Chapter 1: Introduction

1.1 Research Problem and Overall Aim

This thesis has evolved out of my interest in coastal midden sites and the marine fauna associated with them. Attending a seminar presented by Robert Baker, Bob Haworth and Peter Flood in the School of Human and Environmental Studies early in 2000 made me aware of the proposed theories for fluctuating sea-levels during the Late Holocene. I found these theories fascinating and exciting, given their implications for coastal shell midden sites. Marine faunal remains, especially fish, are often only analysed to the point of providing a 'shopping' list. I would like to believe that marine faunal remains have a lot more to offer archaeological research than just the most basic of identification and quantification. The research presented in this thesis has given me the opportunity to explore not only the hypothesis of fluctuating sea-level in the Late Holocene, but also to examine the possibilities of using archaeological fish and shellfish in an exciting new area of prehistoric environmental research.

The overall aim of this thesis is to examine the relationship between coastal shell midden sites on the east coast of Australia and theories of a fluctuating sea-level in the Mid- to Late- Holocene. Theories of sea-level instability, that is, a rise or fall in the mean level of the sea by up to two metres, since the last glacial maximum, have re-emerged in the last decade, giving archaeologists a new viewpoint from which to observe the patterns of location and age in coastal shell midden sites. While shell middens have been used in the study of environmental change in the past (for example, Hope et al. 1985; Woodroffe et al. 1988), theories of Mid-Holocene sea-level fluctuation have not been tested with Australian sites previously, though the hypothesis has been proposed for other tectonically stable coastlines of the Southern Hemisphere.

The very nature of shorelines provides numerous destructive forces that can affect the preservation of coastal shell middens. On a daily and annual scale, tides, currents, wave action, and climatic events such as storms and cyclones, contribute to the ongoing shaping and re-shaping of Australian shorelines. These dynamic coastal processes can lead to the total destruction of the shell middens and the material culture contained within. The effects of these processes on coastal sites is well understood. However, the notion of also taking into account a fluctuating sea-level has not really been considered in Australian archaeology, as it has been assumed that the coastline has remained stable for the past 6,000 years (Bailey 1999:109; Border 1999:130; Dortch 1999:29; Smith 1999:15).

In this research I will investigate the archaeological implications of the fluctuating sea-level hypothesis, and relate it to two sites, Clybucca 3 and Stuarts Point 1, which are extensive shell middens located on the mid-north coast of New South Wales, in the Lower Macleay River region.

1.2 The Study Area

In this section I present a description of the study area, the Lower Macleay floodplain, and discuss its present climate. I also discuss the faunal and floral resources of the region, to place in context the natural resources which would have been available to Aboriginal people. I then present a brief ethnographical background, in relation to the use of marine resources, of the area.

1.2.1 The Macleay River

The Macleay River is located on the mid-north coast of New South Wales, approximately 500 km north of Sydney (Figure 1.1). The major urban centre for the region, the town of Kempsey, is located approximately 12 km inland from the ocean on the Macleay River. The entire Macleay River valley covers an area of 11,461 square kilometres (McDonald 1967:1), however the Lower Macleay floodplain and coastal fringe is 640 square kilometres in area, and 'extends inland for a maximum distance of 16 km' (Hails 1967:140) (Figure 1.1). The archaeological sites at Stuarts Point and Clybucca, which form the basis of this research, lie to the north of the Macleay River on the deltaic floodplain described by Hails as –

> 'characterised by well defined relict meander belts, point-bar accretions, meander scrolls and back-swamps or floodbasins....It is drained by the Macleay River, tidal to Aldaville above Kempsey, and its tidal tributaries Belmore River, Kinchela, Christmas and Clybucca creeks. The flats bordering the trunk stream average less than 3m above mean sea level. Periodic flooding has built natural levees above the major streams, those above the Macleay being less than 6m above sea level, and those along the Belmore River and Kinchela Creek rising to a maximum of 2.5m above adjacent backswamp depressions' (Hails 1967:140-141).

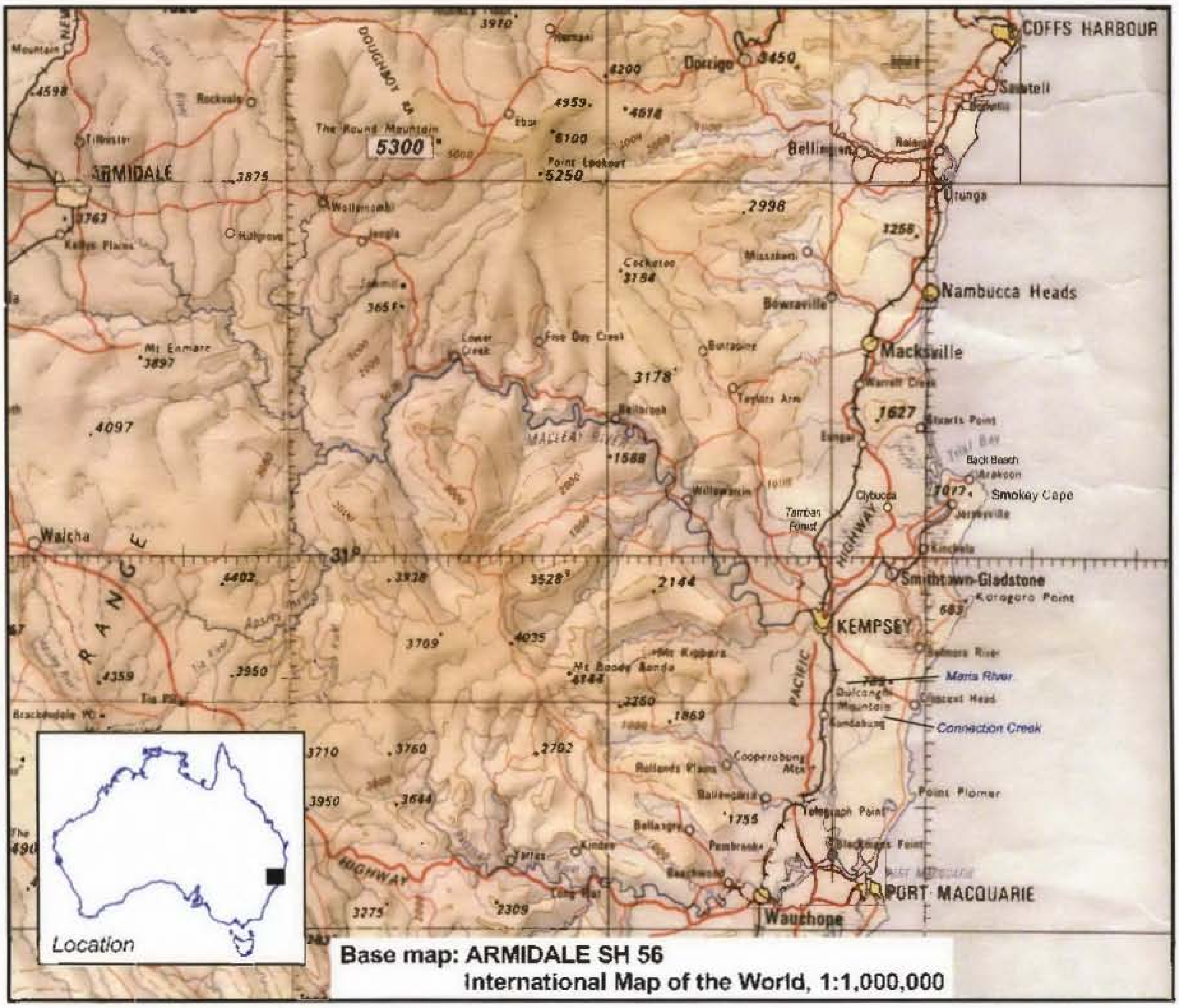

Figure 1.1 The Mid-North Coast of NSW

1.2.2 The Case-Study Shell Midden Sites

The sites of Clybucca 3 and Stuarts Point I both lie to the north of the Macleay River, with Stuarts Point I located on an estuarine peninsula, and Clybucca 3 located at the base of the foothills some 12 kilometres inland from the ocean.

The archaeological shell midden sites at Clybucca and Stuarts Point provide an excellent opportunity for examining the possibility of observing environmental change over time in the marine fauna of coastal midden sites. Both of the sites exhibit large accumulations of cultural deposits containing some stratigraphic definition. The depth of the deposits and the stratigraphic or cultural layering offers the possibility of obtaining temporal information from the deposits, an important requirement when examining any type of change over time, whether it be cultural or environmental. Although these sites were excavated in the 1970s, Professor Connah has made the original field notes and section drawings available for this research.

Both of the sites are located on the same estuarine system, though in different environments today. Clybucca, presently some 12 km inland, is located at the point where the land begins to rise from the flat floodplain of the coastal strip into the foothills of the Great Dividing Range. An elevated sea-level would have made the environment of the Clybucca region much different from what it is today, in that the sites would be adjacent to a much larger body of water. As the aerial photograph (Figure 1.2) taken in 1972 at the time of the excavation shows, the Clybucca 3 site is now 'high and dry', making the presence of marine fauna in the archaeological deposits even more intriguing. Stuarts Point is located adjacent to the sea but separated from the ocean by islands, a narrow coastal strip and channels of the Macleay delta. As will be shown in Chapter 4, both of the sites contain over a metre and a half of deposits and exhibit stratigraphic layering.

If any increase or decrease in the mean height of the sea-level had occurred at the time these sites were occupied, it is probable that this would be reflected in the marine fauna,

Figure 1.2 The Clybucca 3 Site (Connah, 1972)

which may have had to adapt relatively quickly to the changing environmental conditions. By looking for change not only within each site, but by comparing differences between the sites in similar time frames, it may be possible to determine if a sudden environmental change had occurred, through the change in the faunal resources represented in the sites.

Finally, both of the sites contain large amounts of marine fauna. Clybucca is dominated by shellfish, but the Stuarts Point site contains an exceptional amount of fish remains. Many ecologists believe that marine fauna is extremely vulnerable to the effects of even slight changes in their living environment, and any such change should be seen in the fish or shellfish remains represented in archaeological deposits (Wheeler and Jones 1989:11; Harvey and Caton 2003:227). These changes may be as subtle as a slight change in the size of the fish or shellfish inhabiting the estuary, or as drastic as a complete change of species found in the estuary.

1.2.3 Aboriginal Use of Fish and Shellfish

The numbers and distribution of shell midden archaeological sites in the Macleay River Valley and floodplain suggests a marked reliance on estuarine food sources in the Aboriginal people's economy. Known shell midden sites are clustered around the river delta, inland along the Inner Barrier sand dune system, and along the low-relief hills to the west of the floodplain. Sites are also located on the coast to the south of the Macleay River, on the Maria River tributary, Connection Creek, and along the coast to Crescent Head and further south. It is not difficult to imagine the reasons for such extensive use of the Macleay River and its resources. The waters of the Macleay appear to have contained abundant fish and shellfish, and the mild, sub-tropical climate would make for a very pleasant lifestyle. Fish were caught using a multi-pronged spear either from canoes or the banks and sandflats of the river (Godwin 1988:52). The north coast of New South Wales contains a number of fixed stone-walled fishtraps, however these are not evident on the Macleay. It is feasible to presume that brush fishtraps could have been used in the tidal creeks of the Macleay. The netting of fish is also another option (Pierce 1978:116).

Reports from early ethnographers point to a heavy reliance on marine resources by the Aboriginal people of the mid-north coast (Pierce 1978:117).

1.3 Sea-Level Change in the Holocene

In the big picture of the planet, the direct measurement of mean sea-level has a very short history. The first sea-level gauges were used in Amsterdam (1682) and in Venice (1732), for obvious reasons – these low-lying cities can be subject to severe flooding and a knowledge of the height of tides was important to the citizens (Pirazzoli 1991:1). Although sea-level was not measured empirically in prehistory, there are other methods of judging its effect on prehistoric populations.

Many types of phenomena can contribute to a change in the level of the sea, in a short term decadal sense, such as tides, differences in water density, currents, and atmospheric forcing, a change in atmospheric pressure (Pirazzoli 1991:6). However, the type of sea-level fluctuation which is the subject of my research is medium-term change which may be the result of tectonic activity, including hydro-isostatic rebound (Lambeck and Nakada 1990), or eustatic change. Those sea-level fluctuations are not short-term events and may affect the whole planet or a large part of it. Pirazzoli (1991:6) lists the causal mechanisms for global sea-level fluctuation as:

1. fluctuations in the volume of ocean basins;
2. fluctuations in the mass of ocean water;
3. fluctuations in ocean water density;
4. local or regional uplift or subsidence of the land;
5. gravitational or rotational variations;
6. changes in the atmospheric pressure.

The causal mechanisms of global sea-level fluctuation listed by Pirazzoli operate at different time-scales. The present research is concerned with how a changing sea-level, from whatever of the causes listed above, can be identified in archaeological sites.

1.4 Previous Midden Research

Australia is a country with an extensive coastline, no matter where the sea-level may have been at any point in time. This extensive coastline must be seen as an important area for habitation by prehistoric Aboriginal people, just as it has become since European settlement. Shell middens are important subjects of archaeological studies because they offer opportunities for research into many aspects of how people have used coastal environments in the past. Shell midden sites are relatively common, especially on the east coast of Australia, but perhaps because of the extensive and varied types of coastlines, they are comparatively little studied in this country.

An online survey of research topics related to shell middens on the 26th November 2003 using the *Current Contents* and *Expanded Academic* Databases, with the search term 'archaeological shell middens', produced subjects as varied as: studies in the methodological aspect of archaeology, e.g., Stein et al's research into the rate of accumulation of deposits in archaeological midden sites (Stein et al 2003); conditions of habitability of midden sites (Martinez 2002); the prehistory of the Niger Delta (De and Anozie 2002); alternative explanations of shell mounds (Morrison 2003), which studied animal rather than human accumulation of mounds of shell; research into how archaeological shell middens can be distinguished from naturally formed cheniers (Sullivan and O'Connor 1993); and how shell middens form over time (Needham and Spence 1997). Studies in aspects of human evolution and behaviour which have used shell midden research included those by Parkington (2003) and Thomas (2002), and research from the Southern Hebrides which examined settlement models of human occupation of sites (Mithen 2000). A further broad range of topics including fish catch and variability (Anderson 1997; Cannon 2000; Ross 2001; Rick et al 2001); distributional patterns in shellfish (Stoner 1997); maritime adaptation (Okada 1998; Erlandson and Rick 2002; Hardy and Wickham-Jones 2002; Stiner et al 2003; Richards et al. 2003); fish trading (Barrett 1997); and a broad-based survey including prehistoric shell middens in the eastern Caribbean (Anderson et al 2001).

The results of this survey of the type of research being carried out on shell middens around the world shows the wide variety of research interests amongst those archaeologists who investigate prehistoric shell middens. One type of research, not already mentioned in the online survey, is the effect of environmental change on resource procurement for the people who created the middens, and the subsequent effect on the types of archaeological material preserved within the sites. Only two of the papers revealed by the online search were concerned with the effects of environmental change over time – Morey and Crothers (1988, researched freshwater mussels from western Kentucky shell middens to investigate palaeoenvironments, and Estevez et al (2001), proposed a stable climate for the past 6,500 years from their study of shell middens in Tierra del Fuego.

In Australia, research into environmental change in relation to coastal midden sites and, in particular, sea-level change in the Late Holocene has been somewhat sparse, despite the acknowledgement of many coastal sites being younger than three and a half thousand years. Godfrey (1989:68) proposed that a 'gap' in the archaeological shell midden record in south western Victoria between c. 3,800 BP and c. 1,300 BP was evidence of 'coastal erosion and midden destruction' in the last 4,000 years, whereas the lack of midden sites between c. 7,000 BP and c. 500 BP in the Robe Range region of South Australia was described as an opportunity to study the rate of environmental change (Cann et al. 1991:174). Hiscock and Mowat (1993:24) acknowledge that changing environmental conditions since the Mid-Holocene in the Kakadu region have most likely contributed to the changes evidenced in the shellfish species represented in midden sites, but more research was needed to find the cause of the changes in resource procurement and use. Likewise, Hall (1982:92) proposed that more research, and in particular more radiocarbon dates, was needed before factors which determined the use of the Moreton Bay region, only in the last 2,000 years, could be determined.

A number of explanations have been proposed for changes seen in faunal assemblages from archaeological sites over time. Lourandos (1983a) argued for changes in socio-economic factors within Australian Aboriginal populations as the cause of an increase in productivity reflected in increasing numbers of sites and cultural remains in the Late Holocene. Bowdler (1976) proposed that a change in shellfish and the appearance of shell fish hooks in the archaeological sequence over time was related to changing food procuring practices by the women of the Bass Point area. Changes in technology and a consequent increased efficiency have also been posed as reasons for changing faunal assemblages over time (Morwood 1987). Taphonomic processes may also alter faunal assemblages, causing the appearance of a change over time when it does not exist (Lyman 1994). These are all possible reasons why a change in faunal assemblages over time may be evidenced. However, my concern in this research is to primarily explore correlations in environmental change before accepting cultural change, as the type of environmental change I am investigating is likely to have a greater impact on coastal populations.

The Australian debate has polarised into two 'camps'. The 'cultural' determinists and the 'environmental' determinists (Rowland 1999:144). Hall and McNiven (1999) provide a comprehensive coverage of the most recent research of coastal sites in Australia, and the debate between the two theories is presented in this publication. Barker, in his research in the Whitsunday Islands of Central Queensland, found that marine resources were not particularly affected by post-glacial environmental change, and that the most significant environmental changes related to sea-levels had occurred in the Late Pleistocene and Early Holocene (Barker 1999:120-125). Whilst Barker (1999:125) believed that too much emphasis had been placed upon using environmental change to explain the archaeological record in Australia, Rowland proposed 'significant fluctuations' in sea-level for the nearby study site on Keppel Island (Rowland 1999:148). Rowland's (1999:149) proposal for more research to be carried out on a regional level has been taken up by Hall (1999) for the Moreton Bay region in Southern Queensland. However, Hall explains the changing pattern of archaeological sites in this region by progradation of the shoreline after the 6,000 BP stabilisation of the coastline (Hall 1999:173). Because the body of research into changing sea-levels and coastal shell middens is somewhat limited for Australia, I have widened my literature review to include research carried out on tectonically unstable coastlines as well as landforms with a similar tectonic history to Australia, such as South America and South Africa.

1.4.1 Previous Research Into Middens and Sea-Levels

Research in palaeo-environmental studies involves interaction between humanities research and natural science disciplines such as geomorphology, geology, ecology, zoology, soil science, botany and climatology (Butzer 1971:3). 'Environmental archaeology' is about examining human ecology from an archaeological perspective and with the integration of multi-disciplinary research. There are inherent dangers in 'borrowing' theories from other disciplines (Hardesty 1980:161), the least of which is using the 'borrowed' theories for purposes for which they were not intended, which may lead to a simplification of what are really very complex problems and questions. Simply because two events occur at the same time, does not mean that the same causal processes can be defined. It may be that the events are related, or it may be that they are interdependent or independent.

Determining environmental change from the contents of shell middens is not straightforward; it relies on networks of indirect evidence linking together to create a picture of the environmental conditions prevailing at the time of occupation of a site. Geological and geomorphological research in Australia has proposed an hypothesis which, if valid, may have had major implications for the people who occupied coastal sites, and the addition of archaeological evidence to these theories of sea level stability can only add to our understanding of the Late Holocene. Kearney states this well in commenting that, "As testaments to human interactions with the coast, archaeological data add an appealing dimension to sea level studies …" (Kearney 2001:21).

The effect of proposed fluctuating sea-levels on coastal sites has large implications for the archaeological study of midden sites, which has not been fully realised in Australia.

The prevailing thought in Australian archaeology on sea level stability during the Holocene is that sea levels stabilised at around 6,000 BP, giving the shoreline of the continent that we know today (Mulvaney and Kamminga 1999:223). However, new theories of sea-level instability in the Holocene run counter to this view by suggesting that the sea has actually risen and fallen a number of times since the Mid Holocene (Baker et al. 2001). Along with the assumption by archaeologists in Australia of stable sea-levels in the Late Holocene after the sea rose after the last glacial maximum, came the supposition that only coastal sites from the Early Holocene and Pleistocene would have been affected by rising sea-levels; and thus, that the sites which remained represented the time period since 6,000 BP. But if sea-levels have not remained stable for the past 6,000 years, this has some major implications for Australian coastal archaeology, in that a lot of sites from the Late Holocene may have been destroyed during a Late Holocene sea-level fluctuation. If sea-levels rose at, for example, 4,000 BP, shell midden sites located on or near the foreshore may have been destroyed, or covered and reworked by the ocean, as has been suggested for Pleistocene and Early Holocene sites. Baker et al's (2001) research, which is discussed in detail in Chapter 2, suggests that at least two sea-level rises have occurred during the Late Holocene, further reducing the likelihood that coastal shell midden sites represent substantial periods of occupation during the Holocene.

Etheridge had proposed an unstable sea-level as early as 1896 (Etheridge 1896). This research was substantiated by Fairbridge (1961), but appeared to have not been well-received throughout the geomorphological and geological disciplines until quite recently, when sea-level researchers have proposed that changes in sea-level may have occurred in the Late Holocene. Further, a growing body of researchers has proposed that the changes in sea-level are not only the result of post-glacial hydro-isostatic rebound, but may have occurred eustatically as a rapidly fluctuating sea-level, rising or lowering between one and two metres in depth over comparatively short time frames (Pirazzoli 1991; Mundell 2000; Baker et al. 2001).

The current climate of increasing doubt that sea-levels were as stable as was previously believed, combined with my being granted the opportunity to examine material from suitable case study sites in the Lower Macleay, has therefore served to provide the ideal opportunity for researching the potential of archaeological and geomorphological evidence to complement one another in addressing questions about coastline formation and occupation. To this end, the specific objectives of this research are outlined as follows.

1.5 Specific Objectives

The specific objectives of this research are:

1. To examine the use of shell middens as indicators of shoreline change.
2. To investigate the relationship between proposed sea-level models and shell middens on the eastern Australian coast.
3. To investigate two different models of shoreline change on the barrier coast region of the Macleay River, based upon geological, geomorphological and ecological information.
4. To test two alternative hypotheses about shoreline change through the re-analysis and re-dating of two archaeological sites now located on the Lower Macleay floodplain.
5. To determine whether changes observed in the marine faunal component of the archaeological assemblages in these two sites over the Late Holocene time period are consistent with the new sea-level models.

1.6 Limitations of the Research

Research in palaeo-environmental studies involves interaction between humanities research and natural science disciplines such as geomorphology, geology, ecology, zoology, soil science, botany and climatology (Butzer 1971:3). 'Environmental archaeology' is about examining human ecology from an archaeological perspective and with the integration of multi-disciplinary research. Simply because two events occur at the same time, does not mean that the same causal processes can be defined. It may be that the events are related, or it may be that they are interdependent or independent. A keen awareness of these possibilities, and of the potential for misapplication of theories derived from other disciplines, led me to secure expert help from geomorphologists as I was conducting this research.

Similarly, the major difficulty with researching the relationship between coastal midden sites and a fluctuating sea-level is the problem of differentiating between a changing sea-level and other causes of shoreline change. However, equifinality is a problem shared with much archaeological research, and I endeavour in my investigations to consider all of the causes of shoreline change in order to allow conclusions to be drawn about the likelihood of each causal factor.

The inherent limitations of studying material that was excavated thirty years ago are also numerous, and in Chapter 4 I explain in detail how I overcame some of the restrictions that these imposed.

1.7 Outline of Chapters

Following on from this introductory chapter, Chapter 2 focuses on the theoretical aspects of determining environmental change from archaeological sites, and how sea-level fluctuation has been proposed on a world-wide basis. I begin by examining the variables which are required to infer sea-level change from archaeological remains. Also, I will examine how researchers have inferred sea-level change from archaeological midden sites. I examine how the belief in a stable shoreline for Australia for the past 6,000 years has evolved, and how the proposed sea-level fluctuation theories impact on coastal archaeological research in Australia. The new theories of sea-level change in the Holocene proposed for the east coast of Australia are then presented. An understanding of estuarine formation and ecology and the ecology of shellfish and fish populations within an estuary is integral to this research, therefore I will also investigate how environmental change affects these habitats and the fauna which inhabits them. I will also discuss how a changing environment could affect Aboriginal people occupying coastal regions, and propose models for how the shoreline would change in the event of a changing sea-level. Finally in this chapter I will examine how the problems of equifinality can be addressed in archaeological research.

In Chapter 3, I present a background to previous research – archaeological, geomorphological, and geological – carried out in the Lower Macleay. From this review I determine what was 'known' about the Macleay archaeological sites prior to the current research project, and suggest what I believe is missing from this body of knowledge. In doing so, I identify which of the beliefs about the Lower Macleay may be in need of further investigation, and explain how the present research can act to fill gaps in our understanding of this area.

In Chapter 4, I outline two alternative hypotheses for how the Macleay estuary and floodplain have developed over time, and model the differing effects upon the environment that would be predicted by the two hypotheses. I describe the behaviour and habitat of the shellfish and fish which currently inhabit the Macleay region, to understand how environmental change would affect each of these species. I then discuss how I interpret the depositional history of both of the sites, and the methods that I use to re-examine the assemblages from both of the case-study sites. Taphonomic and methodological issues, such as the estimation of size of fish represented in archaeological assemblages, are also discussed here.

Chapters 5 and 6 assemble and present all of the archaeological data that were made available to this research from the excavations carried out at Clybucca in 1972 (Chapter 5) and Stuarts Point in 1975 (Chapter 6). Stratigraphy and contents of the middens are described using the field notes and drawings from the excavations, and the results of my re-examination and re-identification of the shellfish, fish and terrestrial animal remains is presented.

Chapter 7 presents my analysis of the data obtained from Chapters 5 and 6. In it I group the arbitrary spits and the assemblages from each spit into Analytical Units in order to determine any evidence of change over time in the marine fauna excavated. I examine the shellfish data for evidence of changing patterns in the species deposited, and I analyse the fishbone assemblages from both of the sites for changes in predominant species or size of fish represented over time. I then examine the analysis of the assemblages in relation to the hypotheses proposed in Chapter 4 to determine if either of the hypotheses can explain the findings from the analysis of the archaeological assemblages.

In Chapter 8 I present a discussion of my findings: from the literature reviews; the models proposed for environmental change in the Macleay, and the results of the re-analysis of the archaeological marine faunal assemblages. I address the specific objectives presented in section 1.5 of this chapter, and discuss any patterning which may indicate environmental change (as posed in the hypotheses and models in Chapter 4). I also canvass any other explanations for the patterns seen in the archaeological assemblages. In the final section of this chapter I present my conclusions about this research, and propose suggestions for future research which could advance the knowledge of the analysis of coastal shell midden sites in Australia.

1.8 Conclusion

In this chapter I have presented my broad aims for this research, as well as the more specific objectives which I have defined for the present study. I have presented an introduction to my study area, to the study of middens and to the concepts of sea-level change in Holocene eastern Australia. I have also outlined some of the difficulties in observing environmental change in the archaeological record. A review of theories of changing sea-level and how it can be inferred from archaeological sites will be presented in the following chapter. I will examine how the concept of a stable Australian coastline has come about in this country, and how this concept has been challenged in recent times. I also look at the effects of a changing sea-level on estuarine environments and the shellfish and fish which inhabit these environments. Finally in chapter 2 I examine the consequences of a changing shoreline on human populations, and explain how I address problems of equifinality.

Chapter 2: Sea-Levels and Middens: Identifying and Understanding Environmental Change

2.1 Introduction

The aim of this chapter is to review the current understanding of the links between sea-levels and middens, and to provide context for the current research. In this chapter I discuss the way in which archaeologists have used midden sites to infer shoreline change in prehistory. I also examine how views of a stable coastline for Australia during the Late Holocene have developed, and consider the implications for archaeology if this view proves to be false. This chapter then introduces the proposals of Baker et al. (2001) that sea-levels have not been stable in Australia in the Late Holocene. In order to establish the relevance of the study area for addressing the question of sea-level instability, I then present a preliminary analysis of the relationship between location of shell midden sites and their dates in northern New South Wales. The next part of this chapter presents a discussion of information relevant to understanding the impact of changing sea-levels on estuarine ecology and the ecology of fish and shellfish. I then discuss the consequences of changing sea-level on human populations and explain how I address the potential impact on this type of research of differentiating between multiple causal factors.

2.2 Understanding Sea-Level Change

Sea-level change as it affects coastal midden sites is a new area of research in Australian archaeology. This research has not only been stimulated by the disciplines of geology and geomorphology, challenging long-held theories of sea-level stability on the Australian coastline, but also by the need of archaeologists to understand patterns evidenced in coastal middens and the effect of coastline instability on the people inhabiting the sites. This is discussed in Section 2.9 of this chapter.

The identification of changing palaeo-environments, such as changes in sea-levels, from archaeological shell midden sites poses numerous challenges. Dincauze (2000:78) identified the requirements for determining environmental change from changing cultural choice, as the identification of the crucial variables in a situation, identification of the mechanisms that link the variables, and the identification of equifinalities.

In order to identify the crucial variables, or indicators of environmental change, I review research which has attempted to identify changes in sea-level from archaeological sites. That research has mostly been carried out in countries other than Australia. In fact all of this research appears to be from other countries. Hall and McNiven (1999:3) described prehistoric responses to sea-level change, or marine transgressions, as a 'key chronological question' for Australian coastal archaeology. However, in Australia, there is still a widespread belief among archaeologists that sea-levels stabilised around the continent some 6,000 years ago. Mulvaney and Kamminga (1999:223) state that 'by 6000±250 years BP the sea had risen to about its present level'. Australian archaeologists have not fully recognised newer theories of sea-level fluctuation in the Late Holocene, and therefore the avenues for research into this topic in this country have been limited.

Through the review of the overseas literature on changing sea-levels and archaeological sites I determine which variables other researchers have identified as crucial for determining and measuring sea-level change in archaeological sites (these variables are then utilised in my models of sea-level change in Chapter 4). Supporting evidence for climate change and in particular, fluctuating sea-level in the Late Holocene is proposed for many parts of the world. This is discussed in section 2.3. Other evidence from a geological and geomorphological perspective indicating a fluctuating Late Holocene sea-level has been proposed for the South China coast (Davis et al. 2000), the central Great Barrier Reef in north eastern Australia (Larcombe et al. 1995), and on the French Atlantic coast (Ters 1987), supporting Franzen and Larssons' (1998) hypothesis that variation in global climate and sea-level was a feature of the Late Holocene world-wide.

The genesis of the belief that sea-levels have been relatively stable on the Australian continent for a large part of the Holocene, compared to lands which were covered by ice during the Pleistocene ice-age maxima, is discussed in the fourth section of this chapter. In this section I examine Australian archaeological texts from the late 1960s to the present in order to identify the origins of the belief that the Australian coastline has remained stable for the past 6,000 years, and some of the research that this theory is based upon.

The arguments for and against fluctuating sea-levels during the Holocene will be discussed in section five of this chapter. This involves introducing concepts of sea-level variation which have been re-introduced in environmental research in the last decade, based on geological and geomorphological research.

A preliminary test of the hypothesis that sea-levels have fluctuated during the Late Holocene on the northern coast of New South Wales is carried out in section three of this chapter. If sea-levels have fluctuated, this would be reflected by the locations of dated midden sites on the northern coast of New South Wales.

As my research is concerned with identifying environmental change through the study of archaeological marine faunal assemblages, I examine the ecology of estuaries and the estuarine biota in sections seven and eight of this chapter. I discuss the mechanisms within the estuarine environment which affect that environment, and also the marine life which inhabits estuaries, and how changing habitats can affect these populations. Environmental change affecting the areas of resource procurement has to be considered when a change in marine resources deposited in a shell midden over time are identified (Ambrose 1967; Sim 1999:267), and these assemblages may provide evidence of environmental change, complementary or otherwise, as proposed by researchers in other disciplines.

In section nine I consider some of the consequences of a fluctuating sea-level on the human populations occupying the coastal environment. Here I examine how the coastline changes during transgressive and regressive events would affect varying types of coastlines, with particular emphasis on the large barrier coastline of northern New South Wales.

A major issue which has to be considered in research of this type is equifinality. That is, whether more than one causal factor could be responsible for the patterns seen in an archaeological assemblage. This issue is discussed in the final section of this chapter.

2.3 Using Archaeology to Infer Changing Sea-Levels

There is extensive research into environmental change affecting past hunter-gathering societies, for instance, the onset of domestication of plant and faunal resources in the Middle East, Europe and the Americas (Butzer 1971), and to some extent the effect of Aboriginal firing of the landscape in Australia (Singh et al. 1981; Clark 1983; Head 1983), but, very few on sea-level change. In this section I will concentrate on those studies which have attempted to identify sea-level changes from the archaeological record. As these studies will show, sea-level fluctuation is only seen in the archaeological record indirectly, through the principles of uniformitarianism, and the compilation of various different data sets. By incorporating numerous disciplines into the study of archaeological questions, each with their own strengths, researchers may be able to limit the number of causal possibilities for the phenomena they are studying (Dincauze 2000:35).

Identification of the variables related to identifying environmental change and the mechanisms that link these variables is one topic where archaeology can use research from other disciplines (Butzer 1971:3; Hours and Copeland 1998:231; Modderman

1998:59; Moore and Denton 1998:25). One of the strengths of an inter-disciplinary study is the outcome of knowledge which one discipline alone cannot achieve, and using that research to expand and strengthen archaeological research. By incorporating research outside the archaeological discipline the number of variables which may be responsible for complex systems, or ranges of phenomena, may be able to be defined, and in some instances, limited. As each discipline contributes its own theories and hypotheses, uncertainties as to the mechanisms of environmental change can be revealed. The causal factors that produce a relative rise or fall of sea-level in the medium time period, for example one or two thousand years, include climate change, either warming or cooling, and expanding or shrinking of ocean basins along with rise or subsidence of coastlines through tectonic forces, and in the case of estuaries, infilling with sediments. The present review of literature is not concerned with the primary causes of sea-level change, but with the effects of sea-level change as it may influence the archaeological record.

The over-riding effect which becomes evident from the literature reviewed is location of midden sites. Researchers rely on the location of prehistoric middens to evaluate where the sea may have been situated in the past. If middens containing marine fauna are located at a distance of ten kilometres away from the present seashore, it may be interpreted as a change in sea-level, or in special cases, infilling of the waters by sediments, because it has been shown (Meehan 1982:118; Waselkov 1987:114) that food resources, such as shellfish, are not transported a great distance from their collection environment before consumption. Despite the dangers of the use of analogy in archaeological research (Gifford-Gonzales 1989:43; Wylie 1989:2; Gifford-Gonzales 1991:217), ethnographic evidence suggests that shellfish are not transported great distances to habitation sites. Consequently shellfish remains found in midden sites may be evidence of the surrounding environment at the time the middens were being formed. Environmental change in a resource procurement environment has to be considered when a distinct change in marine resources deposited in a midden over time is identified (Ambrose 1967; Sim 1999:267).

Further evidence for a perceived changing sea-level may then be gained from analysis of oxygen isotopes from shellfish, faunal variabilities, and radiocarbon dating. Evidence of past environmental change is difficult to see in the archaeological record, therefore the recognition of the location of prehistoric middens as evidence of sea-level fluctuation is important, because it provides at least a starting point for the investigation of past shorelines. When it is established that middens are located at a distance from present-day shorelines, further evidence can be obtained about past sea-levels from other sources.

In the following section of this chapter I will review how researchers overseas have interpreted sea-level change, both in the Pleistocene and Holocene periods, and the types of evidence which have been used in the research.

2.3.1 Inferring Sea-Level Change in Archaeology – The Evidence

Environmental archaeology has been used in quite diverse ways to elicit information on the effect of climate on the lives of prehistoric peoples. Some of the studies reviewed appear to use archaeological evidence as a means of directly identifying past climates through the identification of, for instance, shell midden sites in locations which would no longer be viable for the collection and consumption of marine fauna, because they are now located some distance from the sea. While sea-level change is not able to be seen directly in the archaeological record, the location of middens containing marine fauna which are now located far inland from the sea is evidence of either a change in the positioning of the sea, or a change in the gathering and transportation of foodstuffs. Other researchers attempt to interpret past behaviours from the environmental record contained within archaeological sites. The reconstruction of the environmental context of an archaeological site is fundamental to our understanding of how humans functioned in the past, not only on an individual level but also on a societal level (Davidson 1988:19). Despite the fragmentary nature of archaeological evidence, it is no longer desirable to study a site as a homogenous unit without taking into account the landscape in which it belongs, and the wider environmental factors affecting the people who inhabited the 'site'.

Suguio et al. (1991) constructed sea-level fluctuation curves for the Brazilian coast for the last 7,000 years. The Brazilian research focused upon the reconstruction of past sea-levels based upon the present location of middens (Sambaqui) in the landscape, correlating sea-level change along with the location from which the shellfish were gathered in a lagoon environment as it also changed with the fluctuations of the sea. Suguio et al. proposed that the position of the inland shell middens can only be explained by higher sea levels at some points in the prehistory of the region (Suguio et al. 1991:92). Oxygen isotope components of the shells excavated from the middens were analysed to determine which areas of the lagoons the shellfish were derived from. Shells derived from the deep, central sections of the lagoon exhibited more negative $\delta_{13}C$ values than those from shells derived from near the sea-edge of the lagoon, because poor circulation in the middle of lagoons allowed the shellfish to take up more carbon from decomposing terrestrial plants which had been washed into the lagoon and settled in the deeper areas in the centre of the lagoon (Suguio et al. 1991:88).

By using the oxygen isotope data along with the radiocarbon dates of the molluscs from shell middens, many of which are now located up to 35 kilometres inland from the present shore, Suguio et al. proposed a sea-level higher than the current sea level by five metres at c. 5,000 BP, followed by a sharp decline in sea level at 4,000 BP to around a metre below present levels, rising again to approximately two and a half metres above present at 3,500 BP, followed by a gradual decline to the present level (Suguio et al. 1991:96) (Figure 2.1).

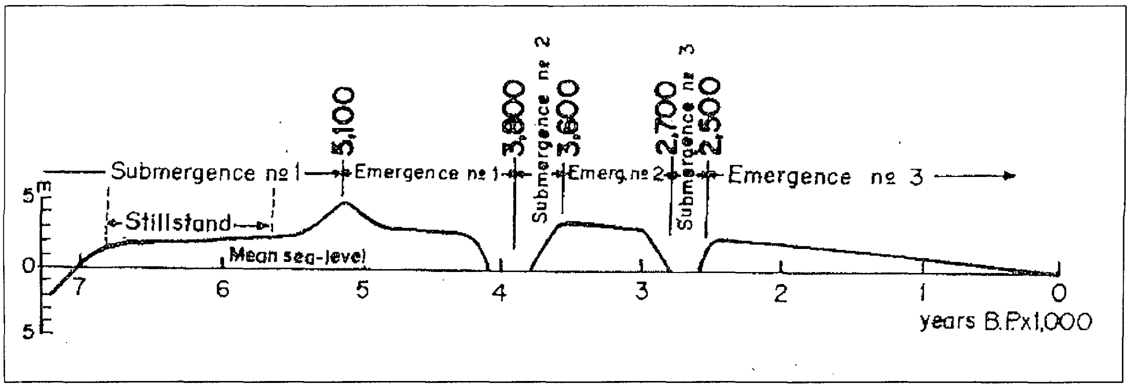

Figure 2.1 Holocene Sea-Level Curve for Brazil (Suguio et al. 1991)

This study illustrates the use of the evidence of location of shell middens in the landscape. As well as the evidence of the distance of the middens from the present shoreline, Suguio et al. attempted to ascertain the height above present day sea-level of the substrate of the abandoned middens. This was not as successful as the substrate underlying the middens consisted of sediments which became compacted under the weight of the shell midden. The authors have used multiple lines of evidence, the location of the middens, oxygen isotope analysis and radiocarbon dating, for the evaluation of sea-level change over time. Suguio et al. reiterate in their conclusions that it is not possible to directly locate prehistoric sea-levels spatially or temporally from the shell midden sites, but that the midden would have had to be above the high water mark at the commencement of the deposition of cultural remains at the site (Suguio et al. 1991:97). Relating this to the lifestyle of the prehistoric population, the authors believe that their research supports their hypothesis that the people did not carry shellfish over great distances, but instead moved their occupation sites to where the shellfish were readily available, thus reflecting the movement of the sea spatially in the landscape.

Research from Alaska investigating migration routes into North America have found significant variations in the sea level within those studies (Fedje and Christensen 1999). Unlike Brazil or the eastern coast of Australia which are not believed to be affected by glacio-isostatic adjustment, Alaskan coastlines would have been subject to the effect of rebound after the last glacial maxima. However, Fedje and Christensens' study is still relating sea-level change to archaeological sites, even though in this case it is the land which has moved in relation to the sea. Again, location of midden sites was an important variable, placing the sites in the context of sea-level change over time. Fedje and Christensen (1999) used geological and geomorphological models, and stone tool typology, to model post-glacial sea level fluctuations in Alaska during the Holocene. In this research it was found that sites situated some 15 to 20 metres above the present shoreline were dated to between 9,000 and 5,000 BP, while those dated to between 5,000 and 2,000 BP were situated down the slope of the shoreline, closer to the current high-water mark. That is, the younger sites were located at a lower elevation than the older sites (Fedje and Christensen 1999:9) indicating that relative sea-levels had become lower in the Late Holocene because glacio-isostacy had led to a rapid uplift of the shore, in comparison with the terminal Pleistocene relationship between the land and the sea-level. As with the Brazilian research (Suguio et al. 1991), the understanding that shell midden sites would be located at or near shorelines is implicit in the Alaskan research, though further evidence from other disciplines (geology and geomorphology), stone typology, and radiocarbon dating were used to support the evidence of location of the sites close to the shoreline.

Johsenhans' et al. (1997) research in British Columbia, another location which is likely to be affected by glacio-isostatic rebound, looks at the importance of location of sites from the opposite aspect to Suguio et al. (1991) and Fedje and Christensen (1999). In the British Columbian case, the authors proposed that the lack of evidence of sites in the early post-glacial phase of occupation could be directly attributed to rapidly changing sea-levels following the Pleistocene glacial maximum caused by eustatic sea-level rise and glacio-isostatic movement (Josenhans et al. 1997:71). This study highlights the point that lack of evidence is not evidence of absence, and the importance of sea-level change in the investigation of coastal midden sites. Johansens' et al. (1997) took cores from former subaerial basins in British Columbia in order to date wood retrieved from the palaeo-contacts between the freshwater and marine sediments, and analysed the diatoms contained within this record. The diatom record showed transitions from freshwater species to marine species, followed by species tolerant of brackish waters, back to freshwater species, at a site which is now located some 16 metres above the present day sea-level (Josenhans et al. 1997:73). They collected 267 radiocarbon dates, and were able to develop terrain models from these, and the use of topographic and bathymetric maps for the region. They found that the sea level had varied between –153 metres and +16 metres compared to the level of the sea today between the years 14,000 and 10,100 BP (Josenhans et al. 1997:5). From this research Josenhans et al. proposed that the search for archaeological sites dated to before 9300 BP would not be fruitful as they would now be deeply drowned, whereas sites dating to 9100-5000 BP would be located in the forest approximately 15 metres above the present shoreline.

Josenhans et al. (1997) and Fedje and Christensen (1999) were researching the probable timing of the migration of people into North America, and indirectly, changes in sea-levels since the final glacial maximum of the Pleistocene. By gaining a picture of where the level of the sea had been at times in the Late Pleistocene and Early Holocene through geoarchaeological research, they were able to set up predictive models for where sites could be located at various times in the past, therefore modelling where and when migration into North America could have occurred. Site location still appears to be the most important criterion in the study of palaeo-shorelines, and the change in the location of coastal sites a prominent variable.

Van Andel's research on changing sea-levels on the Southern South African coast, another passive margin coastline, tectonically stable as is Australia and South America, looks at site location from a different point of view to the previous research reviewed. While the sites referred to in Suguio (1991), Josenhans et al. (1997) and Fedje and Christensen (1999), were able to be related to a changing sea-level, and therefore people moving their habitation sites as the sea-level changed, the sites researched by van Andel (1989) remain in fixed positions in the landscape. Instead van Andel studied the contents of the sites recovered in excavations to determine if there had been a change in resource procurement during the Late Pleistocene which would indicate a varying distance from the sea, where the shellfish resources were located, to the occupation sites in caves. Bathymetric maps were used to plot Late Pleistocene shorelines for Southern South Africa (van Andel 1989). Van Andel found that even though distances from the sea to the occupation sites in caves, during periods of glaciation in the Late Pleistocene, were never a deterrent to the use of marine fauna, until c. 75,000 BP when distances between the shoreline and the occupation sites increased to perhaps more than 30 kilometres (van Andel 1989:134), a similar distance to the relationship between the older midden sites and the present shoreline in the sites researched by Suguio et al. (1991). The author proposed that this led to a greater reliance on plant foods rather than shellfish by the inhabitants of the sites.

Clearly, the authors of the papers cited in this section believed that their research had indicated sea-level fluctuation over time, and had to some extent related this to the lifestyle of the prehistoric people. All found that site location is the most important variable in understanding palaeo-sea-levels. When the positioning of midden sites in the landscape changes, researchers then have to ask why people have moved their habitation sites, and can this be contextualised in the study of changing sea-levels. The alternative outcome of the hypothesis in the location of midden sites in relation to changing sea-level is the absence of sites which have been destroyed by a rising sea-level. Josenhans et al. (1997) predicted that sites dated prior to 9,300 BP would not be located on the British Columbian coast because they would have been drowned by changing sea-level due to eustatic sea-level rise and glacio-isostatic movement – a similar argument to this has been proposed by Australian researchers as being the result of sea-level rise after the last glacial maximum (Bird and Frankel 1991:6).

The other variable to be considered when researching changing sea-levels from shell midden sites is the contents of the midden itself. Does the archaeological assemblage change over time and can these changes be linked to changing sea-levels? As van Andel (1989) proposed for the southern African sites, a change in the food remains represented over time was an indication of a change in the resource procurement areas for the site's inhabitants. If the sea-level had lowered to the point where it was no longer viable to gather marine resources, this would be reflected in the contents of the midden site. In the South African study this was evidenced by a decrease in the amount of shellfish represented in the assemblage, accompanied by an increase in terrestrial resources. This is one form which the evidence may take, however changing sea-levels in relation to habitation sites may also be evidenced by a change in the marine resources, which can be attributed to a replacement of former species occupying the waters adjacent to the site, with species more tolerant of the changing conditions. Jerardino (1997:1031), studying a changing shellfish composition in the archaeological assemblages from a midden site located on the West coast of South Africa, concluded that changes in water turbidity could explain the variability in the mean size of black mussels recovered from the site.

Another point which all of the cited studies have in common is the importance of precise chronology for the sites or phenomena being studied. Without a means of placing events in time these studies would not be possible. Josenhans et al. (1997) obtained 267 radiocarbon dates for their study of sea-level variation in British Columbia. Limitations may be placed on research into palaeo-environmental reconstruction in Australian archaeology by the lack of chronologies precise enough to allow for comparisons to be made intra- and inter- site, and the dearth of fine-grained palaeoecological data (Cotter 2001:162). This has not appeared to be a problem in studying coastal shell middens in Australia while the prevailing belief was that the middens could possibly represent coastal occupation for a considerable amount of time during the Holocene period. However, with the possibility now presented that the coastline may not have been stable over the time-frame from the mid- to late-Holocene, the opportunity is offered to refine these hypotheses further.

In conclusion, the key variable archaeologists have measured when studying potential sea-level changes over time is site location, either a geographical change in the location of the sites, or the lack of sites where they could have been expected to exist. The second variable is the contents of the middens. Changes in the archaeological assemblages over time may be indicative of changing environmental conditions in the proximity of the site. The mechanism which links the variables is the changing position of the seashore itself.

In order to use shell middens as indicators of shoreline change, specific information is needed – such as sea-level information and chronology; and the use of multiple lines of evidence, not just a reliance on the changing contents of shell midden assemblages.

The following section looks at how the belief in a stable Australian coastline for the past 6,000 years has come about.

2.4 Australian Archaeology and Changing Sea-Levels

One of the limiting factors in the comprehensive study of fluctuating Holocene sea-levels in Australia was that the model of a stable coastline for the past 6,000 years has been accepted in Australian archaeology for many years.

> 'The sea rose from the peak of the last glaciation onward ...
> reaching roughly modern levels by 6000 BP Littoral communities
> became more productive thereafter ...' (O'Connell and Allen 1995:856).

The historical background to our understanding of the concept of Late Holocene stability of the coastline will be discussed in this section, through an examination of Australian archaeology texts which have been used extensively since the late 1960s in Australian universities (*The Prehistory of Australia*, Mulvaney 1975; *Sunda and Sahul*, Allen, Golson and Jones 1977; *A Prehistory of Australia, New Guinea and Sahul*, White and O'Connell 1982; *Archaeology of the Dreamtime*, Flood 1983; *Prehistory of Australia*, Mulvaney and Kamminga 1999). These texts covered a broad range of information and collected together the results of a variety of research, offering an overview of Australia's long history of human occupation. Information on Holocene sea-level stability was presented as it was understood at the time, though this was a somewhat limited area of research in a country with such an extensive coastline. Archaeological research lacked specific questions in regard to changing sea-levels, and the status-quo was maintained throughout the decades, until the present (for example Lourandos 1997:312; Mulvaney and Kamminga 1999:223). The limited research which was available on the topic of the Australian coastline was the only source from which archaeologists could contextualise their investigations of coastal site occupation.

In Australian archaeological studies in the latter half of the twentieth century, many of the references to sea-level fluctuations are concerned with how the changing sea-levels would have affected migration into Australia during the Pleistocene. The theories of the settlement of Australia by Aboriginal people proposed that the most advantageous time for people to travel to the continent from south-east Asia is closely related to the times when the sea-level would have been at its lowest during the ice-ages (Mulvaney and Kamminga 1999:105).

Sea-level curves presented in archaeological publications between the 1960s to the present, propose quite detailed projections of sea-levels during the Pleistocene, but with very little consideration of where the coastline was situated after the flooding of the Bass and Torres Straits between 12,000-8,000 BP (Mulvaney 1975:137; Chappell and Thom 1977:281 [in Allen, Golson and Jones]; White and O'Connell 1982:45; Flood 1983:29; Mulvaney and Kamminga 1999:106). This is understandable given that the research questions were focused upon migration into the continent, and that the Holocene period comprises a relatively short time frame in comparison to the Pleistocene. No detailed consideration was given to any change of sea-level during the Holocene, even though this was also a time period when possible sea crossings were made from Asia to Australia, as evidenced by the introduction of the dingo after 4,000 BP (Mulvaney and Kamminga 1999:260).

For example, one of the earliest texts used as a teaching resource for Australian archaeology (Mulvaney 1975) presents a sea-level curve for the time period between 16,000 BP and 5,000 BP in connection with the site of Koonalda Cave, located in the Great Australian Bight (Mulvaney 1975:136-137) (Figure 2.2). The sea-level is shown as rising gradually, from 300 feet (91 metres) below the present sea-level to approximately 150 feet (46 metres) below the present sea-level between 16,000 BP and 12,000 BP. This is followed by a sharp rise from the 45 metre point to approximately 91 metres, reaching a point where the sea is at the same elevation as Koonalda Cave. Emphasis is placed upon the loss of 'territory' during the Late Pleistocene transgression, and the consequent loss of coastal midden sites (Mulvaney 1975:136), but how and if the sea retreated to its present position is not discussed. This is a common occurrence in the literature, where it is stated that sea-levels have changed since the last glacial maximum of the Pleistocene, but the details of the change are not discussed.

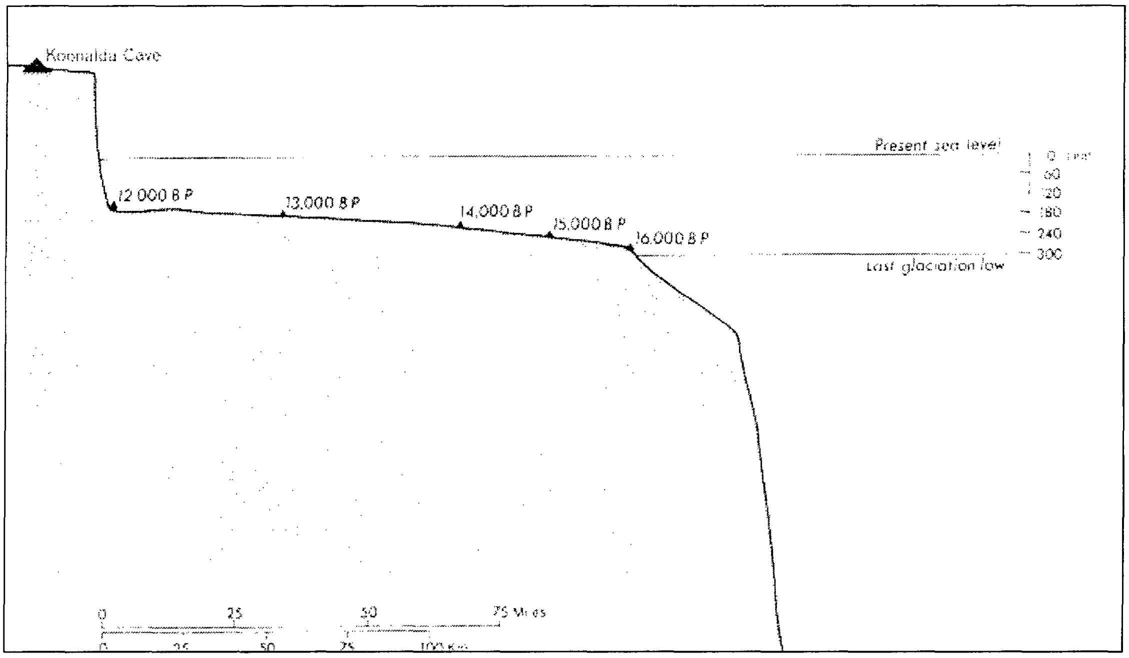

Figure 2.2 Sea-Level Curve for the Great Australian Bight (Mulvaney 1975)

Australian archaeological texts were based upon the research of Thom (1965), Thom et al. (1969), Thom and Chappell (1975) and Chappell and Thom 1977, and were in agreement that sea-levels stabilised at approximately 6,000 BP (Mulvaney 1975:128; Bowdler [in Allen, Golson and Jones] 1977:213; Jones 1977:342 [in Allen, Golson and Jones]; White and O'Connell 1982:49; Flood 1983:218; Mulvaney and Kamminga 1999:226), implying that the mean sea-level remained exactly as it is at present, with the only variation to high-tide level being through storm or cyclone events. For nearly forty years archaeological research has ignored the early geological research on fluctuating sea-levels in the Late Holocene (Fairbridge 1961), and continued to follow the 6,000 years of sea-level stability proposed by Thom (1965). The estimates of the date of this stabilisation vary in the texts from 7,000 BP to 5,000 BP, with one suggestion of as late as 3,500 BP (Mulvaney 1975:128). All of the texts are in agreement that the coastline has been stable for at least half of the Holocene, and this theory has not been questioned in archaeological research in this country until quite recently when Baker et al.(2001) proposed that the effects of sea-level fluctuation could have consequences for the study of coastal archaeological sites. There was no reason to question the 'fact' of the stable coastline while proposed sea-level curves for the entire Quaternary included the whole of the Holocene as almost an afterthought. There also appears to be some confusion as to whether the sea was regressing or transgressing prior to the 6,000 BP 'stabilisation' in the archaeological texts. Mulvaney (1975:137) showed the sea-level as higher than present at approximately 5,000 BP (Figure 2.2), implying that a regression event took place after this time.

Other authors proposed a continual transgression of the oceans after the last glacial maximum until sea-levels reached their present height. For example, White and O'Connell proposed that the sea rose to near its present height at approximately 8,000 BP (1982:99) allowing the formation of coastal shell middens along extant shorelines (Figure 2.3), based upon Chappell's (1976:14) research.

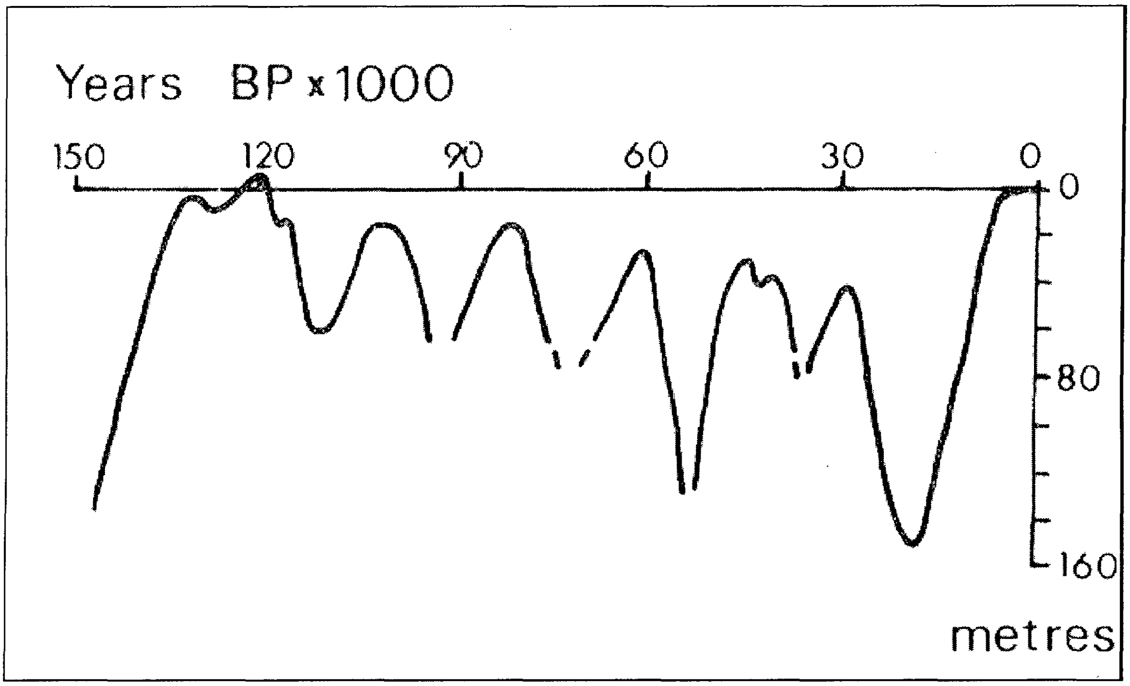

Figure 2.3 Quaternary Sea-Level Curve (White and O'Connell 1982:45)

Using the research of Thom et al (1965, 1969, 1975, 1977) Bowdler proposed that the sea reached its present level between 8,000 BP and 6,000 BP (1977:213), and Jones also proposed that the sea was rising and reached the present coast between 8,000 BP and 7,000 BP (1977:342). Similarly, Flood (1983:218), based upon Chappell and Shackleton (1986), Shackleton (1987), and Chappell (1993) proposed a sea level which was rising rapidly until approximately 7,000 BP and then although the rate of transgression was slower, continued to rise until the present day coastline was reached at 5,000 BP (Figure 2.4).

The 'HP' on the graph refers to the Huon Peninsula curve (Chappell and Shackleton (1986), and the 'NJS' refers to the 'temperature-corrected isotopic sea-level curve' (Shackleton 1987). The bars at the base of the graph indicate the morphology of the shoreline at that point in the Pleistocene sea-level curve cycle, based on Chappell's (1997) research.

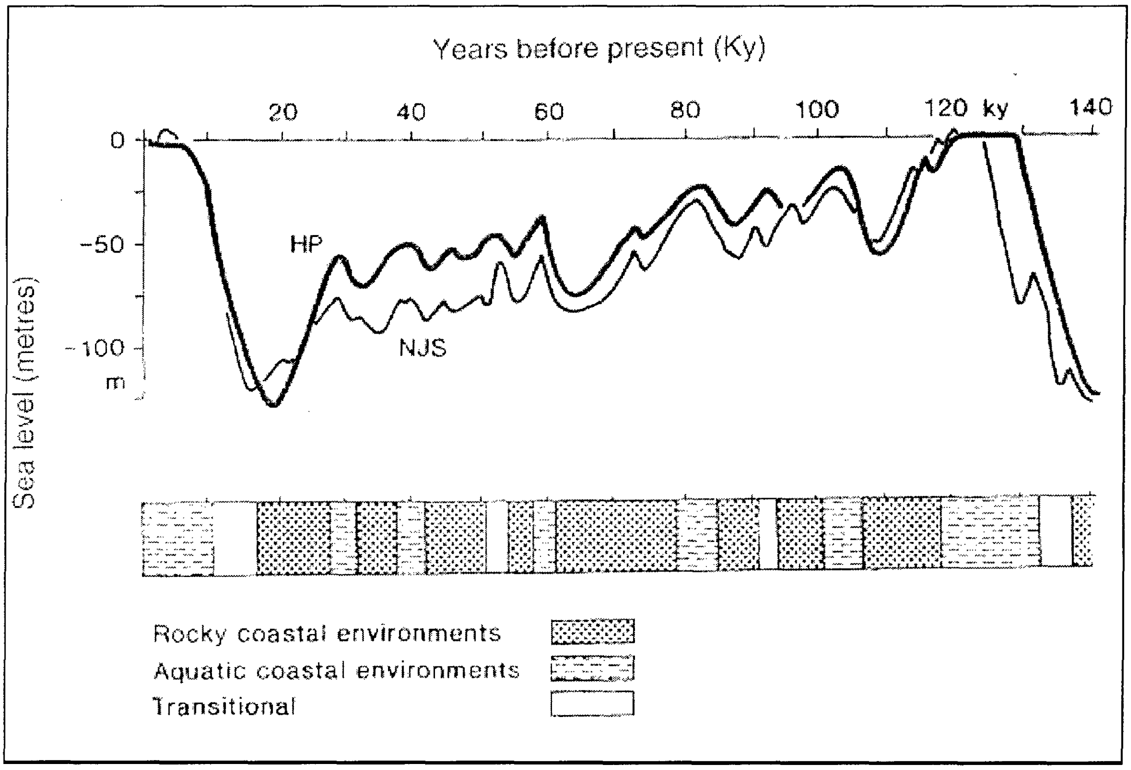

Figure 2.4 Quaternary Sea-Level Curve (Flood 1983:29)

Likewise Mulvaney and Kamminga (1999:223) estimated a rapid sea-level rise of around ten to fifteen metres from approximately 10,000 BP until reaching its present level at 6,000 BP (Figure 2.5). Figure 2.5 is the same graph as that used by Flood (1983, Figure 2.4), which has been reversed. However Mulvaney and Kamminga make an unreferenced suggestion of a sea-level rise during the Late Holocene:

> 'Some geomorphologists assert that at 4500-3000 years BP the sea level fluctuated about a metre or more above its modern level, but today the evidence for this is neither consistent or widely accepted.' (1999:223).

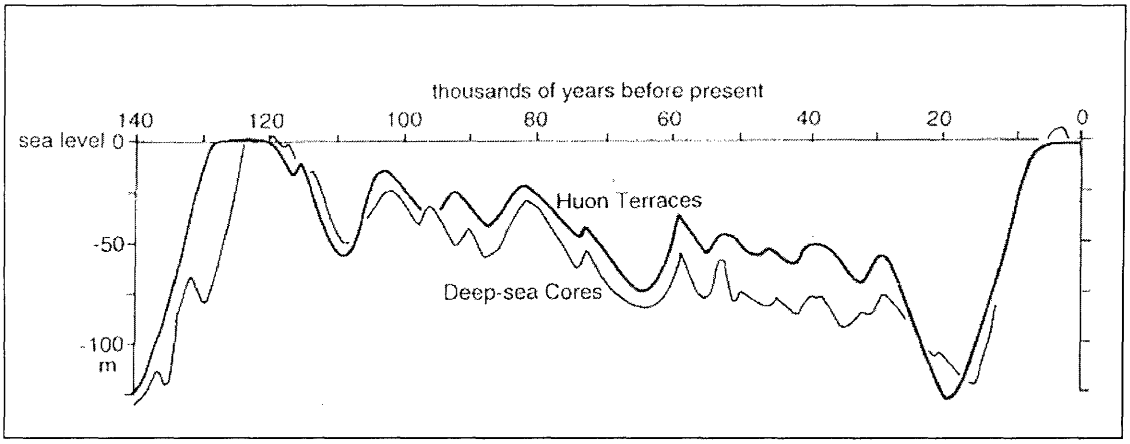

Figure 2.5 Quaternary Sea-Level Curve (Mulvaney and Kamminga 1999:106)

The consensus of opinion in archaeology texts from the late 1970s to the late 1990s appears to be that the sea-level rose after the final glacial maximum until it reached its present level between 8,000 BP and 5,000 BP, and there has been little variation in the coastline since that time. The earliest of the texts, Mulvaney (1969), appears to be the only dissident to this hypothesis, though it is not explained in the text when or how the present sea-level was achieved.

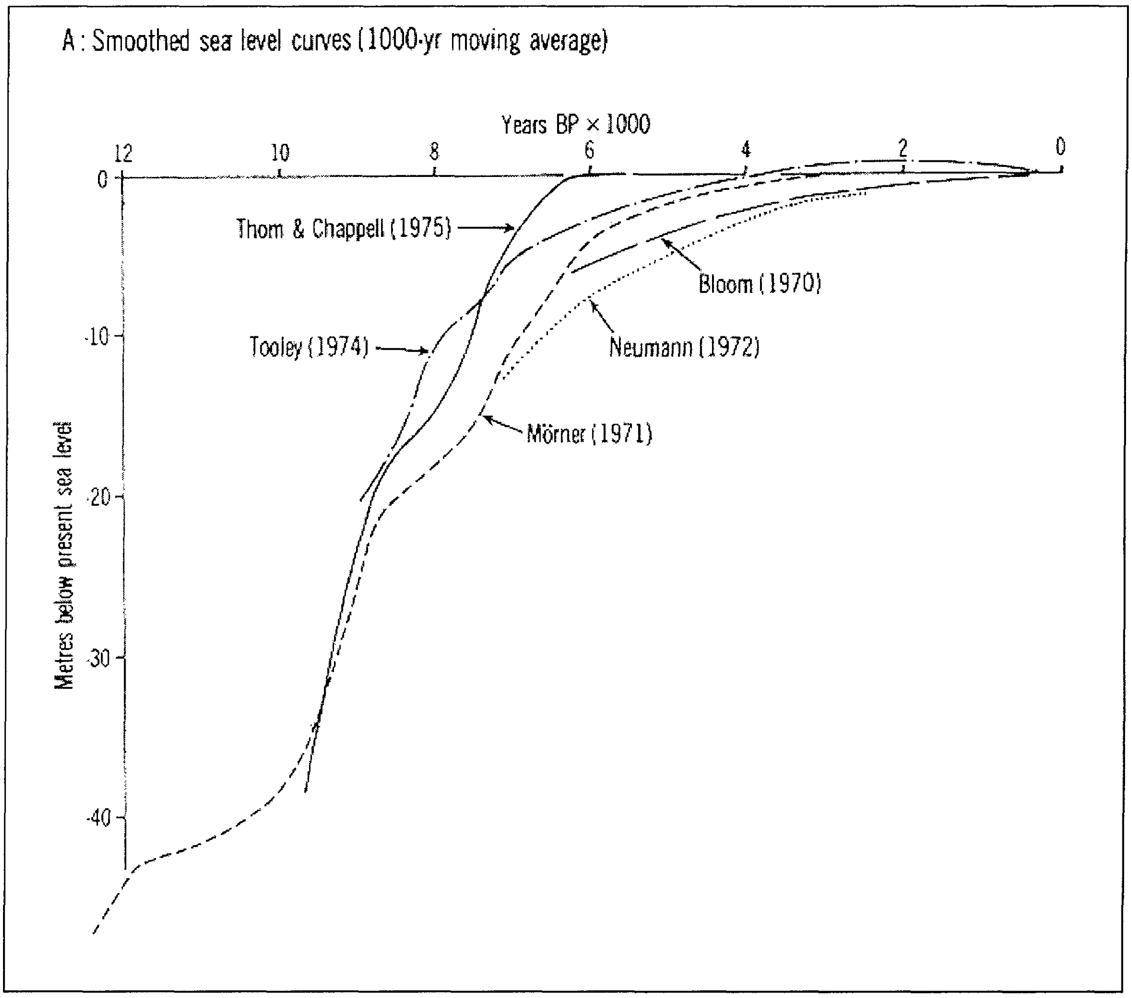

Figure 2.6 Holocene Sea-Level Curve (Chappell and Thom 1977)

Clearly, the theory of a smooth, or non-oscillating sea-level curve was the preferred theory for explaining sea-level during the Holocene, and has become an accepted fact in Australian coastal archaeological research. Graphs produced by researchers such as Chappell and Thom (1977:281), and published in archaeological texts confirmed the theory of the rising sea-level from the late Pleistocene until the still-stand was reached at 6,000 BP (Figure 2.6).

In their introduction to the 2000 volume, *Australian Coastal Archaeology*, Hall and McNiven (1999:3) asserted that 'responses to sea level change and the marine transgression is a key question for Australian coastal archaeology', and questioned why so many shell midden sites were less than 3,000 years old. They also questioned the explanations of either cultural changes having occurred, or, environmental changes, but contended that explanations did not have to be separated into either of the two categories, instead 'a range of environmental and social processes' could be the driving forces behind change seen in the archaeological record of shell middens (Hall and McNiven 1999:3).

Debates on the futility of allocating only one cause to changes seen in the archaeological record offer new means of understanding patterns seen in shell midden sites. However, the theories of a smoothly rising sea after the last glacial maximum (Figure 2.6) are still the preferred theory for Australian archaeologists and have over-ruled earlier researchers who advocated an oscillating Holocene sea-level (Fairbridge 1961; Gill 1970; Gill and Hopley 1972). The sea-level curves proposed by Fairbridge (1961:156) for the period following the last glacial maximum are relatively complicated figures (Figure 2.7), and perhaps this goes some way to explaining why they have not been used. Gill (1970) and Gill and Hopley (1972) do not give a diagrammatic representation of their proposed Holocene sea-levels.

Fairbridge (1961:156) described the mean sea-level since 6,000 BP as being horizontal, and close to the modern sea-level, as would have been the case if the curve was smoothed as Thom and Chappell (1977) (Figure 2.6) proposed. However, Fairbridge projected oscillations of between one and six metres in the Late Holocene, lasting for relatively short time periods when compared with those that had applied in the Pleistocene. The most notable of the oscillations are at just prior to 5,000 BP and just after 4,000 BP according to Fairbridge's model (Figure 2.7). These oscillations are represented as being in the range of less than five metres above the present sea-level.

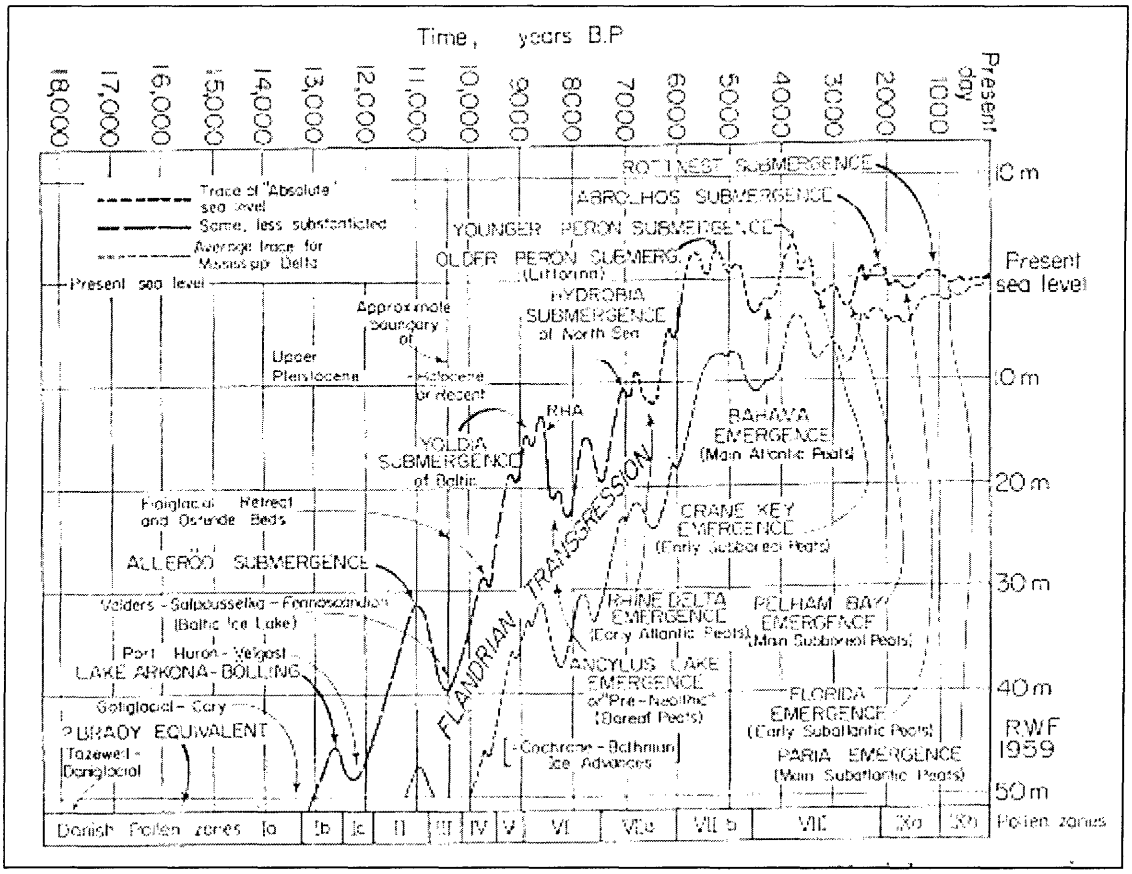

Figure 2.7 Proposed Sea-Level Curve Since the Last Glacial Maximum (Fairbridge 1961:156)

In the following section of this chapter I will discuss new theories of sea-level fluctuation in the Late Holocene which have been proposed by Australian researchers. These theories offer a whole new series of questions for Australian archaeologists. The effect of fluctuating sea-levels on the prehistoric coastal populations could have been substantial, depending on the type of coastline being occupied and the degree of change. Not only does it mean retreating from rising sea-levels, but also means taking advantage of new shorelines opened up by falling sea-levels.

2.5 Questioning Sea-Level Stability in the Late Holocene

As has been seen in the previous section, the prevailing archaeological thoughts on Late Holocene climate and sea-level stability were that at the end of the last Glacial Maximum of the Pleistocene at approximately 20,000 BP, the sea-level was some 120 metres lower than present. As the ice-caps melted world-wide sea-levels rose some 120 metres, and in Australia, finally reached its present level at circa 6,000 BP, and remained at this level, creating the coastline of Australia that we now know (Chappell 1976). Following the Holocene Climatic Optimum from 10,000 - 6,000 BP, when the Australian climate was viewed as being warmer and wetter than the present, the climate became drier with little variation in sea levels until the present. Some researchers contend that lacustrine evidence points to a drier climate than the present between 6,000-4,000 BP, with climatic conditions becoming similar to the present between 3,000-2,000 BP (Allan and Lindesay 1998:231). However, it was still a widely held belief amongst archaeologists that sea-levels have remained stable for some 6,000 years, despite claims to the contrary (Fairbridge 1961; Gill 1970; Gill and Hopley 1972; Pirazzoli 1996; Baker et al 2001).

Kearney (2001:27) described the smoothing of sea-level curves, as had been done by Chappell and Thom (1977), following the Pleistocene the 'connect the dots' method of plotting Holocene sea-level curves. This was a convenient means of producing a sea-level curve, without the need to explain variation. Although Fairbridge (1961), Gill (1961; 1970), and Gill and Hopley (1972) had proposed sea-level changes in the Holocene, researchers in Australia had, in the 1960s and 1970s, proposed that sea levels could not have fluctuated in the Late Holocene, based on the geomorphological research of Thom et al. (1969) and Chappell and Thom (1977). Chappell and Thom (1977:278) described any 'wriggles' from the smooth sea-level curve as being the result of the use of data from different localities, despite some of these 'wriggles' being an amplitude of around two metres. Later, Chappell (1987) and Lambeck (1993) proposed an envelope of possible fluctuations of around one metre, but reiterated that any changes which had occurred in the Late Holocene were the result of global isostactic processes, or 'relaxation processes of the earth' after the last Glacial Maximum of the Pleistocene (Thom and Chappell, 1975:93). By attributing any movement of the sea to geologic processes of the earth, it appears that sea-level stability or instability could be ignored, and sea-level curves smoothed to a mean level.

However, alternative views on sea-level stability in the Late Holocene for Australia have been proposed which account for the 'wriggles' as part of an ongoing process of sea-level change, which is not only related to Pleistocene glacial activity. As early as 1896, researchers proposed that the 'relative levels of land and sea' had changed in 'comparatively recent geologic time' on the east coast of Australia based upon the findings of a 'submerged forest with remains of the dugong' (Etheridge et al. 1896:158). Flood and Frankel (1989) challenged Chappell's (1983) views of a stable sea-level during the Holocene with their research on intertidal marine organisms from Valla Beach, on the northern New South Wales coast. They interpreted the remains of the tubeworm (*Galeolaria caespitosa*), taken from a cave on the headland, as representing a sea-level slightly more than one metre higher than the present at 3420 BP (Flood and Frankel, 1989:195). Species such as tubeworm (*Galeolaria caespitosa*) occupies a tightly constrained habitat within a narrow vertical zonation upon rocky coastlines, and therefore gives the best altimetric indication of sea-level change (Pirazzoli 1996). The importance of Flood and Frankel's initial study was that it opened doors for further research to be carried out in Australia, leading to larger and ongoing studies of the possibility of fluctuating sea-levels in the 1990s and 2000s.

Baker and Haworth (1999, 2000) and Haworth et al. (2002) proposed at least one rise in sea-level over the period of 4000 to 4500 before the present of up to two metres, based on their research of fixed biological indicators, shellfish remains, on rock platforms on the New South Wales coast just south of Sydney. The shellfish chosen for this study are also the tubeworm (*Galeolaria caespitosa*), which were valuable to this research because of their tightly constrained habitat in relation to the level of the sea, and which the authors believed allowed precise measurement of sea-levels by comparing the fossil encrustations of the tubeworm with its current distribution on rocky outcrops along the coast. Baker and Haworth suggested that these fluctuations would have consisted of a one metre range over a 'relatively short time' (Baker and Haworth 1997:7). They also proposed a rapid fall of sea-levels between 2000 and 2500 BP. They believed that these results call into question theories of hydro-isostatic adjustments of the continental shelf during the Late Holocene proposed by other researchers (Chappell 1983; Lambeck 1993), as these theories require a decline in sea-level which is slow and smooth rather than fluctuating. Further studies were carried out on Valla Cave (Baker et al., 2001:262), which gave a result of a sea-level fall of between 1.7 – 1 metre at approximately 3400 BP. An AMS age determination on the tubeworm located on the southern wall of the cave, from one metre above its present range of habitat returned a date of 3120±70 (3460 cal. yr), and a sample from 1.7 metres above the present range gave a date of 3410±55 BP (3820cal.yr) (Baker et al. 2001:263) (Figure 2.8). This correlated with a sample taken from the northern wall at 1.7 metres above present which returned a date of 3360±70 BP (3730cal yr) (Figure 2.8). These results also correlated with evidence obtained from along the coast of south-east Australia, Tasmania and Rottnest Island in Western Australia (Baker et el 2001:263-266), and later the entire southern coast of Western Australia (Baker et al. in press). Based upon these data Baker et al. proposed an oscillating model of sea-level change during the Late Holocene (Figure 2.8), rather than the smooth rise of sea-level to its present point, followed by a still-stand of 6,000 years proposed by Chappell (1983) and Chappell and Thom (1977)(Figure 2.6). When Figure 2.6 is compared with Figures 2.7 and 2.8, the effect of the smoothing of the sea-level curve can be seen. While Chappell and Thom's curve for the Late Holocene shows the sea reaching its present level at approximately 6,000 before the present (Figure 2.6), the curves proposed by Fairbridge (Figure 2.7) and Baker et al. (Figure 2.8) show rises and falls in sea-level over the last 6,000 years.

Baker et al. presented their proposed oscillating sea-level sea level curve (Figure 2.8) based on quartic and quintic polynomial regression statistical data, on both marine reservoir adjusted and calibrated dates. Radiocarbon dates from Vaucluse (Sydney, New South Wales), Magnetic Island (Far North Queensland), Dark Beach and Port Hacking (New South Wales) are used in the model. Although they claim that "no model can claim statistical exclusivity as the best fit for the distribution" (Baker et al. 2001:267), they find it remarkable that both sets of data displayed similar oscillating curves for Late Holocene sea-levels, with the deviation between sets being in the last 1,000 years.

These models show a sea-level approximately one metre higher than the present 5,000 years ago, rising to almost two metres above present between 5,000 – 4,000 years before the present, and dropping to one metre above the present level at 3,000 BP (Figure 2.8). After a slight rise at 2,000 years ago, the graph shows the sea-level dropping to its present level in the last 1,000 years, although the authors state that based on field evidence they believe that the present sea-level was evident around 1,500 years ago (Baker et al., 2001:267).

The sea-level curves proposed by Baker et al. (2001) provide a new viewpoint on the history of the Australian coastline, and offer some insight for coastal archaeologists grappling with the relatively short time frames represented in some coastal middens. However, to complicate matters even further, some researchers believe that a high resolution of evidence is impossible during the Holocene because of the effect on environmental conditions, partly from sedimentation of estuaries, and then from human interaction with the landscape, firstly from the Aboriginal occupants, and then even more dramatic environmental interactions after European settlement (Rowland 1983). While it is true that many coastal shell middens have been destroyed since European settlement, Aboriginal occupation should be reflected in the midden sites, offering valuable insight into habitation of the coasts by prehistoric peoples.

To establish whether it is likely that archaeological evidence from the study area can be used to address the question of fluctuating sea-levels in eastern Australia in the Late Holocene the following section collates published dates from northern New South Wales midden sites to determine whether the location of sites at various dates implies a shifting coastline.

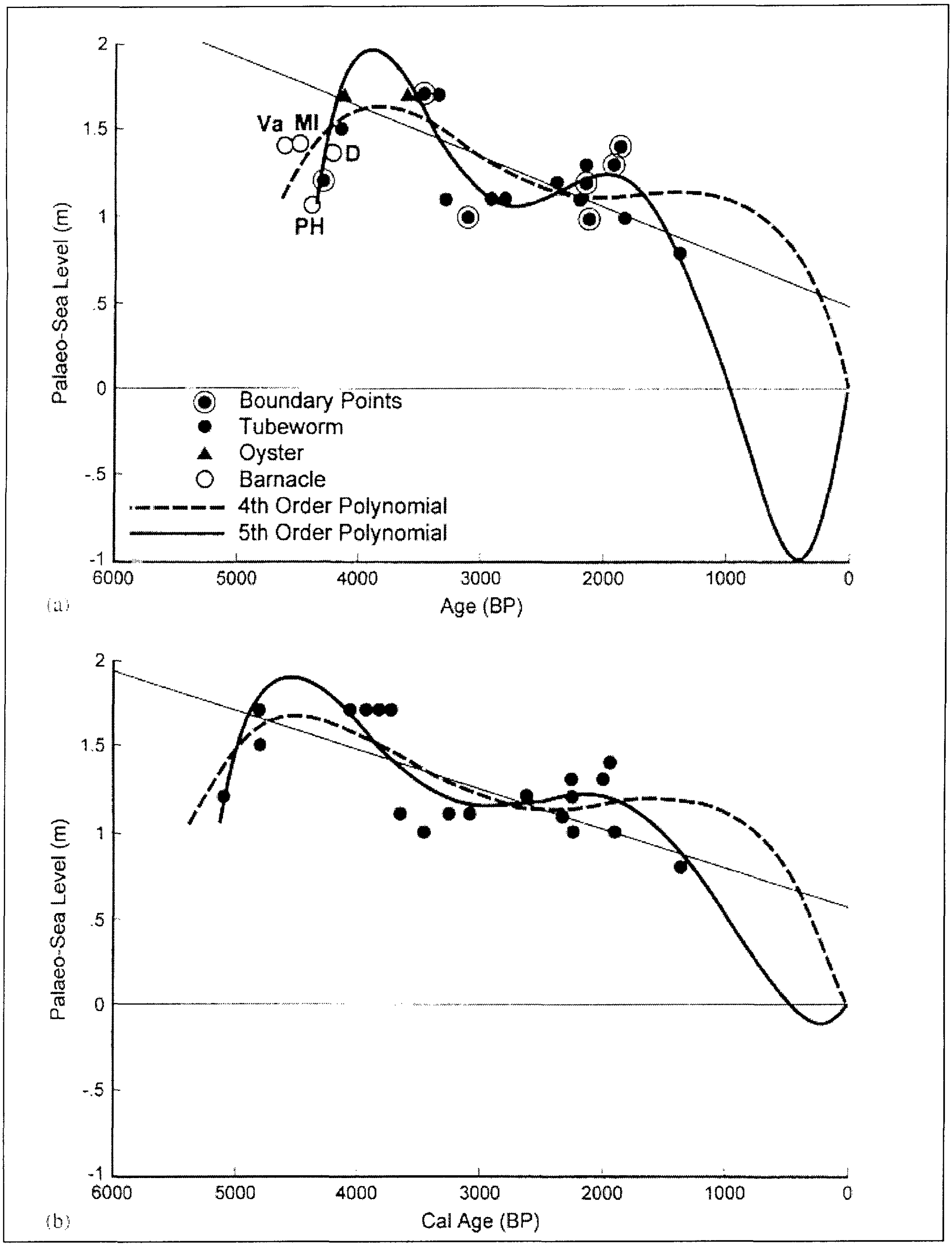

Figure 2.8 Linear and Oscillating Models of Sea Level in the Late Holocene
(a) – Uncalibrated Years BP
(b) – Calibrated Years BP
(Baker et al., 2001:267)

salinity levels within the estuary due to the effects of the mixing of saline ocean waters and the fresh-water sourced from the river, can create a challenging environment for most taxa (Morrisey 1995:161; Edgar 2001:40).

There are three types of estuaries found in south-eastern Australia - barrier estuaries, drowned river valleys and saline coastal lagoons (Figure 2.10). Drowned river valleys are common on the sandstone coasts of central New South Wales (Figure 2.10 [a]). These estuaries are usually narrow with steep sides, and riverine sediments or sand collect behind the marine sands which are carried into the estuary by tides. They have a large tidal range. Saline coastal lagoons are completely cut off from the sea by sand barriers, are not tidal and usually contain predominantly river sand (Figure 2.10[c]). Barrier estuaries are formed by the deposition of sand between the ocean and the river feeding a large deltaic plain (Figure 2.10[b]). Long winding channels of water form, often parallel to the coast.

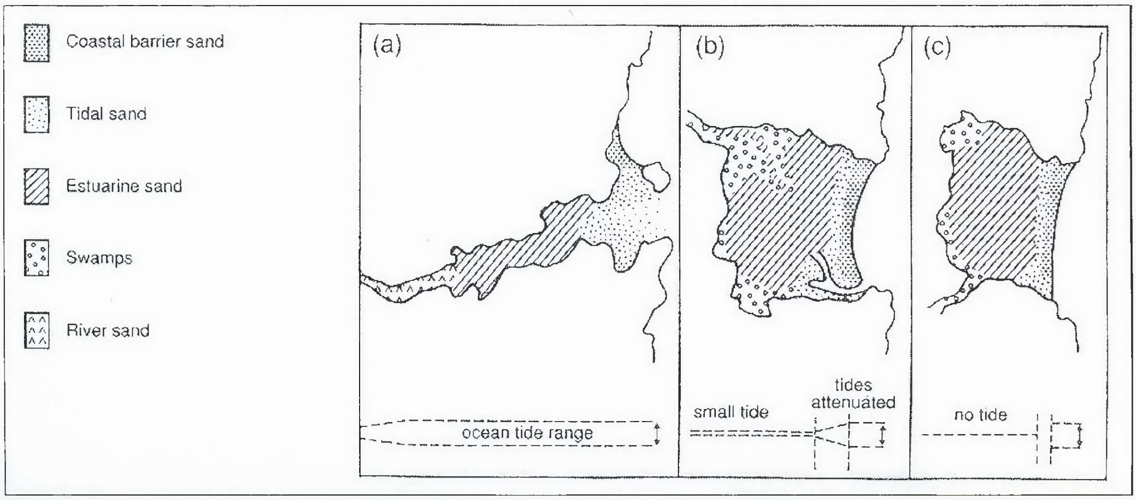

Figure 2.10 Forms of Estuaries (Morrisey 1995:154)
(a) – Drowned River Valleys
(b) – Barrier Estuaries
(c) – Coastal Lagoons

foreshore such as Connection Creek and Wombah were placed in the inland category. Using the OxCal (v3.8) computer program (Ramsey 2002), the dates were calibrated and graphed.

Most of the sites entered into the graph have more than one date, and are represented by their laboratory number rather than site name (Appendix I). Figure 2.9 shows the published conventional radiocarbon date and the calibration range.

The published dates show the sites located in close proximity to the shore, the first ten on Figure 2.9 only become evident at less than 2,000 years before the present. Whereas sites located further inland show a continuous sequence of occupation from just before 1,000 years before the present until a little over 5,000 years before the present (Figure 2.9). The dates obtained by Connah (1976) for the Stuarts Point site are out of sequence with the other dates obtained on Northern New South Wales midden sites. These dates were the subject of some controversy at the time they were published (White and O'Connell 1982), and new dates obtained for this research for the Stuarts Point site will be presented in Chapter 6. This small test offers a fairly striking result, but only for a small section of the eastern Australian coastline, and assumes that there is an equal chance of site survival.

It is these kind of data which has encouraged researchers in sea-level studies (Baker et al. 1999), that archaeological evidence is important to the overall study of sea-level fluctuation in the Late Holocene in Australia. In order for this data to become more robust evidence of the 'youth' of foreshore sites, all published dates for the east coast would need to be graphed, an undertaking far beyond the scope of the present research, and many sites may need to be redated in order to make comparisons between sites. However, this small test of the relationship between the age of midden sites and their location in the landscape, demonstrates the utility of further investigations into the patterns of midden site location and sea-levels of the northern New South Wales coast.

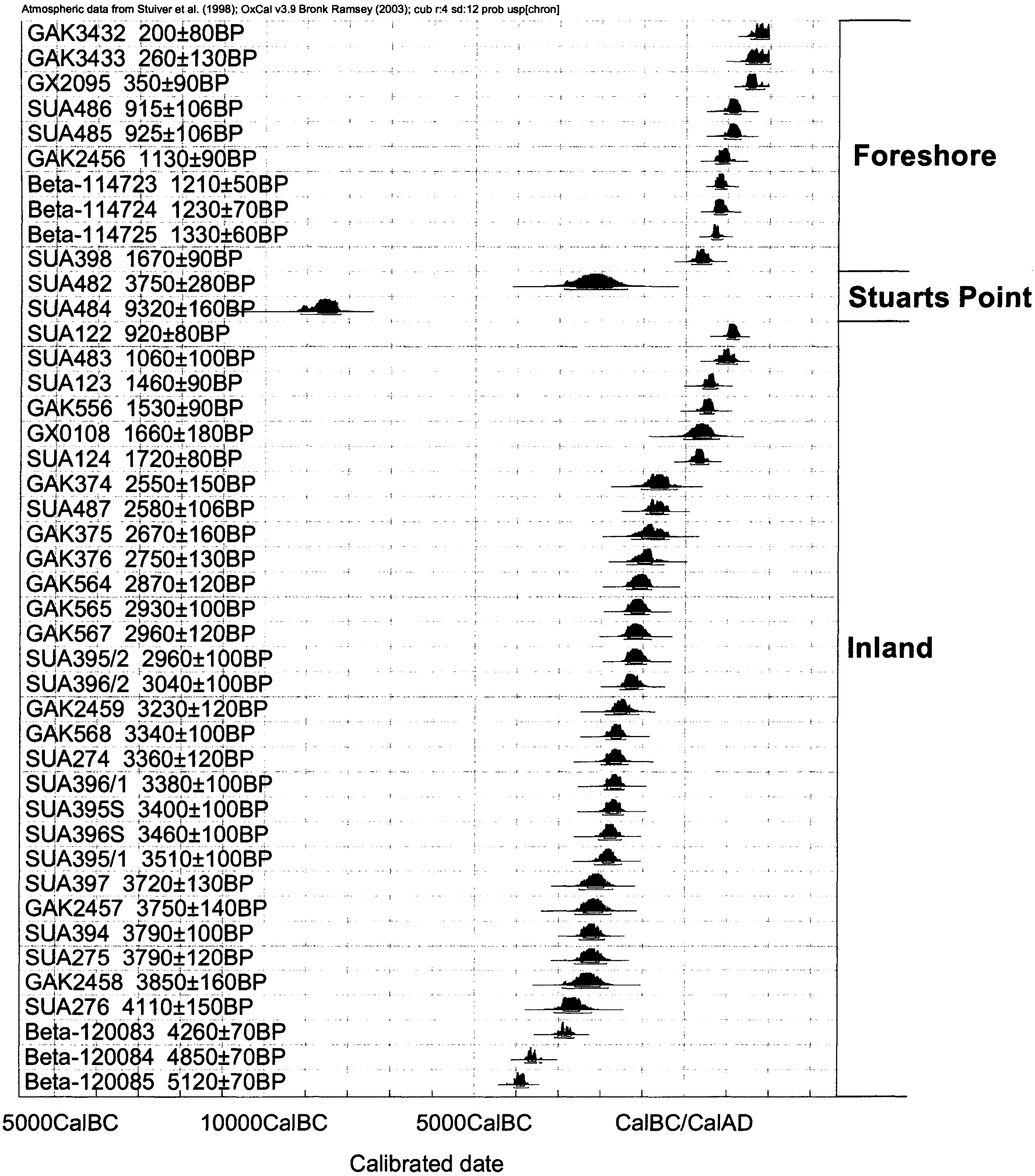

Figure 2.9 Published Dates of Northern New South Wales Midden Sites (Cal BP)

2.7 Changing Sea-Levels and Estuarine Environments in South-Eastern Australia

While most of the literature reviewed to this point has dealt with marine environments that are not specifically estuarine, it is important at this stage to understand the ecology of estuaries, as my study area contains current and estuarine environments. Changing sea-levels would have a dramatic effect on estuarine environments because the lack of elevation means that small changes in the sea-level have large effects on the area of the estuary. However, one problem is that sedimentation over time would add to and possibly complicate the effects of any changing sea-levels. Understanding the ecology of an estuary may be one of the mechanisms which assists in linking the variables of palaeo-environmental research to the archaeological assemblage. By understanding the constraints and how environmental changes are likely to affect the morphology of the estuary, and the fauna which inhabits it, some of the variables may be able to be eliminated from possible causal factors for archaeological variation.

Estuaries contain aspects of both marine and riverine environments, but it is the combination both of these that creates the unique estuarine environment. The estuary consists of a body of water that is semi-enclosed from the sea in which the salt water from the ocean is diluted by fresh water from river drainage. It is therefore both a marine environment diluted by fresh water, and a river inundated by sea-water. Estuaries are somewhat protected in the coastal situation as water movement from tides, ocean currents and winds have less effect on the estuarine water and the surrounding environments than they would have if they were situated in an open coastal situation.

Estuaries are natural traps for sediment carried by the river systems, and therefore tend to evolve into a nutrient-rich environment, forming habitats for plants and animals which are quite different to other nearby coastal environments. Because an estuary is a nutrient rich environment it is a potential source of a large amount of food. This abundance of nutrients, along with the effects of it being a sheltered environment, suggest estuaries would be able to sustain large amounts of animal life. However, the variable nature of salinity levels within the estuary due to the effects of the mixing of saline ocean waters and the fresh-water sourced from the river, can create a challenging environment for most taxa (Morrisey 1995:161; Edgar 2001:40).

There are three types of estuaries found in south-eastern Australia - barrier estuaries, drowned river valleys and saline coastal lagoons (Figure 2.10). Drowned river valleys are common on the sandstone coasts of central New South Wales (Figure 2.10 [a]). These estuaries are usually narrow with steep sides, and riverine sediments or sand collect behind the marine sands which are carried into the estuary by tides. They have a large tidal range. Saline coastal lagoons are completely cut off from the sea by sand barriers, are not tidal and usually contain predominantly river sand (Figure 2.10[c]). Barrier estuaries are formed by the deposition of sand between the ocean and the river feeding a large deltaic plain (Figure 2.10[b]). Long winding channels of water form, often parallel to the coast.

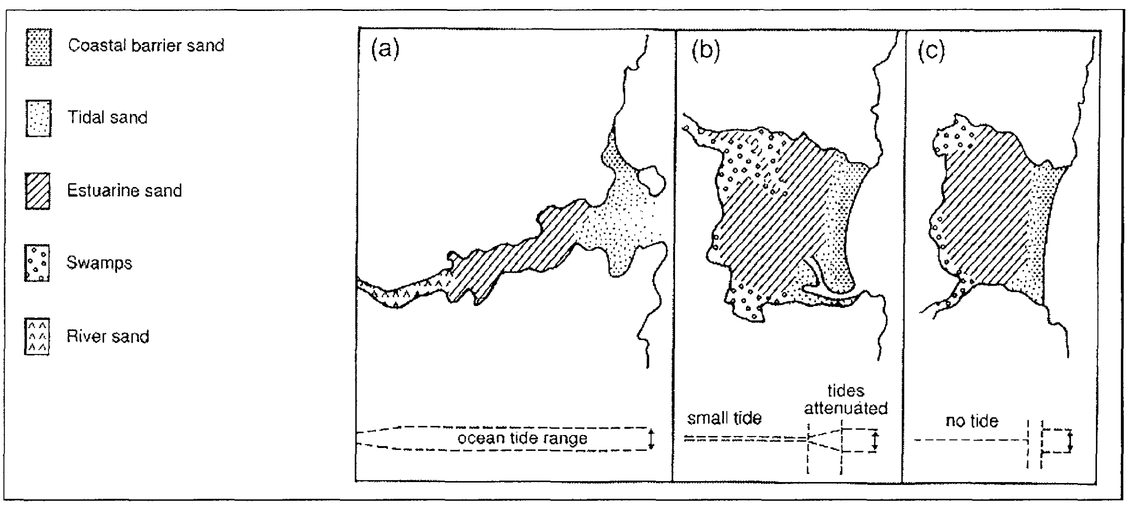

Figure 2.10 Forms of Estuaries (Morrisey 1995:154)
(a) – Drowned River Valleys
(b) – Barrier Estuaries
(c) – Coastal Lagoons

Unlike the rock-bound valleys of the central coast of New South Wales, the Macleay is a barrier lagoon estuary. It has formed in riverine sediments which usually have an intermittent opening to the sea, though at present the Macleay entrance is artificially kept open all year round (West et al., 1985). Barrier estuaries are a common feature of the south-eastern coast of Australia due to the high wave energy created by the long-period swell originating in the Southern Ocean (Jennings and Bird 1967:121). Extensive barriers are built and the river may be closed by the marine deposition when river discharge is low, creating estuarine lagoons, which may be relatively shallow, behind the sand barriers.

The shape of the estuary and in particular the entrance, is extremely important as it is the major feature in the control of the patterns of water exchange between the estuary and the ocean (Morrisey 1995:154), and therefore controls the salinity regime, another characterisation of estuaries. Saltwater is 33-38 parts per thousand of salinity and freshwater less than 5 parts per thousand. Freshwater is relatively lighter and therefore sits on top of the heavier salt water. Estuaries can be graded between negative and positive measures of salinity (Dyer 1973:6-10) with salinity ranging between 38 parts per thousand to 5 parts per thousand when input of fresh water from rivers is high. Most estuaries in temperate Australia are positive estuaries as the evaporation from the surface is less than the input from river discharge and other terrestrial drainage. In a positive salinity situation the freshwater runoff is greater than evaporation, and denser sea water enters the estuary below the freshwater, mixes with the freshwater, and leaves the estuary from the surface. However, the estuary may change from a positively graded salinity regime to a negatively graded one on a seasonal basis due to varying inputs of freshwater from the river, or increased inputs of saline water during storms. Neutral estuaries, those with equal inputs of freshwater from rivers, and loss of freshwater through surface evaporation are uncommon, though they do occur in South and Western Australia (Morrisey 1995:157).

Sediments carried into the estuary are another feature which can affect the fish and shellfish inhabiting the estuary. Sediments can be transported by water, both from the river and the ocean, and also blown across the land surface and be deposited in the estuary. Sediment loads are derived from the erosion of rock, previously deposited sediments which are reworked by the river or ocean, the remains of plants and animals, and the precipitation of dissolved materials. Sediment grain size is directly proportional to the velocity of the water in which it is carried, the faster the current, the larger the particle size which is able to be carried. As with the salinity regime water velocities will vary over time, according to the river flow, however the largest suspended sediment load (the turbidity maximum) is most likely to be in the middle of an estuary where velocity is greatest (Morrisey 1995:159).

Estuaries provide a habitat for freshwater and marine fauna, along with terrestrial fauna and birds, but features such as fluctuating salinity, turbidity, availability of oxygen and the patterns of water movement, will determine the types of animals inhabiting an estuary and their productivity (Morrisey 1995:161; Edgar 2001:37). The fluctuating salinity regime is probably the greatest deterrent to a wide range of species in an estuary. While estuaries are habitats of great productivity due to the high nutrient content and shallow, sheltered waters, only those animals which can tolerate either the decreased or the fluctuating salinity can survive. Some ecologists propose that estuaries are low in diversity of species because the estuary itself is a relatively short-term feature of coastlines, and species have not had the time to make adaptive responses to the ever changing conditions of these habitats. The animals which inhabit the estuary can be abundant, but the diversity of fauna is quite low, and will decrease further away from the mouth of the estuary due to changes in salinity and turbidity. Estuaries are a boundary between the fresh and salt water, and species which are specifically adapted to either habitat cannot cope with the stress of fluctuating salinity levels (Morissey 1995:163; Edgar 2001:41). Some species can make behavioural responses such as burrowing or closing their operculum, but there is usually a much lower diversity of benthic dwelling species in estuaries compared to littoral or freshwater habitats (Morrisey 1995:163).

Despite the challenges of living in an estuarine environment, estuaries play an important role for many species. Many marine fish species of the New South Wales coast are dependent on estuaries as a nursery habitat, including species that are commercially important today such as mulloway, and the Sparid family (snapper, bream and tarwhine) (Edgar 2001:41). Estuaries provide ample food for juvenile fish, the turbidity and poor water clarity allowing small fish to hide from larger predators.

Seagrass beds contained within estuaries provide a habitat for numerous species and will support larger numbers of species and individual fish than seagrass beds in open water (Edgar 2001:133). The plant production of inshore coastal waters is increased when seagrasses are present, broadening the base of the food chain and providing more food for the animals which live in this habitat either directly through the consumption of leaves, or indirectly through an increase in detritus and epiphytes. Crustaceans and fish along with shellfish inhabit seagrass beds, the thick grasses providing shelter for small or young animals from predators. Seagrasses also stabilise the sediments with their root systems, decreasing turbidity, and through the conversion of dissolved nutrients into plant material lower the risk of toxic algal blooms. The loss of sea grass beds through environmental change such as increased fresh water, higher turbidity or temperature change, will result in its replacement with a sand or mud habitat, creating a change in the fauna inhabiting the estuary. Most shellfish are either adapted to a vegetated or non-vegetated habitat, and the loss of the sea grass habitat will result in a change of species inhabiting the area.

Estuaries are not an idyllic environment for many species, but those that are able to adapt to the varying conditions appear to thrive, becoming abundant, and providing a plentiful food supply for the Aboriginal inhabitants responsible for the formation of the large shell middens found around the Lower Macleay River. If an estuary were to be flooded by a rising sea-level of two metres, environmental conditions within the estuary would change swiftly. Changes in salinity and temperature due to deeper waters, and turbidity would all occur. This in turn would affect the populations of marine fauna inhabiting the estuary. The environment of an estuary like the Lower Macleay would become more similar to that of the ocean if a further two metres of water were added as suggested by

Baker et al. (2001). Subsequently, if the sea-level dropped after the two metre increase at around 4,000 years ago, as suggested by Baker et al. (2001), the environmental conditions would again change. Saltwater lagoons would form in the lowest parts of the floodplain, there would be an increase in the land mass surrounding the remaining waters, and this would in all likelihood create more sediment being washed into a smaller area of water. Seagrass beds would be destroyed leaving muddier conditions within the remaining estuary, leading to a change in the marine populations. The new environmental conditions would favour species which were more tolerant of the lower salinity, higher turbidity, and perhaps warmer waters.

2.8 Fish and Shellfish Ecology and the Effect of Environmental Change

In the previous section of this chapter I have examined the characteristics of estuaries. Similarly the ecology of estuarine fauna needs to be understood in order to recognise any changes in an archaeological faunal assemblage which could represent environmental change. The two variables identified from the literature review were location of midden sites and a changing assemblage over time which may be expressed in the marine faunal component of an archaeological assemblage. Variations in the environment of an estuary will be seen spatially in the marine populations as the body of water grows or shrinks due to changing sea-level. Populations inhabiting the margins of the estuary would be affected initially, and ultimately the entire ecology of the estuary will be changed, depending on the time frame of an environmental event. Variation in the marine populations will also be reflected temporally in the contents of midden sites. As will be seen in this section, many marine faunal species can be greatly affected by changing conditions in their habitat, leading to stress, decline in populations, replacement by other species, and in the worse case scenario, total loss of a population of fauna. Decisions about causal factors evidenced by changing faunal assemblages over time in an archaeological midden cannot be made without an understanding of the ecology of the species represented in an archaeological assemblage. Ecology is the study of organisms in relation to their environment, and an understanding of the species composition of an assemblage of fishes in an environment, whether they are a living population in an estuary, or the representatives of an environment in an archaeological assemblage, depends on knowing how individual fish in the populations that form that assemblage are affected by their environment. This includes the presence of individual fish of the other species. The fish are not concerned about the environment, as long as it is an environment which can sustain them, but about the resources they can gain from it. They are concerned with 'allocating limited resources in a way that ensures [their] genetic representation in the next generation' (Sibly and Calow, 1986). 'The axis about which the biology of species revolves' (Meien, 1939) is the ability to reproduce. The input is the food, the output is progeny and somatic growth. If the individual fails to reproduce it can be seen as unsuccessful. If a species fails to reproduce it becomes extinct. Therefore individuals and species must be able to make some adaptive response to changing habitat.

The central questions posed by ecologists -

1. What factors cause fluctuations in the abundance of a population of animals?
2. What factors determine how many different species occur in the assemblage of species found in a habitat? (Wootton 1990:3),

are fundamental in the understanding of faunal species represented in an archaeological assemblage. The next section will review how fish adapt to a changing environment.

2.8.1 Fish Ecology

Popular belief would have it that teleost fish (those with a bony skeleton) are somewhat less evolved than other vertebrate animals, lacking homeostatic mechanisms such as, in the case of birds and mammals, the ability to maintain a core body temperature when confronted with a fluctuating environmental temperature. In the larger evolutionary picture modern teleost fish are as recent a phenomenon as the endothermic vertebrates, and are able to respond with great flexibility to changes in their environment. All species can be faced with the onset of a deviation in their environmental conditions which may, if an individual or population is unsuccessful at adapting, lead to the loss of an individual's genes from the total gene pool, or in extreme cases, extinction of the species. Teleost fish may cope with changing environmental conditions through the regulation of their growth and the age at which their first reproduction takes place, and ultimately through their maximum life span (Wootton 1990:7). The ultimate goal of an individual faced with the onset of environmental change is to use adaptive responses which will limit the effect of the change, and thus minimise the cost to itself firstly in survival, but also in terms of reproductive fitness, ensuring its survival, and the survival of the population as a whole. The particular adaptive response which a teleost fish will use will be dependent on the relationship between the amount of time involved in the environmental change and the life-span of the individual (Wootton 1990:8). Naturally, water temperature plays an important role in the life-span of teleost fishes, as it will affect the rate of chemical reactions in an organism, and can be viewed as "the most pervasive of abiotic environmental factors" (Wootton 1990:9). In shallow water bodies such as estuaries water temperature may fluctuate by several degrees daily. In this case fish can practice a form of 'behavioural' thermoregulation by moving into the waters of their preferred temperature throughout their daily cycle. This method requires a minimal adaptive response in order to ensure the ultimate goal of maximising their reproductive output, and is an effective strategy in times of relative environmental stability.

When a fish is unable to utilise a behavioural response to changing environmental conditions, or when the change is on-going for long time periods, biochemical and physiological responses are required to minimise the effects of environmental factors. As fish are not limited by an ultimate adult size, as are mammals and birds, some flexibility is available to them in rate of growth and sexual maturity within the total life-span. Changes in the population demographics as an adaptive response to environmental change, particularly in the size ranges of fish recovered from archaeological sites, may be the first indication of an environmental change having occurred in the site. Eventually, evolution of the species through an altering of the gene pool and the frequencies of genotype may be the result of long-term shifts in environmental conditions, leading to replacement of the species found in sites.

Many species of fish occupy shallow water coastal habitats and form distinctive assemblages in that habitat. They are highly mobile, exhibiting complex behaviour and social organization (Bone et al. 1995:25). Some may be absent or rare in all but their niche habitat, but others will occupy all shallow water habitats including estuaries, shallow rocky reefs, sandy substrata associated with beaches and intertidal shoals, and seagrass beds. Juvenile fish may occupy a single habitat such as an estuary or seagrass beds, however upon reaching adulthood they may move amongst many habitats.

2.8.2 Shellfish Ecology

As with fish, shellfish also need to make adaptations in their behaviour to cope with environmental change and stress. The priorities of growing and reproducing in shellfish are only possible as long as 'its functional range is not exceeded by the ambient environment' (Rhoads and Lutz 1980:3). A change in growth rates, survival, or reproductive success may be suggesting that the environmental niche of a species is under pressure, and if this pressure is prolonged, may lead to the loss of that species in the habitat.

Apart from predation a number of causes can be found for the demise of marine shellfish species from an environment, though the reasons for these are not fully understood (Claassen 1998:36). Water temperature plays one of the most important roles in the physiological processes of bivalves (Dame 1996:19), because a bivalve's metabolism produces only a small amount of heat with which carry out physiological functions, and therefore are reliant on their environment for body temperature control. North American oysters (*Crassostrea virginica*) have been found to grow faster in a warmer climate than the same species in colder latitudes (Dame 1996:21). Bivalves become acclimatised to seasonal changes in their environment, but if dramatic changes in water temperature, such as those which would be bought about not only by a warming or cooling climate, but also by changes in water depth, occur survival and growth of the bivalve population would be inhibited.

An influx of fresh water, bought on by abnormally heavy rainfall or river discharge, will cause a marine mollusc's cells to fill and expand, finally rupturing. Shellfish which are not able to close their valves or opercula will die quickly under these circumstances. Fluctuations in salinity levels, caused by an influx of fresh or sea water, a common occurrence in estuarine environments, can also cause catastrophic death sequences, from which a shellfish population may take years to recover. Select species of molluscs are able to inhabit all areas of an estuary, from the freshwater regions to the totally marine sections near the coast, but they are adapted to the salinity regime of their own environment and a disruption of their environment will influence many of their physiological processes. Claassen (1998:37) claims that die-offs which are specific to a single species are more common among marine bivalves such as clams, oysters and mussels, than freshwater species, and again, no known explanation may be found for the event. Increased sedimentation rates, and changes in water temperature will also affect an estuarine shellfish population, causing the loss of some species and replacement by species more tolerant to the fresh conditions (Claassen 1998:49). Environmental change may have an adverse effect on some species, may be of benefit to others, or may have no effect at all depending on the species' ability to adapt to the new conditions (Thomas 1981:56).

For example, Sandweiss et al. (1996) researched the onset of ENSO (El Nino Southern Oscillation) in Peru, using pollen analysis to judge the effect of the onset of the ENSO cycle on resource availability for prehistoric Peruvian populations. At present, when an ENSO event forms, tropical marine species invade the coast of Peru while temperate species retreat south or become the subjects of very high mortality (Sandweiss et al. 1996:1532). This pattern can also be seen in the archaeological record for the past 5,000 years. Mangrove molluscs found in sites between 11,000 and 8,000 years old indicate that the climate was much warmer than that presently experienced on the coast of Peru.

Sites which date to 5,000 years or older containing tropical fauna were abandoned 5,000 years ago, however nearby sites containing temperate fauna appear to only become established after 5,000 BP. Sandweiss et al. (1996:1531) attribute this discontinuity in archaeological site contents to the onset of ENSO, and the effects of a changing environment on the species available for resource procurement by prehistoric people. This is one model of how changing environmental conditions can affect marine fauna, and how a changing archaeological pattern can contribute to knowledge of environmental events.

2.9 Consequences of Changing Sea-Level on Human Populations

The current north coast of New South Wales has a warm, temperate and humid climate, with a tidal range of less than 2 metres. The continental shelf is narrow and steeply sloping, and is less than 20 kilometres wide (Division of National Mapping 1976; T. Hatton, R.A.N., pers com) (Figure 2.12). Flood (1995:29) included suggestions for how the coastline would have appeared at various stages of sea-level variation during the Pleistocene (Figure 2.5) in her sea-level curve, but this diagram is somewhat simplistic, as it doesn't take into account the variety of coastlines around the Australian coast. At the height of the last glacial maximum, c. 20,000 BP, the sea-level was 120-130 metres lower than the present which would have taken the coastline into the steeper range of the continental shelf in the region to the east of what is now known as the Macleay River. The waters off the coast at this point would have been very deep, without the bays and inlets which would provide an environment for the procurement of marine resources (Figure 2.11). After the glacial maxima of c. 20,000 BP the sea-level rose onto the more gently sloping regions of the continental shelf, the conditions would have become much more hospitable for coastal occupation. The 30-40 metre contour on the bathymetric map for the region shows, embayments and inlets, and the bedrock of Smokey Cape would have been surrounded by water and become an island (Figure 2.12). As the water continued to rise, the low-lying areas of the Macleay floodplain would have flooded forming a large open waterway, stretching across the floodplain to the low relief of bedrock hills where the Clybucca site is located.

The consequences of changing sea-levels for the human populations of coastlines could include changing the location of their habitation sites, or changing their diet and eliminating foods which become inaccessible, difficult to obtain, or to transport to their habitation sites, as has been seen in the review in section 2.2 of this chapter. The coastline of northern New South Wales is, at the present time, characterised as a large barrier coast (Harvey and Caton 2003:33) (Figure 2.11), adjoining a steep, narrow continental shelf.

After the last glacial maximum, the sea would have needed to rise to between the 40-20 metre depth contour (Figure 2.12) on the continental shelf before the region would have become an optimal environment for fishing and shellfish gathering. Below this level, the increased steepness of the waters adjoining the edge of the coastline would have been too deep owing to the slope of the shelf to allow the growth of estuaries which could support sizeable shellfish populations. Fishing would tended to have been difficult in the inhospitable environment of deeper, possibly more turbulent seas. However, the rocky headlands of what are now the Solitary Islands, approximately 80 kilometres north of Smokey Cape, would have provided ideal conditions for the formation of sheltered estuaries and beaches, providing good fishing and shellfish gathering resources for humans. But any sites from this period would now be under water.

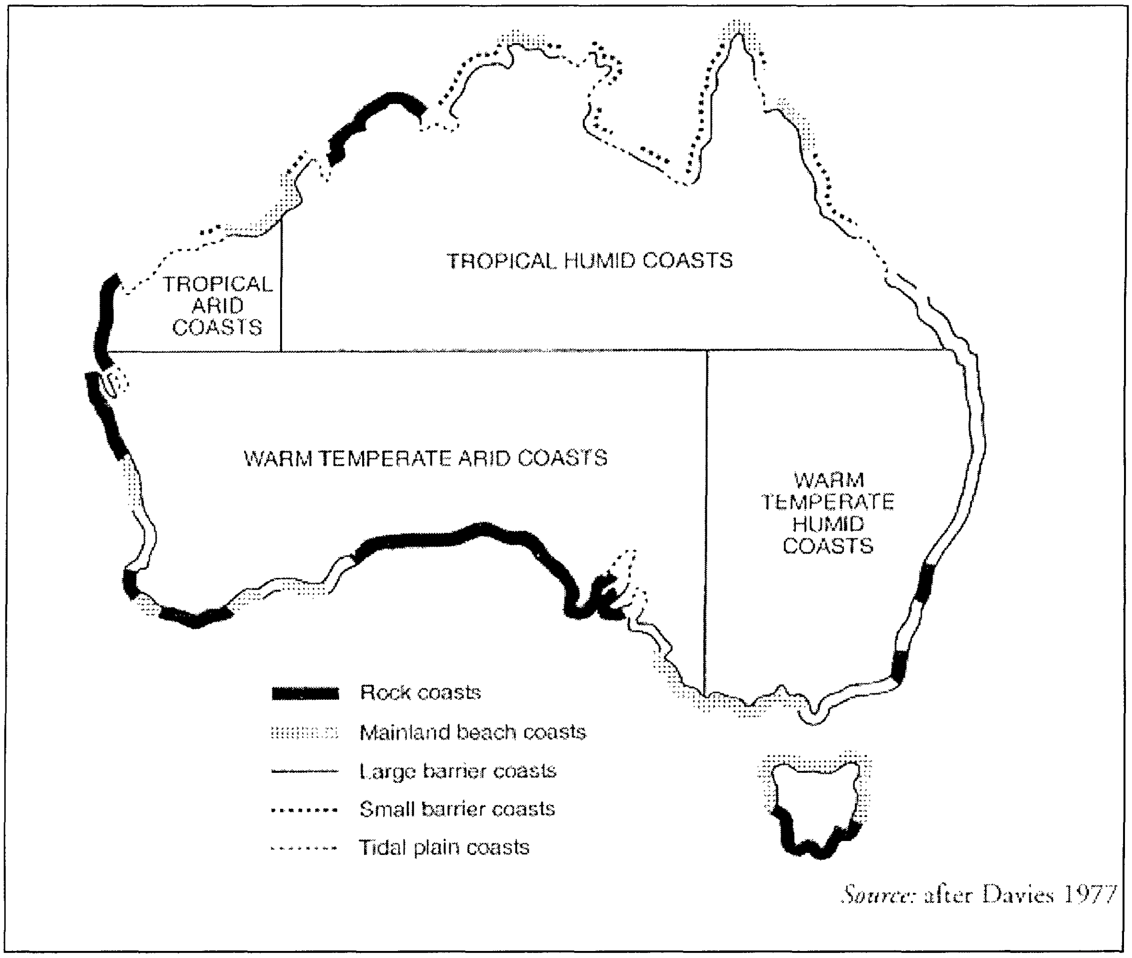

Figure 2.11 Coastline Morphologies of Australia (Harvey and Caton 2003:33)

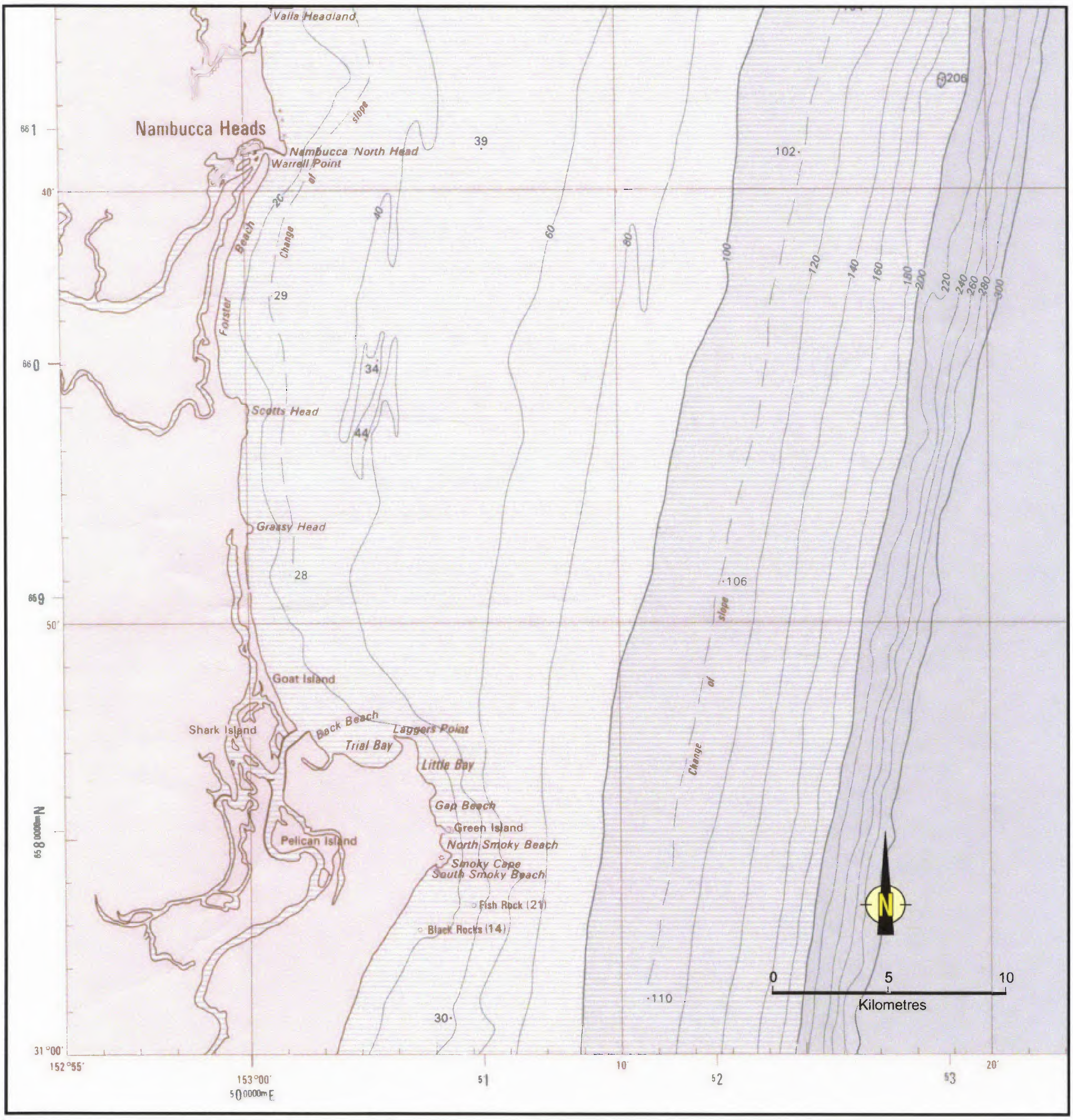

Figure 2.12 Section of the Bathymetric Map showing the ocean adjacent to the Northen Macleay Floodplain (Division of National Mapping, 1976)

Chappell and Thom (1977:284-5) proposed a model for the effect on occupation of coastal sites on a tropical tidal plain of relatively rapid transgression and regression events. They contend that for coastal sites to become vegetated, still-stands in the order of thousands of years are necessary. Figure 2.13 shows their model for the changes which would occur during changes in sea-levels.

On the northern coast of New South Wales, with its relatively narrow continental shelf, the results of oceanic transgressions and regressions may be similar, but events may occur more swiftly as there is a lesser distance between the edge of the continental shelf and the point in the landscape on the mainland which marks the limit of a sea-level rise. On Figure 2.12, a section of the bathymetric map, the study area is located between Trial Bay and Goat Island. As the bathymetric map shows (Figure 2.12) the continental shelf drops steeply from the 120 metre depth contour, the point at which the sea would have been at the last glacial maxima, approximately 20,000 years ago. A change of slope occurs between the 120 metre depth contour and 100 metre, but it is possibly not until the sea reached the 40 metre depth contour line that optimum conditions would have been reached for coastal occupation (Figure 2.12). Upon the sea reaching the 40 metre depth contour, the slope of the land would have allowed rivers to form tidal estuaries, and a wide shallow littoral zone could have been formed. These conditions would have allowed for populations of shellfish to grow, and fish would have been more accessible, than they had been when the sea was lower, in the shallow waters of the estuaries and littoral zone.

Section A (Figure 2.13) of the figure shows a tidal plain coastal region (Figure 2.11) after a lengthy still-stand, where mangroves, beach dunes and tidal creeks and flats have had time to form. During the regression event portrayed in section B (Figure 2.13), evaporite basins have been revealed by the evaporation of marine waters after the lowering of the sea-level, leaving sediments containing precipitates of carbonates and sulphates. Freshwater pools are beginning to form behind what had previously been a foredune. Vegetation in this proposal is sparse, except for where mangroves have started to form at the lowest high water mark. Needless to say these mangroves would not survive in this position if the sea-level continued to fall. Section C (Figure 2.13) shows the effect of a transgression event on the same site following a regression. The mangroves have retreated to the new high-water level, and the beach ridges are steeper. Chappell and Thom (1977:286) argue that during a regression event (Figure 2.13, Section B), the near-shore would consist of a very low

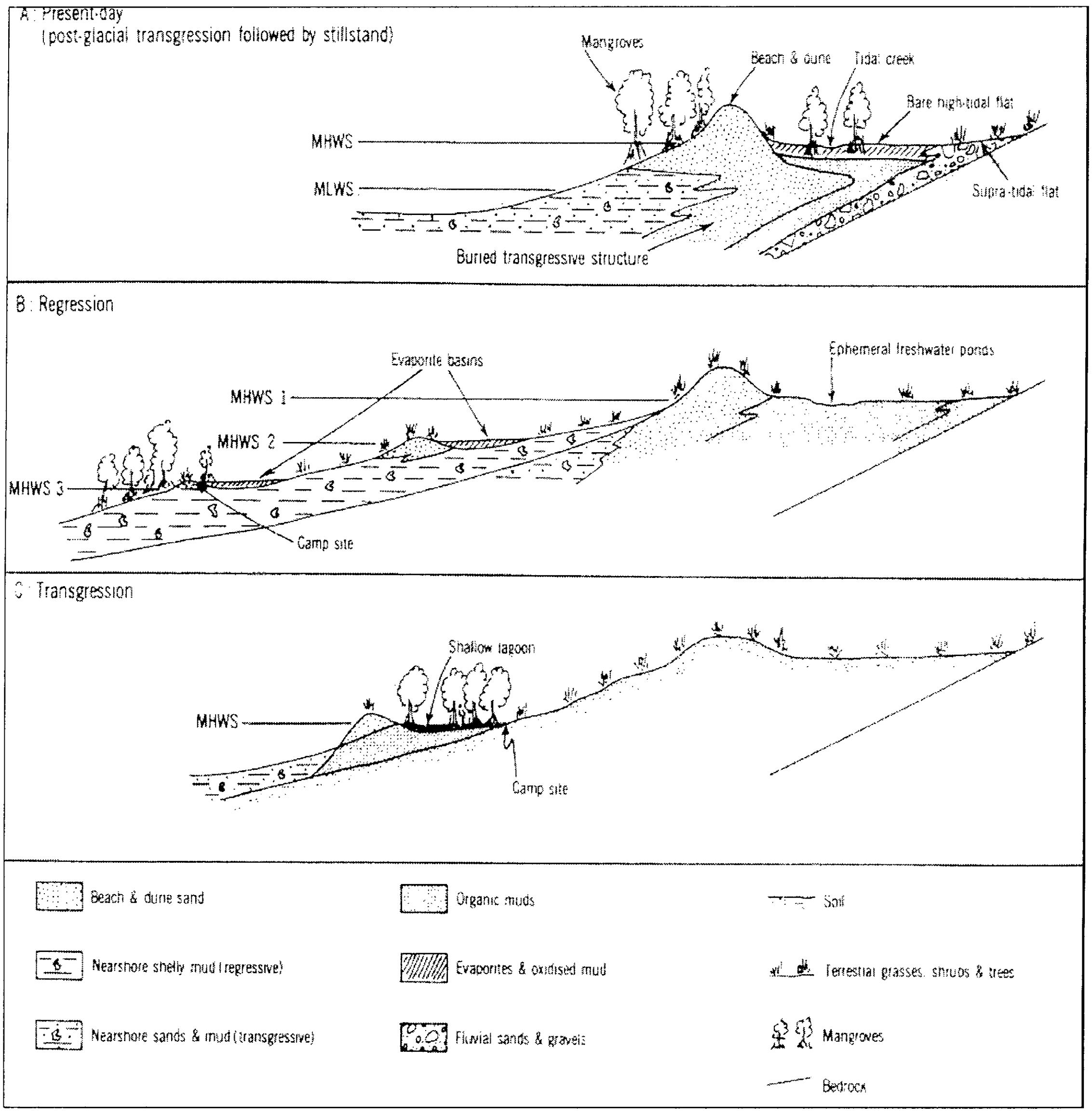

Figure 2.13 The effects of transgressive and regressive phases on coastal habitation sites (Chappell and Thom 1977)

gradient, with mud accumulation and dense growth of mangrove scrub. Shallow lagoons are likely to be left stranded on the mud flats as the sea retreated, perhaps creating a hyper-saline environment, with the majority of biotic production taking place seaward of the active beach. Alternately in the transgression phase (Figure 2.13, Section C), aeolian sand would begin to accumulate until mangrove scrub had grown to block its path, increasing and extending the dune ridges which had formed in previous phases. A richer estuarine biota is proposed for the transgressive phase of coastal growth due to the growth of lagoons receiving constant tidal flushing (Chappell and Thom 1977:287).

As can be seen from Chappell and Thom's model, some phases in the transgressive/regressive movements of the sea would favour occupation of coastal sites. During a transgressive phase, more resources would be available due to the growth of lagoon systems and the constant influx of sea water. Chappell and Thom's model was based upon the broad continental shelf region of north-western Australia, however, the hypothesis of a similarly changing landscape could also hold true for the Macleay region. If the sea rose by two metres the 640 square kilometres which we now know as the Lower Macleay floodplain would have been covered by sea water, creating a marine environment suitable for the growth of large populations of shellfish and fish. According to Baker et al's (2001) model of fluctuating sea-levels, this would have occurred during the c. 4,500-4,000 cal. BP period in the Macleay region. As the sea-level lowered again after 4,000-3,500 cal. BP, the conditions for habitation of the Macleay sites may have deteriorated significantly. Less sea water would be available for a marine biota habitat; sea-grass beds would probably die, further threatening species which rely on sea-grass for food or shelter; the loss of the sea-grass, along with increased terrestrial run-off in relation to sea water influx, would create a muddier habitat, putting further pressure on marine species; mangrove species would starts to grow, limiting access to the remaining waters; and some habitation sites which had been adjacent to marine waters during the sea-level rise would now be left high and dry. The environment of the Macleay floodplain would pass through a period of ecological succession in which different zones of vegetation would form (Miller and Armstrong 1982:67). In northern Australia zones of mangrove growth include salt tolerant species close to the water, with less salt tolerant species behind, which will than blend into the background rainforest. A similar pattern could be expected in the Macleay if the sea-level dropped, with salt tolerant species being replaced by those which favour a less marine habitat. These proposals will be tested in later chapters.

2.10 Addressing the Problem of Equifinality

Equifinality, 'the property of allowing or having the same effect or result from different events' (Lyman 1994:507), is always an issue in archaeological research and, in particular, in the analysis and interpretation of the processes which lead to small faunal remains such as fish becoming a part of the archaeological record. However, Rogers (2000:721) has argued that equifinality is perhaps not as great an issue as archaeologists fear – because, in the true definition of the word 'equifinality', more than one process has to yield outcomes that are identical, not just similar.

Many archaeologists would argue that changes over time – for example, declining species representation which have been attributed to a changing environment – could be the result of cultural choice. Dincauze (2000:78) refers to the 'elusiveness of ideologies' in archaeological remains; and one of the causal variables in identifying palaeo-environments from faunal remains is the cultural choice of a particular species over other species which may be as abundant in an environment but not chosen to be consumed. This is the factor in the current research which is, perhaps, the most difficult to deal with. Only by making the reasoned assumption that cultural groups living within 12 kilometres of each other would not differ significantly in their taste for particular marine resources is it possible to discount the likelihood of this form of cultural choice having a confounding effect on the conclusions drawn from this research.

Another aspect of cultural choice relates to the distance which people are willing to transport food. Suguio et al. (1991) believe that the remains of consumption of shellfish would be located close to where it was collected as it would not be feasible to carry such heavy items for thirty kilometres, as did Mason (1991:57). van Andel (1989) found that the distance from the sea to occupation sites, approximately thirty kilometres when the sea-level was lowered, bore a direct relationship to the amount of shellfish consumed. Meehan's (1982:118) extensive study of shellfish gathering, consumption and disposal by the Anbarra people of Arnhem Land showed that camp sites, and sites purely for consumption, were located approximately 15 metres from the areas of procurement of shellfish. Ethnographic studies have shown that it is likely, in an environment which was capable of producing large amounts of marine resources, such as the Macleay estuary/floodplain, that the food would be consumed close to the point of collection.

A further cultural factor potentially influencing marine faunal assemblages is fishing technology. When investigating fishing technologies, it may be the case that one or a combination of fishing strategies may be responsible for the remains seen in a midden (Colley 1987; Vale 2000). Consequently, when interpreting such a marine faunal assemblage it is necessary to present all of the alternative resource procurement strategies that may have influenced the formation of the assemblage.

In addition to the potential influence of cultural choice, taphonomic processes may also bias archaeological assemblages. Fortunately, shellfish remains preserve relatively well – especially the robust shell types, oyster (*Saccostrea glomerata*), cockle (*Anadara trapezia*), and whelk (*Pyrazus ebeninus*), that are found on the northern New South Wales coast of Australia. They may be subject to such processes as perforation and fragmentation, encrustation, abrasion, acid dissolution and chemical conversion (Classen 1998:55-59). However, on the whole, shellfish remains will preserve quite well and be available for archaeological research – unless of course the midden sites are totally removed by coastal processes such as storms, or more recently, mining and their use in activities such as road making.

However, the remains of fragile fauna such as fish do not always preserve well, and biases may occur in all because of poor preservation, retrieval practices, and the identification of this material (Thomas 1969; Casteel 1972; Payne 1972; Grayson 1984;

Walters 1986; Wheeler and Jones 1989; Shaffer 1992; Gordon 1993; Weisler 1993; Lyman 1994; Nagaoka 1994; Shaffer and Sanchez 1994; James 1997; Gobalet 2001; Vale and Gargett 2002). The loss of small faunal remains commences prior to burial with capture methods (Wheeler and Jones 1989:63), processing prior to cooking (Butler 1988:108; Butler and Chatters 1994:413), cooking practices (Lubinski 1996), bones being consumed along with the flesh (Wheeler and Jones 1989:67), and scavenging by animals including birds (Lyon 1970:214; Kent 1981; Butler and O'Connor 2004). After burial, diagenetic processes, both physical and chemical weathering, affect the bone, causing loss of the material to varying degrees, especially the more fragile elements. These processes may cause fragmentation of the bone, differential loss of specimens, and ultimately lead to an assemblage of small fragmented pieces which are unable to be identified to taxon (Dyall 1980; Wheeler and Jones 1989; Lyman 1994).

The robusticity of the shell species which comprise the middens in the Lower Macleay (see Chapter 3) means that most of the shell would have been preserved to form part of the material excavated in the 1970s. These shells may also have served to protect the fragile fishbones in the middens from being damaged by changeable weather conditions. The bones of smaller animals are also less likely to be broken prior to their deposition in contrast with the sharing the food from large animals amongst a group of people (Yellen 1977:319). The Macleay shell midden fishbone assemblages should therefore be comparatively well preserved and provide a reliable picture of the fish which were being caught and consumed by the people occupying the region.

Whilst the current research cannot hope to entirely eliminate the possibility that cultural choice played a role in the formation of the Macleay middens re-examined here, it is expected that the use of multiple lines of evidence – geological, geomorphological, ecological and archaeological – will help to distinguish between identical and similar outcomes, thereby addressing the problem of equifinality.

2.11 Conclusion

In this chapter I have reviewed the way in which middens have been used to infer sea-level change. I also discussed the proposal that sea levels have fluctuated in the Late Holocene, rather than remaining stable since 6,000 BP as previously thought. I argued that the concept of a fluctuating sea-level has implications for coastal archaeology in Australia, and demonstrated that the shell middens of the Lower Macleay provide an opportunity to test the theories of sea-level fluctuation in the Late Holocene.

In the Lower Macleay there are middens located in many present day environments, which comprise sites on the foreshore, on the estuary, and further inland where the landscape begins to rise into the Great Dividing Range. The variety of midden sites facilitates the study of environmental change. The information presented in this chapter on marine faunal ecology indicates that fish and shellfish are susceptible to changing habitats, and their adaptive response to changing environmental conditions should be able to be seen in the archaeological record through a change in relative abundance and richness in the assemblage through time. The two Macleay sites chosen for detailed re-examination and re-analysis in this study are located twelve kilometres apart, but with differences in elevation of only three to four metres; Clybucca being located beside the western extent of the estuary in the foothills, and Stuarts Point being near the coastline, separated from the ocean by narrow strips of land and estuary. Both of the sites show evidence of stratification in their deposits, and radiocarbon dating carried out in the 1970s indicated some time depth to the deposits, all within the range of the Holocene era.

If a sea-level fluctuation had occurred in the Macleay estuary in the Late Holocene it would be expected that a change in the composition of the fish and shellfish assemblages would also occur through time. Ecological research documented in this chapter has shown that both fish and shellfish will be affected by changes in salinity, turbidity and temperature. They will also be affected by loss of habitat such as loss of sea grass beds. All of this would be the case if sea-levels fluctuated during the Late Holocene in the Macleay estuary region. In Chapter 4 of this dissertation I model the specific changes as they could be expected in the Lower Macleay if a sea-level fluctuation had occurred.

In the following chapter I review previous research carried out in the Lower Macleay region, identify problematic assumptions and remaining gaps in our knowledge, and suggest which of these the present research will attempt to address.