An Overview of Available Information on Sandy Beach Ecology, Coastal Sand Dunes, Rocky Reefs and Associated Biota on the Gold Coast

FINAL REPORT

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Synopsis: This report is an overview of available information on sandy beach ecology, coastal sand dunes, rocky reefs and associated biota on the Gold Coast.

Keywords: Literature review, ecological processes, sandy beaches, Gold Coast
EXECUTIVE SUMMARY

As part of the Gold Coast City Council Shoreline Management Plan the Griffith Centre for Coastal Management was commissioned by Gold Coast City Council to conduct a literature review on the current state of knowledge in regards to Gold Coast's nearshore reefs, sand dunes and intertidal ocean beach fauna. The purpose of this study was to identify critical areas in need of research and aid Gold Coast City Council in decision making for beach and foreshore management.

The Gold Coast’s 37 km of mainly sandy coast (Short, 2000) provide Gold Coast City Council with an enormous natural asset. Gold Coast’s beaches are its most recognised icon and a fundamental lifestyle asset of the city. Beaches underpin much of the area's coastal economy, supporting tourism and coastal development. Beaches also play a crucial role in controlling coastal erosion dynamics, a function which will become increasingly important in face of rising sea levels (Schlacher and Noriega, in press) and frequent and more severe storm conditions. Less acknowledged is the ecological importance of beaches and the wide range of ecosystem services they provide. While beaches may appear barren and largely devoid of life, in reality beaches support a great diversity of fauna. Moreover, sandy beaches are an important ecosystem that links the ecology of sand dunes, the surf zone (Short and Hesp, 1982), intertidal zones, and nearby rocky reefs.

Gold Coast's beaches are under increasing pressure due to population growth and rising number of visitors to the area. The main human impacts on Gold Coast's sandy beaches are coastal development, disruption of sand transport (sea walls and groynes), mechanical beach cleaning, beach nourishment and repprofilling, 4WD vehicles and trampling. During this review it was found that the current management of beaches has been mainly centred on physical aspects such as sand supply, stability and erosion intervention. It was also found that the available scientific knowledge on sandy beach ecology is extremely limited. As a result, there is a need to conduct baseline research on the ecology of sandy beaches and to make these results available to coastal managers and policy makers, who are often unaware of the ecological role of sandy beach organisms. In addition there is a need for science based beach management strategies that address ecological objectives as well as socio-economic ends.

Coastal dunes are an integral part of the coastal environment (NSW DLWC, 2001). They not only protect coastal property from storms, but also are the basis of important ecosystems supporting valuable communities of plants and animals (NSW DLWC, 2001). However, coastal sand dunes have often been regarded as marginal land which is available to the public for recreation (Gadgil and Ede, 1998) or other anthropologic purposes. On the Gold Coast sand dune systems have been heavily altered by human interventions. Coastal development has been without doubt one of the main factors responsible for the degradation of sand dune systems in the area. Environmental problems associated with coastal development include loss of natural dune habitat, threats to natural species, reduction in seed sources, and decreased resilience of plant communities in developed areas following loss by storms (Nordstrom et al., 2000). Other factors that also affect the natural growth of dune systems are beach cleaning operations which are conducted to improve the appearance of the beach for recreational use (Nordstrom et al., 2000), construction of an excessive number of pathways which are built to increase ease of access and construction of rest areas or recreational facilities on dune systems. Finally, the introduction of exotic species has also had a detrimental effect on the native vegetation and fauna.
The amount of scientific research carried out on Gold Coast sand dunes is extremely low. There is no information on the overall species composition and weed coverage and its effects on native vegetation. Therefore, there is a need to conduct baseline research on the ecology of sand dunes and to make these results available to decision making authorities who may be unaware of the ecology of sand dunes. It was also found that despite the extensive work that GCCC conducts on the rehabilitation on sand dunes at certain areas, the current management and rehabilitation program is fragmented. GCCC has not yet developed a management plan for sand dunes. Consequently, there is a need to develop a sand dune management plan which is designed for the area’s ecological requirements and based on scientific research which addresses conservation needs as well as recreational objectives.

The subtidal rocky reefs of the Gold Coast support communities of benthic fauna and flora and fish that represent a transition between the tropical waters of the Great Barrier Reef and the temperate waters characteristic of the mid-New South Wales coast (Cannon et al., 1987; Done 1982). Rocky reefs in the Gold Coast provide: habitat and shelter for many plants; invertebrates and fish communities; help protect the coast from strong currents and waves; help sustain commercial and recreational fisheries; and provide recreational amenity for diving and snorkelling. Because many of the Gold Coast’s reefs are located close to shore, they are often affected by human activities from land or in nearshore areas. This review found that human activities that are likely to be having an impact on reef communities include: beach nourishment practices; alteration of coastline habitats (seawall construction, removal of mangroves); urbanisation and coastal development; domestic and agricultural pollution; oil pollution from boats; stormwater runoff (especially where this carries debris and pollutants) and boat anchoring and over fishing. It was also found that the species abundance and biodiversity of these reefs systems is not well understood or managed. Based on the findings it is recommended that the State Government and GCCC to work cooperatively in order to protect these valuable resources by conducting regular monitoring of all nearshore reefs and by developing environmental education programs aimed at minimising human impacts. GCCC nearshore reefs fall under State Government jurisdiction. However, nearshore reefs are linked to GCCC due to the recreational amenity they provide to local residents and visitors. Hence they directly contribute to Gold Coast’s economy. Both the State and Local government should be involved in protecting these valuable assets.

Several groups of vertebrates make use of sandy beaches for foraging, nesting, and breeding (McLachlan and Brown, 2006). Birds are the most important vertebrates commonly encountered on sandy beaches, both in terms of abundance and diversity and their role in beach ecosystems (McLachlan and Brown, 2006). Shorebirds need food and protection from predators and human disturbances in order to recuperate from long migrations and for breeding (EPA and QPWS, 2006). The information presented in this review suggests that inadequate intertidal resources (a result of constant beach nourishment practices), constant human disturbance, lack of suitable habitat for roosting and general habitat loss and degradation could be the main threats to shorebirds on Gold Coast beaches. Hence there is an urgent need to refine the available knowledge on factors such as seasonal distribution, degree of human disturbances, population number of resident communities, feeding and roosting grounds, nesting sites and distribution and abundance of intertidal resources. In addition there is also a need to develop scientifically based management actions in order to protect feeding and roosting grounds as well as nesting sites from human made disturbances and other.
Turtles, also visit beaches to lay their eggs in the dry sand above the high water mark (Clark, 1998; McLachlan and Brown, 2006). Globally, marine turtle populations are under threat. Green and Loggerhead turtles, two species that nest in the Gold Coast, are listed as endangered by the International Union for the Conservation of Nature (IUCN). In addition, marine turtles are also considered threatened by the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act 1999) and Queensland’s Nature Conservation Act 1992. Community members, Griffith University and GCCC have been successfully working together to conduct monitoring of marine turtles in South Stradbroke Island. There is an ongoing need for further research, community awareness and environmental education programs and scientifically based management strategies.

Present beach management is almost exclusively focused on physical processes, access for recreational amenity and shoreline protection (Schlacher and Noriega, in press). By contrast, the ecological and broader environmental values of beaches are largely ignored (James, 2000). Yet, sandy coastlines are fragile environments and require conservation and special management strategies if they are to continue to function ecologically and provide for quality recreation (Mclachlan and Brown, 2006). Appropriate management actions can only be taken if the complex ecology of these ecosystems is understood and this information is explicitly incorporated into management practices. Robust scientific information on the ecological characteristics of Gold Coast’s beaches and their vulnerability to human impacts is, however, presently limited (Schlacher and Noriega, in press). Hence, there is a need to deepen the scientific knowledge available and translate this knowledge into management plans or strategies that address recreational and economic needs without further damaging reefs, sand dunes and beach fauna and what is more aim at conserving, protecting and improving the ecological health of these systems.
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<th>ACRONYMS</th>
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<tr>
<td>ARI</td>
<td>Australian Rivers Institute</td>
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<tr>
<td>BPA</td>
<td>Beach protection Authority</td>
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<td>BP Act</td>
<td>Beach Protection Act 1968</td>
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<tr>
<td>CAPP</td>
<td>Centre for Aquatic Processes and Pollution</td>
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<tr>
<td>CAMBA</td>
<td>China-Australia Migratory Bird Agreement</td>
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<tr>
<td>CRC Reef</td>
<td>Cooperative Research Centre for the Great Barrier Reef World Heritage Area</td>
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<tr>
<td>DPLWC</td>
<td>Department of Land and Water Conservation, New South Wales</td>
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<tr>
<td>DPI AND F</td>
<td>Department of Primary Industries and Fisheries, Queensland</td>
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<td>DEWR</td>
<td>Department of the Environment and Water Resources</td>
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<td>EIS</td>
<td>Environmental Impact Statement</td>
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<td>EPA</td>
<td>Environmental Planning Agency, Queensland</td>
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<td>EP&amp;A Act</td>
<td>Environmental Planning and Assessment Act 1979, New South Wales</td>
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<td>Environment Protection and Biodiversity Conservation Act 1999</td>
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<td>EWWG</td>
<td>Environmental Weeds Working Group</td>
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<td>GCCC</td>
<td>Gold Coast City Council</td>
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<td>GCSMP</td>
<td>Gold Coast Shoreline Management plan</td>
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<td>GBRMPA</td>
<td>Greta Barrier Reef Marine Park Authority</td>
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<td>IAS</td>
<td>Impact Assessment Study</td>
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<td>IUCN</td>
<td>International Union for the Conservation of Nature</td>
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<td>JAMBA</td>
<td>Japan-Australia Migratory Bird Agreement</td>
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<td>MAFF</td>
<td>Queensland Marine Aquarium Fish Fishery</td>
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<td>NRCCMA</td>
<td>Northern Rivers Catchment Management Authority</td>
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<td>Department of Natural Resources and Water, Queensland</td>
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<td>PBBR</td>
<td>Palm Beach Bait Reef</td>
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<td>PSU</td>
<td>Practical salinity units</td>
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<td>SMA</td>
<td>Special Management Area</td>
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<td>SQE</td>
<td>South-east Queensland</td>
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<td>VMP</td>
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1 INTRODUCTION

Current management of beaches has been mainly centred on physical aspects such as sand supply, stability and erosion interventions. As we face new challenges such as climate change we believe that the sustainable management of sandy beaches, nearshore reefs and sand dunes requires an integrated approach that also encompasses the ecological values of these crucial ecosystems. The main purpose of this document is to review all available scientific information about the ecology of Gold Coast’s sandy beach environment, nearshore reefs and sand dunes. The aims of this review are to identify the current state of our knowledge, identify critical areas in need of research and aid Gold Coast City Council in the development of future management decisions.

The Gold Coast’s 37 km of mainly sandy coast (Short, 2000) provide Gold Coast City Council with an enormous natural asset. Gold Coast’s ocean beaches are its most recognised icon and a fundamental lifestyle asset of the city. Beaches underpin much of the area’s economy, they are the single most important asset supporting tourism, and they provide much needed recreational amenity for the city’s rapidly growing population.

The Gold Coast City Council Shoreline Management Plan (GCSMP), which commenced in 2005, is a 3-year program aimed at improving our understanding of our beach environments. The GCSMP focuses research and planning on how we manage our beaches and shoreline. The management plan includes ecological processes, community values and stakeholder involvement, physical processes, beach management and the economic value of beaches. The following report is part of the ecological component of the GCSMP. This review aims to outline the scientific knowledge available on the ecology of sandy beaches, nearshore reefs, sand dunes and associated biota on the Gold Coast.

As well as the socio-economic importance of Gold Coast beaches, sandy beaches also play an important ecological role by providing habitat for numerous plants and animals (Jones et al., 2003). Beaches are thus far from the ecological deserts of popular belief (Jones et al., 2003). Rather, they harbour unique and diverse suites of species not found in any other marine habitat. Beaches are a unique environment occupied by animals that have adapted to the constant motion of sand. Hence, they also provide a unique habitat for invertebrate species and many important birds, reptiles and other animals which nest, breed, feed and rest on the dunes or open beach (Clark, 1998). Moreover, sandy beaches are an important ecosystem that links the ecology of sand dunes, the surf zone (Short and Hesp, 1982), intertidal zones, and nearby rocky reefs.

Sand dunes are an integral part of the coastal environment. Dunes not only provide protection from storms but are also the basis of important ecosystems which support valuable communities of plants and animals (DPLWC, 2001). Unfortunately, sand dunes adjacent to beaches in urban and developed areas are heavily impacted upon by human activities. Many coastal sand dunes in the Gold Coast have been disturbed by development, installation of parklands facilities, establishment of exotic plants and construction of roads and access tracks (EPA and QPWS, 2006).

The nearshore rocky reefs of the Gold Coast support communities of benthic fauna and flora that represent a transition between the tropical waters of the Great Barrier Reef and the temperate waters characteristic of the mid-New South Wales coast (Cannon et al., 1987; Done 1982). Because many of the Gold Coast's reefs are located close to shore, they are often the first diverse marine habitat to be affected by...
human activities on land or in nearshore areas. Some human activities that are known to have an impact on reefs include: beach nourishment and dredging practices, alteration of coastline habitats (seawall construction, removal of mangroves), urbanisation and coastal development, domestic and agricultural pollution, stormwater runoff, boat anchoring and over fishing.

Several groups of vertebrates make use of sandy beaches for foraging, nesting, and breeding (McLachlan and Brown, 2006). Birds are the most important vertebrates commonly encountered on sandy beaches (McLachlan and Brown, 2006). Commonwealth law such as, the Environment Protection and Biodiversity Conservation Act 1999, and several treaties such as Japan-Australia Migratory Bird Agreement (1974), and the China-Australia Migratory Bird Agreement (1986) aim to protect shorebirds from further population decline. Another vertebrate that visits Gold Coast's beaches are Sea turtles, which come ashore to lay their eggs in the dry beach above the high water mark. Globally, marine turtle populations are under threat. Green turtle Chelonia mydas and Loggerhead turtles Caretta caretta the two species that nest in the Gold Coast, are listed as 'endangered' by the World Conservation Union.
2 SANDY BEACH ECOLOGY

2.1 Introduction

Sandy beaches are an important ecosystem that links the ecology of sand dunes, the surf zone (Short and Hesp, 1982), intertidal zones, and nearby rocky reefs. Beaches feature a constant exchange of sand, organic matter and nutrients, inputs that influence the distribution and growth of beach organisms. Beaches do not have a stable substratum, as a result there are no large plants to provide food for beach organisms. Instead, food is imported from surf-zone in the form of phytoplankton and algae. The former are consumed by filter-feeders and the latter are decomposed by bacteria and fragmented by the grazing of small invertebrates such as isopods, amphipods and insect larvae (Jones et al., 2003). The nutrient-rich faeces of these invertebrate consumers are used by the beach bacterial community or transported back to the sea. These bacteria support various beach fauna, which in turn support more conspicuous beach species such as seabirds (Jones et al., 2003). Other ecological links involve the migration of birds and turtles and the effects of estuarine discharge, which can influence various species abundance (Jones et al., 2003). As well, many fish species use surf zones as nurseries and feed on beach invertebrates (Jones et al., 2003).

2.2 Sandy Beach Invertebrates

Hundreds of species inhabit sandy beaches but most are rarely noticed (Jones et al., 2004). They evade attention because they are small (less than a centimetre long) and live buried in the sand (Jones et al., 2004). They include decomposers (bacteria and fungi), algal plants (mostly diatoms) and invertebrate animals (mostly nematodes, crustaceans, polychaetes and molluscs) (Jones et al., 2004). Most invertebrate phyla are represented on sandy beaches (McLachlan and Brown, 2006), either as meiofauna or macrofauna.

2.2.1 Meiofauna

Meiofauna is defined as those metazoan animals passing undamaged through a 500 µm sieve but trapped on a 42 µm sieve (Kennedy and Jacoby, 1999). On most beaches, the meiofauna is rich and diverse, even exceeding the macrofauna (McLachlan and Brown, 2006). However, there have been few studies concerned with the species composition of sandy-beach meiofaunal communities (McLachlan and Brown, 2006). There is also little information on large-scale patterns in sandy-beach meiofauna distribution, such as latitudinal effects or overall responses to the range of beach types (McLachlan and Brown, 2006). However, within beaches horizontal and vertical meiofaunal distribution shows clear patterns (McLachlan and Brown, 2006). It has been suggested that the vertical distribution of meiofauna is determined by the degree of drainage and oxygenation of the sediment (McLachlan and Brown, 2006).

Meiofaunal species are known to be sensitive indicators of environmental perturbations and pollution (Schratzberger et al., 2000). Thus the state of meiofauna assemblages may reflect the overall health of the marine benthos (Kennedy and Jacoby, 1999). The role of meiofauna as biological indicators was reviewed by Kennedy and Jacoby (1999). To date, this abundant and ubiquitous group of invertebrates has been largely neglected in sampling programs (Kennedy and Jacoby, 1999). This omission is potentially counterproductive because much interaction between pollutants and the biosphere occurs at low levels of phylogenetic
Overview of ecological information on Gold Coast beaches

organisation (Kennedy and Jacoby, 1999). Even though the use of meiofauna as biological indicators has proven viable, there are number of shortcomings associated with their use (Kennedy and Jacoby, 1999). These are complexities related to the design of sampling programs to overcome levels of spatial and temporal variation and the processing difficulties that can make the use of meiofauna more expensive when compared with macrofauna (Kennedy and Jacoby, 1999). The advantages and disadvantages of using meiofauna for environmental monitoring have been documented by Kennedy and Jacoby (1999).

Studies of meiofauna in Gold Coast have been limited to estuarine environments. No meiofauna sampling has taken place on open shores.

2.2.2 Macro-invertebrates

The invertebrate macrofauna is the most well studied component of sandy beaches and comprises benthic forms too large to move in the space between sand grains (McLachlan and Brown, 2006). The benthic macrofauna of sandy beaches includes representatives of many phyla, but crustaceans, molluscs and polychaetes are usually dominant making up more than 90% of species and biomass on ocean beaches (Brown and McLachlan 1990). Their most pronounced characteristic is a high degree of mobility, including the ability to burrow rapidly (McLachlan and Brown, 2006). Their habitat is dynamic and defined by 3 factors: tides, waves and sand characteristics (Defeo and McLachlan, 2005). Other associated factors that influence faunal assemblages include the erosion/accretion dynamics of the sediment, freshwater discharge, food supply, slope of the beach, aeolian transport mechanisms and storm events (Brown and McLachland 2002; McLean 2006).

2.3 Anthropological impacts on sandy beach ecology

In beaches all over the world human influence such as recreational activities, coastal development, pollution, chemical spills and freshwater inputs have been shown to considerably reduce the abundance and diversity of faunal assemblages on sandy beaches (Carlson and Godfrey 1989, McLean 2006).

On the Gold Coast, beaches are under increasing pressure due to population growth and increasing number of visitors to the area. The main anthropogenic pressures on Gold Coast’s sandy beaches are coastal development, disruption of sand transport (sea walls and groynes), mechanical beach cleaning, beach nourishment and reprofiling, 4WD vehicles and trampling.

2.3.1 Beach nourishment

Coastal engineers typically rely on three types of strategies to protect structures from shoreline erosion: hard stabilization; non-structural alternatives, such as relocation or retreat; and soft stabilisation (Pilkey and Dixon, 1996). The ecologically ideal solution is to allow for the natural landward migration of shorelines. Such non-structural alternatives mandate the removal of structures or relocating them further landward. This solution may not necessarily be acceptable because of valuable infrastructure being located too close the beach, but the very real prospect of “coastal retreat” is starting to gain currency in Australia, especially in face of predicted shoreline migrations caused by global climate change (Schlacher and Noriega, in press).

There is mounting evidence that hard engineering solutions (e.g. seawalls, groynes) are generally the ecological most harmful interventions in shore management.
Overview of ecological information on Gold Coast beaches

(Schlacher and Noriega, in press). Consequently, “soft solutions” in the form of beach nourishment and beach bulldozing (i.e. beach scraping) are seen as more environmentally friendly (Schlacher and Noriega, in press). However, these interventions can also have a range of negative ecological consequences which affect all levels of ecological organisation on beaches (Greene, 2002). Beach nourishment can bury shallow reefs, degrade other beach habitats including those of endangered vertebrates, and reduce invertebrate prey for shorebirds and surf fishes (Peterson and Bishop, 2005; Speybroeck et al., 2006). Natural storm events such as Tropical Cyclones or East Coast Lows may have similar impacts to “soft solutions” (Schlacher and Noriega, in press). However, these are relatively rare events to which the sandy beach is adapted through evolution, whereas frequent nourishment is a more continuous form of disturbance and acts in addition to natural disturbance events (Schlacher and Noriega, in press). Ecological impacts of beach nourishment operations are generally most severe if the replenished sand does not match the natural characteristics of the beach deposits.

On the Gold Coast beach nourishment is carried out by GCCC. There are two permanent sand bypassing systems that are able to provide constant beach nourishment to Coolangatta bay and SSI. Occasional or event driven beach nourishment takes place in most beaches along the coast.

Speybroeck et al. (2006) conducted a review on literature from the United States that describes the impacts of beach nourishment on several beach ecosystems components such as microphytobenthos, vascular plants, terrestrial arthropods, marine zoobenthos and avifauna. It was found that most studies that focus on the effects of beach nourishment fail to consider all ecosystem components, tend to have imperfections in the design and fail to quantify the amount of disturbance and survival during nourishment and the process of re-colonization after nourishment (Speybroeck et al., 2006). Thus, monitoring studies are often based on unreplicated field surveys, have not been peer reviewed by third parties, and are not published in scientific journals (Peterson and Bishop, 2005). As a result the conclusions of beach nourishment studies are often flawed by lack of compelling support from adequate evidence, analysis, or interpretation (Peterson and Bishop, 2005). Hence, the widespread flaws in design, analysis, and the fact that most permitting agencies exhibit inadequate expertise to review biostatistical designs, help explain why so much uncertainty still persists over the ecological consequences of beach nourishment (Peterson and Bishop, 2005).

Dolan and Stewart (2006) documented fifteen years of monitoring and research on the beaches of the Outer Banks of North Carolina in the United States. This report outlined that the maximum loss of surf-zone organisms occurs when nourishment or bypassed sand is placed on the beach in a straight line configuration along the coast. This research suggests that if new sand can be distributed in a crescentic configuration that more closely resembles the natural morphology, there will be improvement in maintaining a robust population of swash-zone filter feeders as well as a reduction in time for recovery following dredging (Dolan and Stewart, 2006).

On the Gold Coast, no scientific studies have been conducted on the biological effects of beach nourishment on sandy beach organisms. However, some sampling of benthic meiofauna and macro-invertebrates took place as part of the Stage 1 of the Tweed River Entrance Sand Bypassing Project in July 1994 (Acer Wargon Chapman, 1994). This study will be discussed in section 4.2.1.2 of this review.
2.3.2 Sand characteristics and dredging

Sand originates mainly from erosion of the land and is transported to the sea by rivers. Beaches may, however, also receive sand from biogenic sources in the sea such as animal skeletons, and from sea cliff erosion (McLachlan and Brown, 2006). The two main types of beach material are quartz (or silica) sands of terrestrial origin and carbonate sands of marine origin (McLachlan and Brown, 2006). Sand characteristics like porosity, permeability and penetrability play an important role to sandy beach organisms. Porosity of a sediment is the volume of water needed to saturate a given weight of dry sand. Permeability refers to the rate of flow or drainage of water through the sand (McLachlan and Brown, 2006). Fine sands, although holding more water than coarse sands, have lower permeabilities due to their smaller pore sizes (McLachlan and Brown, 2006). Another important characteristic is the penetrability of sand. This is related to particle size and porosity, but is also dependent on other factors. Penetrability can be important to the macrofauna of sandy beaches, as all species must be able to burrow into the substratum. The proportion of clay and silt, as well as the water content of the sand, plays vital roles in determining its penetrability, as well as its resistance to erosion (McLachlan and Brown, 2006).

McLachlan and Dorvlo (2005) reviewed data from 161 sandy beach surveys from a wide variety of locations to examine the relationships between total marine macrofauna species richness, abundance, and biomass and physical variables. A result from this study was the importance of sand particle size and its correlation with richness and abundance. A change in particle size can directly affect many species (McLachlan, 1996; McLachlan and Dorvlo, 2005). Thus, the number of species recorded in a survey increases with finer sand, flatter slopes and greater tide range (McLachlan and Dorvlo, 2005). This result highlights the importance of selecting appropriate particle size for borrow material in beach nourishment projects (McLachlan and Dorvlo, 2005). It is also important to notice that finer sand from inlets, with a higher heavy mineral content leads to more compact and flatter slopes than the natural beaches (Alexander et al., 1993). Sand from inlets is usually used for beach for nourishment. In some cases such changes in the sand size and mineral content make mobility and feeding of certain species almost impossible (Alexander et al., 1993).

On the Gold Coast sand from Currumbin Creek and Tallebudgera Creek is used for event driven beach nourishment.

2.3.3 Mechanical beach cleaning

Mechanical cleaning of beaches provides a beach free of rubbish and natural debris to improve safety and aesthetic appeal for people. The machines suck up and filter the sand, capturing not only debris, but also small organisms (Brown and McLachlan, 2002). As a result, mechanical beach cleaning severely disrupts the natural ecological processes and modifies the function and structure of the beach ecosystem. Cleaning machines can kill organisms near the sand surface and can crush deeper-living invertebrates inside their burrows (Brown and McLachlan, 2002).

Wrack (the build-up of debris consisting of seagrass/weed, marine organisms and other material deposited on the beach with the tides and waves), which is removed by beach cleaning, is a vital element in maintaining the ecology of sandy beaches (Jones et al., 2003). Wrack provides essential habitat for intertidal organisms and is an important food source for many animals. Wrack lines may also help to stabilise wind blown sand and start the growth of dunes. In essence, beach cleaning reduces the number and type of organisms living in the beach. These environmental impacts
need to be considered along with public expectations of a safe and clean beach environment.

Currently, Gold Coast City Council has three mechanical beach cleaning machines in operation. The machines operate on all Gold Coast beaches. High use beaches such as Burleigh Head, Coolangatta and Surfers Paradise get cleaned everyday. Lower use beaches get cleaned once a week.

2.3.4 Trampling and 4WD vehicles

Trampling on the intertidal slope typically has much less impact than in the dunes, although it is measurable and, even in the lower intertidal, may injure delicate crustaceans and juvenile bivalves (Moffet et al., 1998). Next to the destruction of habitat through development, driving of 4WD vehicles is one of the most harmful of all human activities on sandy beaches (Godfrey and Godfrey, 1980). Cars dramatically change the physical properties of beaches leading to deep rutting. Fragile dune vegetation is easily destroyed by vehicles. Animals inhabiting beaches are highly susceptible to vehicle impacts: 4WDs can destroy nests and kill chicks of shorebirds, turtle hatchlings show lower survival rates on beaches open to 4WD vehicles, and ghost crabs are crushed in large numbers by night traffic. Many other smaller, buried invertebrates of the beach may also be impacted by beach traffic. A recent study on beaches in South-East Queensland showed that beaches open to 4WD vehicles have substantially fewer species of invertebrates and these occur at much reduced densities (McLean, 2006). Further studies on the effect of 4WD vehicles on sandy beach invertebrates have been conducted on North Stradbroke Island by Schlacher and Thompson (In review) and Schlacher et al., 2007a).

Gold Coast beaches (with the exception of South Stradbroke Island) are not open to recreational four wheel driving. Only emergency vehicles or those related to beach dependent activities such as life saving, beach management and limited commercial fishing licenses are allowed on our beaches (Stuart, 2007. pers.comm). There are designated vehicle access points that restrict the damage to dune vegetation (Stuart, 2007. pers.comm). Vehicle speeds are restricted to ensure safety of other beach users (Stuart, 2007. pers.comm).

2.4 Gold Coast’s studies

The only scientific survey of ocean beach macroinvertebrates in the Gold Coast was done in early 2007 at Palm Beach. This survey was part of a South-east Queensland study undertaken by the University of the Sunshine Coast. Palm Beach was a sampling site in this study. Results of this survey are available from South-east Queensland Catchments.

A summary of articles related to human pressures on sandy beaches are presented in Table 1.

<table>
<thead>
<tr>
<th>Key pressure</th>
<th>Reference(s)</th>
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<tbody>
<tr>
<td>Climate change and sea level rise</td>
<td>Feagin et al., (2005); Cowell et al., (2006); Harley et al., (2006); Brown and Mclachlan (2002)</td>
</tr>
<tr>
<td>Coastal infrastructure and development</td>
<td>Nordstrom (2000)</td>
</tr>
<tr>
<td>Shoreline armouring and erosion</td>
<td>Beentjes et al., (2006); Dugan and Hubbard (2006)</td>
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<tr>
<td>Beach nourishment</td>
<td>Peterson et al., (2000, 2006); Peterson</td>
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- Overview of ecological information on Gold Coast beaches

<table>
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<th>Human pressures on sandy beaches</th>
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<tr>
<td>Fisheries</td>
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<tr>
<td>and Bishop (2005); Speybroeck et al., (2006)</td>
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<tr>
<td>Mining/sand extraction</td>
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<tr>
<td>Simmons (2005)</td>
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<tr>
<td>Grooming and cleaning</td>
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<tr>
<td>Llewellyn and Shackley (1996); Dugan et al., (2003)</td>
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<tr>
<td>Recreation and tourism</td>
</tr>
<tr>
<td>Davenport and Davenport (2006)</td>
</tr>
<tr>
<td>Human trampling</td>
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<tr>
<td>Fanini et al., (2005); Gheshkier et al., (2005)</td>
</tr>
<tr>
<td>Off-road vehicles (ORVs)</td>
</tr>
<tr>
<td>Godfrey and Godfrey (1980); Schlacher and Thompson (In review)</td>
</tr>
<tr>
<td>Wildlife disturbance</td>
</tr>
</tbody>
</table>

Table 1. Summary of articles related to human pressures on sandy beaches (Table modified from Schlacher et al., 2007b)

2.5 Future challenges and climate change

Human induced alterations to coastal sediment supply and transport processes (Komar, 1998), together with climate change and climate variability factors such as sea level rise and increased storminess are increasing the trend of beach erosion. In other words coastlines are migrating inland (Schlacher et al., 2007b). Ideally “natural retreat” is the solution. However, in highly populated areas this is generally not possible. As a result, natural shoreline retreat is today constrained along most developed coastlines by human infrastructure (Schlacher et al., 2007b). Therefore, we can predict future compression and loss of critical coastal ecosystems and habitat including not only dunes, but also beaches (Schlacher et al., 2007b). As a consequence there is an urgent need to make appropriate and scientifically founded decisions on how to manage our coastal areas.

Brown and McLachlan (2002) conducted a review on sandy shore ecosystems and predicted possible states of the system by 2025. Some of the climate change induced threats to this ecosystem are temperature increases, climate variability and sea level rise (Jones, 2005). Temperature increases will probably change species distribution and assemblage composition. The mechanisms of ecological change include physiological disruption, reduced dissolved oxygen, greater desiccation and changes in marine productivity (Jones, 2005). Climate variability means that storms will become more intense and frequent as a result enhanced erosion would probably be locally disastrous for both beach and dune biota (Jones, 2005). This would also have an effect on rainfall and water acidity. If the pH of ocean waters decreases, shelled species would find it more difficult to extract calcium carbonate from seawater. Thus, meiofauna may be also at risk from the toxic effects of low pH (Jones, 2005). In addition, sea-level rise will cause the erosion of sand from the upper beach causing the shoreline to recede. Hence, if these changes are accompanied by alteration to dunes, grain size and beach slope, the ecological effect would be large (Jones, 2005).

2.6 Recommendations

Although beaches are consistently valued in our society for the aesthetic, recreational, and storm buffer services that they provide, their ecological contributions have often been ignored. On the Gold Coast, the degree to which humans are impacting on sandy beach ecology is unknown. At present there is almost no information on the distribution or abundance of sandy beach invertebrates.
Present threats to this habitat include human caused erosion, beach nourishment, mechanical beach cleaning, trampling, pollution and 4WD vehicles. Research and conservation of beach habitat could directly benefit a whole range of organisms from plants and invertebrates to high priority shorebirds and mammals. Based on our findings we recommend the following:

- Conduct baseline research on the ecology of sandy beaches and make these results available to coastal managers and policy makers.
- Determine the degree of impact that specific activities such as beach nourishment practices (Coolangatta bay, Seaway, Palm Beach and Burleigh Heads), mechanical beach cleaning and 4WDs are having on intertidal beach invertebrates.
- Develop science based beach management strategies that address ecological objectives as well as socio-economic ends.
3 COASTAL SAND DUNES

3.1 Introduction

Coastal dunes are an integral part of the coastal environment (NSW DLWC, 2001). They not only protect coastal property from storms, but also are the basis of important ecosystems supporting valuable communities of plants and animals (NSW DLWC, 2001). Coastal dunes are characterized by the exchange of sand with beaches and by the influence of wind forces. Many plant species are able to colonize supralittoral sands, despite initially poor nutrient conditions, lack of moisture, and sometimes very high temperatures (McLachlan and Brown, 2006). Such colonization may, on sheltered beaches, begin at or just above the strandline aided by accumulations of wrack and tidal litter, which reduce the sand temperature and increase its moisture content (McLachlan and Brown, 2006). Vegetation is by far the most important component of the biota on sand dunes because it is directly involved in establishing the dune forms and creating the structure of the dune habitat. The primary colonization of aeolian sand along the coast is usually by micro-organisms and fungi. These organisms promote aggregations of sand grains 1 to 2mm in diameter. Fungi are most important in this regard, followed by bacteria and algae. The presence of such aggregates reduces wind erosion, increases soil moisture, and increases the nutrient status of the sand. This is therefore a very important first stage in dune succession (McLachlan and Brown, 2006).

Sand dunes are usually classified as an incipient dune, foredune or hinddune. During storm conditions, incipient and foredunes may be severely eroded by waves. During the intervals between storms, dunes are rebuilt by wave and wind effects. Dune vegetation is essential to prevent sand drift and associated problems (NSW Government 1990). Incipient dunes are the most seaward and immature dune of the dune system and its vegetation is characterised by grasses. On an accreting coastline, the incipient dune will develop into a foredune (NSW Government 1990). A foredune is the larger and more mature dune lying between the incipient dune and the hinddune area. Foredune vegetation is characterised by grasses and shrubs. Foredunes provide an essential reserve of sand to meet erosion demand during storm conditions. During storm events, the foredune can be eroded back to produce a pronounced dune scarp (NSW Government 1990). Finally, Hinddunes are characterised by mature vegetation including trees and shrubs (NSW Government 1990).

3.2 Food web

Dune food chains are driven by primary production of the dune flora, organic inputs from the sea, and inputs from land. A high proportion of plant biomass, both living and dead, may occur below ground where it is more available to the interstitial biota (meiofauna, bacteria and fungi) than to the macrofauna (McLachlan and Brown, 2006). Moist conditions and a high proportion of buried organics favour the development of a rich interstitial community. In wet dune slacks, the biomass of the interstitial community may far exceed that of the macrofauna, and most consumption of carbon in dune slack ecosystems will be via the interstitial pathway (McLachlan and Brown, 2006). Broadly, three main food chains may be recognized in coastal dunes (McLachlan and Brown, 2006). These are:

- A grazing pathway consisting primarily of macroscopic herbivores (insects, mammals, and fruit-and-seed-eating birds).
- Overview of ecological information on Gold Coast beaches

- A detritus pathway consisting of macroscopic animals (insects) feeding on vegetation detritus (litter), which may accumulate in the lee of vegetation hummocks, at the base of slip faces, and elsewhere.
- The interstitial biota, feeding on buried detritus, and in the case of plant parasitic nematodes on the roots themselves (McLachlan and Brown, 2006).

There is very little published quantification of dune food chains (McLachlan and Brown, 2006). To date, McLachlan et al. (1996) has conducted the only study that attempts to quantify energy flow in a coastal dune system. The study looked at moist dune slacks in a transgressive dunefield. Because of fairly rapid dune movement, vegetation showed a clear five-year succession and high burial rates. In the absence of other studies, it is difficult to know how typical this is of dune ecosystems (McLachlan and Brown, 2006).

3.3 Publications of interest

Gadgil and Ede (1998) created guidelines for sand dune management based on their experience in New Zealand. They concluded that any form of sand dune management must recognize the existence of four sources of potential threat (Gadgil and Ede, 1998). These are natural climatic and marine influences, animal interference, human interference, and other biological factors such as nutrient deficiency and extremes of physical conditions (Gadgil and Ede, 1998). They also concluded that remedial measures are available, but their effectiveness is dependent on a good understanding of principles such as vigilance and maintenance, wise use of planting techniques, recognition of chronic nitrogen deficiency in sand and continuing review of current stabilization methods (Gadgil and Ede, 1998).

In 2001, the NSW Department of land and Water Conservation published a manual of coastal dune management and rehabilitation techniques titled “Coastal Dune Management”. The manual targets people and organisations that are actively involved in dune rehabilitation work such as local and state government, community groups, NGO’s and individuals (NSW DLWC, 2001). The manual deals with topics such as coastal evolution and processes, rebuilding and reshaping dunes, stabilisers, fencing, access ways, signage, weeds, revegetation, management and planning.

The effects that certain sand dune species have on the distribution, density, and reproduction of other co-occurring annuals has been studied by Cheplick (2005). In addition, the effects of sand burial on seedling emergence, growth, and reproduction was studied by Cheplick and Grandstaff (1997).

3.4 Gold Coast’s sand dunes

Coastal sand dunes have often been regarded as marginal land which is available to the public for recreation (Gadgil and Ede, 1998) or other human uses. In the Gold Coast sand dune systems have been heavily altered by human intervention over many years. Coastal development is without doubt one of the main factors responsible for the degradation of sand dune system in the area. For example, in places like Coolangatta human intervention has changed the appearance and function of the coast by altering the energy of the waves, the topography of the beach and the natural vegetation and habitat.

Environmental problems associated with coastal development include loss of natural dune habitat, threats to natural species, reduction in seed sources, and decreased resilience of plant communities in developed areas following loss by storms (Nordstrom et al., 2000). Other factors that also affect the natural growth of dune
systems are beach cleaning operations and mechanical grading that is done to improve the appearance of the beach for recreational use and increase ease of access (Nordstrom et al., 2000). Finally, the introduction of exotic species also has detrimental effects on the native vegetation and fauna.

3.4.1 Current Management of Gold Coast’s sand dunes

Gold Coast City Council through its “Policy 15: Management of Coastal Dune Areas” aims to “promote the establishment and retention of appropriate vegetation as the preferred form of dune stabilisation; preserve the function and sustainability of natural dunal systems; provide community guidance on sustainable dunal land use; project a positive city image; for the benefit of present and future generations of the Gold Coast city community” (GCCC, 2007a). The policy is implemented through various areas of council responsibility such as: “development approvals; council works programs; community based rehabilitation programs; and as a promotional and educational tool to encourage the general public to maintain and care for dunal areas in an appropriate manner” (GCCC, 2007a). It is important to notice that this policy is intended to be educational and promotional rather than regulatory (GCCC, 2007a). At present, Gold Coast City Council has not developed a management plan for sand dunes in the area.

Sand dunes management in the Gold Coast fits into two categories. Capital Investment Program and the Maintenance Program (Challenger, 2007. pers.comm). The goal of the Capital Investment Program is to provide large scale dune quality improvement. The program hires external consultants to conduct rehabilitation of sand dunes on specific sites (Challenger, 2007. pers.comm). Currently there are 5 contractors in charge of rehabilitation works. Rehabilitation of sites takes effect by:

- councillor request;
- direct community request;
- development and/or re-development that affects sand dune areas and;
- dune assessment program by GCCC (Challenger, 2007. pers.comm).

The later is a program developed to assess sand dunes and determine priority areas for maintenance (Challenger, 2007. pers.comm). The program judges sand dunes on the following criteria: erosion risk, environmental value and community issues. The Maintenance Program deals with weed reduction, sand dune establishment and aesthetics such as trimming and pruning. The allocation of works to external consultants is done through an open tender process. Contractors and anyone that is considering working on sand dunes need to follow the prepare a Vegetation Management Plan (VMP). Guidelines and examples of VMP’s are provided by GCCC.

3.4.2 Vegetation surveys and mapping on the Gold Coast

Sattler and Williams (1999), conducted a study to report on the conservation status of Queensland’s bioregional ecosystems. The report suggests that the regional ecosystems of Queensland as the primary basis for planning the conservation of biodiversity. Regional ecosystems are defined within a hierarchical framework commencing with the classification of Queensland into bioregions and ending with species. This study represents a continuation of work commenced in 1974 when the bioregions of Queensland were first described together with their major vegetation communities (Stanton and Morgan, 1977). The report proposes regional ecosystems as a tool to describe biodiversity and to plan conservation in Queensland. However, the report acknowledges that regional ecosystems are not a good surrogate for all species and do not necessarily address the conservation needs of many rare and
threatened species and species with patchy distributions (Sattler and Williams, 1999). The report also acknowledges that planning for the conservation of biodiversity should also include other complementary strategies that address the specific requirements of species (Sattler and Williams, 1999). The study classifies sand dunes mainly as regional ecosystems 12.2.13 (Open or dry heath) and 12.2.14 (Strand and fore dune complex). A detailed description of each regional ecosystem is available in Sattler and Williams (1999) and from the EPA website (www.epa.qld.gov.au).

The Queensland Herbatorium was commissioned by Gold Coast City Council to conduct a vegetation mapping review of the local government area (Ryan et al., 2003). The aim of the project was to review and refine the existing Gold Coast City Nature Conservation Mapping. Mapping was undertaken at a scale of 1:20,000, with a minimum polygon size of 0.5 hectares, or 30 meters width for linear features. Map coverage was derived through photo interpretation of aerial photographs at scales ranging from 1:10,000 to 1:31,000. Field surveys and information from existing studies were also used. The report divides Gold Coast vegetation into regional ecosystems. The regional ecosystems classification scheme is part of the biodiversity planning framework that has been developed to assist the EPA to plan for biodiversity. The framework has been incorporated into several planning initiatives such as the Vegetation Management Act 1999. Regional ecosystems were defined by Sattler and Williams (1999) as vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil. The regional conservation status of vegetation communities within South-east Queensland has been determined by the EPA, and is listed in the Regional Ecosystem Description database Version 5 (EPA, 2005) available from the EPA website. This listing outlines the regional status of vegetation communities, based largely on the remaining proportion of their natural coverage in the region prior to clearing and settlement.

In 2006, GCCC conducted a flora survey and habitat mapping project for the South Stradbroke Island Management Area. The management area consists of a series of properties purchased by GCCC (Searle and Maden, 2006). The properties form a continuous land holding to the immediate south of the Couran Cave resort and associated marina development (Searle and Maden, 2006). Mapping for this study was conducted based on 1:8,000 colour aerial photography from 2005. Preliminary mapping was ground-truthed and reviewed using the flora field sites surveyed by the Queensland Herbarium plus other additional sites. ‘Foredune’ or beach-strand and ‘Sandblow’ are the only two types of regional ecosystems identified which fall within the coastal scope of this literature review. The survey report found that foredune or beach-strand communities on coastal sand are considered to be adequately represented throughout both the Gold Coast area and the QLD region overall, however, many of the remaining areas of this community are highly modified or in poor condition with a high incidence of exotic weed infestation, particularly when found adjacent to coastal development. In SSI, an area with no or little coastal development, foredunes generally show healthy regrowth and low incidence of infestation by exotic weeds. Hence foredunes at SSI should be considered as having an elevated conservation status (Searle and Maden, 2006). On the other hand, sandblow communities have limited remaining abundance within the Gold Coast local government area and the QLD region (Searle and Maden, 2006). Moreover, they are classified as ‘Of Concern’ under the regional framework (Searle and Maden, 2006). The survey report outlines that the current status of this community is a result of many of these areas being stabilised by plantations of Casuarina equisetifolia and/or other vegetation, in association with sand mining activities in and adjacent to these dunal areas. Alternatively, it was found that although these communities effectively
restrict the representation of ‘natural’ sandblow they contribute to an increase in habitat stability and complexity, and flora and fauna diversity (Searle and Maden, 2006).

3.4.3 Consultancies, community groups and other organisations involved in sand dune care and management

A number of consultancy firms have been involved or are currently conducting vegetation surveys and rehabilitation works in the area. Some of these consultancies are Ecosure and Gecko Regen. Gold Coast City Council requires consultancies or any other group or individual to complete a Vegetation Management Plan (VMP) before commencing works in the local government area. Specific information about VMPs can be obtained from Gold Coast City Council.

Beach Protection Authority

The Beach Protection Authority (BPA), which was constituted under the Beach Protection Act 1968, was disbanded in August 2003. The BPA Act was replaced by the State Coastal Act. The BPA’s objectives were to regulate and provide advice to local authorities, government departments, and statutory authorities with respect to dune management (Barr, 1983), activities affecting the coast, protection of the amenity of the coast and minimisation of damage to property from erosion or encroachment by tidal water (EPA 2004). The BPA’s activities were directed towards data collection, applied research, the provision of advice to coastal local governments and its regulatory role under the Beach Protection Act (EPA 2004). Data collected by the BPA was mainly used for coastal management and planning purposes, and was also made available to educational institutions, local governments and consultant groups that had a role designing and assessing coastal works (EPA 2004). After the BPA was disbanded in 2003, the EPA took over the role of providing advice on coastal management, carrying out investigations, and monitoring coastal processes and resources (EPA 2004).

The Beach Protection Authority prepared a series of advisory leaflets under the general heading “Coastal Sand Dunes – Their Vegetation and Management”. The purpose of these leaflets was to provide the public with an appreciation of the important role that stable and naturally vegetated dune systems play in protecting the coastline, and to suggest guidelines for the proper management and protection of coastal sand dunes and their vegetation. These information leaflets are still available from the EPA website at: www.epa.qld.gov.au

BeachCare

BeachCare is a community based program facilitated by the Griffith University Centre for Coastal Management with support from the Gold Coast City Council. The program assists in establishing groups to undertake activities caring for the Gold Coast beaches and foreshores. Activities involve dune planting, weeding, seed collection, propagation and beach litter cleanups. The program focus is on the significance and importance of Gold Coast’s coastal zone and its sustainable management. The program encourages valuable community interaction in the management and maintenance of our beaches, foreshores, waterways and coastal areas.

The main aims of the BeachCare program are:

- To encourage community participation in beach management and sustainability
- To improve the quality of native vegetation communities on Gold Coast beach dunes
- Overview of ecological information on Gold Coast beaches

- To increase the community’s awareness on beach management issues
- To encourage and assist in enabling existing community groups to become increasingly self-sufficient.

Federation walk

Federation Walk Coastal Reserve is project concerned with the conservation and restoration of coastal land located at the Spit. The project has been designed to allow the community to experience the area’s particular ecological value, whilst providing minimal disruption to the environment (Main Beach Progress Association, 2002). The project is overseen by the community group Friends of Federation Walk. The group originally started as a Sub Committee of the Main Beach Progress Association Inc. (Main Beach Progress Association, 2002). In 2007, the group received funding for the project from the state government (Clifford, 2007. pers.comm). The same year, Gold Coast City Council employed a ranger to undertake the development of a Master Plan for the site and assist with allocating operational and capital costs for the project (Clifford, 2007. pers.comm).

3.5 Threats to sand dune health

There are a number of human actions that threaten sand dune health on the Gold Coast. Some of these are problems are associated with coastal development which include loss of natural dune habitat, threats to natural species, reduction in seed sources, and decreased resilience of plant communities in developed areas following loss by storms (Nordstrom, et al., 2000). Other factors that also affect the natural growth of dune systems are beach cleaning operations, mechanical grading (Nordstrom, et al., 2000) and the introduction of exotic species.

3.5.1 Weeds

Weeds cause many problems in coastal environments since they often grow faster than native plants and successfully compete for sunlight, water, nutrients and pollinators (NSW DLWC, 2001). Their capacity to establish and spread leads to invasion and displacement of native plant communities thus reducing biological diversity (NSW DLWC, 2001).

A variety of weed control techniques have been described in the manual developed by the NSW Department of Land and Water Conservation titled “Coastal Dune Management”.

In Queensland, the Land Protection (Pest and Stock Route Management) Act 2002 classifies pests plants as declared plants class 1, 2 or 3. These plants are targeted for control because they have, or could have, serious economic, environmental or social impacts. For example, Bitou bush a weed present in the Gold Coast has been declared a Class 1 plant under the act. Thus, Lantana, Fountain Grass and Singapore Daisy three common weeds present on Gold Coast’s sand dunes have been declared a Class 3. Specific weed information sheets have been developed by the Department of Natural Resources and Water (Department of Natural Resources and Water, 2007).

In 1997 the Department of Natural Resources and Mines invited interested parties to come together to develop a strategy for the management of environmental weeds in south east Queensland. These parties became the Environmental Weeds Working Group (EWWG). The Environmental Weeds Working Group developed a document titled “South-east Queensland Environmental Weeds Strategy”. This strategy is
designed to give more weight to environmental issues, in contrast with previous approaches to weed management, which emphasised the impacts of pest plants upon the economy and human health (EWWG, 2002).

The CRC for Australian Weed Management (Weeds CRC) is a Commonwealth funded body which aims to reduce the risks posed by current and new weed incursions through programs in research, education and information delivery across Australia. The Centre has published a variety of documents regarding weeds that are present in Gold coast’s sand dunes. Some of these documents are the Best Practice Management Guide and the Weed Management Guide (CRC for Australian Weed Management, 2007).

In general, although coastal and other weeds have captured the attention of government bodies there is little information published in scientific journals on the impacts that weeds cause to native sand dune vegetation. The following publication by Hilton and Harvey (2002) is an exception and looked at the short and long term potential impacts of exotic species on dune vegetation and the related management implications. The study was conducted on Sir Richard Peninsula, South Australia where Spinefex and other associated native foredune species have been largely displaced by two exotic dune species Ehrharta vollosa var maxima and Thinopyrum junceiforme.

On the Gold Coast, a list of some of the common weed species present in the Gold Coast area is outlined in the GCCC document “Policy 15: Management of Coastal Dune Areas”. In addition, Gold Coast City Council as part of their “Dune Management Program” has developed a dune assessment survey form. One of the aims of this survey form seeks to quantify the percentage coverage of weeds in particular areas of the coast. With the help of trained volunteers this assessment program is performed every couple of years in some Gold Coast sand dunes (Challenger, 2007. pers.comm). Excluding this assessment and other sporadic surveys conducted by consultancy firms there has been no general assessment of weed coverage for the whole coast. Furthermore no detailed studies have been conducted to determine the impact that weed coverage is having on native vegetation and fauna.

3.5.2 Sand mining

The coastal strip from the Tweed to Stradbroke Island has been subject to mining for rutile and other sand-based minerals since the late 1930’s. All mining activities ceased on the Gold Coast by 1960’s. In South-east Queensland topics such as sand mining rehabilitation, coastal dune stabilisation, vegetation succession and sand dune reclamation have been documented and studied by various authors during the 60s and 70s (Barr, 1974; Barr and McKenzie, 1977; Coaldrake, 1962; Coaldrake, 1979; Coaldrake and Roe, 1976; Thatcher and Westman, 1975).

3.5.3 Mechanical beach cleaning

Mechanical beach cleaning, by means of removing wrack, eliminates habitat for nesting birds, seed sources for pioneer dune colonizers and food for fauna (Nordstrom et al., 2000). Moreover, mechanical beach cleaning can result in the removal of pioneer dune stages and associated specialist species. Hence it can inhibit the accretion of new dunes.

A recent study by Hayasaka and Fujiwara, 2005 looked at the relationship between species composition and human activities such as beach cleaning. The study found that rural beaches with no beach cleaning showed high proportions of coastal
Overview of ecological information on Gold Coast beaches

species. The number of weeds was higher in beaches with active beach management. Thus, it was found that the diversity of coastal vegetation was enhanced by discontinuing beach cleaning and mowing (Hayasaka and Fujiwara, 2005).

As mentioned previously, Gold Coast City Council has three mechanical beach cleaning machines in operation. The machines operate on all Gold Coast beaches. High use beaches such as Burleigh Heads, Coolangatta and Surfers Paradise get cleaned everyday. Lower use beaches get cleaned once a week.

3.5.4 Trampling and 4WD vehicles

The detrimental impact of human trampling on sand dunes is a well documented issue (Moffet et al., 1998; Slatter, 1978; Hylgaard and Liddle 1981; Page et al., 2004; Rozé and Lemauviel, 2004). Dunes are highly sensitive to trampling, which often leads to vegetation destruction. Sand dune vegetation has evolved to withstand harsh environmental conditions such as extreme temperature, lack of nutrients, drought and sand burial. However, it does not tolerate trampling very well. Only a few passes can kill the vegetation. The loss of vegetation (e.i. groundcover) de-stabilises the dunes making them more vulnerable to wind erosion. In addition, 4WD vehicles cause the sand to become more compacted. The degree of sand compaction influences factors such as soil moisture, run-off, erosion and as a result has effects on vegetation and micro-organisms.

Gold Coast City Council spends hundreds of thousands of dollars each year maintaining dedicated public access ways to direct beach users away from damaging the dune vegetation (Stuart, 2007. pers.comm). This involves building new fences as the dunes build up and replacing older and broken fences. This is an expensive operation but essential for dealing with the very high levels of beach usage on the Gold Coast (Stuart, 2007. pers.comm).

There is a growing body of evidence on the nature and extent of environmental degradation caused by 4WD vehicles on dune vegetation (Schlacher and Thompson, in press). Vehicle use of beaches is a controversial issue within most coastal communities where it is still permitted (DLWC, 2001). Fragile dune vegetation is easily destroyed by vehicles (Godfrey and Godfrey, 1980). It can be said that next to the destruction of habitat through development, driving of 4WD vehicles is the most harmful of all human activities on sandy beaches. Hosier and Eaton, 1980 documented the impact of 4WD on dune vegetation and grassland in North Carolina in the United States and Rickard, McLachlan and Kerley, 1994 documented the effects of vehicular traffic on dune vegetation in South Africa. In addition, a detail description of the geomorphic and ecological impacts that 4WD vehicles cause on sand dune vegetation has been compiled in the NSW Coastal Dune Management manual (DLWC, 2001).

Gold Coast beaches (with the exception of South Stradbroke Island) are not open to recreational four wheel driving. Only emergency vehicles or those related to beach dependent activities such as life saving, beach management and limited commercial fishing licenses are allowed on our beaches. There are designated vehicle access points that restrict the damage to dune vegetation. Vehicle speeds are restricted to ensure safety of other beach users.
3.6 Recommendations

On the Gold Coast sand dune systems have been heavily altered by human intervention. This review has described a series of factors that over time have compromised the integrity of the Gold Coast’s dune systems. The amount of scientific data available on the state of Gold Coast sand dunes is very low. In addition, there is no information on the overall coverage of weeds and how these are affecting vegetation. At present GCCC has not developed a management plan for sand dunes hence the current management and rehabilitation program of sand dunes is fragmented. Based on our findings we recommend the following:

- Conduct a baseline survey and ongoing monitoring to determine the extent of weed coverage along the whole Gold Coast.
- Encourage and support research to determine the impact that weeds, mechanical beach cleaning and coastal development activities are having on dunes and their fauna.
- Expand the environmental education program currently conducted by BeachCare.
- Develop a sand dune management plan for the local government area.

4 NEARSHORE ROCKY REefs AND BENTHos

4.1 Introduction

The subtidal rocky reefs of the Gold Coast support communities of benthic fauna and flora and fish that represent a transition between the tropical waters of the Great Barrier Reef and the temperate waters characteristic of the mid-New South Wales coast (Cannon et al., 1987; Done 1982). Rocky reefs in the Gold Coast provide: habitat and shelter for many plants, invertebrates and fish communities; help protect the coast from strong currents and waves; help sustain commercial and recreational fisheries; and provide recreational amenity for diving and snorkelling. Because many of the Gold Coast's reefs are located close to shore, they are often the first diverse marine habitat to be affected by human activities from land or in nearshore areas.

4.2 Threats to nearshore reefs

Human activities that are known to have an impact on reef communities include: beach nourishment practices; alteration of coastline habitats (seawall construction, removal of mangroves); urbanisation and coastal development; destructive fishing techniques; domestic and agricultural pollution; oil pollution from boats; stormwater runoff, especially where this carries debris and pollutants; and boat anchoring and over fishing.

4.2.1 Impacts related to the Tweed River Sand Bypassing System

In an attempt to improve navigation at the Tweed River entrance, the New South Wales Government constructed training walls at the river mouth in the early 1990s. These walls were extended between 1962 and 1965. Although the extension of the training walls improved navigation for a period, the entrance sand bar reformed again and created ongoing navigation difficulties (Hyder Consulting P/L et al., 1997). As a result of the construction of entrance training walls, natural patterns of erosion and accretion were significantly altered in the region. Accretion occurred to the south of the southern training wall, resulting in a build up of sand along Letitia Spit and
subsequent significant erosion resulted along the southern Gold Coast beaches (Hyder Consulting P/L et al., 1997).

In order to maintain a safe navigable entrance to the Tweed River and to restore and maintain the amenity of the beaches on southern Gold Coast, the New South Wales and Queensland state governments agreed to implement a permanent sand bypassing system at the mouth of the Tweed River (Hyder Consulting P/L et al., 1997). The project involved dredging to be carried out in New South Wales (NSW) and beach nourishment in Queensland (Hyder Consulting P/L et al., 1997).

In NSW, according to the Tweed River Entrance Sand Bypassing Act 1994, the works are subject to an Environmental Planning and Assessment Act 1979 (EPA Act). As the works were considered likely to significantly affect the environment, the preparation of an Environmental Impact Statement (EIS) was required (Hyder Consulting P/L et al., 1997).

In Queensland nourishment works are considered to be "public works" as defined in the State Development and Public Works Organisation Act 1971-1981 (SD and PWO Act). The works are therefore covered by the provisions of “Impact Assessment in Queensland: Policies and Administration Arrangements”, which outlines the consideration of impact through to the preparation of an Impact Assessment Study (IAS).

In June 1997, the EIS/IAS for the Tweed River Entrance Sand Bypassing Project was completed. The EIS/IAS documents addressed environmental issues related to the construction and operation of the Tweed River Entrance Sand Bypassing Project which involved the implementation of a permanent artificial system to capture and remove sand prior to it entering the entrance of the Tweed River and to use it to re-establish and maintain the eroded southern Gold Coast beaches. Kirra reef was identified as an environmentally sensitive area which could be affected by the sand bypassing system. It was recommended that the disposal of dredged sand be excluded from a defined area around the reef because of the diversity and abundance of marine life on and within the rocks (Hyder Consulting P/L et al., 1997). The recommended defined exclusion zone was of the order of 50m from any portion of the reef outcrops. It was predicted that sediment would slowly accrete around the base of the outcrops as it had always done in the past and that significant direct impacts from the sand deposition process were not expected (Hyder Consulting P/L et al., 1997). The report also recommended monitoring programmes to ensure both that negative impacts were limited and that the project objectives were met. As a result, a series of monitoring studies were conducted at Kirra reef. Table 2 provides a list these studies.

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<tr>
<th>Year</th>
<th>Title</th>
<th>Author</th>
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<tr>
<td>1995a</td>
<td>Tweed River Entrance Sand Bypassing Project</td>
<td>Fisheries Research</td>
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<td></td>
<td>Monitoring Study of the Impacts of Stage 1 (A)</td>
<td>Consultants</td>
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<td></td>
<td>*this report presents baseline data prior to the</td>
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<td>nourishment offshore of Kirra beach</td>
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<td>1995b</td>
<td>Tweed River Entrance Sand Bypassing Project</td>
<td>Fisheries Research</td>
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<td>Monitoring Study of the Impacts of Stage 1 (A)</td>
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<tr>
<td>1996</td>
<td>Tweed River Entrance Sand Bypassing Project</td>
<td>Fisheries Research</td>
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<td></td>
<td>Monitoring Study of the Impacts of Stage 1(A)</td>
<td>Consultants</td>
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4.2.1.1 Kirra Reef monitoring

In 1995 a study to collect baseline information on the possible impacts of the Tweed River Entrance Sand Bypassing Project on the benthic flora, macro invertebrates and fish of Kirra Reef was commissioned by the NSW Department of Infrastructure Planning and Natural Resources (Fisheries Research Consultants, 1995a). Kirra Reef and Palm Beach were sampled for benthos and floral assemblages. Three sites along the eastern and northern edge of Kirra reef were randomly selected to provide early warning of impacts and three sites inshore of these reef-edge sites were randomly selected to indicate whether impacts were affecting the entire reef. Three sites in the shallow section of Palm Beach Reef were also surveyed to be used as control sites (Fisheries Research Consultants, 1995a). At each sampling site, three video transects (approx 10m) were also recorded, still photographs were taken at each location to assist with identification (Fisheries Research Consultants, 1995a). The report concluded that impacts on Kirra Reef may result from: “smothering of the reef by sands mobilized by chronic long shore currents or acute storm events” and “increased water turbidity over the reef, resulting from both deposition and remobilisation of sand” (Fisheries Research Consultants, 1995a).

Shortly after, the first monitoring study of the impacts of nourishment on Kirra Reef was undertaken. Monitoring took place during two days in June, 1995, approximately a month after commencement of the dredging (Fisheries Research Consultants, 1995b). Each of the 6 sites at Kirra Reef and the three sites at Palm Beach Reef, previously selected during the baseline study, were revisited (Fisheries Research Consultants, 1995b). At each site, fifteen 0.25m² replicate quadrants were sampled. Within each replicate, the relative abundance of taxonomic groups were recorded either as a measure of percentage cover or individual species abundance. Flora and fauna were either identified in situ, or in the laboratory with the aid of in situ photographs (Fisheries Research Consultants, 1995b). At each sampling site on Kirra reef, three video transects (approx. 10m) were also recorded. The report concluded that at that time the sand nourishment program had no significant impact upon the benthic fauna and flora, and fish communities of Kirra Reef (Fisheries Research Consultants, 1995b). No changes to the current environmental management program or additional measures were recommended (Fisheries Research Consultants, 1995b).

A second monitoring event of Kirra Reef was undertaken over two days in February, 1996, approximately 10 months after the commencement of nourishment activities.
Overview of ecological information on Gold Coast beaches

(Fisheries Research Consultants, 1996). The methodology employed in this monitoring event was that developed during the previous baseline study and first monitoring event. The report outlined that the major changes subsequent to the beginning of sand nourishment had been an increase in macro-algal cover at all sites, a decrease in ascidian cover at all sites, and an increase in sponge cover at the inshore Kirra sites. The increase in macro-algae and decrease in ascidian cover were found to be unlikely related to sand nourishment as they occurred at all sites, including the control area (Fisheries Research Consultants, 1996). The increase in sponge cover was also found unrelated to sand nourishment. In addition, neither the number of fish nor diversity were found to have decreased (Fisheries Research Consultants, 1996). As a result the report concluded that to that date the sand nourishment program had no significant impact upon the benthic fauna and flora, and fish communities of Kirra Reef (Fisheries Research Consultants, 1996). Thus, no changes to the current environmental management program or additional measures were recommended (Fisheries Research Consultants, 1996).

Five years later, in 2001 a third monitoring event took place. Surveys were carried out at Kirra reef and Palm Beach reef during three days in January (FRC Environmental, 2001). This monitoring event was commissioned at a time when off-shore deposition of sand had been underway for a period of approximately six years and immediately prior to the commissioning of the sand bypass system. As such this monitoring event served two purposes: it provided a final assessment of the impacts that occurred as a consequence of sand deposition; and it served as a baseline against which the future potential impacts of sand bypassing may be assessed (FRC Environmental, 2001). Sand nourishment activities between Snapper Rocks and Kirra had been undertaken over a number of campaigns. Initial nourishment works involved two sub-stages. Stage 1A from April 1995 to August 1996, and Stage 1B from September 1997 to May 1998 delivered a total of 3.2 million cubic metres of clean marine sand (with less than 3% fines) out to 10 metres mean water depth, with approximately 600,000 cubic metres placed on the upper beaches during Stage 1A activities (FRC Environmental, 2001). To maintain a clear navigation channel at the Tweed River entrance until commissioning of the permanent sand bypassing system, additional dredging activities have been undertaken with the placement of approximately 450, 000 cubic metres of clean marine sand in the nearshore areas since April 2000 to just prior to this monitoring event.

The report outlined that throughout all sand nourishment works, environmental management measures had been in place to minimise adverse impacts on Kirra Reef. These measures consisted on the implementation of a sand placement exclusion zone of approximately 100 metres around Kirra Reef to ensure that no sand was directly placed on the reef (FRC Environmental, 2001). P. Boswood, a senior engineer of the Tweed River Entrance Sand Bypassing Project, declared through personal communication to FRC Environmental that “any accumulation of sand on Kirra Reef has been a result of movement of sand into the exclusion zone by natural processes” (FRC Environmental, 2001). The methodology used in this monitoring event was the same as that used in the 1995 baseline study, and the monitoring events of 1996. The report results concluded that there was no evidence to infer that the deposition of dredge sand offshore of Kirra Reef had an impact on the reef's benthic flora or fauna (FRC Environmental, 2001). The most profound change recorded was the increase in macroalgal abundance at Kirra Reef. This result was inconsistent with the expected impacts of nearby sand deposition (FRC Environmental, 2001). This monitoring event also indicated that the finfish community of Kirra Reef was both diverse and relatively stable (FRC Environmental, 2001).
In May 2003, a fourth monitoring study was conducted on Kirra reef. The study found that three eastern reef sites at Kirra reef (two outer sites and one inner site) were completely covered with bare mobile sand (FRC Environmental, 2003). Methods for this monitoring event were similar to the ones used in 2001. At each site, fifteen 0.25 m² replicate quadrats were sampled. Within each replicate, the relative abundance of taxonomic groups was recorded either as percent cover or by number of individuals (FRC Environmental, 2003). Fauna and flora were either identified in-situ, or in the laboratory with the aid of in-situ photographs or video footage (FRC Environmental, 2003).

The loss of reef meant the loss of three of the baseline monitoring sites from the previous studies, reducing the ability to compare current monitoring data to previous events. It was recommended to include new sites in future monitoring. The report outlines that having one outer and two inner sites on the remaining section of Kirra Reef did not provide enough replication or balance of design to allow future impacts of sand deposition on the reef to be analysed (FRC Environmental, 2003). The study concluded that the flora and fauna of Kirra Reef had been significantly impacted by the movement of sand. Since the commencement of long-term sand placement in the mid 1990s, sand had covered approximately half of the rocky outcrops recorded by aerial photography in the late 1960s (FRC Environmental, 2003). The report also mentioned that an increased depth of sand, the seaward migration of the surf zone, and possibly an increased concentration of suspended sediments may also be impacting the flora and fauna of those outcrops that have not been buried. The reduction in extent of exposed reef appeared to have resulted in the concentration of reef-associated fishes over the remaining outcrops (FRC Environmental, 2003). This concentration of fish was considered unlikely to be ecologically sustainable (FRC Environmental, 2003). The report concluded that a decrease in both the abundance and diversity of fish was likely over the coming years (FRC Environmental, 2003).

In March 2004, a fifth survey was conducted on Kirra reef. This report compared the results from past monitoring events to the present survey. The methods used in the March 2004 monitoring event were the same as those developed for the Stage I study conducted in 1995, and applied to monitoring events undertaken in 1996, 2001 and 2003 (FRC Environmental, 2004). Three sites at Kirra Reef were sampled to determine flora and benthic invertebrate composition, and fish presence and abundance, with similar sampling at three sites at Palm Beach Reef used as a control (FRC Environmental, 2004). At the time of this monitoring event the inner reef sites (used in previous surveys) had been completely covered by mobile sand and as a result two new sites were established on the remaining area of Kirra Reef (FRC Environmental, 2004) (see Figure 1).
The most obvious and striking result of the March 2004 monitoring surveys was the increased amount of Kirra Reef and surrounding area that had been buried by sand (FRC Environmental, 2004). The reduction in the extent of exposed reef appeared to have resulted in a decline in the diversity of finfish communities and a reduction in the abundance of several species at Kirra Reef. Changes in community structure were found to correspond to a decrease in the density of carnivore and detrivore species and a consequent dominance of herbivore and planktivore species (FRC Environmental, 2004). The report predicted that further decline in finfish diversity and abundance was likely, if reef burial continued and if the reef area was further reduced (FRC Environmental, 2004). The report also stated “If an ecological equilibrium has yet to be reached, fish diversity and abundance may decline further, even if the reef size is maintained at its current extent. Ongoing monitoring of reef size, and floral and faunal community structure is recommended” (FRC Environmental, 2004).

The last monitoring event of Kirra reef took place in February 2005. The methods used in the February 2005 monitoring event were those developed for the Stage I study conducted in 1995, and used in the 1996, 2001, 2003 and 2004 monitoring events (FRC Environmental, 2005). The report outlined that the Outer Western Reef was the only remaining rocky outcrop at Kirra Reef (FRC Environmental, 2005). The report also stated that Kirra Reef had been further buried by sand since the last
survey conducted in March 2004 and a strong ground swell keep sediment in suspension across the reef and as a result pockets of deposited sand were found across the entire reef (FRC Environmental, 2005). It was determined that the most obvious and ecologically significant change in the flora and fauna of Kirra Reef was the loss of large areas of benthic floral and faunal communities, due to continuous burial by sand (FRC Environmental, 2005). Hence, the reduction in the area of exposed reef resulted in the loss of approximately 80% of the 1995 extent of Kirra Reef (FRC Environmental, 2005). It was also reported that a commensurate proportion of ecologically valuable habitat had been lost, and it was likely that habitat diversity had been reduced (FRC Environmental, 2005). In addition, the report stated that at the time of the survey the floral and faunal communities of Kirra Reef were likely to be more susceptible to influence by storms than they have been over the past 6 decades (FRC Environmental, 2005). This was because the currently exposed reef was found to be surrounded by deposited sand that had both reduced the depth of water, and brought the surf zone seaward and closer to the reef (FRC Environmental, 2005).

The report also includes a section that compares the apparent actual impacts with those predicted, based on material presented in three documents provided by the NSW Department of Infrastructure, Planning and Natural Resources. The three documents were:

- Impact Assessment Review Report for Tweed River Entrance Sand Bypassing Project Permanent Bypassing System, prepared by the Queensland Department of Environment in March 1998; and

4.2.1.2 Benthic studies

As part of the Stage 1 of the Tweed River Sand Bypassing Project the benthic macro-invertebrate fauna in both the removal area and the nourishment area were sampled. Samples were collected in 1994 from nine sites along the Tweed River entrance and off Coolangatta beach. The sampling event found that small crustaceans (amphipods, isopods, decapods, and crumaceans) dominated the mobile sand habitat (Hyder et al., 1997). The EIS/IAS for the Stage 2 of the Tweed River Sand Bypassing Project concluded (based on sampling carried out during the Stage 1 EIS/IAS) that “relocation of bypassed sand would not create significant environmental problems provided large volumes of sand were not placed in one spot”, and that “recolonisation of the soft sediment habitat in the nourishment area would occur within weeks to months after nourishment given that the surrounding area will be available for recolonisation” (Hyder et al., 1997).

4.2.2 Commercial and recreational fishing

The rocky reef finfish fishery comprises a number of demersal and pelagic species associated with inshore rocky reefs, including Snapper, Pearl Perch and Teraglin Jew (DPI and F, 2006). The fishery is restricted mainly to the southern part of Queensland, (DPI and F, 2006). Other minor species in the fishery include Black Kingfish, Dolphin Fish, Yellowtail Kingfish, Amberjack, Samson Fish and Silver
Overview of ecological information on Gold Coast beaches

Trevally (DPI and F, 2006). Management of the rocky reef fishery is the responsibility of the Queensland Department of primary Industries and Fisheries (DPI and F). The department enforces control over size limit, number of landings, number of hooks that can be use by recreational and commercial fishermen and number of commercial operators with the potential to access the fishery (DPI and F, 2006). The Queensland Rocky Reef Finfish Fishery annual status report 2006 estimates that the commercial catch in 2005 was higher that the most recent estimate (2002) of the total recreational catch (DPI and F, 2006). This is in contrast to previous years when the recreational sector was estimated to be taking twice as much as the commercial sector (DPI and F, 2005).

No studies have been conducted to determine if recreational or commercial fishing is having an impact on nearshore reefs on the Gold Coast. However, there is anecdotal evidence that commercial fishing has affected numbers of non-migratory fish on certain Gold Coast reefs (De Paiva, 2007. pers.comm).

4.2.3 Pollution

Human impact on the marine environment can be divided into general categories such as alteration to bottom substrate through dredging, introduction of toxic substances, release of sewage rich in nutrients and heating and release of heated water by power plants (Levinton, 2001). In other words, pollution can be described as the introduction by humans of substances, materials, or heat energy that decreases the quality of the environment (Castro and Huber, 1997).

In the Great Barrier Reef 10 years of monitoring and modelling has demonstrated that sediment and nutrient exports have increase over the last 200 years and that flood events are critical in transporting these pollutants to the reef (Furnas, 2003). Pollutants accumulate in both nearshore sediments and marine mammals (Hutchings and Haynes, 2005). The main causes for a decrease in water quality are urban development, vegetation clearance, cattle grazing and agriculture (Hutchings and Haynes, 2005).

Several studies have documented the impact that increased runoff has had on inshore coral reef communities (Fabricius et al., 2005 and Schaffelke et al., 2005). In addition, Hutchings et al (2005) presents a comprehensive review of papers which deal with the impacts of runoff on inshore marine ecosystems, water quality and management. The review includes many of the papers presented at the Catchment to Reef: Water Quality Issues in the Great Barrier Reef Region Conference, which was held in 2004. Some of the topics addressed were issues such as nutrient runoff through groundwater (Rasiah et al., 2005), impacts of sedimentation on coral recruitment (Birrell et al., 2005), herbicide impacts on algae photosynthesis (Harrington et al., 2005) and elevated levels of heavy metals in biota, water and sediments (Jones et al., 2005).

The coastal environment of the Gold Coast and the whole South-east Queensland has been subjected to pressures associated with increasing coastal development (EPA, 2006). This has impacted on the water quality of coastal water (EPA, 2006). On the Gold Coast the coastal aquatic ecosystems are heavily impacted by human activities through urbanisation, waste disposal, and consumptive exploitation of natural resources.

The Australian Rivers Institute (ARI) was established by Griffith University in 2006 to provide a focus for Australia’s largest group of university based scientists with
expertise in river, catchment and coastal research and education. ARI builds on the strengths of two influential Griffith Research Centres, the Centre for Riverine Landscapes and the Gold Coast based Centre for Aquatic Processes and Pollution (CAPP) (Griffith University, 2007). Research at CAPP has mainly focused on estuarine environments. Recent publications deal with the impact of urbanisation on coastal wetland structure and function (Lee et al., 2006), the movement of carbon among estuarine habitats (Guest and Connolly, 2006), the carbon movement and assimilation by invertebrates in estuarine habitats (Guest et al., 2004) and the use of stable isotope data to determine primary sources of nutrition for fish (Melville and Connolly, 2003).

Nathan Waltham (PhD Candidate, Griffith University) is currently investigating heavy metal and pesticide contamination in fish collected from canal estates, estuaries, artificial tidal lakes, marinas and the Broadwater on the Gold Coast (Waltham, 2007. pers.comm). Waltham is analysing different tissue types (liver, gills and muscle) to determine the uptake pathway of pollutants in Mullet, Garfish, and Bream. The study has been sponsored by Gold Coast City Council and the Griffith Centre for Coastal Management.

4.2.4 Ornamental fish trade

The Department of Primary Industries and Fisheries (DPI and F) manages the Queensland Marine Aquarium Fish Fishery (MAFF) under the Fisheries Act 1994 and Fisheries Regulation 1995. The Marine Aquarium Fish Fishery (MAFF) is a harvest fishery that is focussed on a diverse suite of species (Ryan and Clarke, 2005). Consumptive users include commercial and recreational fishers that collect marine aquarium fish species for display in either private or public aquariums (Ryan and Clarke, 2005). Non-consumptive users of the fish stocks include divers and others viewing fish stocks either recreationally or as part of non-manipulative research or commercial tourism activities (Ryan and Clarke, 2005). The aquarium fishery operates along the Queensland coast from the tip of Cape York to the New South Wales border (CRC Reef, 2005). The fishery area also comprises five Special Management Areas (SMAs) that have been established to protect stocks from localised depletion (CRC Reef, 2005). One of these Special Management Areas includes waters within Moreton Bay Marine Park and stops at the northern rock wall of the Gold Coast Seaway.

Most of the fish that are commercially harvested for the aquarium trade (more than 60 per cent) belong to a few fish families including: Damselfish and Anemone fish (Family Pomacentridae); Butterfly fish (Chaetodontidae); Angelfish (Pomacanthidae); Wrasse (Labridae) and Gobies (Gobiidae) (CRC Reef, 2005).

There is anecdotal evidence to that suggest that at some Gold Coast dive sites (eg. Seaway) the abundance of ornamental fish has declined due to collection of specimens by the aquarium trade or by recreational fishermen and divers. Local dive operators have expressed concern to government authorities about the issue (Banks, 2007.pers.comm).

4.2.5 Climate change

Worldwide, warm and cold water coral species are threatened by an increase in seawater temperatures and altered water chemistry caused by global climate change (Hutchings and Haynes, 2005, Guinotte et al. 2006). Seawater chemistry changes have the potential to alter the abundance of marine organisms (corals, plankton, etc) and the species that depend on them for survival such as fish and marine mammals.
Overview of ecological information on Gold Coast beaches (Guinotte et al. 2006). Moreover, the existence of warm coral species into the future is dependent on minimising the rate and magnitude of further warming. Gold Coast rocky reefs contain tropical and temperate marine organisms. The degree to which increased water temperature or changes in water chemistry are having on the health of corals and to other marine organisms is unknown. Hence, funding is needed to quantify the effects of climate change on Gold Coast rocky reef’s.

4.3 Narrowneck Artificial Reef

It well known that the Gold Coast is an area with extensive coastal development. Due to dune degradation and sand bar removal, the potential for damage to this coastline from erosion caused by large swells has been substantially increased (Restall et al., 2002). Likewise, it is also known that submerged, nearshore reefs help prevent beach erosion by offering stable and long-term physical protection from wave energy (Mead and Black 1999). Few such reefs are present in the Gold Coast area. Consequently, Narrowneck Artificial Reef was designed and constructed to simulate many of the important physical attributes associated with natural nearshore reefs (Edwards and Smith, 2005, Edwards, 2003).

The subtidal assemblages associated with the artificial/geotextile reef Narrowneck were studied by Edwards and Smith (2005). Surveys were conducted over a two-week period in August 2003. Surveys took place three years after the completion of the reef, which was built between August 1999 and July 2000. Narrowneck was compared to Palm Beach, Kirra and Cook Islands reefs. Results showed that the artificial reef was dominated by macroalgae and supported fewer benthic categories while the natural reefs were characterised by a diverse range of sessile invertebrates (Edwards and Smith, 2005). Benthic demersal fish assemblages were less diverse on Narrowneck, but pelagic fish assemblages were similar on both reef types (Edwards and Smith, 2005). It was found likely that the key determinants of the biotic patterns observed in this study are interactions between the age of Narrowneck and the physical properties of a geotextile substratum (Edwards and Smith, 2005). A compilation about the marine flora development of Narrowneck was also presented by Jackson et al., (2004) at the 2004 International Conference on Coastal Engineering in Portugal.

4.4 Palm Beach Bait Reef

In 2004, the GCCC commissioned a study on Palm Beach Bait Reef (PBBR). Its purpose was to determine any evidence of impacts resulting from preliminary dredge-spoil dumping associated with the Palm Beach Nourishment Program. Surveys consisted of general visual inspections of the condition of PBBR and quantitative evaluations of fish and attached invertebrate and algal communities (Smith et al., 2005). Palm Beach, Kirra and Cook Island reefs were also included in the surveys in order to describe the condition of PBBR into a regional context (Smith et al., 2005). Surveys took place in November 2004. The study failed to detect any evidence of impact of the small amount of dredge-spoil that had been deposited adjacent to the reef, immediately before hand, on the fish or benthic communities associated with PBBR (Smith et al., 2005). Nevertheless, the most striking observation during the study was that Kirra Reef presented extensive loss of reef habitat, thus many of the lower lying sections of reef that were surveyed during 2003 were completely buried (Smith et al., 2005). The study concluded that the smothering of Kirra Reef had important implications for the Gold Coast (Smith et al., 2005). The study outlined that the reef’s proximity to shore had meant that they easy access to a range of recreational activities that are fundamental to the life of many residents such as diving and snorkelling was no longer possible (Smith et al., 2005). In addition, Kirra
Reef was found to contain a diverse biological habitat of considerable regional importance therefore it was recommended that, where possible, management steps were taken to reduce further impact of sand accretion (Smith et al., 2005). This report was made available for GCCC review in June 2005.

4.5 Reef Check

Reef Check Australia is currently undertaking a project titled “South East Queensland (SEQ) long-term, community coral reef monitoring and education program”. Reef Check Australia (RCA) is a professional organisation of trained marine scientists that specialise in monitoring the health of reefs (Werry, 2007 pers.comm). Their aim is to directly involve community groups in coral reef conservation, reef monitoring and management. Reef Check is also the United Nations official coral conservation program and as such the locally collected data can be compared to the health of reefs worldwide (Werry, 2007 pers.comm). Reef check received funding for 2007 from SEQ-Catchments. The project will obtain data for 5 reefs in the Sunshine coast, Moreton Bay and Gold Coast areas (Werry, 2007 pers.comm). The Gold Coast reef’s to be monitored by Reef Check will be Kirra Reef, Palm Beach Reef, Narrowneck Reef and the Gold Coast Seaway (Werry, 2007 pers.comm). Reef Check will monitor these reefs once a year to provide a long-term picture of reef health in SEQ. The Reef Check method involves four independent 20m transects (replicates) per reef in any one sampling period (Werry, 2007 pers.comm). For each transect a benthic survey of coral cover, a fish survey, an invertebrate survey, a video survey are performed (Werry, 2007 pers.comm). In addition data on coral damage, bleaching or disease and any rubbish will also collected (Werry, 2007 pers.comm).

4.6 Northern Rivers biodiversity assessment of inshore reefs

In 2006 the Northern Rivers Catchment Management Authority (NRCMA) commissioned the National Marine Science Centre and NSW Marine Parks Authority to conduct a study titled 'Rapid Biodiversity Assessment of Inshore Reefs'. The objectives of this study were to provide initial reports on the biodiversity, condition and health of a number of nearshore and offshore reefs within the marine section of the Northern Rivers region of New South Wales. Work focused on reefs adjacent to three population centres. Measures of biodiversity (fish and molluscs) and benthic community structure were combined with assessments of anthropogenic debris load as well as surveys of coral health and condition (Smith et al. 2006). This study highlights a number of important issues for the management of marine resources in this region. Firstly, it does not support the assumption that reefs in close proximity to each other support similar communities, both in terms of biodiversity and biotic composition (Smith et al. 2006). Thus, decisions to arbitrarily protect reefs in order to achieve a specific quota (i.e. a certain percentage of habitat protected) may not achieve the objective of protecting a range of representative community types (Smith et al. 2006). Secondly, each of the locations assessed support different assemblages of most of the taxa investigated (Smith et al. 2006). It is therefore highly likely that other areas across the coast are likewise dissimilar (Smith et al. 2006). The study concludes that nearshore reefs will be the first to respond to the effects of urbanisation of adjacent terrestrial habitats therefore a greater knowledge of their diversity, productivity and wider importance for other marine resources (i.e. linkages and flow-on effects) is urgently needed (Smith et al. 2006). This study provided a cost-effective protocol which can be applied to further work such as assessing nearshore reefs in other areas and gathering long-term data to measure, and thus facilitate mitigation of the effects of a burgeoning population on these important nearshore reefs (Smith et al. 2006).
Dr. Steven Smith, who directed this study, has expressed interest in extending this program South-east Queensland.

4.7 Benthic Infauna

In general terms benthos is a group of organisms living on or at the bottom of a body of water. Epifauna are animals that live attached to hard substratum or rooted below the surface (i.e. Seaweeds and corals) (Levinton, 2001). Infaunal organisms live below the sediment (Levinton, 2001). They may be burrowers, such as clams and polychaetes or borers such as isopods (Levinton, 2001). The number of species living on subtidal soft bottoms is usually higher than the number of species living on the intertidal zone (Castro and Huber, 1997). This is mainly because the physical conditions below the low tide mark are rather less demanding. Desiccation is not a problem, and there are none of the drastic temperature changes caused by exposure to tides (Castro and Huber, 1997). The ocean floor is a highly complex and diverse environment, but it is the macrofaunal component that dominates the benthic biomass (Rowland, 2007 pers.comm). It is estimated that soft-sediments contain between 500,000 to 1,000,000 macrofaunal species worldwide, dominated primarily by representatives from the class Polychaeta, subphylum Crustacea, and the phyla Mollusca and Echinodermata (Rowland, 2007 pers.comm). Soft-sediment invertebrates occupy almost every trophic level in marine ecosystems, and play a major role in more that one of the oceans energy pathways.

4.7.1 Impacts of off-shore dredging and sand movement on Gold Coast’s benthic infauna

The loss of sand from beach systems is a well known coastal issue. One of the ways used to remediate such erosion is by nourishing beach systems with soft-sediments taken from offshore deposits. The placement of soft-sediments in the nearshore area acts as a buffer to the naturally dynamic coastal system, protecting property from loss and damage. However, the removal of benthic sediments from offshore deposits has environmental impacts (Rowland, 2007 pers.comm).

Jennifer Rowland (PhD Candidate, University of New England) is currently studying local benthic communities in both space and time. Her study focuses on the impacts imposed by dredge works on the resident communities, with particular emphasis on recovery rates and the mechanisms of recruitment. One of her study sites is the Palm Beach/Currumbin area. In the area, sand is being dredged offshore from Currumbin Rock at a depth of 20 meters for replenishment of the nearby Palm Beach beach system (Rowland, 2007 pers.comm).

4.7.2 Benthic infauna studies related to the Tugun desalination plant

Despite numerous attempts over a 4 months period to obtain detailed information about marine studies from Gold Coast Desalination Alliance (GCDA) only partial information was obtained. The information presented in this review has been gathered from the following two reports:

- Desalination Environmental Report 2006 prepared by GCDA.
- Baseline Marine Ecology and Water Quality Monitoring October 2006 – March 2007 (draft version) prepared by Natural Solutions.

Other studies (not reviewed by this literature review) are:
- Overview of ecological information on Gold Coast beaches


The GCDA is a group setup to work on the Gold Coast desalination project. The group is formed by Veolia Water, John Holland Group, Gold Coast Water and SKM Consulting. The alliance is in the process of constructing and operating a reverse osmosis water treatment plant at Tugun. Initial plans were for a $260 million plant producing 55 megalitres a day. The State Government then contributed $869 million to increase the output to 125 megalitres a day to supply water to the Gold Coast and the rest of southeast Queensland. Waste brine, a by product of the desalination process will be returned to the marine environment. The rate of brine return will be a maximum of 206 ML / day (Natural Solutions, 2007). The brine will essentially contain concentrated seawater (concentrated up to 1.8 -1.9 times) and small quantities of process additives (Natural Solutions, 2007). Potential impacts to the marine environment consist of increases in salinity and decreases in dissolved oxygen (Natural Solutions, 2007). These impacts can result in toxicity to benthic fauna from hypersaline waters, suffocation of infauna, changes to fauna abundance, diversity and community composition, release of sediment-bound metals to the water column, and release of nutrients to the water column, which could stimulate plant growth (Natural Solutions, 2007).

As part of the marine ecology and water quality monitoring program Natural Solutions consultants undertook sampling of the benthic infauna community on February 2006, June 2006 (GCD Alliance, 2006) and February 2007 (Natural Solutions, 2007). Samples were sieved in the field using a 1.0 mm mesh sieve and preserved in 4% buffered formalin for laboratory identification (GCD Alliance, 2006).

Samples were taken from 5 sites during the February 2006 sampling event and from 6 sites during the June 2006 sampling event. Three replicates were taken at each sampling site. Results from these surveys indicated that the area was numerically dominated by molluscs, crustaceans and annelid worms but proportions differed considerably between sampling events (GCD Alliance, 2006). Results also indicated that the area has a rich and diverse benthic community (GCD Alliance, 2006). During the February 2007 sampling event 12 sites were sampled and five replicates were taken at each sampling site (Natural Solutions, 2007).

One of the primary environmental concerns relate to the impacts that an increase in salinity could have on benthic infauna. The 2006 Gold Coast Desalination Project Environment Report states that tolerance to hypersaline conditions was obtained from a range of studies based mainly on North American species (GCD Alliance, 2006). A summary of these species presented fauna that are tolerant to salinities of at least 40-45 practical salinity units (PSU) with sensitive species exhibiting tolerances of around 38 PSU (GCD Alliance, 2006). The report adds that at a typical operating scenario of 100% duty with back flows occurring 90% of the time, it is calculated that a 71 fold dilution will be achieved at the edge of the mixing zone with a resulting salinity of 35.9 PSU. In worse case operation scenario of 33 % or 60% plant duty, there would be 40 times dilution of the brine discharge, this is calculated to result in a salinity of 36.26 PSU at the edge of the mixing zone. The report concludes that: “no salinity related impacts are expected beyond the mixing zone as salinities will be less than those for even the most sensitive marine organisms”(GCD Alliance, 2006 p.61)
Another environmental concern relates to dissolved oxygen concentrations. The 2006 Gold Coast Desalination Project Environment Report states that at the worst case scenario the level of dissolved oxygen at the discharge point would be of 3.4 mg/L (GCD Alliance, 2006). After dilution in the mixing zone, oxygen levels at the edge of the mixing zone will remain above 5 mg/L during all proposed plant operating conditions (GCD Alliance, 2006). The report concludes that no impacts to marine organisms are expected from reduced dissolved oxygen conditions (GCD Alliance, 2006). This conclusion is based on oxygen levels presented by Diaz and Rosenberg (1995).

Additives such as antiscalant PermaTreat PC-1020T and Hypersperse MDC220 will form part of the brine to be discharged. The antiscalant PermaTreat PC-1020T is classified as having "low potential for environmental hazard" however no toxicity studies have been conducted to test this assumption (GCD Alliance, 2006). Hypersperse MDC220 is a blend of caustic and phosphoric acids. Based on toxicological data provided by the supplier of these products the 2006 Gold Coast Desalination Project Environment Report concludes that: "predicted antiscalant concentrations in the brine discharge will be well below concentrations that elicit biological effects" (GCD Alliance, 2006). In addition, approximately 200kg/day of Fe(OH)_3 may enter the brine stream and subsequently the marine environment (GCD, 2006). In relation to this the 2006 Gold Coast Desalination Project Environment Report states that: "the dilution provided by the diffuser is expected to return levels to about background concentrations within the 120mx225m mixing zone" (GCD, 2006,p.52). Also, 7kg/day of nitrogen will enter the bay, likewise the environmental report states that this amount will not have a direct or indirect impact to water quality (GCD Alliance, 2006).

This review found that no experimental studies have been conducted to test the individual impacts that hypersaline conditions, low levels of oxygen, additives and metals could have on local species. In addition no experimental studies have been conducted to test the effects that all these elements combined could have on local species.

4.8 Diatom blooms

Many beach systems have resident primary producers in the form of benthic microflora or surf phytoplankton (McLachlan and Brown, 2006). The benthic microflora of marine sands includes bacteria, blue-green bacteria (cyanobacteria), autotrophic flagellates, and diatoms (McLachlan and Brown, 2006). Rich accumulations of diatoms are a typical feature of the surf zones of many exposed beaches. They occur throughout the year and are physically controlled accumulations. (McLachlan and Brown, 2006). Diatom blooms are seasonal phenomena related to water chemistry and temperature (McLachlan and Brown, 2006), which cause green to brown discoloration of the water (McLachlan and Lewin, 1981).

A bloom of surf diatom Anaulus australis was detected at Main Beach in May 2000. While surf diatom blooms have been previously recorded from temperate areas in both the northern and southern hemisphere, there have been few previous reports from subtropical waters (Hewson et al., 2001). This bloom of Anaulus australis is one of the lowest latitude of any recorded diatom bloom and the most northerly reported in Australia (Hewson et al., 2001). During the study of this event it was found that the stable isotope nitrogen signature of these diatoms was substantially higher than diatoms living in coastal waters (Hewson et al., 2001). Higher nitrogen values
frequently indicate nitrogen derived from human made activities. Although, it has been previously argued that surf diatom blooms are unrelated to increases in riverine anthropogenic inputs it is conceivable that anthropogenic nutrients may have stimulated the bloom (Hewson et al., 2001).

4.9 Seagrasses

Seagrasses are common components of the shallow sublittoral of sheltered sandy shores in tropical, subtropical, and temperate regions (Clark, 1998; Levinton, 2001). Further, when cast ashore as beach wrack they can contribute substantially to sand beach energetics (McLachlan and Brown, 2006). The growth of seagrasses creates a unique habitat. It stabilizes the bottom and traps sediment, clarifies the water, and provides habitat for plants and animals (McLachlan and Brown, 2006). Subhabitats created by seagrasses are leaf surfaces available for colonization by macrobenthos such as polychaetes, amphipods, and bivalves; fish, prawns, and cephalopods living among the leaves; and finally the benthos living in the sediment between plants (McLachlan and Brown, 2006). These habitats can be especially important for fish and prawns, particularly commercially important species, which may use them as nursery areas (McLachlan and Brown, 2006). Threats to seagrass meadows include turbidity, sedimentation, eutrophication, dredging, and erosion (McLachlan and Brown, 2006).

Rod Connolly from the Griffith University Centre for Aquatic Process and Pollution has conducted extensive research on seagrass landscapes (Jelbart et al., 2006; Connolly and Hindell, 2006; Connolly et al., 2005; Oakes and Connolly, 2004; Winning et al., 1999; Connolly, 1995; Connolly, 1994).

4.10 Marine habitat mapping

A project titled “Benthic habitat mapping of priority areas within Moreton Bay Marine Park” is currently being conducted by the EPA and the Queensland Parks and Wildlife Service on Moreton Bay Marine Park. The study will stop at the northern side of the Gold Coast Seaway. The end purpose of the project is to develop marine habitat maps for the area. Field work is being conducted with the aid of video footage and acoustic sonar (Udy, 2007 pers.comm)

Stevens and Connolly (2005) conducted mapping of the macrobenthic habitats of Moreton Bay Marine Park. Data was collected using video footage. All sites selected for sampling were located on the northern side of North Stradbroke Island. This study located habitat types not previously described in the Moreton Bay area (Stevens and Connolly, 2005) which is a relatively well known system (Crimp 1992). This highlights the need to carry out habitat mapping before we are reduced to studying only impacted marine ecosystems (Stachowitsch, 2003) or before we even realise these habitats are there (Stevens and Connolly, 2005).

4.11 Recommendations

GCCC nearshore reefs fall within State Governments jurisdiction. However, due to the proximity of these reefs to land they are extremely exposed to activities that occur on GCCC land. In addition, nearshore reefs are linked to GCCC due to the recreational amenity they provide to local residents and visitors. As a result they directly contribute to Gold Coast’s economy. This review found that the species abundance and biodiversity of these reefs systems is not well understood or managed and that they are affected by a series of human activities. For these
reasons we encourage GCCC to collaborate with the State Government to provide funds, encourage and support research and conservation initiatives related to Gold Coast’s nearshore reefs. Based on our findings we recommend the following:

- Regular monitoring of all nearshore reefs is required to better understand their ecology and natural dynamics and to provide an assessment on the health of these communities.
- Develop and environmental awareness and education program to minimise impacts caused by human activities such as recreational fishing and illegal removal of aquarium species.

5 VERTEBRATES

5.1 Introduction

Several groups of vertebrates make use of sandy beaches for foraging, nesting, and breeding (McLachlan and Brown, 2006). Birds are the most important vertebrates commonly encountered on sandy beaches, both in terms of abundance and diversity and their role in beach ecosystems (McLachlan and Brown, 2006). Turtles, also visit beaches to lay their eggs in the dry sand above the high water mark (Clark, 1998; McLachlan and Brown, 2006).

5.2 Shorebirds

5.2.1 Introduction

Shorebirds are typically gregarious and often occur together in very large numbers. Many shorebirds undertake annual migrations of thousands of kilometres between their breeding and non-breeding areas (Barter, 2002). Shorebirds require specific habitat conditions for migration and breeding (EPA, 2006). Migratory birds must have space, food and protection from predators and disturbances to recuperate from long flights. Resident shorebirds need similar conditions for breeding (EPA, 2006).

Some shorebirds use beaches only for roosting (McLachlan and Brown, 2006), others (including shorebirds, waders, and raptors) forage in the intertidal and supralittoral zones, and several lay their eggs and nest on the upper beach or in the dunes (McLachlan and Brown, 2006; Clark, 1998).

5.2.2 Foraging habits

Foraging birds can be divided into three general groups: probers that use tactile cues to locate prey below the surface of the sand, including deep probers with long bills such as oystercatchers and curlews, and shallow probers with short bills such as sanderlings; surface feeders and peckers that forage using visual cues, such as many small plovers and even wagtails and passerines; and scavengers that feed on stranded carrion, typically gulls and raptors (McLachlan and Brown, 2006). Birds that commonly roost on beaches but do not feed in the intertidal zone include terns, cormorants, and pelicans which mainly feed offshore or in other coastal habitats (McLachlan and Brown, 2006). Birds that nest on the backshore include species that also forage on the beach, such as plovers and oystercatchers and others, such as terns (McLachlan and Brown, 2006).

The presence and abundance of birds on sandy beaches fluctuates considerably due to movements of migrants and variations in numbers of resident species (McLachlan and Brown, 2006). Birds are an important component of the sandy beach...
macrofauna, playing a significant role as predators in beach food chains (McLachlan and Brown, 2006). The relationship between shorebirds in intertidal areas and patterns of prey availability has been studied by Smart and Gill (2003); Dugan et al., (2003); and Hubbard and Dugan (2003). Also, in 1991 the International Wader Study Group organised a congress that brought together shorebird ecologists working on food web systems in intertidal areas and invertebrate biologists working on the abundance and distribution of beach organisms. A summary of the papers presented at the conference has been compiled by Piersma and Beukema (1993).

5.2.3 Common threats to shorebirds

The population decline of shorebirds in a particular area could have several causes such as inadequate intertidal resources (Smart and Gill, 2003), constant human disturbance when foraging or roosting (Rogers et al., 2006; Yasue, 2006; Weston and Elgar, 2007), lack of suitable habitat for roosting, disturbance by 4WD vehicles (Watson et al., 1996; Williams et al., 2004), general habitat loss and degradation (Barter, 2002; EPA 2006) and disease.

5.2.4 Shorebirds on Gold Coast’s beaches

A number of shorebird species present on Gold Coast beaches are protected by commonwealth law and several treaties such as the Environment Protection and Biodiversity Conservation Act 1999, Japan-Australia Migratory Bird Agreement (1974) (JAMBA), and the China-Australia Migratory Bird Agreement (1986) (CAMBA).

In 1997, Miller (1997) conducted a study titled “Wader Site Data Collation and Survey Project for south-east Queensland”. The report was prepared for the Queensland Environmental Protection Agency. The purpose of the study was to show the distribution of wader birds and their preferred habitat throughout the coastal areas of South East Queensland. The objectives of the project were to: collate existing information on the distribution and abundance of shorebirds in South East Queensland, conduct field surveys of localities where existing shorebird distribution and abundance data was incomplete and to assess the levels of disturbance that shorebirds and their habitat were subject to. The dataset for this report can be obtained from the Environmental Protection Agency through a licensing agreement. The mapping component of this report that corresponded to the Gold Coast area was later refined by Francis et al. (2005), as part of the Gold Coast City Council Nature Conservation Mapping Review. This review also produced a series of management recommendations for species such as the Little Tern, Beach Stone-curlew, Sooty Oystercatcher and Easter Curlew (Francis et al., 2005).

GCCC is currently conducting a monthly count of shorebirds at four roosting sites at SSI (Bell, 2007). The council has also installed information signage at SSI roosting sites which are also popular weekend recreational areas (Bell, 2007).

During the present literature review it has been noted that there is no survey, report or study that attempts to explain the relationship between intertidal resources and the fluctuation and distribution of shorebirds on Gold Coast’s beaches.

5.2.5 Recommendations

Although GCCC staff dedicates a considerable amount of time monitoring shorebirds at SSI, more research and resources are needed to expand this work to other areas of the coast. The population fluctuation and the seasonal changes in abundance and
distribution of shorebirds is currently unknown. In addition, there is no information on the impacts that human disturbance could be causing to resident and migratory populations. A number of shorebirds species present on the Gold Coast are protected by State and Commonwealth legislation as well as several international treaties. Hence, we encourage both GCCC and the State Government to collaborate and get actively involved in research and conservation of these species. Based on this review's findings we recommend the following:

• Conduct baseline research to determine the population numbers of resident communities.
• Conduct research to monitor the seasonal fluctuations of migratory species.
• Develop management actions in order to protect feeding and roosting grounds as well as nesting sites from human caused disturbances.
• Refine existing habitat mapping.
• Conduct research to address the relationship between intertidal resources and the fluctuation and distribution of shorebirds on Gold Coast’s beaches.

5.3 Turtles

5.3.1 Introduction

Marine turtles spend most of their life in the ocean and exist primarily in warm, tropical seas. All marine turtle species have the same general life cycle, most are slow growing and take decades to reach sexual maturity. For example loggerhead turtles take 20-25 years and green turtles take up to 30-50 years to reach sexual maturity (GBRMPA, 2001). Females do not breed every year and in some species such as green turtles have been known to exhibit non-breeding periods of between 5-8 years (GBRMPA, 2001). This means that marine turtles require high annual survivorship of adults and near-adults in order for populations to be maintained (GBRMPA, 2001).

5.3.2 Conservation status

Globally, marine turtle populations are under threat. Green and Loggerhead turtles, two species that nest in the Gold Coast, are listed as endangered by the International Union for the Conservation of Nature (IUCN). In Australia, marine turtles are also considered threatened and are listed under the Federal Government’s Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act 1999) and Queensland’s Nature Conservation Act 1992.

The Department of the Environment and Water Resources has developed a “Recovery Plan for Marine Turtles in Australia” (DEWR, 2007) which outlines the major impacts associated with each turtle species in Australia. The report identifies coastal development, habitat loss, marine debris and deteriorating water quality as some of the main threats to these species. Other causes of population decline are incidental mortality from commercial fisheries, incidental mortality from recreational activities (e.g. vehicle traffic on beaches), boat strike, entanglement in nets and disease (e.g. Green Turtle Fibropapiloma) (EPA, 2006).

5.3.3 Gold Coast’s studies

In 2005-2006, a marine turtle monitoring program was undertaken by GCCC on South Stradbroke Island, in an effort to monitor and record marine turtle nesting activity and to identify threats to these turtles (GCCC, 2007b). The study was carried
out on the eastern beach of SSI, Gold Coast. Beach surveys involved driving the entire length of the beach looking for turtle tracks. When encountered, the turtle track characteristics were used to identify the species and indicate whether a successful nesting event had occurred (Van De Merwe and Cuttriss, 2006). GPS readings of each nest location were recorded and data loggers were placed in the sand at a depth of 60cm adjacent to the nests (Van De Merwe and Cuttriss, 2006). During the surveys five nests were identified. Three of the nests corresponded to loggerhead turtles and two were green turtle nests (GCCC, 2007b). South Stradbroke Island is potentially the most southern-breeding location for these species of marine turtles in Australia (GCCC, 2007b).

Another component of this project was to identify threats to marine turtles and their nests. Some of the threats identified include native and introduced species that prey on turtles eggs, 4WD vehicles, offshore threats such as boat strikes and entanglement in nets and fishing lines and the consumption of plastic when mistaken for squid or jelly fish. The disturbance caused by pedestrians and 4WD vehicles (Hosier et al., 1981), the impacts of marine debris ingestion (Tomas et al., 2002; Mascarenhas et al., 2004; Bjorndal et al., 1994; and Carr, 1987) and the impacts caused by introduced and native fauna who are known to prey upon marine turtle eggs and hatchlings (Morris, 1997; Lutz and Muscick, 1997) are all disturbances that have been well documented and are common to marine turtles in various locations around the world.

As a response to the South Stradbroke Island 2005/2006 Marine turtle monitoring program report recommendations a memorandum of understanding was developed between GCCC and Griffith University. Researchers will undertake the project titled Movement Patterns, Nesting Behaviour and Disturbance of Sea Turtles in the Gold Coast region SEQ.

In 2007, GCCC released a report on its 2006/2007 Marine turtle nesting densities and trends, post nesting movements and marine turtle threats. The report provides a review of marine turtle monitoring and research activities undertaken on South Stradbroke Island (SSI) between December 2006 and March 2007 (Cuttriss, 2007). During this time one Loggerhead turtle nest and three sets of Loggerhead turtle tracks were observed in SSI. Also, the number of nests on previous marine turtle seasons suggested that tagging of turtles on SSI could be possible however, researchers were unsuccessful in attaching a satellite transmitter or tagging a marine turtle due to the low numbers of turtles emerging during this period (Cuttriss, 2007). It was concluded that the research conducted during this time resulted in a comprehensive community-based marine turtle monitoring program on SSI (Cuttriss, 2007). The local community conducted surveys during 113 consecutive days covering 3882 kilometres (Cuttriss, 2007).

Also during the 2006/2007 season an unknown specie of marine turtle was observed laying a nest near Northcliffe Surf Club at Broadbeach and a total of 11 dead marine turtles were also recorded within the Gold Coast city boundary (Cuttriss, 2007).

Moreover, as part of the Gold Coast City Council Nature Conservation Mapping Review a series of recommendations have been made for the conservation of Loggerhead turtles on South Stradbroke Island (Francis et al., 2005).

5.3.4 Recommendations

Community members, Griffith University and GCCC have been successfully working together to conduct monitoring of marine turtles in SSI. Although a great amount of
time has gone into this monitoring program more research, community awareness, environmental education and scientifically based management is needed to protect these endangered species. Moreover, marine turtles are listed as threatened in Commonwealth and State legislation. Hence, we encourage GCCC to collaborate with the QLD State Government and get actively involved in research and conservation on these species. Based on our findings we recommend the following:

- Map recorded nesting sites.
- Define and map potential nesting sites.
- Continue monitoring program.
- Develop appropriate management actions to address the disturbance and damage caused by 4WD vehicles during nesting period.
- Develop a community awareness and environmental education program to address all types of human disturbance during nesting period (e.g. 4WD vehicle and light pollution) and other common threats such as boat strikes and plastic debris.

6 BEACH MANAGEMENT AND CARRYING CAPACITY

The concept of carrying capacity has received considerable attention as a result of increasing human made pressure in natural environment (MacLeod and Cooper, 2005; Graymore et al., 2002). Most kinds of carrying capacity fall into the following categories: physical, ecological, social, and economic (MacLeod and Cooper, 2005). Ecological carrying capacity is a measure of the population that an ecosystem can sustain, defined by the population density beyond which the mortality rate for the species becomes greater than the birth rate (MacLeod and Cooper, 2005). In a recreational context, ecological carrying capacity can also be defined as the stress that an ecosystem can withstand, in terms of changing visitor numbers or activities, before its ecological value is unacceptably affected (MacLeod and Cooper, 2005). On the other hand, social carrying capacity is essentially a measure of crowding tolerance (MacLeod and Cooper, 2005) and has been defined as the maximum visitor density at which people still feel comfortable and uncrowded (De Ruyck et al., 1997). In the absence of additional changes, beyond this density visitor numbers start to decline (MacLeod and Cooper, 2005). The social carrying capacity can, however, be influenced by factors such as the recreational infrastructure, visitor attitudes, and socio-cultural norms. It is important to note that carrying capacities in society are not fixed, static or simple relations (Arrow et al., 1995). They are contingent on technology, preferences (Arrow et al., 1995) and socio-cultural factors that are constantly evolving. In addition, they are also contingent on the ever-changing state of interactions between the physical and biotic environment (Arrow et al., 1995). On the Gold Coast an initial study attempting to document the carrying capacity of beaches has been undertaken by Williams (2007) as part of a Masters degree. Results from this research shows that Gold Coast beaches have not yet reached their social carrying capacity. In contrast, no attempt has been made to determine if Gold Coast beaches have reached their ecological carrying capacity. Furthermore, the link between the ecological health of beaches, public awareness and tourism has not been researched or documented. Current beach management is based on assumptions on how people want their beaches to be managed.
6.1 Recommendations

- Conduct social science research in order to determine Gold Coast population’s awareness, knowledge and views in relation to sandy beach ecology and the coastal environment.
7 CONCLUSION

Sandy beaches are rich ecosystems, which harbour a great number of species adapted to cope with this harsh environment. On the Gold Coast the biota of sandy beaches face the most significant threats from human activities such as beach nourishment, mechanical beach cleaning, trampling and 4WD vehicles. The environmental impact of these activities has not been fully understood mainly due to the fact that till the 90’s our ecological knowledge of sandy beaches was poor and under represented in published work (Fairweather, 1990). In the last decade there has been a worldwide advance in the understanding of the ecology of intertidal macrofauna. However, the current knowledge of sandy beach ecology on the Gold Coast is still extremely poor.

Beach management has traditionally concentrated on physical processes and the recreational human use of beaches, but has largely ignored the ecological and broader environmental values of beaches (James, 2000). This review has highlighted a number of conflicts between current beach management practices and the ecological value of beaches. In times like today, when easy techniques allow us to stabilise shorelines and accrete beaches and policy makers enthusiastically promote such programs, the sustainable management of beaches has become a challenge (Scapini, 2003). Because sandy coastlines are relatively fragile environments facing many threats and because most are eroding they require conservation and special management techniques if they are to continue to function ecologically, provide high quality recreation experiences (Mclachlan and Brown, 2006) and act as the primary buffer for storm and climate change events. In order to meet goals of ecologically sustainable development and State and Commonwealth Coastal Policies, beaches require credible, scientifically based management strategies that address ecological objectives as well as socio-economic ends (Jones et al., 2004). Appropriate management and successful conservation can only be achieved if the complex ecology of these areas is understood.

Coastal dunes are an integral part of the coastal environment (NSW DLWC, 2001). It is well acknowledged that dune systems provide an invaluable barrier against the impacts of coastal erosion. However, they are also a valuable ecosystem that supports a great number of plants and animals. On the Gold Coast sand dune systems have been heavily altered by human intervention. This review has described a series of factors that over time have seriously compromised the integrity of the Gold Coast’s dune systems. In addition this review has found that the current management and rehabilitation program of sand dunes is fragmented. At present GCCC has not developed a management plan for sand dunes and the policy that serves as a management guide is intended to be educational and promotional rather than regulatory (GCCC, 2007a). However, dune regeneration work has taken place in various locations along the coast by external consultants, community groups and council staff, under the guidance of GCCC. Certain consultancies have even prepared local management plans for certain areas of sand dunes on the coast. In addition GCCC spends hundreds of thousands of dollars maintaining dedicated public access ways to direct beach users away from damaging the remaining dune vegetation (Stuart, 2007 pers.comm).

The subtidal rocky reefs of the Gold Coast support communities that represent a transition between tropical and temperate waters. Because many of the Gold Coast’s reefs are located close to shore, they are often the first diverse marine habitat to be affected by human activities on land associated with increasing urbanisation and coastal engineering works. This review described a series of factors that affect the health of nearshore rocky reefs. This review also found that the species abundance and biodiversity of reefs systems adjacent to Gold Coast beaches is not well
understood or managed. Hence, it is believed that regular monitoring will not only provide an assessment of impact on communities at specific sites under threat but would also provide valuable data on the ecology and natural dynamics of nearshore reefs.

In addition, a number of shorebird species present on Gold Coast beaches are protected by commonwealth law and several treaties such as the Environment Protection and Biodiversity Conservation Act 1999, Japan-Australia Migratory Bird Agreement (1974) (JAMBA), and the China-Australia Migratory Bird Agreement (1986) (CAMBA). Shorebirds need food and protection from predators and human disturbances in order to recuperate from long migrations. Similar conditions are required for breeding (EPA, 2006). The information presented in this review suggests that inadequate intertidal resources (a result of constant beach nourishment practices), constant human disturbance, lack of suitable habitat for roosting and general habitat loss and degradation could be the main threats to shorebirds on Gold Coast beaches. Hence there is an urgent need to refine the available knowledge on factors such as seasonal distribution, degree of human disturbances, population number of resident communities, feeding and roosting grounds, nesting sites and distribution and abundance of intertidal resources. Once this information has been gathered scientifically based management strategies could be developed in order to comply with the mentioned state and commonwealth law and international conservation treaties.

Monitoring of sea turtles has been successfully undertaken by GCCC with the collaboration of Griffith University and SSI community members. Threats have been identified. Moreover, conservation recommendations have been made as part of the GCCC Nature Conservation Mapping. The next step in this process is to develop and implement management actions that favour the conservation of these endangered species.
### Overview of ecological information on Gold Coast beaches

#### SUMMARY OF RECOMMENDATIONS

<table>
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<tr>
<th>Section number</th>
<th>Issue</th>
<th>General knowledge</th>
<th>Research on the GC</th>
<th>Recommendations</th>
<th>Priority</th>
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</table>
| 2.6            | Sandy beach ecology | Medium/ High | Very low | 1. Conduct baseline research on the ecology of sandy beaches and make these results available to coastal managers and policy makers.  
2. Determine the degree of impact that specific activities such as beach nourishment practices (Coolangatta Bay, Seaway, Palm Beach and Burleigh Heads), mechanical beach cleaning and 4WDs are having on intertidal beach invertebrates.  
3. Develop science based beach management strategies that address ecological objectives as well as socio-economic ends. | Immediate |
| 3.6            | Sand dunes | Medium | Low | 1. Conduct a baseline survey and ongoing monitoring to determine the extent of weed coverage along the whole Gold Coast.  
2. Encourage and support research to determine the impact that weeds, mechanical beach cleaning and coastal development activities are having on dunes and their fauna.  
3. Expand the environmental education and dune regeneration program currently conducted by BeachCare.  
4. Develop a sand dune management plan for the local government area. | High |
| 4.11           | Nearshore reefs | Medium/ High | Low | 1. Regular monitoring of all nearshore reefs is required to better understand their ecology and natural dynamics and to provide an assessment on the health of these communities.  
2. Develop and environmental awareness and education program to minimise impacts caused by human activities such as recreational fishing and illegal removal of aquarium species. | Immediate |
| 5.2.5          | Associated biota Shorebirds | Medium | Low | 1. Conduct baseline research to determine the population numbers of resident communities.  
2. Conduct research to monitor the seasonal fluctuations of migratory species.  
3. Develop management actions in order to protect feeding and roosting grounds as well as nesting sites from human caused disturbances.  
4. Refine existing habitat mapping | Immediate |
### Overview of ecological information on Gold Coast beaches

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<td>5. Conduct research to address the relationship between intertidal resources and the fluctuation and distribution of shorebirds on Gold Coast’s beaches.</td>
<td>High</td>
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</tbody>
</table>
| 5.3.4          | Turtles  | High              | Low               | 1. Map recorded nesting sites.  
2. Define and map potential nesting sites.  
3. Continue monitoring program.  
4. Develop appropriate management actions to address the disturbance and damage caused by 4WD vehicles during nesting period.  
5. Develop a community awareness and environmental education program to address all types of human disturbance during nesting period (e.g. 4WD’s and light pollution) and other common threats such as boat strikes and plastic debris. | Immediate   |

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**GCCM**

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