Environmental changes associated with global climatic changes of the late-Pleistocene and Holocene in south-eastern Australia included changes to vegetation patterns and lake levels, as well as rising sea-level. Along the NSW central coast, these changes were of sufficient magnitude to affect both the land and subsistence resources available to inhabitants of the Upper Mangrove Creek catchment and the surrounding regions. People would have responded to these changes, but in doing so, climatic and environmental conditions were determining variables only in so far as they provided a series of options/opportunities and constraints within which the societies operated. Decisions about which options to take, when to adopt them and how resources were utilised were probably based on factors such as social, economical, political and ideological preferences, as well as technological capacities (Fletcher 1977b: 138–40; McBryde 1977: 249; Thomas 1981: 171–2; Gamble 1982: 99–103, 1983: 202, 1984: 250, 256, 1986: 29–31; Bailey 1983b: 150, 164–5; Lourandos 1983b: 43; Rowland 1983: 63; Head 1986: 122).

These environmental changes would have altered the relative abundance and/or spatial distribution of resources across the land, and thus influenced land and resource-use patterns. For example, they would have influenced which parts of the land people used and the methods they adopted to obtain their subsistence needs (including land management practices such as the use of fire and burning patterns), and may have influenced the size of the population which inhabited and exploited particular resource zones (Birdsell 1953, 1971; Hayden 1972; Lampert and Hughes 1974: 231; Bailey 1983b: 149–50; Gamble 1983: 208–9; Ross 1981: 145, 1984: 94; Jones 1985: 293–4; Mooney 1997: 148). In this way, environmental factors may have influenced people’s decisions about their subsistence practices which then led to changes in habitation patterns, the size of local populations, land-management practices, and/or the tool kits made, used and maintained within the catchment. Firing vegetation to aid hunting and/or promote plant growth may have exacerbated or altered changes initiated by climatic effects. Environmental change thus indirectly affected the archaeological record by bringing about changes in human behaviour and material culture and the nature and/or amount of physical evidence that was left behind.
Climatic and environmental factors are examined therefore in exploring possible reasons for the observed temporal changes in the catchment’s archaeological record. The discussions concentrate on the nature and timing of climatic and environmental changes in the Holocene in south-eastern Australia, and on changes to the morphology of the coastline which were associated with the rise in sea-level after the Last Glacial Maximum. Discussions concentrate on the last 11,000 years, the period for which there is archaeological evidence of human occupation in the catchment.

However, there is very little data on climatic and environmental change available for the catchment, with the only specific information coming from excavated faunal remains (Aplin 1981; Aplin and Gollan 1982; Butler 2000). Information about the effect of sea-level rise on the NSW coastline (e.g., Roy 1984, 1994; Ferland and Roy 1994; Roy et al. 1997) and some vegetational histories for the lower Hawkesbury River and its tributaries (e.g., Dodson and Thom 1992; Johnson 2000) are available. Nevertheless, since the latter studies are limited in number and duration, and refer only to pollen evidence, the following discussions also draw on evidence from several widespread regions in south-eastern Australia as well as global trends.

Climate change

The present climate of the Gosford–Wyong region has been described as temperate maritime, with warm to hot summers and cool to mild winters (NSW Department of Public Works 1977, Vol. 2: 55–6). The Commonwealth Bureau of Meteorology (2003) records for Kulnura, on the eastern watershed of the catchment, indicate mean daily temperatures range from a maximum of 26.4°C in summer to a minimum of 5.6°C in winter. More rainfall is experienced during the summer months than the rest of the year and this rainfall is generally of high intensity as it occurs during summer storms. Monthly rainfall ranges from a mean of 169mm in summer to 51.7mm in winter. February is the time of highest mean and median rainfall. In the Mangrove Creek valley, frosts occur regularly in mid-winter as well as fog and mist, which can remain for much of the morning. Maritime effects of the adjacent coast are modified by the intervening terrain. Compared with the coast, the valley is somewhat drier, has a slightly greater seasonal and diurnal temperature range and less strong winds.

The 10,000 years of the Holocene have been regarded by many as stable with very little or no climatic or environmental change (Costin 1971: 33; McBryde 1977: 225; Wasson 1982: 1). However, climatic and environmental changes have been documented for this period, though the observed variations are both smaller in magnitude and shorter in duration than those recorded for the late-Pleistocene (Bowler et al. 1976: 388; Kershaw 1982: 79; de Menocal 2001: 668; Dodson and Mooney 2001). Some researchers consider the Holocene changes were of insufficient magnitude to affect human behavioural patterns (e.g., Pearson 1981: 58–61; Smith 1982: 115), except perhaps at higher elevations (Costin 1971: 37), whereas others argue the changes were significant in terms of their impact on human resources and subsistence and habitation patterns (Stockton and Holland 1974: 48, 56, 58, 60; Pearson 1981: 61; Lourandos 1983b: 43; Rowland 1983: 62, 70–4, 1999: 146; Ross 1984: 81; Williams 1985: 315–16, 1988: 218, 220; Head 1986: 124).

Broad climatic trends in south-eastern Australia during the late-Pleistocene were much drier and colder between ca 25,000 and 15,000 BP than present, with periods of extreme cold and aridity about the time of the Last Glacial Maximum (Fig. 9.1). At the transition from late-Pleistocene to Holocene, ca 10,000 BP, conditions were similar to or still a little drier and perhaps cooler than present, but they became warmer and wetter during the early-Holocene.
Figure 9.1 Upper Mangrove Creek catchment: comparison between timing of changes in habitation and artefact indices and general climatic shifts and sea-level rise in south-eastern Australia. Sea-level curve based on Roy 1998: Fig. 25.5C.
so that from ca 7000 BP to 5000 BP the climate was warmer and wetter than today. In the late-Holocene, temperatures and effective precipitation fluctuated, but for a time became on average colder and drier than today. The reported timing of colder–drier conditions varies regionally, but occurred between 3800 BP and 1500 BP. During the last 1500–1000 years, average temperature and precipitation again increased to values similar to those of today. Wind direction and intensity are not immediately relevant to my current investigations and therefore discussions on climate focus on temperature and precipitation.

The above trends show broad temporal correlation with data from other southern Pacific-Rim countries which are linked to El Niño–Southern Oscillation (ENSO) events indicating that the general long-term climatic changes in Holocene south-eastern Australia were part of global climate changes. ENSO’s mode of operation has not been constant over time, and probably did not operate in its present-day fashion during the period of lower sea-level associated with the Last Glacial Maximum (Markgraf et al. 1992: 194). Timing of the cycles and their strength may also have varied globally. Typical ENSO cycles started to be an influencing factor only about 7000 years ago (albeit weakly at first). They began to exercise a strong presence only about 5000 years ago and were not fully developed until about 3000 years ago (McGlone et al. 1992: 436, 457–8; Rodbell et al. 1999: 519). Onset of its current state in the last 5000 years (Kershaw et al. 2000: 502; or 6000 years according to Markgraf and Diaz 2000: 465; Moy et al. 2002: 164) produced an increase in climate and environmental variability. The South American evidence indicates peak event frequency occurred ~1200 cal BP and then decreased towards the present (Moy et al. 2002: 164). The dominant effect of ENSO in south-eastern Australia was to increase the variability of precipitation (McGlone et al. 1992: 435).

Within the broad climatic trends in eastern Australia, some regional variations, particularly after 5000 BP, were linked to ENSO phenomena, and it has been suggested that changes occurred later in time in north-eastern Australia than in south-eastern Australia (McGlone et al. 1992: 446; Markgraf and Diaz 2000: 474). In addition, there were regional differences, particularly in effective precipitation, which were due to variations in altitude (e.g., southern highlands versus coastal lowlands), geography (e.g., inland versus coastal; semi-arid versus temperate), and hydrologic conditions (Bowler et al. 1976: 388; Chappell and Grindrod 1983b: 2, 1983c: 27–8; Kodela 1992; Markgraf et al. 1992: 195; Harrison and Dodson 1993; Kershaw et al. 2000: 492; Markgraf and Diaz 2000: 474). Variations in the timing and duration of peak conditions have also been reported, sometimes depending on the palaeoenvironmental records used; for example, lake levels or pollen data (Bowler et al. 1976: 388; Harrison and Dodson 1993: 280; Dodson and Mooney 2002: 456, 460).

Late Pleistocene

During the late Pleistocene (ca 35,000 BP to ca 10,000 BP), glacial and periglacial conditions developed in south-eastern Australia and then retreated. This phase of glaciation began about 34,000–31,000 years ago. Mean annual temperatures were probably only 3°C below present at that time, but during the period from ca 25,000 to ca 15,000 BP, they would have been between 6°C to 10°C lower than present (Galloway 1965: 603–6; Costin 1971: 33, 1972: 581, 588–9; Bowler et al. 1976: 359, 370; Singh 1983a: 66, 1983b: 24; Markgraf et al. 1992: 194–5; Kershaw 1995: 660; Kershaw et al. 2000: 490). Throughout the late-Pleistocene, conditions were generally drier than today in the south-east of the continent (Bowler et al. 1976; Rognon and Williams 1977: 301–2; Dodson and Thom 1992: 121, 132). Absolute and effective precipitation during the Last Glacial Maximum has been estimated as being about 50% of today’s values (Kershaw et al. 2000: 491).

Glacial conditions and periglacial conditions existed above 1000m, and periglacial conditions existed along the Great Dividing Range as far north as the NSW New England
Tablelands. Along the eastern coast and foothills of the Great Dividing Range, conditions may not have been as extreme during the Last Glacial Maximum due to the ameliorating effect of oceanic influences and, in post-glacial times, may have been ameliorated by the rising sea-level (Costin 1971: 35; Kershaw et al. 2000: 490–1).

By about 15,000 BP, temperatures were rising and deglaciation was in progress, though the colder-than-present conditions lasted until about 10,000-9000 BP (Costin 1971: 33, 36, 1972: 589; Bowler et al. 1976: 387, 389). In southern Australian coastal areas, the evidence indicates a gradual increase in rainfall and vegetation growth conditions between ca 15,000 BP and ca 10,000 BP rather than an abrupt change (Dodson and Hope 1983: 75).

The Holocene
At the beginning of the Holocene, ca 10,000 BP, conditions in many coastal areas in southern Australian were similar to those at present, though some areas remained drier, possibly until ca 9000 BP (Dodson and Hope 1983: 75; Harrison and Dodson 1993: 282; Markgraf and Diaz 2000: 471). Most changes at this time in southern coastal areas can be attributed to decreased continentality associated with the rising sea-level, which in general resulted in an improvement in the rainfall/evaporation ratio, which continued into the Holocene.

The increasing temperatures and precipitation culminated in an early- to mid-Holocene ‘optimum’, which was warmer and wetter than the preceding 10,000 or so years, and had the highest temperatures and precipitation in the Holocene period (Bowler et al. 1976: 378, 388; Rognon and Williams 1977: 305; Kershaw 1995: 667–9). It was up to 25% or 30% wetter and 1°C warmer than present (Kershaw et al. 2000: 490; Dodson and Mooney 2002: 456). These conditions lasted from about 8000 BP to 4000 BP, although timing of peak conditions varied regionally, being reached earlier in the south of the continent than in the north (McGlone et al. 1992: 435, 446; Markgraf and Diaz 2000: 474; see also Costin 1971: 33; Bowler 1976: 73; Chappell and Grindrod 1983d: 87; Kershaw 1982: 79, 1989: 89; Harrison and Dodson 1993: 282, 287–8). In the south-eastern lowlands, maximum moisture conditions existed between ca 7000 BP to 5000 BP (Bowler et al. 1976: 378; Markgraf et al. 1992: 195–6; Markgraf and Diaz 2000: 474).

The evidence generally points to a return to a cooler drier climate from about 5000 or 4500 BP. It is in this period, especially after 3000 BP, that ENSO began to operate as now and there is evidence for increasing seasonality and variability in precipitation, leading to more marked winter–summer precipitation patterns in some areas (Markgraf et al. 1992: 196, 208; McGlone et al. 1992: 435–6, 457; Markgraf and Diaz 2000: 475). Temperatures and precipitation continued to drop until conditions became cooler and drier than at present. Dates attributed to the duration of this ‘colder-drier’ period fall between 3800 BP to 1500 BP, with most between 3500 BP and 2000 BP (e.g., Costin 1971: 36–7, 1972: 589; Bowler et al. 1976: 371, 373; Dodson 1987: 79; McGlone et al. 1992: 446; Harrison and Dodson 1993: 276, 279–80). Costin (1971: 36; 1972: 589) estimated temperatures in the Snowy Mountains from ca 4000–3000 to 1500 BP to be about 2°C or 3°C lower than today.

With moister conditions, some vegetation zones may have expanded at the expense of others: more closed vegetation communities increased in area and more open conditions decreased; for example, rainforests and wet sclerophyll forests increased and dry sclerophyll forest decreased, forest expanded into woodland areas, woodland expanded into grasslands, and swamps increased in size and some perhaps became lakes (Bowler et al. 1976: 371–3; Williams 1985: 316; Kodela and Dodson 1988 [1989]: 324–5; Dodson and Thom 1992: 133; McGlone et al. 1992: 446; Jones and Dodson 1997: 20). Alternatively, changes may have occurred as variations in species abundance within vegetation communities (Scott Mooney, pers. comm., 2003). With drier, more arid conditions, the reverse of these conditions would...
have applied and more open conditions prevailed. Changes in water availability and vegetation patterns brought on by climatic change would in turn have influenced the animal distribution patterns. Fire regimes (natural and/or human) may have altered as well.

Locally, pollen and charcoal records come from cores from swamps on Mill Creek, a tributary of the Hawkesbury River near its junction with Mangrove Creek, and in Ku-ring-gai Chase National Park on the southern side of Broken Bay. These suggest drier conditions occurred between 2900 BP and 1800–1900 BP. At Mill Creek, one core dating from ca 9100 BP to ca 2500 BP indicates that about 2800 BP to 2500 BP the forest was more open than in the preceding period, 9000 BP to 2800 BP, and that the rainforest elements, locally at least, declined at this time (Dodson and Thom 1992: 127–31, 133). Dodson and Thom (1992: 133) suggest that abundant charcoal in the core sections containing rainforest elements indicates that the decline in rainforest and development of more open vegetation was in part due to increased occurrences of either anthropogenic or natural wildfires, and make no reference to climatic change. Another Mill Creek core extending over 863 years to 1993 indicates the presence prior to 1790 AD of dry sclerophyll forest on the valley sides with wetland communities on the valley floor (Johnson 2000). There was little charcoal input during the prehistoric period compared with that of the subsequent European agricultural period beginning in the 1790s (Johnson 2000: 217, 223). In Ku-ring-gai Chase National Park, pollen evidence from a core extending back ca 6000 years suggests there was a possible dry period about 2900 BP, that climatic conditions ca 2000 BP may have been drier than present, and that conditions possibly became slightly drier and the eucalypt canopy opened towards a more woodland type about 1800–1900 BP (Kodela and Dodson 1988 [1989]: 324–5). In contrast with Mill Creek, charcoal declined in Ku-ring-gai Chase National Park within the last 200 years (p. 323), perhaps reflecting the absence of Aboriginal burning and/or the lack of agricultural opportunities in this catchment.

Aboriginal burning patterns have been proposed by several environmental scientists as being responsible for some vegetation and geomorphological changes (or at least for accelerating changes) during the late-Holocene, though their impact is much debated (Bowler et al. 1976: 388; Hughes and Sullivan 1979: 24–5, 1981, 1986; Hughes 1981; Colhoun 1983: 93; Hope 1983: 98; Sullivan and Hughes 1983: 124; Head 1989; Dodson and Thom 1992: 133; McGlone et al. 1992: 449, 455–6, 458; Kershaw et al. 2000: 490, 503). However, others state that in many Australian, New Zealand and South American pollen records, evidence for increasing fire frequency cannot be ascribed to anthropogenic factors alone, and were likely to be the result of increasing climatic variability (Markgraf and Diaz 2000: 475; Dodson and Mooney 2002: 456).

During the last 1000 years, climatic conditions in eastern Australia appear to have been relatively stable with slight increases in precipitation compared with the preceding period (Harrison and Dodson 1993: 276, 279), and slight increases in temperature until those of today were reached (Dodson 1987: 79–80). Marked climatic fluctuations have been documented in the Northern Hemisphere; for example, Europe’s Medieval Warm Period in the 11th and 12th centuries AD (950–750 BP), and the subsequent Little Ice Age of the 16th to 19th centuries AD (450–100 BP) (Markgraf and Diaz 2000: 478–9; de Menocal 2001: 668; Jones et al. 2001: 663–5). However, such periods have not been identified in south-eastern Australian records to date (Jones et al. 2001: 664; Mooney 1997: 140), though they have in other Southern Hemisphere regions (e.g., the Little Ice Age in South America [Peru] and New Zealand, Mooney 1997: 147).

**Palaeoenvironmental evidence from the Upper Mangrove Creek catchment**

Temporal changes in excavated faunal assemblages from the catchment may provide some evidence for environmental change during the last 3000 years, the period during which faunal remains have been preserved. Three excavated archaeological deposits — Loggers, Mussel
and Deep Creek — have sufficient faunal remains for changes over time to be investigated. In two of these rockshelter sites — Mussel and Deep Creek — there was a change in the faunal assemblages, particularly in the macropodid component, about 1200–1000 BP (Aplin 1981: 33–4, 51–3; Aplin and Gollan 1982: 20–6; Butler 2000: 85–8). However, it was not identified in the sequence at Loggers, which is in a more open section of the valley system. In some south-eastern Australian regions — e.g., the Snowy Mountains — colder–drier conditions have been recorded as persisting as late as 1500 BP, but as described above, such conditions have not been documented this late in local pollen cores.

In both Mussel and Deep Creek, the lower assemblages are characterised by the presence of *Macropus giganteus* (eastern grey kangaroo) and the relative importance of *M. rufogriseus* (red-necked wallaby). In the upper assemblages, *M. giganteus* and *M. rufogriseus* are absent (the latter is presently uncommon in the catchment) and there is a corresponding rise in *Wallabia bicolor* (swamp wallaby) and *Thylogale* sp. (pademelon) (Aplin 1982: 20–1). In present-day faunal studies, the two species characterising the earlier levels are observed most often in areas of relatively dry, open forest and woodland; both are grazers feeding on grasses, herbs and forbs (Strahan 2000: 335–8, 350–2). The two species characterising the later levels are commonly associated with dense, wet understorey communities; the swamp wallaby is primarily a browser of shrubs and bushes rather than grass, and pademelons have a varied diet of leaves and fruit, or feed on the grassy edges of dense forest (Strahan 2000: 397–400, 404–5).

Aplin suggested that this change in the faunal assemblages could be interpreted as either (1) a shift in the catchment vegetation patterns involving the areal expansion of wet, closed communities at the expense of drier, more open vegetation (Aplin 1981: 52–3; Aplin and Gollan 1982: 21), or (2) a shift in subsistence activities, within a stable environment, towards the resources of wetter, more closed forests (Aplin and Gollan 1982: 21). He (1981: 53) suggested that two factors may account for the postulated variation in vegetation: either variations in magnitude and frequency of firing events, or water-table fluctuations in the valley fill and associated changes to the hydrologic regime of the drainage system. Subsequently, Aplin and Gollan (1982: 24) said, ‘a reduction in the frequency of firing events would probably be sufficient to bring about the envisaged vegetational change in the Deep Creek valley.’ However, they (1982: 21) argued that since the faunal changes involved ‘the local extinction of at least one species of mammal, the grey kangaroo’, it was strong support for an environmental interpretation of the sequence. A change in the Aboriginal burning regime seems an unsatisfactory explanation because of the small distances between Deep Creek, Mussel and Loggers shelters (<5km) and because of the implications that the burning was restricted to the vicinity of shelters which show a decrease in the accumulation rates for both artefact and faunal assemblages at this time (Attenbrow 1982a: 42–4).

An environmental interpretation for the change in the faunal assemblages accords with the evidence for a generalised widespread climatic change in the later Holocene from very dry conditions to the moister present-day regime. However, the date for the faunal change in Mussel and Deep Creek (ca 1200–1000 BP) is much later than that indicated by the local palaeoenvironmental records (ca 2000 BP). The reason for this difference is not known. It is possible that the pollen records, which are from swamp contexts, may not reflect exactly the changes that were occurring in the surrounding forests or higher up in the river catchment (e.g., Kodela and Dodson 1988: 324). Further excavated faunal sequences as well as more detailed palaeoenvironmental records from within or near the catchment are needed to establish the nature of the vegetation changes that occurred during this period. Until such data are available, it is not possible to say unequivocally that the excavated faunal sequence is a consequence of environmental changes or changing fire regimes, or whether it represents a change in the animal species people preferred to hunt and eat, which occurred for purely social reasons.
Changes in sea-level

The eastern boundary of the Upper Mangrove Creek catchment is presently ~33km from the ocean coastline (in the closest direct line), and, to the western shores of Tuggerah Lake and Lake Macquarie, it is ~25km and ~28km respectively. The catchment’s southern boundary is presently ~18km from estuarine conditions in the lower reaches of Mangrove Creek, and ~28km from the Hawkesbury River.

Although the entire catchment is within the freshwater reaches of Mangrove Creek, its use and occupation would have been affected by physical changes to the adjacent country brought about by the rising sea-level associated with late-Pleistocene and Holocene climatic events. Rising sea-level affected NSW coastal regions in two main ways: by reducing the area of dry land, and altering the configuration of the coastline. The reduction in landmass and westward movement of the coastline in turn affected the degree of continentality experienced by the coastal hinterland. Even after the sea-level stabilised ca 6500 BP, the coastline did not remain a stable environment.

Changes to country

During the Last Glacial Maximum, between 25,000 BP and 15,000 BP, when the sea was between 110m and 130m below its present level (Ferland and Roy 1994: 184–5; Roy 1998: 368), the coastline at Broken Bay would have been between 20km and 25km further east and the Hawkesbury River and its present estuary would have been freshwater (Roy and Thom 1981: Figs 5 and 6; Roy 1983: Fig. 4A). As the sea-level rose during the period ca 18,000–17,000 BP to ca 6500 BP, the catchment itself was not directly impacted by the changes in sea-level, but land between the former (LGM) and current coastline was gradually inundated. At the same time, estuarine conditions gradually extended into the Hawkesbury River valley, with its mouth becoming and remaining marine-dominated. The Hawkesbury River is the largest drowned river estuary on the NSW coast.

The rise in sea-level was not constant: the sea rose rapidly until about 8000 BP (ca 1m/century), but then slowed down to about half that rate between 8000 BP and 6500 BP (Roy 1998: 368). By ca 10,000 BP, it had fallen to ~35m; by ca 9000 BP to between ~15m and ~20m; and, by ca 7000 BP, to between ~4m and ~6m (Chappell 1983: 121; Chappell and Grindrod 1983d: 87; Roy 1994: 255, 1998: 368). Although it reached its present level and stabilised ca 6500 BP, the sea had reached the base of the cliffs which form the present coastline about 10,000–9000 BP (Roy 1994: 241). When Loggers Shelter was first inhabited, about 11,000 BP, the sea-level was still rising and the shoreline was about 4km to 8km east of the present coastline. To the south, the ocean waters were already extending into the lower sections of the Hawkesbury River palaeo-valley.

On its south-eastern margin, the continental shelf is steeper and narrower than in other parts of Australia and the loss of land along the NSW coastline was not as extensive as it was along the continent’s northern or southern coastlines. The rising sea drowned the river valleys along the NSW coast forming ‘rias’ such as the Broken Bay–Hawkesbury River and Sydney Harbour (Port Jackson) systems. The present NSW coast is essentially a drowned embayed coast where prior bedrock valleys are partially infilled by sandy barriers, tidal flats, lagoons (often called lakes) and deltaic plains (Roy 1984: 99–100, 1994; Roy and Thom 1981: 471). The drowning of these river valleys substantially increased the length of shore with estuarine conditions, and extended the availability of estuarine resources further into the coastal hinterland. By 6500 BP, estuarine conditions extended ~29km up the Hawkesbury River and into the lower reaches of Mangrove Creek; and brackish conditions reached upstream some 50km inland (as far as Windsor).
Although sea-level is usually described as having stabilised ca 6500 years ago, there is evidence that between 4100 BP and 3200 BP the sea-level along the NSW coast was at least 1m, and possibly 2m above the present level due to hydrostatic readjustments (e.g., Chappell 1983: 122; Flood and Frankel 1989; Baker and Haworth 1997, 1999, 2000a, 2000b; Roy 1998: 368, 371). Evidence for higher sea-levels in this period comes from Valla Beach on the NSW north coast (Flood and Frankel 1989) as well as Port Jackson (Sydney Harbour) and Port Hacking (Baker and Haworth 1997, 1999, 2000a, 2000b).

Changes to the southern Australian shoreline after ca 8500 BP have been described as minor compared with those in the period between 15,000 BP and 10,000 BP, and, after ca 6500 BP, to be negligible except for local progradation in some areas (Chappell and Grindrod 1983d: 87) or to be related to gains or losses to the coastal sediment budget (Chapman et al. 1982: 42). However, locally, along the NSW central coast, mid- and late-Holocene changes were somewhat greater and more diverse than these statements imply. They included the formation and/or modification of rock platforms, the building of coastal barriers, the infilling of estuaries, as well as the formation of lagoons when barriers developed across the mouths of drowned valleys (Langford-Smith and Thom 1969; Roy 1984, 1994). The coastline east of the Upper Mangrove Creek catchment includes large barrier estuaries such as Lake Macquarie, Tuggerah and Munmorah Lakes, and Brisbane Waters (Roy 1994: 247). Lake Macquarie, one of the deepest barrier estuaries in NSW, began to form as the sea-level was rising and was ca 5m deep about 8000 BP (Roy 1994: 250–1, 255, Fig. 8).

Coastal productivity and resource availability
In presenting their case for population increase (see Chapter 2), Lampert and Hughes (1974: 228) stated that when the sea-level was rising before ca 7000 BP, any barrier systems that existed on the inner continental shelf would have been less well developed and would have held back smaller bodies of water than those of more recent times; there were probably fewer lagoons and they may even have been ephemeral. There were also fewer rock platforms at that time than in the later period of stable sea-level, and the inter-tidal/near-tidal zone was therefore narrower. Thus, they said, within the period of human occupation, inter-tidal rock platforms and coastal lagoons of reasonable size seem to have been restricted to periods of stable sea-level and perhaps the period just before the sea began its most recent transgression, that is, during the last 7000 or 5000 years. Lampert and Hughes concluded that coastal resources would have been less accessible during the initial period of rising sea-level, but marine resources, particularly molluscs, would have become more abundant in the late-Holocene as a result of coastal developments.

Callaghan (1980: 47) posited that it took 2000 years, between ca 6000 BP and ca 4000 BP, for the marine coastal ecology to stabilise and become favourable for fishing and shellfishing. He based his proposition on basal radiocarbon dates for mid-north coast middens containing some molluscan remains, which cluster ca 4000 BP, and a similar date for a drastic increase in deposition rates in shell middens at Bass Point and Burrill Lake. White and O’Connell (1982: 99) argued that when south-eastern Australian littoral environments were less extensive, shellfish would have been significantly less numerous than they are today, and were thus unlikely to have been as important to coastal populations of 6000 years ago as they were later. Extensive progradation is also said to have changed the nature of subsistence resources over time in Princess Charlotte Bay in north-eastern Australia (Chappell 1982: 75), where Beaton (1985: 13) argued that the ‘food base offered during the transgressive intertidal period’ was much less productive in terms of numbers of individuals of all shellfish species than in the late-Holocene.

The probability that the late-Holocene shoreline was more productive than shorelines of earlier periods has been substantiated by geological investigations on the continental shelf.
What's changing: population size or land-use patterns? The archaeology of Upper Mangrove Creek, Sydney Basin

(e.g., Roy 1984, 1994, 1998, pers.comm. 1986; Pye and Bowman 1984). Present-day rock platforms are the product of long periods of erosion during highstands of the sea and are composite features formed over hundreds and thousands of years, but there were no equivalents to them at the time of the lowest Last Glacial sea-level. The inner continental shelf has bedrock reefs and rocky headlands that extend to depths of 50m to 70m below present sea-level, but below this the inner and outer shelf consists of sediment with few outcrops. At the height of the Last Glacial Period, the coastline was a relatively unbroken sandy beach without the current configuration of headlands, cliffs, beaches, lagoons and deep invasive estuaries and rock platforms. Estuaries in the palaeo-valleys extending across the continental shelf would have been much smaller than today and, combined with the less extensive rock platforms, there would have been correspondingly less abundant fish and shellfish resources. Transgressive barrier estuaries and lagoons did exist throughout the marine transgression, but initially the coastal lagoons would have been small with low productivity. They would have attained their maximum size only towards the end of the transgression and at the beginning of the stillstand period (ca 7000–5000 BP). During stillstand, they have been progressively decreasing in size as they infill with sediment (Roy 1984: 115, Fig. 5; 1994).

With regard to the effects of progradation on the NSW central and south coast, the Shoalhaven and the Hunter Rivers are the only large rivers in areas of subdued coastal topography where relatively extensive estuarine sedimentation has occurred (Roy 1994, 1998; Roy and Thom 1981). Many other smaller areas of infill have occurred in both embayments and estuaries, such as Brisbane Waters and in Lake Macquarie. The degree and effects of progradation vary from estuary to estuary depending on their stage of infilling (Roy 1984); and, in large, deep and steep-sided estuaries such as the Broken Bay–Hawkesbury River system, it would not have been as great as in the smaller barrier estuaries. Roy (1984: 117–18) states that population densities of marine fauna would be highest in estuaries in youthful stages, and that in mature estuaries, estuarine plant and animals experience a general decline in distribution, population numbers and species diversity. In contrast with other parts of the coastline, maximum estuarine productivity was probably reached about 7000 to 5000 years ago.

Coastline modifications associated with the rising sea-level over the last 11,000 years affected the availability of land and subsistence resources on the NSW central coast, though the exact nature and magnitude of the variations in resource abundance are still largely unknown.

The effect of sea-level change on occupation of the Upper Mangrove Creek catchment

The land
The area of land lost from the coastal plain (i.e., land which now forms part of the continental shelf) as the sea-level rose between ca 11,000 BP and ca 6500 BP was not as great as that lost in the previous 7000 or so years (i.e., between 4km or 8km compared with 16km or 17km). People would have moved from the lands being inundated, but the area lost after 11,000 BP was probably insufficient to influence in any major way the distribution of people within a region which would have included the catchment. The loss of land between 18,000 BP and 11,000 BP is more likely to have affected population distributions.

The Hawkesbury River valley experienced changes of a different and more dramatic nature than those of the continental shelf. Drowning of the Hawkesbury palaeo-valley started when the sea-level was at –50m between 12,000 and 11,000 BP. The long, narrow valley bottoms were flooded rapidly up to about Wisemans Ferry. The flooded valley reached its maximum size about 9000 BP or 8000 BP, after which shoaling and infilling began as river sediments were deposited in standing water bodies and point bars began forming.
The formation of Broken Bay and the presence of a broader and deeper Hawkesbury River had several implications. The land lost through inundation may have included alluvial terraces forming river banks (Langford-Smith and Thom 1969: 578), which may have been used as access routes for movement along the river as well as habitation locations. It is more likely, however, that the Hawkesbury River excavated its valley fill during the sea-level lowstand, and few terraces were left when the sea-level started to rise (P. Roy, pers. comm., 1986). The river may also have formed a greater barrier to movement between areas north and south of the river than previously existed, or alternatively, provided an easier mode of crossing the valley — that is, crossing by boat as opposed to having to walk up and down the sides of a deep valley.

Loss of the broad river terraces, if present, may have affected subsistence strategies and the movement of people for other activities, and the presence of the broad river may have affected relationships between local groups of people north and south of the river. No archaeological evidence for either of these possibilities is apparent in the data retrieved to date from the Upper Mangrove Creek catchment.

**Availability of resources**

Environmental changes associated with the rising sea-level would have affected the distribution and abundance of resources available for people who utilised the catchment in several ways. The land lost due to the sea-level rise meant loss of terrestrial resources, that is, animals and plant foods in the coastal zone. However, in hinterland areas such as the catchment, rainfall/evaporation improved due to decreased continentality and this is likely to have increased water availability and possibly productivity of the timbered lands. In addition, the increased length of estuarine shoreline produced a greater abundance of marine resources. The rise in sea-level also brought abundant marine resources (both ocean and estuarine) much closer to the Upper Mangrove Creek catchment.

These changes in the location, morphology and productivity of the ocean shoreline and estuarine reaches of the Hawkesbury River, lower Mangrove Creek and Brisbane Waters must have influenced the subsistence movements of those people using the catchment. The nature of the effects would have depended on the distribution of local groups (clans and language groups), their subsistence ranges and the ‘territorial’ boundaries within which they operated. If, in any period, the range of the group/s that inhabited the catchment extended to the coast and/or Hawkesbury River, then changes in the productivity of the ocean and estuary shorelines may have contributed (wholly or partially) to the changing site and artefact distribution patterns in the catchment.

If decreasing continentality in areas such as the Upper Mangrove Creek catchment increased productivity of the forests as well as water availability, it may have encouraged people to extend into or increase their use of these hinterlands by the end of the Pleistocene period. Redistribution of marine resources, both before and after stabilisation of the sea-level, may have influenced local and regional subsistence patterns in the hinterland, including the catchment, as well as along the coastline itself. There is no direct archaeological evidence to indicate that life in the catchment after 11,000 BP was affected by environmental changes associated with the rise in sea-level in a way that would have altered the distribution of habitations, the habitation establishment rate, the number of habitations used or the artefact accumulation rates. However, general correspondence between the earliest date for a catchment habitation and the time when the Hawkesbury River palaeo-valley began to be flooded (ca 12,000 BP to 11,000 BP) suggests there may be an association between initial occupation of the catchment (or at least a level of occupation that is now archaeologically visible) and sea-level rise at this time. People would have been moving westward from inundated coastal lands and also northwards from the inundated Hawkesbury Valley.
Conclusions: correlations between climate and environmental changes and catchment trends in habitation and artefact indices

The earliest evidence for occupation in the Upper Mangrove Creek catchment dates to the terminal Pleistocene, ca 11,200 BP, when conditions were warming up after the glacial conditions of the Last Glacial Maximum and rainfall-evaporation ratios were improving as continentality decreased due to the rising sea-level (Fig. 9.1). The initial or increased level of occupation in the Upper Mangrove Creek catchment just over 11,000 years ago could reflect the last stages of the westward movement of people as the sea-level rose and coastal lands were inundated, combined with their movement into hinterland areas where resource productivity and water availability increased due to decreasing continentality.

As the climate became even warmer and wetter in the early Holocene (reaching a peak sometime between ca 8000 BP and ca 5000 BP, when conditions were warmer and wetter than today), the habitation establishment rate and the number of habitations used increased slowly. An increase in habitation establishment rates is evident in the seventh millennium BP. Early-Holocene trends in the artefact accumulation rates differed slightly to those for both the establishment and use of habitations. They remained low until the fourth millennium BP, apart from a small peak in the 10th and ninth millennia BP, that is, just before the climate became warmer and wetter than today.

Although the climate began to get cooler and drier ca 5000-4500 years ago, it was not until the fourth millennium BP that there was a small increase in the habitation establishment rate; however, the trend in the number of habitations used and the artefact accumulation rate did not change, but continued to increase gradually.

In the last 3000 years, there is not a clear correlation between the timing of the climatic changes and the times at which dramatic changes occurred in the habitation and artefact indices. In the third millennium BP, when the climate became much cooler and drier and more variable than it had been over the previous 7000 years, the local artefact accumulation rate increased dramatically, but the habitation indices continued increasing gradually as before. It was not until later, in the second millennium BP, that there was a dramatic increase in the habitation establishment rate and the number of habitations used. By that time, the climate was still colder and drier than today but average temperatures and rainfall had begun to increase. In contrast with the habitation indices, the local artefact accumulation rate did not increase — it decreased slightly, and remained almost as high as in the second millennium BP. During the first millennium BP, when the climate became yet warmer and wetter until the present climatic regime prevailed, the rate at which habitations were established increased markedly and the number of habitations used rose substantially again, with an increase as great as that in the second millennium BP. In strong contrast with the habitation indices, the artefact accumulation rate dropped substantially, though the rate was still much higher than those before the third millennium BP.

Lack of correlation in the timing and direction of the trends in the catchment’s habitation and artefact indices over the last 3000 years could be interpreted as there being no causal relationship between climatic events and the human behaviour which produced the quantitative changes in the archaeological record, but this need not necessarily be the case. The documented trends in habitation and artefact indices in other areas of eastern Australia also indicate much variability. They suggest that dramatic changes in the habitation and artefact indices occurred principally within the latter half of the Holocene, but were not necessarily restricted to that period. A similar pattern is seen in the growth rates for each of the indices indicating that the presently documented dramatic increases are not solely the result of exponential increase. Again, such regional variation could suggest that changes in the
archaeological record and the climatic changes were unrelated. However, the extent to which the subsistence resource base was affected would have varied from region to region depending on local factors — in some areas, climatic changes may have been beneficial, but in others detrimental. In addition, the timing of the onset and duration of changed environmental conditions in response to a particular climatic variation was not uniform across the continent. Thus, because of variations in the range of options available to each group, the cultural changes that occurred were unlikely to be uniform in all regions (cf. Allen 1996: 201).

Environments with limited water supplies, or an excess of water, were probably affected more markedly and earlier than richer environments and thus the subsistence strategies of people occupying these areas are likely to have been affected at an earlier date than those of people in other types of environments. In some areas, the change may have promoted movement into previously unoccupied environments or the use of specific resources within the same environment, or prompted changes in exploitation strategies which involved changes in the degree of mobility or the types of material technology used. Regional variation will have occurred because of specific local conditions: geographical, social, technological and the history of events that occurred in the past. For these reasons, the timing and direction of changes in habitation and artefact indices are unlikely to be uniform in all regions.

Even though the exact nature of the impact of climatic changes on resources is often uncertain (cf. Veth et al. 2000: 60, 62), it is generally agreed that variations in the abundance and distribution of subsistence resources occurred at times of climate and environmental change. Warmer–wetter conditions are often referred to as ‘optimal’, and a change to warmer–wetter conditions as ‘ameliorating’, whereas a change to colder–drier conditions is seen as ‘deteriorating’ (e.g., several contributors to Chappell and Grindrod 1983a; Kershaw 1984: 69). Many archaeologists appear to accept or assume that periods of colder–drier conditions had less abundant resources and were more stressful, and that the number of people inhabiting a particular area or region was related to the level of resources available (e.g., Lampert and Hughes 1974: 231; Pearson 1981: 57–8; Ross 1981, 1984). Lourandos, for example, says: ‘If there is a close relationship between population and environment, then declining populations could be expected as conditions became drier and more stressful’ (1985b: 38), and, ‘the early-Holocene was generally more humid than the late-Holocene which, being drier, was a more stressful period’ (1997: 311). However, in some regions, the colder–drier period may not have had fewer subsistence resources than the warmer–wetter periods, and may not have had a lower human population. The consequences of climatic changes may have been beneficial in some areas but detrimental in others (White and O’Connell 1982: 99; Rowland 1983: 63; Head 1986: 124, 1987: 457; Bird and Frankel 1991a: 10). Similarly, the effect of sea-level changes will not have been the same in all parts of the continent (Chappell 1982: 70, 78). Although some information is available for the Upper Mangrove Creek catchment, there are still many unknowns, for example:

1. what was the nature of changes in vegetation and faunal distribution patterns at a regional level — did the faunal changes documented in the catchment occur elsewhere and at the same time?
2. how did overall resource availability and/or productivity change with the climatic changes?
3. was resource productivity greater in the recent warmer–wetter period than in the preceding cooler–drier period; that is, was the change advantageous or detrimental to the region’s inhabitants?

More detailed studies are needed, but in the meantime, ways of interpreting and explaining the catchment’s archaeological record, and of exploring possible influences of the regional climatic and environmental changes on habitation, subsistence and land-use patterns, are addressed in the following chapter.