Key Issues in the Conservation of the Australian Coastal Archaeological Record: Natural and Human Impacts

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Abstract

Australia has an extensive coastline extending over 60,000 km through diverse tropical and temperate environments. Indigenous archaeological sites are found along this coastline from the time of earliest settlement at least 50,000 years ago. However, Pleistocene sites are rare owing largely to the destructive impacts of sea-level change associated with the end of the last ice age around 10,000 years ago. After this sites are more numerous but there is variability around the coastline due to the impact of a range of both natural and human factors. Here we focus on six key issues impacting on the development and conservation of coastal archaeological deposits: sea-levels, climate change, cyclones, storms, tsunamis and contemporary human impacts. A number of examples of these impacts are discussed from across Australia. Managing and monitoring of sites has been limited in Australia and geoindicators are discussed as a means of developing a long-term measurement of continuing impacts.

Keywords: Australia; Sea-levels; Cyclones; Tsunamis; Climate change; Monitoring; Management; Geoarchaeology

1. Introduction

Coastal zones are drawn as precise lines on maps but coastal cliffs, rocks and sands change under the influence of tides, storms, tectonic movements, global climate change and other natural and human impacts. The coastal zone might therefore be described as a 'battlefront', a fragile environment where land, sea, and air meet, that changes from second-to-second, season-to-season, decade-to-decade, millennium-to-millennium (Rowland 1992:32). Past human populations responded to these impacts in a number of complex ways and in the process also modified coastal environments and resources. Many of these past and ongoing impacts are manifest on existing coastal archaeological sites together with information on climate variability which is of global relevance. These themes are developed in respect to the Australian coastal zone, focussing on the key controls on coastal change – sea-levels, climate change, cyclones, storms, tsunamis and contemporary human impacts. We also outline how these changes might be measured in the future with a view to effectively managing coastal sites. Our emphasis in on Australia's northern coastlines.

Background

The Australian Coastal Zone

Australia has one of the most extensive and diverse tropical and temperate coastal environments in the world (Figure 1). The mainland coast is over 30,000 km in length and when the surrounding 12,000 islands, several hundred estuaries, coastal lagoons, lakes and bays are included the coastline exceeds 60,000 km. Australian coastal landform types and processes are well-defined and Australia has over 10,600 beaches each of which can be classified into one of 15 distinctive beach types based on the nature of their waves, tides and sediments (Short and Woodroffe 2009; Woodroffe 2002). The coastal zone spans 9 to 42°S and includes a number of diverse habitats (e.g. Voice et al. 2006, Woodroffe 2009). Australian beaches are exposed to tides ranging from less than 1 m to 11 m and to wave energy from very low seas to the world's most persistent and energetic swell environments.

The coast of northern Australia (north of 23°) is largely low-energy and depositional with long sandy and muddy beaches, irregular coral-fringed embayments and extensive deltaic floodplains. Headlands and rock platforms of the high energy coastlines of southern Australia are rare in the north. Deltaic floodplains or deltaic-estuarine plains of the major northern Australian rivers mainly take the form of chenier plains (elongated low ridges of shell, or shelly, and occasionally gravely, sand) or beachridge plains. Chenier plains are common in areas characterised by hot wet summers where rivers are subject to seasonal flooding and intermittent tropical cyclones may induce storm surges and subsequent reworking of shelly sediments. Beach ridges comprise deep facies of coarse sandy to gravely deposits formed by episodic, commonly storm-driven wave action at the backs of active beaches. Unlike cheniers, beach ridges accumulate episodically, and former surfaces are subsequently covered by later deposits (Woodroffe 2002). The nature and formation of chenier and beach ridge deposits has major implications for the location of archaeological sites. While archaeological material is likely only to be found on the surfaces of chenier ridges, such deposits may lie intact or reworked beneath the surface layers of beach ridges, and will be located only when the beach ridge is eroded or otherwise excavated.

Over 80% of Australia's current population lives in the coastal zone and by 2051 it is estimated that the population will have grown by between 4 and 13 million, with a similar high percentage in coastal areas (Australian Bureau of Statistics 2005) thus greatly impacting coastal sites.

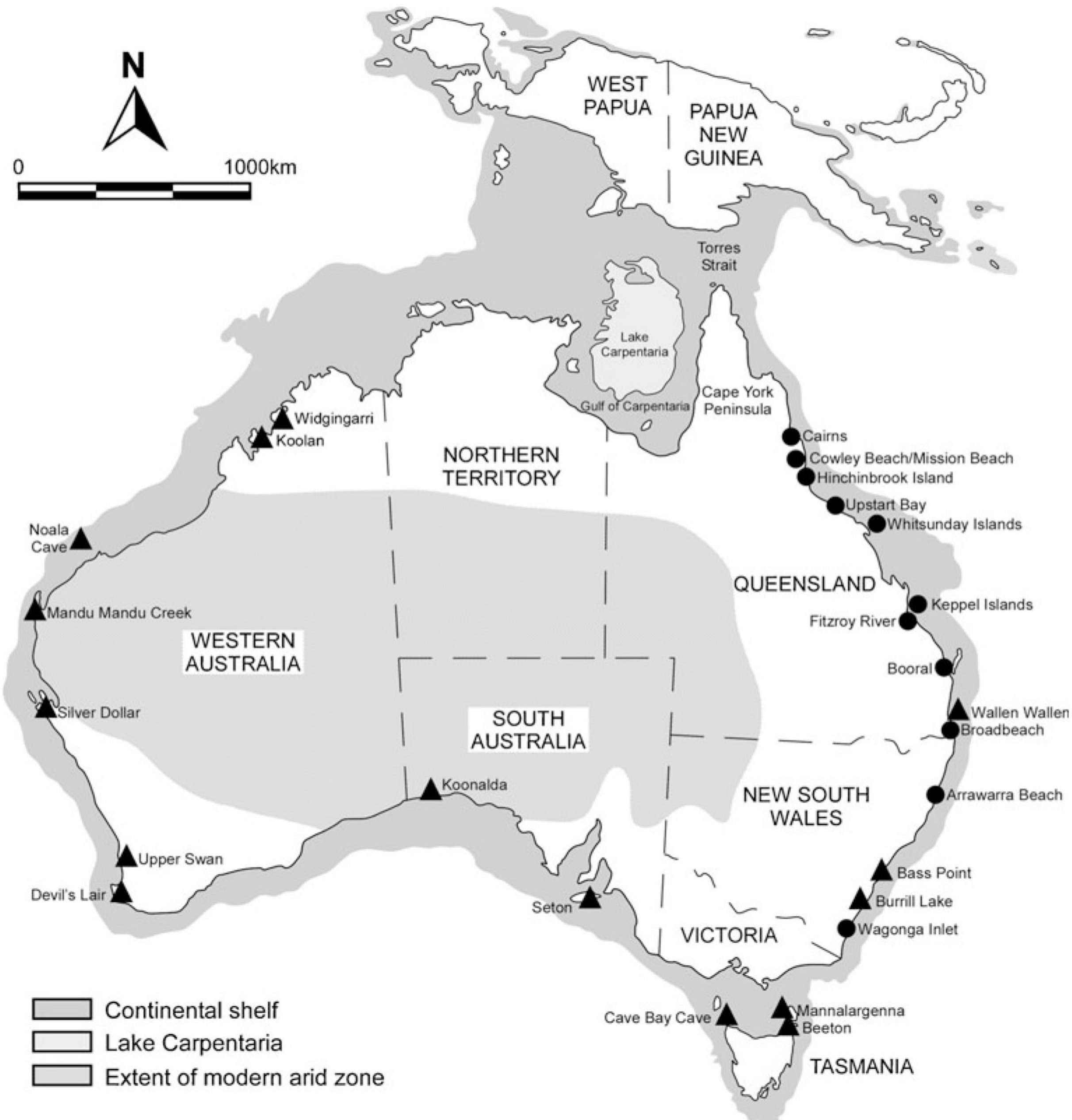

Figure 1. Australia, showing places mentioned in the text. Grey shading shows the extent of the continental shelf (exposed at times of low sea-level). Triangles show selected coastal archaeological sites more than 15,000 years old. Circles show other places mentioned in the text.

The Australian coastal archaeological record

On theoretical grounds, coastal areas worldwide have long been viewed as an optimum habitat for human development (e.g. Erlandson 2001; Erlandson and Rick 2008; Sauer 1962). In a seminal paper Bowdler (1977; see Bowdler 1990 for a response to opposing views, revisions and modifications of the model) hypothesised that Australia was colonised by people adapted to a coastal way of life. At the time, however, the late appearance of shellfish in the archaeological record worldwide had lead many researchers to consider coastal resources to be relatively unimportant in human history (see Erlandson 2001; Erlandson et al. 2008; Rowland 1996a). For Australia, Beaton (1985:18), for example, proposed that the distribution and dates of shell middens were a real phenomenon of the archaeological record, not simply a residual of sampling error. He proposed a 'time-lag' in the development of coastal economies of 2000-4000 years following the Holocene marine transgression paralleling a similar global perspective of a relatively recent broad-spectrum revolution (cf. Erlandson 2001:295). Others, however, maintained that a range of taphonomic factors might account for the apparent differential pattern of site distribution and survival (Bird 1992, 1995; Godfrey 1989; Head 1987; Hughes and Lampert 1977; Hughes and Sullivan 1974; O'Connor 1996a; O'Connor and Sullivan 1994a,b; O'Connor et al. 1999; Rowland 1983, 1989, 1992; Veth and O'Brien 1986) while the distribution and composition of shell middens also requires explanation in terms of environmental and/or social factors (Rowland 1999a; Sullivan 1987).

Marine resource use is now known from South Africa as early as 164,000 ka (Marean et al. 2007) and from the Red Sea coast approach to Australia as early as 125,000 ka (Oppenheimer 2009). Some of the earliest archaeological sites in Australia also include evidence for marine resource use (e.g. Morse 1999; O'Connor 1996b, 2007). Hunter-gatherer populations also appear to have begun to influence the size and structure and improve the productivity of certain coastal resources as early as 23 ka (Rick and Erlandson 2008, 2009). There is therefore no longer a case for a 'time lag' in the development of coastal economies (e.g. O'Connor 1996a; Veitch 1999). Indeed it is now considered that it would be more difficult to explain an abundance of Pleistocene shell middens on the modern coastline than their absence (Morse 1999). It is also now widely recognised that the emergence of cultural complexity can be stimulated in part by increased competition for resources caused by successive changes in sea-levels, shorelines and climate (e.g. Kennett and Kennett 2006). The formation of archaeological shell midden sites reflects a complex interplay of local and subregional geomorphic changes, sea-level changes, sediment substrate evolution and human social behaviour and economic scheduling. The survival of such sites in highly energetic coastal settings is then subject to the impact of cyclones, storms and tsunamis.

Shell middens, mounds and scatters are found across Australia where they may represent specialised marine or maritime subsistence economies focussed on offshore resources, or a generalised and flexible coastal subsistence tied to the land (e.g. Bourke 2004; Faulkner 2009; McNiven 2006). They may be coastal/estuarine or freshwater (e.g. Brockwell 2006) and some are important Indigenous story places (Cribb 1986). The great mounds of Cape York Peninsula (Bailey 1999) were claimed to be a mixture of natural shell deposits and midden material scraped up into nesting mounds by orange-footed scrub fowls (*Megapodiuos reinwardt*) (Stone 1995) but they appear to be predominately anthropogenic in origin (Bailey 1999; Cribb 1996). The timing and causes of change in coastal site distributions is complex and continues to be reviewed (e.g. Clune and Harrison 2009).

For some time, it has been recognised that on the Queensland coast in particular and on the Australian coast generally a large number of coastal middens post date c.2000 BP with markedly fewer sites dating prior to this time (Rowland 1983, 1989; Ulm and Reid 2000), with a major expansion only in the last 1000 years (Ulm 2006, in press). The age and distribution patterns of coastal sites have been used to support theories of intensification (Barker 2004; Lourandos 1997) and/or population increase (Beaton 1985; Lampert and Hughes 1974), a time lag in coastal developments (Beaton 1985), the possible impact of external population pressures (Rowland 1989), environmental change affecting availability of resources (Bailey 1983), and dramatic re-ordering of land-use patterns (Ulm 2006), but it has also been the case that environmental/preservational factors have not been adequately addressed in explaining the patterns (Rowland 1983, 1989).

Apart from temporal variations in the distribution of sites, spatial variation has also been identified which does not equate with the ethnographically known distribution of Aboriginal populations. For example, ethnohistoric sources for north Queensland coastal areas, in particular the humid tropic zone, include numerous references to Aborigines collecting shellfish and other coastal resources but this is not reflected in the archaeological record (Rowland 1989:32). The humid tropic zone is Australia's highest rainfall region. Mean annual temperatures are also high. Rainfall regularly occurs as heavy downpours and all major rivers flood frequently. Sand from the floodwater discharge is washed ashore by southeast waves generating a northward longshore drift causing limited beach ridge progradation up to 1 km wide. Prior to European penetration in the 1860s, rainforest was the dominant vegetation type in the area and the predominately steep coastline is still dominated in many areas by rainforest extending down to high-tide level. High population densities and sedentism evident in the ethnohistoric records for the area but this was not clearly reflected in the coastal archaeological record. Archaeological surveys have found few sites and most were located in sheltered headland positions and are not associated with dune complexes which are rare landforms (Rowland 1989).

A range of environmental factors, including temperature, rainfall, vegetation, cyclones, storm surges, coastal erosion and sea-level changes have therefore impacted on the Australian coast and have been responsible for the selective destruction of at least a part of the archaeological record (Rowland 1983, 1989, 1999a,b,c). Sites can also be disturbed by a wide range of climate related stochastic events (see below). Inter-site continuities and hiatuses must of course be interpreted with considerable care and cannot unquestionably be attributed to environmental change (O'Connor et al. 1999).

The number of sites and quantities of objects found at sites has been central to debates about intensification in Australia over the last three decades (Lourandos 1997). However there are problems with the simple correlation of numbers of sites or objects and numbers of people (e.g. Attenbrow 2004; Hiscock 2008; Holdaway et al. 2008; Lilley 2000) and importantly it has been recognised for some time that site preservation factors are important in any assessment (e.g. Bird and Frankel 1991; Fresløv and Frankel 1999). On the coast in particular an increase in site numbers can be explained in part at least by erosion of older coastlines (Rowland 1989, 1999a). Higher discard rates of stone tools are also argued to reflect increases in population, but contrary to expectations Lamb and Barker (2001) found increases in discard rates in the early Holocene and a significant reduction in the late Holocene at Nara Inlet 1 on Hook Island in the Whitsunday Group.

Key issues in the conservation of the Australian coastal archaeological record

We have identified 6 key issues which are crucial to understanding the development and conservation of coastal archaeological deposits in Australia: sea-levels, climate change, cyclones, storms, tsunamis and contemporary human impacts.

Sea-levels

Sea-level change is the most critical factor in understanding coastal site locations and numbers (Erlandson 2001:300) and in fact coastal archaeological sites may be considered sea-level change markers. For Australia, a 123 m sea-level low during the LGM was followed by a comparatively rapid rise starting around 19.6 ka cal BP and lasting for some 800 years with a magnitude around 10 m (Hanebuth et al. 2009). The lower sea-levels of the LGM resulted in increased continentality associated with an expanded arid zone and much of the continental shelf was exposed, resulting in the land area of Australia and New Guinea being up to 25% greater than present (Petherick et al. 2008:787-788). This created an expanded coastal zone which is now under water but did not necessarily provide the most hospitable conditions for human occupation. The Great Barrier Reef Province, for example, would have been a cliffed coast facing the open ocean. Changes, however, were rapid as sea-level rose over the shoulder of the continental shelf and the presence of archipelagos of limestone islands, sheltered estuaries, and extensive mangrove and potential seagrass areas provided a range of rich habitats not only for Aboriginal peoples but for many of the plants and animals which currently inhabit the area. Mangroves, so important as the habitat for a wide range of species and the nursery ground for many others, reached their maximum during the early Holocene. The stillstand of the last 6.5 ka has allowed the stabilisation of ecological communities but is probably not the richest period in the geological past (Nott et al. 2009). During the late Pleistocene the Gulf of Carpentaria was also dominated by the large shallow Lake Carpentaria (see Figure 1) (Jones and Torgerson 1988).

Sea-level changes at the time of the marine transgression would have had considerable impacts on people's use of the coast. Barker (2004; see Hiscock 2008:166-170 for a critical review), however, argues that the changes had little or no effect proposing instead that marine ecosystems especially in the tropics are extremely resilient to environmental change. Barker (2004) argues for continuity of use throughout this period based on interpretation of sites in the Whitsunday Group of islands. There is a hint of mid-Holocene occupation at Nara Inlet 1 in the Whitsunday Islands (Barker 2004), but even if this equivocal suggestion of use is proven it indicates only very ephemeral occupation at this time (Sim and Wallis 2008). It is more likely as Ulm (2006:253) suggests that reduced predictability of coastal resources linked to fluctuations in marine productivity induced by the final stages of marine transgression may have led to a general reduction in the use of coastal areas in favour of increased use of subcoastal areas.

The timing and magnitude of Holocene sea-level changes on the coast of Australia following the LGM is still under review. Chappell's et al. (1983) smoothly falling sea-level from 6000 years ago long remained the paradigm but is now challenged. Larcombe et al. (1995) suggested sea-level remained approximately 1.5 m above present between 6500 and 3000 BP and then fell sharply. More recently, Baker et al. (2001) have suggested sea-level oscillated up to three times over the last 6000 years. Lewis et al. (2007) have proposed a high stand of +1.0-1.5 m was reached approximately 7000 cal BP and that sea-level fell to its present position after 2000 BP. In between this they identify two distinct periods (4800-4500 and 3300-2700 BP) of possibly lower sea-level of +0.5 m. Sloss et al. (2007) propose present sea-level was attained between 7900 and 7700 cal BP, approximately 700-900 years earlier than previously proposed. Sea-level continued to rise between +1 and +1.5 m between 7700 and 7400 cal BP, followed by sea-level highstand that lasted until 2000 cal BP followed by a gradual fall to present. They also note a series of minor negative and positive oscillations in relative sea-level during the late Holocene sea-level highstand that appear to be superimposed over the general sea-level trend (Sloss et al. 2007). Woodroffe (2009) found sea-level to be relatively stable between 6700-3500 cal BP, and indicates the end of the peak of the high stand at or before approximately 3500 cal BP. The more recent sea-level evidence is consistent with a clear hiatus in dune development and cultural deposits in a midden complex at Mazie Bay on North Keppel Island at 3500 BP which Rowland (1989, 1996a, 1999a,b) has long argued was related to a change in sea-level. It has also been proposed that the Great Barrier Reef itself only began to form at c.3000 BP. Maximum reef productivity was restricted to 3000 to 2000 BP, an interval which corresponds to a fall in relative sea-level and a regional climate transition from pluvial (wetter) to more arid conditions of today (Frank 2008).

Immediately preceding the attainment of present sea-levels in northern Australia there appears to have been a phase when mangroves were more extensive (Allen 1996). After the mangroves decline, shell mounds appear for the first time and it has been debated whether ecological changes or cultural changes are the cause of these changes. Veth (1999:69), for example, considers that human occupation on arid coastlines probably has considerable antiquity and is not just a product of sea-level stabilisation nor late Holocene social transformations. O'Connor (1999:48), considers environmental/ecological factors to be critical but not in a deterministic way. She notes that approximately 4200 years ago shell mounds appear in northern Western Australia for the first time and display a south to north gradient in time across their distribution which she attributes to the northward movement of the northwest Asian monsoon.

The extent of sea-level change in Australia means that in general there are very few coastal Pleistocene sites and that most sites are likely to date within the last 3500 years (Figure 2).

Climate change

Climate change is a regular occurrence and is a persistent factor in cultural change while also impacting on archaeological site preservation. For Australia, the strongest driver of regional climate variability is the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). ENSO is reported to have significant effects on archaeological sites (e.g. Jordan 1991:413: Table 13.2). The potential impact of 'enhanced greenhouse warming' is a factor that now also requires consideration (Figure 3).

The Holocene in Australia is characterised by significant climate change. Recent investigations in the Southern Ocean, for example, shows a strong 1550 year cycle with prominent cold phases at 9.2, 7.3, 5.8, 4.3, 2.7 1.4 ka BP and possibly the Little Ice Age (LIA) (Moros et al. 2009). The Holocene is also characterised by increasing ENSO event frequency from 5.5 ka BP towards the present culminating at ~1,200 cal BP, and then decreasing towards modern times (Shulmeister and Lees 1995; Wanner et al. 2008). Lees (2006) correlated periods of chenier and sand dune formation in northern Australia and has demonstrated that three drier periods appear to have prevailed during the late Holocene in northern Australia – 3500 to 2600 BP, 2,100 to 1600 BP and during the last 1000 years. McLean et al. (2009; but see Foster et al. 2009) claim that ENSO accounts for as much as 72% of global tropospheric temperature anomaly and as much as 81% in the tropics. They conclude that the Southern Oscillation Index (SOI) is a dominant and consistent influence on mean global temperatures and perhaps recent trends in global temperatures. ENSO has had and continues to have significant impacts on coastal landforms (Hopley et al. 2007) and has had long-term cultural impacts (see Black et al. 2008; Turney and Hobbs 2006). A recent analysis by Williams et al. (in press) of 1277 radiometric ages from 607 archaeological sites across northern Australia demonstrated apparently close correlations between archaeological indices for occupation and climate variability over the last

2000 years (see also Brockwell et al. 2009; Turney and Hobbs 2006). Results reveal a general increase in archaeological records across northern and central Australia over the last 2000 years, with notable declines between c.1300-900 BP and c.550-250 BP. Declines were greatest in the lower latitudes, encompassing the northern Australian coastline. Williams et al. argue that the declines between c.1300-900 BP and c.550-250 BP represent disruption to critical resources, including water, animal and plant foods, that can be correlated with changes in the ENSO state, which reveal a shift towards the La Niña mean state with wetter conditions between 1450-950 BP; followed by a shift towards the El Niño mean state with drier conditions between 950-450 BP; and increasing variability between both states between 450 BP and the present.

The potential impact of human induced global warming on coastal heritage sites has been slow to be recognised in Australia (see Rowland 1992, 1996b, 1999c, 2008; Pearson and Williams 1996) and the impact of climate change on coastal systems is difficult to predict (e.g. Cowell et al. 2006). The IPCC Fourth Assessment report, for example, notes that there is no trend in the frequency of tropical cyclones in the Australian region from 1981 to 2003 but that there has been an increase in intense systems (Hennessy et al. 2007). However, there is also evidence of much more intense cyclones in the past (see below). The IPCC Report also notes that relative sea-level rise around Australia averaged 1.2 mm/yr from 1920 to 2000 (Hennessy et al. 2007). However, the causes of sea-level variation and other coastal changes, that are independent of global warming, may be overlooked. Eustatic changes, for example, remain an important factor in many regions of the world so that relative sea-level in some locations is still falling (Forbes and Liverman 1996:179) and Australia had a slightly lower (1.2 mm) rate of sea-level rise than the global average of 1.8±0.3 mm per year between 1950 and 2000 which has yet to be fully explained (Church et al. 2006). Ongoing environmental changes and increasing human development will continue to impact on heritage resources and the global warming debate should therefore re-emphasise the need to continue to define and refine the processes involved in cultural resource management. Complex changes will therefore continue to occur in the coastal zone whether caused by 'normal climate' variation or anthropogenic induced change (Rowland 1996b:131-133) (Figure 4).

Rowland (2008) combined evidence of long-term environmental trends and personal observations over a period of 30 years to indicate the likely causes of damage to coastal sites on the Keppel Islands off the central Queensland coast. He found that the major cause of damage over the last 5000 years was the long-term impact of wind and wave climates exacerbated in recent times by natural and human induced vegetation removal. Introduced sheep, goats and possums were also a major source of vegetation destruction on the islands. Contrary to expectations tourists had probably had a limited impact on sites. 'Normal' weather conditions had a significant impact on sites by causing damage to vegetation, resulting in substantial erosion over short time-spans. Stochastic events such as cyclones and flood discharges from the Fitzroy River also had significant impacts. For example, Cyclone Fran which passed within the vicinity of the islands in March 1992 had significant impacts on a number of beaches. More than 1 m of sand was lost from Fisherman's Beach though it is important to note that this has now largely been replaced and revegetated. On South Keppel Island, local fishermen have reported erosion of at least 15 m over a 40 year period at Putney Beach and Fisherman's Beach and these beaches, not surprisingly, produced no evidence of Aboriginal occupation. Rowland (2008) recommended the establishment of some measures (geoindicators) that can be used to identify future changes in the nature and direction of changes in the coastal zone (see below).

Figure 2. Typical shell midden scatter in central Queensland dominated by *Donax deltoides* (Photograph: Sean Ulm).

Figure 3. Eroding shell midden in central Queensland (Photograph: Sean Ulm).

Figure 4. Distinctive shell mound on Cape York Peninsula composed of shellfish, dugong, crocodile, turtle, fish, lizard, bird, mammal and other unidentified bone fragments and a range of stone artefacts (Photograph: DERM Database).

Cyclones

Cyclones and storm surges have had a demonstrable impact on cultural heritage places in parts of Australia and the Pacific (Przywolnik 2002; Rowland 1989; Sullivan 1996; Sullivan and O'Connor 1993). Unfortunately, with rare exceptions (Bird 1992, 1995) archaeologists have not yet monitored these impacts in any detail.

The entire coast of northern Australia (5-30°) is prone to the influence of tropical cyclones where sea-surface temperatures are normally above 27°C in the months of December to April (Nott 2006a,b) at a mean of 2.8 cyclones per year (Puotinen 2004, 2007). Tropical cyclones produce both strong winds and marine inundation composed of storm surge, tide, wave set-up, wave action, and wave run-up (Nott 2006a: 49). Ridges composed of coral fragments, marine shells, pumice, lithic gravel and coarse to very coarse grained sand up to 6-8 m AHD most likely owe their origin to marine inundations generated by extreme intensity tropical cyclones. Extensive dune erosion can occur during such inundations along with deposition of washover sand splays or sheets. Although gradual processes play a very important role in shaping the sedimentary coasts of northern Australia, less-frequent, high-energy events may completely destroy the low energy features. Landforms created by the extreme events may in turn be modified by higher frequency events. The tropical coast is therefore a mosaic of landforms from different scale energy events (Nott 2006a:61).

Substantial sections of the coast of northern Australia are also composed of beach ridge plains and, to a lesser extent, chenier plains. This is particularly the case around the shores of the Gulf of Carpentaria. Here in places up to 80 individual ridges, paralleling the shore, form beach-ridge plains that extend far inland. The ridges, along the eastern and southern shores of the Gulf, contain non-cultural shell-rich layers up to 1-2 m thick interspersed within medium-to-coarse-grained sand (Rhodes et al. 1980). They rise up to 6 m above mean sea-level (tidal range of approximately 2 m) and extend along the shore for over 10 km in places. Rhodes et al. (1980) first suggested that the ridges were deposited during tropical cyclones and this is supported by Nott (2006b; Nott et al. 2009).

At Cowley Beach 130 km south of Cairns a ridge plain 2.5 km wide of nearly 30 Holocene beach ridges extending inland and paralleling the coast are argued to have been formed by cyclones (Nott 2006a:50; Nott et al. 2009). The beach ridges vary in age from approximately 5000 BP at the landward margins of the sequence to less than 1000 BP nearer the coast. An earlier brief survey of this dune system located no archaeological sites and in fact only two sites were located in adjacent sheltered headland locations (Rowland 1989:34).

At Mission Beach 100 km south of Cairns an intense tropical cyclone struck in March 1918. Eyewitness observations and results from numerical storm surge and wave models of the event along with knowledge of the tide level at the time shows that the storm tide (surge plus tide) and wave set-up combined amounted to an inundation level of 4.7-4.9 m AHD (Nott 2006a) and a 4.5-5.1 m high (above AHD) ridge of pumice was deposited by a surge as the cyclone crossed the coast (Nott et al. 2009:87). Again few archaeological sites have been found in this area.

Nott (2004a, 2004b) has highlighted the necessity of incorporating archaeological data in the analysis of cyclone effects to account for the lack of stationarity through time. For example, in the historical record, the largest storm tide (surge plus wave set-up) in Cairns has been 0.7 m above HAT, but in the archaeological record there are at least three events with storm tides between 2.5 m and 4.5 m. Extreme intensity cyclone or 'super-cyclones' have thus effected the area in the past (Nott et al. 2009) and must have had unprecedented impacts on sites and peoples use of the coast.

In 1987 Bird (1992, 1995) undertook a baseline survey at Upstart Bay, north Queensland and resurveyed the area following cyclones Charlie in 1988 and Aviu in 1989. She found that over this period 50% of sites were destroyed. During the preliminary survey in 1987 Bird recorded 93 archaeological sites. Most were deflated shell middens and scatters located in a narrow band of mobile Holocene sand dunes. Following cyclone 'Charlie' in 1988, 14 of these sites were completely destroyed and 23 were significantly reduced or modified. Of the 79 sites which survived this cyclone, a further 37 sites were obliterated in 1989 during severe cyclone 'Aivu'. Further surveys from 1992-94 exposed a new archaeological record. In October 1993 nine previously unrecorded shell scatters were located along the present foredune system. While erosion was ongoing some parts of the coast were also prograding. Thus at least three sites were being capped by mobile sand deposits and were being reburied within the dune system, enhancing their long-term preservation (Bird 1995). These changes have occurred over a period of only seven years so that one can only speculate on the long-term effects of such processes (Head 1987; Rowland 1989; Sullivan 1981).

At Abbot Point, Barker (2006) found midden material was spatially extensive with discrete and often dense concentrations of midden material located within an almost continuous 'background' scatter of lower density shell resembling the sites recorded by Bird (1992) at Upstart Bay. Barker suggests the very late date of all the remains (500-600 BP) is a true reflection of the archaeological signature rather than solely a product of cyclonic events as suggested by Bird (1992, 1995) and Rowland (1989). Neither Bird nor Rowland suggest the archaeological record is solely a product of cyclonic events but there is no doubt that cyclones have had a significant impact on the archaeological record.

It is predicted that global warming will increase the frequency and intensity of cyclones and that they will also move further south, threatening more impacts on coastal archaeological record (Hennessy et al. 2007).

Storms

Apart from cyclones there are other types of storm activity that can impact on the coast and coastal sites (Hughes and Lampert 1977; Hughes and Sullivan 1974). The east coast of Australia in particular is prone to east coast lows or 'winter cyclones'. These develop during the winter months on the east coast between 25° and 40° S. They can develop rapidly and become quite intense and contribute significantly to flooding, wind damage, storm surge and beach erosion (Allen and Callaghan 1999; Leslie and Speer 1998). For example, at Broadbeach on the Gold Coast a succession of large wave events occurred during the period March-July 2006. The resulting dune retreat in this single event was estimated to be about 10-15 m (Castelle et al. 2007). Earlier extrapolations suggest 210 m erosion as a 1 in 1000 year event and 350 m as a 1 in 5000 year event (Smith and Jackson 1990). At Arrawarra Beach midden, in northern New South Wales, an excavation undertaken prior to dune stabilisation suggests that the foredune was stable for over 1000 years then c.30 years ago the current cycle of erosion began (Smith 1998). While periods of coastal erosion may destroy sites they may also reveal new sites and in some cases expand the visible form of archaeological remains across the landscape (McNiven 1997) (Figure 5).

Tsunamis and other impacts

The impacts of tsunamis have been studied on many parts of the Australian and New Zealand coast (Bryant 2001; Goff and Dominey-Howes 2009; Nott 2004a, 2006b) and coastal Aboriginal middens may have been disturbed by such events (Bryant et al. 1992; Fullager et al. 1999). However, a recent comprehensive review of evidence from archaeological sites on the south-central New South Wales coast by Hutchinson and Attenbrow (2009) could find no support for the hypothesis that mega-tsunamis inundated the coastline in the late Holocene and the tsunami hypothesis must be treated with caution (Felton and Crook 2003). Surprisingly the recovery time from tsunamis may be quite short, as for example, following the 2004 Indian Ocean tsunami, which devastated coastal areas along the coast of Thailand and Sumatra (Liew et al. 2010). Nevertheless, the impact on prehistoric sites and resources is likely to have been considerable.

Other potential impacts on coastal landscapes include earthquakes and plate tectonics, landslides, volcanoes, and asteroid impacts (Nott 2006b). Rafts of pumice found in middens in the Torres Strait might also indicate that catastrophic volcanic events or intense tropical cyclones also impacted on some sites (Nott 2006a; Rowland 1985). At a smaller scale the stratigraphical integrity of coastal sites may be totally destroyed by crab burrowing activity (Specht 1985).

Human impacts

Coastal sites are initially disturbed by the original occupants moving about on them (Hughes and Lampert 1977), often built on or destroyed by land clearance, and have been mined for a wide range of economic purposes (Ceci 1984). In New South Wales, for example, for many years the major supply of lime for building came from shells collected from beaches and Aboriginal middens (Pearson 1981). At Wagonga Inlet, also in New South Wales, of a survey of middens undertaken in 1890 it is estimated that only 10% of the volume remained in 1980 where they had mainly been damaged by residential development (Sullivan 1981). Unfortunately, very few studies of this nature have been undertaken so we do not know how much has been lost to human development. Legislation to protect archaeological sites has only been in place in Australia since the mid-to-late 1960s (Figure 6.

Management and monitoring

The management of coastal sites has not been widely discussed in Australia (cf. Smith 1998; Snelson et al. 1986). The management of any type of coastal site is difficult and includes critical issues of scale and cost (for a brief but useful overall review see Sullivan 1989) and it is important to develop strategic frameworks for the monitoring of coastal areas. There is an extensive literature on methods of dune stabilisation but the methods do not take into account the specific needs of Aboriginal site protection (Snelson et al. 1986:25).

Figure 5. Deflated midden on the Queensland coast on the crest of a sandstone ridge containing predominately oyster shell and a range of stone artefacts (Photograph: DERM Database).

Figure 6. Midden at Booral in southeast Queensland. It contains a range of shell and bone and some glass fragments (Photograph: DERM Database)

Figure 7. Part of a large fish trap complex on Hinchinbrook Island associated with nearby shell middens (Photograph: DERM Database)

Geoindicators are a useful way to measure change in coastal zones at a scale relevant to the management of coastal sites. Geoindicators are measures (magnitudes, frequencies, rates, and trends) in geological processes and phenomena occurring at or near the Earth's surface which are subject to changes that are significant in understanding environmental change over periods of 100 years or less. They measure both catastrophic events and those that are more gradual, but evident within a human lifespan. A range of geoindicators have been developed during a three year international project by the Commission on Geological Sciences for Environmental Planning of the International Union of Geological Sciences. Geoindicators can apply to all land systems and measure what is happening in the environment, why it is happening and what impacts it is having (see Berger 1996; COGEOENVIRONMENT (IUGS) Working Group on Geoindicators 1996; see also Young et al. 1996:194: Table 1 who have developed further geoindicators that can be used for the qualitative assessment of shoreline erosion or accretion).

Three coastal geoindicators – dune formation and reactivation, relative sea-level rise and shoreline position – are discussed by Rowland (2008) in respect to the monitoring of change to coastal sites on the Keppel Islands off the coast of Central Queensland.

The dune formation and activation geoindicator, for example, is a useful, cheap and reasonably easy geoindicator to measure. It reflects a range of climatic and environmental variables, including wind speed and direction, moisture and sediment availability and sea-level change. Changes in dune morphology and position or development of new dunes may indicate variations in aridity, wind velocity and direction, and/or disturbance by humans. Active dunes can bury or disturb coastal sites.

Changes in the size, shape and position of sand sheets and dune fields can be monitored by repeated ground surveys and measurement of active and dormant/relic dunes by air photos and/or satellite images. Early air photos may also be used to predict what might might/not have happened to sites over time. Dune systems can be monitored every 5 to 10 years to observe changes associated with drought cycles for example, and more frequently when catastrophic events (e.g. cyclones) occur to determine what impacts they have on coastal sites.

Because coastal environments are so dynamic it is important to identify and monitor geoindicators that are sensitive indicators of change, even though they may not be diagnostic in identifying the casual factors responsible for the observed changes. The causes of coastal change at a particular site may never be fully understood, but this could not deter the establishment of long-term monitoring programs that will provide the robust observational data need for future coastal planning and site management strategies.

Rowland (2008:25) was able to use information on dune formation and reactivation deduced from air photos from 1962 to present along with anecdotal information gathered from a number of observers to describe impacts on coastal archaeological sites at Wreck Beach on South Keppel Island. The next step will be to apply geoindicators in a systematic fashion in long-term monitoring programs on a larger geographical scale. Some geoindicators are complex and costly to measure, others relatively simple and easy to apply (Figure 7).

Conclusions

From the time of their formation, heritage places, particularly in coastal areas, are subject to processes that may modify and ultimately destroy them. In the past threatened sites were often excavated to salvage as much information as possible. But with increasing emphasis throughout the 1970s on archaeological sites as 'non-renewable' resources focus shifted from an exploitative model to a more conservation focused model resulting in an extensive literature on Cultural Resource Management (e.g. Schiffer and Gumerman 1977; Sullivan and Bowdler 1984). With increasing coastal development and the potential impact of human induced warming salvage however may again become an important consideration (Rowland 1992, 1996b, 1999c). If worst case scenarios of global warming occur, archaeological sites will have a relatively low priority and it is unlikely that funds would be available to preserve sites in situ. The current global warming debate is controversial and there is still uncertainty. But there is no uncertainty that populations will increase and demand more space and resources. The climate change debate must therefore heighten our awareness of all possible impacts in developing cultural resources management strategies and of the need to undertake monitoring programmes that can measure the causes and direction of change. It would be costly, time consuming and probably impossible to maintain a comprehensive and sophisticated monitoring system for all coastal sites. Nevertheless, experience on the Queensland coast suggests at least two approaches to the monitoring could be applied in general.

First, anecdotal information can be used along with occasional observations (such as was, for example, undertaken on the Keppel Islands) to identify general trends in coastal change. This can be supplemented by establishing photographic points and marker pegs at some sites to determine longer term trends in shoreline movement. Observations can be undertaken on an annual basis, but in the case of major climate events observations should follow as soon as practical after the event.

Second, major projects should be developed that focus more broadly on coastal areas. This would require a risk management analysis of sections of the coast mapping such factors as landform type, vegetation coverage, climate, storm surge, and predicted global sea-level rise. It would also involve mapping past and present impacts such as past urban development, present and future development, and other coastal works, including mining, tourism, agricultural, and industrial developments. At the broadest scale the geoindicators discussed above – dune formation and reactivation, relative sea-level and shoreline position – could be mapped as indicators of trends in respect to potential global warming and other natural and human induced changes. A series of risk assessment maps could then be produced for the coastline. Digital models of the coastline could also be developed that could be rapidly updated as new data become available.

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