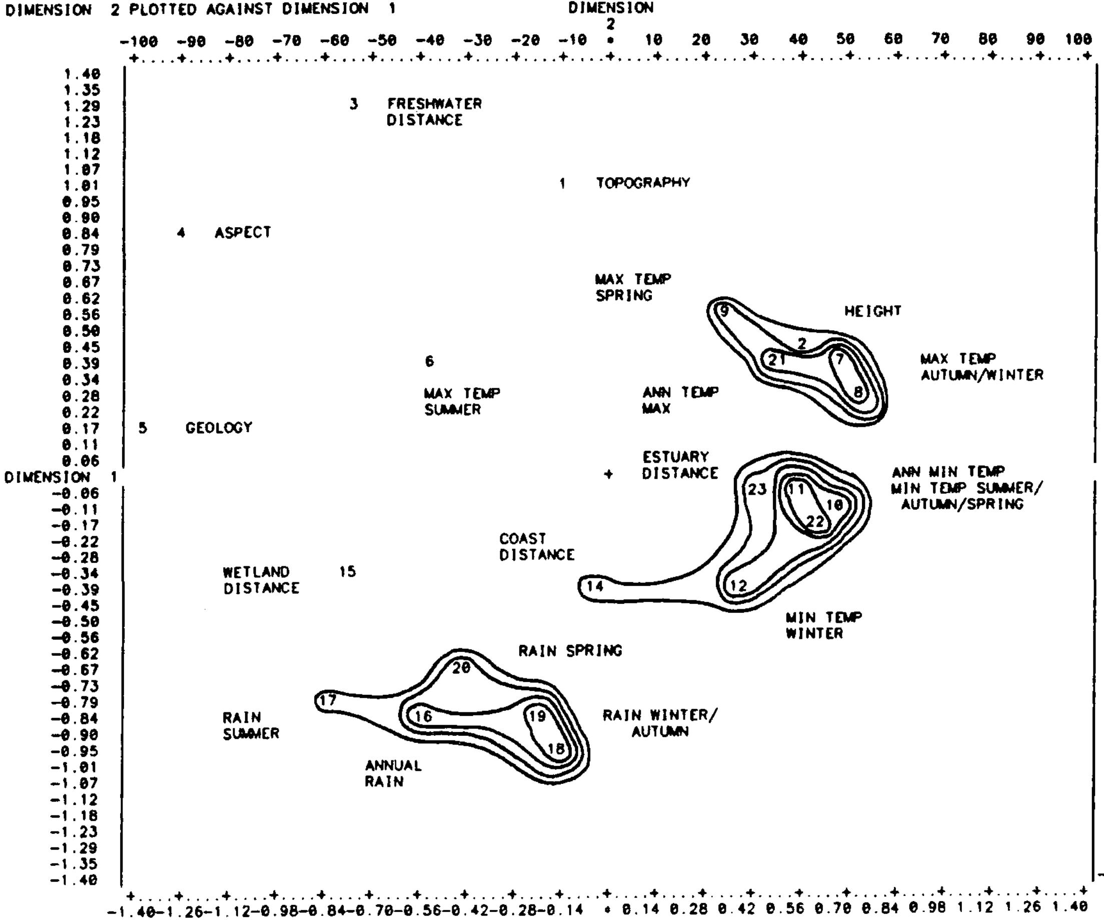
DIMENSION 3 PLOTTED AGAINST DIMENSION 1



gure 7.11: The identities of probable independent and multivariate influences upon Aboriginal locational decisions (Function Open sites excluding grinding grooves and middens).

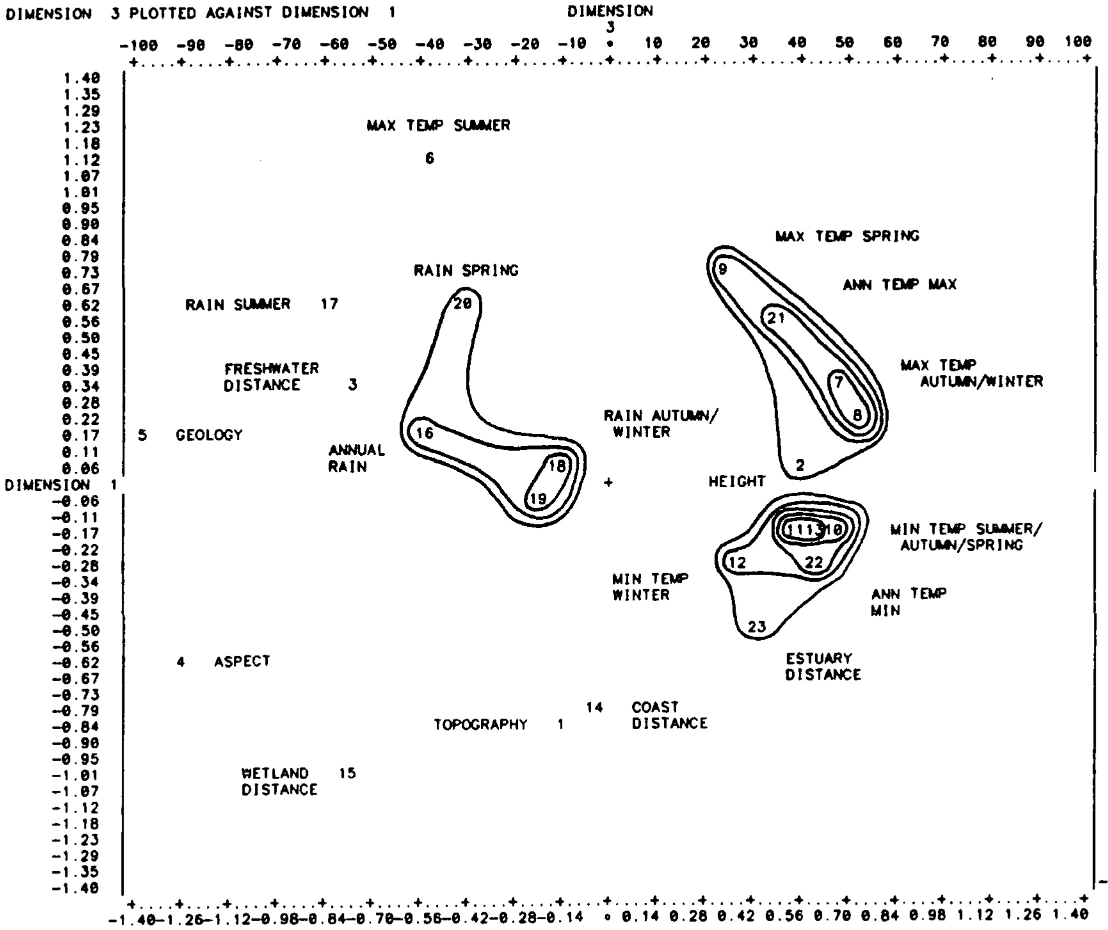
```
SOLUTION IN  3 DIMENSIONS:
STRESS DHAT = 0.127686  STRESS BASED ON APPROXIMATION TO RANDOM DATA = 0.238487
```

DIMENSION 2 PLOTTED AGAINST DIMENSION 1



N.B. POINT 22 OVERLAYS POINT 13

DIMENSION 3 PLOTTED AGAINST DIMENSION 1



gure 7.12: The identities of probable independent and multivariate influences upon Aboriginal locational decisions (Function Shelter sites excluding grinding grooves and middens).

correlated, the MDS technique neither requires this information or allows its derivation); or about the relative importance of group or individual influences upon Aboriginal locational decisions, and hence the closeness of fit with the behavioural model.

However, the technique does allow us to make some general points about the nature of the association of influences upon locational decisions which should be borne in mind:

1. The climatic variables of landscape are most closely associated with variables of their own type. Thus, rainfall variables remain a single group throughout, despite the fact that summer rainfall has a consistent tendency to outlie the main group.

2. Of the non-climatic variables, height possesses a consistent and close association with maximum temperature (particularly in autumn and winter); and both coastal and estuarine distance display a close association with minimum temperature variables (particularly with winter minimum temperature). Note also that the closeness of this latter relationship is reduced when middens are removed from the analysis, suggesting that away from the coast the influences of climatic variables are likely to become independent of these aquatic associations.

3. A number of landscape variables display large degrees of independence not only from the major groups but also from each other. These are

the distances of sites to freshwater and wetlands; the terrestrial structure components of geology, topography; and aspect.

In summary, then, multi-dimensional scaling techniques help us to identify both i) groups of variables whose influence upon Aboriginal locational decisions is likely to have been concerted (though not necessarily in the same direction); and ii) individual variables whose influence on behaviour is likely to be very largely independent of that of all other variables. In order to be in a position to confirm or deny the validity of the behavioural model, however, it is necessary to establish which of these groups and independent influences were the most important in Aboriginal locational decisions, to a large degree this can be achieved through the use of factor analysis.

7.7 FACTOR ANALYSIS - THE IDENTIFICATION OF ORTHOGONAL FACTORS AND INFLUENTIAL VARIABLES

7.7.1 Introduction - value and limitations

The term 'factor analysis' refers to a variety of techniques whose common objective is to represent a set of variables in terms of a smaller number of hypothetical variables (see Kim & Mueller 1978a, 1978b). These latter variables or 'factors' are assumed to be responsible for the covariation among observed variables.

Initial factoring usually determines the minimum number of factors which can adequately account for observed correlations, and in the process determines the communalities of the data (i.e. the variance of an observed variable accounted for by the common factors); then by the process of 'rotation', a simpler structure of factors is sought by specifying that they must be orthogonal (or uncorrelated).

The statistical workings of factor analysis impose certain strictures upon its usage. Principal among these is that the analysis requires that variables be measured at least at the interval level (Kim & Mueller 1978b:73; this requirement is implied by the use of correlation and covariance data as the basic input). In the present case, this would require that the topography and geology variables be dropped from the analysis (temperature variables are by convention considered as interval variables; while aspect is based upon a code which is the equivalent of a scale of degrees from north). However, by transforming the nominal data into an ordinal scale (of slope in the case of topography; of nutrient richness of derived soils in the case of geology) and applying approximate numerical values which reflect the underlying true distances (i.e. degrees 0, 15, 30, 60, 75 from the horizontal and estimates of phosphorus ppm) some of this difficulty can be removed, because correlation coefficients are known to be fairly robust with regard to this form of distortion of measurement (Kim & Mueller 1978b:74).

Nonetheless, because the degree of distortion caused by the inclusion of these two variables is unknown, in the analysis below, factors are determined in the proper manner for all metrical data and then as an exploratory technique with the altered variables included.

The factors extracted here are those with an Eigenvalue greater than one - a well-known and generally approved convention (see Kim & Mueller 1978b:43). They were obtained using the recently reorganized SPSS package (SPSSX; Norusis 1985) and the VARIMAX rotation option - a method of orthogonal rotation which simplifies the factor structure by maximizing the variance of a column of the pattern matrix (Kim & Mueller 1978b:35).

Two final, but important points, must be made before proceeding to the analysis. Firstly it should be noted that although percentage of variance accounted for by each factor is noted before the rotated factor matrix is presented, these figures are only relevant to factor extraction before rotation (i.e. initial factoring); once different dimensions are separated out through rotation, it is not crucial to know how much variance in the data each factor explains (op.cit:77). (Though, in broad terms factor one will still explain more of the variance within the data than factor two, and factor two more than factor three - and so on.) In addition, the present dataset contains a number of closely related climatic variables imposed upon the analysis because of the lack of knowledge concerning the relevant time-scale appropriate to the study of Sydney Aboriginal behaviour. These close associations, and effects imposed by the use of a variety of dissimilar scales, are likely to exaggerate the percentage of variance accounted for by the initial factors in which these variables are present.

Factor analysis is applied here not only in order to establish which variables are independently influential concerning the characteristics of the whole data; but also to identify those variables which contribute most highly to the independent (orthogonal) factors (i.e to identify the seasonal climatic variables (and hence the time-scale) which most influenced Aboriginal locational decisions).

As a final point, it should be noted that the sign of a factor-loading has no intrinsic meaning and cannot be used to assess the magnitude of the relationship between the variable and the factor. (However, the probable direction can often be inferred from the previous comparative analysis.) Yet, the signs associated with a variable in relation to a factor do have a specific meaning relative to signs associated with other variables within the same factor. The different signs mean simply that the variables are related to the factor in different directions. For example, average rainfall and height may load upon a factor positively and negatively respectively - we may not infer directions from these relationships to the factor, but we may assume economically (based upon the information derived from the comparison of the Function and Style populations above) that the relationship is one in which as the influence of rainfall increases, so the influence of height relative to the factor decreases. Similarly where a variable such as wetland distance or coastal distance is the only variable to load upon a factor (i.e. a unique factor) and it loads positively this cannot be said to suggest that the distance is not being minimized, for this assumes that the factor direction is positive - an assumption which cannot be substantiated. The evidence of the preceding analysis would lead us to suggest, however, that this is likely to be the case.

7.7.2 Factor analysis - data modifications

Three major modifications have been made to the data in order to maximize the amount of information which may be gained concerning the relationship between Aboriginal locational decisions and the behavioural model. These modifications are as follows:

1. The division between Function Open and Function Shelter sites is maintained because of the difference in these two populations with regard to the fundamental ties to a narrow range of geological and topographic characteristics which is associated with the Function Shelter population (i.e. in contrast to the theoretical ability of Function Open sites to be located at any point in the landscape).

2. A division is made between coastal and inland sites in order to facilitate better understanding of the factors produced. It has been suggested in the preceding analysis that coastal and estuarine variables may not exert any particular influence upon locational decisions in inland areas (i.e. that site locations may reflect the behaviour of a separate ecological population within the inland areas). This separation into coastal and inland areas prevents the blanketing influence of the coastal bias in site distribution and hence coast-related factors.

3. Only data from the sub-regions (three coastal and three inland) are utilized. These areas represent all the major characteristics of the region and in addition provide the least-disturbed and best-studied archaeological data.

In addition, an increase in derived information is sought by the modification of the data by the extraction of grinding grooves and (where appropriate) middens, though for the sake of comparison, the whole data are considered first. It has been suggested above that these two sub-populations have an extreme influence upon evidence of Aboriginal locational decisions: the one because the behaviour which caused it to come into being was not closely related to the food-quest; the other because of the compression of the sub-population upon the coast and its consequent contribution to the Function populations of coastal characteristics.

7.7.3 Coastal factors

The rotated factor matrix for all Function Open sites (including grinding grooves and middens) using only metrical data is presented in Table 7.2a. Rainfall variables (principally annual rainfall) load highly and positively upon the first factor; while maximum temperature variables load highly and negatively. The implication of these results are likely to be that the principal influences upon Aboriginal locational decisions were the maximization of rainfall and the minimization of maximum temperature. In neither case is there more than a little evidence to

Abbreviation	Definition
GEOLOGY	Phosphorus content of soils associated with parent material
TOPOGRAPHY	Degrees of slope
HEIGHT	Height above sea-level
ESTUARY	Distance to an estuary
COAST	Distance to the coast
WETLAND	Distance to a wetland
FRESHWATER	Distance to a freshwater source
ANNUALRAIN	Average annual rainfall
RAINSUMMER	Average summer rainfall
RAINAUTUMN	Average autumn rainfall
RAINWINTER	Average winter rainfall
RAINSPRING	Average spring rainfall
ANNUALTMIN	Average annual minimum temperature
MINTSUMMER	Average summer minimum temperature
MINTAUTUMN	Average autumn minimum temperature
MINTWINTER	Average winter minimum temperature
MINTSPRING	Average spring minimum temperature
ANNUALTMAX	Average annual maximum temperature
MAXTSUMMER	Average summer maximum temperature
MAXTAUTUMN	Average autumn maximum temperature
MAXTWINTER	Average winter maximum temperature
MAXTSPRING	Average spring maximum temperature
ASPECT	Aspect (degrees from north)

Key to abbreviations used in factor analysis tables.

```
a  FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

     1       8.38820       39.9         39.9
     2       7.39058       35.2         75.1
     3       1.57512        7.5         82.6
     4       1.10481        5.3         87.9

   ROTATED FACTOR MATRIX:

                    FACTOR  1     FACTOR  2     FACTOR  3     FACTOR  4

   ANNUALRAIN         .93710        .22962        .02717        .11929
   MAXTSUMMER       -.92793       -.00052        .34340        .02161
   RAINSUMMER         .91662       -.15700        .16200        .09067
   RAINSPRING         .91357        .19735        .18057       -.09595
   RAINAUTUMN         .91157        .32221       -.06822       -.07419
   ANNUALTMAX        -.89838        .25698        .19552       -.03740
   RAINWINTER         .89680        .14229       -.23396       -.07519
   MAXTSPRING        -.73383        .41535        .48941        .10728

   ANNUALTMIN         .11715        .96815        .00996        .00882
   MINTSPRING         .11730        .96347        .12448        .04486
   MAXTAUTUMN        -.26653        .90834        .25164        .05999
   ESTUARY            .21254       -.89379       -.06038       -.01799
   MINTSUMMER         .41407        .87158       -.14766        .00581
   MINTWINTER         .50707        .84844        .03520       -.03911
   MINTAUTUMN         .57471        .81000       -.04229        .03641
   HEIGHT             .06575       -.80775       -.07574        .03778
   MAXTWINTER        -.62879        .70066        .25655        .00916

   COAST             -.32014       -.06899       -.78445        .21080
   WETLAND            .05893        .21992       -.73461       -.10172

   ASPECT            -.12656        .09133       -.13511        .84538
   FRESHWATER        -.27068        .44756       -.20798       -.55766
```

```
b  FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

     1       8.49278       36.9         36.9
     2       7.75311       33.7         70.6
     3       1.87268        8.1         78.8
     4       1.43725        6.2         85.0

   ROTATED FACTOR MATRIX:

                    FACTOR  1     FACTOR  2     FACTOR  3     FACTOR  4

   MAXTSUMMER        -.93600       -.00792        .32092        .03676
   ANNUALRAIN         .93465        .22612        .04548        .16219
   RAINAUTUMN         .91814        .31297       -.02089       -.05626
   RAINSPRING         .91499        .17362        .22686       -.02311
   RAINSUMMER         .90967       -.16576        .18109        .12701
   RAINWINTER         .90533        .14014       -.20441       -.05407
   ANNUALTMAX        -.89972        .25089        .18108       -.02512
   MAXTSPRING        -.74418        .40262        .48474        .13083

   ANNUALTMIN         .12369        .96539        .05052       -.01002
   MINTSPRING         .12002        .95656        .15499        .06652
   MAXTAUTUMN        -.26711        .89910        .27418        .07247
   ESTUARY            .20527       -.88796       -.11072        .04225
   MINTSUMMER         .42373        .87152       -.10699       -.01360
   MINTWINTER         .51398        .83675        .08183       -.01134
   HEIGHT             .06388       -.81083       -.13545        .24654
   MINTAUTUMN         .58009        .80713       -.00397        .03630
   MAXTWINTER        -.63018        .69139        .25881        .02608
   TOPOGRAPHY         .09474       -.59616        .17309        .51006

   COAST             -.34599       -.08855       -.74464        .33095
   WETLAND            .03763        .19013       -.71287       -.03882
   GEOLOGY            .00619        .29686        .63448       -.56206

   FRESHWATER        -.26985        .47785       -.21948       -.59165
   ASPECT            -.09113        .03799       -.08070        .52325
```

Table 7.2: Factor analysis results - coastal open sites for a) only metrical data; and b) all data.

suggest that these climatic variables influenced the location decisions at anything other than an annual scale. This latter emphasis is also suggested by the predominance among the positive loadings on the second factor of annual minimum temperature. In this case the presence of estuary distance and height which load negatively, increases the likelihood that the loadings can be interpreted as the influence upon Aboriginal locational decisions of the maximization of minimum temperatures and the minimization of distance to estuaries and height.

That the Sydney region Aborigines tended to minimize distances to aquatic resource areas is emphasized by the negative loading upon the third factor of coastal and wetland distance[1]. Aspect and freshwater distance are associated with a fourth factor, presumably indicating the low degree of influence of these landscape variables upon Aboriginal locational decisions. None the less, it is evident that the Aborigines tended to maximize aspect (i.e. south to north-west) and minimized distance to freshwater.

The inclusion of the modified categorical variables - geology and topography - in this consideration of all Function Open data (Table 7.2b) does not fundamentally alter the factor structure. However, the results indicate the relative importance of landforms of low slope (second factor - negative loading) and rocks which produce soils of relatively high

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[1] Note that although the negative loadings of these two variables are convenient, it is not possible to infer the minimization of these distances directly from the factor structure alone because there are no opposing variables associated with the factor - the inference is derived from the general tendencies noted for the data in the analysis above.

phosphorus content (third factor - positive loading) upon Aboriginal locational decisions.

The removal of grinding grooves from the analysis brings us closer to a consideration of influences upon Aboriginal locational decisions which are likely to be associated with the food quest. The absence of these sites brings about major changes in the factor structure (Table 7.3a). Now minimum temperature variables load highly and positively upon the first factor (particularly average annual spring and winter minimum temperature) while estuarine distance and height load highly and negatively. In terms of Aboriginal locational decisions this would seem to indicate that an important influence was the maximization of minimum temperatures (particularly in winter and spring) and the minimization of estuarine distance and height. Rainfall variables form a consistent group, loading upon the second factor; so much so, that this factor may be described as a discrete rainfall factor influencing locational decisions - presumably indicating the preference for wetter areas upon the coast. The variables which load upon factor three may be taken to suggest the influence of the minimization of maximum temperature (particularly summer and spring maximum temperatures) and distance to the coast; while aspect and wetland distance load highly upon the fourth factor suggesting the apparent importance of the maximization of the former (i.e. south to north-west) and the minimization of the latter. Freshwater distance forms a unique fifth factor which presumably indicates the relative unimportance of this influence upon locational decisions on the coast (though the distance is still likely to be minimized).

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a   FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

       1      7.30347        34.8        34.8
       2      6.01571        28.6        63.4
       3      1.97284         9.4        72.8
       4      1.21701         5.8        78.6
       5      1.08279         5.2        83.8

    ROTATED FACTOR MATRIX:

                  FACTOR  1    FACTOR  2    FACTOR  3    FACTOR  4    FACTOR  5

    ANNUALTMIN      .94615       .08118     -.07146      -.04767      -.06617
    MINTSPRING      .92263       .05350      .06860       .01977       .05913
    MINTWINTER      .85738       .44794     -.05178       .00749      -.09388
    MINTSUMMER      .83525       .13345     -.43791      -.03453      -.10675
    MINTAUTUMN      .81945       .34813      .01753       .07336       .05681
    MAXTWINTER      .77993      -.07295      .47152      -.01331      -.01133
    HEIGHT         -.75395       .01478     -.45315      -.13013      -.07947
    ESTUARY        -.74280       .15786     -.56624      -.06958      -.07888
    MAXTAUTUMN      .72529      -.23940      .57380       .04704       .06295

    RAINSPRING      .19258       .90945      .02144      -.03125      -.11599
    ANNUALRAIN      .07688       .90902     -.19447       .03278       .13828
    RAINAUTUMN      .25183       .88029     -.23659      -.06843      -.02176
    RAINSUMMER     -.38097       .81334      .01290       .00317       .05531
    RAINWINTER      .33790       .79125     -.30757      -.03319      -.13768

    MAXTSUMMER     -.07049      -.30547      .88956      -.01159       .07015
    MAXTSPRING      .15103       .01166      .87710      -.04379      -.09151
    ANNUALTMAX      .36942      -.53011      .61176       .07121       .08943
    COAST          -.41260      -.37960      .47768       .35997       .23675

    ASPECT         -.09651      -.08871      .01658       .74907      -.30006
    WETLAND         .22804       .05790     -.01795      -.71178       .27272

    FRESHWATER     -.00631      -.03426      .02993      -.01883       .90262
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b  FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

     1       7.45699        32.4        32.4
     2       6.06550        26.4        58.8
     3       2.11335         9.2        68.0
     4       1.25250         5.4        73.4
     5       1.09796         4.8        78.2
     6       1.07306         4.7        82.9

   ROTATED FACTOR MATRIX:

                 FACTOR  1    FACTOR  2    FACTOR  3    FACTOR  4    FACTOR  5    FACTOR  6

   ANNUALTMIN      .94992       .08091       .05102      -.04577       .03795      -.07031
   MINTSPRING      .90730       .03993       .17646       .02905      -.01668       .07270
   MINTSUMMER      .88065       .15061      -.31010      -.03589      -.08145      -.11916
   MINTWINTER      .86222       .43856       .06636       .01244       .00333      -.08003
   MINTAUTUMN      .81286       .34325       .12856       .07949       .04739       .05788
   MAXTWINTER      .71759      -.11181       .54954      -.00036      -.02947       .03457
   HEIGHT         -.69222       .03182      -.54428      -.13596      -.13758      -.07895
   ESTUARY        -.67098       .19298      -.62490      -.08240      -.10810      -.10466
   MAXTAUTUMN      .65454      -.27989       .61710       .06131       .09537       .09868
   COAST          -.45537      -.40068       .33760       .36473       .32666       .23778

   ANNUALRAIN      .09916       .91904      -.13532       .03609      -.03382       .13020
   RAINSPRING      .19632       .89344       .07336      -.02595      -.02766      -.08728
   RAINAUTUMN      .28532       .88838      -.16840      -.07065       .03799      -.02814
   RAINSUMMER     -.37255       .81687      -.01034       .00386       .11975       .04464
   RAINWINTER      .36812       .79604      -.19833      -.03130      -.22257      -.12434

   MAXTSPRING      .04905      -.04440       .86941      -.03194       .06474      -.02963
   MAXTSUMMER     -.17120      -.35330       .82711      -.00268       .18129       .11127
   TOPOGRAPHY     -.17239      -.15969      -.64132      -.00990       .18690       .10283
   ANNUALTMAX      .29149      -.57320       .60738       .08189      -.00333       .13427

   ASPECT         -.10892      -.08110       .03657       .73925      -.04655      -.34294
   WETLAND         .22815       .04455      -.02570      -.72098      -.04558       .30416

   GEOLOGY         .10250      -.00189       .03390      -.07327       .94233      -.08109

   FRESHWATER     -.02531      -.02817       .02529      -.01121      -.06387       .87792
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Table 7.3: Factor analysis results - coastal open sites (excluding grinding grooves for a) only metrical data; and b) all data.

When the modified variables - geology and topography - are introduced (Table 7.3b) the major change is that coastal distance loads upon the first factor rather than the third, suggesting the importance of this influence upon Aboriginal locational decisions. In general, the new first factor suggests that the primary influences upon Aboriginal decisions upon the coast were likely to have been the maximization of minimum temperatures; the minimization of estuary and coast distances; and the minimization of height. The principal position of average annual minimum temperature upon the first factor and the same position of annual rainfall upon the second, suggest that the annual scale of influence upon Aboriginal locational decisions is most appropriate.

The introduced variable - topography - loads upon the third factor with maximum temperature variables, suggesting the tendency for locational decisions to be influenced by areas of low relief and relatively lower maximum temperatures. Both aspect and wetland again load highly upon the independent fourth factor; while geology forms a unique fifth factor and freshwater - a unique sixth. This latter part of the factor structure suggest the influences upon Aboriginal locational decisions of facing south to north-west; being in close proximity to wetlands and areas characterized by geological parent materials which produce soils of high fertility; and proximity to water.

The most cautious interpretation of these results suggests that the exclusion of geology and topography variables is likely to distort our knowledge of the influences upon Aboriginal locational decisions considerably. The presence of the full dataset re-positions coastal distance upon the first factor (where on the basis of the multi-dimensional scaling analysis it might be expected) as well as indicating that geology, itself, is an influential variable forming a unique orthogonal factor. In addition, it appears reasonable to assume that an annual scale is the most appropriate for considering the two climatic variables (minimum temperature and rainfall) which are likely to have most influenced Aboriginal locational decisions.

When the principal influence binding the locational data hard to the coast and estuarine border - middens - are also removed, important changes again occur in the factor structure (Table 7.4a). Minimum spring temperature and annual minimum temperature load positively and most highly upon the first factor; while estuarine distance and height load negatively and highly. This relationship suggests the tendency for Aboriginal locational decisions to be influenced by areas of higher minimum temperatures, low height and close proximity to estuaries. The second factor produces some evidence of seasonal influence upon locational decisions for summer rainfall and summer maximum temperature predominate in the positive and negative loadings respectively; this would appear to suggest that away from the coast these summer extremes were important influences upon Aboriginal locational decisions.

Coastal distance forms a unique third factor which, while reflecting the expected lower degree of influence, still suggests that the minimization of this distance was an influence upon Aboriginal decisions.

a

FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
1	7.28905	34.7	34.7
2	7.06113	33.6	68.3
3	1.21277	5.8	74.1
4	1.07343	5.1	79.2
5	1.00809	4.8	84.0

ROTATED FACTOR MATRIX:

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
MINTSPRING	.92735	.16186	.13102	.03152	.05293
ANNUALTMIN	.89539	.16304	.24945	.03789	-.01770
ESTUARY	-.89116	.14701	.21509	-.01800	-.02841
MAXTAUTUMN	.85194	-.18719	-.28616	.05771	.09293
HEIGHT	-.84829	.10001	.06010	-.01352	-.01415
MAXTWINTER	.82946	-.32174	-.08467	-.11447	.13589
MINTAUTUMN	.81362	.38626	.17713	.13144	-.00751
MINTWINTER	.78949	.44408	.35691	.07358	.00675
MINTSUMMER	.61212	.33070	.60243	.10336	.02331
MAXTSPRING	.61075	-.32998	-.53607	-.16264	.05083
RAINSUMMER	-.23391	.92219	-.13488	-.01265	-.03355
ANNUALRAIN	.11554	.92149	.23577	.05766	.05714
RAINAUTUMN	.18880	.87549	.30442	-.00887	-.01723
RAINSPRING	.17322	.86849	.23852	-.07209	.00794
RAINWINTER	.04512	.74487	.53444	.02448	.02367
ANNUALTMAX	.50717	-.70187	-.25814	-.11681	.13078
MAXTSUMMER	.30919	-.62838	-.61935	-.14525	.05160
COAST	-.01959	-.30243	-.79095	.15540	.04153
ASPECT	-.01808	.09075	-.08516	.87041	-.07692
WETLAND	.32730	-.20369	.17279	-.43722	.34621
FRESHWATER	.04593	.04108	-.06862	-.03821	.94438

b

FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
1	7.58643	33.0	33.0
2	7.07549	30.8	63.7
3	1.29448	5.6	69.4
4	1.11849	4.9	74.2
5	1.04413	4.5	78.8

ROTATED FACTOR MATRIX:

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
MINTSPRING	.92706	.15394	.12346	.05467	-.01933
ANNUALTMIN	.91361	.18847	.08670	-.07543	-.01819
MINTWINTER	.83434	.49201	.04925	-.10553	.01395
MINTAUTUMN	.82239	.38772	.12719	.00994	.08941
ESTUARY	-.80722	.23175	-.34210	-.16030	-.01712
MAXTWINTER	.79017	-.36459	.17498	.12902	-.15006
HEIGHT	-.78482	.13755	-.40269	.03902	-.01082
MAXTAUTUMN	.77036	-.28709	.30379	.27075	.05350
MINTSUMMER	.73934	.45216	-.25441	-.21889	-.00336
WETLAND	-.46012	-.15839	-.36118	.21339	.31240
ANNUALRAIN	.15845	.94449	-.02082	.06869	.04130
RAINAUTUMN	.22342	.91711	.03921	-.06231	-.01868
RAINSPRING	.19226	.89119	.06494	-.01127	-.07441
RAINSUMMER	-.28499	.86232	.18514	.21250	.05077
RAINWINTER	.15373	.85372	-.18769	-.22445	-.02593
MAXTSUMMER	.15385	-.77832	.40398	.30097	-.08360
ANNUALTMAX	.44352	-.76209	.19308	.11439	-.12384
TOPOGRAPHY	-.36177	.06086	-.58980	.26920	-.00853
GEOLOGY	.19964	.00363	.50712	-.00654	.03515
MAXTSPRING	.45207	-.48218	.49063	.29882	-.10942
FRESHWATER	.14280	.03263	-.21665	.64307	-.12856
COAST	-.16778	-.49555	.28939	.57621	.22991
ASPECT	.01047	.06318	.03125	-.07707	.90185

Table 7.4: Factor analysis results - coastal open sites (excluding grinding grooves and middens for a) only metrical data; and b) all data.

In comparison, both aspect and wetland distance (fourth factor) and freshwater distance (fifth) appear as relatively minor influences upon these decisions.

When the modified variables are introduced (Table 7.4b), the influence upon behaviour of spring and winter minimum temperatures becomes evident. More remarkably, wetland distance loads upon the first factor suggesting the apparent importance of minimizing distance to these areas upon Aboriginal locational decisions associated with site other than middens. Rainfall was also apparently an important influence upon locational decisions (second factor) as were landforms of low relief; geological parent materials which contributed to soils of relatively high nutrient status; and maximum spring temperature (third factor). The relatively minor influence of coastal proximity (as opposed to wetland and estuarine proximity) and freshwater distance is indicated by their association with the fourth factor. While the low degree of influence of aspect, away from the coast is indicated by the variable's contribution to a unique fifth factor.

Overall, the analysis of coastal open sites excluding both middens and grooves suggests that Aboriginal locational decisions were most influenced by minimum temperature in spring and winter, wetland distance, estuarine distance and height, rainfall characteristics, maximum summer temperature, coastal distance, freshwater distance, and aspect. However, before discussing the degree to which these factor structures validate the behavioural model we must consider the factor structure associated with the other half of the Function population.

When Aboriginal locational decisions as they are represented by Function Shelters (including grinding grooves and middens), are considered using only metrical data (Table 7.5a); minimum temperatures (annual, spring and autumn) and maximum temperatures (autumn and winter) load positively; and height and estuary distance load negatively upon the first factor. This appears to suggest a tendency for the Aborigines to select shelters which were at low height and in close proximity to estuaries; and in areas with relatively high minimum temperatures (particularly, relatively high minimum autumn and winter temperatures). In addition, those shelters which were associated with comparatively high rainfall and proximity to wetlands (second factor); low maximum temperatures and high winter rainfall (third factor) appear to have been selected. Freshwater distance and aspect appear to have been relatively minor influences upon Aboriginal locational decisions.

The inclusion of the modified variables (Table 7.5b) makes no substantial difference to the variable construction of the first factor, nor substantially to the second: though winter rainfall falls in with this latter factor, leaving maximum summer and spring temperature and coastal distance loading negatively upon the third factor, while the introduced factor - geology - loads positively. Freshwater distance and aspect are associated with a discrete fourth factor; while topography forms a unique fifth factor. Surprisingly, then, geological structure is likely to have been a comparatively important influence upon Aboriginal locational

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a  FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

     1       9.00678        42.9        42.9
     2       5.88654        28.0        70.9
     3       1.77122         8.4        79.4
     4       1.11310         5.3        84.7

   ROTATED FACTOR MATRIX:

                   FACTOR  1    FACTOR  2    FACTOR  3    FACTOR  4

   MINTSPRING        .95467       .05280       .13273       .04511
   ANNUALTMIN        .95241      -.02352      -.00170      -.03875
   MINTWINTER        .91975       .20657      -.11463       .16575
   MINTSUMMER        .89571      -.06689      -.30059       .14688
   HEIGHT           -.81991       .22954      -.26168      -.12939
   ESTUARY          -.79378       .20058      -.45207      -.15564
   MINTAUTUMN        .78794       .11330      -.09275       .21813
   MAXTAUTUMN        .71364      -.25873       .53971       .16122
   MAXTWINTER        .70874      -.34337       .52423       .09387

   RAINSPRING        .05595       .91638      -.22901      -.07709
   ANNUALRAIN        .04700       .89288      -.31606       .04668
   RAINAUTUMN        .17196       .87945      -.30814      -.06819
   RAINSUMMER       -.47228       .80954      -.16125      -.10270
   WETLAND           .36155      -.57733      -.05474       .44263

   MAXTSPRING        .20821      -.18346      -.90291       .07392
   MAXTSUMMER        .00015      -.35584      -.89565      -.08431
   RAINWINTER        .21767       .57700       .70198       .01827
   ANNUALTMAX        .48886      -.51342      -.63586      -.00869
   COAST            -.52675      -.12160      -.60000       .19482

   FRESHWATER        .06543      -.05649       .16541      -.81612
   ASPECT           -.47301       .09226       .15639       .58764
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b  FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

     1       9.05330        39.4        39.4
     2       5.94118        25.8        65.2
     3       2.04083         8.9        74.1
     4       1.14443         5.0        79.0
     5       1.09302         4.8        83.8

   ROTATED FACTOR MATRIX:

                   FACTOR  1    FACTOR  2    FACTOR  3    FACTOR  4    FACTOR  5

   MINTSPRING        .95732       .04448       .12547       .03378      -.00162
   ANNUALTMIN        .95460      -.00572      -.02715      -.04143       .01277
   MINTWINTER        .90883       .25766      -.03948       .17595      -.09699
   MINTSUMMER        .88991       .00521      -.30764       .15853      -.09319
   HEIGHT           -.81587       .26441      -.24957      -.12026       .24185
   ESTUARY          -.80084       .27082      -.40808      -.13341       .05134
   MINTAUTUMN        .78019       .13901      -.06065       .21152      -.11830
   MAXTAUTUMN        .73510      -.33583       .45107       .13960       .18406
   MAXTWINTER        .72856      -.42308       .41789       .07433       .13064

   RAINSPRING        .04143       .95052      -.06555      -.08515       .06958
   RAINAUTUMN        .15855       .91209      -.17553      -.08808       .01756
   ANNUALRAIN        .03658       .90687      -.20707       .01001       .02188
   RAINSUMMER       -.49005       .81684       .00507      -.11375      -.04369
   RAINWINTER        .19087       .70804      -.55177       .04387      -.16158
   ANNUALTMAX        .51245      -.60888       .50389      -.02179       .15872
   WETLAND           .37943      -.52547      -.15009       .46561       .15197

   MAXTSUMMER        .02206      -.51499      -.80033      -.11369       .12866
   MAXTSPRING        .23352      -.36442      -.79608       .01770       .16005
   GEOLOGY           .07679       .20309       .68656       .10604      -.28049
   COAST            -.50678      -.25840      -.53360       .14730       .12342

   FRESHWATER        .06810      -.07161       .19304      -.81632      -.00830
   ASPECT           -.47576       .05335       .16171       .58126       .03658

   TOPOGRAPHY       -.16532       .01388       .05484       .00653      -.91724
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Table 7.5: Factor analysis results - coastal shelter sites for a) only metrical data; and b) all data.

decisions and was associated with areas of relative nutrient richness. Topography, by contrast, is - as would be expected of these sites - likely to have been a relatively minor influence.

When grinding grooves are removed from the analysis (Table 7.6a), the evidence suggests that the Aborigines tended to use those rock shelters in areas where annual and winter minimum temperatures, and winter maximum temperature, were relatively high; and height and distances to the coast and estuaries were low. Relatively high rainfall (particularly in spring, autumn and throughout the year) and proximity to wetlands also seem to have been important influences (second factor). In addition, shelter sites appear to have been chosen because of relatively lower maximum temperatures, particularly in summer (third factor), while proximity to freshwater and the tendency for shelters to face south to north-west appear to have been minor influences upon locational decisions.

When the modified variables - geology and topography - are introduced into the analysis (Table 7.6b), minimum temperatures (particularly summer and winter) and maximum temperature in winter continue to load positively upon the first factor. This would tend to suggest that while Aboriginal use of shelters tended to occur in areas of relatively high minimum temperature throughout the year, winter minimum and maximum temperatures may have tended to influence locational decisions in particular. Note also that while low coast distance and height appear to have been equally major influences upon decisions, estuarine distance is removed to the third factor. Rainfall and wetland distance load highly upon the second

a
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FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

  1        8.27765       39.4        39.4
  2        5.76141       27.4        66.9
  3        2.07435        9.9        76.7
  4        1.10370        5.3        82.0

ROTATED FACTOR MATRIX:

                FACTOR  1    FACTOR  2    FACTOR  3    FACTOR  4

ANNUALTMIN        .93230       .00637       .15101      -.03182
MINTWINTER        .92881       .23570       .02216      -.00857
MINTSUMMER        .91463      -.08644      -.27533      -.01601
MINTSPRING        .87536       .03549       .32614       .07858
MINTAUTUMN        .81464       .05420      -.00564       .22550
MAXTWINTER        .70330      -.25213       .56599       .03384
HEIGHT           -.68029       .26021      -.50121      -.13888
COAST            -.67475      -.33325       .35339       .19065
ESTUARY          -.66389       .24955      -.61360      -.17763

RAINSPRING        .18075       .92385      -.12247      -.12418
RAINAUTUMN        .25052       .87306      -.25209      -.06257
ANNUALRAIN       -.01217       .84497      -.33019       .13557
RAINSUMMER       -.42937       .79441      -.17320      -.08515
WETLAND           .26154      -.69807      -.10766       .31504
RAINWINTER        .39209       .68191      -.48298      -.04520

MAXTSUMMER       -.10362      -.21396      -.92539      -.02463
MAXTSPRING       -.00772      -.05851      -.89583       .17617
ANNUALTMAX        .36797      -.43004      -.75537       .03940
MAXTAUTUMN        .61336      -.29937      -.66054       .14344

ASPECT           -.13002       .05805      -.00308       .81825
FRESHWATER       -.02073      -.08590       .13532      -.51262
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b
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FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

  1        8.38276       36.4        36.4
  2        5.81962       25.3        61.7
  3        2.26697        9.9        71.6
  4        1.13503        4.9        76.5

ROTATED FACTOR MATRIX:

                FACTOR  1    FACTOR  2    FACTOR  3    FACTOR  4

MINTWINTER        .93372      -.06093      -.20353      -.04760
ANNUALTMIN        .92038       .24299       .12685      -.04779
MINTSUMMER        .91496      -.00378       .21704      -.02466
MINTSPRING        .84690       .01457       .38557       .09068
MINTAUTUMN        .81792       .06336       .05941       .19622
COAST            -.69230      -.35594       .26577       .22848
MAXTWINTER        .65817      -.29593       .58122       .07604
HEIGHT           -.64683       .28477      -.54781      -.10999

RAINSPRING        .17480       .92657      -.04203      -.13067
RAINAUTUMN        .25726       .88497      -.17657      -.06678
ANNUALRAIN        .00834       .85936      -.29496       .14028
RAINSUMMER       -.42518       .80591      -.13291      -.11456
RAINWINTER        .42139       .71735      -.38975      -.10147
WETLAND           .28598      -.67504      -.13782       .30117

MAXTSUMMER       -.17592      -.28318      -.89357       .02527
MAXTSPRING       -.07384      -.12853      -.86113       .23766
ANNUALTMAX        .31120      -.48694      -.73279       .09465
MAXTAUTUMN        .56410      -.34583      -.66387       .19016
ESTUARY          -.61980       .28865      -.63564      -.19486
GEOLOGY           .19910       .23491       .45409      -.23843
TOPOGRAPHY       -.20611      -.11687      -.29401       .21697

ASPECT           -.15061       .03000       .00232       .79708
FRESHWATER       -.01552      -.08454       .12420      -.46602
```

able 7.6: Factor analysis results - coastal shelter sites (excluding grinding grooves for a) only metrical data; and b) all data.

factor indicating the relative importance of areas of higher rainfall and proximity to wetlands. Other influences upon locational decisions appear to have been the minimization of maximum temperatures; and an association with areas of low relief and geological parent materials which produce high nutrient soils (third factor). The tendency to face south to north-west and to be close to freshwater appear to have been relatively minor influences upon Aboriginal locational decisions.

When middens are also excluded from the analysis (Table 7.7a), landscape variables appear to have influenced Aboriginal locational decisions in broadly the same way as that outlined above. Minimum temperature variables and maximum winter temperature load most highly and positively upon the first factor; while height, coastal distance and estuarine distance all load highly and negatively. This suggests that shelters were chosen because of their association with warmer areas (particularly in winter), their low altitude and their proximity to coastal and estuarine resources. Secondary influences appear to have been, relatively high rainfall and proximity to wetlands; while areas of relatively low summer and spring maximum temperature (third factor); aspects from south to north-west; and proximity to freshwater (fourth factor) tended to be relatively less influential.

When the modified variables are introduced (Table 7.7b) the variable loadings tend to differ, to a small extent, from those associated with only metrical data. Aboriginal locational decisions appear to have favoured areas of relatively high minimum temperatures (particularly in

a
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FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

  1       8.21302       39.1         39.1
  2       5.78134       27.5         66.6
  3       2.09632       10.0         76.6
  4       1.10420        5.3         81.9

ROTATED FACTOR MATRIX:

                 FACTOR  1     FACTOR  2     FACTOR  3     FACTOR  4

ANNUALTMIN        .93342        .00846        .14273       -.03410
MINTWINTER        .92773        .23831        .01386       -.00359
MINTSUMMER        .91173       -.08464       -.28418       -.01288
MINTSPRING        .87747        .03837        .31857        .07735
MINTAUTUMN        .81328        .05569       -.01268        .22529
MAXTWINTER        .70786       -.24796        .55862        .03696
HEIGHT           -.68320        .25765       -.49391       -.13985
COAST            -.67230       -.33409        .35753        .18640
ESTUARY          -.66750        .24739       -.60850       -.17892

RAINSPRING        .18091        .92430       -.12087       -.12055
RAINAUTUMN        .25140        .87315       -.24983       -.05940
ANNUALRAIN       -.00809        .84588       -.32471        .13450
RAINSUMMER       -.42695        .79661       -.16385       -.08762
WETLAND           .26213       -.69686       -.11176        .31024
RAINWINTER        .39173        .68161       -.48327       -.03889

MAXTSUMMER       -.10508       -.20944       -.92570       -.02767
MAXTSPRING       -.00762       -.05411       -.89538        .17124
ANNUALTMAX        .36853       -.42928       -.75311        .04211
MAXTAUTUMN        .61711       -.29774       -.65661        .14320

ASPECT           -.14729        .06553       -.01734        .79262
FRESHWATER       -.03103       -.08094        .12595       -.56014
```

b
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FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

  1       8.31615       36.2         36.2
  2       5.83722       25.4         61.5
  3       2.28851       10.0         71.5
  4       1.13657        4.9         76.4

ROTATED FACTOR MATRIX:

                 FACTOR  1     FACTOR  2     FACTOR  3     FACTOR  4

MINTWINTER        .93007       -.05901       -.21829       -.04574
ANNUALTMIN        .92055        .24720        .11159       -.04834
MINTSUMMER        .91748        .00045        .20294       -.03020
MINTSPRING        .85194        .02044        .37388        .08393
MINTAUTUMN        .81834        .06590        .04926        .18989
COAST            -.68768       -.35550        .27795        .22694
MAXTWINTER        .66692       -.28795        .57240        .07211
HEIGHT           -.65476        .27994       -.53975       -.09652

RAINSPRING        .17361        .92701       -.04702       -.12726
RAINAUTUMN        .25619        .88438       -.18077       -.06268
ANNUALRAIN        .01035        .85856       -.29169        .13941
RAINSUMMER       -.42496        .80646       -.12517       -.11607
RAINWINTER        .41852        .71481       -.39682       -.09760
WETLAND           .28738       -.67350       -.13731        .29824

MAXTSUMMER       -.17199       -.27466       -.89680        .01448
MAXTSPRING       -.06769       -.12039       -.86426        .22288
ANNUALTMAX        .31673       -.48215       -.73165        .09092
MAXTAUTUMN        .57265       -.33995       -.66006        .18423
ESTUARY          -.62854        .28280       -.63046       -.18660
GEOLOGY           .19671        .24036        .44590       -.22778
TOPOGRAPHY       -.21167       -.11460       -.28912        .25026

ASPECT           -.16905        .03632       -.01974        .77834
FRESHWATER       -.02017       -.07726        .12105       -.49948
```

able 7.7: Factor analysis results - coastal shelter sites (excluding grinding grooves and middens for a) only metrical data; and b) all data.

summer and winter) and maximum winter temperature, which were also associated with low height and proximity to the coast (though not, as in the analysis above, with the estuaries). Relatively high rainfall and proximity to wetlands (factor two), however, maintain their high degree of probable influence. The introduced variable - geology - and the displaced estuary distance variable are associated with maximum temperature (particularly in summer and spring) variables in such a way as to suggest that an influence upon Aboriginal locational decisions was the location of areas which were: cooler, particularly in summer; associated with geological parent materials which produced nutrient rich soils; low lying; and were close to estuaries. The tendency for sites to face south to north-west and to be close to water appear to have possessed less influence upon Aboriginal decisions.

7.7.4 Coastal factors and the behavioural model

The highest loading variables upon the factors associated with coastal Function sites are presented in Tables 7.8 and 7.9. In comparing the two site groups, it is readily apparent that while the removal of grinding grooves clearly influences the variable structure within open site factors, this is not so evident in the case of shelter sites. However, some broad patterns emerge from the analysis which may be said to characterize coastal Aboriginal locational decisions and their relationship to the behavioural model.

	OPEN	OPEN FULL	OPEN XGG	OPEN XGG FULL	OPEN XMGG	OPEN XMGG FULL
FIRST Positive	ANNUALRAIN RAINSUMMER RAINSPRING RAINAUTUMN	ANNUALRAIN RAINAUTUMN RAINSPRING RAINSUMMER	ANNUALTMIN MINTSPRING MINTWINTER MINTSUMMER	ANNUALTMIN MINTSPRING MINTSUMMER MINTWINTER	MINTSPRING ANNUALTMIN MAXTAUTUMN MAXTWINTER	MINTSPRING ANNUALTMIN MINTWINTER MINTAUTUMN
Negative	MAXTSUMMER ANNUALTMAX MAXTSPRING	MAXTSUMMER ANNUALTMAX MAXTSUMMER	HEIGHT ESTUARY	HEIGHT ESTUARY COAST	ESTUARY HEIGHT	ESTUARY HEIGHT WETLAND
SECOND Positive	ANNUALTMIN MINTSPRING MAXTAUTUMN MINTSUMMER	ANNUALTMIN MINTSPRING MAXTAUTUMN MINTSUMMER	RAINSPRING ANNUALRAIN RAINAUTUMN RAINSUMMER	ANNUALRAIN RAINSPRING RAINAUTUMN RAINSUMMER	RAINSUMMER ANNUALRAIN RAINAUTUMN RAINSPRING	ANNUALRAIN RAINAUTUMN RAINSPRING RAINSUMMER
Negative	ESTUARY HEIGHT	ESTUARY HEIGHT TOPOGRAPHY			ANNUALTMAX MAXTSUMMER	MAXTSUMMER ANNUALTMAX
THIRD Positive		GEOLOGY	MAXTSUMMER MAXTSPRING ANNUALTMAX COAST	ASPECT		GEOLOGY MAXTSPRING
Negative	COAST WETLAND	COAST WETLAND		WETLAND	COAST	TOPOGRAPHY
FOURTH Positive	ASPECT	ASPECT	ASPECT	ASPECT	ASPECT	FRESHWATER COAST
Negative	FRESHWATER	FRESHWATER	WETLAND	WETLAND	WETLAND	
FIFTH Positive			FRESHWATER	GEOLOGY	FRESHWATER	ASPECT
Negative						
SIXTH Positive				FRESHWATER		
Negative						

Table 7.8: High loading variables - coastal open sites

	SHELTER	SHELTER FULL	SHELTER XGG	SHELTER XGG FULL	SHELTER XMGG	SHELTER XMGG FULL
FIRST Positive	MINTSPRING ANNUALTMIN MINTWINTER MINTSUMMER	MINTSPRING ANNUALTMIN MINTWINTER MINTSUMMER	ANNUALTMIN MINTWINTER MINTSUMMER MINTSPRING	MINTWINTER ANNUALTMIN MINTSUMMER MINTSPRING	ANNUALTMIN MINTWINTER MINTSUMMER MINTSPRING	MINTWINTER ANNUALTMIN MINTSUMMER MINTSPRING
Negative	HEIGHT ESTUARY	HEIGHT ESTUARY	HEIGHT COAST ESTUARY	COAST HEIGHT	HEIGHT COAST ESTUARY	COAST HEIGHT
SECOND Positive	RAINSPRING ANNUALRAIN RAINAUTUMN RAINSUMMER	RAINSPRING RAINAUTUMN ANNUALRAIN RAINSUMMER	RAINSPRING RAINAUTUMN ANNUALRAIN RAINSUMMER	RAINSPRING RAINAUTUMN ANNUALRAIN RAINSUMMER	RAINSPRING RAINAUTUMN ANNUALRAIN RAINSUMMER	RAINSPRING RAINAUTUMN ANNUALRAIN RAINSUMMER
Negative	WETLAND	ANNUALTMAX WETLAND	WETLAND	WETLAND	WETLAND	WETLAND
THIRD Positive	RAINWINTER	GEOLOGY		GEOLOGY		GEOLOGY
Negative	MAXTSPRING MAXTSUMMER RAINWINTER COAST	MAXTSUMMER MAXTSPRING COAST	MAXTSUMMER MAXTSPRING ANNUALTMAX MAXTAUTUMN	MAXTSUMMER MAXTSPRING ANNUALTMAX MAXTAUTUMN	MAXTSUMMER MAXTSPRING ANNUALTMAX MAXTAUTUMN	MAXTSUMMER MAXTSPRING ANNUALTMAX MAXTAUTUMN
FOURTH Positive	ASPECT	ASPECT	ASPECT	ASPECT	ASPECT	ASPECT
Negative	FRESHWATER	FRESHWATER	FRESHWATER	FRESHWATER	FRESHWATER	FRESHWATER
FIFTH Positive						
Negative		TOPOGRAPHY				

Table 7.9: High loading variables - coastal shelter sites

Principal among these characteristics is the association between Aboriginal behaviour and proximity to the coast and estuaries and to areas of relatively high minimum temperatures. However, if we turn to the tripartite division of landscape variables used in the earlier part of this chapter, a number of points can be made:

Aquatic structure

It is evident, particularly from the analysis of open site locations, that the ranking of aquatic resource areas by patch value (wetland - estuary - coast) influenced Aboriginal locational decisions. This apparent ranking is clearly suggested by the tendency for coastal distance to be separated from estuary distance (i.e. to load upon another lower factor); while wetland distance tends to be found (once grinding grooves are removed from the analysis) within the variable structure of the first factor.

However, this tendency is not as apparent in the shelter population. Here estuary distance tends to be displaced to a more lowly factor while coast and wetland distances retain stable high positions. None the less, the locational decisions which this represents are not inconsistent with the behavioural model - but, it is suggested, represent differences in Aboriginal locational decisions in relation to seasonal changes in the distribution of patches (see 'climatic structure' below).

The apparent support for the behavioural model (or more specifically the high ranking of aquatic patches) is underlined by the consistently low ranking of distance to freshwater - a ubiquitous commodity.

Climatic structure

The results suggest that climatic characteristics did influence Aboriginal locational decisions to the extent that there appears to have been a general tendency toward areas of relatively higher annual minimum temperatures, higher rainfall and lower maximum temperatures. At least in part, this is likely to be a reflection of the close association between minimum temperature and coastal distance revealed in the multi-dimensional scaling analysis, but there is evidence of an independent influence related to seasonal extremes. For example, while there appears to have been a general (i.e. annual) pattern of climatic influence upon Aboriginal locational decisions, it is evident that maximum winter and summer temperatures exerted an influence separately from their associates.

In addition, shelter sites (while they share the same broad annual pattern with regard to climatic influences) also display some seasonal influences. While maximum summer temperature is likely to have exerted an influence, it is clear that winter/spring minimum temperatures tended to exert a greater influence upon Aboriginal locational decisions. In addition, winter maximum temperature appears to have exerted a higher degree of influence than its associates. It is tempting to suggest on the basis of this evidence that shelter sites represent (to a greater degree than can be said to be true of open sites) the Aboriginal locational response to winter and spring. (This appeals, of course, on common-sense grounds - the appeal of shelters is shelter.) If this is the case, then the greater degree of association with the coast rather than estuaries exhibited by shelter sites becomes explicable; for the behavioural model suggests that Aboriginal behaviour should be located in closer association with the coast (principally because of the presence of migratory species and the reduced rank of estuary resources) in winter.

In comparison, with other climatic variables, aspect appears to have been a relatively minor factor. However the importance of facing south to north-west appears to have been an underlying consideration.

Terrestrial structure

It is clear that Aboriginal activity was a low altitude phenomenon (height always loads highly within the factor structure). This is suggestive of associations with 1) points in the landscape of nutrient accretion and 2) aquatic resource areas.

The significance of the two categorical variables - geology and topography - is indicated by the way their inclusion restructures the whole factor matrix. (In fact, the variable structure generally becomes more coherent when these data are included.) Of the two variables, geology tends to load upon a higher factor than topography.

The position of geology in the factor structure always appears to be lower than those associated with aquatic structure variables - but nevertheless indicates the importance of geological parent materials which produce soils of relatively greater natural fertility. In terms of the behavioural model this characteristic supports the ranking associated with patch distribution; the influence of aquatic structure upon Aboriginal locational decisions appears to have been more important than that associated with the richness of the land. However, the tendency for geology to underlie the aquatic structure is suggestive of the secondary role of resources from the more nutrient-rich areas (including buffer foods).

Topography seems to have been a relatively minor influence upon Aboriginal locational decisions, yet the association with low slope angle lends some support to the general principle that Aboriginal behaviour is likely to have been associated with areas of nutrient accretion.

In general, then, the factor analysis of coastal sites tends to support the model of optimal foraging behaviour in that:

a) Aboriginal locational decisions appear to have been most influenced by the proximity of aquatic resources in the general order of cost/benefit ranking: wetland - estuary - coast.

b) There is no evidence to suggest that the occupation of coastal areas (in the broadest sense) was seasonal. This lends support to the division within the behavioural model of the Aboriginal population into two ecological populations.

c) Evidence of a locational response to winter climate (among shelter sites) is also associated with an appropriate shift in the relative association of aquatic variables within the factor structure (i.e. marine influences predominate over estuarine influences).

d) The consistent middle-ranking of geology in the factor structure is suggestive of an influence associated with security and proximity to buffer foods.

7.7.5 Inland factors

The rotated factor matrix for all Function Open sites (including grinding grooves) using only metrical data is presented in Table 7.10a. The evidence suggests that the major influence upon Aboriginal locational decisions in inland areas was the location of warmer areas (higher minimum temperatures and annual and winter maximum temperatures) which were low in height and in autumn, summer and spring maximum temperatures (first factor). The interpretation of the second factor is more complex, but assuming, on the basis of the preceding analysis that there is likely to be a close relationship with areas of higher rainfall, we must also assume that a greater distance from the sea and estuaries was also an

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FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

   1       11.52811      54.9        54.9
   2        3.81955      18.2        73.1
   3        1.24841       5.9        79.0
   4        1.02935       4.9        83.9

ROTATED FACTOR MATRIX:

                FACTOR  1    FACTOR  2    FACTOR  3    FACTOR  4

HEIGHT           -.85184       .36137       .14127       .12538
ANNUALTMIN        .84902      -.22216       .25557      -.13109
MINTSPRING        .81760      -.32105       .39751      -.07928
MINTSUMMER        .80257      -.46103       .12674       .09700
ANNUALTMAX        .78253      -.39135      -.39651       .02848
MAXTWINTER        .76719      -.59014      -.18648       .09514
MAXTAUTUMN       -.76679      -.57206      -.23104       .07896
MAXTSPRING       -.75106      -.35235      -.48543       .15088
MAXTSUMMER       -.58717      -.47963      -.47520       .06915

RAINSUMMER       -.40926       .81311       .17397       .03240
RAINSPRING       -.33182       .79677       .21119      -.13633
MINTAUTUMN        .46155       .79390       .16953       .04948
ANNUALRAIN       -.39568       .79143       .37278      -.01468
COAST            -.30133       .73865      -.11942       .20318
ESTUARY          -.44323       .68508      -.20761       .20865
RAINAUTUMN       -.25297       .66199       .61123      -.12282

WETLAND           .05789       .06258      -.89522       .05945
MINTWINTER        .31499      -.12832       .88383      -.13171
RAINWINTER       -.23515       .31370       .85143      -.02700
ASPECT           -.11788      -.17584       .30794       .24507

FRESHWATER        .04395       .09577      -.04163      -.90194
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b
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FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

   1       11.83212      51.4        51.4
   2        4.02694      17.5        69.0
   3        1.42289       6.2        75.1
   4        1.29197       5.6        80.8
   5        1.02496       4.5        85.2

ROTATED FACTOR MATRIX:

                FACTOR  1    FACTOR  2    FACTOR  3    FACTOR  4    FACTOR  5

HEIGHT           -.83528       .38096       .12020       .25168       .01743
MINTSUMMER        .79542      -.48639       .12805       .03104       .06638
ANNUALTMIN        .79069      -.29413       .31027      -.17559      -.12526
MINTSPRING        .77288      -.37274       .42443      -.09699       .03787
ANNUALTMAX       -.76290      -.42996      -.37561      -.07843      -.02266
MAXTSPRING       -.76088      -.37579      -.48395       .06698       .03206
MAXTWINTER       -.74760      -.62477      -.17861       .02707       .02615
MAXTAUTUMN       -.73978      -.61767      -.21042       .02635      -.04252
MAXTSUMMER       -.55968      -.52086      -.45813       .01290       .00517

MINTAUTUMN        .42343       .81856       .17041       .02958       .01834
ANNUALRAIN       -.36967       .80000       .37603       .05377      -.01512
RAINSUMMER       -.39645       .79965       .19106       .10149      -.04922
COAST            -.21166       .78257      -.14930       .24788       .04321
RAINSPRING       -.34049       .77707       .24160      -.05347      -.04710
ESTUARY          -.37593       .71719      -.23217       .22550       .06145
RAINAUTUMN       -.24138       .67088       .61322      -.03967       .03575

MINTWINTER        .27426      -.15487       .89888      -.07782       .05744
WETLAND           .07050       .07917      -.86196       .09241       .21120
RAINWINTER       -.22107       .33295       .83526       .05714       .05948
GEOLOGY          -.38691      -.15353       .58599      -.14432      -.33092

FRESHWATER        .06556       .01114      -.05723      -.84540      -.13112
TOPOGRAPHY       -.39454       .20634       .11256      -.68539       .19476

ASPECT           -.04095      -.04808       .15348      -.04135       .91175
```

Table 7.10: Factor analysis results - inland open sites for a) only metrical data; and b) all data.

influence upon Aboriginal locational decisions. This interpretation is consistent with the lack of influence imposed by coastal and estuarine distances upon archaeological sites, which was noted in the comparative analysis above.

The influence of winter variables upon locational decisions is indicated by the variable structure of the third factor (particularly, minimum winter temperature and winter rainfall). In addition aspects from south to north-west and proximity to wetlands (factor three) and freshwater (a unique fourth factor) appear to have influenced inland Aboriginal decisions.

When the modified variables - geology and topography - are introduced into the analysis (Table 7.10b), no substantial changes occur in the first two factors. However, the influence of geological structure upon Aboriginal locational decisions is indicated by the variable's placement within the third factor with wetland distance, minimum winter temperature and winter rainfall. Topography and freshwater distance (factor four) and aspect (a unique fifth factor) were apparently minor influences upon locational decisions.

The rotated factor matrix for all Function Open sites without grinding grooves is presented in Table 7.11a. It is immediately apparent that the removal of these sites (which are likely to have had little connection with food acquisition) has a fundamental effect upon the factor structure. (It should be noted that no statistics reproduced here are the product of

a

FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
1	8.70430	41.4	41.4
2	4.97542	23.7	65.1
3	1.42340	6.8	71.9
4	1.30024	6.2	78.1
5	1.04142	5.0	83.1

ROTATED FACTOR MATRIX:

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
RAINWINTER	.93532	-.16724	-.00228	.01474	-.05771
MINTWINTER	.91500	.16752	-.16837	.21241	-.06566
WETLAND	-.89410	-.04535	-.03784	-.07971	-.01444
ANNUALTMAX	-.80921	.31116	.05760	.13996	-.01676
MAXTSUMMER	-.78081	.45001	-.20640	-.23837	.00468
MAXTSPRING	-.77396	.43469	.24956	.05175	.13151
RAINAUTUMN	.77382	-.53925	-.06043	.06735	.01775
MINTSPRING	.69892	.34270	-.27298	.32884	-.02418
HEIGHT	-.51125	-.28323	-.16823	-.43421	.41038
MAXTWINTER	-.33512	.90667	-.07120	.12311	.04785
MINTAUTUMN	.18501	.86009	-.30259	.09131	-.03754
RAINSUMMER	.27511	.81836	.32101	-.08067	.06484
MAXTAUTUMN	-.49011	.79805	.01564	.19659	-.01494
RAINSPRING	.28609	.78784	.13665	.20578	.04658
MINTSUMMER	.43619	.76672	.22462	.21982	-.00182
ANNUALRAIN	.53489	.72864	.29964	.02697	.03822
COAST	-.13181	-.33531	.84430	.06710	.11961
ESTUARY	-.12728	-.39327	.75124	-.30019	.05880
ASPECT	.04757	-.09143	.38040	.11532	.22636
ANNUALTMIN	.10608	.06422	-.24955	.90442	.02092
FRESHWATER	-.14515	.02886	.00499	.00955	-.90981

FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
1	8.85159	38.5	38.5
2	5.09685	22.2	60.6
3	1.72803	7.5	68.2
4	1.46415	6.4	74.5
5	1.11611	4.9	79.4
6	1.02648	4.5	83.8

ROTATED FACTOR MATRIX:

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6
RAINWINTER	.92853	-.20032	-.05366	-.01581	.00006	-.00291
MINTWINTER	.91817	.14465	-.20338	.00301	.19119	.05710
WETLAND	-.88553	-.07203	-.07540	.09536	-.07557	-.07531
ANNUALTMAX	-.78889	.33659	.08167	-.08771	.13530	-.05466
MAXTSUMMER	-.78041	.46709	-.19750	.05554	-.21375	-.07821
RAINAUTUMN	.75329	-.54879	-.05250	.10217	.07000	.03757
MAXTSPRING	-.74965	.47121	.32304	.06039	.05449	-.04571
MINTSPRING	.70484	.33707	-.27212	.06175	.31762	.04123
MAXTWINTER	-.30951	-.91879	-.05344	.02774	.12373	-.04565
MINTAUTUMN	.19895	.85170	-.31418	-.03394	.07923	.06993
RAINSUMMER	.25728	.83483	.29721	.03066	-.07442	.02958
MAXTAUTUMN	-.45845	-.80524	.00873	-.10834	.18921	-.07197
RAINSPRING	.27186	.78756	.12916	.11765	.21573	-.05822
MINTSUMMER	.47529	.75799	.22181	-.08267	.18058	.03290
ANNUALRAIN	.52304	.74395	.28789	.00999	.01910	.04020
COAST	-.10420	-.33085	.85412	-.02508	.04954	-.12654
ESTUARY	-.11482	-.40941	.70987	-.04654	-.30434	-.13613
GEOLOGY	.29868	-.12920	.52707	-.13841	.22612	-.21133
FRESHWATER	-.21658	.00917	.07664	-.77614	.20008	-.16456
TOPOGRAPHY	.23406	-.08203	-.01793	-.75137	-.23114	.17267
HEIGHT	.45511	-.28274	-.08118	-.55480	-.35356	.19043
ANNUALTMIN	.11728	.07939	-.21645	-.07160	.89549	.09723
ASPECT	.02745	-.01292	-.06138	.03364	.08084	.95319

Table 7.11: Factor analysis results - inland open sites (excluding grinding grooves for a) only metrical data; and b) all data.

a single run. All statistics were derived on several occasions so that chance factors which might produce artificially significant results were minimized.)

The evidence suggests that the major influences upon inland Aboriginal locational decisions were: i) high winter rainfall; ii) high minimum winter temperature; iii) proximity to wetlands; iv) low annual maximum temperature; v) low summer maximum temperature; and vi) low height (factor one). The association of inland Aboriginal decisions with the extremes of winter and summer is indicated by the predominance of maximum winter temperature and summer rainfall loading upon the second factor - it is likely that warmer and wetter areas (respectively) were preferred. The lack of influence of coast and estuary distances is indicated again by their positive loading (factor three). Other relatively minor influences appear to have been: facing south to north-west (factor three), minimum temperature on an annual scale (a unique fourth factor); and proximity to freshwater (a unique fifth factor).

When the modified variables - geology and topography - are introduced (Table 7.11b) into the analysis no substantial changes occur within the first two factors. However, geology loads positively upon the third factor. This lends support to the suggestion that while there is no evident influence concerning coastal and estuarine distance, geological parent materials which produce nutrient-rich soils were influential with regard to Aboriginal locational decisions. Proximity to freshwater, low landforms, and low height (factor four), high annual minimum temperature (a unique fifth factor), and aspects from south to north-west (a unique sixth factor) appear to have been lesser influences upon locational decisions. Note that when grinding grooves are removed, height is displaced from the first factor to the fourth - a fact which is symptomatic of the location of many of these sites upon the Cumberland Plain whereupon the degree of variation in height is small.

The factor structure for all inland shelter sites using only metrical data is presented in Table 7.12a. The predominance of geological and topographic influences may explain why such a large number of variables load upon the first factor. Shelters in areas which possessed relatively high annual rainfall and low annual maximum temperatures seem to have been most influential, but minimum temperatures are also within the first factor. Note also that the results seem to suggest that coastal and estuary distance were important (i.e. in this case loading negatively with, for example, maximum temperature variables), this is likely to be a symptom of the generally eastward distribution of these sites (associated with the location of extensive areas of Hawkesbury sandstone).

The inclusion of the modified variables makes little difference to the factor structure (Table 7.12b). With or without these added variables the first factor seems to suggest a rather general pattern of climatic influence which, to a large extent, is likely to be the result of geological distribution and the topographic ties which are characteristic of shelter sites. The second factor indicates the importance of proximity to wetlands and the tendency for sites to be distributed from south to

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FACTOR    EIGENVALUE    PCT OF VAR    CUM PCT

   1       13.15503        62.6          62.6
   2        2.40545        11.5          74.1
   3        1.71036         8.1          82.2
   4        1.00441         4.8          87.0

ROTATED FACTOR MATRIX:

                  FACTOR  1     FACTOR  2     FACTOR  3     FACTOR  4

ANNUALRAIN          .96549        .12487       -.02185        .03063
ANNUALTMAX        -.96112       -.10341        .05348       -.06258
MINTAUTUMN          .95825        .01076        .03322       -.02689
RAINSUMMER          .94836       -.03982       -.02203        .04049
ESTUARY            -.94603       -.08175       -.05538       -.02208
MAXTAUTUMN         -.94239       -.05485       -.24218       -.07968
MAXTWINTER          .92337       -.00651       -.33114       -.08704
HEIGHT             -.92332       -.07581       -.06253        .20453
MINTSPRING          .91964        .32215        .05983       -.03835
COAST              -.90807        .04192       -.05180       -.06701
RAINSPRING          .83953        .25284        .05384        .10925
ANNUALTMIN          .82930        .12867        .08645       -.08192
RAINAUTUMN          .82026        .44973        .00995        .02017
MINTSUMMER          .79333        .16780       -.52180       -.09036
MAXTSPRING         -.76991       -.12038        .50466       -.07331
RAINWINTER          .69682        .58171       -.02137       -.01236
MINTWINTER          .67430        .66051        .04728       -.00799

WETLAND            -.08656       -.85787        .09334       -.04362
ASPECT              .04547        .59187       -.30319        .05687

MAXTSUMMER          .03950       -.04699       -.97914       -.00209

FRESHWATER         -.11912        .00497       -.00275       -.97941
```

b

```
FACTOR    EIGENVALUE    PCT OF VAR    CUM PCT

   1       13.44116        58.4          58.4
   2        2.42730        10.6          69.0
   3        1.86670         8.1          77.1
   4        1.20563         5.2          82.4

ROTATED FACTOR MATRIX:

                  FACTOR  1     FACTOR  2     FACTOR  3     FACTOR  4

MINTAUTUMN          .95528       -.01253       -.05029       -.08392
ANNUALRAIN          .95426        .14363        .06699        .10592
ESTUARY            -.95311       -.06220        .00819        .03228
ANNUALTMAX         -.94584       -.14488       -.07826       -.14789
RAINSUMMER          .94202       -.02258        .04811        .12092
MINTSPRING          .92718        .29176       -.00514       -.10795
COAST              -.91248        .05701        .01090        .00644
HEIGHT             -.90421       -.03767        .04690        .29152
MAXTAUTUMN         -.90364       -.06363       -.35096       -.12460
MAXTWINTER          .87676       -.00820       -.43505       -.13177
ANNUALTMIN          .82056        .07670       -.03578       -.17948
RAINSPRING          .80792        .26128        .14318        .19343
MAXTSPRING         -.80188       -.20663        .36223       -.11264
RAINAUTUMN          .79366        .46325        .11757        .09390
MINTSUMMER          .73447        .18727       -.59287       -.12887
MINTWINTER          .69894        .64635        .05733       -.06381
RAINWINTER          .67091        .59920        .09531        .05434

WETLAND            -.05074       -.82509        .12074       -.02022
ASPECT              .04003        .61728       -.24868        .04544

MAXTSUMMER          .13363       -.14325       -.93872       -.01094
GEOLOGY            -.24598        .28393        .47661        .12047

FRESHWATER         -.05718       -.01860       -.02111       -.86876
TOPOGRAPHY         -.30639        .06621        .13010       -.69935
```

able 7.12: Factor analysis results - inland shelter sites for a) only metrical data; and b) all data.

north-west. The third factor suggests that shelters close to areas of relatively lower summer maximum temperature and association with rock types which produce soils of relatively greater fertility were chosen. Freshwater distance and topography appear to have been relatively minor influences upon Aboriginal locational decisions - a fact which reflects the ubiquity of water and the low degree of variation in shelter positions.

The results of the factor analysis of shelter sites without grinding grooves is presented in Table 7.13a. Again the data tend to produce a rather general first factor of climatic variables, probably because of the fundamental geological and topographic characteristics of these sites. The first factor loadings suggest that relatively high annual and summer rainfall, low annual maximum temperatures and height were important influences upon Aboriginal locational decisions. Note that when grinding grooves are removed from the analysis, the apparent influence of coastal and estuarine distance upon Aboriginal locational decisions concerning shelter sites, disappears. Shelters in areas which were close to wetlands, and relatively warmer in winter; faced south to north-west (second factor); were relatively cooler temperatures in summer (a unique third factor); and were close to freshwater (a unique fourth factor) - appear to have been generally preferred.

Finally, when the two modified variables - geology and topography - are introduced (Table 7.13b), there is little change in the variables loading upon the factors. Generally, the analysis tends to confirm the pattern of

a

FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
1	12.80373	61.0	61.0
2	2.47364	11.8	72.7
3	1.87844	8.9	81.7
4	1.04779	5.0	86.7

ROTATED FACTOR MATRIX:

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
ANNUALRAIN	.97342	.11865	.00588	.01554
RAINSUMMER	.96195	-.06480	.00250	.03014
MINTAUTUMN	.95866	.01417	-.01552	.01003
ESTUARY	.95657	-.10302	-.01906	-.05146
ANNUALTMAX	-.94780	-.13561	.01944	-.16985
COAST	.91647	.03287	-.01931	-.11771
MAXTAUTUMN	-.90991	-.08004	-.32129	-.14593
MINTSPRING	.90544	.35556	.01252	-.05423
HEIGHT	-.90063	-.06821	-.02590	.29626
MAXTWINTER	.88121	-.03800	-.41733	-.15031
RAINSPRING	.81842	.27522	.08972	.12361
RAINAUTUMN	.80567	.46233	.02095	.07037
ANNUALTMIN	.78427	.11862	.05300	-.20407
MINTSUMMER	.72316	.14245	-.62000	-.15926
MAXTSPRING	-.72054	-.14848	.53910	-.18839
RAINWINTER	.68450	.59053	-.02620	.05877
WETLAND	-.08752	-.84996	.08055	-.08380
MINTWINTER	.66670	.69454	.00847	.02221
ASPECT	.03171	.52554	-.32014	.07894
MAXTSUMMER	.01437	-.02652	-.98225	-.00404
FRESHWATER	-.13462	.00962	-.00043	-.93877

b

FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
1	13.04358	56.7	56.7
2	2.48855	10.8	67.5
3	2.06938	9.0	76.5
4	1.22174	5.3	81.8
5	1.05208	4.6	86.4

ROTATED FACTOR MATRIX:

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
ANNUALRAIN	.96992	.13419	-.01256	.09315	.03166
ESTUARY	.96539	-.07024	-.01537	.03583	-.07023
MINTAUTUMN	.96423	-.01345	-.01163	-.06130	.02875
RAINSUMMER	.96025	-.04774	-.01320	.11203	-.00144
COAST	.92888	.08104	.00326	.00961	-.11730
ANNUALTMAX	-.91718	-.10457	.08614	-.18915	-.26105
MINTSPRING	.90675	.33782	.02301	-.11643	.02942
MAXTAUTUMN	-.89429	-.05261	-.25524	-.14585	-.26571
HEIGHT	-.86645	-.10097	-.09650	.31780	.21667
MAXTWINTER	.86522	-.00910	-.35094	-.15659	-.28874
RAINSPRING	.80728	.28024	.05949	.18576	.07984
RAINAUTUMN	.78729	.44758	-.02792	.10899	.17626
ANNUALTMIN	.74547	.16290	.12396	-.21752	-.29150
MINTSUMMER	.71374	.16800	-.56136	-.17311	-.26470
MINTWINTER	.68683	.65114	-.01885	-.06251	.21524
MAXTSPRING	-.68314	-.10252	.60971	-.10965	-.23647
RAINWINTER	.65797	.56109	-.08495	.08129	.24815
WETLAND	.09305	-.87964	.09957	-.00635	-.06000
ASPECT	-.05424	.52154	-.32352	.07607	.05757
MAXTSUMMER	-.00395	-.03733	-.96301	.03575	.18107
FRESHWATER	.08346	-.02247	-.07139	-.85754	.09606
TOPOGRAPHY	.31525	.11886	.13723	-.71523	-.13727
GEOLOGY	.14594	.10286	.15650	-.02450	.89674

Table 7.13: Factor analysis results - inland shelter sites (excluding grinding grooves for a) only metrical data; and b) all data.

probable influences upon Aboriginal locational decisions. Again the first general climatic factor suggests that shelters in areas of relatively high annual rainfall and minimum temperature; and low maximum temperature and height, were disproportionately favoured by the Sydney region Aborigines. In addition, proximity to wetlands and aspects facing south to north-west (factor two); relatively low maximum summer temperature (a unique third factor), proximity to freshwater; and association with low landforms (factor four) appear to have influenced locational decisions. The introduced variable - geology - forms a unique fifth factor, which indicates its separateness from other variables. The indication of the relatively low degree of influence exerted on Aboriginal locational decisions by this variable is likely to be a function of the fundamental characteristic of shelter sites as quirks of nature associated with a very small degree of variation in parent material; even so the indication of association with rock-types which produce soils of relatively greater natural fertility is present and is apparently independent of the influence of all other factors.

7.7.6 Inland factors and the behavioural model

Tables 7.14 & 7.15 present a summary of the high loading variables associated with inland sites. Perhaps the most striking evidence in support of the general model, and the principles which underlie it, is the nature of the fundamental change that occurs in the factor structure when grinding grooves are removed from the analysis. Once these sites (which are unlikely to possess any close association with food acquisition) are

	OPEN	OPEN FULL	OPEN XGG	OPEN XGG FULL
FIRST Positive	ANNUALTMIN MINTSPRING MINTSUMMER ANNUALTMAX	MINTSUMMER ANNUALTMIN MINTSPRING	RAINWINTER MINTWINTER	RAINWINTER MINTWINTER
Negative	HEIGHT MAXTAUTUMN MAXTSPRING MAXTSUMMER	HEIGHT ANNUALTMAX MAXTSPRING MAXTWINTER	WETLAND ANNUALTMAX MAXTSUMMER	WETLAND ANNUALTMAX MAXTSUMMER
SECOND Positive	RAINSUMMER RAINSPRING MINTAUTUMN ANNUALRAIN	MINTAUTUMN ANNUALRAIN RAINSUMMER COAST	MAXTWINTER RAINSUMMER MINTAUTUMN MAXTAUTUMN	MAXTWINTER RAINSUMMER MINTAUTUMN MAXTAUTUMN
Negative				
THIRD Positive	MINTWINTER RAINWINTER ASPECT	MINTWINTER RAINWINTER GEOLOGY	COAST ESTUARY ASPECT	COAST ESTUARY GEOLOGY
Negative	WETLAND	WETLAND		
FOURTH Positive			ANNUALTMIN	FRESHWATER
Negative	FRESHWATER	FRESHWATER TOPOGRAPHY		TOPOGRAPHY HEIGHT
FIFTH Positive		ASPECT		ANNUALTMIN
Negative			FRESHWATER	
SIXTH Positive				ASPECT
Negative				

Table 7.14: High loading variables - inland open sites

	SHELTER	SHELTER FULL	SHELTER XGG	SHELTER XGG FULL
FIRST				
Positive	ANNUALRAIN MINTAUTUMN RAINSUMMER MAXTWINTER	MINTAUTUMN ANNUALRAIN RAINSUMMER MINTSPRING	ANNUALRAIN RAINSUMMER MINTAUTUMN ESTUARY	ANNUALRAIN ESTUARY MINTAUTUMN RAINSUMMER
Negative	ANNUALTMAX ESTUARY MAXTAUTUMN HEIGHT	ESTUARY ANNUALTMAX COAST HEIGHT	ANNUALTMAX MAXTAUTUMN HEIGHT	ANNUALTMAX MAXTAUTUMN HEIGHT
SECOND				
Positive	ASPECT	ASPECT	ASPECT	ASPECT
Negative	WETLAND	WETLAND	WETLAND MINTWINTER	WETLAND
THIRD				
Positive		GEOLOGY		
Negative	MAXTSUMMER	MAXTSUMMER	MAXTSUMMER	MAXTSUMMER
FOURTH				
Positive				
Negative	FRESHWATER	FRESHWATER TOPOGRAPHY	FRESHWATER	FRESHWATER TOPOGRAPHY
FIFTH				
Positive				GEOLOGY
Negative				

Table 7.15: High loading variables - inland shelter sites

removed from the analysis the results are readily interpretable in terms of the association of Aboriginal behaviour with high-ranking patch distribution.

If we again follow the pattern of the tripartite division of landscape variables, a number of points can be made:

Aquatic structure

The location of aquatic variables within the factor structure clearly suggests that proximity to wetlands was a major influence upon Aboriginal locational decisions, and that coastal and estuarine distances exerted no (or, at best, very little) influence. This supports the propositions made in the behavioural model concerning the ranking of wetland patches above estuarine and marine patches; and also lends support to the division of the Sydney region Aborigines into two ecological populations. (In addition, there is some evidence that the association with wetlands, was to some extent seasonal (see climatic structure).)

The strength of the influence of wetland proximity upon locational decisions is indicated by the low ranking of the distance to freshwater - a ubiquitous commodity.

Climatic structure

In general, rainfall and minimum temperature appear to have been a general influence upon Aboriginal location. However, there can be little doubt that winter weather was a major influence upon Aboriginal locational decisions (though maximum summer temperature also appears to have influenced these decisions). The readily apparent association between open sites and winter climatic variables and proximity to wetlands, lends a great deal of support to the behavioural model which suggests the likelihood that the inland Aborigines would have been located around wetlands in winter.

Climatic associations tend to be less clear with regard to shelter sites (a situation readily interpretable in terms of the geological and topographic ties which bind these sites to specific areas). In general the pattern with regard to climatic variables appears to have been a general one (based upon annual measures), but particularly associated with areas of relatively greater rainfall. However, the consistent separation of maximum summer temperature from associated maximum temperature variables suggests that shelters tended to be utilized to a greater extent in areas of relatively lower summer temperature.

Aspect tends to be a relatively important influence in shelter sites (in comparison to open sites) and the tendency appears to be in favour of directions form south to north-west.

Terrestrial structure

Geology tends to occupy a higher position in the factor structure associated with open sites than in that associated with shelter sites (presumably as a function of the greater degree to which shelters are tied to Hawkesbury sandstone). However, it is clear, even among shelter sites that there was a general tendency for the Aborigines to utilize areas which were characterized by geological parent materials which produced soils of relatively high nutrient content. As has been noted previously with regard to coastal sites, this apparent underlying role of geological structure is consistent with the provisions of the behavioural model with regard to the security offered by such areas, particularly in the form of buffer foods. In contrast, both topography (low slope angle) and low height tend to be relatively minor influences.

In general, then, the analysis of inland Aboriginal behaviour as it is made manifest through the factor structure of archaeological sites offers a great deal of support to the behavioural model:

1. There is little evidence to suggest that occupation of the inland area was a seasonal phenomenon, there is, for example, evidence of the influence of climatic variables in both summer and winter. This tends to validate the suggestion that the inland area supported a separate ecological population not associated with maritime influences.

2. The principal association of open sites with winter variables and wetland distance, clearly supports the predictions of the model that Aboriginal behaviour should be located in close proximity to the high-ranking wetland patches in winter.

3. The suggestion that relatively lower maximum summer temperatures may have influenced Aboriginal choice with regard to shelter sites also lends a measure of support to the behavioural model. The model suggests that the Aborigine's range would have expanded in summer (when high value patches were extensive and widely distributed) and contracted in winter (toward wetlands); and that, in terms of geographical areas, this contraction would have been most clearly associated with the Cumberland Plain (and open sites), while the summer expansion would have been associated with the surrounding uplands (and shelter sites - which are only available in the uplands). That shelters are located in areas which are cooler in summer tends to support this notion.

4. The clear pattern of influence upon Aboriginal behaviour with regard to proximity to wetlands supports the behavioural model which stresses the high rank of these aquatic areas on the basis of cost and benefit.

5. Association with areas of geological parent material which produce soils of relatively high natural fertility appears to be a consistent underlying influence inland (though this is less clear among shelter sites than among open sites, because of the fundamental geological and topographic characteristics of the former group). This characteristic supports the view expressed in the model that these areas of greater fertility would offer the Aborigines a measure of security, which in the absence of estuarine and coastal resources are likely to have been an important influence upon decisions.

7.7.7 An assessment of factors and the behavioural model

The results of factor analysis upon the landscape characteristics of open and shelter sites both inland and upon the coast lend a remarkable degree of support to the behavioural model. It is evident, for example, that these two areas are likely to have been occupied throughout the year by separate 'ecological populations'. This view is supported by the major influences of a number of seasonal climatic components upon Aboriginal locational decisions (particularly the extremes of summer and winter). Primary among the differences between the inland and coastal ecological populations is the relationship between the archaeological evidence of Aboriginal behaviour and coastal and estuarine patches. Upon the coast, proximity to estuarine and marine patches appears to have been a high priority; while inland this priority is reversed to the extent that the factor structure almost gives the impression that these aquatic resource areas repelled the inland population.

Yet there are elements in the factor analysis which clearly unite the responses of these two ecological populations into something recognizable as a regional behavioural response. This is particularly true of the apparently major influence of wetland distance both inland and upon the coast. As areas associated with high-ranking patches of eels and avifauna in autumn, winter and spring (and as areas of general nutrient accretion) wetlands hold a pre-eminent place within the behavioural model, which is largely justified on the basis of the factor analysis.

Another important 'regional' Aboriginal response appears to be proximity to geological parent materials which produce soils of relatively high nutrient content. This characteristic tends to underlie the predominant locational influences in both inland and coastal areas, and is suggestive of the influence of the location of medium-ranking patches and buffer foods upon Aboriginal location. Other regional locational influences appear to be relatively minor, such as proximity to freshwater and the tendency for sites to face south to north-west.

In the next section, an attempt is made to continue this analysis in order to elucidate the Aboriginal behavioural response upon the regional scale through the study of the geographical distribution of high factor scores.

7.8 FACTOR ANALYSIS - FACTOR SCORES AND THE SYDNEY REGION

Factor scores are a by-product of factor analysis. They consist of an estimate of the relationship between the case and an underlying factor, and they allow us to see which cases contribute most highly to the establishment of high positive and negative loadings within a factor. Owing to the presence, within the data set, of locational information (i.e. grid references) it becomes possible to plot the most influential cases (here the most influential cases were deemed to be the top and bottom 10% of the factor scores).

In the factor analysis above, a differentiation was made between open and shelter sites and between coastal and inland areas. Although necessary in order to maximize the amount of information obtained, the divisions are artificial. Here the whole region is considered and, although separately identifiable, all open and shelter sites are included.

However, two data modifications remain. Firstly, grinding grooves are omitted from the analysis; it has been clear throughout this chapter that these archaeological features (which are not closely associated with food acquisition) have a consistent tendency to obscure the relationship between other site types and landscape variables. Indeed, the principal reason why they have been retained in the preceding analysis was in order to emphasize the closeness of the relationship between the other site elements and landscape characteristics. Secondly, only data from the sub-regions is used because it provides the most detailed and complete information concerning the relationships not only between Function sites and landscape variables; but also between open and shelter sites.

Rotated factor matrices were obtained for two sets of data, a) Function excluding grooves; and b) Function excluding grooves and middens. In addition, because of the complications caused by the presence of the two modified categorical variables (geology and topography), an assessment was made first using only metrical data and then with the latter variables added. The factor scores were obtained as a product of the SPSSX run to produce the appropriate factor matrix. The scores were combined with the grid-reference appropriate to the case and the top and bottom 10% of factor scores were then input to the MIDAS package (Fox and Guire 1976) and plotted upon a previously constructed basemap. Positive and negative scores for open or shelter sites were represented using separate symbols.

7.8.1 The location of factors scores and regional behaviour

The rotated factor matrix for all Function sites excluding grinding grooves and using only metrical data is presented in Table 7.16. This suggests that the major influences upon Aboriginal locational decisions over the whole region were proximity to the coast and estuaries, low height and high minimum annual and winter temperatures. However, when the factor scores are plotted by case (Map 7.1) it is clear that the apparent regional association with proximity to the coast and estuaries is largely the product of the two coastal sub-regions - Gosford-Wyong and the Royal National Park. In these areas, then, the association of Aboriginal behaviour with coast and estuary is so strong that it contributes high scores which help to establish the first factor. There is no evidence to suggest that this strong tendency was displayed by the third coastal sub-region - Cataract Dam. This latter sub-region shares in common with the inland sub-regions a strong tendency which suggests that Aboriginal locational decisions were primarily influenced by relatively high annual and winter minimum temperatures. This pattern is consistent with the behavioural model in that minimum temperature is likely to influence the length of the growing seasons, and hence the availability of vegetable foods in the land-locked areas. (Cataract Dam is different from the other two coastal sub-regions in that it does not possess an estuarine border.

```
FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

   1       8.96780       42.7        42.7
   2       6.00253       28.6        71.3
   3       1.24229        5.9        77.2
   4       1.02115        4.9        82.1

ROTATED FACTOR MATRIX:

                FACTOR  1     FACTOR  2     FACTOR  3     FACTOR  4

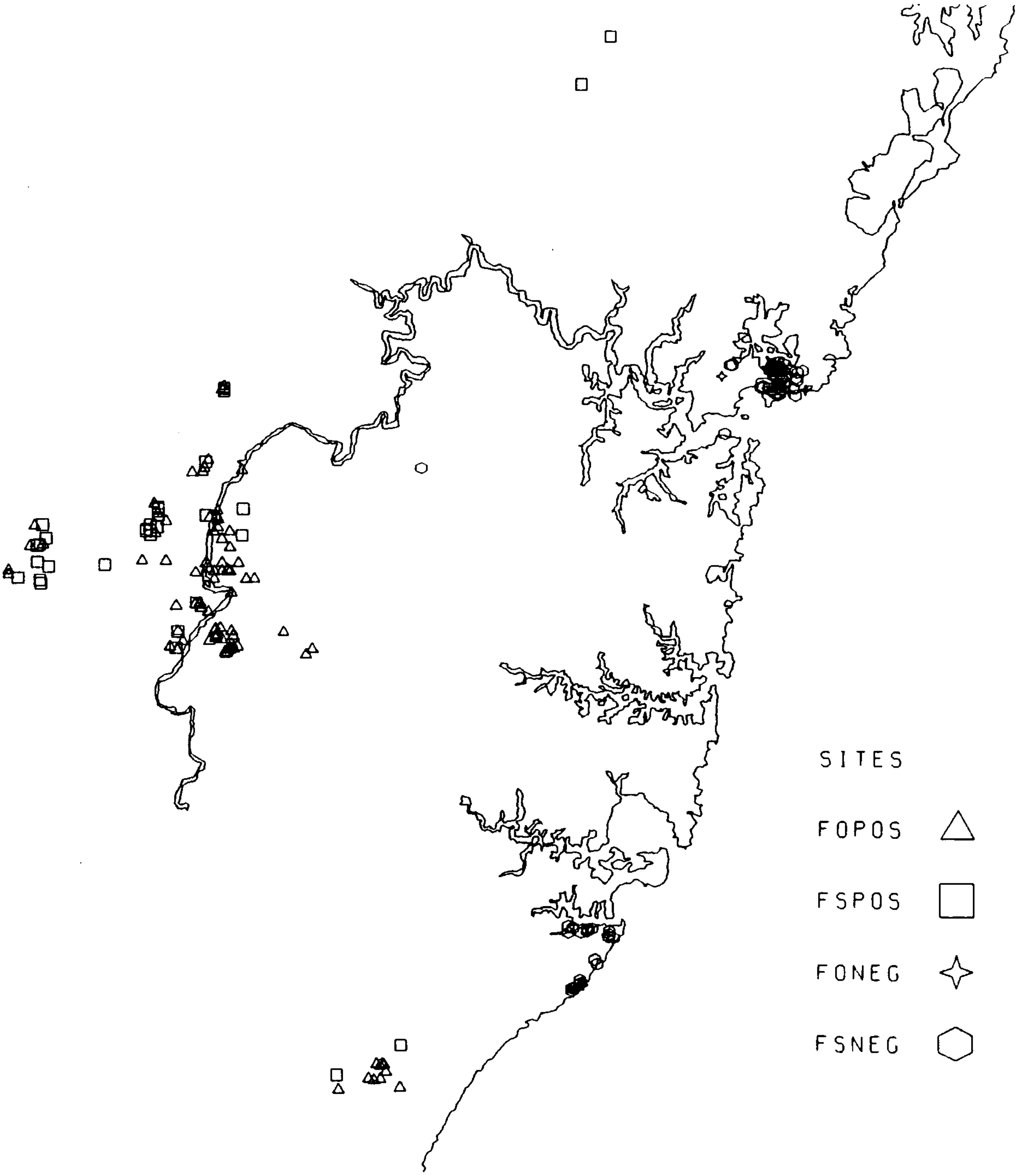
MINTSPRING        .95176       -.03165        .00652       -.02892
ANNUALTMIN        .93938        .02946        .01864       -.07383
MINTWINTER        .92154        .27578       -.13735       -.01399
MINTSUMMER        .91541       -.06863       -.24289       -.10921
MINTAUTUMN        .91388       -.04435       -.01406       -.09129
ESTUARY          -.89550       -.04145       -.00456        .24636
COAST            -.85347       -.24645        .10920        .26517
MAXTWINTER        .69273       -.62966        .12159       -.01585
HEIGHT           -.61739        .58936       -.31463       -.12180

RAINSUMMER       -.11946        .88046        .08496       -.00247
ANNUALTMAX        .13376       -.86291        .35079        .04808
ANNUALRAIN        .41099        .85749       -.03607       -.08667
MAXTAUTUMN        .38452       -.82131        .18653        .04132
RAINSPRING        .45779        .80246        .07550        .02503
RAINAUTUMN        .59288        .76231       -.06277       -.02347
RAINWINTER        .64764        .67702       -.19334       -.01190

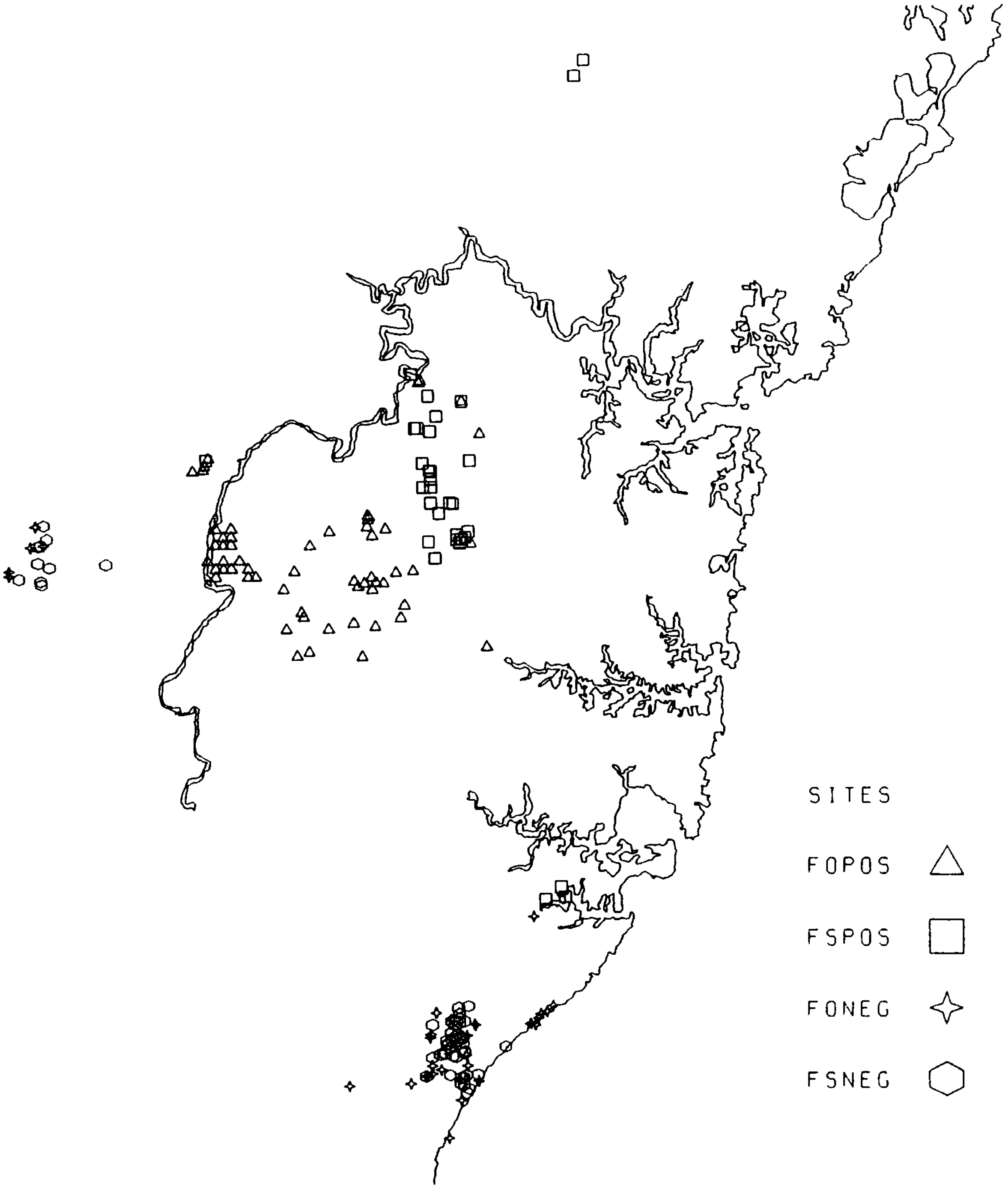
ASPECT            .03781        .01308        .64406        .24282
MAXTSPRING       -.11538       -.61806       -.63866        .20025
MAXTSUMMER       -.44153       -.36934       -.57427        .24529

FRESHWATER        .06688       -.01956       -.04987       -.72371
WETLAND          -.28138       -.13184       -.26020       -.59974
```

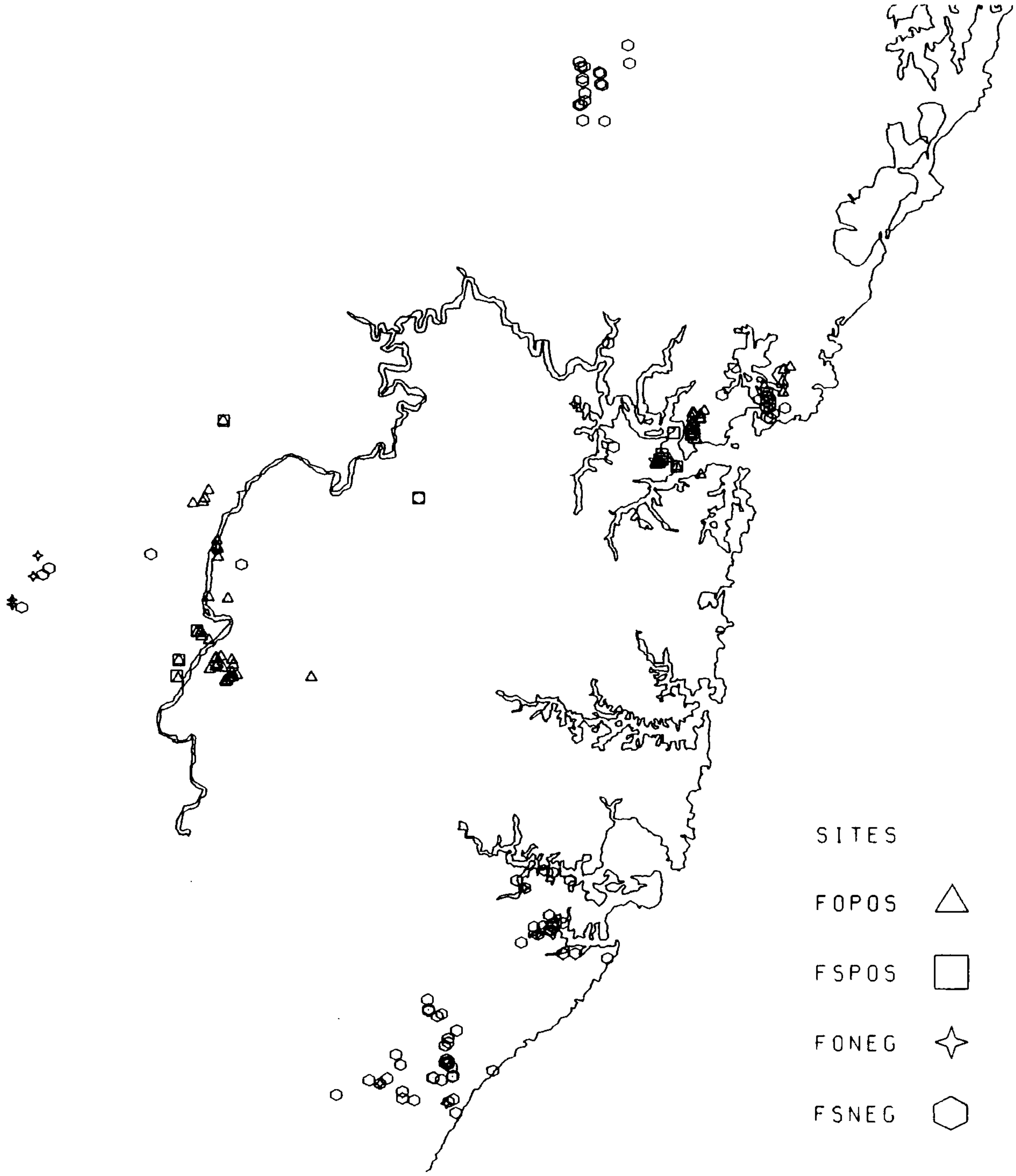
Table 7.16: Factor analysis results - all sites (excluding grinding grooves) in all sub-regions for only metrical data.



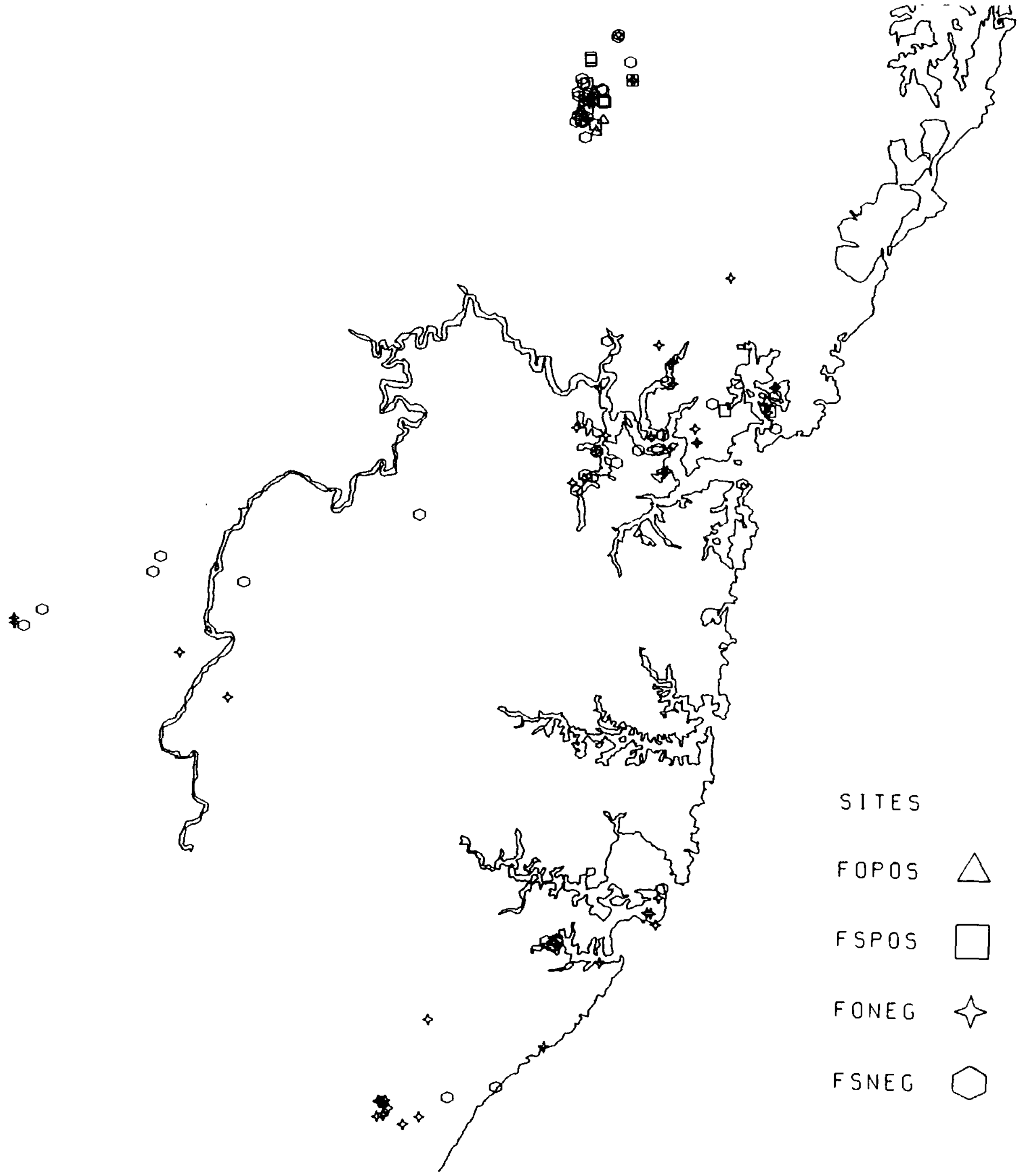
Map 7.1: The location of high positive and negative factor scores.
Factor One - all metrical data excluding grinding grooves.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)



Map 7.2: The location of high positive and negative factor scores.
Factor Two - all metric data excluding grinding grooves.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)



Map 7.3: The location of high positive and negative factor scores.
Factor Three - all metrical data excluding grinding grooves.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)



Map 7.4: The location of high positive and negative factor scores.
Factor Four - all metrical data excluding grinding grooves.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)

As a consequence of the low ranking of marine patches for three-quarters of the year, patterns of vegetational production are likely to have had a greater degree of influence within this sub-region than in the other two coastal sub-regions.)

The influences upon regional locational decisions suggested by the structure of the second factor are associated with areas of relatively higher rainfall and annual average maximum temperatures. The distribution of factor loadings (Map 7.2) illustrates clearly that the importance of relatively high rainfall is contributed to the regional factor structure, principally by sites upon the Cumberland Plain and in the Upper Mangrove Creek sub-region (Two locations within the coastal Royal National Park also appear to be associated with this influence). In contrast, the influence of relatively low maximum temperatures upon Aboriginal locational decisions is clearly associated with the Cataract Dam and Blue Mountains sub-regions. Both of these groups of factor scores are consistent with the behavioural model in that the effects of these climatic characteristics are likely to be more influential inland than upon the coast (except in the Cataract Dam sub-region for the reason suggested above). The division may also indicate a measure of seasonality inland, for the influence of rainfall is likely to be greatest in winter upon the Cumberland Plain; while the influence of low maximum temperatures is likely to be associated with summer in the Blue Mountains and the Cataract Dam sub-regions. In general this would tend to support the behavioural model and particularly the proposal that the spatial distribution of inland Aboriginal behaviour should display a measure of contraction onto the Cumberland Plain in winter and expansion in summer onto the surrounding plateau.

The third regional factor (Map 7.3) suggests that facing south to north-west and associations with areas of relatively low maximum summer and spring maximum temperatures influenced Aboriginal locational decisions. Sites contributing to the aspect factor scores are distributed primarily along the coast and along the valley of the Hawkesbury-Nepean river. In the former case it is likely that aspect reflects protection from coastal winds, whereas the associations are more likely to be associated with the degree of xeromorphy in the inland areas. It is probable that maximum summer and spring temperature are minimized in all sub-regions, but it is particularly evident in the Upper Mangrove Creek, the Blue Mountains and Cataract Dam sub-regions. Again, this supports the winter/summer expansion in inland areas associated with high-value patch distribution upon the Cumberland Plain in winter and the more widely-spaced patch distribution in summer.

Both freshwater and wetland distance load negatively upon the fourth regional factor (Map 7.4), presumably indicating that the Aborigines tended to minimize distances to both these aquatic areas. This is evident particularly in the Cataract Dam, Blue Mountains and Gosford-Wyong sub-regions. Cases which contribute <u>positively</u> to the factor tend to be associated with large groups of sites whose contribution to one part of the factor score may be overwhelmed by a negative association with the other. In the case of the Upper Mangrove Creek catchment, for example, it is highly probable that freshwater distance is minimized but we know from the evidence reviewed above that there is little association with wetlands; this characteristic is apparently so strong that it may mask the likely association with freshwater.

When the whole data are considered (Table 7.17; Maps 7.5-7.9), no substantial change is evident in the structure or location characteristics of the first two factors. The introduced variable, topography, displaces spring maximum temperature and loads negatively (with maximum summer temperature) upon the third factor; and is particularly associated with the Cataract Dam, Blue Mountain and Upper Mangrove Creek sub-regions. This suggests that Aboriginal locational decisions were influenced by the distribution of areas of low-slope landforms particularly in these uplands. The other modified variable - geology - loads positively upon the fourth factor; while wetland distance loads negatively. Geological structure appears to have been a particularly important influence upon locational decisions in the Upper Mangrove Creek catchment, along the fringes of the Gosford-Wyong sub-region and in the Blue Mountains (each one is dominated by soils of relatively high phosphorus content derived from the Narrabeen series).

Interestingly, freshwater distance loads upon a unique fifth factor. The map of factor scores shows a clear differentiation between open and shelter site with regard to this variable; while open sites are generally associated with proximity to water, shelter sites tend to display positive characteristics with regard to this factor - this division reflects the

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FACTOR    EIGENVALUE    PCT OF VAR    CUM PCT

   1        8.98094        39.0         39.0
   2        6.15316        26.8         65.8
   3        1.35990         5.9         71.7
   4        1.23094         5.4         77.1
   5        1.02784         4.5         81.5

ROTATED FACTOR MATRIX:

                FACTOR  1     FACTOR  2     FACTOR  3     FACTOR  4     FACTOR  5

MINTSPRING        .95444       -.03868       -.03185        .06984        .04246
ANNUALTMIN        .94126        .03043       -.05201       -.01488        .00429
MINTWINTER        .93082        .26700        .11132        .10635        .03060
MINTSUMMER        .92300       -.06949        .20598       -.15657       -.03175
MINTAUTUMN        .91807       -.04477       -.01716       -.02984        .02919
ESTUARY          -.91048       -.05067        .04384        .10399       -.12772
COAST            -.86857       -.25405       -.08480        .19669       -.08898
MAXTWINTER        .68141       -.62493       -.15594       -.09698       -.07354
HEIGHT           -.59652        .57751        .38613       -.07297        .15634

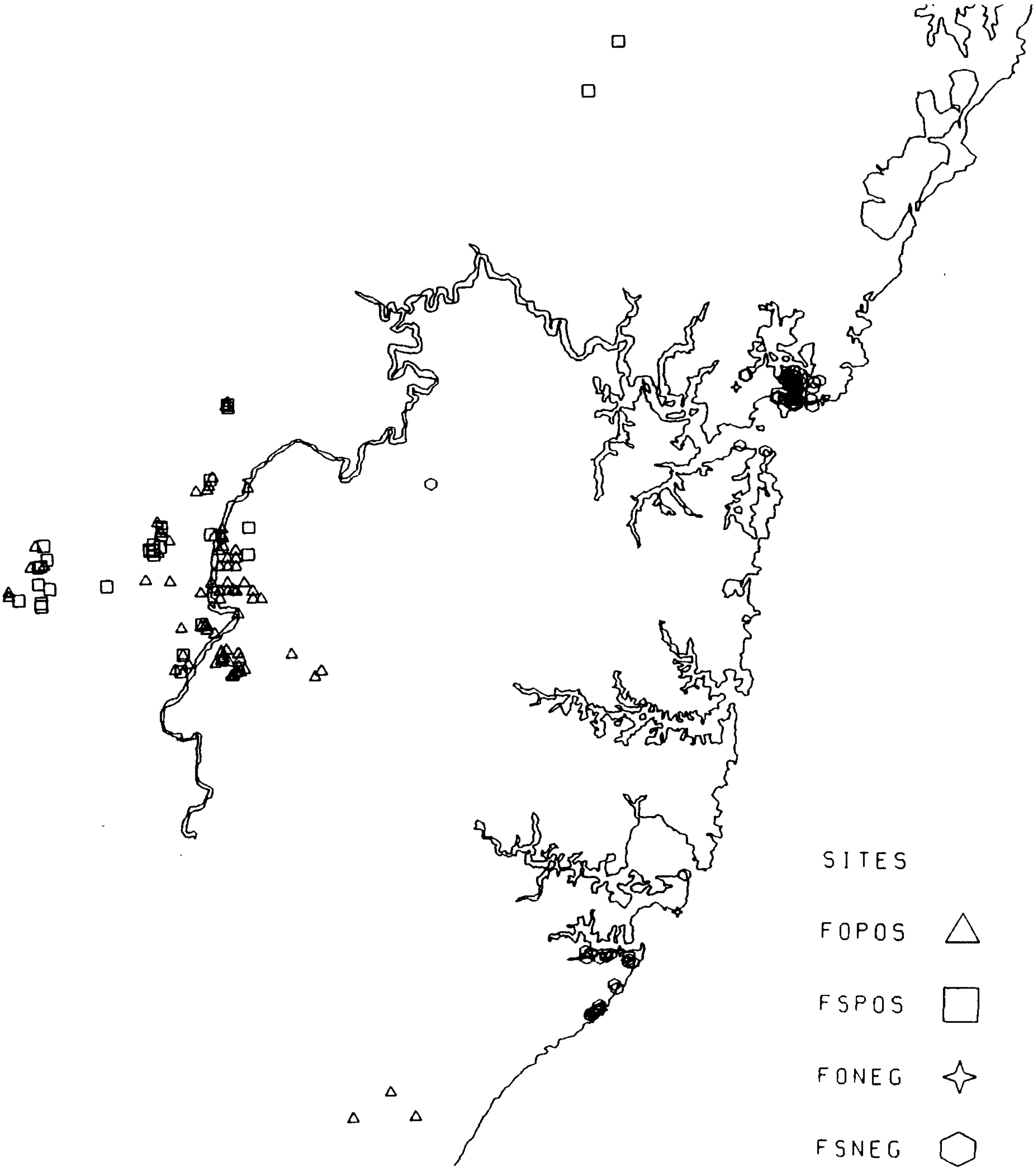
RAINSUMMER       -.12549        .88734       -.06811       -.01025       -.04243
ANNUALTMAX        .11590       -.85687       -.36602        .00674       -.03503
ANNUALRAIN        .41242        .85377        .04413       -.05947        .05055
MAXTAUTUMN        .36677       -.81476       -.21109       -.09250       -.11997
RAINSPRING        .44834        .79969       -.06145        .02157       -.05440
RAINAUTUMN        .59404        .75647        .06574        .02203        .00149
RAINWINTER        .65425        .66437        .19164        .04101        .02335
MAXTSPRING       -.15847       -.61841       -.60904        .06254       -.12284

ASPECT            .04922        .01196        .58760        .11568       -.28761
TOPOGRAPHY       -.06369        .20344       -.57350        .03175        .43160
MAXTSUMMER       -.47043       -.38099       -.51788        .29970        .00566

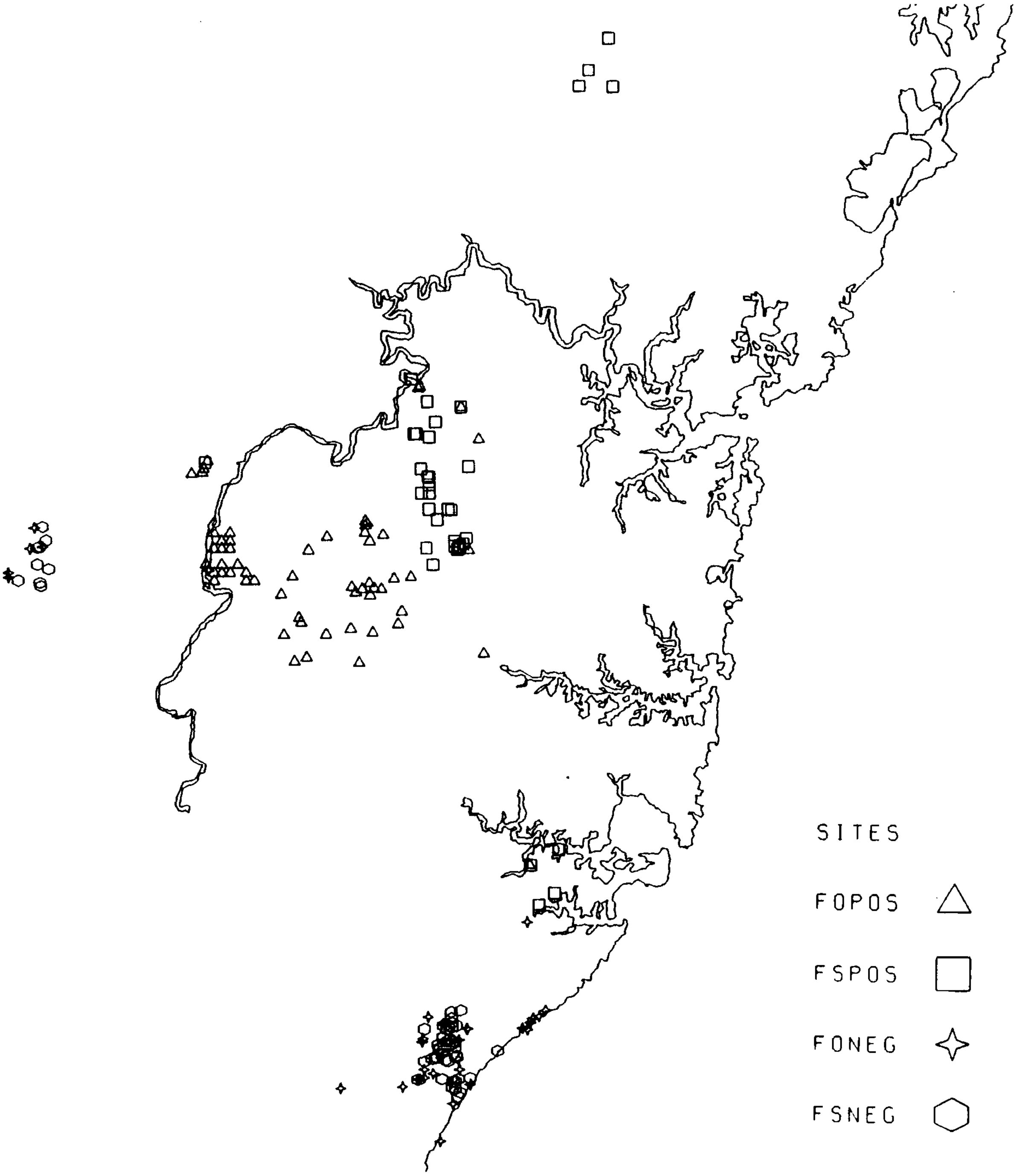
GEOLOGY           .07682        .15528       -.09666        .78863        .01872
WETLAND          -.29166       -.18752        .28891       -.63754       -.06725

FRESHWATER        .14353        .00466       -.06760       -.01733       -.85582
```

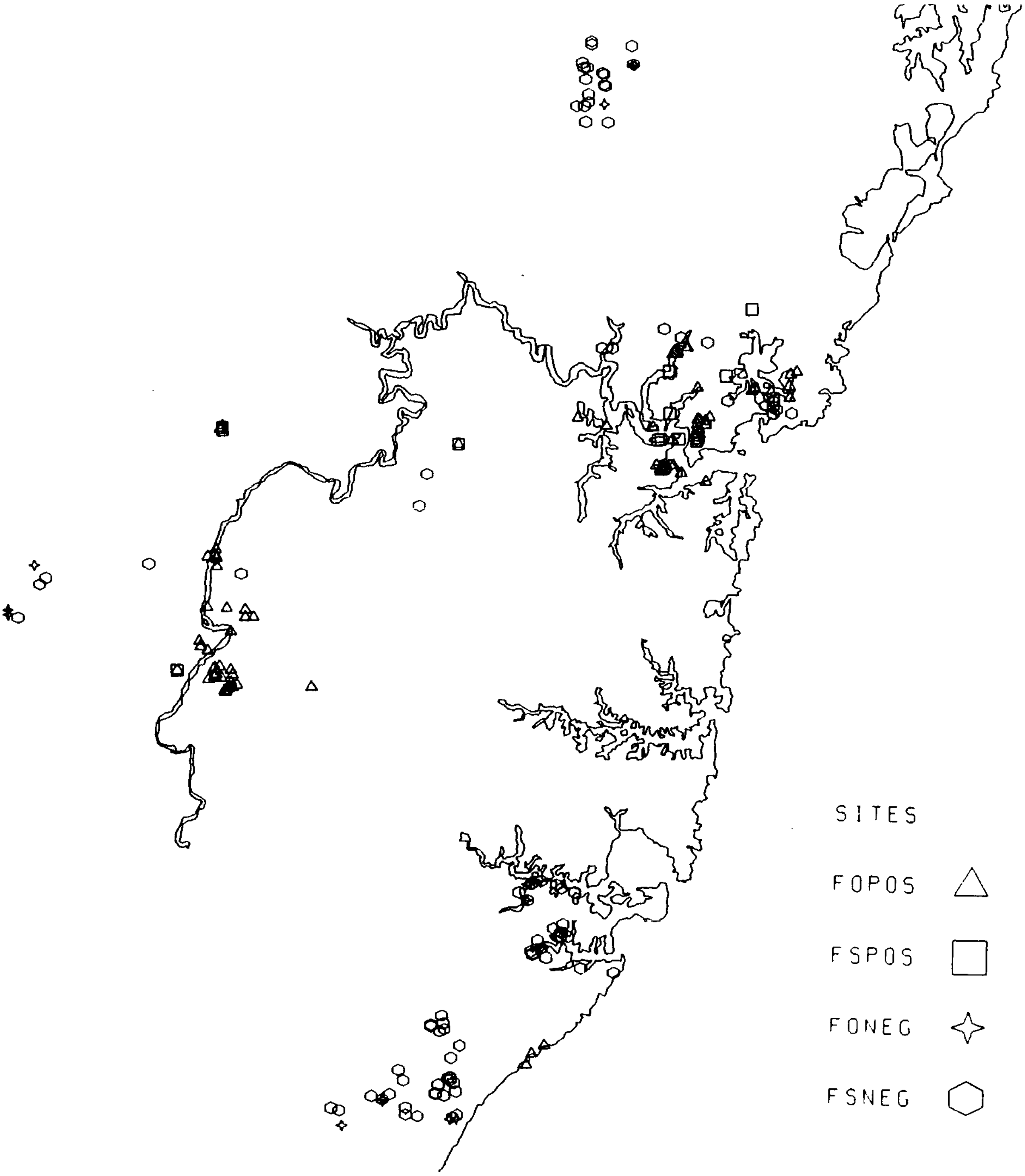
Table 7.17: Factor analysis results - all sites (excluding grinding grooves) in all sub-regions for all data.



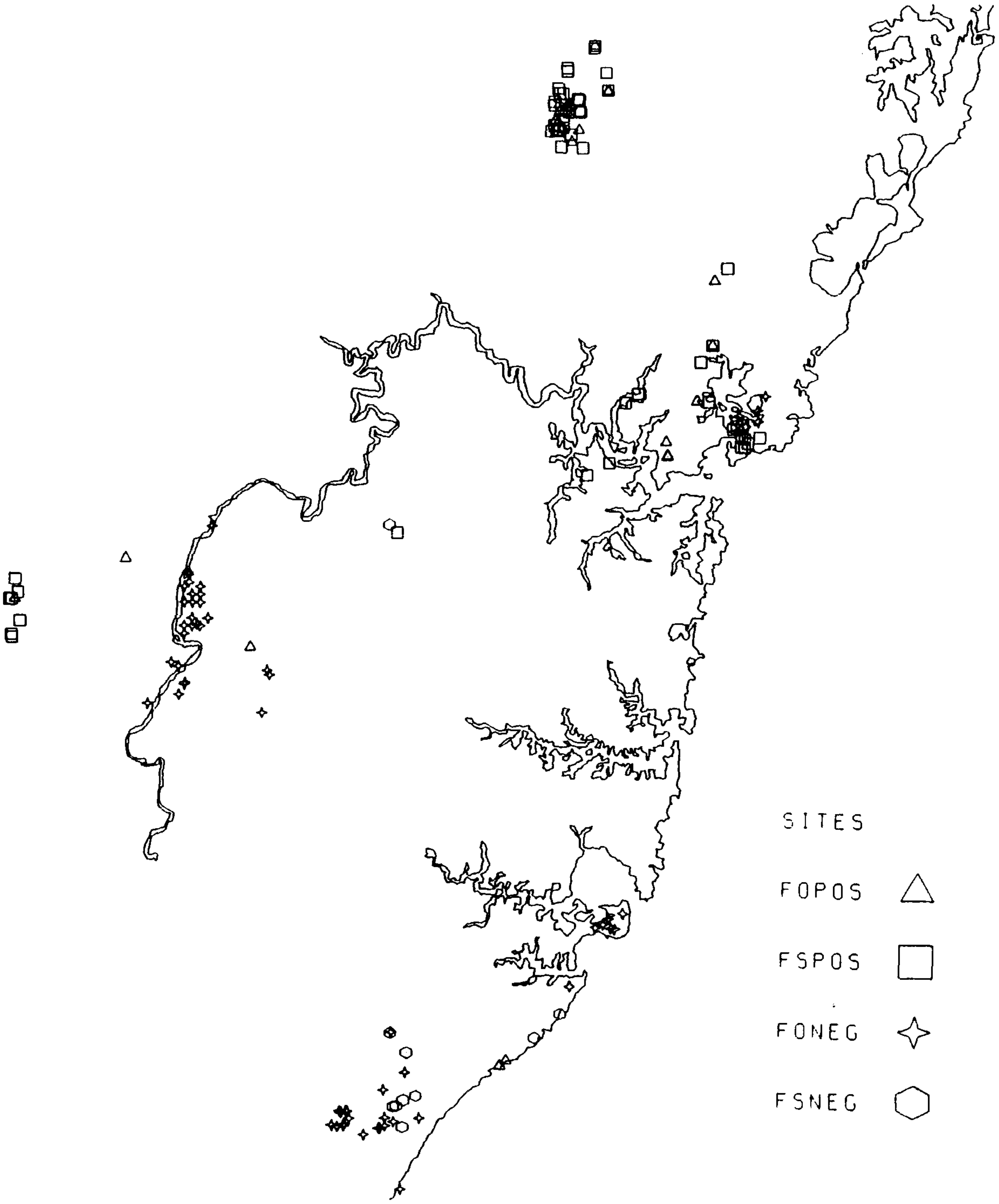
Map 7.5: The location of high positive and negative factor scores.
Factor One - all data excluding grinding grooves.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)



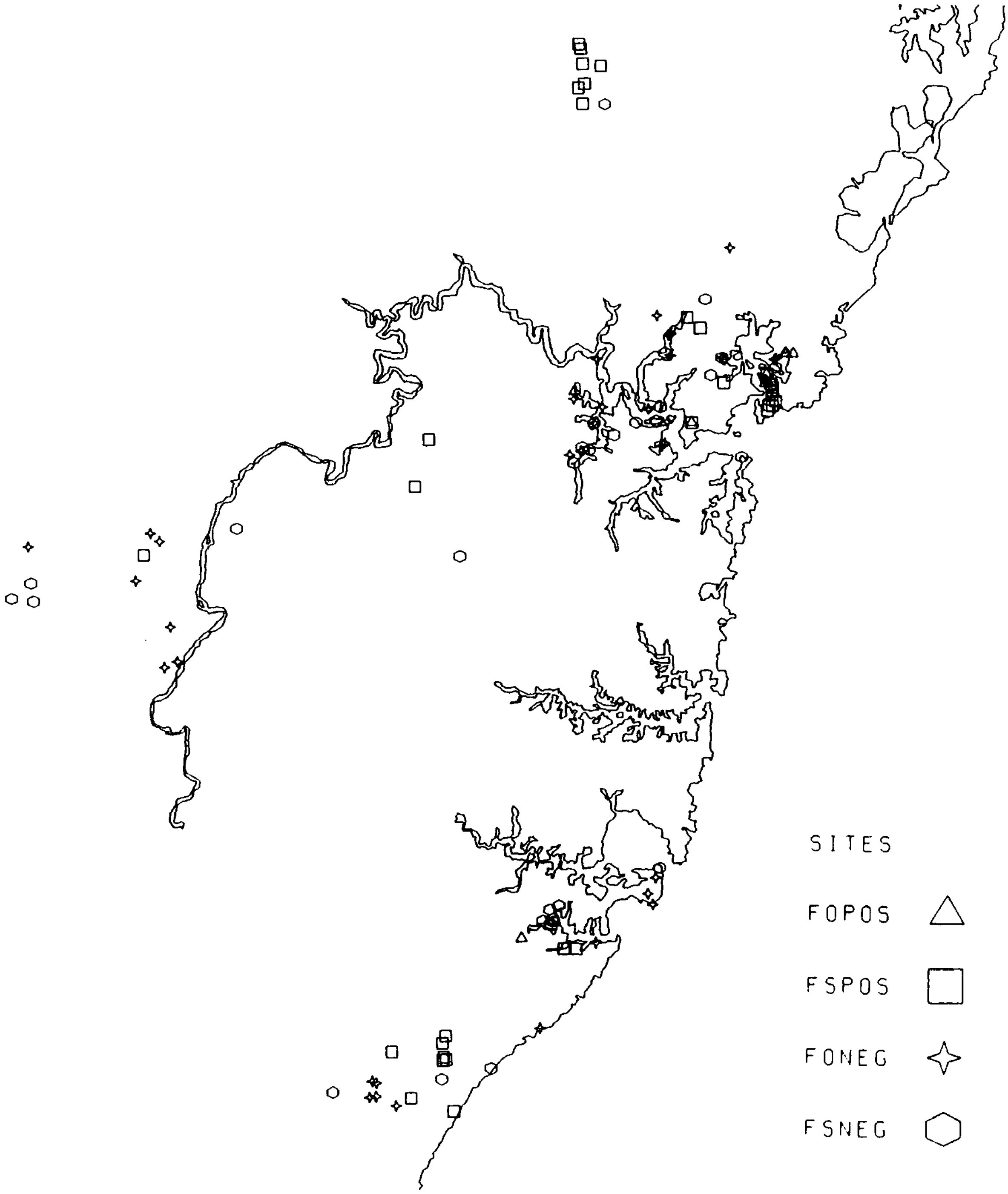
Map 7.6: The location of high positive and negative factor scores.
Factor Two - all data excluding grinding grooves.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)



Map 7.7: The location of high positive and negative factor scores.
Factor Three - all data excluding grinding grooves.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)



Map 7.8: The location of high positive and negative factor scores.
Factor Four - all data excluding grinding grooves.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)



Map 7.9: The location of high positive and negative factor scores.
Factor Five - all data excluding grinding grooves.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)

fundamental geological and topographic ties of the latter site group.

When the influence of middens (which tend to bind the whole data to the estuaries and coast) is removed from the analysis the variable structure of factors undergoes large-scale changes (Table 7.18). Maximum temperature variables (particularly annual, spring and summer); and height load negatively and highly upon the factor while rainfall (particularly annual spring and summer) loads positively. The shift of emphasis from coast to hinterland, when middens are removed, is particularly illustrated (Map 7.10 - 7.13) by the fact that the principal areas in which sites contribute most highly to the first factor, are nearly all inland areas (though Cataract Dam, which tends to display characteristics which are dissimilar to those of other coastal sub-regions is also associated with these factor scores). The influence upon Aboriginal locational decisions of localities which possess relatively low maximum annual, spring and summer temperatures is most evident in the Cataract Dam and Blue Mountains sub-region; while the influence of rainfall is associated particularly with the Cumberland Plain and to some extent the Upper Mangrove Creek sub-regions.

Minimum temperatures load positively upon the second factor while estuary and coastal distance load negatively. The division is plainly geographical and in accordance with the behavioural model. Localities which possess a relatively high minimum temperatures appear to have influenced Aboriginal decisions inland, while estuarine and coastal proximity seem to have influenced locational decisions upon the coast.

```
FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

   1       8.33306       39.7        39.7
   2       6.92881       33.0        72.7
   3       1.24343        5.9        78.6
   4       1.05503        5.0        83.6

ROTATED FACTOR MATRIX:

               FACTOR  1     FACTOR  2     FACTOR  3     FACTOR  4

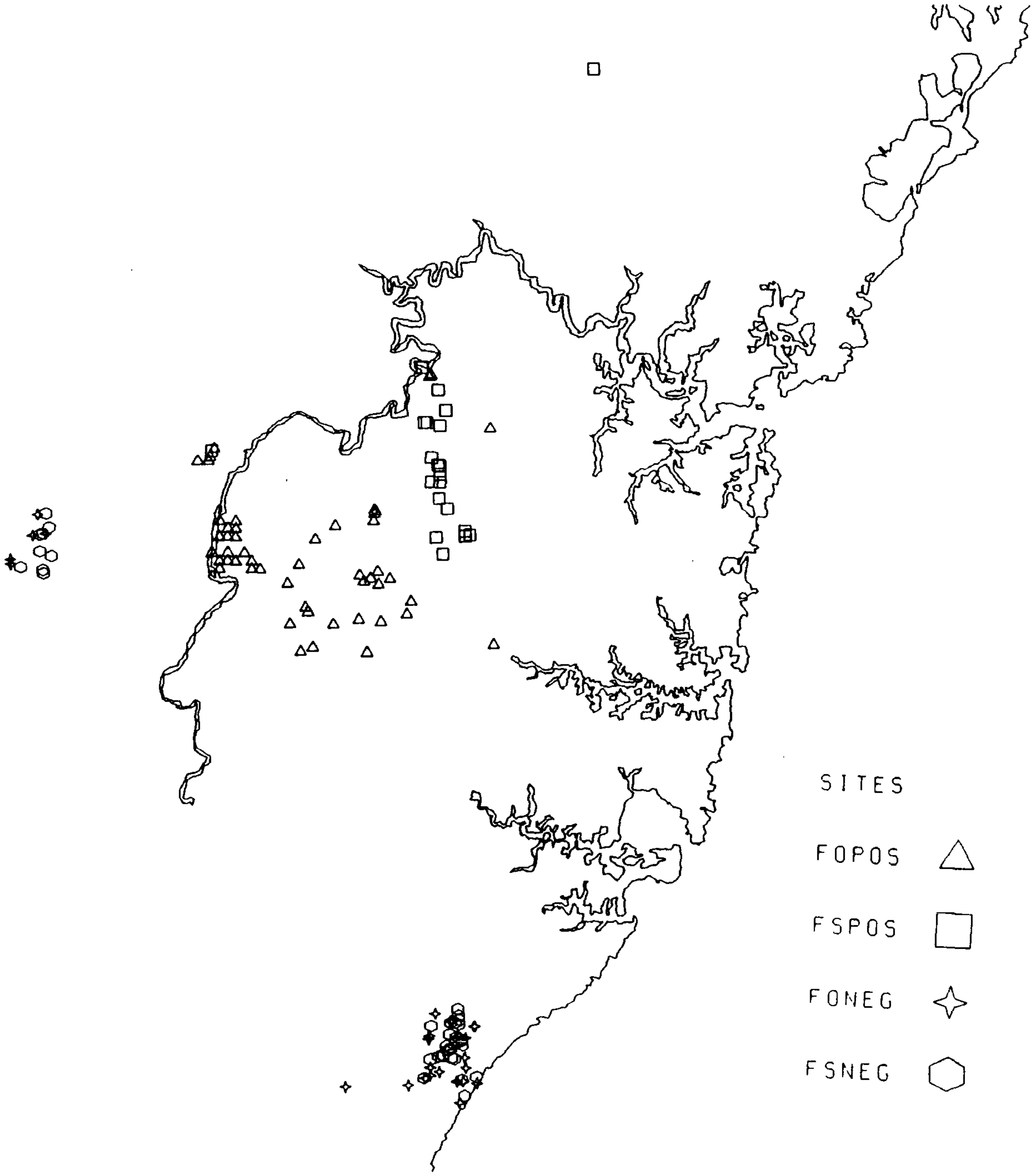
ANNUALTMAX      -.94825        .08233        .00314        .07472
ANNUALRAIN       .90812        .28344       -.03883        .05207
MAXTSUMMER      -.88411       -.17737        .08631        .18082
RAINSUMMER       .86830       -.20692       -.07192       -.01063
MAXTSPRING      -.86215        .37767       -.06219       -.07326
RAINSPRING       .85599        .24124       -.03085        .07152
RAINAUTUMN       .84657        .45925        .01834        .01793
RAINWINTER       .79471        .53018        .09371       -.05449
HEIGHT          -.75263       -.47893       -.10750       -.07549
MAXTWINTER       .74693        .59409       -.09162       -.07771
MAXTAUTUMN      -.51555       -.44160        .26874        .34632

MINTSPRING      -.08281        .95115        .13238        .08815
MINTSUMMER      -.05409        .93676       -.13915       -.12302
ANNUALTMIN      -.01804        .91412       -.03363        .16266
MINTWINTER       .34584        .90428        .14826       -.00436
ESTUARY         -.05973       -.90357        .21105       -.05666
MINTAUTUMN      -.11658        .88783       -.04033        .06064
COAST           -.28050       -.82060        .31531        .01947

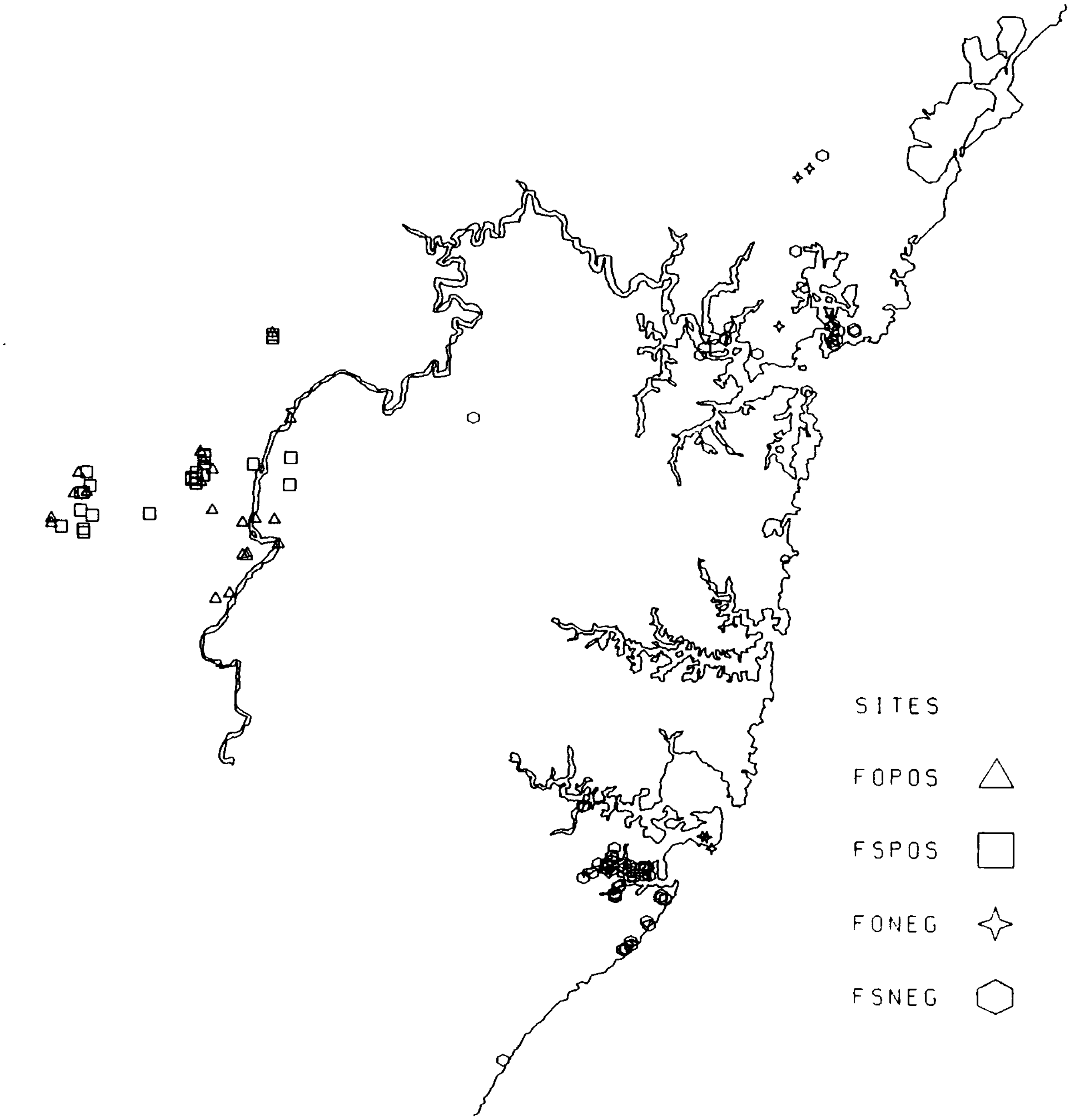
WETLAND         -.04235       -.14350       -.94208       -.12927

ASPECT           .16693        .09929        .13378        .77422
FRESHWATER       .12343        .23548        .00287       -.54256
```

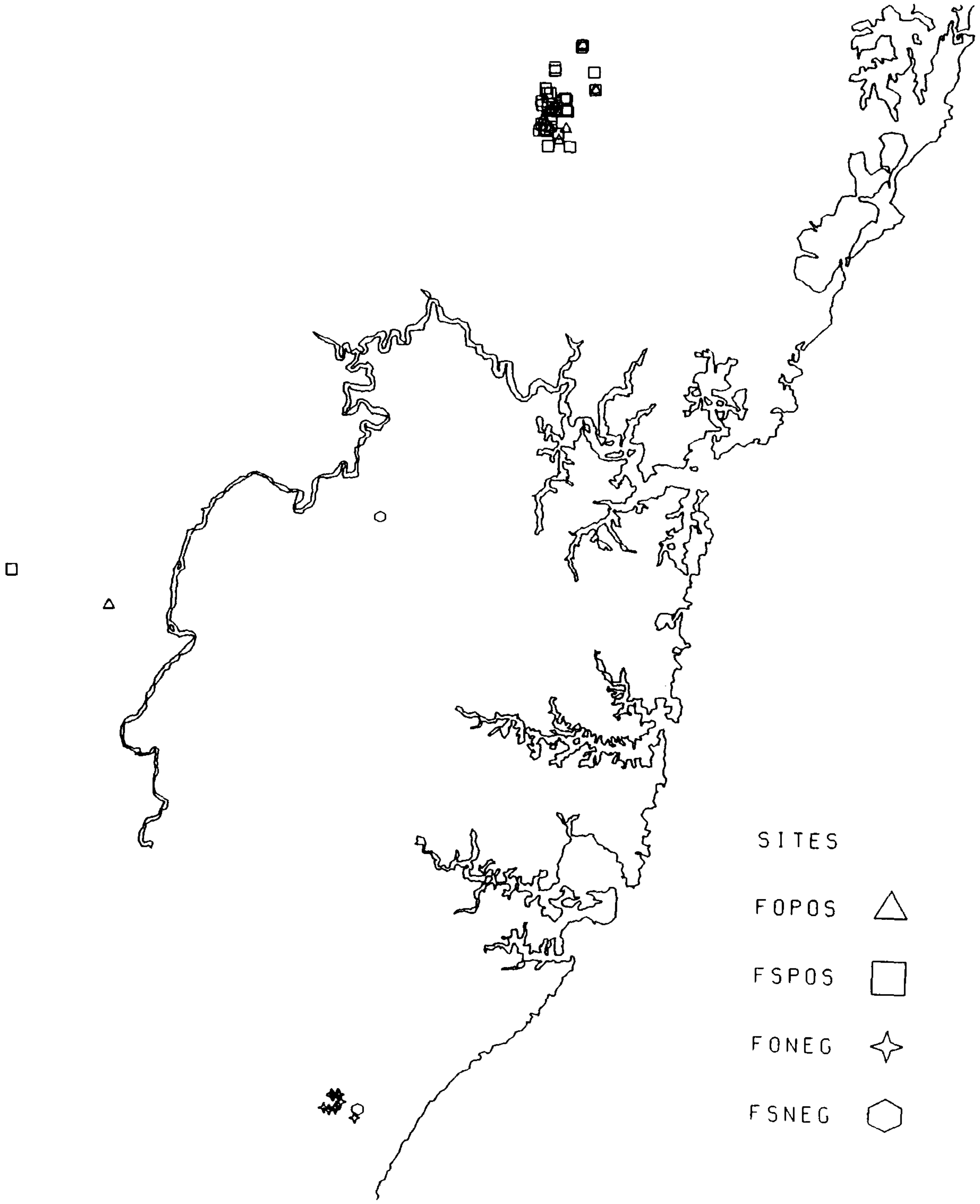
Table 7.18: Factor analysis results - all sites (excluding grinding grooves and middens) in all sub-regions for only metrical data.



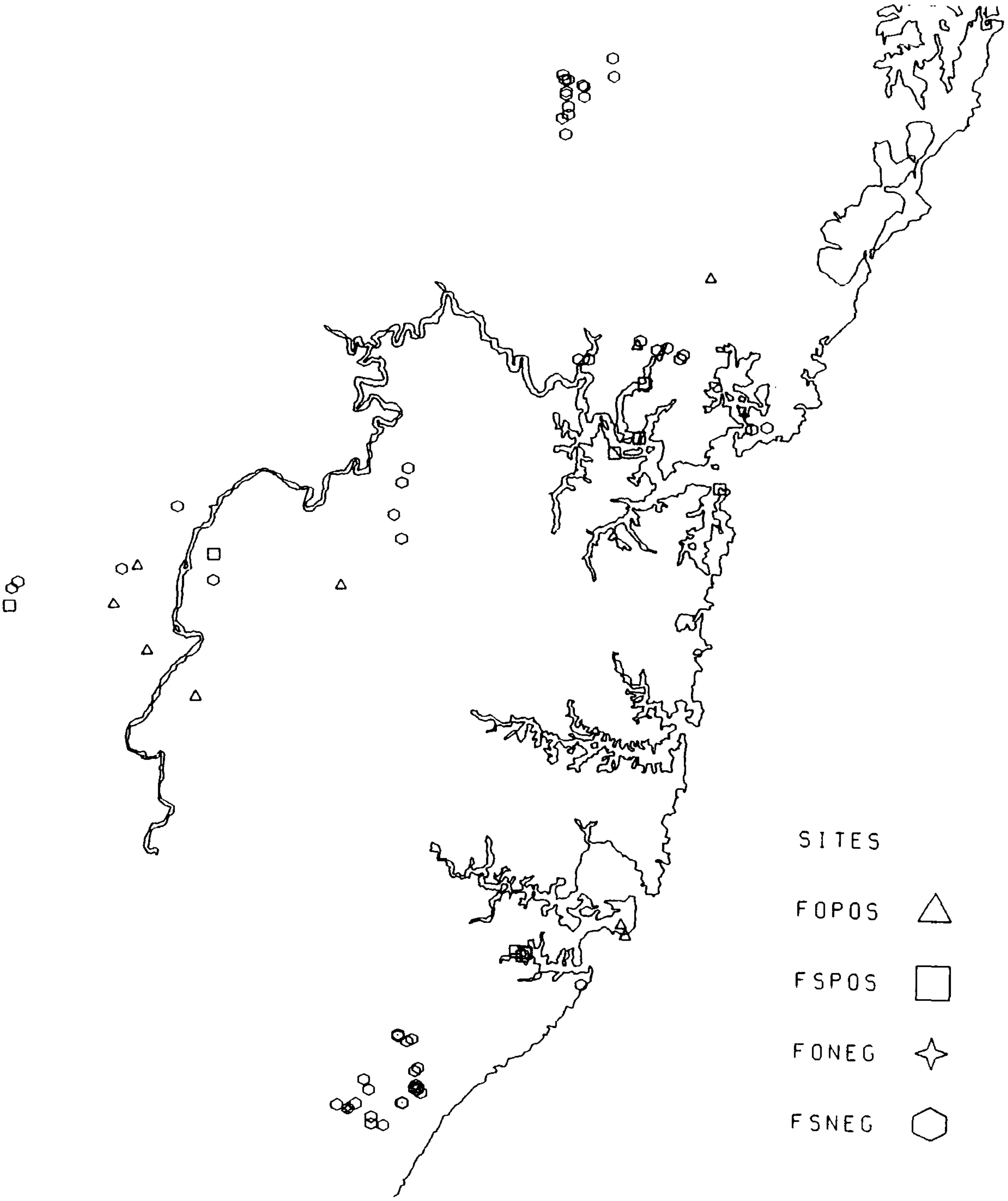
Map 7.10: The location of high positive and negative factor scores.
Factor One - all metrical data excluding grinding grooves and middens.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)



Map 7.11: The location of high positive and negative factor scores. Factor Two - all metrical data excluding grinding grooves and middens.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)



Map 7.12: The location of high positive and negative factor scores.
Factor Three - all metrical data excluding grinding grooves and middens.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)



Map 7.13: The location of high positive and negative factor scores.
Factor Four - all metrical data excluding grinding grooves and middens.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)

Wetland distance is the only variable to load upon the unique third factor. The sites which makes the largest contribution to the factor scores are within the Cataract Dam and Cumberland Plain sub-regions. Sites in the Upper Mangrove Creek and, to some extent, the Blue Mountains sub-regions, display a counter tendency, which is (again) suggestive of occupation in summer rather than winter (when wetlands are associated with high-value patches).

Aspect loads positively upon the fourth factor while freshwater distance loads negatively. While it is highly probable that freshwater distances were minimized by Aborigines in all parts of the region, it is evident that this was particularly important in the Cataract Dam and Upper Mangrove Creek areas. Similarly, facing south to north-west appears to have been important particularly along the coast and the Hawkesbury-Nepean river.

When the modified variables are introduced into the analysis (Table 7.19; Maps 7.14 - 7.18) there is no apparent substantial change in the structure of the first two factors. The introduced variable - geology - loads positively upon the third factor. Again, those sites which contribute the highest factor scores are particularly associated with areas which contain a high percentage of the Narrabeen series parent materials.

Aspect loads positively upon a unique fourth factor. The cases which contribute to this positive loading (indicating south to north-west) are

```
FACTOR   EIGENVALUE   PCT OF VAR   CUM PCT

   1       8.51696       37.0        37.0
   2       7.03146       30.6        67.6
   3       1.43071        6.2        73.8
   4       1.14330        5.0        78.8
   5       1.06429        4.6        83.4

ROTATED FACTOR MATRIX:

               FACTOR  1     FACTOR  2     FACTOR  3     FACTOR  4     FACTOR  5

ANNUALTMAX      -.93901        .09253       -.03633       -.11826       -.05966
ANNUALRAIN       .91073        .27769       -.04417        .00867        .06265
RAINSUMMER       .87954       -.20691       -.02718        .00010       -.01861
MAXTSPRING      -.87223       -.16051        .03364       -.22894       -.05715
RAINSPRING       .86634        .24330       -.00285       -.03764        .02982
MAXTSUMMER      -.84988        .37826       -.12217        .03163       -.11598
RAINWINTER       .84707        .45406        .01789        .05009        .04985
RAINAUTUMN       .77892        .51609        .08154        .16227        .09617
MAXTWINTER      -.74569        .58564       -.15766        .09269       -.02101
HEIGHT          -.72337       -.50434       -.06050        .17268        .23777
MAXTAUTUMN      -.51142       -.40961        .31507       -.36774        .04965

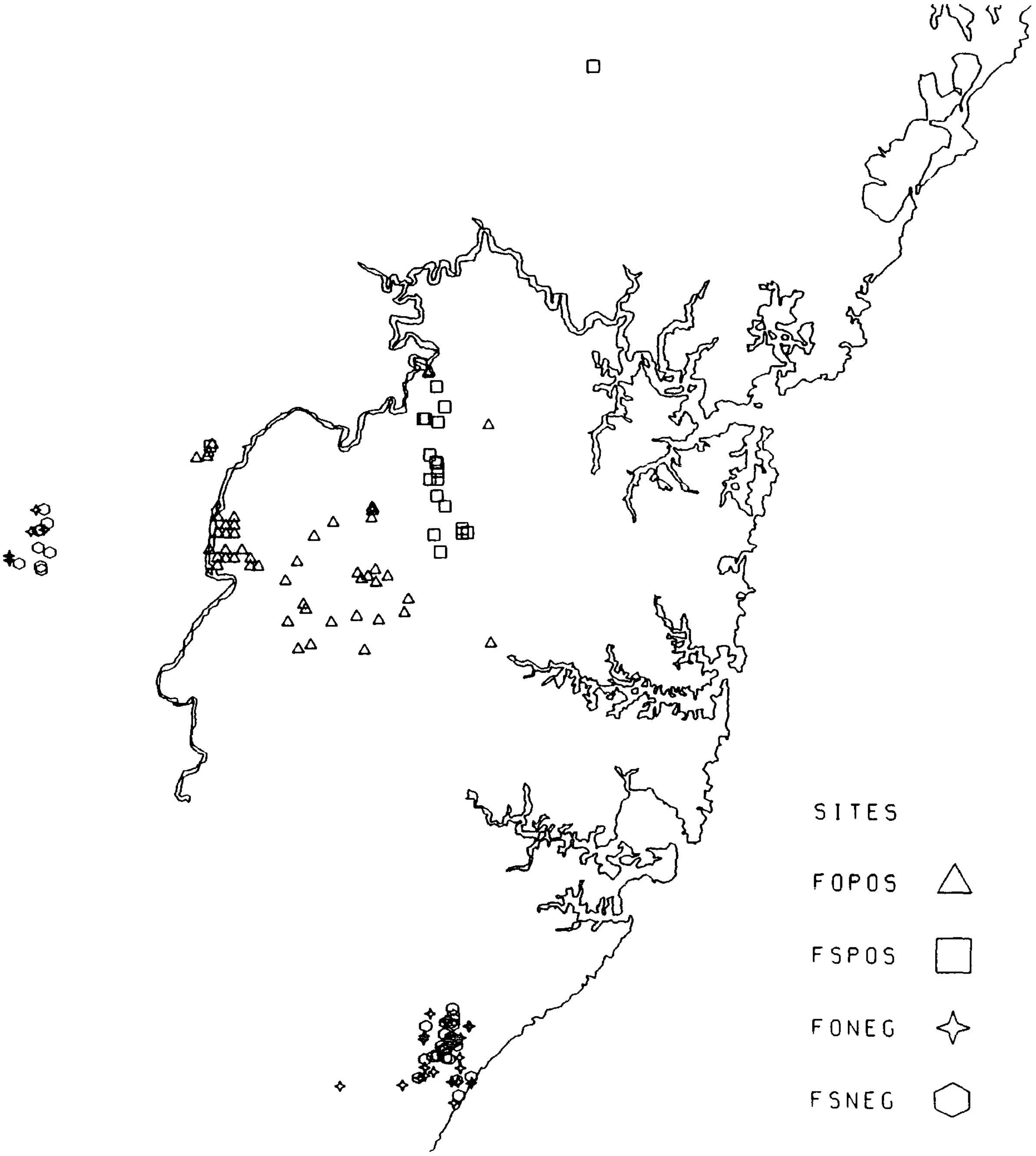
MINTSPRING      -.08456        .95469        .10753       -.00728        .05175
ANNUALTMIN       .00061        .92613       -.04703       -.13396        .00012
MINTSUMMER      -.05211        .91978       -.22060        .17707       -.01045
ESTUARY         -.06669       -.90293        .15529       -.00377       -.12038
MINTWINTER       .33232        .89858        .15142        .11770        .09893
MINTAUTUMN      -.10711        .89249       -.03226       -.01804        .02839
COAST           -.28980       -.81272        .26144       -.07182       -.10788

WETLAND         -.11119       -.16010       -.76666        .27519        .01105
GEOLOGY          .15260       -.02273        .75387       -.10876       -.05071

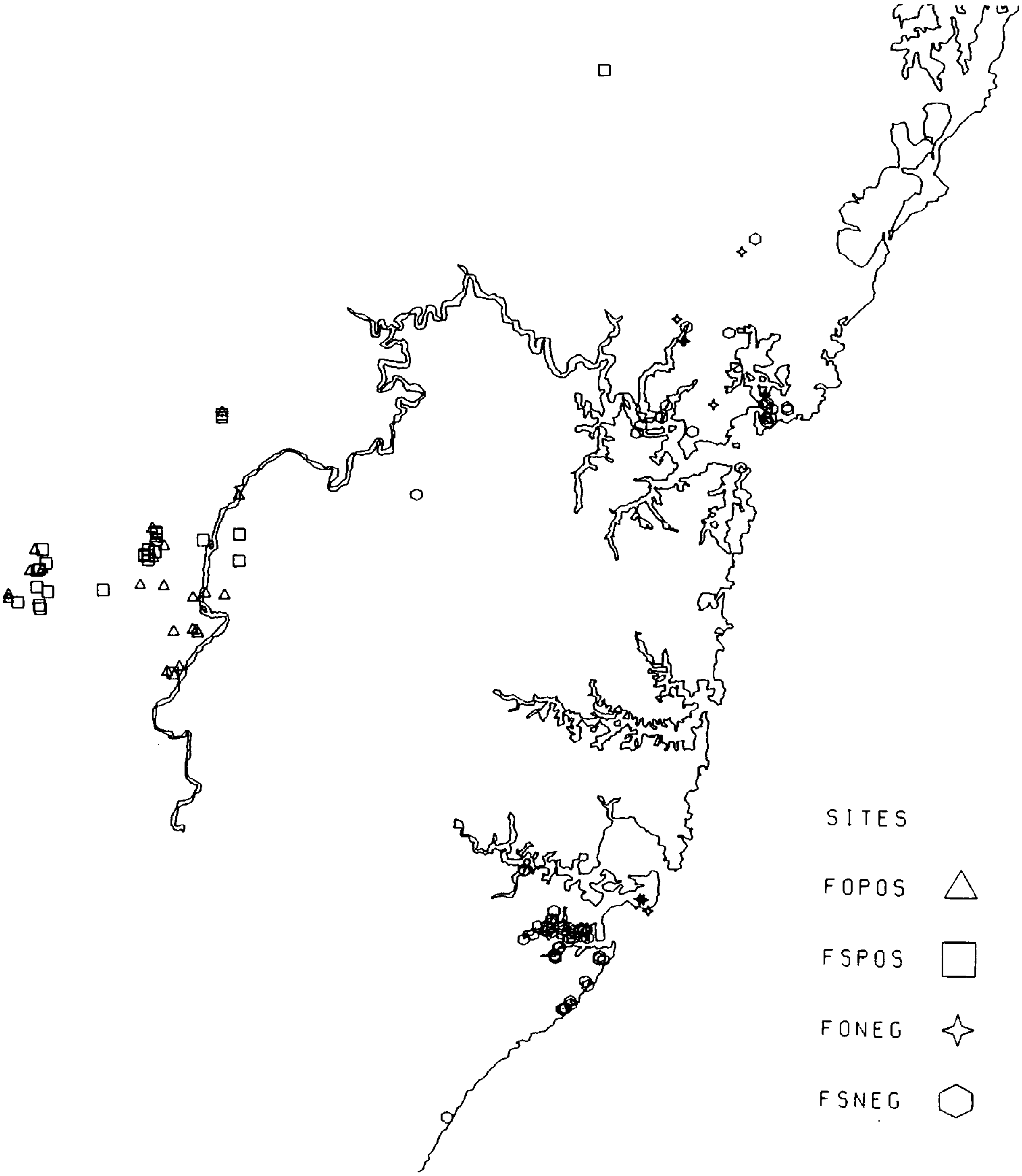
ASPECT           .11004        .04450        .09552        .83570       -.04848

FRESHWATER       .02810        .20329       -.03289       -.16901       -.84760
TOPOGRAPHY       .41415       -.01603       -.02506        .38706       -.58271
```

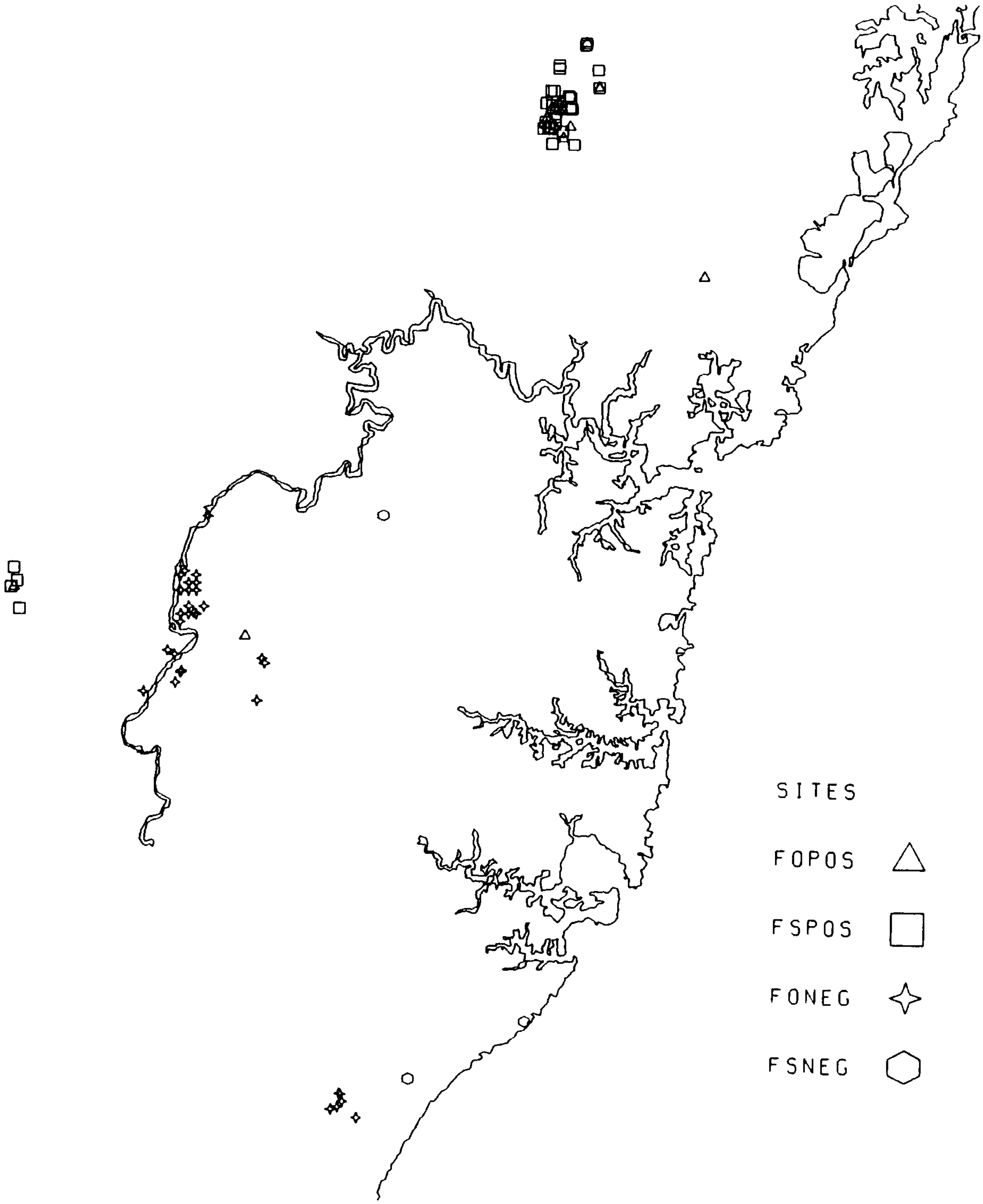
Table 7.19: Factor analysis results - all sites (excluding grinding grooves and middens) in all sub-regions for all data.



Map 7.14: The location of high positive and negative factor scores. Factor One - all data excluding grinding grooves and middens.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)

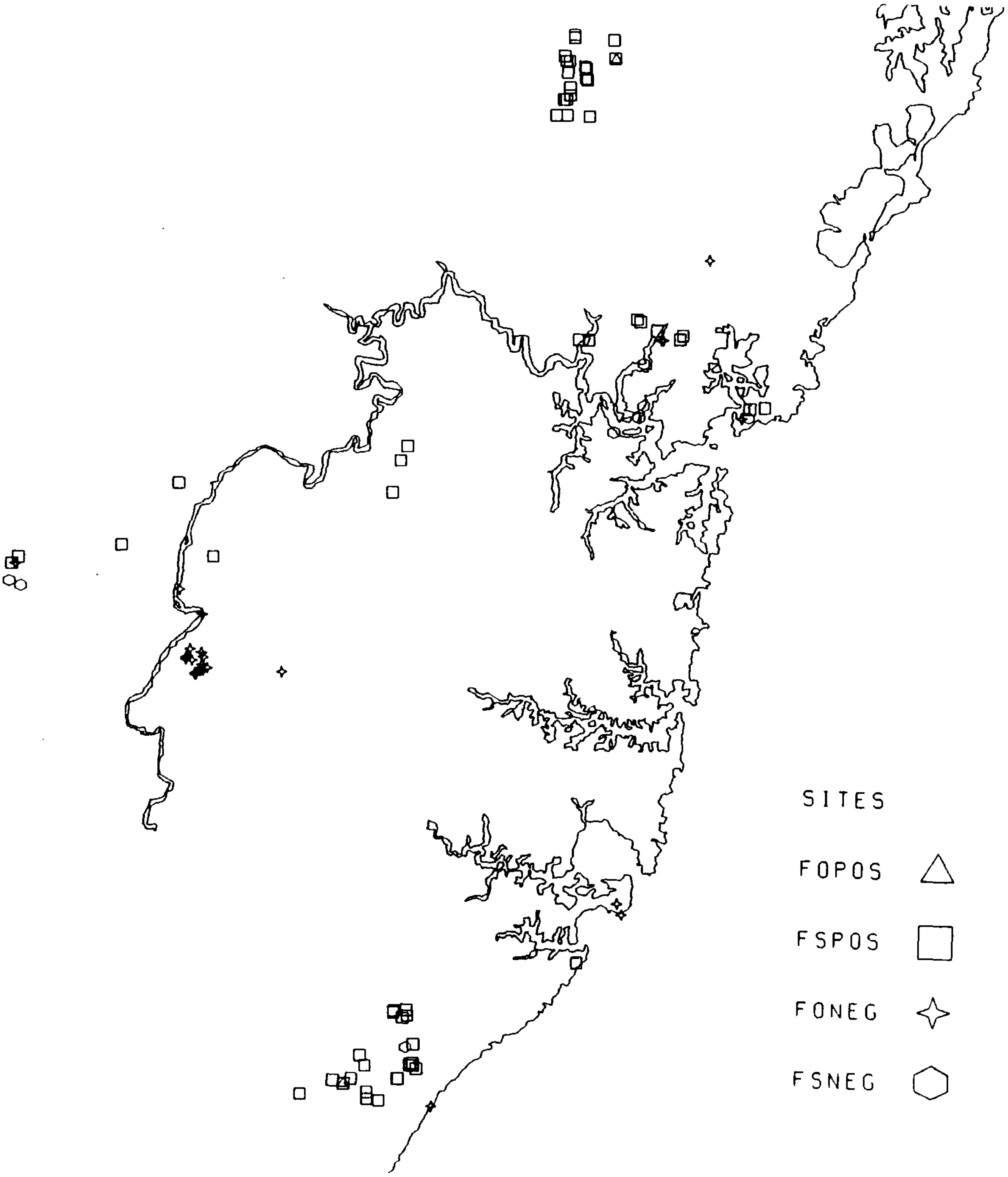


Map 7.15: The location of high positive and negative factor scores.
Factor Two - all data excluding grinding grooves and middens.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shélter.)



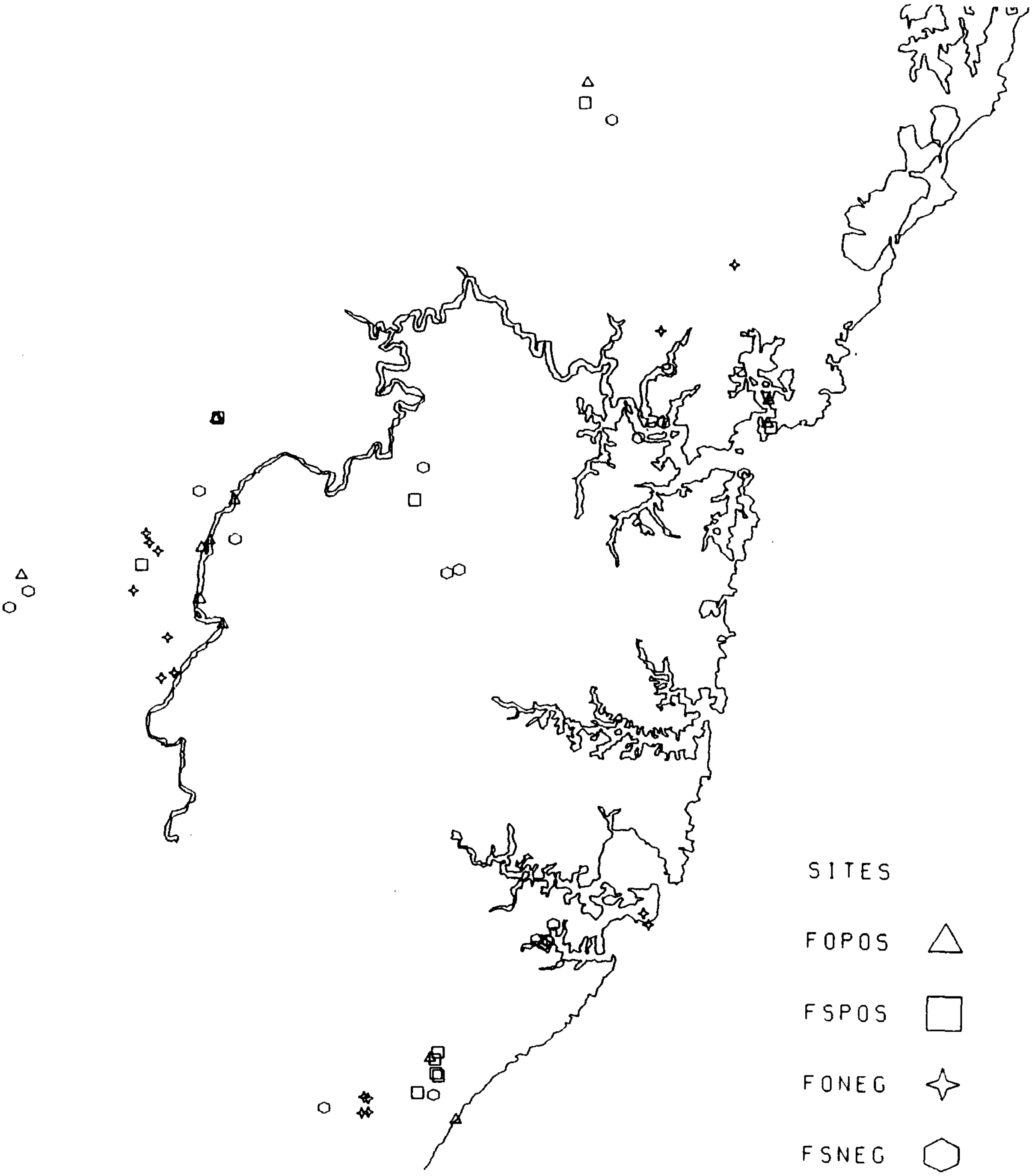
Map 7.16: The location of high positive and negative factor scores. Factor Three - all data excluding grinding grooves and middens.

(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)



Map 7.17: The location of high positive and negative factor scores. Factor Four - all data excluding grinding grooves and middens.

(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)



Map 7.18: The location of high positive and negative factor scores. Factor Five - all data excluding grinding grooves and middens.
(Note: FOPOS = positive factor score - Function Open.
FSPOS = positive factor score - Function Shelter.
FONEG = negative factor score - Function Open.
FSNEG = negative factor score - Function Shelter.)

widely distributed. Negative loading (indicating north to south-east aspects) are limited to the Cumberland Plain near to the river and also to some few sites in extreme proximity to the coast.

Both freshwater distance and topography load negatively upon the fifth factor. The cases which contribute to this negative loading are widely distributed. It should be noted that cases which contribute a positive loading are mostly shelter sites which, because of their geological and topographic ties, are likely to be found at a greater distance from water and upon a steeper slopes than open sites.

7.8.2 Sub-regions, factor scores and the behavioural model

Tables 7.20 to 7.23 summarize the relationships between regional factors and the positive and negative loadings from the sub-regions, while Tables 7.24 & 7.25 indicates the strength of the contribution made by each sub-region towards regional factors (established by a count of sites represented per factor). Why, then, are Sydney region sites distributed where they are? Using the top and bottom 10% of the factor scores, the answers (based upon the ways in which the sub-regions fit into the regional whole) are suggested below by sub-region.

GOSFORD-WYONG

It is clear that Function sites in the Gosford-Wyong sub-region are most closely tied to coastal and estuarine resources and height. Estuarine distance, coastal distance, height, geological structure,

FACTORS	HIGH LOADING VARIABLES	POSITIVE CONTRIBUTION						NEGATIVE CONTRIBTION					
		G	U	C	B	D	R	G	U	C	B	D	R
1 (METRICAL DATA EXCLUDING GROOVES)	MINTSPRING +		?	&	&	&							
	ANNUALTMIN +												
	MINTWINTER +												
	MINTSUMMER +												
	ESTUARY –							&					&
	COAST –												
	HEIGHT –												
		G	U	C	B	D	R	G	U	C	B	D	R
2	RAINSUMMER +		?	&			?						
	ANNUALRAIN +												
	ANNUALTMAX –										&	&	
	MAXTAUTUMN –												
		G	U	C	B	D	R	G	U	C	B	D	R
3	ASPECT +	&		&	?								
	MAXTSPRING –							?				X	X
	MAXTSUMMER –												
		G	U	C	B	D	R	G	U	C	B	D	R
4	FRESHWATER –		&					&	&	&	&	&	&
	WETLAND –												

Table 7.20: High loading variables and the contribution of the sub-regions. All sites excluding grinding grooves - metrical data. (Note: (&) indicates a contribution by both Open and Shelter sites; (*) indicates a contribution by Open sites alone; (X) indicates a contribution by Shelter sites alone; and (?) indicates that there is small amount of evidence (a few sites) of an contribution.)

FACTORS	HIGH LOADING VARIABLES	POSITIVE CONTRIBUTION						NEGATIVE CONTRIBTION					
		G	U	C	B	D	R	G	U	C	B	D	R
1 (ALL DATA EXCLUDING GROOVES)	MINTSPRING +		?	&	&	*							
	ANNUALTMIN +												
	MINTWINTER +												
	MINTSUMMER +												
	ESTUARY −							&					&
	COAST −												
	HEIGHT −												
		G	U	C	B	D	R	G	U	C	B	D	R
2	RAINSUMMER +		X	&			?						
	ANNUALRAIN +												
	ANNUALTMAX −										&	&	?
	MAXTAUTUMN −												
		G	U	C	B	D	R	G	U	C	B	D	R
3	ASPECT +	&		&									
	TOPOGRAPHY −							&	&		&	&	X
	MAXTSUMMER −												
		G	U	C	B	D	R	G	U	C	B	D	R
4	GEOLOGY +	&	&	?	&								
	WETLAND −							*		*		&	&
		G	U	C	B	D	R	G	U	C	B	D	R
5	FRESHWATER −	&	X	?		X	?	&	?	?	&	&	&

Table 7.21: High loading variables and the contribution of the sub-regions. All sites excluding grinding grooves - all data.
(Note: (&) indicates a contribution by both Open and Shelter sites; (*) indicates a contribution by Open sites alone; (X) indicates a contribution by Shelter sites alone; and (?) indicates that there is small amount of evidence (a few sites) of an contribution.)

FACTORS	HIGH LOADING VARIABLES	POSITIVE CONTRIBUTION						NEGATIVE CONTRIBTION					
		G	U	C	B	D	R	G	U	C	B	D	R
1 (METRICAL DATA EXCLUDING GROOVES & MIDDENS)	ANNUALRAIN + RAINSUMMER + RAINSPRING + RAINAUTUMN +		?	&									
	ANNUALTMAX − MAXTSUMMER − MAXTSPRING − HEIGHT −										&	&	
2	MINTSPRING + MINTSUMMER + ANNUALTMIN +			&	&								
	ESTUARY − COAST −							&				?	&
3	WETLAND −		&	?	?							&	
4	ASPECT +	&		?	&		&						
	FRESHWATER −							&	&	X	X	X	?

Table 7.22: High loading variables and the contribution of the sub-regions. All sites excluding grinding grooves & middens - metrical data. (Note: (&) indicates a contribution by both Open and Shelter sites; (*) indicates a contribution by Open sites alone; (X) indicates a contribution by Shelter sites alone; and (?) indicates that there is small amount of evidence (a few sites) of an contribution.)

FACTORS	HIGH LOADING VARIABLES	POSITIVE CONTRIBUTION						NEGATIVE CONTRIBTION					
		G	U	C	B	D	R	G	U	C	B	D	R
1 (ALL DATA EXCLUDING GROOVES & MIDDENS)	ANNUALRAIN + RAINSUMMER + RAINSPRING + RAINWINTER +		?	&									
	ANNUALTMAX − MAXTSUMMER − MAXTSPRING − HEIGHT −										&	&	
		G	U	C	B	D	R	G	U	C	B	D	R
2	MINTSPRING + ANNUALTMIN + MINTWINTER +		?	&	&								
	ESTUARY − COAST −							&				?	&
		G	U	C	B	D	R	G	U	C	B	D	R
3	GEOLOGY +	?	&	?	X								
	WETLAND −							?		&		&	?
		G	U	C	B	D	R	G	U	C	B	D	R
4	ASPECT +	X	X	X	X	X	?	?		*	?	?	?
		G	U	C	B	D	R	G	U	C	B	D	R
5	FRESHWATER − TOPOGRAPHY −		?	&	?	&		?	?	&	&	*	?

Table 7.23: High loading variables and the contribution of the sub-regions. All sites excluding grinding grooves & middens - all data. (Note: (&) indicates a contribution by both Open and Shelter sites; (*) indicates a contribution by Open sites alone; (X) indicates a contribution by Shelter sites alone; and (?) indicates that there is small amount of evidence (a few sites) of an contribution.)

a

GOSFORD-WYONG	UPPER MANGROVE CREEK	CUMBERLAND PLAIN	BLUE MOUNTAINS	CATARACT DAM	ROYAL NATIONAL PARK
ESTUARY AND COASTAL DISTANCE AND HEIGHT GEOLOGY WETLAND FRESHWATER ASPECT	GEOLOGY TOPOGRAPHY AND MAXIMUM SUMMER TEMPERATURE FRESHWATER	RAIN SUMMER ANNUAL RAIN MINIMUM TEMPERATURES WETLAND	MINIMUM TEMPERATURES MAXIMUM TEMPERATURES GEOLOGY	MAXIMUM TEMPERATURES TOPOGRAPHY MAXIMUM SUMMER TEMPERATURE WETLAND FRESHWATER	COAST AND ESTUARY DISTANCE AND HEIGHT TOPOGRAPHY MAXIMUM SUMMER TEMPERATURE

b

GOSFORD-WYONG	UPPER MANGROVE CREEK	CUMBERLAND PLAIN	BLUE MOUNTAINS	CATARACT DAM	ROYAL NATIONAL PARK
COASTAL AND ESTUARY DISTANCE AND HEIGHT ASPECT	FRESHWATER MAXIMUM SUMMER AND SPRING TEMPERATURES	RAINFALL MINIMUM TEMPERATURES	MINIMUM TEMPERATURES MAXIMUM TEMPERATURES MAXIMUM SUMMER AND SPRING TEMPERATURE	MAXIMUM TEMPERATURES MAXIMUM SUMMER AND SPRING TEMPERATURES FRESHWATER AND WETLAND DISTANCE	COAST AND ESTUARY DISTANCE AND HEIGHT MAXIMUM SUMMER AND SPRING TEMPERATURES

Table 7.24: The principal influences upon Aboriginal locational decisions within each sub-region. a) all data; b) metrical data. (excluding grinding grooves)

a

GOSFORD-WYONG	UPPER MANGROVE CREEK	CUMBERLAND PLAIN	BLUE MOUNTAINS	CATARACT DAM	ROYAL NATIONAL PARK
ESTUARY AND COAST DISTANCE ASPECT FRESHWATER AND TOPOGRAPHY	GEOLOGY ASPECT FRESHWATER AND TOPOGRAPHY	ANNUAL AND SUMMER RAIN WETLAND DISTANCE ASPECT	MINIMUM SPRING ANNUAL AND SUMMER TEMPS FRESHWATER AND ASPECT MAXIMUM ANNUAL SPRING AND SUMMER TEMPS GEOLOGY	MAXIMUM ANNUAL SPRING AND SUMMER TEMPS ASPECT WETLAND FRESHWATER AND TOPOGRAPHY	ESTUARY AND COAST DISTANCE

b

GOSFORD-WYONG	UPPER MANGROVE CREEK	CUMBERLAND PLAIN	BLUE MOUNTAINS	CATARACT DAM	ROYAL NATIONAL PARK
ESTUARY AND COAST DISTANCE FRESHWATER	WETLAND FRESHWATER	ANNUAL AND SUMMER RAINFALL FRESHWATER AND ASPECT	MINIMUM TEMPERATURES MAXIMUM TEMPERATURES FRESHWATER AND ASPECT	ANNUAL AND SUMMER MAXIMUM TEMPERATURE FRESHWATER WETLAND	MINIMUM TEMPERATURES FRESHWATER

Table 7.25: The principal influences upon Aboriginal locational decisions within each sub-region. a) all data; b) metrical data. (excluding grinding grooves & middens)

wetland distance, freshwater distance and aspect (in that order) appear to account for the principal influences upon Aboriginal decisions within this area (from a regional perspective). When middens are removed from the analysis, estuary and coastal distance, aspect, freshwater distance and topography appear to be the major influences upon Aboriginal locational.

The pattern of association with estuaries, the coast, areas of nutrient-rich soils and wetlands: and the lack of apparent seasonality supports the suggestion of the existence of a coastal ecological population optimally located with regard to high-value patches.

UPPER MANGROVE CREEK

The damage done to the data structure by the exclusion of geology and topography is nowhere better emphasized than in the Upper Mangrove Creek sub-region. Although the structure based on metrical data is interpretable in terms of freshwater distance and maximum summer and spring variables, the association with wetland distance (a unique factor) is misleading. The association is a positive one (i.e. a positive loading) which suggests the distancing of sites from these landform characteristics rather than a tendency towards proximity. When geology is included in the analysis it is clear that it is the most important characteristic from a regional perspective, though topography, maximum summer temperature, freshwater distance and aspect are also influential.

It is likely that the primary reason why sites are located in the upper Mangrove Creek sub-region is the presence of Narrabeen deposits, topographic features, freshwater distance and aspect (presumably all four relating to the creek valley), and, perhaps, maximum summer temperature. (This latter association is only displayed when middens are included in the analysis and is probably the result of a linkage between topography and maximum summer temperature elsewhere in the region.)

There is, then, a clear link between Aboriginal behaviour, nutrient rich soils and summer temperatures which is consistent with the pattern of summer expansion in inland areas (because patches are more widely dispersed than in winter).

CUMBERLAND PLAIN

The data from the Cumberland Plain contribute greatly to the establishing of rainfall (particularly annual and summer rainfall) to the factor structure of the whole region. Minimum temperature, wetland, freshwater distance and aspect also appear to have influenced Aboriginal decisions in this area.

The results lend support to the inland aspects of the behavioural model, for they suggest that the Cumberland Plain was occupied throughout the year. The connection between behaviour and areas of relatively greater rainfall and higher minimum temperatures is suggestive of the limiting effects of these characteristics upon vegetation. In addition, the relationship between Aboriginal locational decisions, minimum temperature and distance to wetlands suggests the winter importance of the area.

BLUE MOUNTAINS

Minimum and maximum temperatures (particularly spring and summer maximum temperatures), geology, freshwater distance and aspect are likely to have been the major influences upon Aboriginal locational decisions within the Blue Mountains.

The conclusion that these characteristics suggest a pattern of utilization similar to that evinced for the Upper Mangrove Creek seems inescapable. The locational characteristics of Aboriginal behaviour (particularly in association with areas of relatively low summer maximum temperature and areas of Narrabeen deposits) apparently reflect the pattern of expansion in summer and contraction in winter suggested for inland areas in the behavioural model.

CATARACT DAM

The evidence of Aboriginal behaviour in the Cataract Dam sub-region suggests that maximum temperature (particularly summer and spring maximum temperature), freshwater and wetland distance, topography and aspect influenced locational decisions - from a regional perspective. (Note that when middens are removed from the dataset the maximum temperature variables resolve into a more general group in which annual maximum temperature predominates.)

In general there is evidence to suggest that Aboriginal occupation of this sub-region occurred throughout the year, though the extremes of summer temperature may have been a major influence upon decisions. Wetland proximity appears to have been another dominating influence, and the fact that the shoreline does not appear to have exerted much attraction supports the prediction derived from the behavioural model concerning the relative ranking of these two resource areas.

ROYAL NATIONAL PARK

Coast and estuary distance, height, topography, maximum summer temperature and freshwater distance loadings are introduced into the regional factor structure by the sites within the Royal National Park. It is important to note that when middens are removed from the data the contribution is made solely by estuary and coastal distance (in that order).

The apparent predominance of estuarine and coastal proximity as an influence upon locational decision is clear within this area (which is dominated by Hawkesbury sandstone) and supports the behavioural model. There is some suggestion that the presence of middens tends to increase the influence of coastal over estuarine proximity (which might be interpreted as evidence for the higher ranking of coastal patches in winter).

In summary, then, the essential characteristics of Aboriginal locational decisions within the sub-regions - from a regional perspective

- support the behavioural model. This is particularly evident in the fact that, among the primary factors, a division can be made between the positive and negative loadings, which coincides with the division between inland and coastal areas. This is clearly suggestive of the division of the Aborigines into an inland and a coastal ecological population.

The inclusive regional analysis (open sites and shelters; coastal and inland) is likely to obscure many relationships between Aboriginal behaviour and aspects of Sydney region ecology. For example, the deflexion in those relationships brought about by the occupation of shelters is likely to weaken links in the whole structure. Yet, the primary characteristics of the whole data in the sub-regions is readily interpretable in terms of the behavioural model. Ecological techniques appear capable of explaining the location of Aboriginal behaviour (as it is represented by the archaeological record) in the Sydney region to a remarkable degree.

In short, the tendency toward optimal location with regard to patches of high-value is clearly present in the behaviour of the Sydney region Aborigines.

7.9 ABORIGINAL BEHAVIOUR AND PATCH CHOICE

In this chapter the locational characteristics of the archaeological and art sites of the Sydney region have been used in order to test a model based upon the ecological characteristics of the area and optimality principles. The aim has been to establish whether it is possible to determine a tendency in the behaviour of the Sydney region Aborigines toward optimal location with regard to high-value (i.e. low cost/high benefit) patches of food.

Through the analysis of the relationship between Function and Style sites it has been firmly established that, as predicted, the former site group, shows a clear, consistent and statistically significant tendency to be more closely associated with those aspects of landscape variables which would appear to indicate the strong influence of patch proximity. In particular, elements of terrestrial structure - the basis of many of the characteristics of faunal and floral distribution within the area - are clearly associated with the location of Function sites throughout the region. At the other extreme, the relationships observable between Function sites and climatic variables are, generally, difficult to interpret - though it is clear that for the most part, predicted relationships do occur. Undoubtedly, part of this uncertainty is the product of the coarseness of the scale imposed. In addition to these tendencies, the relationships between Aboriginal sites and aquatic areas tend to justify the division within the behavioural model between a coastal and an inland 'ecological population'.

This division between a coastal and an inland population is substantiated by the results of factor analysis, which indicate (both through the associations with the predicted terrestrial and/or aquatic structure variables, and, more importantly, with the appropriate climatic variables) that both areas were occupied throughout the year. A number of more specific results support the model and underpin these general conclusions:

1. Although there is a general lack of seasonality associated with the evidence for Aboriginal behaviour, summer and spring maximum temperatures clearly influenced locational decisions in the Upper Mangrove Creek and Blue Mountain sub-regions. This apparent evidence of seasonal occupation is wholly predictable in terms of the behavioural model, which suggests that in autumn (in association with eel congregations), winter and early spring (in association with waterfowl aggregations) the optimal forager should limit attention to wetland areas, and only in the summer when high-value patches are more widely dispersed (and more numerous) should the upland areas be occupied.

2. It is an inescapable conclusion that aquatic patches possessed a fundamental influence upon Aboriginal locational decisions within the whole Sydney region. Upon the coast the association follows the expected pattern (by cost/benefit rank) of wetland - estuary - coast. In only one area in which all three elements occur is this sequence broken - Function Shelter sites in the Gosford-Wyong sub-region

display a greater tendency toward proximity to the coast than to the Broken Bay estuary.

However, these sites also display a distinct tendency to be associated with winter minimum temperature; and the behavioural model suggests that in winter the Aboriginal population (as optimal foragers) should display a greater measure of proximity to marine areas because of the presence of high-value patches in the form of fish shoals, both earned (i.e. moved from estuary) and unearned (i.e. migratory).

The general pattern is also underlined by the apparent relationships in coastal areas where estuarine resources are unavailable. In the Cataract Dam sub-region proximity to wetlands completely dominates any tendency toward proximity to the sea, to the extent that middens (the internal archaeological structure of which might lead the unwary to suggest the coast as the major source of food) are far closer to wetlands than they are to the coast.

3. The broadest connection between Aboriginal locational decisions and primary productivity which influences patch location (apart from those patches which are 'unearned') both directly and indirectly, is indicated by the relationship between Aboriginal behaviour and climate factors. Minimum temperatures (which determine the length of the local growing season) appear to have influenced Aboriginal decisions particularly upon the coast; while rainfall distribution appears to

have been an influence principally inland (this latter relationship is at least suggestive of the general validity of Birdsell's (1953) correlation which was applicable only in inland areas).

4. Perhaps, the most fascinating association between Aboriginal behaviour and the Sydney region landscape is the consistent tendency in both inland and coastal situations for geological parent materials which produce soils of relatively high fertility to underlie the major influences upon locational decision (though it is clear, from a regional perspective, in the Upper Mangrove Creek and Blue Mountains sub-regions they *are* the major influences upon Aboriginal locational decisions). This position is consistent with the role envisaged for these areas as sources of secondary patches and of 'buffer foods'.

Finally, factor analysis of the data for all the sub-regions and including both open and shelter sites tends to confirm the association between Aboriginal behaviour and the probable distribution of high-value patches upon a regional scale. Despite the element of obscuration which doubtless results from the inclusive nature of the analysis (open/shelter - coastal/inland), the results tend to validate the behavioural model in almost every respect. Those landscape variables which might be predicted to most influence the location of Aboriginal behaviour within the six sub-regions, appear to do so (for example, wetlands, geology and rainfall among inland areas; and wetland, estuary and coastal distance among coastal areas). This regional analysis also tends to confirm the suggestion of the existence of two ecological populations within the region as well as supporting the notion of a contraction of inland occupation onto the Cumberland Plain in winter and expansion into the uplands in summer.

In general, then, there is a great deal of evidence to suggest that high-value patch distribution was an influence upon Aboriginal locational decisions in the Sydney region. Nevertheless, in the next chapter an attempt is made to identify some local ecological characteristics which may have influenced the distribution of sites, beyond these landscape factors identified upon the regional scale.

8 CHAPTER EIGHT:

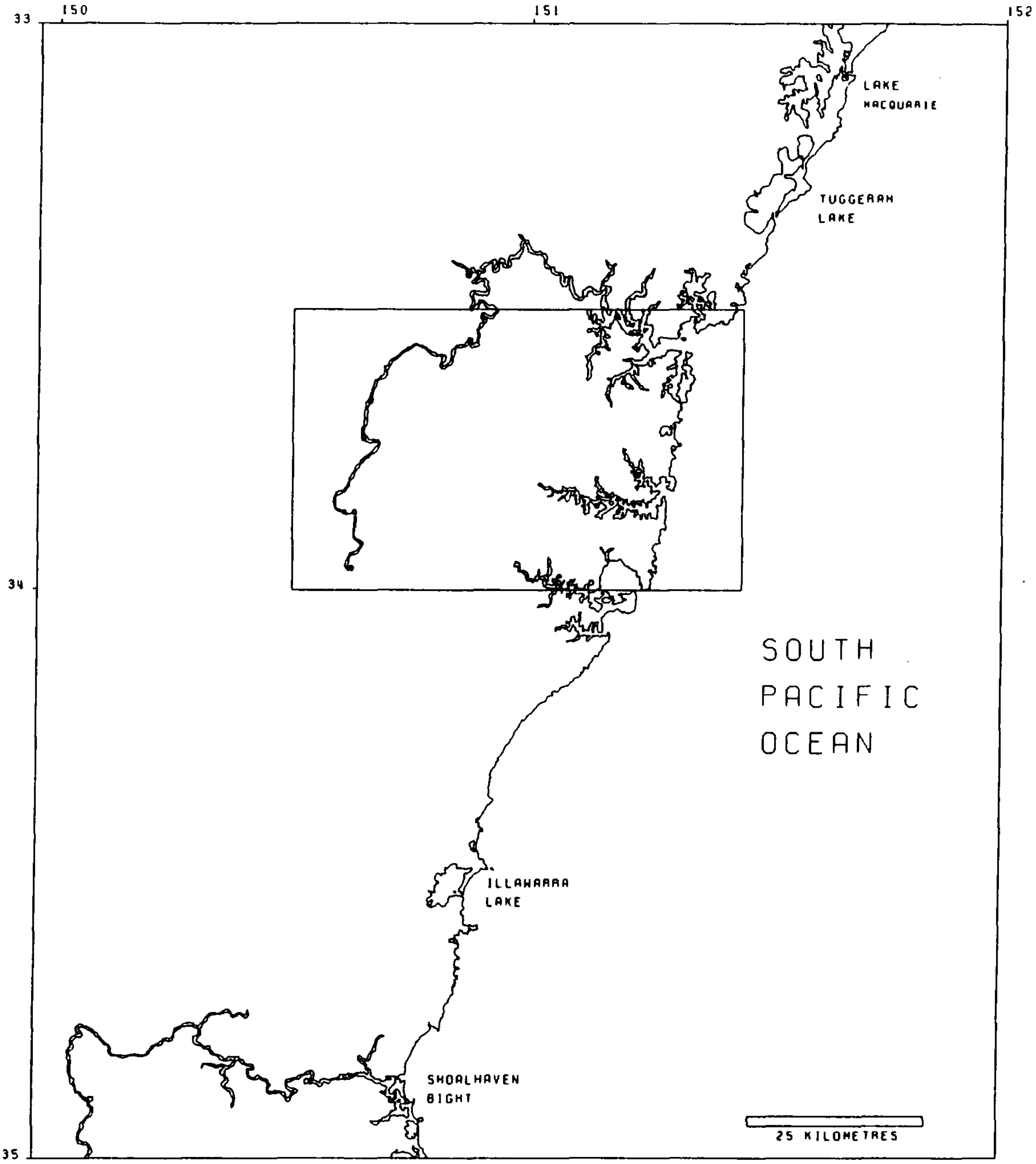
BEYOND THE BEHAVIOURAL MODEL: LOCAL ECOLOGICAL INFLUENCES

As Yesner has said, regional dietary analyses ".....serve as an effective compromise between the minimum size necessary for accurate (environmental) reconstruction and a maximum size necessary for a sufficient sample" (1979:86) and in this study, owing to the nature of the archaeological data, it has been necessary to study the relationship between sites and landscape variables upon a coarse regional scale. In this chapter, the area around the city of Sydney itself is studied in closer detail and an attempt is made to identify some local ecological influences upon Aboriginal locational decisions.

8.1 THE SYDNEY AREA

The Sydney area is defined by the boundaries of the Penrith and Sydney 1:100000 topographic and vegetation maps (Benson 1980, 1981a); that is, between eastings 3500 and 4500 and northings 8000 to 8600 on the Sydney 1:250000 scale topographic map (Map 8.1). To the west of the area, the foothills of the Blue Mountains rise steeply from the Cumberland Plain over the Lapstone monocline. Elsewhere the only areas of comparatively high ground lie to the north-east of the Cumberland Plain upon the Hornsby Plateau (Figure 8.1).

The choice of an area which has been so manifestly disturbed by European expansion, and which has been exposed to the associated processes



Map 8.1: The location of the Sydney area.

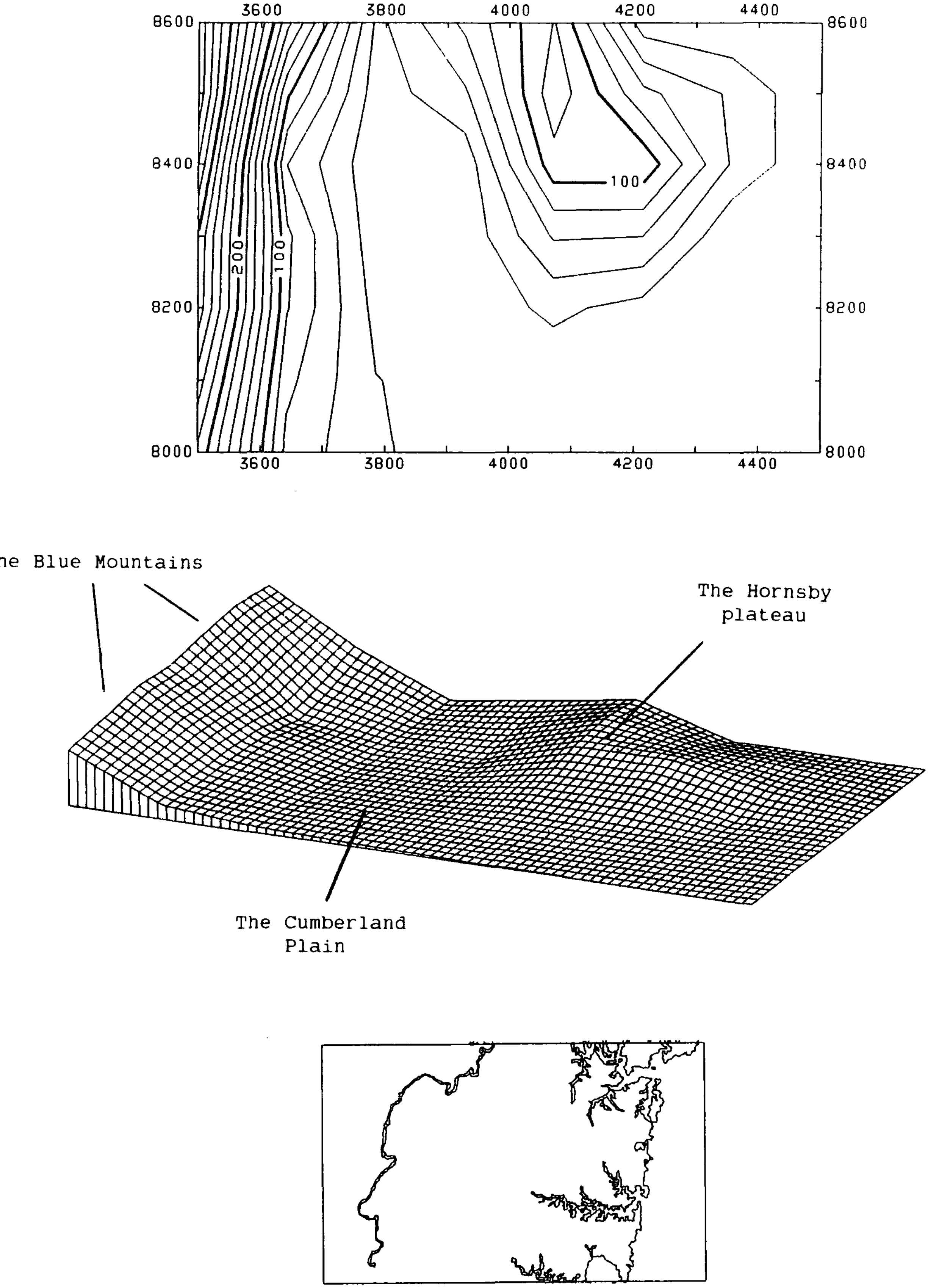


Figure 8.1: The topographic characteristics of the Sydney area.
(Note: contour interval = 20metres)

longer than any other in the continent, may at first seem perverse. However, there are a number of advantages attached to the study of this area:

1. It is precisely because it is the oldest area of European occupation within Australia, that data concerning various ecological aspects of the pre-1788 environment are reasonably well understood. Much information is available through the work of the many university departments and government institutions which are located within the area. A major part of these data have been provided by the work of the vegetation mapping unit attached to the Royal Botanical Gardens, which has mapped and described the remnant communities of 'native' vegetation within the city limits - these are the principal data for the vegetation reconstruction presented below.

2. The area is archaeologically well-known, though the availability of data is to some extent counterbalanced by the destruction of sites during the process of urban expansion. However, a large proportion of sites which have been destroyed since the last decades of the last century have been recorded in the NPWS site register.

3. The area around Sydney was one of the first scenes of contact (the first of prolonged duration) between Europeans and the Aborigines. The result of this encounter was a series of intelligent observations concerning the behaviour of an Aboriginal group prior to their decline, which are probably unequalled in other parts of Australia

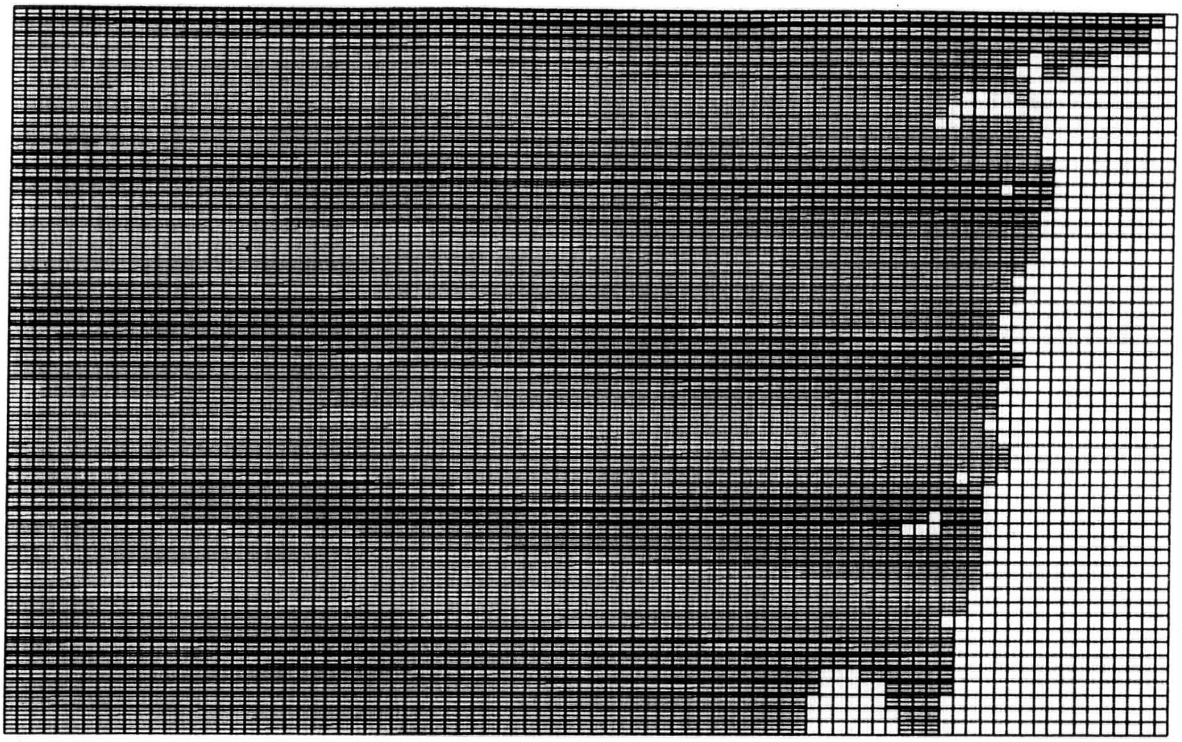
where disease and the dregs of society most often formed the vanguard of the European invasion (see Reynolds 1980, 1982).

4. The geological structure of the area is not dominated by Hawkesbury sandstone to the extent which is true of the region as a whole. Within the area, Hawkesbury sandstone covers approximately 1700sq. km, while a comparable area (1558sq. km) is underlain by Wianamatta shale (the Cumberland Plain).
5. Finally, the majority of landform types (e.g. mountain, estuary, plain, river, plateau) which are representative of the range in the whole region are to be found within this sub-region.

8.1.1 Cells and sites - distribution in the Sydney area

Following the practice adopted by Bettinger (1977) and Thomas (1973) the Sydney area was sub-divided into a 1km grid of 87 columns and 55 rows (4785 cells) in order to facilitate the mapping of environmental characteristics (Figure 8.2).

The archaeological data were also divided into two groups: firstly of archaeological sites without grinding grooves; and secondly of archaeological sites without middens or grooves. Grinding grooves are totally excluded from the analysis because the evidence suggests that they represent behaviour which is unlikely to have been closely related to the acts of food acquisition and, indeed, have been shown to influence the



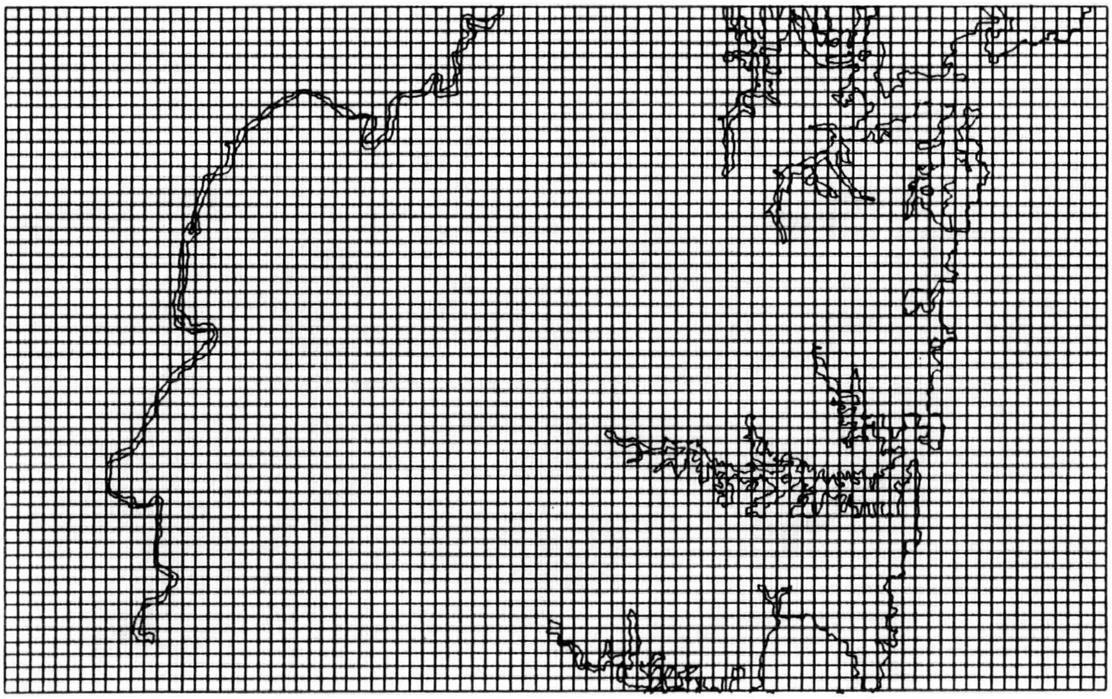


Figure 8.2: The relationship between cells and geographical area.

archaeological data in such a way as to obscure the relationship between sites and high-value patches.

The distributional characteristics of the two site sets a) Function without grooves (FXGG); and b) Function without middens or grooves (FXMGG) - are illustrated in Maps 8.2 and 8.3. Each dataset was also contoured using the SURFACE II graphics system (Sampson 1978) to indicate the general trend in the spatial distribution of the data (Figures 8.3 and 8.4).

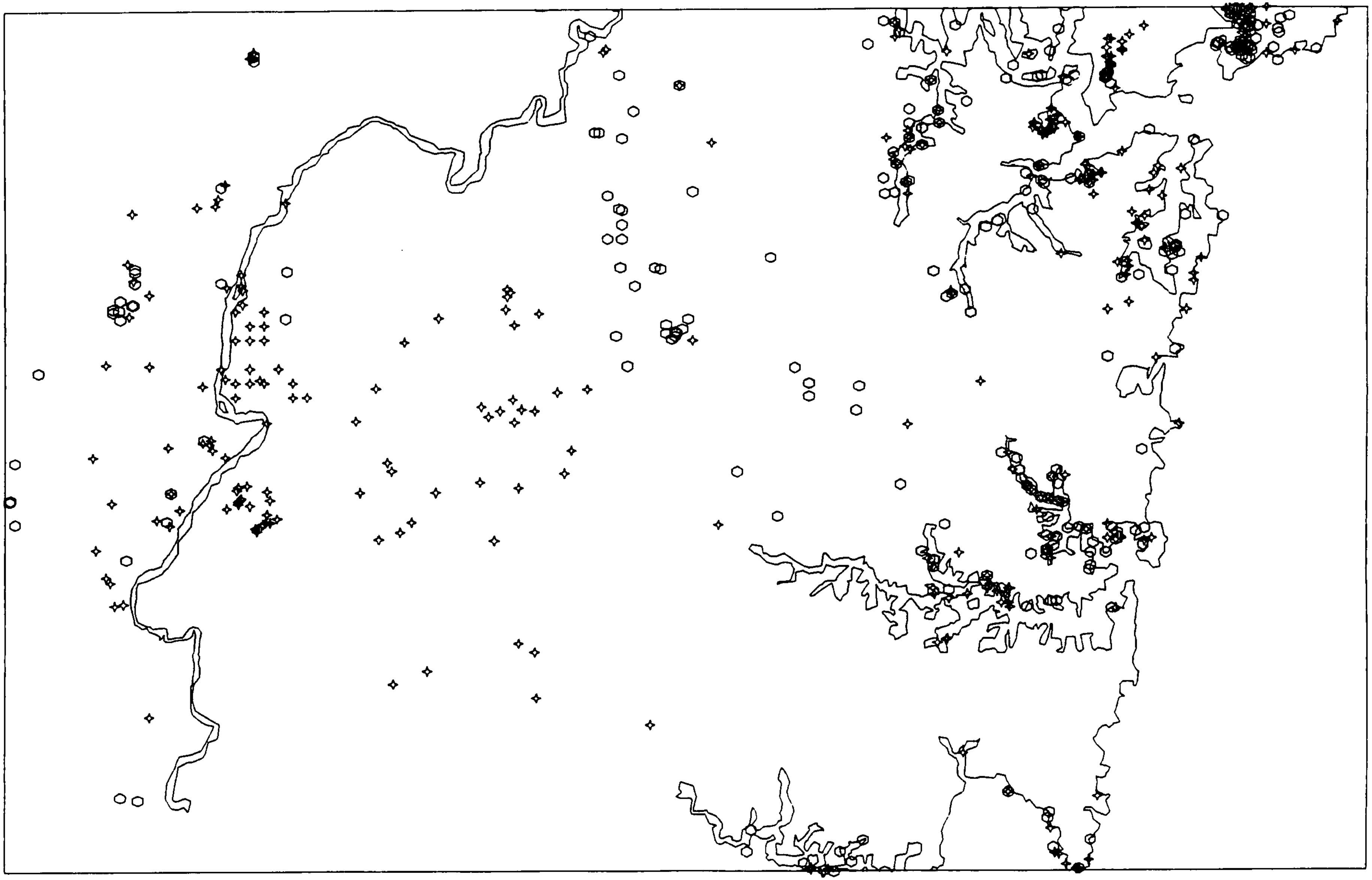
8.1.2 The characteristics of archaeological distribution within the Sydney area

The FXGG data can be seen to centre upon two separate areas one upon the coast and the other (of lesser dimensions) inland. When middens are excluded (FXMGG), the coastal population is clearly reduced, and sites centre upon the Hawkesbury-Nepean river.

These characteristics of the archaeological data are wholly consistent with those examined in the previous chapter which suggest the existence of two 'ecological' populations within the region - one on the coast and the other inland. (In fact, this sub-area contains the data from the Cumberland Plain, and data from the eastern extremities of the Blue Mountain; the southern edge of the Gosford-Wyong; and the northern edge of the Royal National Park sub-regions).

KEY TO MAPS 8.2 & 8.3: SYDNEY AREA ARCHAEOLOGICAL SITES

SITE TYPE	SYMBOL
FO	✧
FS	○



Map 8.2: The distribution of open and shelter sites (excluding grinding grooves) in the Sydney area.

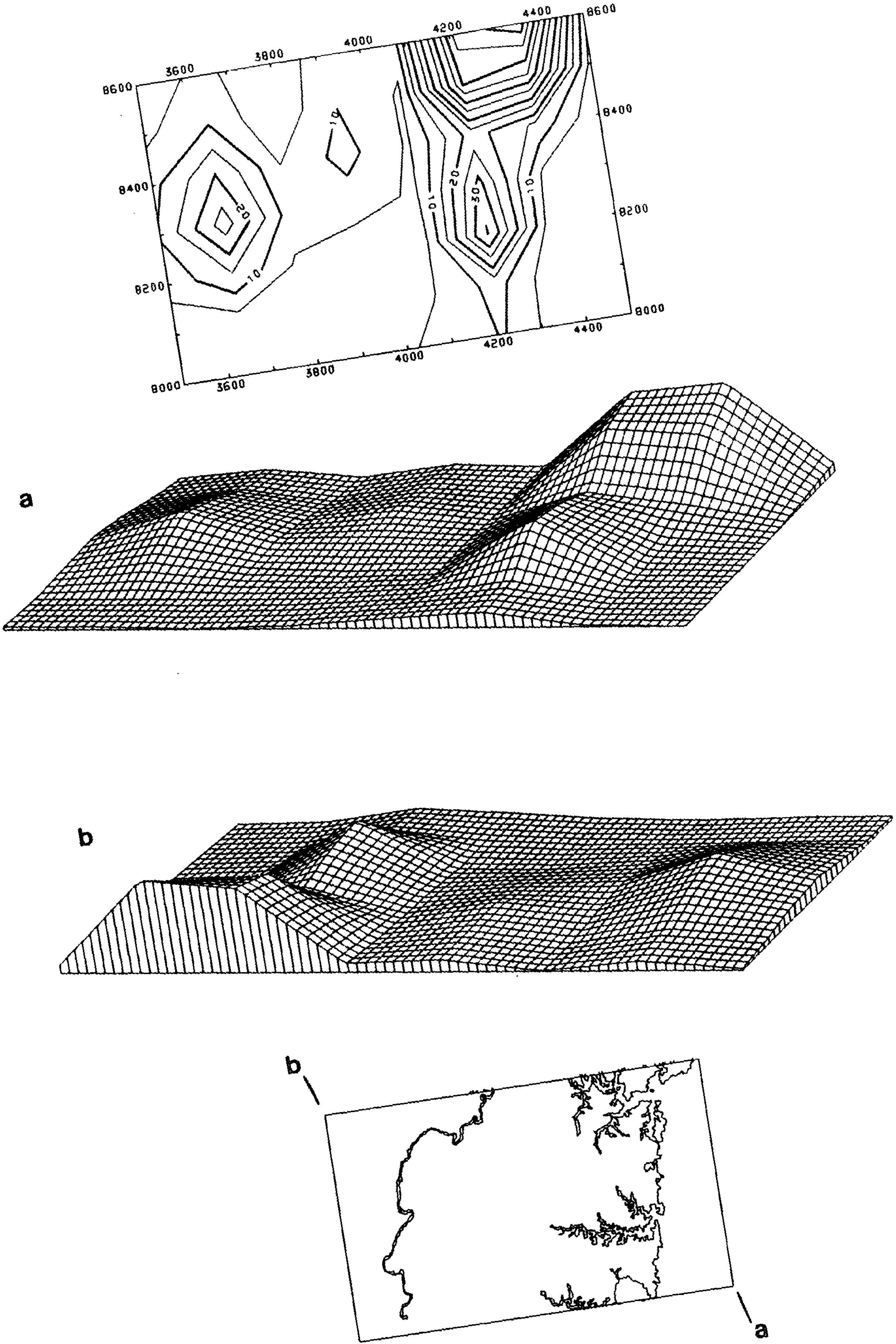
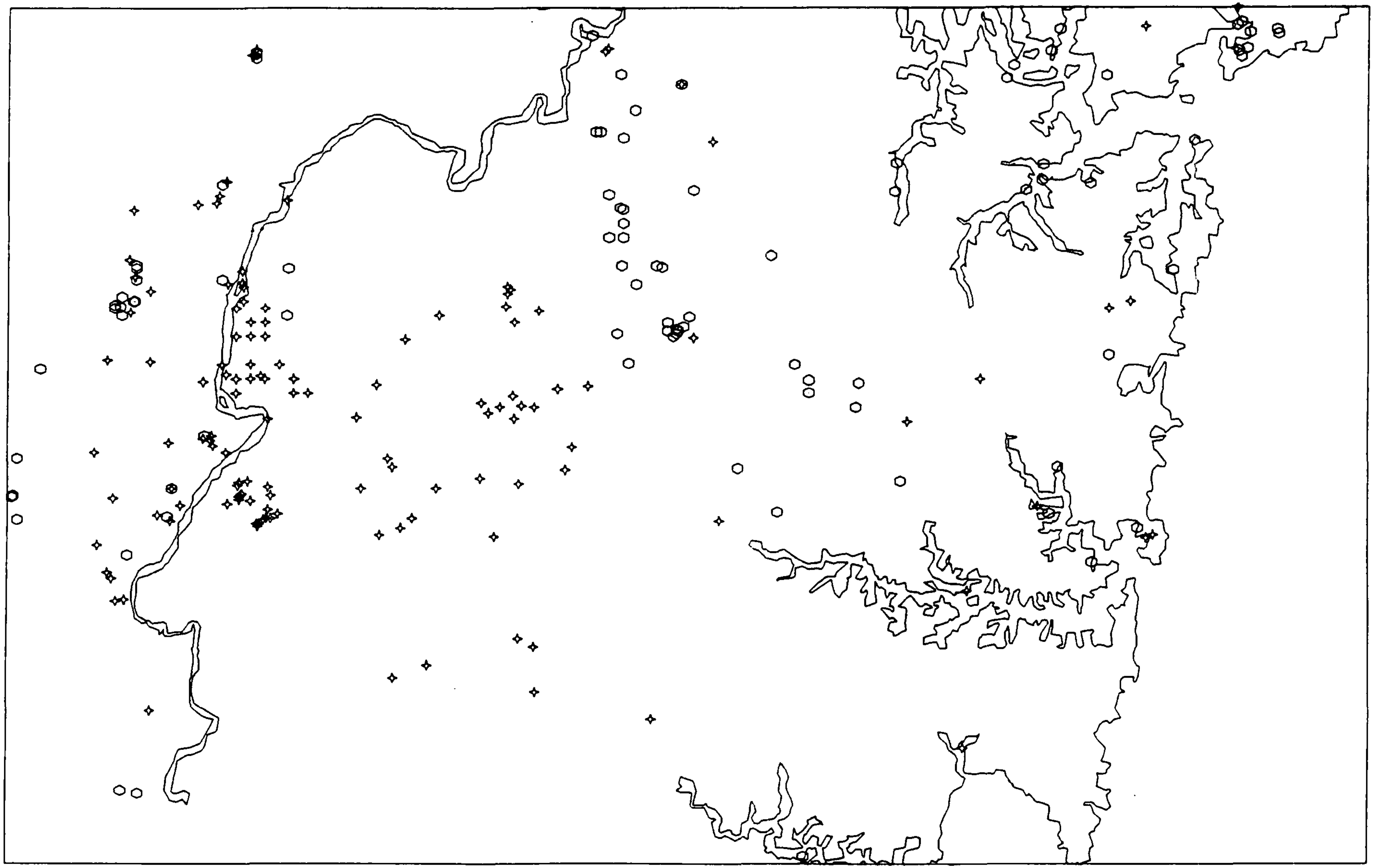


Figure 8.3: The distribution of archaeological sites within the Sydne
area (excluding grinding grooves).
(Note: Contour interval = 5)



Map 8.3: The distribution of open and shelter sites (excluding grinding grooves and middens)

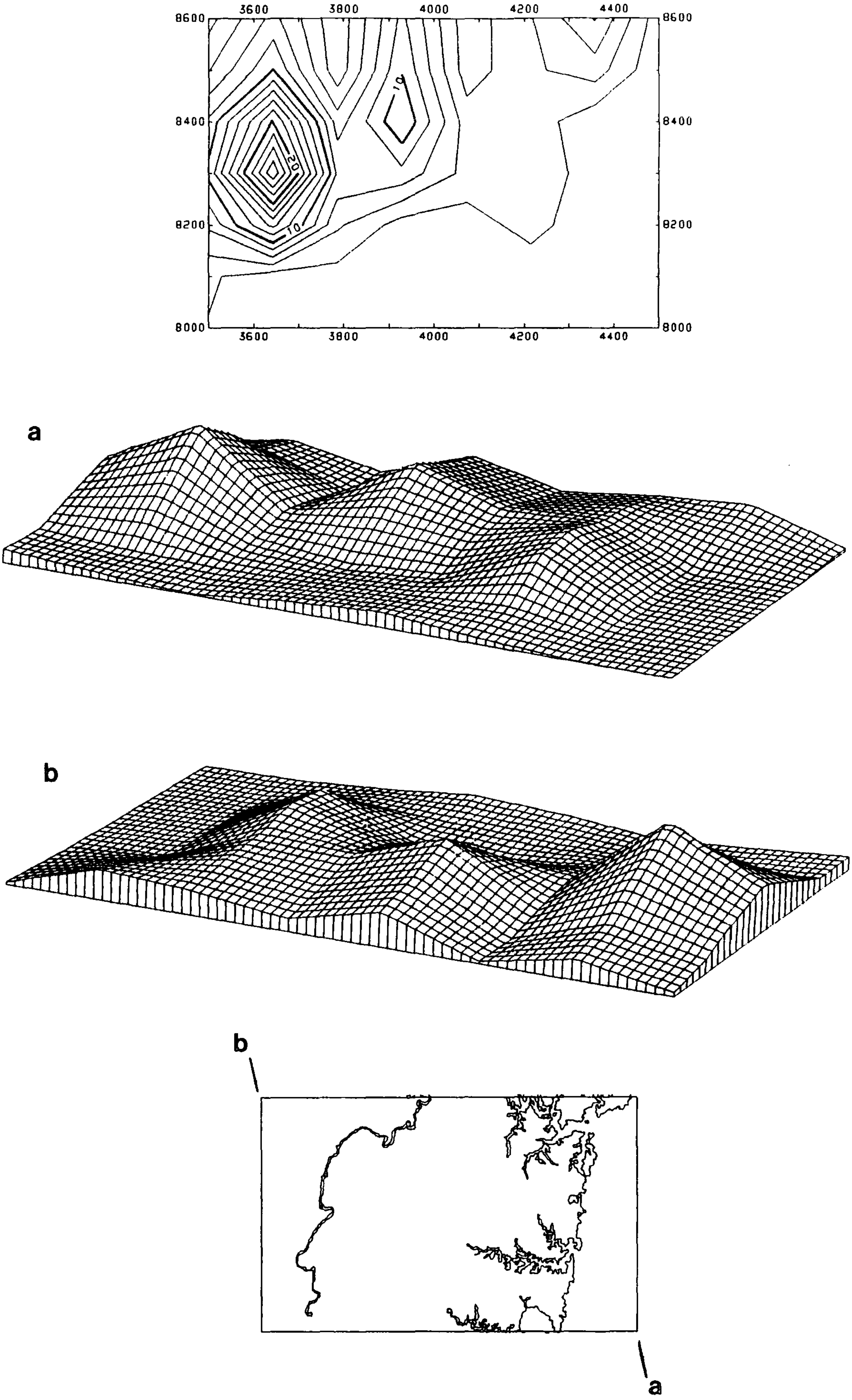


Figure 8.4: The distribution of archaeological sites within the Sydney area (excluding grinding grooves & middens).
(Note: Contour interval = 2)

8.2 ABORIGINAL BEHAVIOUR, STRUCTURE AND VEGETATION

Owing to the imposition of a regional scale upon the analysis, it has not been possible to discern the more local associations between Aboriginal behaviour and geological and vegetational characteristics which would be likely to have influenced the probability of patch formation. In this section, an attempt is made to redress this balance.

8.2.1 Aboriginal behaviour and geology

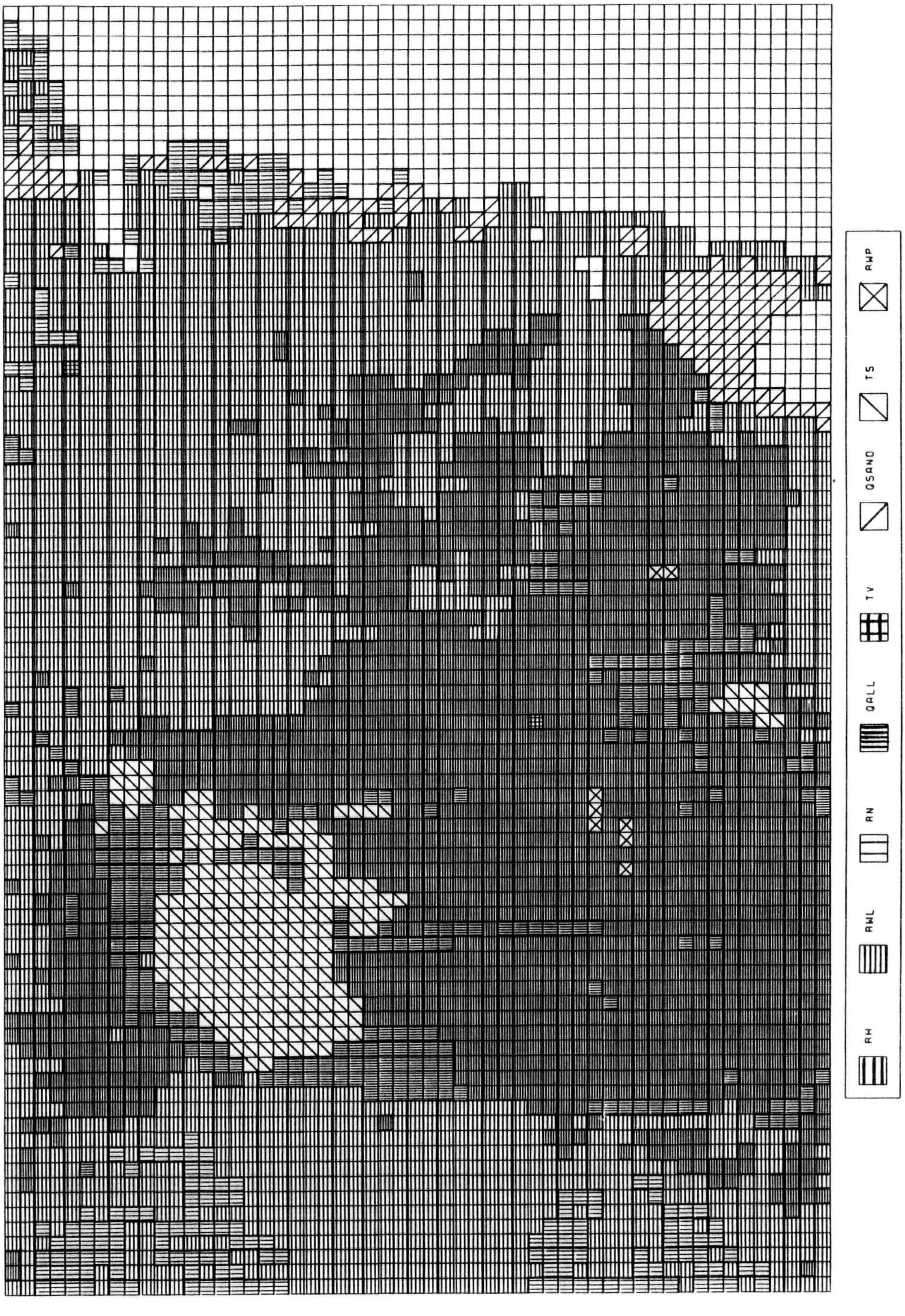
Map 8.4 illustrates the distribution of parent materials within the sub-region. It is clear that Aboriginal behaviour tended to be located away from the Hawkesbury sandstone plateaux and in close association with other rock types which would have produced soils of higher nutrient content. This is most evident from the association of sites with recent alluvial deposits, Wianamatta shale, and with the Narrabeen deposits of the Blue Mountain piedmont. Upon the coast there is also clear evidence of a close association between Aboriginal behaviour and Narrabeen sandstone and Wianamatta shale.

When middens are removed from the analysis, the lack of association between Aboriginal behaviour and Hawkesbury sandstone is particularly evident, but it should be noted that there is also a lack of association with alluvium and Tertiary gravels and sands within the north-eastern part of the Cumberland Plain. The absence of sites upon the alluvial areas is likely to be a function of several taphonomic processes, principally the

Map 8.4: The geology of the Sydney area: based upon principal representation in one kilometre grid cells.

Key to Map 8.4:

RH	Hawkesbury sandstone	TV	Basalt outcrop
RWL	Wianamatta shale	QSAND	Quaternary sand
RN	Narrabeen sandstone	TS	Sands, silts and clays
QALL	Quaternary alluvium	QALL	Quaternary alluvium


RH
RWL
RN
QALL
TV
QSAND
TS
RWP

occurrence of seasonal inundation (Map 8.5) and the present use of the land for agriculture; but it is likely that the general low fertility of soils based upon the Tertiary gravels and sands (in comparison with areas in the immediate vicinity) is the major factor involved, in other areas further from the river.

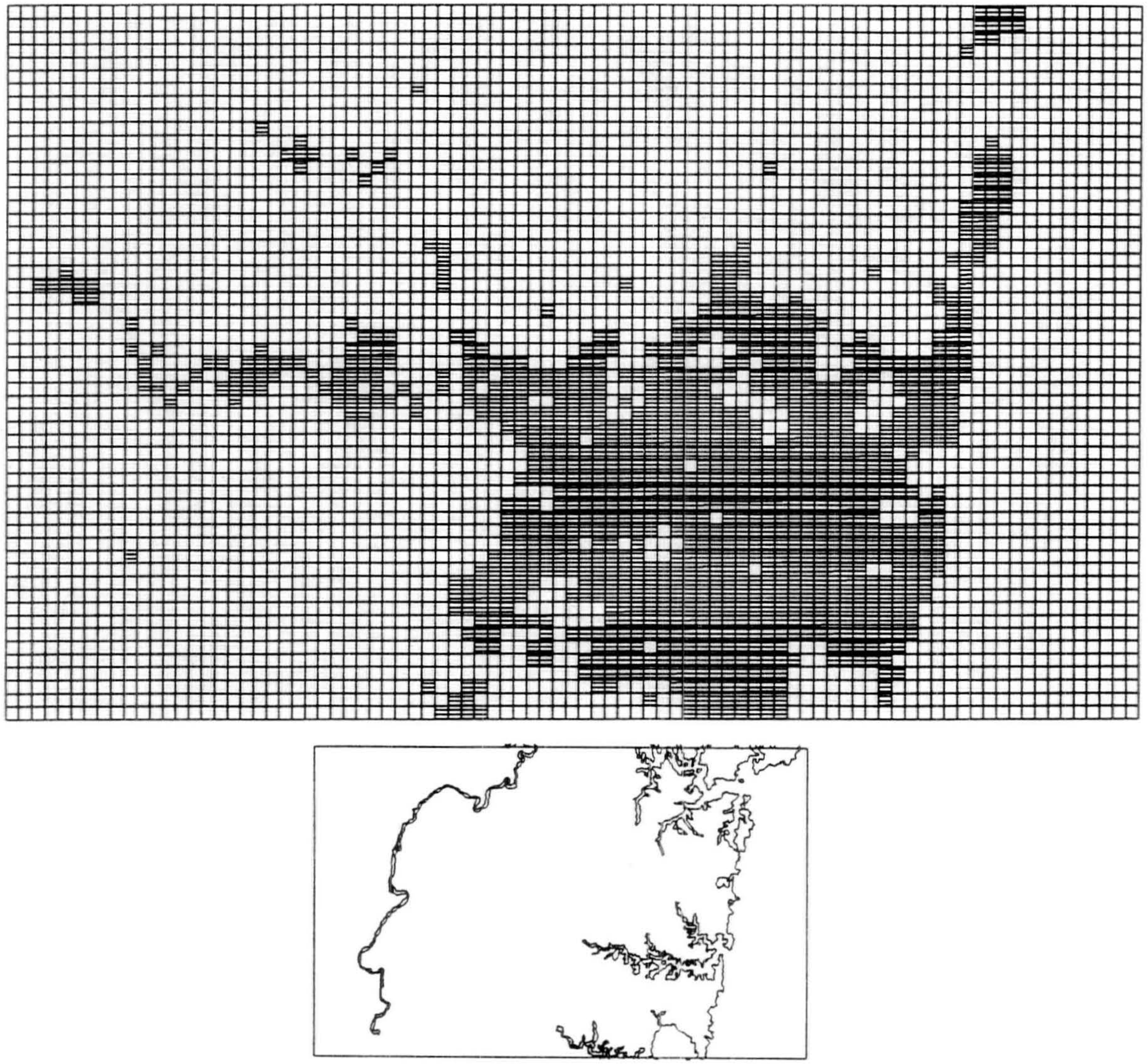
Undoubtedly, the expansion of the city of Sydney has removed most of the sites in the sub-region, but it is remarkable that the relationship between Aboriginal behaviour and the more fertile areas (which have been the main focus of that expansion) is still evident; while the lack of sites in the relatively undisturbed (yet well-known) Hawkesbury sandstone areas, speaks for itself.

8.2.2 Aboriginal behaviour and vegetation structure

In the foregoing analysis it was only possible to establish associations between sites and vegetation patterns through the mediation of geology. However, within the Sydney area it is possible to obtain some idea of the association of Aboriginal behaviour with particular vegetation structures.

Despite the fact that urban expansion has destroyed much of the 'original' vegetation of the area (Map 8.6; approximately 59% of the area has been cleared), large areas of the 'native' vegetation still persist because of the low value of the land for agriculture. The present distribution of the vegetation has been mapped by members of the

Map 8.5: Freshwater and marine seasonal inundation areas within the Sydney area. (Vertical shading = freshwater; Horizontal shading = marine).



Map 8.6: The extent of urbanization within the Sydney region.

vegetation mapping unit attached to the Royal Botanical Gardens, Sydney; and there is sufficient information, when these data are combined with material from other sources, to attempt a tentative reconstruction of the vegetation patterns prior to 1788.

The vegetation structures likely to have been present in the pre-European Sydney environment may by classified into the structural formations proposed by Specht (1970), these may be further subdivided into plant communities depending on the dominant species, and an alphanumeric code used to distinguish between them. The descriptions of these communities follows those of Benson (1980, 1981a; Table 8.1; full botanical descriptions of species can be found in "The Flora of the Sydney Region" by Beadle, Evans & Carolin (1972) and the reader is also referred to Beadle (1981) & Groves (1981)):

Estuarine Complex

Small patches of estuarine vegetation are found on alluvial mudflats in Broken Bay and Georges River, and were originally common in Port Jackson. These generally consist of a sequence of zones of different vegetation formations related to duration of tidal inundation and salinity. The general zonation is as follows - on the seaward edge of the mudflat is an open scrub (1-5m high) of mangroves, Avicennia marina var. australasica (Grey Mangrove) and the smaller Aegiceras corniculatum (River Mangrove). The mangroves generally receive daily tidal inundation. Behind them may be a zone of salt

Map unit	Vegetation formation	Main canopy species	Geological association	Present occurrence
SCRUB	Open scrub	Avicenna marina var. australasica Aegiceras corniculatumm	Recent Alluvium	Estuarine mudflats, regular tidal inundation.
	Herbland	Sarcocornia quinqueflora Suadea australis	"	Occassional tidal inundation.
	Rushland	Juncus kraussii	"	Infrequent tidal inundation.
6B	Tall Open Forest / Open Forest	E. pilularis E. saligna	Wianamatta shale	Broad ridges with residual shale soil. North shore to Hornsby.
6C	Tall Open Forest	E. deanei	Tertiary basalt	Isolated outcrops Blue Mountains.
6D	Tall Open Forest	E. benthamii	Recent alluvium	Nepean river at Bents Basin.
9A	Open Forest	E. maculata E. paniculata	Narrabeen group	Barrenjoey peninsula and west Pittwater
9B	Open Forest	E. maculata E. moluccana	Wianamatta shale	Hoxton Park and Cecil Park
9C	Open Forest	E. crebra E. fibrosa	Wianamatta shale	Shale remnants at Glenbrook

Table 8.1: The present-day vegetation structures of the Sydney region. (Sources: Benson 1980,1981a)

9D	Open Forest	E. fibrosa E. moluccana	Wianamatta shale/ Tertiary alluvium	Transition zone between these geological units
9E	Open Forest	E. fibrosa	Tertiary alluvium	Castlereagh on clay soils
9F	Open Forest	Angophora subvelutina E. amplifolia E. tereticornis	Recent alluvium	Alluvial flood-plains along the Hawkesbury-Nepean and major tributaries
10A	Open Forest/ Woodland	E. pilularis E. piperita Angophora costata	Hawkesbury sandstone	Sheltered hillsides & gullies.
	Low Woodland	E. gummifera E. haemostoma E. oblonga E. exemia E. sclerophylla	"	Ridges, plateaux and dry exposed hillsides
	Open Scrub	Banksia ericifolia Hakea teritifolia	"	Poorly drained sites
10C	Woodland	E. moluccana E. territicornis	Wianamatta shale	Flat to gently undulating basin of the Cumberland Plain. Clay soils
10D	Woodland	E. moluccana E. tereticornis E. crebra	Wianamatta shale	Undulating to hilly country on margins of Cumberland Plain. Clay soils
14A	Low Woodland	E. sclerophylla Angophora bakerii	Tertiary alluvium	Castlereagh, Londonderry and Holsworthy on sandy soils
14B	Low woodland /open scrub	E. sclerophylla Angophora bakeri Banksia serrata	Tertiary alluvium	Confined to sand deposits at Agnes Banks.

Table 8.1 (cont.): The present-day vegetation structures of the Sydney region.

Heath	Closed Scrub	Banksia integrifolia Leptospernum laevigatum Acacia longifolia Banksia serratifolia Monotoca elliptica	Aeolian sand	Coast. Sand dunes generaly exposed to onshore winds
	Open Heath	Banksia ericifolia Casuarina distyla Hakea tertifolia	Narrabeen group/ Hawkesbury sandstone/ Aeolian sand	Coast. Deep sandy to very shallow poorly drained soils
	Sedgeland	Backea imbricata Melaleuca thymifolia Sedges	Narrabeen group/ Hawkesbury sandstone	Sites with impeded drainage
Sedge	Open Sedgeland	Eleocharis sphacelata Juncus usitatus Polygonum spp.	Recent alluvium	Freshwater swamps
C	Cleared	These areas are mostly zones of suburban development upon Wianamatta shale or Hawkesbury sandstone or areas of better agricultural soils along the river alluvial flats or on the Cumberland Plain.		

Table 8.1 (cont.): The present-day vegetation structures of the Sydney region.

marsh, a herbland dominated by the succulent stemmed members of the Chenopodiaceae, *Sarcocornia quinqueflora* (Samphire) and *Suaeda australis* (Seablite). Behind this may be a zone of rushland with *Juncus krausii* and *Sporobolus virginicus*. These areas receive infrequent tidal inundation. Finally there is a zone of swamp forest with *Casuarina glauca* (Swamp Oak) or *Eucalyptus robusta* (Swamp Mahogany).

Where sandstone hills meet the waters edge directly and there is no build up of alluvium, the zonation is truncated to a line of mangroves and a few *Casuarina glauca*.

Detailed studies of mangrove and salt marsh communities and the requirements of individual species have been carried out by Clarke and Hannon (1967, 1969, 1970, 1971) at Towra Point on the south shore of Botany Bay.

TOF6B

Tall Open Forest - Eucalyptus pilularis & E. saligna.

This was the original vegetation of the higher rainfall (>1100mm p.a.) Wianamatta shale areas of Sydney, but has been mostly destroyed. Remnants survive at St. Ives and at Beecroft and in a number of smaller areas.

E. pilularis (Blackbutt) and *E. saligna* (Sydney Blue Gum) are the main trees. *E. pilularis* tends to favour ridges and *E. saligna* lower slopes and depressions. Other tree species are *Angophora costata* (Smooth-barked apple), *E. paniculata* (Grey Ironbark), *E. globoidea* (White Stringybark) and *Syncarpia glomulifera* (Turpentine). An open, small-tree layer of saplings of canopy tree species and mature individuals of *Casuarina torulosa* is often present on drier sites, or *Pittosporum undulatum* on moister ones.

Shrubs up to 2m high are common, and often form a dense cover. Common species on drier sites are *Platylobium formosum*, *Leucopogon juniperinus*, *Dodonaea iriquetra* and *Hibbertia aspera*. On moister sites and in depressions these shrubs are replaced by ferns, particularly *Culcita dubia*, *Adiantum aethiopicum* and *Doodia aspera*, and moister shrubs, such as *Breynia oblongifolia* and *Polyscias sambucifolius*.

Remnants of this vegetation exist on shale with a much lower rainfall around Duck River, Auburn and Rickwood (circa 816mm p.a.). These are remnants of Tall Open Forest of *E. fibrosa* ssp. *fibrosa* (Broad-leaved Ironbark) and *E. moluccana* (Grey Box) which was once common here. Common shrub species associated with these remnants are *Melaleuca decora*, *M. styphelioides*, *M. nodosa*, *Exocarpos cupressiformis*, *Bursaria spinosa*, *Daviesia ulicifolia*, *Lissanthe strigosa* and *Dillwynia juniperina*.

Other remnants of this shale-associated vegetation survive along the edges of predominantly sandstone reserves; or where this shale overlies sandstone; or where there is the influence of previously eroded shale. The vegetation in these areas generally differs from that of the deep shale and includes some sandstone species. The structure is generally that of Tall Open Forest and tree species may be *Syncarpia glomulifera*, *E. punctata* (Grey Gum), *E. paniculata* and *E. globoidea*. *E. sieberi* (Black Ash) is common on laterized shale remnants around Duffys Forest and Frenchs Forest - shrubs may include *Acacia myrtifolia*, *Pultenaea villosa* and *Telopea speciosissima*.

TOF6C

Tall Open Forest: E. deanei.

Tall Open Forest is found on volcanic outcrops of the lower Blue Mountains, such as Tobys Glen and St. Helena. These volcanic outcrops possess a richer soil (often derived from basalt) than the surrounding Hawkesbury sandstone soils, and are often located in sheltered valleys. The TOF is usually dominated by *E. deanei* (Deane's Gum), though in drier situations or where the soil is derived from breccia rather than basalt other species may occur. The valley, at Valley Heights, now mainly cleared, has remnant trees of *E. amplifolia* (Cabbage Gum). The distinctive difference between the grassy, open understorey on a volcanic outcrop and the shrubby understorey of the surrounding sandstone is evident from Cox's Journal of Road Construction over the Blue Mountains in 1814. "Nine and a half miles (from Emu Plains) grass and water in valley to right of road about a quarter of a mile" (quoted in Benson 1981a).

The ground cover at Toby's Glen and St. Helena is dominated by ferns, particularly *Culcita dubia* and *Pteridium esculentum*. Scramblers such as *Smilax* spp. and *Cissus* are common. Carne described St. Helena as having "well-grassed forest land" (quoted in Benson 1981a).

TOF6D

Tall open forest: E. benthamii

A localized TOF community is restricted to a sand bank and adjacent riverbank of the Nepean at Bent's Basin, south of Wallacia. This community is dominated by large trees of *E. Benthamii* (Camden White Gum) up to 40m in height. *E. benthamii* is now rare but formerly occurred along the Nepean River floodplain as far downstream as the Grose River junction and along parts of the Cox River and Kedumba Creek. Clearing has reduced its occurrence along the Nepean River to scattered trees, and Warragamba Dam has flooded much of the Cox distribution.

Associated with *E. benthamii* at Bents Basin is *E. elata* (River Peppermint). The understorey of the community has tall shrubs of *Acacia glaucescens* and *A. floribunda* with smaller shrubs such as *Breynia oblongifolia* and *hymenanthera dentata*. Ground cover is variable with patches of *Lomandra longifolia*, *Pteridium esculentum* and *Cynodon dactylon*. Weed species, including *Olea africana*, *Tradescantia albiflora*, *Araujia hortorum* and *Ligustrum sinense*, are common.

OF9A

Open Forest: E. maculata & E. paniculata.

Open Forest of *E. maculata* (Spotted Gum), *E. paniculata* (Grey Ironbark), *Syncarpia glomulifera* (Turpentine), *Casuarina torulosa* (Forest Oak) and *E. gummifera* (Red Bloodwood) is found in the Barrenjoey-Pittwater area upon outcrops of the Narrabeen Group. This generally has a dry shrubby understorey, but on sheltered aspects the rich soil from the Narrabeen shales has enabled 'rainforest type' species such as *Diospyros australis*, *Synoum glandulosum*, *Glochidion ferdinandi* and *Ficus coronata* to become established. Creepers and scramblers such as *Cissus hypoglauca* and *Geitonoplesium cymosum* are common. *Livistona australis* (Cabbage Tree Palm) is conspicuous around Bilgola.

OF9B

E. maculata - E. moluccana.

Open Forest of *E. maculata* (Spotted Gum) and *E. moluccana* (Grey Box) is found on Wianamatta shale on hilly country at Hoxton Park and Cecil Park. Most has been cleared but a few small patches remain. Other tree species include *E. fibrosa* (Broad-leaved Ironbark), *E.*

crebra (Narrow-leaved Ironbark), *E. tereticornis* (Forest red gum) and *E. longifolia* (Woolybutt).

The understorey at Hoxton Park is mainly grassy with local, dense patches of shrubs, mostly of *Bursaria spinosa* and occasionally *Dillwynia juniperina* and *Indigofera australis*. Common grass species are *Aristida vagans*, *Entolasia marginata*, *Eragrostis leptostachya* and *Themeda australis*. The community at Werombi is richer in shrub species with *Breynia oblongifolia*, *Casuarina torulosa*, *Acacia implexa* and *Clerodendrum tomentosum*.

OF9C

Open forest: E. crebra & E. fibrosa.

This community is found on a remnant of Wianamatta shale near Euroka. The dominant trees are ironbarks, *E. crebra* (Narrow-leaved Ironbark) and *E. fibrosa* ssp. *fibrosa* (Broad-leaved Ironbark). There is an understorey of grasses and scattered shrubs of *Daviesia ulicifolia*. The vegetation contrasts with the surrounding Hawkesbury sandstone vegetation; but also appears to differ somewhat from the vegetation on nearby Wianamatta shale between Glenbrook and Springwood. Though much of the vegetation has been cleared for urban development, *Syncarpia glomulifera* (Turpentine) appears to have been a major constituent of the vegetation near Springwood.

OF9D

Open Forest: E. Fibrosa & E. moluccana

This community, which is found between Penrith and Windsor, occurs on the transitional zone between Wianamatta shale and Tertiary alluvium, and contains a mixture of species found on both these areas. E. fibrosa ssp. fibrosa (Broad-leaved Ironbark), one of the commonest species on the Tertiary alluvium, and E. moluccana (Grey Box), a common species on Wianamatta shale, are the main dominants. Other tree species are E. eugenioides (Thin-leaved Stringybark) and E. sclerophylla (Scribbly Gum). Small trees of Melaleuca decora are often conspicuous. The understorey is dominated by low shrubs with a mixture of the hardier species from the Wianamatta shale and Tertiary alluvium. Bursaria spinosa, Daviesia ulicifolia, dillwynia juniperina, Hardenbergia violacea, Exocarpos cupressiformis, Melaleuca nodosa and Acacia parramattensis are the most common species.

OF9E

Open Forest: E. fibrosa.

Open Forest of E. fibrosa ssp. fibrosa (Broad-leaved Ironbark) is found on reddish clay soils of the Tertiary alluvium around Castlereagh. The best remaining stand is in Castlereagh State Forest where trees are up to 25m high. E. fibrosa is the dominant tree species generally forming pure stands, but may also be associated with E. sideroxylon (Mugga Ironbark) and E. crebra (Narrow-leaved

Ironbark). Other tree species may be E. sclerophylla (Scribbly Gum) and Angophora bakeri (Narrow-leaved Apple), generally found where the soil is more sandy. A small-tree layer of Melaleuca decora is generally conspicuous.

An understorey of sclerophyllous shrubs up to 2m high is normally associated with pure stands of E. fibrosa. No particular species predominates though the Fabaceae are well represented. Shrub species which may be locally abundant are Dillwynia tenuifolia, Dodonaea filifolia, Hakea sericea, Melaleuca nodosa, Mirbelia rubiifolia and Pultenaea villosa.

OF9F

Angophora subvelutina - E. amplifolia.

Open forest of Angophora subvelutina (Broad-leaved Apple), E. amplifolia (Cabbage Gum) and E. tereticornis (Forest Red Gum) appears to have been the original forest vegetation of the alluvial flats of the Hawkesbury-Nepean River system, though this has almost all been cleared for agricultural land. Scattered remnants survive along the lower Hawkesbury below Windsor and along tributary creeks such as Wheeny Creek. The only areas mapped are at Agnes Banks, where a degraded Open Forest of Angophora subvelutina & E. amplifolia survives (though the structure and composition of the understorey have been very much disturbed); and at Kemps Creek, where E. amplifolia and Casuarina glauca are found along the creek. The latter appears to indicate a saline influence in the ground water.

OF10A

Open Forest/ Low Woodland/ Open Scrub.

This community is widespread upon Hawkesbury sandstone and contains considerable local variation depending particularly on topographic position and aspect. Various sub-units can be recognized but because of the large area involved, it has been practical to map only a very broad unit.

The community ranges from Open Forest to Woodland and Low Woodland to Open Scrub. Open Forest is generally confined to gullies and sheltered hillsides, particularly on southern and eastern aspects. The main trees are *E. piperita* ssp. *piperita* (Sydney Peppermint) and *Angophora costata* (Smooth-barked Apple) though *E. pilularis* (Blackbutt) may be locally abundant. *Casuarina torulosa* (Forest Oak) is a common small tree. The understorey is dominated by a variety of shrubs, 0.5-2m high, the main families being Proteaceae, Fabaceae and Myrtaceae. There is a distinctive shrub flora along creeks with species such as *Tristania laurina*, *Backhousia myrtifolia*, *Ceratopetalum apetalum* and *Callicoma serratifolia*. In deep, very sheltered gullies, *E. saligna* (Sydney Blue Gum) may occur with ferns in the understorey.

With increasing exposure, Open Forest grades into Woodland, and on dry hillsides *E. gummifera* (Red Bloodwood) and *E. oblonga* and *E. capitellata* (Stringbarks) predominate - though *E. piperita* and *Angophora costata* may still occur. Low Woodland is found on ridges and plateaux, either with *E. eximia* and *Angophora bakeri* (Narrow-leaved Apple) or *E. haemastoma* and *E. racemosa* (Scribbly Gums). There is often an integration between these latter two species. Patches of mallee eucalypts, included the restricted species, *E. burgessiana* (Faulconbridge Mallee Ash) and *E. multicaulis* (Whip-stick Ash) are frequent along ridges north of Springwood, and patches of *E. luehmanniana* (Yellow-top Ash) may also occur. These dry exposed communities have a rich sclerophyllous shrubby understorey with species of Proteaceae, Fabaceae, Epacridaceae and Myrtaceae.

Where drainage is impeded patches of Open Scrub with tall shrubs of *Banksia ericifolia* and *Hakea teretifolia*, and sedge-dominated swamps are present.

WOOD10C

E. moluccana & *E. tereticornis*.

Woodland dominated by *E. moluccana* (Grey Box) and *E. tereticornis* was originally the main vegetation on the heavy Wianamatta shale-derived clay soils of the drier part of the Cumberland Plain. Clearing for grazing and urban development has reduced this woodland to small remnant stands of trees, while the ground layer has commonly been replaced with improved pasture.

E. moluccana and E. tereticornis are the dominant trees, E. moluccana preferring topographic rises and E. tereticornis the more poorly drained depressions. With increasingly impeded drainage, E. tereticornis may be replaced by the closely related E. amplifolia (Cabbage Gum) and may grade into open-forest (community 'OF9F'), as at Kemps Creek.

Ground cover is generally grassy with scattered shrubs or patches of dense scrub of Bursaria spinosa. Common native grasses are Themeda australis, Eragrostis leptostachya and Aristida spp.

WOOD10D

Woodland. E. moluccana - E. tereticornis - E. crebra.

This community is similar to the previous woodland (community 'WOOD10C') but is found on more hilly Wianamatta shale areas with E. crebra (Narrow-leaved Ironbark) as a co-dominant species. The community was originally extensive around the edge of the Cumberland Plain, and around Camden and Picton, Kurrajong to Glossodia and Cattai to Prospect.

The understorey is generally grassy with patches of shrubs. Grass species include Themeda australis, Eragrostis leptostachya and Aristida spp. Bursaria spinosa is the most common shrub species, often forming dense thickets. Other, less common, shrub species include Acacia implexa, Acacia parramattensis and Indigofera australis. A small stand of this community can be found at Pitt Town.

LOWWOOD14A

Low Woodland: E. sclerophylla - Angophora bakeri.

Low Woodland is found on sandy soils upon Tertiary alluvium around Castlereagh-Londonderry and at Holsworthy. E. sclerophylla (Scribbly Gum) and Angophora bakeri (Narrow-leaved Apple) are the most common species. Other tree species that may be present are E. fibrosa (Broad-leaved Ironbark), E. eugenioides (Thin-leaved Stringybark) and E. gummifera (Red Bloodwood). In poorly-drained sites, E. parramattensis (Drooping Red Gum), E. sideroxylon (Mugga Ironbark) and Melaleuca decora may also occur.

The understorey is of sclerophyllous shrubs. These may form a continuous cover or may be more open, with grasses in between. Common shrubs are Banksia spinulosa, Grevillea mucronulata, Hakea sericea, Leptospernum attenuatum and Melaleuca nodosa.

LOWWOOD14B

Low woodland/ Open scrub: E. sclerophylla - Angophora bakeri - Banksia serrata.

At Agnes Bank, near Richmond, is a deposit of windblown sand of Pliocene or Plio-Pleistocene age which supports an interesting plant community floristically similar to that found on coastal sand dunes such as Myall Lakes. Community structure ranges from woodland to low woodland, with small areas of open scrub. The dominant tree species on well-drained sites are E. sclerophylla (Scribbly Gum) and Angophora bakeri (Narrow-leaved Apple); and on poorly-drained sites - E. parramattensis (Drooping Red Gum). Banksia serrata, although included as a dominant species, is generally a smaller but very distinct tree species. The flora as a whole represents a drainage gradient from well-drained to poorly-drained conditions.

SCRUB

Closed Scrub/ Open Heath/ Sedgeland.

This vegetation unit is restricted to coastal vegetation, which is often low and shrubby both because of the low nutrient status of its soils, and because it is exposed to onshore winds, which restrict the tree growth. Around Sydney, coastal vegetation may be found on Narrabeen group, Hawkesbury sandstone and aeolian sand deposits.

Closed to Open Scrub is mainly restricted to coastal sand dunes. Common species are Banksia integrifolia (Coast Banksia), Leptospernum laevigatum (Coastal Tea-tree), Acacia longifolia (Sydney Golden Wattle) and Banksia serratifolia. Examples still survive at La Perouse. Similar vegetation was probably once common on the sandy areas of the Eastern Suburbs between Botany Bay and Bondi.

Open-heath is found on all three types of geological parent material. It is found in Bouddi National Park on both Hawkesbury sandstone and Narrabeen series; at North Head and Long Bay on Hawkesbury sandstone; and at Le Perouse on Hawkesbury sandstone and aeolian sand. Common species are Banksia ericifolia, Casuarina distyla and Hakea teretifolia, though local species composition depends on soil depth and drainage. At Bouddi, Siddiqi et al. (1972) divided heath into 'sand heath' on deeper sand and 'ground water heath' on more shallow soil.

Sedgeland is found on very poorly drained sites. It is generally dominated by sedges but may also contain shrubs such as Baeckea imbricata or Melaleuca thymifolia.

SEDGE

Open Sedgeland.

This unit covers the freshwater swamp communities which were once a feature of the Hawkesbury-Nepean floodplain, but most of which have now been cleared or drained. A good example has been retained at Long Neck Lagoon at Pitt Town.

Freshwater swamps generally consist of a series of concentric zones related to depth, period and frequency of inundation. Permanent standing water with no emergent vegetation generally occupies the lowest and most poorly-drained areas of large swamps. Around this is shallower water, with a zone of emergent vegetation, generally reedland of *Eleocharis sphacelata* which may grow to 1-2m above the water level. Outside this zone is rushland of *Juncus* spp., most commonly *J. usitatus*, and *Polygonum* spp. This zone does not usually have standing water, except following rain, but the soil is often waterlogged or very moist. Beyond the rushland may be tall shrubland, with *Melaleuca linariifolia*, *M. styphelioides* or *Casuarina glauca*, which grades into eucalypt woodland.

CLEAR

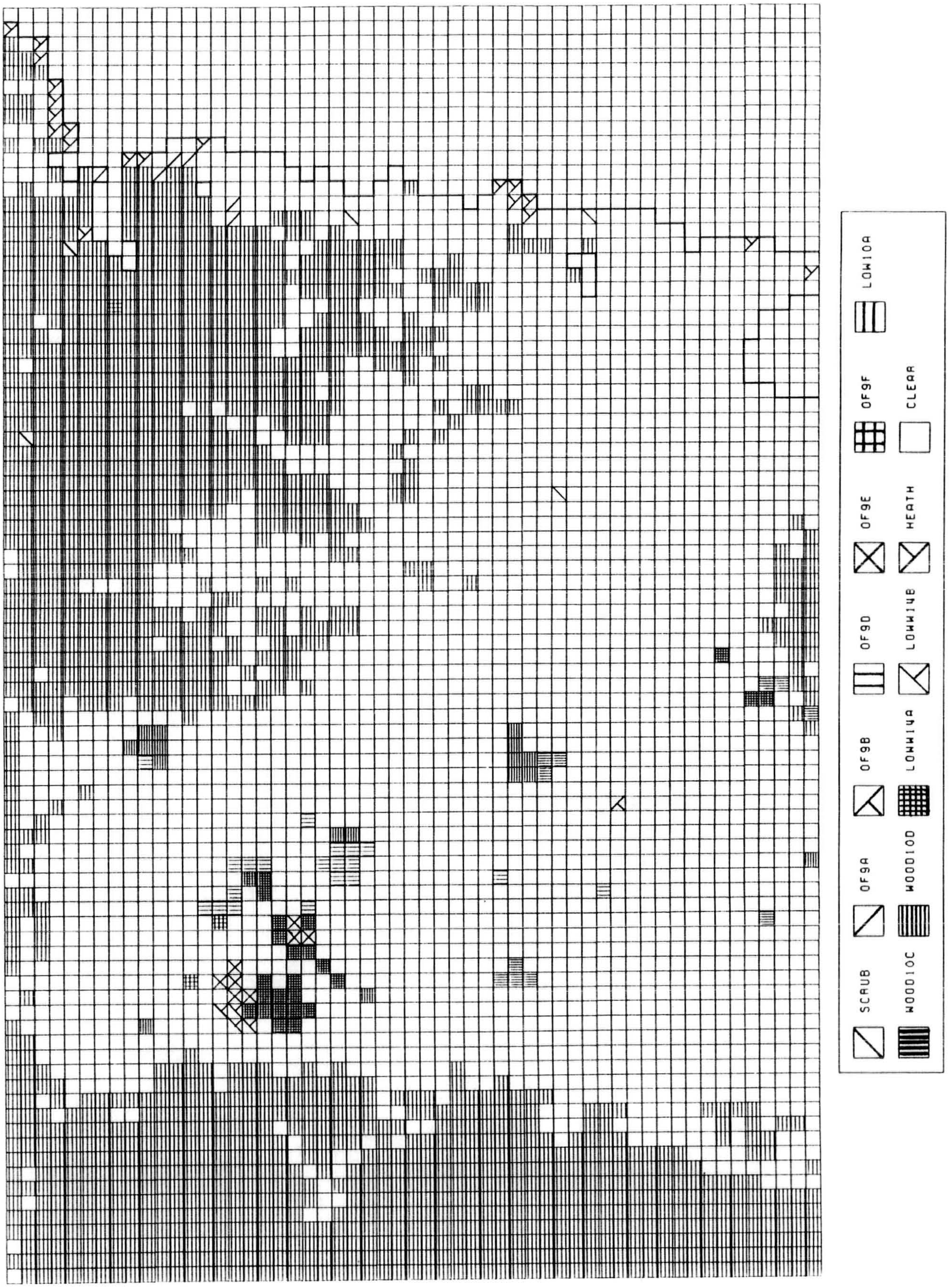
Agriculture and urban settlement have generally followed the more fertile soils of the alluvial flats and the Wianamatta shale of the Cumberland Plain. The poor agricultural soils of the Hawkesbury sandstone and Tertiary alluvium have frequently survived with 'natural' vegetation.

The present extent of these communities is illustrated in Map 8.7. However, through the use of these data and the studies of Pidgeon (1937, 1938, 1940, 1941), Beadle (1981), Benson (1980, 1981a) on vegetation; Walker (1961) on soils; and the Bureau of Meteorology (1979) on climate, it is possible to make a tentative reconstruction of the vegetation patterns prior to the arrival of the Europeans, allowing for the influence of topography, coastal proximity and rainfall distributions, rather than

Map 8.7: The present distribution of 'natural' vegetation within the Sydney region.
(Data: Benson 1980, 1981a)

Key to Map 8.7:

OF	Open Forest
LOW	Woodland/Open Forest
WOOD	Woodland
LOWWOOD	Quaternary Alluvium


SCRUB
OF9A
OF9B
OF9D
OF9E
OF9F
LOW10A
WOOD10C
WOOD10D
LOWW14A
LOWW14B
HEATH
CLEAR

simply the phosphorus distribution of parent materials (Map 8.8)[1]. The broad structure associations (Specht 1970) are displayed in Map 8.9 and can be seen to concur broadly with the distribution which would have been expected from the geological sequence.

Within the Sydney area, Aboriginal behaviour was closely associated with Open Forest, Woodland and Low Woodland which possessed an understorey of grasses, rather than with Open Scrub/ Low Woodland/ Open Forest (10a) upon the Hawkesbury sandstone (or any other unit possessing a shrub understorey) - though this is not obviously true within the Blue Mountains. However, Aboriginal sites within the piedmont, tend to be closely associated with areas of Narrabeen sandstone and it is likely that Aboriginal behaviour would have been principally associated with the Open Forest end of the continuum represented by this unit.

The concentration of sites at the mouth of the Broken Bay estuary are associated with areas of Open Heath and Open Scrub/ Low Woodland/ Open Forest (10A), thereby displaying no obvious association with floras which would be likely to be associated with patch formation. There are two possible explanations for this anomaly; firstly, Aboriginal behaviour associated with this area may have been unconnected with the potential of floral elements to form patches (as the sites are closely associated with the mouth of the estuary it is highly likely that they were located in

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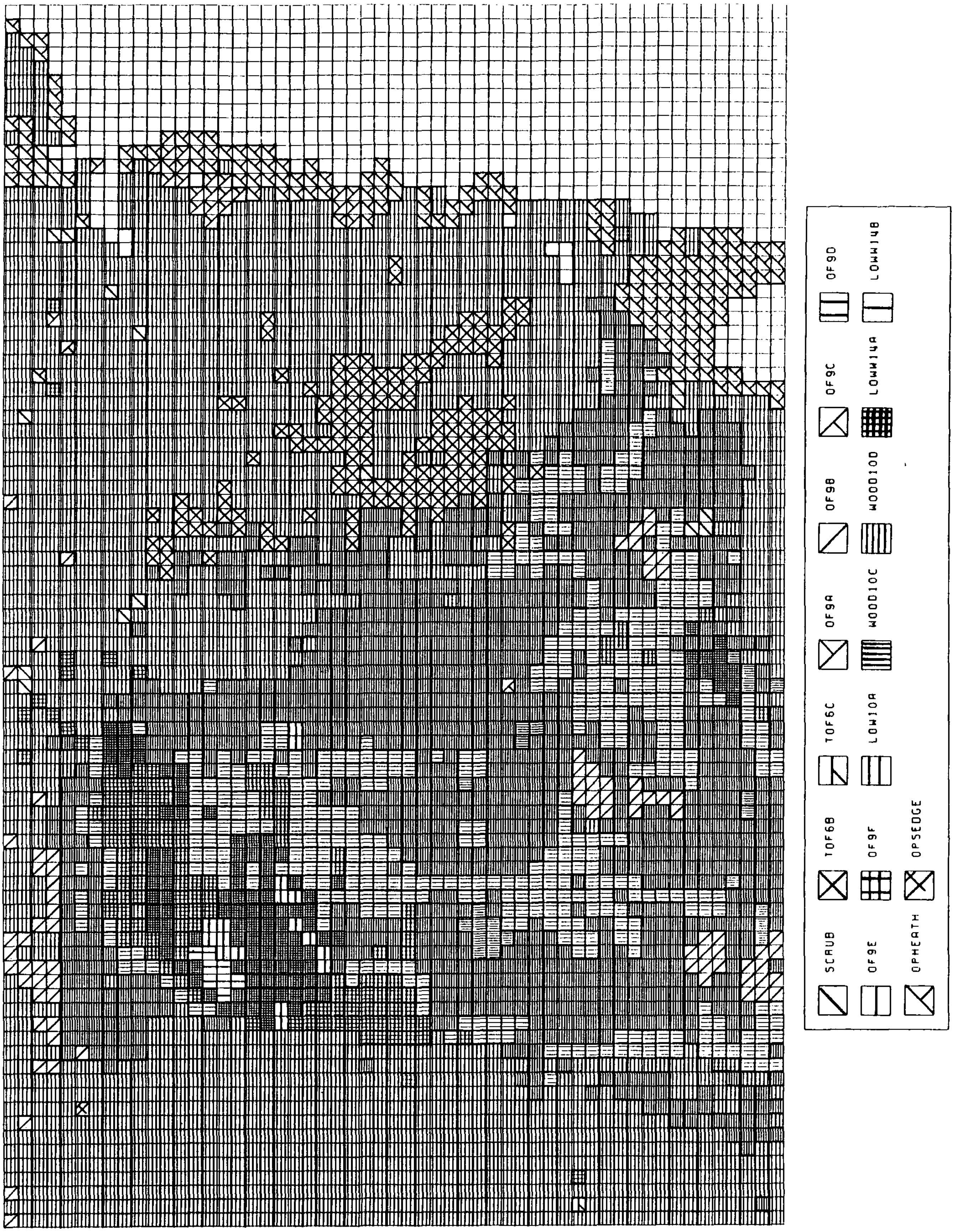
[1] Note that TOF6D is not included and SEDGE is under-represented on the map. These associations probably formed narrow, discontinuous bands particularly along the Hawkesbury-Nepean river, while the kilometre grid reconstruction is based upon the presence of an association covering over 50% of the cell).

Map 8.8: A reconstruction of the probable vegetation patterns of the Sydney region prior to 1788.

Key to Map 8.8:

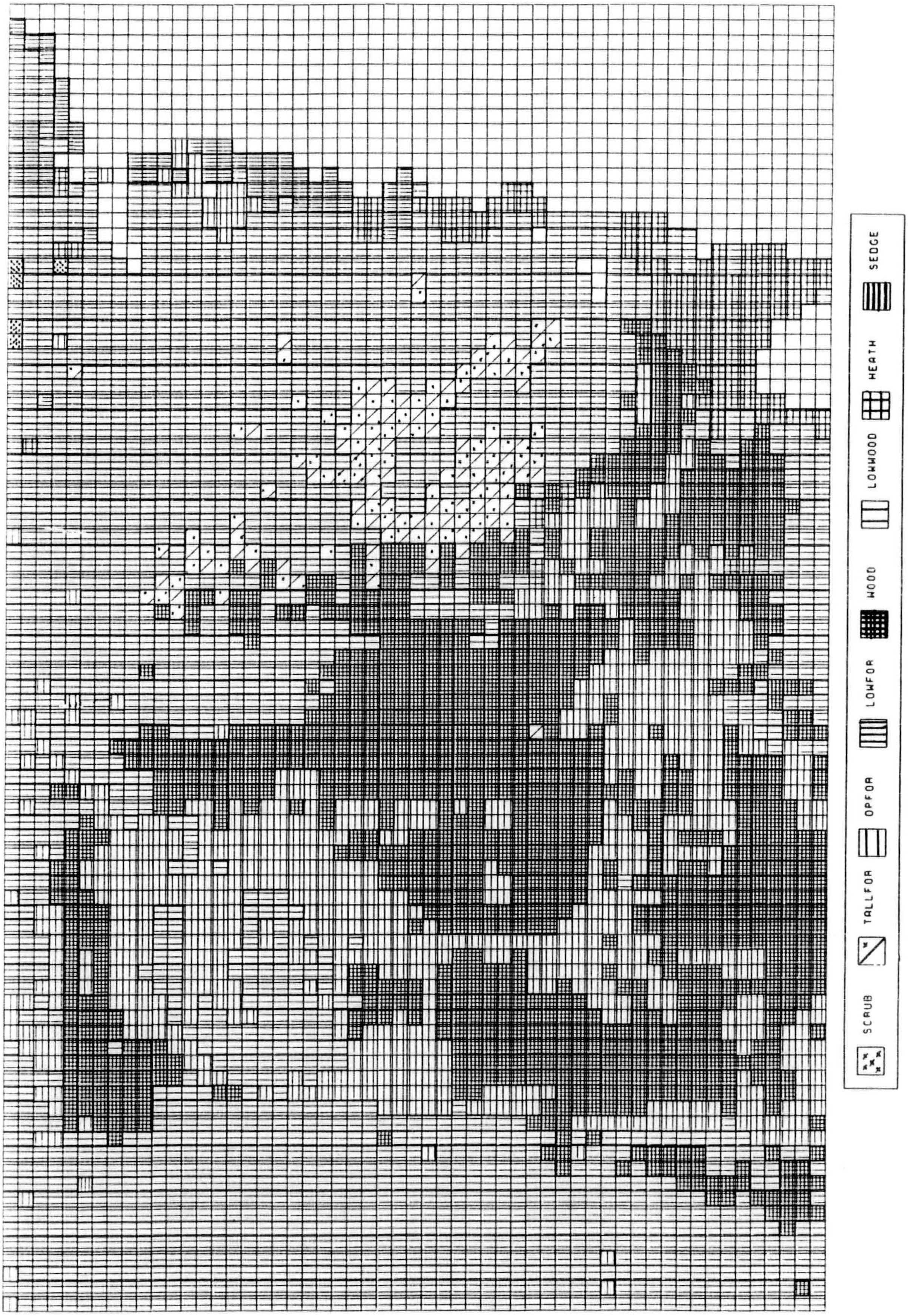
TOF	Tall Open Forest	LOWWOOD	Low Woodland
OF	Open Forest	OPHEATH	Open Heath
LOW	Woodland/Open Forest	OPSEDGE	Open Sedge
WOOD	Woodland		


SCRUB
TOF6B
TOF6C
OF9A
OF9B
OF9C
OF9D
OF9E
OF9F
LOW10A
WOOD10C
WOOD10D
LOW14A
LOW14B
OPHEATH
OPSEDGE

Map 8.9: A reconstruction of the probable broad vegetation structures within the Sydney area prior to 1788.

Key to Map 8.9:

TALLFOR	Tall Open Forest
OPFOR	Open Forest
LOWFOR	Woodland/Open Forest
WOOD	Woodland
LOWWOOD	Low Woodland


SCRUB
TALLFOR
OPFOR
LOWFOR
WOOD
LOWWOOD
HEATH
SEDGE

close proximity to winter fish patches); or secondly, these sites may be more closely associated with small areas of recent alluvium and mangrove stands than the scale of the map can reveal. (Note, for example, that in Port Jackson similar concentrations of middens are particularly associated with the southern-most extension of Tall Open Forest connected with the Hornsby Plateau.)

However, the top of the Hornsby Plateau displays some interesting characteristics with regard to the distribution of Aboriginal behaviour, for there are few sites associated with this area. Extant sites are all shelters, and it is likely that open sites were destroyed early in the history of the colony by clearing for agriculture (the soil is derived from Wianamatta shale). However, an explanation of this paucity of sites could also be sought in the fact that the height of the area, rapid run-off and proximity of the coast has meant that the associated flora possesses many more xeromorphic characteristics than are associated with the low-lying areas of soils derived from Wianamatta shale upon the Cumberland Plain to the west.

A similar anomaly occurs in relation to the areas of Narrabeen series geology in immediate proximity to the coast which tend not to produce the Tall Open Forest which would be expected on the basis of their probable nutrient profile. The influence of the immediate coastal environment clearly tends to produce scrub vegetation regardless of underlying structure.

Interestingly, when the cells in which vegetation changes between the major structural groupings are likely to have occurred are mapped (Map 8.10), there is a suggestion of association between Aboriginal behaviour and these areas, particularly around the Cumberland Plain, but also upon the coast and in the Blue Mountains. This would seem to suggest that patches associated with ecotones (wherein the density and diversity of species tends to be greatest (see Rhoades 1978)) may have influenced the distribution of behaviour.

8.2.3 Local geology and vegetation - a summary

Broadly, the distribution of Aboriginal behaviour within the Sydney area tends to concur with that which would be expected on the basis of probable patch location based on geological structure. The local analysis does, however, suggest that other influences may have affected Aboriginal locational decisions, particularly with regard to the ecotonal properties of the divisions between major structural types. In addition, some areas of relatively fertile soils seem to be under-represented in terms of numbers of sites. While this may be largely a function of the destruction of sites in these areas through the expansion of agriculture, it is at least as likely that this reflects a real characteristic of the location of Aboriginal behaviour in relation to the increased degree of xeromorphy brought about by a number of topographic factors. The likelihood of this is increased by the fact that where the Tall Open Forest of the Hornsby Plateau meets the estuarine fringe a large number of sites are to be found but that further from the low-lying fringe, sites are a rarity.

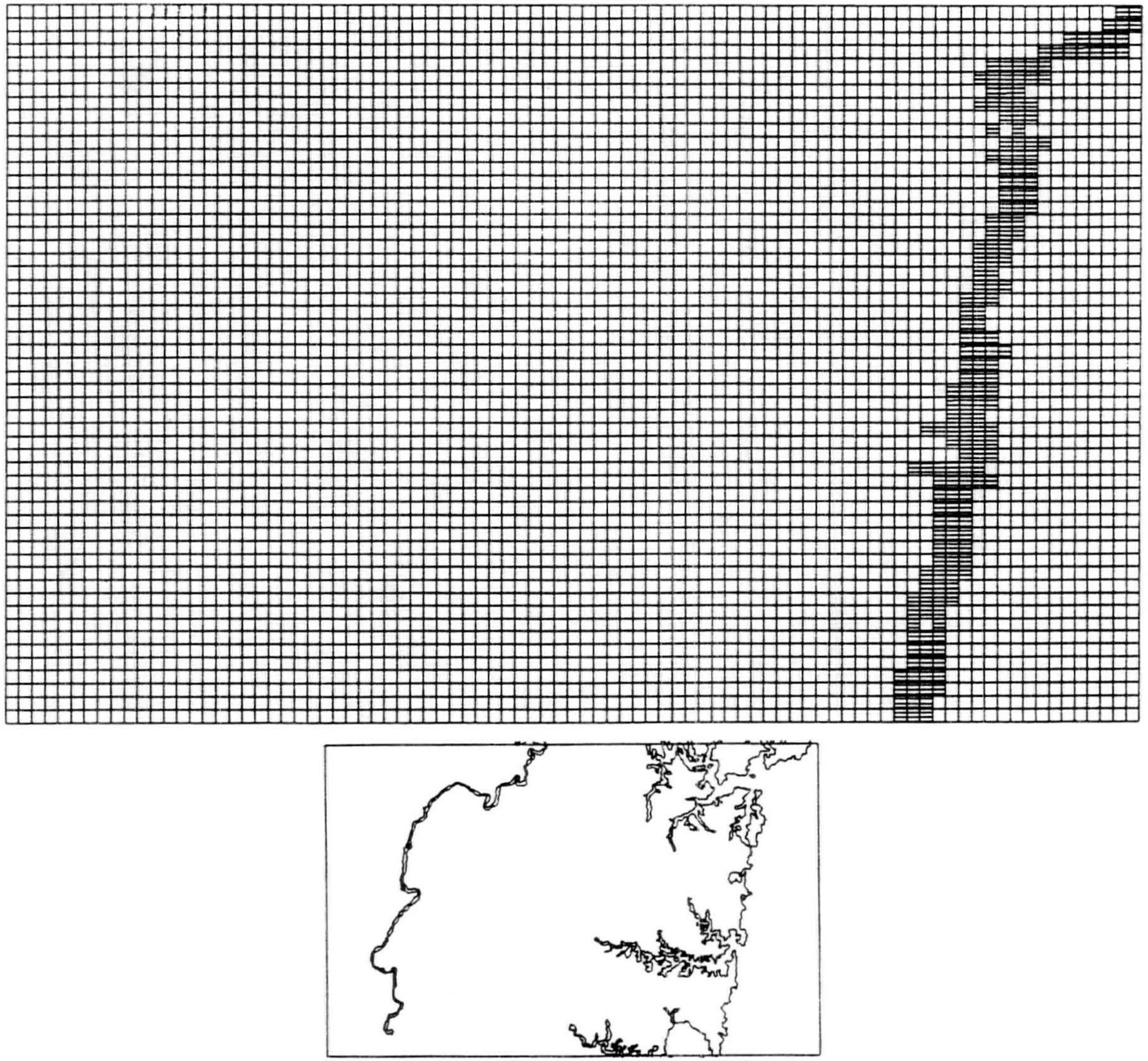
Map 8.10: The distribution of boundaries between vegetation structures within the Sydney area.

8.2.4 Aboriginal behaviour and aquatic structure

Maps 8.11 and 8.12 indicate the distribution of those areas within which marine and estuarine waters flow. That Aboriginal behaviour, especially that part represented by middens are associated with these areas is a trivial observation, but the large number of sites associated with the boundary between the two is particularly reminiscent of expectations based upon the behavioural model concerning the distribution of fish patches in winter. (Note that the extent of the destruction of sites within Port Jackson can, to some extent, be judged by the comparison of the distribution of sites to the north - which is relatively undeveloped - and the built-up south of the estuary .)

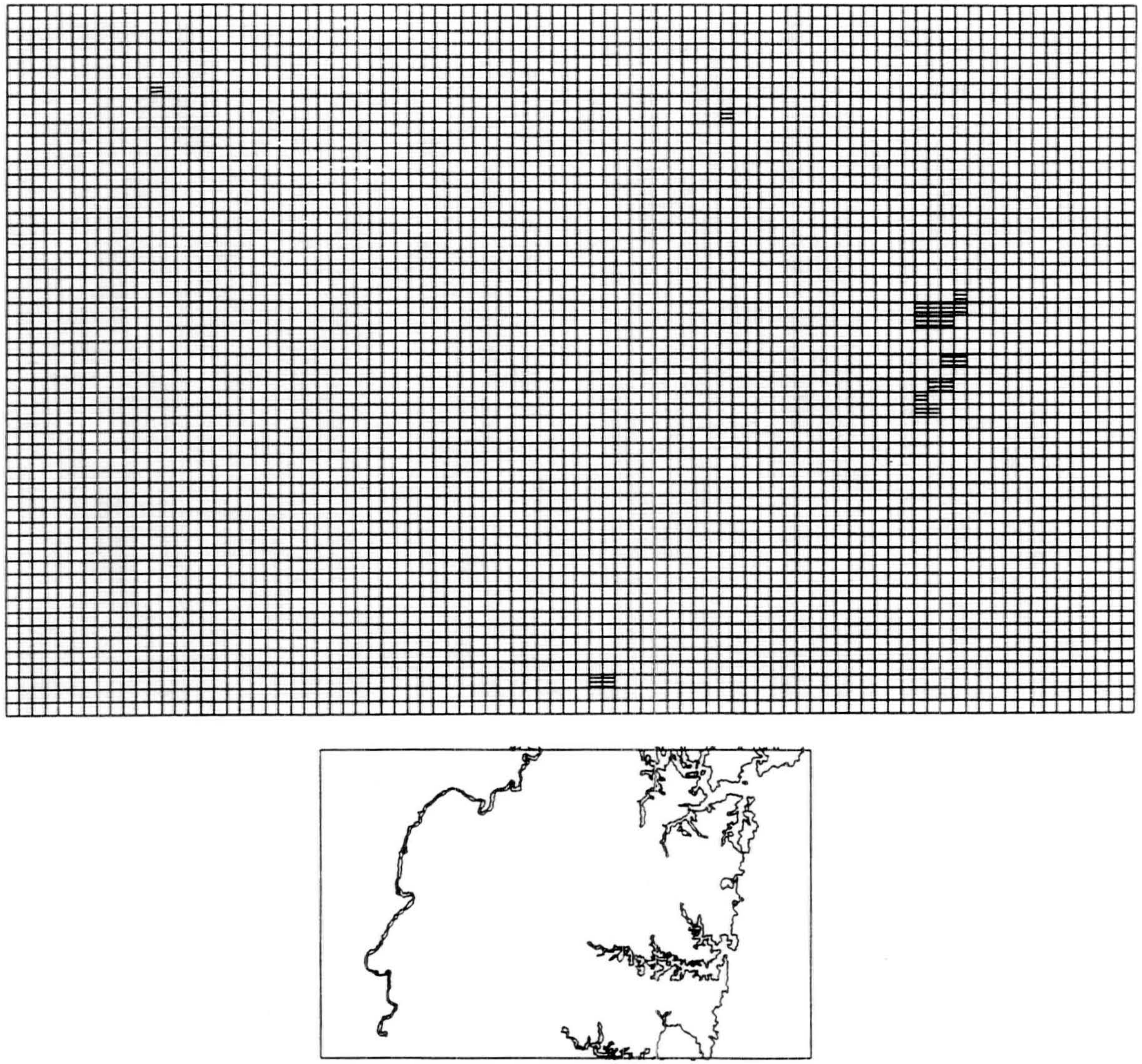
There is no clear pattern with regard to the distribution of sites and marine resources. This is likely, for the most part, to reflect taphonomic processes associated with the prevalence of recent and shifting sand dunes; but may more generally reflect the paucity of high-value resource patches likely to be recognized in all seasons (except winter and early spring) along the coast. The lack of evident Aboriginal behaviour in relation to lagoons (Map 8.13) - important winter waterfowl refuges - is probably also explicable in terms of their close association with dune systems.

River, wetland and pond distributions are illustrated in Maps 8.14, 8.15, 8.16 respectively. While little has influenced the distribution of the first category, European expansion has had a great influence upon the

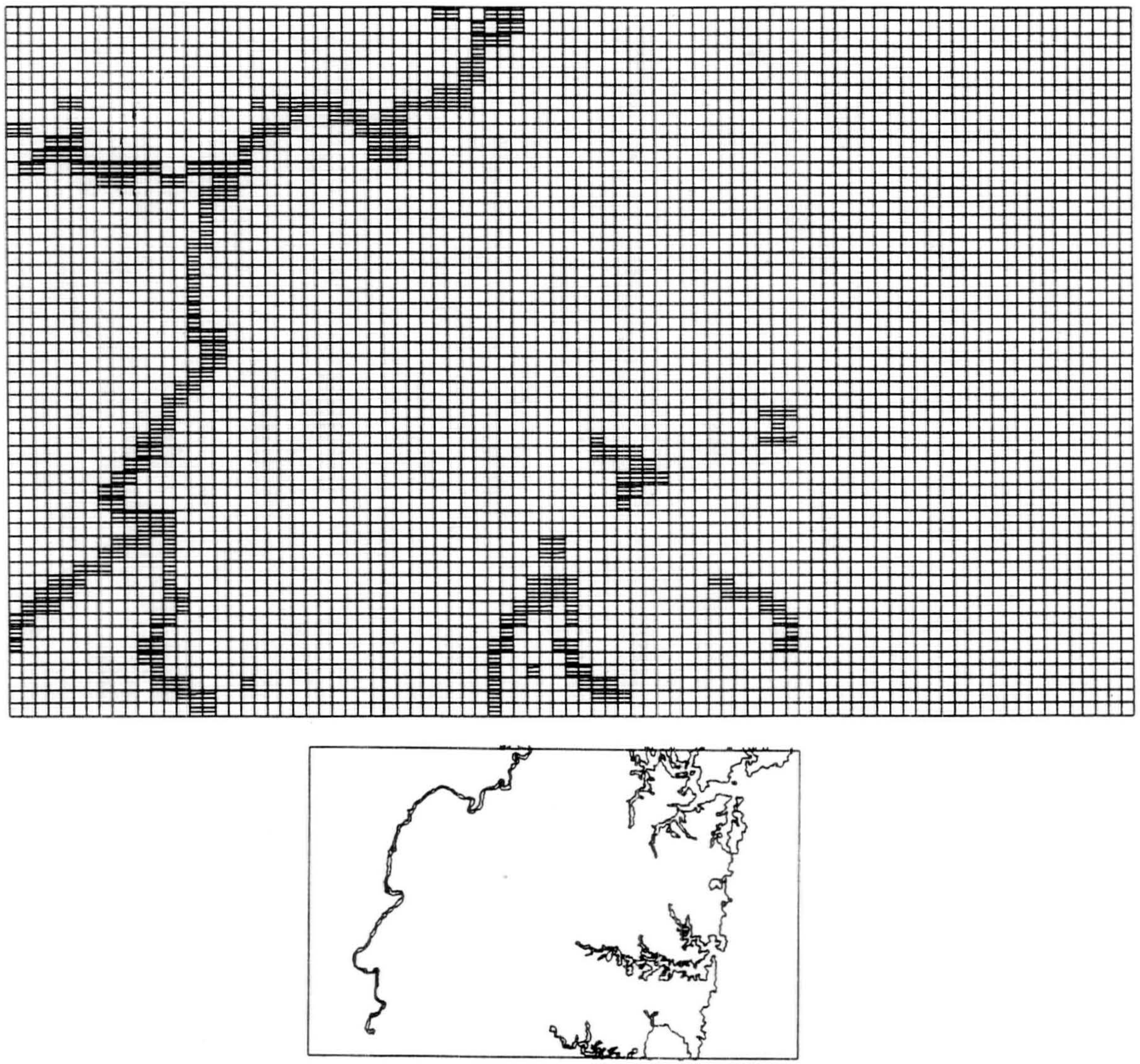


Map 8.11: The distribution of land areas possessing a marine border.

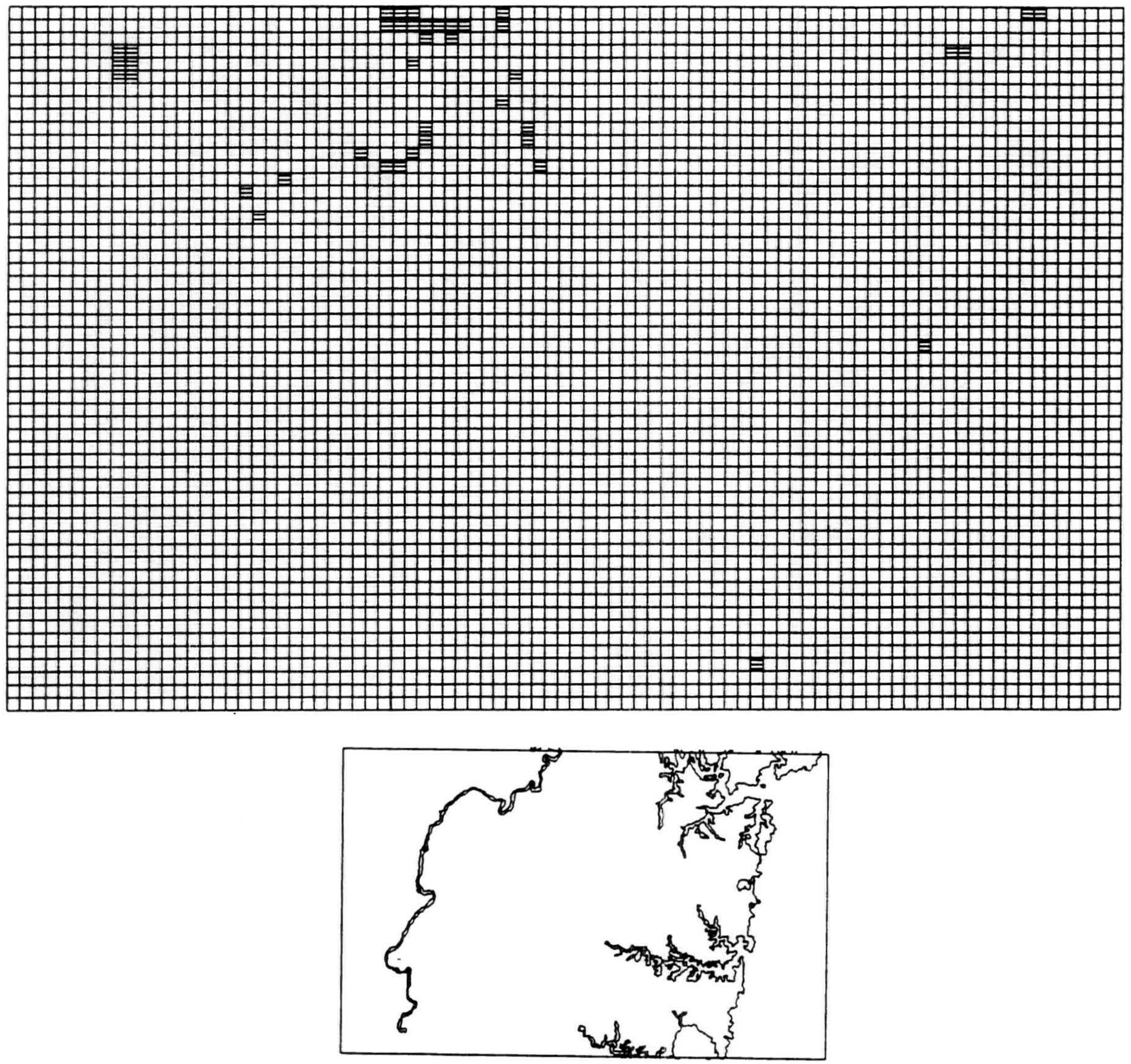
Map 8.12: The distribution of land areas possessing an estuarine border.



Map 8.13: The distribution of areas in which lagoons are present.



Map 8.14: The distribution of rivers within the Sydney area.



Map 8.15: The distribution of the larger wetlands within the Sydney area.

Map 8.16: The distribution of ponds - open water areas of small areal extent - within the Sydney area.

latter two landform elements (for example, most of the centre of Sydney is built upon a major wetland area at the head of the Tank Stream). Generally, however, the major areas of low-lying land most suitable for extensive wetland formation are still identifiable, particularly upon the Cumberland Plain. It is evident that Aboriginal behaviour (especially that part not associated with middens) was closely associated with these areas, particularly in the vicinity of the Hawkesbury-Nepean river.

Of necessity, it has been assumed throughout the analysis that freshwater is a ubiquitous commodity within the region. When the incidence of major freshwater sources is plotted, the general validity of this assumption is made manifest (Map 8.17). However, while there is a high likelihood of finding water at almost any point in the landscape, this may not always be true. For example, Map 8.18 records the distribution of creeks which are recorded as being seasonally dry. There is a clear inland bias in the distribution of these seasonally dry areas - only a few high points near the coast possess the characteristic. Seasonal creeks are particularly a feature of the Blue Mountain piedmont and the southern parts of the Cumberland Plain and may, particularly in the latter case, help to explain the paucity of sites within these areas.

A more tenuous factor in the positioning of sites may be the incidence of confluences in the landscape (Map 8.19). Confluences are important because the increased aeration of the water and mixture of nutrients often promotes a greater biomass of freshwater species. However, no clear pattern emerges from a comparison between the evidence for Aboriginal

Map 8.17: The distribution of freshwater sources within the Sydney region.

Map 8.18: The distribution of areas within which freshwater may be seasonal.

Map 8.19: The distribution of confluences within the Sydney area.

behaviour and this characteristic. Though it is probably true to say that away from the coast absence of sites is broadly associated with absence of confluences.

8.3 ABORIGINAL BEHAVIOUR AND LOCAL ECOLOGICAL INFLUENCES

In this chapter a number of local, and principally biological, influences upon the local distribution of sites have been examined. In a number of cases it has been suggested that at this level some of the relationships expected on the basis of a regional viewpoint may not necessarily be confirmed.

In the case of the geological distribution, for example, it is clear that while there is an avoidance of Hawkesbury sandstone areas (reinforced by the fact that there are far fewer sites in these unmolested areas than in those areas which have been utilized in the course of the expansion of the city), other areas which might be expected to display some measure of Aboriginal usage, do not. This is particularly true of the Tertiary gravels and sands along the course of the Hawkesbury-Nepean river but more significantly of the Wianamatta shale capping of the Hornsby Plateau.

In addition, it is clear that middens within the sub-areas are as likely to be located without regard to the locational characteristics of geological structure as they are with regard to that factor - though in the case of the middens at the mouth of Broken Bay there is a likely explanation of the concentration of sites in the favourable position associated with the distribution of high-value fish patches.

Strong associations with local vegetation structures are broadly consistent with those assumed in the regional pattern described in the last chapter (based upon geological structure). However, on the basis of a tentative reconstruction of pre-1788 vegetation patterns, three anomalies can be described. Firstly, there is no clear association with the Tall Open Forest upon the Hornsby Plateau, which might be expected on the basis of the nutrient content of the Wianamatta shale-based soils. In part this may be because of the destruction of data, but is also likely to be because the characteristics of the area produce a greater degree of xeromorphy than might be expected on the grounds of nutrient contribution alone. Secondly, in close proximity to the coast Narrabeen sandstones may not produce the Tall Open Forest which would be expected on the basis of probable nutrient distribution - the rigours of the coastal environment ensuring high degrees of xeromorphy and sclerophylly. Thirdly, there appears to be a clear association between site distribution and the incidence of boundaries between vegetation structural units, which is particularly evident upon the fringes of the Cumberland Plain.

In addition, although the evidence is tenuous, there is some suggestion that some aspects of freshwater distribution may have influenced the location of sites. In particular, the distribution of seasonal water sources appears to have been particularly influential upon the southern Cumberland Plain.

With these exceptions there appears to be a satisfactory congruity between the characteristics of the region and those of the Sydney area, despite the disruption of the latter by the expansion of European settlement.

9 CHAPTER NINE:

ETHNOHISTORY: OBSERVATIONS OF REAL BEHAVIOUR

> "I doubt not my readers will be as glad as I feel myself, to conclude the dull detail of the last chapter. If they please they may turn from the subtle intricacies of the Law, to contemplate the simple, undisguised workings of nature in her most artless form" (Watkins Tench 1979:74 (orig. 1791)).

9.1 INTRODUCTION

The model of optimal behaviour used throughout the preceding analysis was based upon ecological data and principles; while the data used to test the model have been wholly archaeological. In this chapter the observations of the real behaviour of the Aborigines who lived within the Sydney area are introduced. This information is used to examine aspects of the degree of fit between the archaeological distribution and the behavioural model. The evidence for the presence of two ecological populations (coastal and inland) is reviewed; and details of reported Aboriginal movements are examined for evidence in support of or at variance with the behavioural model. The small amount of information concerning diet is compared with the expectations based upon patch distribution. Finally, the tiny amount of information concerning the characteristic of Aboriginal site usage is reviewed.

9.2 HISTORICAL BACKGROUND

Mulvaney is, of course, quite correct in emphasizing that we should not overstress the value of early primary sources in the Australian context (1975:70): they are not ethnography. Yet it is also true that within the Sydney region these same primary sources represent a rare event in hunter-gatherer studies; they are the witness of the first contact between an agricultural people and a hunter-gatherer people. Indeed, the people of the Sydney region were one of very few aboriginal populations to be caught, as it were, by surprise, in the full-flourishing of their subsistence activity. Elsewhere in Australia, for example, knowledge and disease spread before the European settlement (see Reynolds 1980, 1982) undoubtedly causing massive disruption to the behavioural patterns of the populations. Even within the Sydney region the glimpse of the population is brief. It lasts only from January 1788 to the full-fury of the pox epidemic in the April of 1789. When Captain Tench marched out from Rose Hill to find the source of the Hawkesbury in 1790 the Aborigines he met were pock-marked, and it was the view of the coastal Aborigines who were with him that many had died in the hinterland (Tench 1979:153; Hunter 1968:513).

The exceptional qualities of the First Fleet record are also emphasized by the fact that it has been a rare event in Australian history that the first European contact with an Aboriginal population should contain intelligent observers of behaviour. Elsewhere, in general, first contact was an event between the Aborigines and hard-bitten frontiers-men. The officers of the First Fleet recorded their first impressions, no doubt, in the light of the concept of noble savagery[1]. Yet it is also true that some of these officers (for example, Bradley and Tench) had served (amongst other places) in America, where they had presumably observed the aboriginal population. As a result of these experiences, their observations in Sydney are for the most part comparative and their descriptive terminology is based upon their American knowledge. These were not men fresh from England lost in an alien environment.

A characteristic of all European gentlemen of the period was there readiness to describe the nature of things. Yet in the case of the gentlemen of Sydney, the description of the nature of the Sydney region was sharpened by the very real pangs of hunger. Expeditions were sent out in all directions within a year of the establishing of the settlement, to describe the country and to bring back evidence of land suitable for cultivation (Wood 1926; Robinson 1962). They could find little. The alluvium and shale area around Rose Hill (Parramatta) was cultivated and became exhausted; the basalt plug at Prospect Hill was cultivated and proved to be more of a success though severely limited in area; the alluvial banks of the Hawkesbury-Nepean proved more fertile, though they were subject to severe periodic flooding.

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[1] This light shone on some observers more than others. It is clear that the other officers recognized that Watkins Tench saw in everything that this was "the best of all possible worlds". Governor Phillip expressed this wryly in his naming of a small tump, overlooking a particularly barren part of the landscape, 'Tench's Prospect Mount' (needless to say Tench was delighted).

It was not until 1795 that the fertile area at the head of the Nepean (Camden) was discovered. It is interesting to note, from our present perspective, that this area was occupied when discovered, by a herd of wild cattle - the progeny of the herd which had been lost at Sydney in 1788. Even this seemingly trivial tale tells us something of the country of relevance - that the cattle were limited to this small area some 40km south-west of Sydney is indicative of the hazards of herbivory in the land (and also their presence there at all, is indicative of the 'wave' effect before the First Frontier (see Reynolds 1982)).

A by-product of this constant search for agricultural land (combined with genuine interest) was a series of descriptions of the Aboriginal populations - along the coast, upon the Cumberland Plain and within the foothills of the Blue Mountains. Yet the primary purpose was to discover the nature of the country.

9.3 THE CHARACTERISTICS OF THE LAND IN 1788

> "The general face of the country is constantly pleasing, being diversified with gentle ascents and little winding valleys, covered for the most part with large spreading trees which afford a succession of leaves in all seasons. In those places where trees are scarce a variety of flowering shrubs abound." (Tench 1979:65).

The general potential of the land was quickly assessed by the members of the First Fleet who were searching for good agricultural land and, in the mean time, for food from the bush which might support the colony. The new country was dominated by "either a rocky or a sandy or a swampy surface crowded by large trees, and almost impenetrable from brushwood" (Worgan 1978:9; see also Phillip 1982:122); and it was soon clear that the productivity of the land was not seasonal in its characteristics, and that the edible component of the production was small:

> "A list of the esculent vegetables and wild fruits is too contemptible to deserve notice, if the sweet tea ..... and the common orchis root be excepted ..... The mountain cabbage, is found in freshwater swamps, within six or seven miles of the coast; but is rarely seen inland. Even the banks of the Hawkesbury are unprovided with it" (Tench 1979:263).

Within a few months, several journalists had discovered the nutrient poverty of the soil - Worgan, for example, provides a classic description of nutrient starvation (1978:12-13):

> "Nothing seems to flourish vigorously long, but they shoot up suddenly after being put in the ground, look green and luxuriant for a little time, blossom early, fructify slowly and weakly and ripen before they come to their proper size. Indeed many of the plants wither long ere they arrive at these periods of growth."

No less evident was the influence of nutrient deficiency upon the fauna. In the country around Sydney most of the introduced animals could not survive - only the fowl thrived (this is, of course, very largely true of the native fauna as well). However, it was quickly discovered that the area to the west (the Cumberland Plain) appeared in patches to be better country (Tench op. cit:155, 174); and the banks of the Hawkesbury - covered in timber and with 'a rich light mold (sic)' (White 1975:148) - held out some promise. The same general pattern appears to have been true of the fauna (as indeed would be expected). Upon the coast, Tench remarks:

> "Of quadrupeds, except the kangaroo, I have little to say. The few we met with are almost invariably of the oppossum (sic) kind, but even these do not abound" (Tench 1979:67).

but again as the colonists moved west they found more abundant fauna (Hunter 1968:77).

In fact, the First fleet writers are able to add a new dimension to our knowledge of the constraints upon the fauna. For they particularly note the depredations of the principal carnivore - the dingo (_Canis familiaris dingo_) - and suggest that it may have had a significant limiting influence upon the native fauna (as, indeed, they are thought to have in modern grassland environments (Caughley et al. 1980)). Several writers describe kangaroos being run down and killed by packs (see for example Tench op.cit:270; Hunter op.cit:67), and a particular example from the early settlement at Rose Hill (Parramatta), is suggestive of the likely extent of this predatory influence (though the particular circumstances may have produced a phenomenal opportunity for this highly-adaptable predator). Collins notes that:

> "Rose Hill people have been much molested by dogs. Which have been seen together in great numbers and attacked the pigs at night" (1971:112).

Interestingly, notice of the influence of predation was not limited to the terrestrial sphere. Sharks were observed to greatly influence the fish populations - Worgan notes that "enormously large sharks are very numerous in the harbours and are very destructive to the other fish" (1978:22).

The general observations of the First Fleet, then, are concordant with those modern observations upon which the present study is based; particularly with regard to the nutrient deficiencies at the coast and the improvement in nutrient levels associated with the Cumberland Plain and the Hawkesbury-Nepean river. Yet the observations also introduce new elements. In Chapter Four it was suggested that the extent to which dingo predation may have influenced faunal population structure was largely unknown - the evidence of the First Fleet, however, suggests that, in addition to the major direct and indirect influences of nutrient deficiencies and fire history, predation by dingo may have been another limiting factor upon the densities of fauna. If this was so, then the emphasis of the optimal foraging strategy appropriate within the Sydney region would be likely to have been even more strongly associated with the distribution of high-value fish resources.

9.4 ASPECTS OF ABORIGINAL DISTRIBUTION

In Chapter Seven, the results of the analysis clearly supported the notion that two viable ecological populations - one coastal, high-density and closely packed; the other inland, low-density and loosely packed - could have occupied the Sydney region. The rapid exploration of the region which occurred in the first few years of European settlement provides us with a considerable amount of information concerning the disposition of the Aboriginal population, which can be used to examine this assertion and to assess other locational characteristics, such as the relationship between Aboriginal movements and high-value patches.

The population of the area between Botany Bay and Broken Bay was estimated to be approximately one thousand five hundred by Governor Phillip (1982)), and such high densities seem to have been characteristic of the coastline. The population numbers of the hinterland are unknown, but when Tench struck out for the Hawkesbury-Nepean in 1790 he found few people. It is probable, however, that the inland population was already a remnant - for it was the opinion of the coastal Aborigines who accompanied him, that many had died here of the pox, and Tench himself describes meeting Aborigines with pock-marked faces [2] (Tench 1979:153).

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[2] It is interesting to note that the common ascription of the disease to smallpox is historically and diagnostically improper, cow pox is at least as likely to have been the agent of the Aborigines' destruction (Dr. K. McCarthy pers. comm.).

That there were separate inland and coastal Aboriginal populations within the Sydney area is unequivocally clear. The evidence of the First Fleet indicates that there was a distinct division between the people of the coast and the people of the inland plain. Nowhere is this more dramatically emphasized than on the occasion in 1790, already alluded to, when Tench set forth from Rose Hill to the Hawkesbury-Nepean taking with him two Aborigines from Port Jackson (Colbee and Ballederry). Beyond Rose Hill the country was unknown to them (Tench op.cit:225) and they stared at the river in surprise and could not tell the direction from which they had come (loc.cit.).

Further evidence from the same expedition indicates that barriers between the two populations were artificially maintained. Colbee and Ballederry informed Tench that the people of the interior were long-standing enemies (loc.cit.) and the Europeans noted that the feeling was reciprocated: little affection for coastal men was displayed by the inland Aborigines. In fact, the cultural nature of the division is emphasized by the apparent differences in dialect:

> "Although our natives and the stranger conversed on a par and understood each other perfectly, yet they spoke different dialects of the same language" (Tench loc. cit.).

Other more tenuous data support this general view of a culturally reinforced division between these two ecological populations. For example, the coastal Aborigines were clearly reluctant to be drawn into a discussion of tooth avulsion (which was not evident inland) in front of the inlander (op.cit:230). In addition, the songs and dances of the two groups were thought to be different (Collins 1971:586).

There is, in fact, some small indication of the existence of a third population which utilized some parts of the Blue Mountains - for Captain Paterson, who travelled up the Grose River in 1793, met a few Aborigines who were almost unintelligible to those who accompanied him (Collins op.cit:313).

With regard to these divisions, it is interesting to note that, in a recent paper, Flood (1982) has re-emphasized Howitt's (1904) division of the people of the south-east coast into the 'Katungal', 'Paiendra' and 'Bemeringal' - that is the sea, hinterland and mountain people. It seems an inescapable conclusion that this pattern (or a very similar one) occurred in the Sydney region (see Capell (1970) on the linguistic divisions within the area which tend to support this tripartite scheme).

On the basis of the ecological data, however, it appears very unlikely that the putative mountain population could have survived throughout the year within these areas (cf. Bowdler 1981). As a consequence, it is probably more economical to suppose that the strangers Paterson met, were at the extremities of their summer range, and that for the greater part of the year their subsistence would have been based within the piedmont on the other side of the Blue Mountains.

However, to return to the coast. It was suggested in the first chapter of this thesis that upon ecological grounds it would be expected that coastal populations would display a measure of dense-packing in association with the coastal fringe. There is some evidence that this was true within the Sydney region, for the First Fleet sources clearly suggest that in addition to the lack of knowledge of the hinterland displayed by coastal Aborigines (alluded to above), there were clear spatial limitations to their knowledge of the coast. For example, when a Sydney Aborigine offered to guide parties southward from Sydney he did not know the country any further south than Botany Bay and "trusted to the whites to bring him back" (Collins op. cit:369).

Interestingly, there is also considerable evidence of a consistently high degree of aggressive behaviour among the coastal Aborigines which is quite probably a function of the close-packing of these groups. In this regard, it should be noted that because territories are likely to have been small (because of the abundance of high-value patches in the estuaries), the relative costs of expressing territoriality through aggressive rather than ritual behaviour are likely to have been more finely balanced than they are likely to have been in areas wherein territories are large and the patches are more widespread (cf. Cashdan 1983; Peterson 1975). Relatively large-scale fights are described by the First Fleet writers, both between Sydney bands; and between the Sydney bands and the interior bands (for example Tench op. cit:50; Hunter 1968:205; White 1962:167; King in Hunter op.cit:412); and the generality of this aggression is particularly remarked upon by Tench (op.cit:208):

> "The relative weight and importance of the different tribes appeared to be the highest object of their estimation, as each tribe deemed its strength and security to consist wholly in its powers aggregatedly considered".

Hunter (op.cit:62) also remarks in this context: "in the case of any dispute with a neighbouring tribe, they can soon be assembled" and also alludes to the appointing of "war-leaders" (loc.cit.).

This general pattern also appears to have been extended inland, for it is interesting to note that King suggests that inland areas of particular fertility may have been divided between bands in much the same way as it is apparent the coastline was - for he notes of the area between Rose and Prospect Hills (which is underlain by Wianamatta shale and basalt): "although the distance between these two places is only four miles, yet the natives divide it into eight different districts" (Hunter op.cit:403-4). It does not appear to be impossible that this represents the division of islands of fertility in a background of sterility.

Further support for the notion of dense-packing and territoriality upon the coast can be derived from the fact that the Aborigines were generally wary about crossing boundaries between groups. This relationship between territoriality, dense-packing and linear compression upon the coast, is neatly illustrated by an incident at Botany Bay when Governor Phillip fell in with a large armed band (approximately 300 strong):

> "When the natives saw that the English were going forwards towards the next cove, one of them, an old man, made signs that he must be

> allowed to go first. He did so, and as soon as he ascended the hill, called out, holding up both his hands (the usual sign of amity among these people) to signify to the natives in the next cove that those who were advancing were friends" (Phillip op.cit:115).

In summary, then, there is clear support for the existence of two ecological populations within the Sydney region. In addition, the evidence suggests that the coastal population was distributed in territories of small areal extent, compressed into linearity along the coastline; while inland, there is evidence that the population was generally more widely dispersed and less numerous - but also that islands of relatively greater natural fertility may have produced similar behavioural characteristics to those observable upon the coast in relation to high-value resource areas.

9.4.1 The ecological basis of population division

The First Fleet records, in addition to establishing the existence of two distinct populations within the Sydney region, also reveal something of the ecological characteristics upon which the division is likely to have been based. This information takes the form of observations concerning the inland and coastal diet.

The First fleet opinions concerning the differences between the diet of the coastal people and the diet of the hinterland people are unequivocal, and are summarized by Collins thus:

> "Those who live on the sea-coast depend entirely on fish for their sustenance, while the few that dwell in the woods subsist on such animals as they can" (1971:550).

That this division is not just the simplifying construct of a European is clear from the evidence that the Aborigines themselves recognized the same differences. When asked how the people of the interior lived Tench's Aboriginal guides replied that they lived "on birds and animals, having no fish" (Tench op.cit:226).

In either case, of course, the statements do simplify the complexities of the food quest to neat phrases. Fortunately there is a little more information concerning the actual contents of the coastal and inland diet. General dietary observations concerning the coastal Aborigines insist that they lived entirely on fish and "the few fruits they gather and the roots they dig up in the swamps" (Tench op.cit:48; see also Hunter op.cit:65). Indeed comments on food other than fish are rare. Fern root and wild figs are mentioned by Hunter (op. cit:65) and White (op.cit:190) respectively; and the eating of duck is also recorded by White (op.cit:197). In contrast, as has been noted above, the coastal Aboriginal people considered that the diet of the interior consisted principally of birds and animals (Tench op.cit:226). Tench's own opinion was that they depended little on fish (having only mullet), and that their principal support was small animals and roots (Tench op.cit:230).

This evidence from the First Fleet, then, tends to support the behavioural model in two particular respects, for it suggests that the two posited ecological populations were real, and (on the basis of diet) that the essential differences between them were ecological (despite the fact that they appear to have been reinforced through cultural means). However, the sources are capable of telling us much more about these populations and the behavioural components of food acquisition.

9.5 THE BEHAVIOURAL COMPONENTS OF FOOD ACQUISITION

The foraging behaviour observed by the First Fleet writers can be divided into three parts: a) seasonal population movements; b) the division of labour; c) food values: I) the fat hypothesis; II) buffer foods.

9.5.1 Seasonal population movements

Poiner (1971, 1976) has suggested that winter scarcity in foods would have forced the coastal population of the central and south coast of New South Wales to tend toward inland dispersal in this season. As we have seen the disposition of the population and the clear distinction into a coastal and inland population make the second part of this model improbable in the Sydney region. However, Poiner's suggestion of winter scarcity of resources (or in present terms - 'resource depression') influencing population movements is more valuable, though her analysis of the degree of winter scarcity is likely to be in error. Essentially, Poiner based her model upon the reduced availability of estuarine fish and plant foods in winter, remaining apparently unaware of the high likelihood of the winter abundance of marine fish and aggregations of avifauna (a part of the vertebrate fauna which Poiner does not consider).

What then are the features of this winter scarcity and how may it have influenced population movements?

Almost certainly, Poiner owes much of the 'winter scarcity' component of her model to a misinterpretation of the words of the First Fleet. There are indeed a number of comments concerning the winter scarcity of estuarine fish in the record - Phillip, in particular, notes that fish were scarce in the estuary in June, July, August and early September (op.cit:135). However, it is clear that when the information is put back into its context, it is their own lack of success in catching fish which they bemoan in Port Jackson, principally because of their lack of boats - "The scarcity of boats will prevent our being well supplied with fish" (White op.cit:183). At the same time it is equally clear that they admire the facility with which the Aborigines continued to catch fish throughout the winter and throughout the estuaries. This is nowhere better emphasized than in Hunter's writing in June 1793 concerning the possibility of persuading the Aborigines to supply the settlers with fish throughout the winter because they "frequently caught more fish than was necessary for their own immediate use" (op.cit:532). Indeed by the June of 1791, the Aborigines were supplying Parramatta with estuarine mullet and bream throughout the winter (Collins op.cit:165).

Interestingly, it is quite evident that this difference in ability to catch fish was a function of the operation of a superior network of information among the Aborigines. In Chapter Four it was suggested that the establishing of fish patches is difficult because of the cryptic nature and distributional characteristics of the prey. Efficient fishing requires an efficient information network. The settlers of 1788 did not share in this network but they left an impression of its efficiency and, more particularly, evidence of how knowledge of prey characteristics could be used to the fisher's advantage. For example, White notes in July 1788 (op.cit:192):

> "About 10-20 yards from shore, among the long grass, in the shallow water, he struck and took with his fish-gig, several good fish, acquisition of which at this time of the year, it being cold and wet, we were unequal. While he was engaged in watching for them, both he and the woman chewed something which they frequently spit into the water; and which appeared to us, from his immediate striking of fish, to be a lure".

Perhaps a more sophisticated example of the operation of the information network and particularly the knowledge of prey attributes, comes from Bradley who records the Aborigines fishing at night by torchlight in the estuary (1969:141). It is highly probable that the Aborigines were fishing for bream which gather to feed in the early night, much in the manner that their modern counterparts (armed with Gregory's guide) do.

There is, then, little evidence to suggest that estuarine resources where particularly scarce in winter, provided that the forager knew where to look. For this reason, it is suggested that any evident population movements in winter are likely to have been related, not to winter scarcity of estuarine fish resources but to the recognition of new higher-value patches within the environment, which required a locational shift.

If we return to the First Fleet sources we can identify some of the probable high-value patches which would have brought about this locational shift upon the coast in winter[3]. Witness the following quotations:

1. April 1788 at Broken Bay. "On freshwater streams and on salt, we saw a great many ducks and teal" (White op.cit:149). (The same comment was made for Port Jackson (White op.cit:154).)

2. Winter 1788. "A shoal of fish appeared on the coast which extended as far as the eye could reach" (Hunter op.cit:466-7).

3. June 1788. "(we) fished with great success in Pittwater (Broken Bay) for mullet". "vast quantities" were caught (Hunter op.cit:142).

4. August 1788. Botany Bay - "Fish can be caught in all sandy bays" (Hunter op.cit:159).

Although these descriptions are not conclusive, they are certainly suggestive of the presence of potential high-value patches within wetlands, at the mouths of estuaries and upon the coast. In addition, they do not tend to support the notion of winter resource scarcity.

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[3] There is comparatively little information concerning the inland distribution of possible high-value patches in the inland areas in winter - though Tench does refer to "vast flocks of wild duck" upon the Hawkesbury-Nepean in the July of 1788 (op.cit:154).

In fact, there is a completely independent line of argument against the notion of general winter scarcity of resources posited by Poiner, which revolves around the observed activities of the Aborigines during this season. These data also serve the purpose of casting doubt upon Poiner's winter dispersion model. These winter Aboriginal activities may be divided into three groups, <u>viz.</u> conflict, gatherings and maintenance activities.

1. <u>Conflict</u>. Conflict situations occur for a number of reasons, one of the most important of which is the protection of resources for exclusive utilization (i.e. territoriality). Large-scale conflict situations entail the aggregation of people which - among people with no storage technology - requires that there is sufficient food in a spatially circumscribed locality; and also implies sufficient time away from the food quest in order to aggregate (and dispute). Poiner would allow the people of the central and south coast of New South Wales neither of these in winter. Yet large-scale disputes are recorded around Sydney in winter which appear to have involved up to 200-300 men, women and children. The following observations reinforce this point:

   i) In May 1788, Bradley (op.cit:112) reports a large party of Aborigines (about 300, including women and children) in Botany Bay - all males were armed for fighting - another large party was beyond.

   ii) In July 1788, there was a large conflict in Port Jackson involving two hundred Aborigines (White op.cit:207).

iii) In August 1788 White mentions another large conflict between Aboriginal groups in Port Jackson.

iv) In September 1788, "a considerable number of natives" met to fight (Hunter op.cit:205).

These conflicts took place a) within the small area between Port Jackson and Botany Bay in the same year; b) (more importantly) in the same winter; and c) in the estuarine environment. They surely neither lend credence to the notion of winter scarcity or of dispersion.

2. <u>Gatherings</u>. There is at least some evidence that winter was sometimes a period for even larger peaceful gatherings. In August 1791, large numbers of Aboriginal people started to pass through Port Jackson. These were "strange men and women, who had not visited Sydney before ..... going to a dance at Broken Bay" (Hunter op.cit:542).

Aggregations of this kind within the Australian context, were normally features of periods of great ecological abundance (for example see Flood 1980). Certainly this form of aggregation, which included populations from afar - from the south and from the hinterland - is unlikely to have taken place during a period of great ecological stress.

Other winter gatherings, though on a smaller scale, belie the notion of dispersion into the hinterland. In particular, the gatherings noted by a number of writers associated with the beaching of whales in the winter of 1788 (Phillip op.cit:132; Bradley op. cit:120 (19th August); Hunter op.cit:205 (September 7th)). These gathering were of hundreds; Tench (op.cit:176), for example, describes an occasion when over two hundred were gathered together "broiling flesh and feasting on it".

3. <u>Maintenance</u> <u>activities</u>. After noting that there had been a reduction in the number of Aborigines within Port Jackson in July 1788; Governor Phillip, unlike subsequent researchers, emphasizes that not much meaning can be attached to the fact because:

> "..... it was the season in which they make their new canoes and large parties were known to be in the woods for this purpose" (op.cit:134).

It is clear that winter was the principal period of maintenance activity within the Sydney area. Time spent upon maintenance activities must surely conflict with time available for subsistence activity in a population which has been viewed as being under severe stress. Witness the following comment by White (August 14th 1788):

> "(We saw) ..... fourteen natives returning from the woods, where they had been cutting bark either for their canoes or huts, and had with them no other instruments other than those necessary for the business on which they were engaged, such as a stone hatchet and the shell stick" (op. cit:196; the shell

> stick is the spear-thrower, with a shell mounted in the distal end, which was used for trimming wood in much the same manner as stone was used elsewhere).

and at Manly Cove in August 1788:

> "A body of men came out of the woods with a new canoe made of cork (sic), also new paddles, spears and fish gigs."

Overall, then, the evidence suggests that during the period of greatest resource depression within the year, there was sufficient time for a variety of activities which must surely have conflicted with foraging behaviour if the population was under severe food shortages.

9.5.2 The winter disposition of people

The evidence of the First Fleet writers suggests that the population was not, necessarily, under great ecological stress in winter, yet the Aborigines did redistribute themselves during the winter period. The First Fleet writers supply a small amount of information about these movements which can be compared with the behavioural model.

There is no evidence in the First Fleet sources to suggest that there was a movement of the coastal population into the hinterland (cf. Poiner op.cit.). Hunter (op.cit:65) specifically says of the decrease in numbers observed in Port Jackson:

> ".... but still very few are found inland, there is no reason to believe they retire back into the interior."

The final nail in the coffin of this notion comes from White, who actually went inland from the coast in April 1788 and climbed onto the Hornsby Plateau:

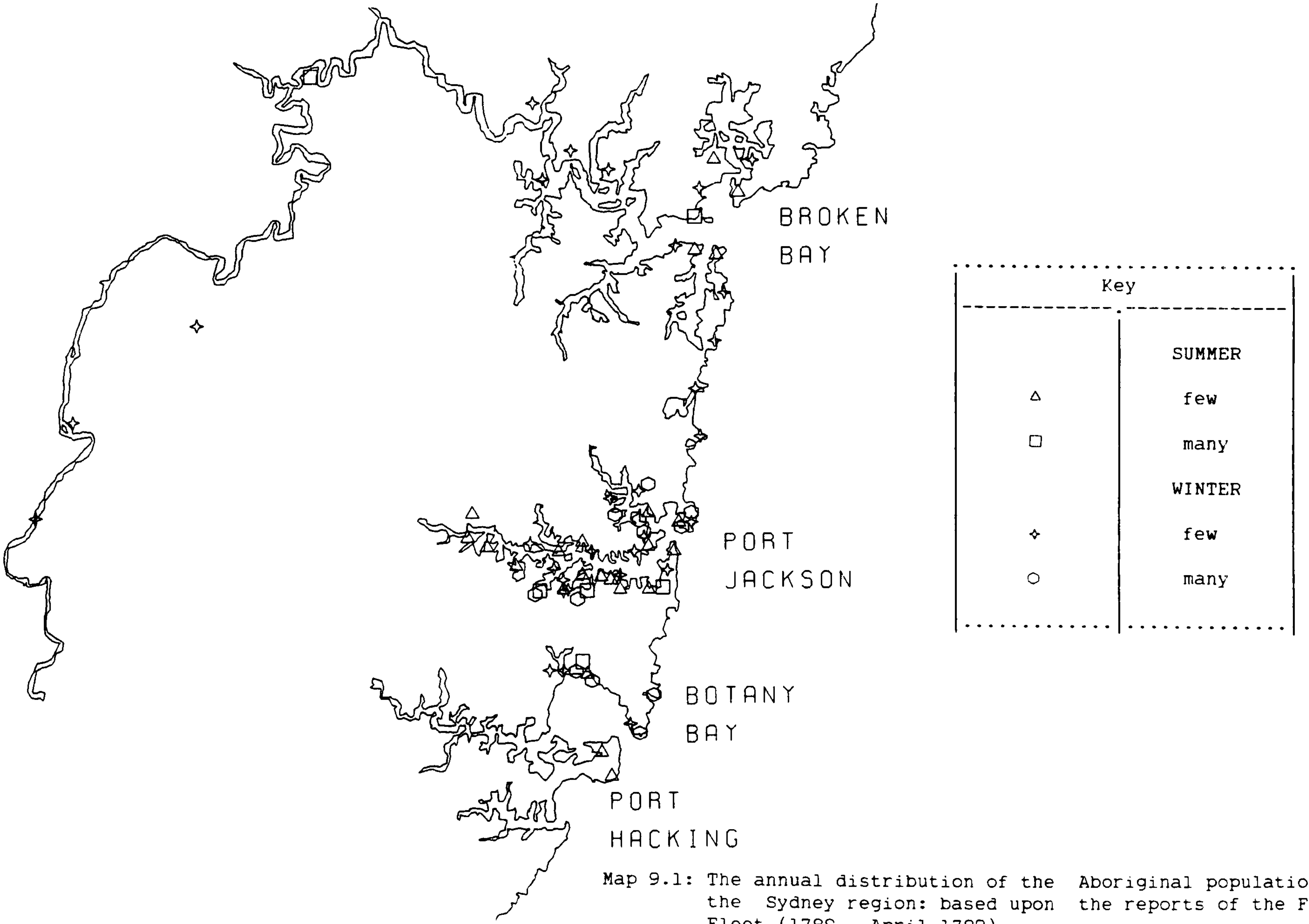
> "(The party proceeded) many miles inland, without being able to trace by a single vestige, that the natives had been recently in these parts. We saw however, some proofs of their ingenuity, in various figures cut on the smooth surface of the stone ..... the country all around was high and rocky and the soil - sand, parched and inhospitable." (White op.cit:141).

In fact, it is clear that many Aborigines remained in the immediate vicinity of the estuaries. These groups were of sufficient size that in June 1788 it was declared that: "No party under six armed men was to go into the woods on account of the natives being so numerous" (Bradley op.cit:112; see also White op.cit:187).

Indeed, the sightings of large groups of people in the estuaries in winter are impressive (see Map 9.1; see also Ross 1976). Apart for the aggregations mentioned above, a number of other large groups were seen in the winter of 1788:

1. Hunter reports "considerable numbers" of people on the lower Hawkesbury in July 1788 (op.cit:148).

2. In August 1788, White saw about 90 people at Manly Cove (op.cit:197) and a large party in Broken Bay (op.cit:199).



Map 9.1: The annual distribution of the Aboriginal population of the Sydney region: based upon the reports of the First Fleet (1788 - April 1789).

3. In July 1788, a party of over 20 men took fish by force from settlers while "a much greater party stood nearby" (Phillip op.cit:132).

4. On August 17th, Phillip ordered a census taken within Port Jackson (it should be noted that by this time the Aborigines were avoiding the settlers) and found 67 canoes, 94 men, 34 women and 9 children. As has been noted above, Phillip was not much impressed with this statistic for he was aware of the large numbers of largely invisible groups engaged in maintenance activities in the woods.

While it is clear that large numbers of the Aboriginal population continued to occupy the estuarine fringe throughout the winter, there is clear evidence of a tendency toward dispersion onto the coastline which is commensurate with the distribution of changes in high-value patch location. Hunter (op. cit:65), for example, was of the opinion that most of the population went north (i.e. following the coast) in winter; while Bradley was even more specific: "natives and fish incline northwards in winter" (op.cit:125 (Oct 1st 1788); see also Worgan op.cit:39). Circumstantial evidence suggests that these generalizations were not without foundation. For example, owing to the nature of the flora with its overwhelming shrub understorey, it was the practice of the members of the First Fleet to follow the 'native paths' through the bush. Their notes concerning the direction and condition of the paths gives a good indication of the directions of Aboriginal movement during the winter on the coast[4]:

1. Hunter, travelling from Port Jackson to Broken Bay in June 1788, fell in with "well trodden native paths running along the coast" (op.cit:137-8).

2. In July, 1788 Bradley followed a "good native path along the coast to Botany Bay" (Bradley op.cit:116; 8th July).

These paths clearly indicate a) the coastal orientation of the population; and b) the constant movement of the population upon the marine border in winter; or as Phillip says:

> "From the beaten paths that are seen between Port Jackson and Broken Bay and in other parts, it is thought that the natives frequently change their situation" (Phillip 1982:136).

On the basis of comments like the one above, Poiner has suggested that the population of the central coast was 'nomadic' in the winter (1976; she suggests that the summer population was 'semi-sedentary' based upon the evidence of 'villages' at Botany Bay (Tench op.cit:52, 210) which appear to have been more or less permanently occupied (though not necessarily by the same people) continuously during the summer).

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[4] Again, there is little information about the behaviour of the inland population. However, Hunter's description of a path running along the banks of the Hawkesbury, which was shown to them by an old man after he had seen the Europeans struggling through the vegetation, tends to indicate the winter importance of the river (Hunter op.cit:520).

On the whole, The term 'nomadic' is unhelpful, for it is clear that the population was not nomadic in the sense of their free-ranging over large territories. The evidence suggests that this winter 'nomadism' was of a very specific nature. Concerning the disposition of the Aborigines upon the marine fringe, White writes:

> "All along the shore we met the natives, who seemed to have no fixed residence or abode; but indiscriminately when they met with a hut, or what is more common, a convenient hole in the rock take possession of it for a time" (White op.cit:199).

While Worgan notes that upon the coast in winter:

> "It does not appear that the poor creatures have any fixed habitation, sometimes sleeping in a cavern of a rock, which they make as warm as an oven by lighting a fire in the middle of it. They will take up their abode here, for one night, perhaps, then in another the next night ...... indeed it seems pretty evident that their habitations, whether caverns or wigwams are common to all, and alternately inhabited by different tribes (Worgan 1979:15-16).

Both these authors describe a pattern of movement along the coast using fixed points as habitations. The image which this (and the distribution of native paths) suggests is one of constant movement along the shoreline and back again. It is suggested that, given the time of year, it is likely that the Aboriginal population upon the marine fringe were tracking the movements of inshore fish shoals. Some evidence that this was indeed the case is provided by Hunter's observation in June 1788 of women fishing on the coast (op.cit:137); while Worgan noted that the people took their canoes "..... up and down the coast, keeping as close to the rocks as possible" (op.cit:16).

The probable characteristics of this part of Aboriginal winter movements, then, are not really nomadic, for it is evident that the movement had a pattern based upon tracking up and down the coast using fixed points as resting places. The likelihood that migratory fish were the high-value patch to which the Aborigines were responding is poignantly suggested by Hunter's observations during a period of bad weather in July 1788 - the people he saw upon the coast were miserable and hungry in their rock shelters as they waited for moderate weather on the sea coast so that they could fish (op.cit:80). (It should be noted that this observation is also suggestive of the general bankruptcy of the Hawkesbury sandstone coastline in terms of other high-value patches.)

Two further pieces of locational information from the First Fleet records suggest the association between Aboriginal movements and the location of high-value patches. Firstly, in autumn the coastal Aborigines retired from the estuarine fringe to the wetlands and lagoons in order to fish for eels (Collins op.cit:72). This movement is wholly consistent with the provisions of the behavioural model which suggests that these highly nutritious resources should have been discerned as a very high-ranking patch during the period in which they aggregate, but not at other times. Secondly, early in spring the Aborigines reassembled in the estuaries as the fish returned ("In the course of the last month (September), the natives appear to be very numerous and the fish in great quantities" (Bradley op.cit:125)). This movement is again wholly consistent with expectations based upon optimality principles, for as 1) unearned resources upon the coast; and 2) waterfowl patches in the wetlands; began to fail to be discerned as patches; and there was a concurrent rise in the recognition of estuarine fish patches - the attention of the efficient predator should have switched to the estuaries.

Overall, then, the evidence from the First Fleet writers undoubtedly supports the features of the behavioural model of coastal population movements based upon the ecology of the area. However, it is readily apparent that there are two major discrepancies within these sources. Firstly, there is very little information available concerning the relationships between inland Aborigines and the distribution of high-value patches. The small amount of information which does exist is completely compatible with the behavioural model, however. The emphasis of Aboriginal location during winter and early spring (the likely periods of the greatest ecological stress) is clearly associated with the river margins (Hunter op.cit:520, 150), which are likely to have been associated with high-value patches (such as avifauna - Tench records "vast flocks" upon the Hawkesbury in July 1788 (op.cit:154)) and with buffer foods (see below). The other anomaly within the texts is that there is no clear association between Aboriginal activity and the winter/spring distribution of waterfowl which is a principal component of the behavioural model.

This discrepancy perhaps highlights the dangers of using ethnohistorical data as a basis of modelling, for it is possibly because of the lack of explicit association that Poiner failed to consider waterfowl. Or is it that the ecological model is deficient, the presence of so great a number of waterfowl is a modern phenomenon that cannot be extended into the past?

Fortunately, the First Fleet writers firmly establish that the ecological model is correct. White (op.cit:8) speaks of "great numbers" of waterbirds; Tench (op.cit: 154) of "vast flocks" both on the coast and on the Hawkesbury river; Hunter mentions black swans in the "lagoons and swamps" (op.cit:71); while White describes them upon small salt-lagoons (op.cit:137) and also mentions the many duck and teal in Port Jackson and Broken Bay (op.cit:154).

Yet, while, as Bradley put it "there is no doubt that they lay in wait for birds and animals" (op.cit:166. 30th June), actual associations between the Aborigines and the waterbirds are hard to glean from the record. Yet there are many hints which suggest that these high-value resources were an influence upon Aboriginal decisions. This circumstantial evidence concerning the importance of waterfowl is summarized below:

1. There is only one description of an Aborigine actually eating a duck which he had caught himself (birds were often shot and given to the Aborigines). White describes how a party came upon an old man "with a very fine duck", near a lagoon between Port Jackson and Broken Bay (op. cit:197), but Tench describes the methods in which birds were cooked which possibly indicates a frequent observation (op.cit:288).

2. That some Aboriginal activity may have been associated with (at least)

the nesting sites of waterfowl is suggested by Tench's (op.cit:272) comment that the Aborigines were "ravenously fond of eggs".

3. There is some indication that waterfowl were held in some esteem in the fact that one of the reasons why Colbee and Ballederry accompanied Phillip eastward from Sydney on an expedition to the Hawkesbury-Nepean was that they thought that the Europeans wanted to kill ducks (Hunter op.cit:519).

4. Most tenuous of all, is the story of an occasion when the settlers took a Sydney Aborigine to Norfolk Island. When his friends enquired after him, on being told that he had gone "to a place which afforded plenty of birds ..... innumerable volunteers presented themselves to follow him" (Tench op.cit:218-219). The form of the reply to the question, no less than the reaction it received, is surely indicative of the fact that the writers have missed something from their account.

In fact, the explanation of the lack of mention of an explicit association between the Aborigines and waterfowl may be a simple one. It has already been mentioned that during the winter large numbers of Aborigines were known to be in the woods; but their activities were not under the scrutiny of the First Fleet observers. The locations of large numbers of people between Port Jackson and Botany Bay, and at the head of the estuary are consistent with the distribution of major wetland areas (most of the centre of Sydney is built upon the extensive swamplands associated with the valley and tributaries of the Tank Stream). It is conceivable, that waterfowl populations supported the maintenance activities, the conflicts between large groups (both of which were broadly associated with the same areas of wetlands) and perhaps may have supported even larger gatherings.

9.5.3 The division of labour

While the case of the Aborigines and the waterfowl may warn us of the dangers of too much reliance upon historical data; the detailed observations of aspects of real behaviour should warn us about too much reliance upon ecological theory when dealing with man. For example, optimal foraging theory (like most biological theory) assumes that all individuals within a group behave in broadly the same way in relation to a given stimulus (though, of course, differences in the efficiences of individual's responses are the basis of these theories). In some respects this assumption cannot easily be carried over into the consideration of human populations - particularly, because of the frequent occurrence in the species of a division of labour between the sexes. Indeed, even when both sexes are engaged upon the same activity there may be fundamental differences in extractive efficiency because of differences in technological usage. For example, in the Sydney region, a clear division is reported by the First Fleet writers associated with fishing and is based upon the equipment used - women fished with hook and line: men fished with spears.

Interestingly, it is evident that women spent a large part of their time fishing from canoes both in summer and in winter (Worgan 1788:10; Bradley op.cit:108; Hunter op.cit:63; Collins op.cit:556). Clearly this activity is likely to have been undertaken at the expense of gathering vegetable foods, in fact, the only explicit mention of gathering vegetable foods concerns men not women (Bradley op.cit: 110, 117) (This may simply be a case of male-orientated bias, but women were constantly observed in other subsistence activities). While in other hunter-gatherer populations women's foraging activity is associated with the gathering of vegetable materials, it is clear that among the coastal Sydney region Aborigines the principal contribution toward the diet, made by women, was in the form of fish.

In fact this attribute is wholly consistent with the ecological characteristics of the region and with optimal behaviour, because in the shrub-dominated coastal environment, edible vegetation and edible fauna are at a minimum because of the dominance of nutrient-poor Hawkesbury sandstone and the tendency toward xeromorphy associated with coastal proximity. As a consequence of these factors, fishing is the only possible strategy for the main part of the year - fish protein replaces vegetable carbohydrate. (Note that the energy yield of proteins and carbohydrates are more or less the same - 17kJ/g protein versus 16kJ/g carbohydrate.)

As both men and women fished during the summer, the division of labour upon the coast only really became evident during the winter. For during this period, the First Fleet writers suggest that men left the shores to concentrate particularly upon small mammals (and birds?) (Hunter op.cit:469). In fact, a similar pattern is evident in the hinterland, the available ethnohistorical evidence suggests that during this period while men hunted birds and animals, women fished and caught large mullet in the river (Hunter op.cit:523).

In both areas, then, women appear to have continued to fish throughout the year, while men concentrated upon hunting during the winter months. The ways in which this behaviour would be optimal in the environment of the Sydney region are largely self-evident. Although fish density tends to be generally lower in winter they still represent an important resource with regard to nutritional value and the provision of essential nutrients. Yet, during the same period the limited populations of small mammals would be likely to rise in the patch-ranking because of the increased lipid content associated with at least some species. In addition, vast flocks of waterbirds in both the interior and coast would be likely to be highly-ranked. Yet both these patch types are associated with elements of risk (associated with possible large search times) because both resources are distributed over planar areas (in comparison to the linear distributions of fish upon the estuarine, marine and riverine fringes).

In essence, then, it appears that women were responsible for obtaining the more dependable (medium-ranked) food. Owing to the nature of the environment and the low availability and nutritional complications associated with vegetable resources, this appears to have been fish (though some vegetable resources may have serve as 'buffer foods' which were even more dependable but possessed a lower nutritional value than fish, see below).

In contrast, the orientation of male activity toward foods with a large or increased fat content in winter may be seen as an adaptation related to an increase in the efficient utilization of protein sources during one of the few times of the year when this can be efficiently achieved because of the aggregation of fatty resources (particularly waterfowl).

9.5.4 The First Fleet and food values

One of the principal assumptions upon which the behavioural model was based was the direct and indirect influence of nutrient deficiencies within the Sydney region. Largely due to the high degree of sclerophylly associated with the vegetation, the faunal population is likely to have been low density; and as a consequence of this, and the high level of toxicity in the flora, the optimal forager must have relied heavily upon fish protein. As has been indicated above this appears to have been very largely the case. However, there is a high likelihood that the use of fish protein would have brought other nutritional factors into play. Of course, the First Fleet writers did not directly describe such relationships, yet there is sufficient evidence in the texts to indicate that the nutritional assumptions based upon ecological theory and data did possess a validity in the real world of the Sydney Aborigines. This evidence can be divided int two groups: 1) evidence in support of the fat hypothesis; and 2) evidence concerning the use of 'buffer foods'.

9.5.5 The First Fleet and evidence in support of the fat hypothesis

It was suggested in Chapter Four that lipid availability may have been a very important factor in the Sydney Aboriginal diet, particularly because of its great energetic potential (37kJ/g) and its effect upon the efficiency of protein absorption. The First Fleet texts make it plain that lipids were in short supply within the Sydney region. For example, concerning the presence of fat in the native fauna, the observers where quick to note the low nutritional value of kangaroo meat:

> "Here, where no other animal nourishment is to be procured, the kangaroo is considered a dainty; but in any other country, I am sure that such food would be thrown to the dogs, for it has little or no fat about it, and when skinned, the flesh has some likeness to that of a fox or lean dog" (White op.cit:183-4; see also Phillip op.cit:105).

There is some evidence which suggests that the influence of this lack of lipid and the high fish protein diet did bring about some degree of protein starvation in the Aboriginal population. The Aborigines clearly displayed at least one of the symptoms of this nutritional complication in the amount of fish that they ate, which presumably reflects the inefficiency of their absorption of protein:

> "The quantity of fish they eat is beyond everything incredible. Twelve pounds of fish does but little towards satisfying them for one meal" (Bradley op.cit:183; see also Tench op.cit:211).

However, A more direct line of evidence in support of the operation of fat limitations, lies in the observed Aboriginal preference for certain foods and their behaviour in relation to those foods. Witness the following observations:

1. "The tail of the kangaroo is accounted the most delicious part" (Tench op.cit:268).

2. The Aborigines "are ravenously fond of eggs" (op.cit: 272).

3. "They esteem lizards and iguana" (op.cit:273).

4. "(Bats) are very fat and are reckoned by the natives excellent food" (Hunter op.cit:507. (Bats, and particularly flying-foxes, may sometimes have been a resource of great value - on a particular occasion (related to drought) Hunter records a camp of 20000 foxes around Rose Hill (Loc.cit. February 1791).)

5. In April 1788 Collins noted that the Aborigines congregated at the lagoons "where they subsist on eels" (op.cit:72).

In each of these examples, whether the reference is explicit or not, a case can be made for fat content being the attractant. The case is in fact most clearly supported in the First Fleet notes concerning Aboriginal behaviour and beached whales. For example, Tench writes:

> "Over two hundred were gathered at the coast in winter "broiling flesh and feasting on it with the most extravagant marks of greediness and rapture" (Tench op.cit:176).

Tench, ever perceptive, also notes the way in which the Aborigines prepared there food, and his writings indicate that also at this level lipids were treated with reverence, he notes:

> Fish were not gutted after being caught, but were thrown onto the fire and the scales rubbed off ..... "Now and not before they gut it, but if the fish be mullet, or any other which has a fatty substance about the intestines, they carefully guard that part, and esteem it as a delicacy. A bird, a lizard or a rat they treat in the same way" (Tench op.cit:288; see also Worgan op.cit:16-17).

In addition, Hunter (op.cit:80) and Bradley (op.cit:110) also note that all parts of birds (including bones but excluding head and feet) were eaten. The eating of bones after crushing has a number of attractions in that it provides a source of lipid, but also of phosphorus (which is likely also to have been particularly important) and calcium stored in the marrow. (Note in passing that eating bones would also leave little to posterity!)

Overall, then, there is good evidence to suggest that fat distribution was an important nutritional influence within the Sydney region. Yet, it is interesting to note that the clearest evidence which suggests the vital necessity of increasing the efficiency of protein absorption, is in fact related to the limited vegetational resources within the region (both carbohydrate and lipid may act upon protein in this way). Dietary carbohydrate in the Sydney region was in short supply because of the prevalence of toxins and inedible compounds. Hence it is all the more likely that the reliance upon fish-protein did bring about major nutritional complications within the Sydney population because of the observations of the First Fleet concerning the association between fern-root (a source of carbohydrate but also of a bitter-tasting toxic tannin) and fish:

> "We have observed that they chew a fern-root at the time they are eating the fish, but this they spit out having chewed it with six or eight morsels of fish."

9.5.6 Evidence for buffer foods

Protein is almost always a mobile component within an environment. As a consequence of this source of unpredictability, as any modern hunter or fisher will avow, there are days when nothing can be caught. For the most part in the Sydney region, because of the general lack of edible primary production, there are few alternative medium-value patches, which would rise up the ranks to take the place of those higher, depressed ones. The efficient forager therefore must fall back upon emergency 'buffer foods', such as shellfish in the estuaries and on the coast; and discrete and abundant roots within the hinterland (and also upon the coast and estuaries).

Neither of these two group of food is wholly satisfactory from a nutritional standpoint: the one because of its low calorific content; the other because of the lack of available carbohydrate and/or the high level of toxins - but either will serve in an emergency.

Most of the foods described in the First Fleet records clearly are 'buffer foods' in this sense. Those identifiable are: shellfish; fern root (_Blechnum_) or _Pteridium_ spp.); and the yam-daisy (_Microseris scapigera_):

1. _Shellfish_.

> "(There are vast quantities of oyster and other shells in the harbour, and oysters of amazing size in the uppermost creeks" (Bradley op.cit:133).
>
> "Oysters, cockles and muscles (sic) are to be got with little trouble" (Worgan op.cit:22).

The few direct references to Aboriginal use of shellfish in the First Fleet observations, suggest that their collection was not seasonal (for example, February 3rd 1788 and June 25th 1788 (Bradley op.cit:75,115). Interestingly, in all observations it was men who were seen collecting them, though this may be an example of male observational bias.

2. _Fernroot_.

Fernroot was clearly used principally as an emergency food (Bradley op. cit:107; Phillip op.cit:135), though the use of it as a food adjunct was also observed (see above).

In the hinterland there is evidence that insects were added to a paste made from fernroot (Collins op.cit:558) - perhaps this represents a method of balancing fat, protein and carbohydrate intakes, and particularly maximizing the absorption of protein.

3. Yam-daisy.

The association between Aboriginal behaviour and the yam-daisy was observed by a number of writers upon the banks of the Hawkesbury river in winter. Hunter gives the following account:

> The low (river) bank appears to have been ploughed up....(we) found wild yams in considerable quantities, but in general very small. They appear to be in great plenty on the banks of this river (Hawkesbury), a little way back they are scarce" (Hunter op.cit:150).

The association between the use of these roots and winter in the hinterlands is certainly suggestive of their role as 'buffer foods'.

By now it should come as no surprise to the reader that it is Tench who puts the role of these foods in perspective:

> "When prevented by tempestuous weather or any other cause from fishing, these people suffer severely. They have no recourse but to pick up shellfish, which may happen to cling to rocks, and be cast on the beach; to hunt particular reptiles and small animals, which are scarce; to dig fern root in the swamps; or to gather a

> few berries, destitute of flavour and nutrition, which the woods afford. To alleviate the sensation of hunger, they tie a ligature tightly around the belly, as I have often seen our soldiers do from the same cause" (Tench op.cit:287).

9.6 THE ABORIGINES AND THE ARCHAEOLOGICAL RECORD

To end this chapter, a few points can be made concerning the nature of the archaeological record in the Sydney region. In Chapter Six the influence of Aboriginal technology upon the archaeological record has, of necessity, already been described using the First fleet texts. Yet the early sources also supply a small amount of information concerning the differences between open and shelter sites:

Shelters

> "They made use of excavations in the rock, and as the situations of these were various, they could always choose them out of the reach of wind and rain" (Collins op.cit:555).

In the view of the First Fleet writers, shelters were primarily used in order to shelter from the wind and rain (which would tend to explain why so many of them tend to face away from the south-east). Hunter (op.cit:134) says that they were used to shelter whole families in bad weather, and he particularly remarks upon their use in winter along the coast.

Open sites

> Bark huts were used by "..... those employed in hunting the

> kangaroo oppossums (sic), or in short any other animals which are to be found in the woods" (Hunter op.cit:60).

Extensive use was made of bark huts both inland and on the coast - in particular, they were seen along the Hawkesbury during the winter of 1788 (Tench op.cit:227 and map). These inland huts were evidently used as habitation and hunting blinds (Hunter op.cit:516). Bark huts were also seen along the coast in winter (Hunter op.cit:137) and in the estuaries (White op.cit:199). Collins (op.cit:555) notes that the huts inland were for individual use while those on the coast could cover six to eight people. At Botany Bay Tench describes two villages in the summer of 1788 with more than a dozen huts "and five times that many people". (op.cit:52, 210).

There is evidence, then, in the comments of the First Fleet, which supports the assumptions about the relationships between open and shelter sites that have been part of the basis of this thesis. For it is clear that open sites are indeed likely to have been more closely associated with the food-quest than shelter sites. One of the primary attractions of shelters was, unsurprisingly, shelter - a factor which is likely to have deflected the degree of association with high-value patches to a greater degree than is likely to have been the case concerning open sites.

9.7 THE VALUE OF THE FIRST FLEET SOURCES

The value of the early accounts of the behaviour of Aborigines in the Sydney region lies (as does the value of most ethnohistory) in its ability to lend corroborative support to proofs of hypotheses derived from outside such data - not as sources of hypotheses themselves.

In this thesis the hypotheses have been formed using ecological principles and data, and have been tested through the use of the concrete remnants of human behaviour. The evidence of the First Fleet supports the behavioural model to a very large degree. In particular, the reports clearly support the division of the Sydney area Aborigines into two ecological populations (one inland and one coastal) and adds flesh to the theory by suggesting that the ways in which the boundary between the two was maintained was through cultural differences and consequent mutual suspicion and conflict. These processes also seem to have maintained the boundaries of the closely-packed and densely-populated coastal territories, which are clearly present - as the ecological theory predicts.

However, there are details within the model upon which the ethnohistorical sources are silent. In particular, while it is comparatively easy to reconstruct the 'process of the year' upon the coast; the First Fleet sources tell us almost nothing about occurrences inland - other than that the population tended to be concentrated along the Hawkesbury-Nepean in winter (which, incidentally, supports the model).

This is solely because the First Fleet writers had not visited the interior in any other season and it says a great deal about the usefulness of ethnohistorical information as a source of behavioural hypotheses, that Poiner (1971, 1976) was apparently misled by this hiatus into proposing a tendency for the coastal population to move inland during winter, in the face of the unequivocal evidence against such a movement, in the very same sources.

Another apparent discrepancy between the ecological model and the First Fleet writers has led to the close scrutiny of the documents and an apparent resolution. Within the behavioural model an important place is set aside for the role of waterfowl upon the coast and in the hinterland in winter and early spring; yet the First Fleet maintain an almost complete silence about any connection between Aboriginal behaviour and these potential resources. Yet there is, in fact, enough evidence concerning the Aboriginal association with waterfowl to be gleaned (without clutching at straws!) to indicate something approaching support for this aspect of the model. The facts appear to indicate that such activities may not have been emphasized by the First Fleet writers because the activities were hidden to a much greater extent than others - such as fishing - which occupied so much of the rest of the Aborigines' year.

However, the ethnohistorical sources also illuminate aspects of real behaviour which the model could not reveal because it is the product of ecological principles and studies of animal behaviour. These aspects are:

1. The division of labour. For the greater part of the year it is clear that, particularly upon the coast, both sexes were involved in the extraction of high-ranking fish resources and therefore are likely to have conformed to a large degree with the patterns suggested in the behavioural model (which assumes that all individuals within a species try to acquire high-ranking food resources in as efficient manner as possible). In the winter, however, there was a more apparent divergence in the behaviour of the two sexes - women acquired medium and low-ranking resources; while men sought higher-ranking prey.

2. The information network. Though it was assumed that in order to exploit resources such as fish shoals and beached whales, the information network would have to be efficient, the ethnohistorical record clearly illuminates both the sophistication of this network and, in particular, the great knowledge of prey attributes (cf. Foley 1983).

Finally, the limited amount of information concerning the usage of sites reveals another broad characteristic of Aboriginal behaviour which could not be accounted for directly in the behavioural model. While open sites appear to have been closely associated with the food-quest, it is apparent that one of the major influences upon the use of rock shelters was not related to the food-quest, but was related to comfort. Yet despite this fact, there is little reason to suppose that the degree of deflexion between Aboriginal behaviour related to shelters and the acquisition of food was great. The First Fleet sources offer us some support for this suggestion - for it is clear from these observations that shelter sites were principally used in winter (Hunter op.cit:134); and in this season (on the basis of the behavioural model) the efficient forager should have displayed a tendency to be located along the coast in order to take advantage of the high-value unearned patches which could be discerned at this time. It is hoped that the reader remembers the results of the factor analysis of shelter sites within the coastal sub-regions and the remarkable superiority of coastal over estuarine proximity and the close association of winter climatic variables. It is suggested that this small indication of the verity of the results of the analysis used in this thesis contributes to the suggestion of the greater validity and utility of the ecological techniques and theory which are its basis.

10 CHAPTER TEN:

CONCLUSION

The aims of this thesis have been to demonstrate the value of optimality principles derived from evolutionary ecology in the study of man's interaction with the environment; and coincidentally to illustrate aspects of the behavioural ecology of the Sydney region Aborigines - an extinct hunter-gatherer group. Aboriginal decisions have been shown to conform to a remarkable degree with expectations based upon optimality principles and ecological data. In this chapter the value and limitations of these results is discussed in relation to archaeology, Aboriginal studies and evolutionary theory.

10.1 ARCHAEOLOGY AND OPTIMALITY

In the main, it is impossible to distinguish adaptive, neutral or maladaptive behaviour within the archaeological record. We may only detect the material remnant of an individual act or, more often, a palimpsest of individual acts at a circumscribed locus - the site. The behavioural strategy within which these acts are based remains a 'black box' (Clarke 1968). Largely because of these intractable problems and the lack of a suitable theoretical base it has been broadly assumed within both archaeology and anthropology that all behaviour is adaptive to some degree - one must only observe the behaviour and find the need which it fulfils.

Optimality theory, while it can not aid the detection of neutral or maladaptive behaviour in the archaeological context, can be used to examine distinguishable sub-sets of behaviour for evidence of adaptation (the process of more closely fitting the environment), provided that the environmental context is sufficiently (and independently) known. The Aboriginal site data from the Sydney region provides an exceptionally good basis for this kind of examination, because there is a clear and readily apparent dichotomy in site types which is interpretable as representing two alternative behaviours. Of these, it has been assumed that archaeological sites are most likely to represent behaviour which would have influenced the Darwinian fitness of the Aboriginal population; while art sites represent behaviour of unknown adaptive significance. (It should be stressed again that this does not suggest that creative behaviour is either maladaptive or neutral with regard to adaptation; the division is one of degree - 'Function' characteristics are likely to display less variation with regard to ecological variability than 'Style' characteristics.)

The principal value of this approach to archaeology lies in its independence of the tyranny of the ethnographic record (Wobst 1978). In addition, because the approach is concerned with regional patterns of location within a heterogeneous environment, evidence of human behavioural patterns is accessible even in those areas were taphonomic processes have eliminated internal data concerning food acquisition. Yet, in the end, it is taphonomic processes which limit the value of the technique for archaeology. For the approach is not likely to be of <u>practical</u> use to archaeologists (nor was it intended to be - our principal interests are evolutionary not archaeological) owing to the requirement of archaeological data which is very recent, contemporaneous and well-known over a regional distribution.

10.2 EXTINCT ABORIGINES AND ADAPTATION

Studies of the relationships between extant Aboriginal groups and their environment have made a major contribution to our understanding of the hunter-gatherer way of life. Indeed, it is largely because of these analyses (and those concerning the South African San) that the hunter-gatherer is now viewed as an adapting element of the environment rather than an unchanging one. This thesis represents a contribution toward the continuation of these developments.

The modern study of Aboriginal adaptations has (of necessity) been limited to desert and tropical coast localities, and many of the results have been broadly assumed to possess a pan-Australian relevance by researchers dealing with extinct groups in other environments. This study suggests that such reliance is likely to be misguided and serves mainly to obscure the subtleties of Aboriginal adaptation. O'Connell and Hawkes (1981) clearly recognized this in their proposals (based upon optimal foraging theory) concerning the colonization of Australia - Bowdler's (1977) 'coastal pre-adaptation' has given way to an emphasis upon high-value patches. This thesis follows this beginning.

Those researchers who have tried not to rely upon northern ethnography, have relied upon ethnohistory, and there is no doubt that such techniques can illuminate aspects of Aboriginal adaptations (as the development of studies in the New England region clearly indicates (see Chapter One)). Yet such material is seldom accurate enough for the analysis of adaptation and, indeed, may mislead both through the absence of material (as in the case of information concerning waterfowl in the present case) and simply through misunderstandings (as in the case of the distribution of the Sydney Aborigines in winter).

In general, the methods and theory utilized in this thesis offer an alternative to ethnography and ethnohistory in the study of Aboriginal adaptation in areas which have no extant hunter-gatherer population, yet possess a wealth of Aboriginal sites. In this study, freedom from ethnographic and ethnohistorical components within the behavioural model has assisted the clear demonstration of the fact that Aboriginal adaptations in the south-east of Australia were very different from those in the tropical north. It can be shown, for example, that seasonality was a comparatively minor influence upon Aboriginal locational decisions within the Sydney region, while the distribution of nutrients possessed a fundamental role with regard to these decisions.

It is hoped, then, that this thesis has illuminated some aspects of the life of the Sydney region Aborigines, who were the first to suffer extinction because of the European invasion. The lack of good archaeological material and a minimum of historical information has meant that in the past researchers have relied very heavily upon ethnographic analogy from the north. Through the use of an ecological framework and theory, this thesis has attempted to understand the extent to which the Sydney Aborigines were adapted to the Sydney environment. The evidence suggests that the Aborigines tended to behave optimally with regard to the location of high-value patches throughout the year, but further, it suggests that the distribution of these patches was such that two 'ecological populations' could live within the region. The distribution of the inland population is likely to have been characterized by an expanding (summer) and contracting (winter) range centred upon the wetlands and relatively fertile soils of the Cumberland Plain. The coastal population is also likely to have displayed a measure of contraction and expansion in its range - The Aborigines are likely to have been principally located in the estuaries in the summer; but in the winter they are likely to have incorporated the high-value patches associated with the marine fringe and wetlands.

The linguistic evidence utilized by Tindale (1974) and Capell (1970) suggests that the distinction between these two populations was real and was expressed in cultural terms. The evidence of the First Fleet journalists also indicates that the boundary between these two populations was one characterized by differences in ritual (in particular tooth avulsion); but also suggests that the boundary was to some extent maintained by force - for, in general, there appears to have been a marked degree of territorial behaviour associated with the coastal population. It is interesting to note in this context that because it is likely that territories were of small areal extent around the estuaries (because of the abundance of high-value patches), the relative costs of expressing territoriality by aggressive rather than through ritual behaviour are likely to have been more closely balanced than in areas wherein the range is likely to have been large (because of the widespread distribution of high-value patches; cf. Cashdan 1983; Peterson 1975).)

The use of optimality principles in this thesis to study Aboriginal behaviour represents a small contribution toward the continuance of a distinguished recent tradition of human ecological research in Australia. The evidence suggests that we can know more about the life of people who were often destroyed before the first commentator arrived on the scene. The techniques utilized here are capable of examining the relationship between the Aborigines and their land without recourse to what may often be totally inappropriate ethnographic analogy - and hence they are capable of promoting our knowledge of the subtlety of the Aborigine's relationship with, and understanding of, the land.

10.3 HUMAN ADAPTATION AND OPTIMALITY PRINCIPLES

That optimality principles are a useful tool in the analysis of human adaptation has already been established within anthropology (Winterhalder & Smith 1981; Foley 1985). This thesis has attempted to extend these principles into the study of past hunter-gatherer populations known only from the archaeological record (an area which has received relatively little attention (but see Yesner 1979, 1980, 1981, 1984)). The subset of optimality principles known as optimal foraging theory have been tested here through the construction of an ecological model and the analysis of the relationships between that model and the locational characteristics of Aboriginal sites.

In addition, though the behavioural model used here was based largely upon the distribution of energy within the Sydney palaeoenvironment, the influence of nutrient constraint has been shown to affect the relationship between energy and optimal behaviour. This represents a contribution in support of Pulliam's (1975) mathematical appraisal of nutrient constraint upon the optimal diet, as well as supporting the evidence of ethnography (Meehan 1977, Harpending & Davis 1977).

The results clearly indicate that Aboriginal locational decisions were influenced by the distribution of high-value patches in space and time, and to a lesser extent by the distribution of low-value but reliable 'buffer foods'. To this extent there can be little doubt of the great value of optimality principles derived from animal ecology in the study of human adaptation. Yet this thesis also makes a further contribution to the assessment of this value, for it has been possible to independently examine the closeness of fit between Aboriginal activities and the behavioural model based upon ecological data, through the use of ethnohistorical information, because it does not form part of the basis of modelling. This information clearly substantiates the evidence of optimal behaviour derived from the analysis of Aboriginal site locations, and yet also warns us about the dangers of over-reliance upon general animal ecology models in the study of human populations. In particular, because the models assume that all individuals strive to obtain limiting resources as efficiently as possible, they are (at present) unable to account for the division of labour, which in the Sydney region can be shown, (at least upon a seasonal basis) to have men efficiently foraging in high-value patches; while women forage in medium and low-value patches *of lower risk*. This is closely related to the problem of food-sharing in general, which is a difficult area of behaviour to deal with through the application of optimal foraging theory without utilizing sociobiological concepts and equating 'generalized reciprocity' with 'reciprocal altruism' (Dwyer 1985:244; see also Blurton Jones 1984). A specific extension of optimal foraging theory to take account of this difference would appear to be a high priority, if the theory is to be used to the maximum of its potential (see Kaplan & Hill 1985).

10.4 POSSIBLE DIRECTION OF FUTURE RESEARCH

One of the most important aspects of optimal foraging theory is that, because it focuses upon the tendencies of a small area of human behaviour (the part most closely related to fundamental human physiological requirements) to be associated with recognizable and ranked discontinuities in the environment, it is possible to use the technique to test the degree of adaptation displayed by widely separated peoples who possess different socio-cultural histories. Though the techniques used here have, for the sake of convenience, involved data concerning the Aborigines of the Sydney region, this does not limit the implications to

Australia: this thesis is not concerned with Australian Aboriginal adaptations per se but rather with Darwinian mechanisms and their relationship with human behaviour. That said, it is clear that Australia offers much of the best data for the development of the techniques established here, and, in general, because of the characteristics required of the archaeological data, the techniques are likely to be largely limited to the southern hemisphere. The early extension of the techniques into South Africa (particularly Cape Province which shares many of the characteristics of the Sydney region) seems most appropriate.

At the other end of the scale, it seems likely that this form of adaptational research would benefit for the removal of the crudity of many aspects of the data. (In Chapter Eight, for example, it has been noted that on a local level the relationships between Aboriginal activity and the regional behavioural model may be altered by very local influences, such as vegetation boundaries or seasonality of freshwater availability.) A detailed study, building upon the archaeological work of Vinnicombe (1980) and Attenbrow (1981, 1982) and the vegetation maps of the Brisbane Water (Benson & Fallding 1981) and Upper Mangrove Creek (Benson 1981c) areas of the Sydney region would be likely to be profitable.

The importance of this extension of the techniques on a small and large scale, lies, as does the value of this thesis itself, in the contribution which they make to the establishing of an explanatory human ecology and, hence, the better understanding of the fundamental characteristics of the whole human species.

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