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Movement patterns and habitat usage of Shark Bay dugongs

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MOVEMENT PATTERNS AND HABITAT USAGE OF SHARK BAY DUGONGS

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Bachelor of Applied Science

This thesis is presented in fulfilment of the requirements for the degree of Master of Science (Environmental Management)

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EDITH COWAN UNIVERSITY
ABSTRACT

In order to define small and large scale spatial and temporal individual movement patterns of dugongs (*Dugong dugon*) within the Shark Bay World Heritage Property (SBWHP) a total of 19 dugongs were fitted with remote location recording and transmitting devices. Combined locations from all units totalled over 10,000 locations. This spatial and temporal data was used to define movement patterns of dugongs within Shark Bay as well as areas of high use deemed to be indicative of foraging activity. Platform Transmitting Terminals (PTT’s) using the ARGOS location collection system tracked animals over large temporal scales with 4 animals tracked up to periods of 11 months. Using these instruments it was possible accurately define a previously identified large-scale seasonal movement pattern within the confines of Shark Bay. These four animals showed distinct seasonal home ranges defined by changes in Sea Surface Temperature.

Additionally another eleven animals were captured and new remote tracking technology in the form of Geographical Positioning System (GPS) devices were attached to define finer scale spatial resolution distribution with a degree of accuracy of each recorded position of approximately 10m. Using positions gained from the deployment of GPS units, seagrass habitat at high use locations were sampled as representative of seasonal dugong distribution. High use sites were compared with habitat at locations where dugongs were only recorded to be moving through. High use winter- spring- autumn locations were comprised predominately of habitat consisting of the seagrass species *Amphibolis antarctica* with a percentage cover of 30-80% and above ground biomass of 110-360gm\(^{-2}\) in waters <5m.
In addition to defining movement patterns and habitat preferences of individual dugongs an aerial survey was undertaken during the summer of 2002 to define population distribution and abundance estimates and to compare with previous winter surveys. This survey returned a population estimate of 11021+/-1357(s.e.) a result similar to the first two winter surveys of dugongs in Shark Bay in 1989 and 1994 but considerably lower than the 1999 survey. Distribution was markedly different in this survey compared with all previous surveys, which were conducted during winter, confirming that dugongs within Shark Bay undertake a seasonal migration driven by changes in sea surface temperature. In addition to this distribution pattern it was identified that 24% of the population during summer occurred within an area known as Henri Freycinet Harbour. That is, while dugongs have been reported in this southwestern region of the bay previously in summer, this is the first time that the substantial size (2629 +/-780 s.e.) of the summer dugong population has been quantified.

The abundance estimates and distribution of animals as observed from the aerial survey have consequences for the continued management of this large and important dugong population. As shown from the aerial survey differences in the population estimate between the 1999 survey and this survey may be explained through large scale movement patterns of dugongs between Shark Bay and Ningaloo Reef and Exmouth Gulf to the north, patterns that should be considered in the management of dugongs for the entire region. The seasonal distribution pattern as recorded from instrumented dugongs as well as the described habitat types also provides the critical spatial and temporal information on how the dugongs utilise Shark Bay throughout the year. This information should be considered in future management programs of the dugong and the Shark Bay marine environment.
DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

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ACKNOWLEDGEMENTS

This thesis is the result of a large amount of assistance from a lot of people both in the field and elsewhere. First and foremost my supervisors, Dr Nick Gales for the instigation and development of the project and introduction to a unique animal and Dr Paul Lavery for the induction into the realms of the seagrass and ongoing support over the years.

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CHAPTER 1
THE DUGONG (*Dugong dugon*)

1.1 General Introduction

This thesis presents the results of research conducted on the movement patterns and habitat usage of the dugong (*Dugong dugon*, Muller 1776) within the Shark Bay World Heritage Property (SBWHP) on the mid-West Coast of Western Australia (Figure 1.1). The research was conducted as a collaborative project with the Department of Conservation and Land Management, the Shark Bay Yadgalah Aboriginal Corporation and James Cook University, Townsville, Queensland. This thesis combines a number of projects conducted with these organisations into the one document within a management framework for the provision of information directly relevant to the continued conservation of this internationally significant dugong population. New and established techniques were applied to obtain the data presented in the thesis, which fills gaps in the existing knowledge base. The research outcomes are presented in a manner that will provide management agencies with information important for the continued conservation and management of the Shark Bay dugong population.

The distribution pattern of the dugong (*Dugong dugon*), a large benthic herbivore foraging almost exclusively on seagrasses (Heinsohn et al. 1977; Marsh, et al. 1982), is broadly coincident with the occurrence of its preferred seagrass forage within the families Potamogetonaceae and Hydrocharitaceae (Husar 1978). The dugong is distributed within the tropical and sub-tropical latitudes of the Indo-West Pacific, and is usually confined to those areas within large sheltered embayments and in the lee of offshore coastal islands (Heinsohn et al. 1979). In Shark Bay (Figure 1.1) exists one of the largest and healthiest populations of dugongs. The significance of this population is reflected in its size and status being one of the criteria for the listing of Shark Bay on the World Heritage Register (CALM 1996).
The dugong, along with three species manatee, is a member of the order Sirenia, an order that evolved concurrently with its favoured species of seagrass in the warmer waters of the Eocene, 54-38 million years ago (Domning 1982). The present day distribution of Sirenians in the warmer tropical and subtropical waters around the equator, reflect not only the distribution of preferred seagrass species, but also intolerance towards cooler temperate waters. Within those tropical regions seasonal shifts in water temperature are insignificant. However, in some subtropical locations at the higher latitudes of the Sirenians global range, water temperature fluctuates on a seasonal basis, falling below suspected critical thresholds.

Studies of manatees have revealed high thermal conductivities, low metabolic rates, and limited thermoregulatory abilities (Anderson 1986). Researchers have reported critical temperatures of between $20^\circ\text{C}$ and $23^\circ\text{C}$ for manatee species (Galvin et.al. 1983; Bengston 1981 and Hartman 1979: in Anderson 1986). In Shark Bay it is suggested that a sea surface temperature of $18^\circ\text{C}$ is the lower thermal tolerance level below which this dugong population will seek out exposure to warmer waters (Anderson 1986).

The occurrence of dugongs within the higher latitudinal limits of their range, such as Shark Bay in Western Australia and Moreton Bay in Queensland, results in substantial movements of these populations in response to seasonal change in water temperature (Preen 1992; Anderson 1986). A large and distinct seasonal movement pattern of dugongs each year may place stress upon the population viability of these animals when combined with the impacts from anthropocentric activities. These stresses may result from direct changes in ambient water temperature and indirect changes in habitat type and structure. A seasonal movement pattern may also result in the distribution of animals to areas where they may be at greater risk of predation or disturbance from natural or anthropocentric events.

In these higher latitudinal areas an understanding of seasonal movement patterns and subsequent use of habitat frequented by dugongs is an important requirement at both an individual and population level. By determining the full extent and timing of
seasonal movement patterns and subsequent habitat usage those who have the responsibility for the conservation of this species and its habitat will be able to make more informed and justified decisions in relation to dugong conservation and proposed and existing human activities.

To achieve therefore, an adequate understanding of dugong seasonal movement patterns and habitat usage requires the use of existing tools and methods as well as unique and novel approaches for specifically measuring the spatial and temporal distribution of animals. Dugongs spend their entire life in the marine environment often in extensive, remote and turbid waters, and this makes it impracticable to use simple visual observational techniques (Marsh and Rathbun 1990). Whilst observation of individual animals has been used in Shark Bay (Anderson 1982a, 1982b, 1995), the application of recording and transmitting devices attached directly to the animal to remotely measure dugong behaviour has not been used at this location.

The use of remote measuring instruments allows for unimpeded and continuous gathering of the movements of the individual animal providing greater insight into an animal’s behaviour and requirements (Fancy et al. 1988). At the population scale, the use of aerial surveys is regarded as an effective mechanism for obtaining estimates of population abundance as well as determining centres of population activity (Marsh 1995). Conducted on a regular basis and following standardised procedures, aerial surveys are also a useful although limiting tool (Marsh and Sinclair 1989) for the monitoring and management of dugong populations.
Figure 1.1. Location map of Shark Bay, Western Australia with place names mentioned in the text.
Within Shark Bay, the identification of seasonal movement patterns has to date been via the use of spatially and temporally limited aerial surveys, observational and correlative studies (Anderson 1982a, 1986, 1998; Marsh, 1994; Prince, 1981) as well as anecdotal information from Indigenous community members and from long term residents. Results from previous workers are used in the current management document for the area, the Shark Bay Marine Reserves Management Plan 1996-2006 (CALM 1996). However, there are gaps in the knowledge base and further work is required to gain an appropriate understanding of dugong habitat usage and requirements within Shark Bay, particularly the extent of seasonal movement and associated habitat usage.

Within the current management plan, a number of research requirements are outlined as strategies for the continued effective conservation of this dugong population within Shark Bay.

The strategies, in order of priority, as listed in the current plan (CALM 1996) are to:

1. Control activities that may adversely impact on dugongs;
2. Encourage further research on dugong distribution, abundance, biology and behaviour in the reserves;
3. Implement a long term monitoring program for dugongs;
4. Investigate and report on any observed cases of dugong breeding or calving in the reserves; and
5. Encourage the wise management of important dugong habitats outside the reserves.
In addition, a recent document, ‘A Dugong Status Report and Action Plan for Countries and Territories’, produced for the United Nations Environment Program (UNEP) (Marsh et al. 2002) details research initiatives for local regions that can facilitate global dugong conservation. Within this document those research initiatives for Shark Bay within a Western Australian context include:

1. Conducting summer surveys of Shark Bay to determine the seasonal distribution of dugongs.

2. Conducting detailed studies on the extent and range of dugong movements and habitat use to determine the appropriateness of management measures in specific locations with priority being given to Shark Bay and locations in the Kimberley such as Beagle Bay, Roebuck Bay and One Arm Point because of the likelihood of resident dugong populations.

Combined, a number of the above research priorities, which are aimed at increasing our understanding of the Shark Bay dugong population and therefore contributing to maintaining its viability, formed the basis of this study. Inter-seasonal movement patterns have not been directly recorded for Shark Bay because of the limited ability to follow individual dugongs. This program utilised remote recording and transmitting devices to measure the inter-seasonal movement patterns of individual dugongs. Using a combination of existing satellite technology, commonly used for the tracking of a wide variety of animal species, and new Geographical Positioning Systems (GPS) technology, this study provides individual dugong movement patterns at both the large and fine scale resolution necessary with which to measure dugong seasonal movements, and assess habitat structure at high density dugong visitation sites. In addition at the population scale, this study determined the distribution and abundance of dugongs within Shark Bay during the summer, by undertaking a fully standardised aerial survey that allowed comparison with existing winter aerial surveys.
1.2 Background

1.2.1 Taxonomy and Life History

The dugong, (*Dugong dugon*, Muller, 1776) family Dugonidae, is the only truly marine herbivorous mammal (Marsh et al. 1984). The dugong, along with the three species of manatee (*Trichechus manatus*, *T. senegalensis* and *T. inugius*) which occur in riverine and eurahyline environments, constitute the order Sirenia, or sea cows (Marsh and Lefebvre 1994). The order Sirenia also contained one other recent member, the Steller’s sea cow (*Hydrodamalis gigas*), which was hunted to extinction within 27 years of its discovery in the eighteenth century (Stejneger 1887).

Dugongs, and the other members of the order Sirenia, are large marine mammals with a long life span, low reproductive rate, long maternal investment and distribution ranges within warm inshore coastal and island waters and estuarine systems (Marsh *et al*. 1984, 1995). Because of this life history and distribution pattern the dugong is predisposed to direct impacts and disturbance from humans and human activity (Marsh *et al*. 2002). Mature adult dugongs are between 2.4m and 3m long and weigh between 250- 420kg. The shape of the dugongs’ skull, ventral position of the mouth and the broad flat muzzle are adapted for seagrass grazing (Bryden *et al*. 1998). Females bear their first calf between 10 and 17 years and may live up to 70 years of age. Gestation is approximately 13 months with calves suckled for at least 18 months (Marsh 1995). Estimated population simulations indicate that any population of dugongs, given no human induced mortality and low natural mortality, is unlikely to increase at more than 5% per year (Marsh *et al*. 1999).
1.2.2 Distribution and Status

The dugong has a large distribution range than spans 37 countries and territories and includes tropical and subtropical island waters from East Africa to Vanuatu between about $26^\circ$ north and south of the equator (Marsh et al. 2002) (Figure 1.2). A significant proportion of the World’s dugong populations occur within the northern inshore coastal waters of Australia and Papua New Guinea from Moreton Bay in Queensland through to Shark Bay in Western Australia (Marsh, 1999).

![Figure 1.2. Global historic and current distribution of the dugong (Dugong dugon), after Marsh et al. (2002).](image)

All of the extant members of the order Sirenia are currently listed as vulnerable to extinction at a global scale on the International Union for the Conservation of Nature’s (IUCN) ‘Red List of Threatened Species’ (Hilton-Taylor, 2000). The dugong, because of its broader distribution pattern, has a greater prospect of survival than that of the manatee (Marsh et al. 2002), which has a more localised distribution pattern (Reynolds and Odell 1991). However, throughout much of its range, the dugong is believed to survive only in relict populations separated by large areas with depleted or extirpated populations (Marsh et al. 2002). In Australia the dugong is protected under the
Commonwealth Environment Protection and Biodiversity Conservation Act 1999 as a marine and migratory species. Whilst Australian waters contain possibly the largest remaining dugong populations in the world, there is strong evidence of significant population decline in some parts of the dugong’s Australian range (Marsh 2000). Effective conservation of these populations is a major requirement for the survival of the species globally.

Throughout its range the dugong selectively forages upon lower seral or ‘pioneer’ species of seagrass such as *Halodule uninervis* and *Halophila ovalis*, (Preen 1995). These species have higher levels of total nitrogen than many perennial species occurring in these regions and have a greater proportion of nitrogen available for assimilation by the dugong (Lanyon 1991). Dugongs may also forage upon marine algae (Marsh *et al.* 1982; Whiting 2001) as well as macro-invertebrates (Anderson 1989; Preen 1995). In Moreton Bay, which forms the southern distribution limit for dugongs on the east coast of Australia, the preferred seagrasses for forage, in decreasing order, are: *Halophila ovalis > Halodule uninervis > Halophila spinulosa > Syringodium isoetifolium > Cymodocea serrulata* (Preen 1995).

Dugongs are generally located in wide shallow protected bays, in mangrove channels and in the lee of large inshore islands (Heinshohn *et al.* 1979), areas broadly coincident with sizeable seagrass beds. Dugongs may also be located in deeper offshore waters where the continental shelf is wide, shallow and protected (Marsh 1999). Dugong movement patterns are generally restricted to the vicinity of seagrass beds (Marsh 1999), though they are capable of large movements within both tropical (De Iongh *et al.* 1998; Preen 1995a) and sub-tropical locations (Marsh and Rathbun 1990; Preen 1992). The impact of catastrophic events such as cyclones may result in dugongs undertaking large movements on a population level (Preen and Marsh 1995; Gales *et al.* 2004) in order to find suitable forage resources. Seasonal movement patterns of dugongs in Moreton Bay results in many dugongs undertaking regular movements of between 15 km and 40 km (Preen 1992).
1.2.3 Threats

Because of the proximity of dugongs and manatees to anthropocentric centres of activity, they are particularly sensitive to disturbance (Marsh et al. 1999). Anthropogenic threats to dugongs and manatees can be divided into direct and indirect impacts. Direct impacts include; traditional and non-traditional hunting, boat strikes and entanglement as a result of commercial fishing practices. Indirect impacts include agricultural practices such as land clearing and the application of fertilisers with subsequent run-off impacting upon seagrass beds (Marsh et al. 1999). Other indirect impacts include disturbance and alteration of habitat from mining, dredging and trawling activities and displacement of animals from activities such as aquaculture, tourism and the generation of chemical and acoustic pollution (Marsh et al. 2002).

Although Australia is regarded as the last stronghold for the dugong within its global range (Marsh et al. 1999), there have been significant declines in dugong population because of threatening activities. Within the Southern Great Barrier Reef region, results from dedicated aerial surveys conducted over a number of years suggest that there has been a 50% decline in dugong numbers between 1987 and 1994 (Marsh 1996). The decline in this population is widely accepted as being substantially the result of the capture and drowning of dugongs in mesh-nets (Great Barrier Reef Ministerial Council 1996).

Taking of dugong by indigenous peoples can lead, in some regions, to over harvesting, and this is thought to have resulted in some localised population declines. The hunting of dugong is culturally significant to many Aboriginal and Torres Strait Islander communities in Northern Australia (Marsh et al. 2002). Given that population simulations using the most optimistic combinations of life history parameters (e.g. low natural mortality and no human induced mortality) suggest a dugong population is unlikely to increase at more than 5% per year (Marsh 1984), a sustainable harvest is likely to be in the order of 2% of the female population per year (Marsh et al. 1999).
1.2.4 Dugongs in Shark Bay

Shark Bay contains the western most point of the Australian coast (Figure 1.1) and lies between latitudes 24° 35’S and 27° 00’S. It is a large (13,000km$^2$) shallow (mainly <15 m) basin with restricted oceanic exchange and high rates of evaporation (Logan et al. 1970). The Bay is located near the northern limit of a latitudinal transition region between temperate and tropical marine flora and fauna (CALM 1996). Seagrass meadows cover more than 4,000km$^2$ of the bay and are reported to be the largest in the world (Walker 1989). Of the 12 species of seagrass found in the bay, several are of essentially southern distribution, at the northern limit of their range, and several are of tropical affinity (Walker et al. 1988). The tidal regime within the Bay varies within the different embayments, on average though the spring range is 1.70m while the neap range at Carnarvon is 0.61m (CALM 1996).

Dugongs within the bay are at the southern limit of their range on the Western Australian coastline and approximate the southward limit of large dugong concentrations on the eastern Australian coast, at Moreton Bay (Anderson 1982a). Aerial surveys conducted since 1977 (Prince et al. 1981; Anderson 1982a, 1986; Marsh et al. 1994; Preen et al. 1997; Gales et al. 2004) have shown that Shark Bay is a location with a significant dugong population. It has been suggested that Shark Bay has supported a stable population of approximately 10 000 individuals over the last decade (Preen et al. 1997). Indications are that this population continues to remain stable with the latest estimates between 11 -14 000 individuals (Gales et al. 2004). It is the most important known dugong area in the Indian Ocean (Preen 1998).

Movements of individual dugongs within Shark Bay have previously been determined from boat and shore based observations. Photographs and sketches taken of distinguishing scars and features of individual animals resulted in the resighting of 15 dugongs at least twice. Distances between sightings were up to 19 km. This method is of limited value for understanding individual dugong movements, as the behaviour of the animals restricts the effectiveness of both behavioural observation and attempts to record scars and other distinguishing marks (Anderson 1982a).
Population movement patterns of dugongs in Shark Bay have been determined from aerial surveys. Early surveys covered areas thought to be of significance to dugongs at different times of the year (Prince et al. 1981; Anderson 1982a, 1986, 1994). Later surveys conducted during winter periods were standardised to account for missed observations and dugongs unrecorded due to water clarity and depth (Marsh et al. 1994; Preen et al. 1997; Gales et al. 2003). These aerial observations showed that dugongs concentrate near the eastern shore of Shark Bay in summer and near the western shore in winter. Analysis of satellite imagery shows a close correspondence between this movement pattern and sea surface temperature (Anderson 1986). Movements of dugongs within Moreton Bay, Queensland, at similar latitude to Shark Bay, are also linked to changes in water temperature (Preen 1992).

Detailed knowledge of dugong habitat usage within Shark Bay is limited. Anderson (1986) suggested that within Shark Bay dugongs abandon preferred feeding areas due to the seasonal movement pattern identified, with habitat differing markedly between seasons. During summer, dugongs prefer to forage on tropical species of seagrass such as *Halodule* spp. Within a small cove in the eastern gulf of Shark Bay the loss of *Halodule* biomass due to dugong activity during January to April was estimated to exceed 50% of production (Masini et al. 2001). *Halodule* has also been identified, albeit in inadequate amounts, as the only seagrass present in another cove where the only recorded observations of dugong Lek mating activity has been observed (Anderson 1997, 2002).

During winter periods, it appears that Shark Bay dugongs are restricted to areas dominated by the temperate seagrass species, *Amphibolis antarctica* and possibly *Halophila spinulosa* for foraging (Anderson 1986, 1994). Nowhere else in the dugong’s range does the overlap with *A. antarctica* occur. Unlike most other seagrass, species of *Amphibolis* have perennial, woody stems. As a consequence, dugongs forage on *A. antarctica* by stripping leaf clusters from the canopy of the plant (Anderson 1986), as opposed to sifting through sediment and consuming both rhizomes and above ground plant material of their, presumed, favoured species.
Anderson (1986) concluded that the nutritional quality of *A. antarctica* was markedly lower to that of preferred tropical species and that sea surface temperatures during the winter periods were at the lower end of the dugong’s physiological limits. Boat based observations of dugong behaviour at deeper water locations within the winter distribution indicated that animals were undertaking long, deep dives that were potentially energetically costly for the dugongs. Benthic surveys indicated the presence of *Halophila spinulosa*, a species with a higher carbohydrate content of the rhizomes, sufficient for dugongs to undertake this diving behaviour and, therefore, of greater nutritional value than *A. antarctica* (Anderson 1994). As a result of the occurrence of the nutritionally limited *A. antarctica* and scattered presence in deeper waters of *Halophila spinulosa*, Anderson (1986) suggested that dugongs within their winter distribution pattern in Shark Bay may be energetically stressed, and that by moving back into the summer feeding grounds they optimise both diet and temperature.

### 1.3 Scope

This thesis will attempt to define the extent and scope of the seasonal distribution pattern of Shark Bay dugongs by measuring movements both the individual and population scale. In addition variables such as depth, temperature and seagrass distribution and composition will be analysed in relation to any identified movement pattern and at high density visitation locations frequented by dugongs. In determining the seasonal movement patterns and habitat usage of dugongs within the Shark Bay World Heritage Property this thesis will be set out as follows;

1. Develop methods and techniques associated with the attachment, application and release of remote transmitting platforms to allow finer scale resolution of dugong distribution (Chapter 2).

2. Apply these methods in the field as well as develop and refine techniques for the appropriate ethical approach to the chase, capture and handling of dugongs within the waters of Shark Bay (Chapter 2).
3. By use of developed remote recording techniques, define large scale seasonal movement pathways and fine scale critical habitat areas for individual dugongs within the Shark Bay World Heritage Property (Chapter 3).

4. Through the use of ground truthing techniques characterise the benthic habitat at those locations deemed to be of significance as established through remote recording devices (Chapter 3).

5. Using established aerial survey techniques determine the summer distribution pattern and abundance estimates for the entire Shark Bay population and compare this with previous winter survey distribution patterns (Chapter 4).

6. Undertake this research within a framework for management purposes, and establish relationships and foster ownership of results with traditional Indigenous owners of Shark Bay (Chapter 5).
CHAPTER 2
DEVELOPMENT AND APPLICATION OF UNIQUE APPROACHES IN DETERMINING INDIVIDUAL DUGONG MOVEMENTS IN SHARK BAY

2.1 Remote Recording and Transmitting Devices to Determine Movement Patterns of Dugongs.

In order to appropriately measure dugong movement patterns and to have greater confidence in categorising their habitat requirements, suitable techniques are needed to adequately measure these variables over significant temporal and spatial scales without any major disturbance to the animals’ natural behaviour. A key aim of this study was to therefore develop and test appropriate technologies as well as utilising the most appropriate and ethical animal handling procedures to achieve these overarching objectives. Previous methods to define dugong behaviour involved simple observational techniques (Anderson 1982b, 1995) to define dugong movements and coarse scale habitat surveys to categorise habitat (Anderson 1986, 1989). These techniques are however inappropriate over the scale required to confidently manage this population and its habitat requirements. This project therefore sets out to track dugongs and measure the various environmental variables which define choices they make on as fine a scale as possible using the latest in biotelemetry technologies.

2.1.1 Historical Use of Biotelemetry as a Tool for Determining Sirenian Habitat Use and Movement Patterns.

Biological telemetry or ‘biotelemetry’ is a powerful technique that allows the continuous and simultaneous monitoring of animals in their natural environment in both space and time (Cote et al. 1998). The use of biotelemetry to understand animal behaviour and ecology has been used in a wide range of wildlife studies (Fancy et al. 1988). The most effective and popular means for the remote tracking of marine species
has been through the use of radio transmitters and Platform Transmitting Terminals (PTT’s) attached directly to the animal (Fedak et al. 1983). These platforms (also referred to as units or ‘tags’) transmit radio signals that are received by a series of CLS Argos polar orbiting satellites. Using the principle of doppler shift, processing centres on the ground calculate the position of the received transmitter signal which is then made available to the user often with a delay of less than one hour. Whilst the calculated positions can often be several kilometres in error, a strong and constant signal will allow for a reasonably accurate location of within a few hundred metres (Service Argos, Inc. 1996) guaranteeing they are sufficiently reliable and regular to define medium to large-scale movement patterns.

The application of biotelemetry and specifically PTTs as a tool for the understanding the behaviour and ecology of Sirenians was first employed in 1985 on the West Indian manatee (*Trichechus manatus*). As part of the United States Geological Service (USGS) Sirenia Project, a ten year radio tracking project was embarked upon (Deutsch et al. 1998) to characterise the movements, migratory behaviour, site fidelity and habitat use of manatees in order to provide information for the development of effective management strategies (Reid et al. 2001). The application of PTT’s on Sirenians required a different approach to that used on other marine mammals such as Pinnipeds (Seals, and Sea lions), which have fur allowing instruments to be glued directly to the animal. As Sirenians don’t have this coat of fur, researchers developed a system incorporating a floating tag attached by a flexible tether to a padded belt around the base of the tail of the animal (Deutsch et al. 1998). This system is more practical than direct attachment, as it means the tag can be at the surface for long periods except when the animal is moving at speed or diving to depths greater than that of the tether (Marsh and Rathbun 1990).

The use of biotelemetry to further understand movement patterns and habitat usage of dugongs was first undertaken when six dugongs were caught and satellite and VHF radio transmitters attached for between 1 and 16 months off the North Queensland coast (Marsh and Rathbun 1990). Based upon the design employed for the tracking of manatees (Figure 2.1), the same floating tag and harness system was used on the
dugongs, with the results from that project demonstrating that a floating transmitter was ideally suited for this species (Marsh and Rathbun 1990).

Even with the associated error inherent in PTT tracking studies they have been used on a number of occasions to determine movement patterns and habitat usage of both manatees and dugongs (Reid *et al.* 2001, Deutsch *et al.* 1998, Marsh and Rathbun 1990, De Iongh *et al.* 1998). With the advent of Geographical Positioning System (GPS) technology, in which a receiver calculates an estimated position from transmissions from multiple satellites in predictable orbit patterns and the removal of ‘selective availability’ that was applied by the US Government for defence purposes, calculated positions now have sub-10 m accuracy.

In order for a GPS unit to successfully record a location the tags need longer periods at the water surface than PTT’s to be successful in position acquisition. Access to these calculated positions usually requires the retrieval of the archival tag, although developments to enable the transmission of these data via the Argos and other systems have been achieved. The trade-off for the improved precision of the calculated position are the greater uninterrupted, at-surface time required to acquire a location estimate, greater power consumption, and the need to retrieve the tag to access the data. These limitations have so far restricted the use of GPS technology with marine mammals.

The first application of GPS for Sirenian tracking was with the application of a GPS unit incorporated into a housing unit similar to that used for PTT studies, on a number of West Indian Manatees in Florida, USA. The results from this study were the recording of frequent locations allowing detailed insight into the movements of these animals (Reid *et al.* 1999). The use of GPS offers the possibility of higher resolution spatial data, allowing analyses of habitat use and better determination of travel paths by tagged animals (Reid *et al.* 2001).
2.1.2 Aims

The purpose of this chapter is to outline methods and results for four specific developmental aims, these being:

1) The refinement of appropriate dugong capture and handling techniques, developed and used in Queensland (Lanyon et al. 2002), for conditions in Shark Bay.

2) The development of a suitable tag attachment and retrieval mechanism for GPS data loggers.

3) Determine the effectiveness of GPS archival data loggers in measuring and describing dugong behaviour and habitat requirements and

4) the use of PTT units to define large scale long term movement patterns

2.2 Methods

In order to achieve the aims as set out above a series of development field trials were conducted in the Shark Bay World Heritage Area. Initial trials in September 1999 focussed on developing a reliable capture technique that had minimal stress on the target animals and on trialling attachment and release mechanisms. Following on from field trials, the study began with deployments of PTT units in March 2000 with GPS units deployed to acquire data from August 2000.

2.2.1 Capture and Handling of Dugongs

Dugongs were captured in Shark Bay for the purpose of tag application using a ‘chase and grab technique’, modified from a ‘rodeo’ system (Limpus and Walter 1980) developed for the capture of marine turtles. This technique has been developed as an alternative to the use of a hoop-net captures (Preen 1992), and has been successfully applied to dugong captures in shallow water in Queensland over the past few years.
(Lanyon 2002). The risk of dugong mortality from capture is regarded as low, with less than 1% mortality from more than two hundred captures (Marsh et al. 2002). Of the recorded mortalities both occurred during the use of hoop net captures in Moreton Bay in the spring, a period when dugongs in that location have poor body condition. Additionally both dugongs suffocated due to the capture attempt being made before the animals surface to breathe (Marsh et al. 2002). With the low occurrence of mortality events the potential is always present and, therefore, the information gained from each capture should be maximised.

The capture team within Shark Bay was comprised of members from the local Shark Bay Yadgalah Aboriginal Corporation, CALM employees and volunteers from Edith Cowan and James Cook University. Dugong capture sites (Figure 2.2) were selected from areas of known seasonal dugong aggregation determined by aerial surveys (Marsh et al. 1994; Preen et al. 1997; Gales et al. 2004) as well as from detailed local knowledge. The capture technique required candidate dugongs to be in water depths of less than about 1.8m at the point of restraint. As dugongs move up onto shallow seagrass beds to feed, the edges of these banks were visually surveyed from two small boats travelling approximately 100m apart.

When dugongs move into shallow waters, they commonly do so in groups and cow-calf pairs are often included in such feeding herds. The capture technique requires an intense period of pursuit and herding during which an acute level of disturbance is caused to the target animal and any dugongs in the immediate vicinity. In areas of high dugong density, boat-dugong collisions are a real risk. As a result, the following capture selection protocol was developed:
**Candidate Selection**

- Dugongs in or close to, water of 1-1.8 m were selected. In order to enable the catchers to maintain an adequate hold on an animal they must be able to stand. The catch sequence was not initiated until the animal had moved at least 50m from water >1.8m.

- Only dugongs estimated to be longer than 2.2 m were selected. These animals were assumed to be of sufficient age to be nutritionally and socially independent (Marsh 1984).

- Where possible dugongs more than 100 m from other dugongs were selected.

- When capturing dugongs from a herd only those animals on the edge were selected. The pursuit and herding procedure attempted to direct the dugong away from the group.

A maximum of two capture attempts from any one herd (group within about 100m of each other) was made to avoid creating too much disturbance to the herd.

- Captures were not made from groups containing cow-calf pairs.

**Chase**

Once a suitable dugong was located the dugong was approached at less than wake speed (approximately 5 km/hr) from between it and the nearest deep water. The approach was maintained until the dugong was startled and swam rapidly away from the capture boat. Three dugong catchers were positioned on the bow of the catch boat and maintained visual contact with the dugong, pointing towards it to direct the boat driver who would attempt to position the boat into the capture position, immediately behind and just to one side of dugong. If the dugong headed for deep water, as was often the case, the catch boat would attempt to move to the side and just ahead of the dugong and herd it back towards shallow water. If necessary, the second small boat would assist with the herding operation and might temporarily take over the primary chase position.
(just behind the dugong) if the dugong turned suddenly and temporarily evaded the chase boat.

The initial chase speed was likely to be the maximum swimming speed of the dugong in shallow waters (approximately 20-30 km/hr). Great care was needed to coordinate the close manoeuvres of the two boats around the dugong. High speed chases were aborted if a capture had not been effected within 3 minutes, or the dugong had taken more than 3 breaths. Chases in excess of either of these limiting parameters only occurred if the dugong slowed down to rest, taking several breaths, at a time when the capture boat had not been able to maintain the catch position. Dugongs are not capable of sustained high-speed swimming and rapidly become exhausted during this type of pursuit. The potential for chase induced myopathy (mortality as a result of high stress brought on by capture) is unknown.

**Capture**

During a chase the pursued dugong would slow and come to the surface to breathe. The breath cycle takes at least 2 seconds, during which the animal first presents its head at the surface, inhales and then raises its back and tail peduncle to the surface prior to diving. If the catch boat is in position during a surfacing, the dugong is allowed to take a full breath, and, when the back and tail peduncle are presented, the nominated catcher leaps from the boat onto the dugong and wraps his arms rapidly and firmly around the peduncle. It is essential to establish this firm grip prior to the animal being able to establish a powerful tail beat, as this is likely to dislodge and potentially injure the catcher.

Once the grip is established, the catcher then stands up with the dugong’s fluke held down against his body. Two other catchers immediately follow the primary catcher into the water and attempt to grip one each of the dugong’s pectoral fins. While establishing the restraint, the capture boat manoeuvres alongside and an addition person enters the water from the second boat with a 120 cm long x 12 cm diameter foam
flotation device (‘noodle’) with 1.2m of rope attached to each end. This is placed under the dugong, immediately behind the pectoral fins with the ropes being secured to an inflatable pontoon of the capture boat. The noodle acts as a cradle preventing the animal from rolling and ensures that the animal is able to lift its head out of the water to breathe. The primary catcher continues to hold the dugong by the tail fluke. If during any stage of the restraint and stabilisation procedure the dugong was not able to acquire a breath for a period in excess of 30 s, the animal was released immediately.

Once secured alongside the boat the following procedures are undertaken:

- Measurements of standard length (straight lie from tip of face to mid-fluke) and of axillary girth
- Dorsal skin biopsy taken with a 5mm biopsy punch*
- Application of temporary paint mark
- Determination of sex from inspection of anal-genital openings
- Collection of a facial vibrissae for stable isotope analysis*
- Application of the remote recording /transmitting tag (see below).

*Samples were taken for use in independent studies of DNA and diet analysis.

To assess the suitability of the catch process, tag functionality, harness attachment and release mechanism as well as to familiarise the catch team with the restraint and handling of the dugong, a pilot study was conducted in September 1999. During a five day period a total of eight dugongs were caught from 18 attempts. This study was useful in highlighting the importance of allowing animals to move into shallow waters before capture as restricting capture attempts to when the sea state was below Beaufort 3.

In addition to this capture method there were periods when water depth restricted the ability of the dugong catchers to maintain an adequate hold of the animal. In these
situations the main catcher would attach a padded Velcro™ belt, which was secured back to the boat, around the tailstock of the animal as they entered the water and grabbed the animal. As deep water usually prohibits the catchers maintaining an adequate hold of the animal while the noodle is put in place and secured to the boat, this line served as suitable restraint while the animal was further secured. Once the animal was completely secured alongside the boat this line was removed.

2.2.2 Instrument, Harness and Release Mechanism Descriptions for Units Deployed on Shark Bay Dugongs.

For this project, spatial data were obtained from 18 remote tracking tags deployed on dugongs over a two-year period at a number of locations within the Shark Bay World Heritage Property (Figure 2.2). Of these 18 tags, eight were PTT satellite tags, eight were GPS data logger tags, and two were combination PTT/GPS tags capable of both transmitting and logging. All units incorporated a VHF radio transmitter on its own frequency to enable each unit to be tracked at sea. In order to optimise unit recovery a novel remote release was incorporated into the harness design for the GPS and PTT/GPS tags. Full descriptions of each type of tag and harness designs are outlined below.

Due to the nature of the attachment method - a floating tag connected to a 3m tether attached around the tail stock of the dugong - there is an anticipated bias in the depth distribution of recorded fixes. It is envisaged that if the animal is in water of more than 3m depths and regularly diving to feed, the number of recorded positions from the tags will be fewer as the tag is dragged below the water surface and unable to transmit or record a signal. This reduction in numbers of fixes is likely to be greater for GPS tags due to the longer time required fixing a position.
Figure 2.1. Illustration of tag attached to a manatee. (Adapted from Lotek 1999.)
Figure 2.2. Location of dugong captures and tag deployments during the study period 2000 – 2002 in the Shark Bay World Heritage Property.
**PTT Tags**

Each PTT tag consisted of transmitter terminals, Lithium batteries, and a magnetic switch manufactured by Telonics Corporation, Mesa, Arizona, housed inside a PVC pipe with a PVC nose cone and whip aerial. Each unit weighed approximately 2.4 kg with a length of 50 cm, excluding the aerial and was scheduled to transmit to the Argos system of satellites on a programmed duty cycle 16 hours every second day. It was estimated that on this duty cycle battery life would be approximately 8 months. These tags (Figure 2.3) were refurbished units that had been deployed previously on dugongs in Queensland over a number of years (Marsh and Rathbun 1990; Preen 1992). For a full description of the PTT tags see Marsh and Rathbun (1990).

Location data from the PTT tags were transmitted to a base station and included universal date and time, latitude and longitude, number of satellites used for the calculation of each position, and a number of sensor readings including temperature. Each transmission also gave a location class for each position (Table 2.1).

### Table 2.1
Estimated Accuracy for Calculated Positions Using the Argos System.

<table>
<thead>
<tr>
<th>Service</th>
<th>Class</th>
<th>Estimated Accuracy in Latitude and Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Location:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>calculated from at least four messages</td>
<td>3</td>
<td>&lt; 150 m</td>
</tr>
<tr>
<td>received during the satellite pass</td>
<td>2</td>
<td>150 m - 350 m</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>350 m - 1000 m</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>&gt; 1000 m</td>
</tr>
</tbody>
</table>
Figure 2.3. PTT tags used in deployments in this study. The tag is 50 cm long, excluding the aerial.

**GPS Tags**

The GPS data loggers used in this study were MGS-3 GPS tags manufactured by Lotek Engineering Inc., Ontario, Canada (Lotek 1999). Each unit consisted of a GPS engine and VHF transmitter sealed in aluminium housing, sleeved in a polycarbonate tube with a delrin antenna cap and nosecone (Figure 2.4). The diameter of each unit was 9 cm with a length excluding aerials of 63 cm. The top 23 cm of the unit, from the aluminium housing to the antenna cap, contained only cabling and airspace, thus providing for increased buoyancy. Each unit weighed 2.7 kg with most of that weight distributed towards the nosecone, which contained a 15 V lithium battery pack to power the unit and a 9 V battery to provide the charge for the remote release. This distribution in weight promoted the antenna cap, with diametrically opposed beacon and release antennas, to sit higher in the water, increasing the chances of satellite uplinks. A piece
of compressed foam was secured around the top of the unit at the base of the aerials and this further aided in keeping the antennas above water.

For position acquisition each unit used an 8-channel receiver, which could lock on up to eight satellites simultaneously. Using Lotek’s GPS 2000 Host software the MGS_3 GPS tag was pre-programmed to fix a position at intervals ranging from 5 min to 6 hours and scheduled to occur at a predetermined time and date. Up to 10 different GPS fix intervals could be entered in a given day. Interval rate selection affected the time frame within which a unit could obtain a fix. It is estimated that a unit with a current almanac and with a fix rate lower than once per hour will take approximately 40 seconds to get its first fix (Lotek 1999). When that interval is less frequent, then the unit loses its reference satellites and the time to obtain its next fix is increased by about 15 seconds as the unit searches for new satellites. Higher fix rates result in higher power consumption and, therefore, reduced deployment time; lower fix rates result in longer times for the unit to acquire its first fix but extended deployment time.

Each MGS_3 GPS unit transmitted a unique VHF frequency with a customized beacon schedule created using GPS 2000 Host (Lotek). As the VHF transmitter used the same aerial as the GPS receiver, VHF transmission ceased during the GPS location acquisition. The VHF beacon also provided feedback during initialization of the unit. Once a unit was programmed with the user specified GPS receiver and beacon transmitter schedule, it needed a current almanac to indicate which satellites would be in orbit at any particular time, an accurate time of day and an approximation of its position.

At each successful GPS fix attempt, the MGS_3 GPS recorded latitude and longitude in milliseconds in the World Geodetic System 1984 (WGS 84) datum. The units also record time, date, temperature, receiver status, activity sensor values and satellite information including satellite identification and signal strength. Dilution of Precision (DOP) was also recorded; this refers to the contribution of satellite geometry to the uncertainty in a position fix. Once a unit was retrieved, data were downloaded into a portable personal computer via Lotek’s Download Link Unit - DL1. This unit
connected to the MGS_3 GPS via a specialised serial cable and to the computer through a port interface.Running the GPS 2000 Host software, data were formatted into a comma-delimited file (.csv), and then converted into a text-delimited file (.txt) and imported into the GIS software package Arcview 3.2.

Figure 2.4. Lotek GPS data loggers used in study. The tag is 63 cm long excluding aerials.
**PTT/GPS Tags**

Manufactured by Telonics Corporation, Mesa, Arizona, these tags were essentially the same weight and design as the GPS tags with the exception that the foam collar was constructed of syntactic foam and pre-attached to each unit. Each tag could be programmed in the same manner as the GPS tags through specifically designed software provided by the manufacturer. The PTT component could also be programmed to switch on when necessary through dedicated Telonics software, such as when searching for tags remotely. Additionally GPS locations could be downloaded through the ARGOS system, however for this project the tags were utilised in the same manner as the MGS_3 GPS tags built by Lotek.

Due to problems associated with software programming and issues with a new harness system, only data obtained from two of these tags was of sufficient quantity to be used in this study.

**VHF Tracking**

To listen to each frequency of all tag types while initializing each unit and for the purposes of tracking the units at sea, a Lotek SRX_400 Telemetry Receiver and a standard yagi aerial were used. For tracking animals from the air, two yagi aerials were attached to the struts of a Cessna 172 aircraft with cables attached to the receiver inside the cockpit. The SRX 400 is a 4 MHz bandwidth receiver. It was capable of scanning all frequencies of deployed units at a user-defined period, allowing for the tracking of all units simultaneously. From the water the units could be heard up to 6 km away through the receiver; from the air this distance was far greater.
Harness Attachment and Release

Each PTT tag was deployed using the harness system of previous researchers and described and illustrated in Marsh and Rathbun (1990). This consisted of a three-metre nylon tether attached to the transmitter at one end, in such a way that allowed the transmitter to move in 90° vertical planes. At the other end, the tether was secured to the harness with a corrodbile brass link. Each link had an expected life span of 3-6 months, and incorporated a weak link that would break if the tether became entangled. The harness consisted of nylon webbing encased in latex tubing.

For the GPS units, the harness was designed to incorporate a remote release mechanism. The unit at one end was attached to a nylon tether, as in the PTT system, the peduncle attachment incorporated the remote release. One end of the strapping was adjustable and locked down when attached to the animal (Figure 2.5). The other end was attached to a section of plastic coated multi-strand stainless steel fishing trace (230 kg breaking strain). This in turn was attached to a wire within the harness that attached to the positive terminal of a 9 volt battery housed in the MGS_3 tag. The final 1 mm of the fishing trace at the harness end was exposed to seawater by removing the plastic coating; this acted as the anode in a circuit. The negative terminal, via the remote switch, was wired down the harness to a stainless steel washer (the cathode) situated within 15 mm of the exposed stainless steel wire.
In order to effect the retrieval of the instrument the dugong was first located via telemetry. Once the tag was sighted, or estimated from the strength of the radio signal to be within about 1 km, a separate VHF frequency to the tracking signal was transmitted to activate the release. When the MGS_3 GPS received the specific VHF signal from the RRT-1 transmitter (Lotek Engineering Inc., Ontario, Canada) and transmitting aerial, the switch was activated, opening the 9 volt circuit. A rapid electrolytic reaction occurred which dissolved the stainless steel wire in an estimated 5-10 min period, thus releasing the harness from the dugong. For the deployment of the PTT/GPS units this system was redesigned and modified to allow for repeat usage of components.
2.3 Results and Discussion.

2.3.1 Chase, Capture, Handling and Descriptions of Tagged Dugongs.

With any process involving the capture and handling of large wild animals there is an associated level of risk to the animal; the animal may be injured or killed during capture and handling or after the completion of the procedure and following release. There is also the possibility of injury to catchers due to the size and strength of the animal. The ‘chase and grab’ technique described here for the capture and handling of dugongs was ideally suited for the population within Shark Bay. The shallow and relatively clear waters of the Bay and the presence of large numbers of animals resulted in relatively easy captures as well as short chase and restraint times. The use of this method is clearly the most effective for capture and restraint of dugongs through the brief chase and handling procedures, limited restraint and the capacity for immediate release of the animal if complications arise.

During the course of the research program, from March 2000 to 2002, a total of 58 attempts were made for the successful capture of 31 dugongs. Of these 31 animals, 19 tags remained attached for extended periods (Table 2.2). Of the successful captures, the mean chase to release time was 12 m 05 s ± 3 m 18 s (range: 7 m 20 s to 23 m 00 s). The mean chase capture and restraint time was 15 m 05 s ± 4 m 30 s (range: 8 m 03 s to 22 m 00 s). Of the 27 unsuccessful attempts, 15 were terminated without an attempt to jump on the animal. In these cases, either the chase exceeded the protocol time (3 min: n=5) or number of breaths (3: n=6), or the dugong escaped into water that was too deep for the capture method (n=6).
Table 2.2. Details of Tag Deployments in Shark Bay 2000-2002: Biological Descriptions of Tagged Dugongs, Duration of Deployments and Number of Locations Recorded.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Tag Type</th>
<th>Sex</th>
<th>Length (cms)</th>
<th>Girth (cms)</th>
<th>Deployment Date</th>
<th>Retrieval Date</th>
<th>Days Deployed</th>
<th>Number of Locations</th>
<th>Locations Per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>5534</td>
<td>PTT</td>
<td>M</td>
<td>238</td>
<td>155</td>
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<td>25/10/2000</td>
<td>217</td>
<td>261</td>
<td>1.2</td>
</tr>
<tr>
<td>5519</td>
<td>PTT</td>
<td>M</td>
<td>247</td>
<td>160</td>
<td>22/03/2000</td>
<td>11/12/2000</td>
<td>265</td>
<td>551</td>
<td>2.1</td>
</tr>
<tr>
<td>5536(1)</td>
<td>PTT</td>
<td>M</td>
<td>253</td>
<td>160</td>
<td>23/03/2000</td>
<td>04/04/2000</td>
<td>13</td>
<td>37</td>
<td>2.8</td>
</tr>
<tr>
<td>5536(2)</td>
<td>PTT</td>
<td>M</td>
<td>252</td>
<td>-</td>
<td>06/04/2000</td>
<td>28/05/2000</td>
<td>53</td>
<td>228</td>
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</tr>
<tr>
<td>5065</td>
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<td>166</td>
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<td>15</td>
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<td>-</td>
<td>-</td>
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Of the 31 animals caught, 23 were male and eight female. Total lengths ranged from 2.10 - 2.86 m with a mean of 2.57 ± 0.2 m, while the girth measurements ranged from 1.4 - 2.26 m with a mean of 1.66 ± 0.17 m. There was no difference in mean lengths of males and females (T test: P = 0.316). Twelve of the 19 tagged animals in which length and girth measurements were taken exceeded 2.5 m in length and were therefore considered sexually mature (Marsh 1984). Another four animals that were between 2.2m and 2.5m (Table 2.2) may either be classed as immature or mature (Marsh 1984).

The short term impact on the dugongs from the chase, catch and restraint process was observed to be acute and was highlighted through distress vocalisations while restrained as well as increased respiration rates, exhaustion and avoidance of boats after the procedure. Where possible, animals were closely observed after the procedure to observe the impact of the process and to ensure that they recovered. Figure 2.6 highlights the increase in respiration rate of an animal immediately post capture (shorter intervals between each breath) compared with that of another tagged animal that was observed six weeks post-capture. Both animals were observed in similar water depths of 2-5 m to account for differences in diving behaviour due to depth, and at approximately the same location from a distance from non-motorised platforms (sailboat and kayak).

The combined impact of the chase and restraint procedure also had implications when relocating animals and attempting tag retrieval. Often when a tagged animal was approached during radio tracking, even months after tagging, upon hearing the boat the dugong would disappear into deeper water and surface infrequently making tracking and observation difficult. This was also experienced by Marsh and Rathbun (1990) while attempting tag retrieval during that study.
2.3.2 Efficacy of PTT Tags to Describe Dugong Locations and Movement Patterns.

The eight PTT tags deployed on dugongs during the course of the study remained attached between 40 and 265 days (Table 2.2). The number of guaranteed locations per day (Location Class 1-3) ranged from 1.2 – 4.3 with an overall mean of 2.3 locations per day. The location class for each received fix (Figure 2.7) was skewed towards location classes one and two, with 69% of fixes obtained from the PTT’s in the error range of 350 –1000m (Table 2.1). Given that the most accurate reading from these units is to 350 m, this is too limited (Weimerskirch et al 2002) to confidently determine habitat at core dugong usage areas, as many of the areas in which dugongs forage may consist of a variety of seagrass species and differing benthic compositions within a 350m radius. However, the results from the PTT deployments in this study should be considered sufficiently reliable for describing the large scale dugong movement patterns, particularly movements ranging over the entire Bay.

Figure 2.6. Respiration rates of a dugong immediately following capture and 6 weeks post capture.
Depth at recorded locations from the PTT tags (Figure 2.8) shows that while there was a bias towards water depths of less than 3 m, there were still a considerable proportion of fixes within deeper water. This is due to the tags remaining attached as the animals moved into their winter distribution pattern resulting in an increase in water depth for foraging (Anderson 1986). This distribution pattern is discussed further in the following chapters.

![Frequency Distribution of PTT Location Classes](image)

*Figure 2.7. Frequency distribution of location classes from PTT tags deployed on dugongs in Shark Bay during the period 2000 - 2002.*

![Depth Distribution PTT Units](image)

*Figure 2.8. Number of retrieved locations from PTT fixes at each of five depth categories, for tags deployed over the period 2000-2001 in Shark Bay.*
2.3.3 Efficacy of GPS Tags to Describe Dugong Locations and Movement Patterns.

The high number of recorded locations (8644) obtained from the GPS tags over a shorter duration (397 days) than that of the PTT tags (Table 2.2) results from the program scheduling of these tags to attempt to record a location throughout a 24 hour period every 10 or 20 min, compared with a duty cycling of 16 h on every second day for the PTT’s. It was considered that with the GPS units taking longer to obtain a fix than PTT tags to transmit a position, it was necessary to maximise the opportunity for the tags to obtain a position. The downside to a high scheduling rate was increased power consumption, and therefore the tags could only record positions for periods of up to six weeks. From the deployments at these intervals the mean number of locations obtained per day for all the GPS units combined were 19.8.

Behaviour and location of the dugong influenced the ability of the attached unit to acquire a fix more than that of the PTT units. Water depth was a major determinant for fix acquisition: with an average time of 47 sec to fix a position the distribution of fixes heavily skewed to those areas where the depth of water was less than 3 m (Figure 2.9). Time of day was also a determinant for recording of fixes with the majority of fixes (31.7%) occurring within the evening hours (1800-0000). The fewest fixes (18.2%) occurred within the morning hours (0600-1200).

The GPS units record no category with which to assign the accuracy of each location. In a test to determine the locational accuracy of the MGS_3 GPS tags, a unit was placed for 28 h at a stationary location with a 360° view of the sky and was scheduled to fix its position every five minutes. Plotting the positions of the recorded fixes from this test relative to 50% and 95% probability radii (Figure 2.10), 50% were within 4.7 m and 95% were within 17.8 m. This is compared with Reid et al (2000) who, in a similar test with the same tags, recorded 50% of locations within 22 m and 95% of locations within 52 m. The discrepancy between the two tests may relate to timing: Reid et al.’s (2000) test was conducted during a period when the United States Government applied Selective Availability (SA) to all GPS systems. SA meant that every GPS position obtained prior to May 1st 2000 had an associated error.
Figure 2.9. Number of retrieved locations from GPS fixes at each of five depth categories, for tags deployed over the period 2000-2001 in Shark Bay.

Figure 2.10. Plot of GPS fixes from a Lotek unit left in static location for 28 hours prior to deployment on dugongs.
2.3.4 Suitability of Harness Attachment and Release Mechanisms.

The harness attachment system used for the PTT tags with the incorporated corrodible brass link did not function during this study as it had in previous deployment on dugongs in Queensland. In this study, some tags remained attached for up to 11 months as opposed to the anticipated period of 3-6 months, thus giving the large range in length of deployments for these tags. A possible reason for this failure for the harness to detach may be due to the high saline environment in which dugongs were tagged. Salinity values for the areas where these animals were tagged and moved through were greater than 42\% (CALM, 1996). It is feasible that the higher salt content of the water in Shark Bay had initially speeded up the corrosion process. Upon inspection of retrieved units, it was found that a salt crust had formed over the link from the initial corrosion, and this may have prevented or significantly slowed further corrosion.

The failure of the release link meant that an extended movement pattern of dugongs was obtained from the tags. However, the energetic cost to the dugongs from carrying these tags for an extended duration is unknown. From those animals that were recaptured and the tags removed assessment of the tailstock was undertaken to determine if there were adverse reactions to the extended attachment period. Of the three animals that were recaptured it appeared that the harness attachment had caused some minor irritation with minor scarring present. The behavioural implications from the presence of the harness is unknown, but given the presence of only limited signs of irritation it is suspected that the animal would have become accustomed to the presence of the tag and subsequently not modified its behaviour to any great extent.

For retrieval of these tags, three animals were located in areas suitable for recapture. These animals were caught and the tag removed before the animal was immediately released. The use of the catch method for tag retrieval would have again placed the animals under considerable and acute stress. Of the remaining tags, three were recovered after they had eventually detached, one was never recovered and a further tag was found floating free with what appeared to be teeth marks, suggesting a
shark had attacked either the harness or dugong. Teeth marks from sharks were common on tethers deployed on dugongs in Queensland (P. Bousi, pers. comm.)

The use of the remote release mechanism for the retrieval of the GPS and PTT/GPS tags was successful on six occasions during 2000 and 2001. However, problems associated with a new harness design undertaken to minimise wastage, (the previous harness once released could not be reused) meant that there were a number of tethers which experienced problems with the remote release mechanism. These problems have since been overcome and the release mechanism is functioning in deployments in Queensland (Ivan Lawler, pers. comm.). Of the 11 GPS deployments in which sufficient locations were obtained to describe dugong movement patterns, six were retrieved through the remote release, three became detached (including one which looked as though it had been hit by a propeller), one was lost, and one retrieved through recapture.

Of the successful remote releases, the harnesses detached from the dugong within the range of 30-45 minutes of the VHF trigger being fired. Once it was deemed that there had been sufficient time for the wire trace to corrode, it was found necessary to startle the dugong, through approaching by boat, to enable any remaining wire attachments to break from the force of its tailstroke. There were a number of other successful deployments, however, due to the breaking strain of the wire used in the release being too low, all the harnesses detached prematurely. No spatial data from those deployments is used here although data obtained on measurements of dugongs was used in section 2.2.1 of this chapter.

2.3.5. Suitability of VHF Tracking for locating units and behavioural observations.

The VHF transmitters incorporated into each tag were essential for the location of all units, in particular the MGS_3 GPS units that don’t have any satellite transmitter capability as found in the PTT’s. For locating these units an aerial search was required before tracking from a boat. For all units, tracking in shallow water allowed for rapid
location of target animals. When animals were in deeper water the signal could only be heard when the animal surfaced, thus increasing the time taken to visually locate the animal. Adverse wind and wave conditions also reduced the ability to rapidly track the animal. The use of the VHF transmitter on all units was also critical for the observation of respiration rates, with the radio signal providing an indication of surfacing if visual contact was lost.

2.4 Discussion on Suitability of Remote Recording Devices to Measure Dugong Spatial Usage and Impact of Catch Procedure.

2.4.1 Remote Recording Devices.

The application of the remote recording devices in this study was successful in the recording of the movements and site fidelity of 19 dugongs throughout the Shark Bay World Heritage Area. From the combined deployment of all tags over 10,000 recorded locations were obtained, something not possible through direct observation alone. The use of these recorded locations for determining individual movement patterns and use of habitat by dugongs will be discussed in chapter 3.

From the eight PTT deployments in this study over a total of 966 days, a total 1678 guaranteed locations were obtained with mean locations per day of 1.2 – 4.3 (Table 2.2), this is within the ranges of other studies utilising PTT tags. In their study in North Queensland, Marsh and Rathbun (1990) recorded a range of 2.5 – 3.9 locations per day, while in Indonesia De Jongh et al. (1998) recorded a range of 2.8 - 4.1. In the Townsville-Cardwell region of Queensland, Preen (2001) tagged 13 dugongs with a range of 1.1 – 6.1 guaranteed locations per day. In both the Queensland studies, despite the limitations in spatial accuracy, the information gained on dugong movement paths and habitat usage was used to support and develop management actions for effective dugong conservation in these locations (Marsh and Rathbun 1990; Preen 2001). This study is therefore comparable with previous studies within the dugongs range and even without the added benefit of using GPS units to define movement pathways and habitat
usage it would contribute significantly to meeting management objectives for this population.

The vast majority of locations were however obtained from the GPS loggers giving finer spatial resolution. The implications from these data are greater confidence in site fidelity and the movement paths of dugongs within Shark Bay. These benefits of GPS-derived data came at the cost of a clear bias towards shallow water, with the units’ ability to fix a position within deeper water appearing to be inhibited by the processing time of ~47 seconds. Strong wind and wave conditions are also likely to inhibit a unit in fixing a position in deeper water by swamping the aerials. Due to the problems associated with harnesses releasing early from a number of dugongs, a complete temporal and spatial resolution of dugong movements and therefore complete seasonal habitat usage could not be wholly determined from the GPS tags. This was achieved through the PTT units though, with their ability to record distribution over a greater temporal and spatial scale evidenced through the longer deployment period and a described seasonal movement pattern from those individuals, which will be further discussed in chapter 3.

2.4.2 Capture and Handling

The chase and catch procedure used in this study is the safest and most appropriate method for the capture of dugongs in Shark Bay. The clear water and shallow banks of Shark Bay together with large herds of dugongs allowed for careful assessment of approaches and selection of target animals for capture. The adherence to a clearly defined capture protocol is essential in minimising any disturbance and risk of injury to either the dugong or the catchers. As with all programs of this nature weather conditions and team experience all contribute to the success of a capture.

Although this procedure has been shown to be successful here and previously in Queensland (Lanyon et al. 2002), with no dugong mortality events known to have
occurred (mortalities have occurred with the use of a hoop net procedure (Marsh, unpublished data), it can however be reasoned that the immediate disturbance to the dugong created by this activity is acute. Aside from the direct impact upon dugongs that were tagged, there were usually many other animals in the vicinity of the tagging operation, and whilst the capture was focused upon the candidate animal it was observed that on occasion this activity did disturb adjacent animals. The combined disturbances created from the catch process on non-target as well as target animals, particularly at identified catch locations over an extended period, will make further capture and observation of animals difficult and may increase the population’s susceptibility to mortality. The ability to therefore maximize the collection of data through the capture and deployment of instruments on dugongs is essential and that the information gained is the most appropriate for management activities aimed at the continued conservation of the species within the targeted study area. In addition considered opinion amongst some other researchers involved in this project, as well as similar projects elsewhere within the dugongs range, is that the number of dugongs captured within discrete populations should be minimised to reflect the size of that population.

2.5 Conclusions

The results of this study have shown the effectiveness of these methods in measuring the behaviour and habitat requirements of dugongs within the SBWHA. The chase, capture and handling methods are clearly suitable for obtaining animals for the purposes of deploying remote recording devices. The use of a novel harness system with a remote retrieval device proved to be appropriate for not only the retrieval of units and recorded data, but was also successful in reducing stress on target animals due to there being no requirement for recapture.

The operational capabilities of both the GPS tags and the PTT’s for the intended use of measuring distribution over both fine and coarse scales also represents a unique ability to define dugong behaviour within Shark Bay. Although there is some associated cost to the data acquisition capability of both tag types, their application represents a
first for this dugong population and represents a major achievement in the ability to understand more about this illusive animals’ behaviours and requirements. Chapter 3 will follow with the full spatial and temporal results from these deployments as well as habitat analysis of those areas deemed to be of significance as recorded by the GPS units.
CHAPTER 3
INDIVIDUAL DUGONG MOVEMENT PATTERNS AND HABITAT DESCRIPTIONS WITHIN SHARK BAY

3.1 Introduction

3.1.1 Known Dugong Movement Patterns and Habitat Usage.

Remote recording devices (satellite and VHF transmitters) have been used for measuring dugong movement behaviour and identifying habitat in locations throughout Australia and Indonesia. To date a total of 60 animals throughout the dugongs range have been tagged. Of the tracking studies to occur within tropical and sub-tropical Australia, all have occurred along the Queensland coast. Results from these studies have shown that dugongs are capable of undertaking large distance movements with one tagged animal travelling 600km between locations over a period of five days (Preen 1995). Other tagged animals exhibited large movements as well as showing consistent return movements (Preen 1992, 1995, 2001; Marsh and Rathbun 1990). In addition to the Queensland studies three females and a juvenile male were tracked between 41 and 285 days in a tropical environment in Indonesia, moving distances of between 17 and 65km (DeLongh et al. 1998).

The determination of movement patterns and habitat use by dugongs has not previously been determined from remote instrumentation within Shark Bay or elsewhere along the Western Australian coastline. Within Shark Bay previous determination of individual dugong movements was by observations from a catamaran using photographs of unique scars on individual animals for identification. Using this method five individual animals were resighted 14 times over a period of 2 - 35 days (Anderson, 1995). The ability to determine individual movement patterns from this technique is however difficult and unreliable. Dugongs spend a lot of time feeding in often turbid water and combined with adverse weather conditions the probability of following an individual over an extended period of time is low.
Anderson’s (1982b, 1986, 1994) descriptions of habitat in Shark Bay are based upon behavioural observations of large groups of animals at a number of locations from these boat as well as aerial and shore based platforms. Habitat is described as consisting of dense beds of the seagrass *Amphibolis antarctica* in depths of 0.5 – 3m with water temperature varying between 17.9 and 23°C during winter (Anderson 1982b, 1986). While summer water temperatures were between 25-27°C and the seagrass was predominate*ly Halodule* sp.

3.1.2 Aims

To fill in the gaps in the knowledge base of dugong behaviour and foraging ecology within Shark Bay this study employed the use of the two different types of remote recording instrumentation as fully described in the previous chapter to define large scale seasonal movement pathways and fine scale critical habitat areas for individual dugongs within the Shark Bay World Heritage Property. This chapter will present and discuss the results as well as the management implications from these deployments.

3.2 Determination of Individual Dugong Movements and Habitat Classification.

3.2.1 Tag Descriptions

As described fully in Chapter 2, two types of remote recording instrumentation devices were used in this study, Platform Transmitting Terminals (PTT) and Global Positioning System (GPS) tags. Due to the issues associated with the tag attachment mechanisms on both the PTT and GPS harnesses for this study, many deployments did not proceed as originally planned in order to account for the complete spatial and temporal coverage of dugongs within Shark Bay. During the deployment period in which the PTT tags inadvertently remained attached to the dugongs, they did continue to transmit and provided an extended movement pattern.
The first five GPS deployments occurred during August 2000 for periods between 39 and 49 days on three males and two females (Table 2.2) with all tags deployed around Guischenault Point in the Eastern Gulf (Figure 2.1). Further GPS deployments were staggered over two years following on from 2000. A deployment was carried out during September 2001 in which two tags were deployed at Guichenault Point. During June 2002 three tags were deployed, one at Guichenault Point (Male) and the remaining two were deployed along the eastern shoreline of Dirk Hartog Island (1 male and 1 female).

A total of eight PTT tags were deployed during the period March 2000 – July 2001 (Table 2.2, Figure 3.5). Seven of these tag deployments occurred during one field program in March and April 2000 at locations surrounding Pelican Island. With the remaining tag deployed during July 2001 within the lower reaches of Henri Freycinet Harbour, the only deployment to occur within that region (Figure 2.1). Of the tags deployed during March 2000, tag 5536\(^{(1)}\) was found detached from an animal on the Wooramel Seagrass Bank. The harness of this tag was sliced by what appeared to be a shark bite. The harness was retrieved and repaired and subsequently deployed on another dugong as tag 5536\(^{(2)}\).

### 3.2.2 Data Representation and Analysis.

Dugong behaviour, as recorded from tags deployed on dugongs throughout Shark Bay as well as analysing movement patterns, home range size and habitat usage were determined with use of a Geographical Information System (GIS) using ArcView 3.2 (ESRI). In addition an extension to this software package, Animal Movement Analysis (AMAE) (Hooge and Eichenlaub, 1987), allowed for additional movement, and home range analysis. All geographic data were plotted in the datum World Geodetic System (WGS) 1984 and then converted to the Australian Geodetic Datum (AGD) 1994.

Other GIS datasets specific to Shark Bay used within the study include bathymetry and seagrass percentage cover and composition (Bruce, 1997) along with Sea Surface Temperatures.
Seagrass composition and percentage cover used in broad scale habitat descriptions was obtained from remotely sensed data and verified with ground survey techniques (Bruce, 1997). In addition marine charts of the Shark Bay region, for additional bathymetric analysis and for nomenclature (Commonwealth of Australia, 1999), and thematic landsat images were imported as backdrops to recorded dugong distribution and movement. Representation of location data against these thematic datasets required the data be projected from the datum AGD 1994 onto the Australian Map Grid (AMG) zone 49. Analysis of variables as functions of dugong distribution as provided by these additional datasets involved the use of identity functions within ArcView to extract these descriptors relative to each recorded dugong location.

Sea Surface Temperature relative to the deployment period of four of the PTT units was obtained from NOAA SST imagery. The PTT units do have temperature sensors, however with the use of broad scale NOAA imagery a clearer picture can be obtained of the whole bay rather than just the dugongs’ location, which was more appropriate for showing distribution over greater spatial and temporal scales. Images were imported in ArcView GIS with individual dugong positions plotted over the grided images and corresponding values then exported into spreadsheets for analysis. For the GPS units, the onboard temp sensors were used due to the greater resolution and higher frequency of readings. Readings were taken at the same time as a position was recorded within the MGS_3 GPS.
3.2.3 Home Range Determination

The calculated home range or utilisation distribution analysis used on individual as well as combined dugong distributions is defined as a probabilistic model describing the relative amount of time an animal spends in any place (Jenrich and Turner 1969). Home range determination for tagged animals during the study period involved the use of the fixed kernel density estimator, a non-parametric statistical method for estimating probability densities. This density information forms the basis for investigations into habitat use and preference (Seaman and Powell 1996). Calculation of combined home ranges, pooled GPS units and PTT units, involved sub-sampling the datasets to avoid bias towards those individuals with more recorded locations. With the exception of unit 803 a subset of 75 locations were randomly selected and then categorized from within a ten day period for each of the GPS units, kernel densities were then calculated upon these locations. The calculation of home ranges for the PTT tags was undertaken using all reliable locations (i.e. location classes 0-3 from information received from service Argos).

Within AMAE, 95% and 50% fixed kernel probability contours (or isopleths) were calculated using an ad hoc smoothing factor that controls the amount of variation in each component of the estimate (Worton 1989). The 95% contour can be described as the area that the animal actually uses (as it contains 95% of recorded locations) and the 50% contour as the core area of activity (containing 50% of clustered locations) (Hooge et al. 2000). For the purposes of describing core dugong locations only the 50% contour is displayed in this study. Where contours overlapped unavailable habitat, such as land, they were clipped to more accurately reflect probable home range. In addition some travel paths for individual animals have been adjusted where features such as land were intersected to give a more accurate representation of the true movement path, however true distances travelled may not be accurately reflected for all animals.

For all of the GIS datasets used throughout this study a metadata statement using the ANZLIC 2002 Guidelines for Core Metadata Elements was created detailing a
description of each dataset, dataset currency, status access and quality. All statements are located within Appendix 1.

3.2.4 Habitat Determination and Survey Techniques.

To assess fine scale habitat structure and identify the composition, density and biomass of seagrass forage species that occurred in areas preferred by dugongs (the 50% kernel contours calculated from positions obtained from the GPS tags), a total of 14 sites were sampled. Sites were chosen based upon a subset of the spatial and temporal distribution recorded from two of the GPS tags deployed on female dugongs during their autumn-winter-spring distribution pattern. Insufficient locations were obtained from GPS deployments on dugongs during the summer periods to allow for comparative seasonal habitat assessment.

Using ArcView, sites indicative of preferred dugong habitat (foraging sites) were selected from areas where the fix density was high and concentrated over more than 24 hours. This information indicated that the animal was moving slowly between recorded fixes, suggesting a period of foraging. Within these groupings, a single point was selected where the distance from the previous fix was less than 50m and the distance to the next fix was of a similar distance. In order to determine if there was a difference in habitat between high and low density areas, a number of ‘travelling’ sites were also sampled. Travelling sites were indicative of habitat where dugongs were deemed to have travelled through, and were classified as areas where the distances between fixes were greater than 1km.

Habitat surveys were conducted during August 2002, the month when recorded animal locations had been obtained over the previous two years. At each site, four 50m transects were laid out on the benthos in a north, south, east and west direction respectively from a randomly located point. A video of the benthos was then taken along each individual transect at a constant speed and height of 50cm above the bottom. Seagrass percentage cover and composition were later determined from the video.
through consensus of three observers. In addition, eight replicate 0.5 m$^2$ quadrats were sampled by SCUBA divers at locations selected randomly over the four transects at each site. Seagrass percentage cover was estimated within each quadrat. Shoot density was determined within a 0.1 m$^2$ sectioned corner of the quadrat after which the seagrass within that corner was harvested for above ground biomass determination. Biomass was measured for dry weight by drying samples at 60°C for a 48-hour period. These seagrass measurement methods are commonly utilised for the acquisition of baseline data for understanding the health of seagrass meadows (Kirkman 1996).

In order to determine habitat structure and composition for large scale movements from PTT tags with inherent spatial error, locations were plotted against existing GIS data sets of seagrass distribution and abundance (Bruce, 1997) as well as other classified habitat types. Whilst this method does not provide the resolution achieved through on ground survey it is useful for comparative analysis.

3.2.5 Statistical Analyses

In addition to the routines used to estimate probable home ranges other specific statistical tests were conducted. A Mann-Whitney rank sum test was applied to test for any difference between tagged males and females in total distance travelled. A Students T Test was also used to test for difference in the calculated average speed travelled between males and females. These tests were performed due to the inability to actively select either sex of dugong during the capture process, and to therefore determine if sex difference results in difference in speed travelled or total distance travelled.
3.3 Results showing Home Range, Movements and Habitat of Dugongs in Shark Bay.

3.3.1 Geographical Positioning System (GPS) Tag Deployments.

A total of 8644 positions were recorded from the ten GPS tags (eight Lotek and two Telonics) deployed on dugongs throughout Shark Bay from 2000 – 2002. The total deployment period of the GPS tags was 397 days and the numbers of recorded locations for each of the units, deployment start and end dates, locations per day as well as biological details of these animals are shown in Table 2.2. Distribution of all animals tagged with GPS tags over Shark Bay bathymetry is shown in figure 3.1.

The distribution of GPS positions, were skewed towards the shallow water regions of the Bay, with majority of fixes (62%) occurring within 0-3m of water (21% in 3-5m, 15% in 5-10m and 2% of fixes in water deeper than 10m) (Figures 2.8, 3.1). Temperature readings ranged from 15°C through to 31°C, with mean temperatures for each unit within the 18-25°C bracket (Figure 3.2). While average temperatures fit the thermal threshold range as identified by Anderson (1986) a number of animals regularly occurred in waters below these values. There was an even distribution of fixes throughout the day period (52% of readings during from 6pm-6am and 48% 6:00 AM-6:00 PM).

Generally, fixes for each animal were grouped within a small number of locations with some animals clearly moving large distances between these grouped locations (e.g. units 0702 and 8004, Figure 3.1).
Figure 3.1. Distribution of all GPS units deployed on dugongs 2000-2002 in Shark Bay overlaid on a bathymetric profile.
Figure 3.2. Mean temperature and depth distribution (±s.d) for all GPS tag deployments on dugongs in Shark Bay between 2000-2002.

The maximum distance travelled by any animal between fixes was 61.6km when unit 8003 undertook a movement from north of Faure Island (Figures 1.1, 3.1) around Peron Peninsula to a location to the north west of the Peninsula in three days. There was no significant difference in the calculated average speed of males and females (Table 3.1; $T_{10} = -1.37; P=0.201$) or for total distance travelled (Mann-Whitney rank sum test $T_{11} = 3.4; P=0.214$).
Table 3.1. Distance Travelled and Average Speed and Daily Distance for All GPS Deployed on Dugongs in Shark Bay from 2000 – 2002.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Days Deployed</th>
<th>Locations Per day</th>
<th>Total Distance (km)</th>
<th>Av Daily Distance (km)</th>
<th>Average Speed (Km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8001</td>
<td>49</td>
<td>18.2</td>
<td>284.23</td>
<td>5.8</td>
<td>0.24</td>
</tr>
<tr>
<td>8002</td>
<td>47</td>
<td>3.4</td>
<td>127.75</td>
<td>2.72</td>
<td>0.11</td>
</tr>
<tr>
<td>8003</td>
<td>46</td>
<td>10.1</td>
<td>366.76</td>
<td>7.97</td>
<td>0.33</td>
</tr>
<tr>
<td>8004</td>
<td>39</td>
<td>23.1</td>
<td>374.96</td>
<td>9.1</td>
<td>0.4</td>
</tr>
<tr>
<td>8005</td>
<td>43</td>
<td>48.5</td>
<td>276.20</td>
<td>6.42</td>
<td>0.27</td>
</tr>
<tr>
<td>7301</td>
<td>8</td>
<td>11.1</td>
<td>170.70</td>
<td>21.34</td>
<td>0.89</td>
</tr>
<tr>
<td>7001</td>
<td>9</td>
<td>8.6</td>
<td>72.60</td>
<td>8.06</td>
<td>0.34</td>
</tr>
<tr>
<td>0803</td>
<td>52</td>
<td>12.1</td>
<td>188.61</td>
<td>3.63</td>
<td>0.15</td>
</tr>
<tr>
<td>0702</td>
<td>39</td>
<td>44.5</td>
<td>734.06</td>
<td>18.82</td>
<td>0.78</td>
</tr>
<tr>
<td>0606</td>
<td>52</td>
<td>28.5</td>
<td>796.78</td>
<td>15.32</td>
<td>0.64</td>
</tr>
<tr>
<td>0602</td>
<td>13</td>
<td>10</td>
<td>254.62</td>
<td>19.59</td>
<td>0.82</td>
</tr>
</tbody>
</table>

**Home Range and Movements.**

The 50% isopleth data (Figure 3.3) highlight the significance of the Guischenault Pt- Point Peron region for dugongs in the spring and summer periods of 2000 and 2001 as well as the importance of the eastern shoreline of Dirk Hartog Island in the winter of 2002.

A number of animals tagged around Guischenault Pt during spring of 2000, (units 8001 and 8004) moved out of the area for a number of days before returning, in what may be described as exploratory movements. Other animals, units 8002, 8003 and 0602 remained within that location before moving with the tags retrieved at other locations, while units 8005 (spring 2000), 7001 and 7301 (summer 2001) remained entirely within the region until the tags were retrieved. Unit 0702 undertook the biggest movement, circumnavigating almost the entire Bay from the deployment location off Dirk Hartog Isl. in a large exploratory movement, including 3 days within the Guischenault Pt – Peron Peninsula region (Figure 3.1).
Figure 3.3. Fifty Percentile Home Ranges by season and year on all GPS tagged dugongs in Shark Bay during the period 2000–2002.
3.3.2 Platform Transmitting Terminal (PTT) Tag Deployments.

Four of the eight PTT tagged dugongs retained tags long enough to define distinct core areas of activity, these were associated with a shift in Sea Surface Temperature and depth (Figures 3.6, 3.7). Tags 5519, 5534, 5535, and 5537 remained attached and transmitted location data for 266, 217, 215 and 148 days respectively (Table 2.2). This period of transmission extended from March 2000 towards the end of the Austral summer through to the beginning of the following summer.

Three of these four dugongs were males (5519, 5534, and 5537) and showed seasonally distinct 50% contours separated by the Peron Peninsula (Figures 3.8, 3.9). For these males, summer activity was concentrated within the lower eastern gulf and winter activity within the mid-western gulf. At the onset of the summer at the end of 2000-01 all males returned to the eastern gulf. Distances between each core area of activity, around Peron Peninsula were approximately 120 –150 Kms. The only tagged female was 5535. Whilst showing a distinct seasonal distribution pattern (Figure 3.9) the entire deployment period was spent within the eastern gulf, with a small shift of approximately 35 Kms between each centre of core seasonal activity. With the exception of the winter home range of animal 5535, all home ranges overlapped.
Figure 3.4. Distribution of locations as transmitted by all deployed PTT units on dugongs in Shark Bay during the period 2000 – 2002
Figure 3.5. Distribution of 4 PTT units deployed on dugongs in Shark Bay During 2000-2002 relative to shifts in Sea Surface Temperature.
Figure 3.6. Mean seasonal water depths (±2sd) of 4 dugongs in Shark Bay with PTT units attached in 2000.
Figure 3.7. Seasonal Home Ranges of PTT Units 5535 and 5534 Deployed on Dugongs in Shark Bay during 2000.
Figure 3.8. Seasonal Home Ranges of PTT Units 5519 and 5537 Deployed on Dugongs in Shark Bay during 2000.
In addition to the summer and winter core areas of activities, two animals, 5537 and 5519, spent time at intermediary locations. Animal 5519 spent 2 periods of 5 days duration each at the same location upon departing both his summer and winter home ranges. Upon departing his summer home range animal 5537 spent 9 days to the North West of the tip of the Peron Peninsula and returned along the eastern shore of the Peninsula towards the end of July 2000, coincident with the 50% isopleth identified from the GPS units. This male then spent another month in this region before the tag was removed.

Tagged animals 5519, 5534 and 5537 also exhibited exploratory movements similar to that shown by some of the GPS tagged animals. These movements lasted less than 8 days, involved return journeys from core areas of activity, and were not characterised by any site fidelity. For the male 5519, a return journey of 222 km was undertaken north from his winter home range. The male 5534 travelled a return journey of 192 km from his summer range into what would become his winter home range while the remaining male, (5537) completed a round trip of 186 km from his winter home range pattern travelling north. Due to the associated error range with the PTT tags these distances don’t have the resolution as calculated from the GPS tags.

The shorter deployment period for tags on the remaining four male dugongs resulted in the distribution of these animals being centred on the catch location and summer aggregation area, with the exception of 1311. Two of these tags, 5536(1), and 5065, which was found detached possibly due to a shark attack, remained in the area adjacent to the catch location. Unit 5536(2), which was attached for a longer period of 52 days, undertook a movement north after spending three weeks within the catch region, travelling 324 km in 30 days before the tag detached and floated inshore north of Carnarvon. Unit 1311 was attached to a large solitary male within the lower reaches of Henri Freycinet Harbour. Once tagged he immediately left this area and moved to a location along the south eastern shoreline of Dirk Hartog Island where the tag detached after a period of approximately six weeks, determined through a lack of movement in recorded positions as obtained through Service Argos. Individual home ranges were not calculated for these animals.
The maximum distance travelled between fixes was 87 km: tag 5537 travelled from a location near Gladstone to a position off the north western tip of Peron Peninsula in 6 days. Total travel distances average speeds, and range of distances travelled between fixes for all PTT tagged animals are shown in Table 3.2, while movement paths for the combined GPS and PTT units are shown in Figure 3.9.

The location data from both PTT and GPS tagged animals showed that dugongs are utilising waters outside of the existing Shark Bay Marine Park boundary. Although the majority of locations and defined critical habitats from this study fell within the existing reserves (Figures 3.1 & 3.4), and all deployments occurred within the boundaries of the park (Figure 2.1), a number of recorded locations (3% of total recorded fixes from all deployments) occurred outside. In addition, the travel paths of a number of tagged dugongs (5% of total movements from all deployments) crossed this boundary (Figure 3.9), with the majority of these movements occurring when dugongs were travelling to and from identified seasonally important locations.

Table 3.2.
Distance Traveled, Average Speed and Daily Distance for Dugongs in Shark Bay with All PTT Units during the Period 2000 - 2002.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Days Deployed</th>
<th>Locations Per Day</th>
<th>Total Distance (Km)</th>
<th>Average Daily Distance (Km)</th>
<th>Average Speed (Km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5065</td>
<td>53</td>
<td>3.5</td>
<td>165.1</td>
<td>3.1</td>
<td>0.46</td>
</tr>
<tr>
<td>5536(1)</td>
<td>13</td>
<td>2.8</td>
<td>228.2</td>
<td>17.6</td>
<td>0.73</td>
</tr>
<tr>
<td>5536(2)</td>
<td>53</td>
<td>4.3</td>
<td>1224.1</td>
<td>23.1</td>
<td>0.96</td>
</tr>
<tr>
<td>5535</td>
<td>215</td>
<td>1.4</td>
<td>1540.6</td>
<td>7.2</td>
<td>0.30</td>
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<tr>
<td>5537</td>
<td>148</td>
<td>1.6</td>
<td>551.1</td>
<td>3.7</td>
<td>0.16</td>
</tr>
<tr>
<td>5519</td>
<td>265</td>
<td>2.1</td>
<td>2118.4</td>
<td>8.0</td>
<td>0.33</td>
</tr>
<tr>
<td>5534</td>
<td>217</td>
<td>1.2</td>
<td>1683.3</td>
<td>7.8</td>
<td>0.32</td>
</tr>
<tr>
<td>1311</td>
<td>40</td>
<td>1.4</td>
<td>216.4</td>
<td>5.4</td>
<td>0.23</td>
</tr>
</tbody>
</table>
Figure 3.9. Movement Paths of All Dugongs Tagged with GPS and PTT Tags in Shark Bay during the period 2000-2002.
3.3.3 Habitat Structure and Composition.

Ground truthing of the selected GPS locations indicated that the preferred habitat for tagged dugongs during the autumn - winter – spring periods are seagrass beds where there was 30-80% coverage of the species *Amphibolis antarctica* with an estimated above ground biomass of 110-360 gm$^2$ in waters <5m (Table 3.3). Ninety percent of the foraging survey sites were within 1000 m of areas of a depth gradient into deeper water (>5m). Figure 3.10, based on existing GIS datasets of seagrass type and coverage, shows the distribution of this habitat type and its proximity to deeper water. Observations of dugongs prior to capture events, as well as when following tagged animals during the spring period from non motorised platforms to record respiration rates (as shown in Figure 2.6), showed that animals were clearly foraging on *A. antarctica* in areas of 30-80% coverage within site of deeper waters.

Sites that were surveyed as low use or ‘travelling’ sites were either deeper (>10m) and with no seagrass present, or shallow (<5m) with a sparse coverage (<10%) of *Posidonia australis* (not recorded as part of dugong diet) mixed throughout sand and/or rubble.
Table 3.3.
Habitat Composition and Descriptions for all Survey Locations.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>SITE NAME</th>
<th>DUGONG BEHAVIOUR</th>
<th>SEAGRASS SPECIES/HABITAT</th>
<th>MEAN COVER (%)</th>
<th>MEAN BIOMASS (gms/0.1m²)</th>
<th>MEAN SHOOT DENSITY (0.1m²)</th>
<th>DEPTH (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Passage</td>
<td>SP1</td>
<td>Travelling</td>
<td>Sand/Rubble</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>South Passage</td>
<td>SP2</td>
<td>Foraging</td>
<td><em>A. antarctica</em></td>
<td>40.82</td>
<td>18.55</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>Bellefin Flats</td>
<td>BF1</td>
<td>Foraging</td>
<td><em>A. antarctica</em></td>
<td>69.04</td>
<td>21.20</td>
<td>32</td>
<td>1.5</td>
</tr>
<tr>
<td>Bellefin Flats</td>
<td>BF2</td>
<td>Foraging</td>
<td><em>A. antarctica</em></td>
<td>36.67</td>
<td>36.03</td>
<td>31</td>
<td>2.4</td>
</tr>
<tr>
<td>Bellefin Flats</td>
<td>BF3</td>
<td>Travelling</td>
<td>Sand</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>Dirk Hartog</td>
<td>DH1</td>
<td>Foraging</td>
<td><em>A. antarctica</em></td>
<td>70.48</td>
<td>11.34</td>
<td>51</td>
<td>2.5</td>
</tr>
<tr>
<td>Dirk Hartog</td>
<td>DH2</td>
<td>Travelling</td>
<td><em>P. australis</em></td>
<td>11.98</td>
<td>1.31</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>Dirk Hartog</td>
<td>DH3</td>
<td>Travelling</td>
<td>Sand</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>Dirk Hartog</td>
<td>DH4</td>
<td>Foraging</td>
<td><em>A. antarctica</em></td>
<td>68.09</td>
<td>11.63</td>
<td>79</td>
<td>3.5</td>
</tr>
<tr>
<td>Dirk Hartog</td>
<td>DH5</td>
<td>Foraging</td>
<td><em>A. antarctica</em></td>
<td>53.71</td>
<td>17.30</td>
<td>130</td>
<td>1.5</td>
</tr>
<tr>
<td>Guischenault Pt.</td>
<td>GP1</td>
<td>Foraging</td>
<td><em>A. antarctica</em></td>
<td>40.12</td>
<td>26.86</td>
<td>59</td>
<td>2</td>
</tr>
<tr>
<td>Guischenault Pt.</td>
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<td>Foraging</td>
<td><em>A. antarctica</em></td>
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<td>14.44</td>
<td>59</td>
<td>3</td>
</tr>
<tr>
<td>Guischenault Pt.</td>
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<td>Travelling</td>
<td><em>A. antarctica</em></td>
<td>86.4</td>
<td>27.83</td>
<td>76</td>
<td>1.5</td>
</tr>
<tr>
<td>Guischenault Pt.</td>
<td>GP4</td>
<td>Travelling</td>
<td><em>A. antarctica</em></td>
<td>15.94</td>
<td>10.74</td>
<td>20</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Figure 3.10. Distribution of Seagrass Habitat in Shark Bay as Described from Habitat Mapping.
Table 3.4.
Number of Recorded Fixes for All PTT Units within Seagrass Habitats as Defined by Type and Percentage Cover.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Amphibolis antarctica</th>
<th>Amphibolis antarctica, Posidonia australis</th>
<th>Amphibolis antarctica, Posidonia australis, Cymodocea spp</th>
<th>Sand</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-20</td>
<td>21-40</td>
<td>41-60</td>
<td>61-80</td>
<td>81-100</td>
</tr>
<tr>
<td>55065</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>79</td>
</tr>
<tr>
<td>5536 (1)</td>
<td>-</td>
<td>3</td>
<td>16</td>
<td>8</td>
<td>35</td>
</tr>
<tr>
<td>5536 (2)</td>
<td>1</td>
<td>-</td>
<td>2</td>
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<td>26</td>
</tr>
<tr>
<td>5535</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>46</td>
</tr>
<tr>
<td>5537</td>
<td>2</td>
<td>3</td>
<td>9</td>
<td>7</td>
<td>25</td>
</tr>
<tr>
<td>5519</td>
<td>2</td>
<td>1</td>
<td>8</td>
<td>20</td>
<td>36</td>
</tr>
<tr>
<td>5534</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>1311</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>24</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 3.5.
Number of Recorded Fixes for all PTT Units Within Described Habitat Type.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Perennial Seagrass</th>
<th>Ephemeral Seagrass</th>
<th>Sand</th>
<th>Silt</th>
<th>Unknown</th>
<th>Algal Mat</th>
<th>Macro-algae</th>
<th>Reef</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dense</td>
<td>Medium</td>
<td>Sparse</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55065</td>
<td>81</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>5536(^{(1)})</td>
<td>49</td>
<td>19</td>
<td>30</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5536(^{(2)})</td>
<td>46</td>
<td>15</td>
<td>20</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>17</td>
<td>-</td>
</tr>
<tr>
<td>5535</td>
<td>79</td>
<td>6</td>
<td>11</td>
<td>-</td>
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</tr>
<tr>
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<td>8</td>
<td>1</td>
</tr>
<tr>
<td>5519</td>
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<td>-</td>
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<td>1.8</td>
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<td>-</td>
</tr>
<tr>
<td>5534</td>
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<tr>
<td>1311</td>
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<td>-</td>
<td>-</td>
<td>2</td>
<td>56</td>
<td>4</td>
<td>2</td>
<td>-</td>
</tr>
</tbody>
</table>
Comparisons of PTT locations, which were not categorised as either foraging or travelling, to GIS datasets of habitat and seagrass types (Tables 3.4 and 3.5) show the greatest proportion of fixes occurring over perennial seagrass habitat comprised essentially of *A. antarctica* with 81-100% cover. Preliminary investigations of high density sites, where PTT tagged dugongs had aggregated during the summer distribution pattern indicated that as well as the presence of *Halodule uninervis* there were beds of *Amphibolis antarctica, Halophila spinulosa* and *Halophila ovalis*.

### 3.4 Discussion of Distribution and Habitat Usage.

The described movement pattern and habitat descriptions from the deployment and retrieval of location recording instrumentation within Shark Bay are a first for this population. These results have confirmed previous research carried out by Anderson, (1982b, 1986, 1994, and 1998), Prince *et al.* (1981) and Marsh (1994) in addition to considerable anecdotal evidence and historical knowledge from members of the Yadgalah Aboriginal Corporation. Dugongs undertake a defined seasonal distribution pattern coincident with a decrease in Sea Surface Temperature (Figures 3.6, 3.8 and 3.9) within the inner areas of the Bay. During the summer dugongs congregate within the lower reaches of both the eastern and western gulfs, foraging on preferred species of seagrass. With a decline in water temperatures within these areas at the onset of winter, the dugongs will move out to the outer regions of Shark Bay to take advantage of warmer oceanic waters. This distribution pattern has consequences with a change in seagrass species available for forage as well as an increase in water depth in which suitable forage species occur.

This seasonal distribution pattern of dugongs is similar to that exhibited by dugongs within Moreton Bay in Queensland (Preen 1993; Lanyon 2003), a location representing the southernmost distribution of dugongs on Australia’s East Coast. Here temporal distribution of animals is also reflected through changes in water temperature with animals seeking out warmer oceanic water when Bay temperatures fall below 18°C (Preen, 1993).
No other locations within the dugongs range that observational or tracking studies have been undertaken, have reported a seasonal distribution pattern similar to that described for Shark Bay and Moreton Bay, due to consistency of water temperature throughout the year. However there is indication that seasonal climatic conditions such as monsoons may influence the distribution of dugongs within the Philippines (Aragones 2000). Of those tracking studies within the lower latitudes of the dugongs range, (De Iongh et al. 1998, Preen 1995, 2001) there is evidence that tagged animals do move consistently between core areas, and that these movements are highly individualistic although there is considerable overlap in these movements, suggestive of aggregating or herding animals. This individualistic pattern is also reflected in the diving behaviour with individual variation dominating effects on diving behaviour (Chilvers et al. 2004).

The travel paths of animals moving between the two gulfs of Shark Bay are determined by the Peron Peninsula, with the majority of animals making direct movements from the Eastern Gulf across the tip of the Peninsula to those preferred locations along the eastern shoreline of Dirk Hartog Island. In addition it can be seen that for the majority of movements’ animals tend to follow edges of large seagrass banks or adjacent coastline. However for movements within the Eastern Gulf, particularly from Guischenault Point to the lower sections of this Gulf, animals tended to move more directly across the Bay, this might be due to the presence of shallow seagrass banks within centre of the Eastern Gulf providing foraging opportunity.

Anderson (1986) also suggested that in summer dugongs also aggregate in the lower western gulf of Shark Bay within Henri Freycinet Harbour (Figure 1.1). Only one dugong, unit 1311, was tagged during this study at this location. No other animals were sighted around this region and upon tagging this animal, a male, he immediately departed the region for Dirk Hartog Isl. Results from the aerial survey chapter of this study (see Chapter 4) indicate that 25% of the overall Shark Bay dugong population estimate occurred within Henri Freycinet Harbour during summer.
The paucity of positions and movement paths along the western shoreline of the Peninsula, as opposed to the high density of locations along the eastern shore may be a consequence of wind and fetch conditions along this section of coastline. Direct exposure, particularly in the summer months, to the predominant south-westerly wind stream results in strong onshore conditions here. Aside from affecting the performance of tags ability to record locations in these conditions, these conditions may also influence a dugong’s travel preference as well as restricting foraging activity. Protection from weather, in addition to seagrass distribution, may also partially explain the distribution of defined core areas of activity within sheltered shallow waters in the lee of the prominent coastal features within the Bay.

The habitat surveys demonstrate that during the winter distribution pattern the only reliable forage available for dugongs is the seagrass species *Amphibolis antarctica* (Table 3.3). It has been suggested that dugongs may also forage upon another species of seagrass, *Halophila spinulosa*, during the winter in Shark Bay (Anderson, 1994). However, no presence of *H. spinulosa* was recorded at sites investigated in this study, highlighting the significance of *A. antarctica* for dugong forage requirements in Shark Bay. The presence of *H. spinulosa* may be sporadic both spatially and temporally within the Bay. In Exmouth Gulf surveys for Panaeid prawns (Loneragan et al. 2003) subsequent to a category 5 cyclone discovered large meadows of this species as well as groups of dugongs foraging in these areas. Previous surveys in this area (McCook et al. 1995) before the cyclone recorded no presence of *H. spinulosa* suggesting this is a pioneer species.

The habitat surveys for this study also determined that dugongs not only foraged in areas vegetated solely by *A. antarctica*, but that there were a number of similar habitat characteristics defining the high use sites. The description of forage habitat of beds of the seagrass *A. antarctica* with a mean cover between 30% and 70% and in waters less than five metres deep (Figure 3.10) implies that here dugongs aggregate and selectively forage in these areas.
No comparative summer habitat survey was undertaken during this study, though Anderson (1982b, 1986) and Masini et al. (2001), describe a number of locations within the lower eastern gulf that coincide with the relatively dense summer aggregations recorded within this study. They describe the seagrass habitat at these locations being comprised of the species *Halodule uninervis* and *Halophila ovalis*, with mean above and belowground biomass of 69.8gm⁻². Both of these species of seagrass have previously been identified as among the preferred forage species for dugongs throughout their global range (Marsh et al. 1999).

The change in habitat accessed by dugongs as a result of seasonal movement in response to thermal cues, results in a shift of available forage as suggested by Anderson (1986, 1994). Anderson (1986) put forward the hypothesis that this shift may have negative consequences for the dugongs’ energy budget, particularly during the winter months when the primary forage is *Amphibolis antarctica*, a perennial species with lower nutritional value than the ephemeral species (Anderson 1986) available during the summer. No nutrient composite analysis of seagrass was undertaken during this study. Consequently, no conclusions can be drawn regarding differences in the calorific content among species and throughout the year. If dugongs are already nutritionally stressed during the winter, human activity on the waters of the Bay that is greatest at this time of year (Summner and Malseed 2000) may exacerbate the disturbance levels. There is, however, no evidence of higher mortality levels during the winter periods than summer.

The application of information gained from this study on individual dugong movements and described habitat types can provide the means for the continued effective conservation of this population through a greater understanding of individual dugong requirements throughout the year across the entire Bay. The spatial information presented here, such as the recording of movements outside of the Marine Park boundary, reinforces observations by Preen (1997) that during previous winter aerial surveys approximately 50% of sightings of dugongs were found to occur outside of the reserve structure. This type of information should provide impetus to the extension of zoning structures of the Shark Bay Marine Park Boundary to match that of the World
Heritage Property in order to ensure access by dugongs through unobstructed pathways to identified core areas throughout the year.

This information is also applicable for use in the assessment of proposed aquaculture leases, as many of the biological and physical requirements for a commercial lease are the same as required by dugongs. This is highlighted in Figure 3.11, where proposed and existing leases along the southern and eastern shores of Dirk Hartog Island are surrounded by recorded dugong locations as well as preferred dugong seagrass foraging habitat.

In addition the information described here highlights the applicability of carrying out similar research projects throughout the rest of the dugongs range within Western Australia, particularly in those areas to the north such as the Kimberley and Exmouth Gulf where information on dugong distribution and habitat usage and association is limited or non existent. The ability to remotely record high use locations at a fine scale is particularly relevant in those marine environments to the north of Shark Bay as they experience greater levels of turbidity, thus ruling out efforts to undertake any form of visual observation and tracking.
Figure 3.11. Distribution of a Sample of Recorded Dugong Locations in 2000, Seagrass Habitat and Aquaculture Leases.
In addition there are likely to be numerous additional areas critical to a large segment of the population particularly within the Henry Freycinet Harbour region, which are unaccounted for through these series of deployments. Development of detailed GIS seagrass habitat datasets, which is currently underway, will aid in the identification of similar habitat to the descriptors provided here and should be used in conjunction with findings from this study, in the decision making process for development activities within the Bay.

The capture of dugongs for programs such as this one within Shark Bay should also be a consideration in the continued conservation of this population. As discussed in chapter 2 it can be reasoned that the disturbance created by this activity is probably acute based on the observations of animals immediately post capture and through wariness by tagged animals up to many months after the tagging procedure.
CHAPTER 4
POPULATION DISTRIBUTION AND ABUNDANCE OF DUGONGS
DURING SUMMER IN SHARK BAY

4.1 Historical Dugong Population Estimates and Winter Distribution Patterns.

Aerial surveys of dugongs within Shark Bay throughout the 1980s identified the significance of this population and defined areas of importance to dugongs (Prince et al. 1981; Anderson 1982, 1986). These surveys were counts of animals observed and were flown over areas where large numbers of dugongs were thought to be present. In July (winter in the southern hemisphere) of 1989 the first fully standardised aerial survey was undertaken to determine the overall population abundance and distribution in Shark Bay (Marsh et al. 1994). The standardised aerial survey technique had been used to determine population abundance estimates and for monitoring of dugongs in Queensland (e.g. Marsh and Saalfeld 1989, 1990, 1991), the Northern Territory (Bayliss 1986; Bayliss and Freeland 1989) and in the Arabian Gulf (Preen 1989). The 1989 Shark Bay survey was conducted to determine a baseline for future surveys that would form part of management of this population. After the July 1989 (Marsh et al. 1994) survey, it was determined that an interval of five years between surveys would be appropriate to assess change in the Shark Bay dugong population (CALM 1996).

In the July 1989 survey, the minimum population estimate was 10 146 ± 1 665 (s.e.) dugongs with an overall density of 0.71 ± 0.12 (s.e.) dugongs km\(^{-2}\), the highest density ever recorded on a large-scale dugong survey. This confirmed Shark Bay as probably the second most important dugong population in the world, after Torres Strait (Marsh et al. 2004). In June 1994 a subsequent survey was undertaken. The population estimate for Shark Bay for this survey was 10 529 ± 1464 (s.e.), a result very similar to the previous survey (Preen et al. 1997). The most recent survey was conducted during July 1999 (Figure 4.1) and returned an estimate of 13,929 ± 471 (s.e.), a 40% increase on the previous two surveys. The increase was interpreted as a large scale movement of
dugongs southwards into Shark Bay in response to loss of seagrass habitat following a severe tropical cyclone to the north (Gales *et al.* 2004).

A key characteristic of all the surveys described above was that they were conducted in winter. This is significant because all refer to the effect of low water temperature on the distribution of dugongs. Dugongs prefer water warmer than approximately 18°C and so tend to shift westwards in the winter, away from key summer habitat where water temperature drops below 18°C, such as the Wooramel Seagrass Banks. (Anderson 1986, this study Chapter 3) While differences in distribution have been recorded among the winter surveys, they are largely explainable in terms of water temperature.

It is clear that winter surveys of dugong distribution and abundance are insufficient to characterise the habitat use by dugongs in Shark Bay across all seasons. Some attempts have been made to conduct complementary summer surveys, but these have been hampered by the difficult survey conditions and focused on an area on the eastern side of Peron Peninsula known in advance to support significant numbers of dugongs. Additionally, unfavourable conditions and observer inexperience meant that the resultant estimates of populations were deemed underestimates (Marsh *et al.* 1994).

The objective of this study was to carry out the first whole bay, standardised aerial survey of dugongs in Shark Bay during summer in order to determine if summer distribution differs to winter, and if abundance differs between seasons. Using the standardised format applied to the whole Bay as used in previous surveys, this survey therefore provided the first data set to allow valid comparisons against winter distribution and abundance estimates.
4.2 Methods

4.2.1 Aerial Surveys

The survey design and procedures used for this summer survey, as well as the previous three winter surveys, are based on the protocols of Marsh and Saalfeld (1989) and Marsh and Sinclair (1989) that were developed when standardized aerial surveys commenced in Queensland and the Northern Territory. The number and location of transects and blocks used for the calculation of regional density are as per Marsh et al. (1994) and Preen et al. (1997) during their Shark Bay surveys to allow for a more direct comparison between summer and winter.

The survey was conducted from 4th –10th February 2002 and was timed to occur in the summer period when broad heat troughs regularly form off the WA coast. In Shark Bay, these heat troughs may provide windows of up to several days of light winds, creating ideal conditions for aerial surveys; surveys can only be with Beaufort sea state less than or equal to 3 and at times when glare is minimal (early morning, midday and late afternoon were avoided). Flying times were limited to a maximum of approximately 3.5 hrs (based on fuel capacity and mass of aircraft load). When weather conditions permitted two flights were conducted each day.

A Partenavia 68B aircraft was used for the survey. The aircraft was equipped with pseudo wing-struts fitted with markers to delineate a transect 200 m wide on the water surface either side of the aircraft when flown at 450 feet (137m) altitude. Shark Bay was stratified into six blocks and within blocks parallel east-west transects were spaced approximately 2.5 nautical miles apart, giving survey coverage of 7.8 - 9.1% of the Bay. The previous (winter) surveys used lower survey intensity in the southern parts of the Bay, due to expected low numbers of dugongs in the shallow, colder waters. As we thought it more likely that significant numbers of dugongs would use these areas in summer, we used the same transect spacing as in the remaining survey blocks.
Two observers operated on each side of the plane. The observers were visually and aurally isolated from each other and recorded their observations into different tracks of a two-track tape recorder. Separation of the observers allows estimation of perception correction factors using a modified mark-recapture technique (Marsh and Sinclair 1989) to adjust for animals that were available to be seen but were missed by the observers (Table 4.1). Additionally, corrections were made for availability bias to adjust for animals that were too far below the surface of the water to be seen as the aircraft passed over (Table 4.1) (Marsh and Sinclair 1989). Due to their higher probability of being seen, groups of dugongs larger than ten were stratified out of the population estimate. When a large group was encountered it was circled until a reliable count was obtained and this estimate was then added back into the population estimate for that block. Each confirmed dugong observation was recorded against the location of the aircraft through an onboard GPS system pre-programmed for each transect.

Final population size is estimated using the above parameters. The number of groups of animals seen on each transect is multiplied by average group size and by the perception and availability correction factors described above. These are then summed within blocks and divided by survey intensity to estimate population for that block. Due to differences in transect size, the variance is estimated using the ratio method (Jolly 1969, Caughley and Grigg 1981) to which are then added the estimated variances for the average group size and the correction factors. Full details of variance estimation are given in Marsh and Sinclair (1989).
Table 4.1. Perception and Availability Correction Factors for all Standardised Surveys Within Shark Bay.

<table>
<thead>
<tr>
<th>Survey</th>
<th>Group size (C.V)</th>
<th>Perception correction factor estimate (C.V)</th>
<th>Availability correction factor estimate (C.V)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Port</td>
<td>Starboard</td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>1.39 (0.597)</td>
<td>1.04 (0.015) 1.13 (0.080)</td>
<td>2.75 (0.139)</td>
</tr>
<tr>
<td>1994</td>
<td>1.23 (0.467)</td>
<td>1.09 (0.020) 1.19 (0.039)</td>
<td>2.19 (0.137)</td>
</tr>
<tr>
<td>1999</td>
<td>1.294 (0.035)</td>
<td>1.015 (0.002) 1.012 (0.002)</td>
<td>2.4891 (0.116)</td>
</tr>
<tr>
<td>2002</td>
<td>1.218 (0.036)</td>
<td>1.068 (0.010) 1.035 (0.006)</td>
<td>2.394 (0.120)</td>
</tr>
</tbody>
</table>

4.2.2 Sea Surface Temperature Estimates.

Sea Surface Temperatures (SST) for Shark Bay were estimated from the Advanced Very High Resolution Radiometer (AVHRR) sensors on board the NOAA series of satellites. Estimated temperatures are considered accurate to within 0.5ºC on 64% of occasions and within 1ºC for 87% of the time (Pearce 1989). To allow comparisons of dugong distributions relative to SST in summer and winter, AVHHR images were obtained on a clear day for both this survey (9th February 2002) and the 1999 winter survey (9th July 1999). Images were imported into the GIS package ArcView 3.2 with individual dugong observations matched with the corresponding temperature at that location.
4.3 Results

4.3.1 Distribution and Abundance of Dugongs

During the February 2002 survey of Shark Bay a total of 687 dugongs were observed. Of these, 386 were in small groups (<10 animals), with most sightings of single animals (n=278) and the mean small group size was 1.22. The remaining 301 animals were seen in herds of 25, 32 and 244 (and hence were not included in the final estimate), on the Wooramel seagrass bank on the eastern side of the bay (Figures 4.2 and 4.3).

The total dugong population for Shark Bay in February 2002 was estimated to be 11 021 +/-1357(se), with a density of 0.74 dugongs km$^{-2}$. This is similar to the previous winter surveys in 1989 and 1994, but less than the winter survey of 1999 (Table 4.2). The frequency of calves was very low, only 14 (or 3.6% of individuals) being recorded in the groups of less than 10 individuals and none in the larger herds.
Figure 4.1. Distribution of Observed Dugongs in groups of less than 10 individuals, which are used in the final estimate calculation in the 2002 Summer Survey, overlaid on estimated Sea Surface Temperature.
Figure 4.2. Dugong Group Size Distributions in Shark Bay observed in the 2002 summer aerial survey overlaid on Bathymetry.
Table 4.2.

<table>
<thead>
<tr>
<th>BLOCK</th>
<th>AREA (km²)</th>
<th>ESTIMATED NUMBERS (+/- se)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1198</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1160</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1631</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>2388</td>
<td>170 (68)</td>
</tr>
<tr>
<td>4</td>
<td>2726</td>
<td>4467 (819)</td>
</tr>
<tr>
<td>5</td>
<td>812</td>
<td>4040 (1171)</td>
</tr>
<tr>
<td>6</td>
<td>2243</td>
<td>1293 (847)</td>
</tr>
<tr>
<td>7</td>
<td>2747</td>
<td>176 (90)</td>
</tr>
<tr>
<td>Total</td>
<td>14905</td>
<td>10146 (1665)</td>
</tr>
</tbody>
</table>

The distribution of dugongs in Shark Bay summer was markedly different from that recorded during winter surveys, though the abundance was within the range of previous estimates (Figs 4.1, 4.2, 4.3, Table 4.2). Compared to winter, the summer distributions showed a shift from the deeper western part of the Bay (Block 4) to the east (Block 3) and south west of the Bay (Block 0) (Fig 4.3). Significant numbers of dugong were observed around Faure Island and the Wooramel Delta and 24% of the total population was estimated to occur in the Henri Freycinet Harbour, southwest of Peron Peninsula (Table 4.2).

The majority of dugongs were sighted in blocks 0 and 3, in the waters at the southern ends of both the eastern and western gulfs of the Bay (Figure 4.3). Sea Surface Temperatures throughout the bay were well above 18⁰C (Figures 4.2, 4.4), which is believed to be the limit of dugong thermal tolerance (Anderson, 1986; Marsh et al.
1994; Preen et al. 1997) and a primary determinant of dugong distribution in Shark Bay during winter. During summer, SST was consistently above 18°C. Few dugongs were seen in southern end of Block 2 (Hamelin Pool), a hypersaline area compared with the metahaline blocks 0 and 3 (CALM 1996). The proportion of dugongs observed outside of the existing Shark Bay Marine Park boundary was 15.4% (Figure 4.2).

Figure 4.4. Comparison of SST at locations of dugongs as observed during a winter (1999) survey and summer (this study) survey.
Table 4.3.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer – Temp (°C)</strong></td>
<td>318</td>
<td>21.79</td>
<td>28.77</td>
<td>26.67</td>
<td>1.21</td>
</tr>
<tr>
<td><strong>Winter – Temp (°C)</strong></td>
<td>355</td>
<td>12.69</td>
<td>23.28</td>
<td>18.78</td>
<td>1.66</td>
</tr>
<tr>
<td><strong>Summer Depth Range (m)</strong></td>
<td>317</td>
<td>0-3</td>
<td>15-20</td>
<td>8.53</td>
<td>5.53</td>
</tr>
<tr>
<td><strong>Winter Depth Range (m)</strong></td>
<td>353</td>
<td>0-3</td>
<td>15-20</td>
<td>10.51</td>
<td>5.04</td>
</tr>
</tbody>
</table>

### 4.4 Discussion.

#### 4.4.1 Summer distribution.

Previous studies have noted that in Shark Bay the summer distribution of dugongs is different from the winter distribution and that there are concentrations in the south west (Henri Freycinet Harbour) and east (Faure Sill, Wooramel Banks) of the bay in summer (Prince *et al.* 1981, Anderson 1986). However, the importance of the Henri Freycinet Harbour could not be fully assessed as previous efforts were hampered by poor weather. This study confirms the overall pattern for summer distribution, and that it is markedly different to that of the winter distribution.

The pattern of distribution that was observed is consistent with the interpretation of previous studies (Prince *et al.* 1981; Anderson, 1986; Marsh *et al.* 1994; Preen *et al.* 1997). During the winter, the temperature profile of Shark Bay is a primary determinant of dugong distribution, as areas such as Henri Freycinet Harbour and Faure Island/Wooramel Banks fall well below 18° C, which is perceived to be the lower thermal limit of dugong tolerance (Anderson, 1986; Marsh *et al.* 1994; Preen *et al.* 1997). During this period dugongs concentrate in the deep, warm waters of the western bay (Anderson 1986, Marsh *et al.* 1994; Preen *et al.* 1997; Gales *et al.* 2002).
With the removal of this constraint during the summer, distribution is probably more reflective of other constraints, such as availability of preferred seagrass species. The temperature profile of Shark Bay during the summer is far greater than 18°C (Fig 4.1) and dugongs are more widespread. In particular, there is a distinct movement of dugongs into shallow waters that are apparently too cold in winter (Table 4.3). Given that these shallower waters are known to contain extensive seagrass beds (Anderson 1982, 1998; Walker 1988, 1989) of species known to be preferred dugong forage (e.g. *Halodule uninervis* and *Halophila ovalis*), it would appear that the presence of suitable food is the primary determinant of dugong distribution in summer.

That seagrass is the main determinant of dugong distribution is supported by the lack of dugongs in the south east of the bay (Block 2). Although water temperature was well above 18°C within this area, few dugongs were observed. This region, known as Hamelin Pool (Fig. 1.1), is a hypersaline environment as a result of limited oceanic exchange due to the presence of the Faure Sill. Analysis of satellite imagery, aerial photography and ground truthing has determined that due to this high salinity regime throughout the pool and particularly at the lower end there is minimal seagrass (Bruce 1987; Bancroft and Davidson 2002). It is possible also that the water temperature was too high in this shallow part of the bay. However, sea surface temperatures were similar to those recorded in Henri Freycinet Harbour (Fig. 4.1).

While it has been shown that Henri Freycinet Harbour supported a significant population of dugongs during the summer (Prince *et al.* 1981, Anderson 1986), we have found that approximately 25% of the total Shark Bay dugong population were observed here during this survey. To put this into an Australian perspective, this area of approximately 30km x 40km (1200km²) houses a dugong population greater than that estimated for the entire Southern Great Barrier Reef in 1994, an area of over 24000km². In terms of total numbers of dugongs within a small area it is rivalled only by Hervey Bay (2200 dugongs in 1988 prior to the loss of seagrasses following flooding) (Preen and Marsh 1995), the Starcke River region in far northern Queensland (approx 5300 dugongs in 2000) (Marsh and Lawler 2002) and central Torres Strait (3500 dugongs) (Marsh *et al.* 2004). The density of dugongs in this area (2.2 dugongs/km²) is only exceeded by Missionary Bay (2.6 dugongs/km²) in north Queensland (Marsh and
Lawler 2001) and the Starcke River region (3.35 dugongs/km²) (Marsh and Lawler 2002).

In Moreton Bay, the southern most limit of distribution on the Queensland coast and where there exists a seasonal distributional shift, Lanyon (2003) recorded an estimate of 503± 64 (s.e.) in July to 1019 ± 166 in January. That survey showed a different dispersal pattern than Shark Bay with dugongs being more widespread during the winter than in the summer (Lanyon 2003). Globally, there have been few quantitative surveys done to determine dugong abundance to allow similar comparisons. The only areas outside Australia known to support populations comparable to Shark Bay are the Arabian Gulf and the Red Sea where quantitative surveys have been conducted (Preen 1989). Preen’s 1989 survey of the Arabian Gulf (survey area 34 604 km²) returned an estimated 7307 (± s.e. 1302) animals, while his survey of the Saudi Arabian waters of the Red Sea (survey area 22 370 km²) returned an estimated 1818 (± s.e. 382) animals.

A key feature of the distribution recorded in this study is the clear separation into two distinct groups of dugongs during summer. This survey confirmed the already suspected importance of the area around Faure Island/Wooramel Banks in the Eastern Gulf during the summer. Perhaps more importantly, however, it has also allowed us to identify the area to the southwest of Peron Peninsula within Henri Freycinet Harbour (Block 0) as a key area for the Shark Bay dugong population during this period. Given that the waters in this area are deeper than those within the Eastern Gulf, there may be somewhat different seagrass habitat composition and associated foraging behaviour adaptations not dissimilar to what occurs during the winter months further out in the Western Gulf. No analysis of seagrass composition of this area was undertaken during this study, and as mentioned in chap 3 only one animal was tagged within this region, but departed the area immediately after capture. Targeted seagrass habitat mapping within this region is a recommended approach to address these questions, and if further satellite tagging were to occur within Shark Bay this region should be focused on.
The implications of this summer distribution pattern are unknown, but may affect population genetics for the Bay overall. Anderson (1997, 2002) observed that male dugongs within South Cove (Figure 1.1), in the Eastern Gulf, exhibited Lek mating activity. Whilst the exact timing of calving within Shark Bay is unknown, these males were observed in South Cove from November through to January (Anderson 1997), suggesting that the mating season is during the summer months. In addition to the Lek mating activity, a large mating herd was observed in the vicinity of South Cove within block 3 from the air during the summer previous to this survey (personal observations). This herd comprised of more than 10 animals in a tight cluster, behaving significantly differently from other herds of >10 dugongs within the vicinity and similar to mating herds described by Preen (1989).

If this survey is indicative of the entire summer distribution pattern, with the population essentially split between the gulf s and individual breeding age animals exhibiting a degree of site fidelity, then there may be some level of reproductive isolation. To address this issue would require either genetic analysis or extensive data on the movements of individuals over summer. In the latter case, even if movements between the two sub-populations were relatively common, they could easily be overlooked because of the strong limitations on sample sizes imposed by the cost and logistics of satellite tracking. However, movements over this scale (approx. 200 km) have been recorded quite frequently in eastern Australia (Preen 2001) (Sheppard et al 2006) and in Shark Bay during winter as shown in Chapter 3 through satellite tracking.

4.4.2. Changing Abundance of Dugongs in Shark Bay.

Shark Bay has supported a globally significant dugong population at least since quantitative aerial surveys commenced in 1989. It was also notable, until 1999, in having an apparently stable population. The most significant outcome of the survey conducted in 1999 by Gales et al. (2004) was an observed increase in the population of approximately 40% (to 14 000 animals) while also recording declines in the sizes of populations at Exmouth Gulf and Ningaloo Reef 350 km to the north. Their conclusion was that the most plausible explanation for that result was that dugongs had moved
southwards from the Exmouth/Ningaloo area, most likely as a result of loss of seagrass food resources following category five Cyclone Vance, which passed through Exmouth Gulf a few months previous to that survey. A subsequent survey of the Pilbara coast including Exmouth Gulf in April 2000 by Prince (2001) confirmed the scarcity of dugongs with only 2 animals sighted during that survey. This 2002 survey has shown a return to pre-1999 numbers. Based on results from previous winter surveys and the hypotheses put forward by Gales et al. (2004), there appear to be four possible explanations for this, including large scale die-off of dugongs, variation in survey conditions, a northward return of animals which migrated down from Exmouth or an annual seasonal migration of dugongs from regions to the north. These possible explanations are discussed briefly below.

For this summer survey it was anticipated that conditions would be marginal, given the experience of previous studies, particularly because of high winds. However sea conditions for the most part were below Beaufort 2 or 3, consistent with the previous winter surveys and observations of glare were consistent on both sides of the aircraft. Additionally, estimates of group size and correction factors (which are based on both conditions and personnel) are close to those for previous surveys (Table 4.1). While some proportion of the estimated change in population between winter 1999 and summer 2002 may result from differences in correction factors, they appear not to be sufficient (Table 4.1) to explain the majority of the decrease.

Similarly, massive mortality is unlikely to explain the difference in 1999 and 2002 population estimates. If such mortality were due to a single event, then it would have come to the attention of the numerous users of the Bay. If not, and the decline was due to mortality at a constant rate, then it would have to be approximately 8-9% per year and would lead to a catastrophic situation if it continued. Again, the death of 1000 dugongs per year is unlikely to go unnoticed. In the time between surveys a total of three dugongs were reported dead of unknown causes (Holley unpublished data). Similarly, any event or activity likely to cause such a decline should be easily identified. Possibilities include indigenous hunting (e.g. Heinsohn et al. 2004; Marsh et al. 2004) or seagrass die-off (e.g. Preen and Marsh 1995). However, no increase was recorded in
indigenous hunting over that period (Holley unpublished data) nor was there loss of seagrass recorded at a scale that would cause such an effect.

The most likely theories explaining the reduction in dugong numbers that are observed here is that of a northwards return of those animals that shifted south to Shark Bay following Cyclone Vance or that these are movements indicative of a regular exchange of animals during this time of year. Movements at these scales are increasingly recorded when dugongs are tracked via satellite telemetry, as shown by the movements from instrumented animals in Chapter 3 and the over 50 dugongs which have recently been tracked on the east coast of Queensland (Sheppard et al. 2006). Nearly one third of the Queensland animals ranged over distances greater than 100 km and approximately 10% moved distances as great, or greater, than the distance between Shark Bay and Ningaloo Reef (~500 km). Additionally, in other areas where repeat aerial surveys have been conducted over large scales, similar trends are emerging with respect to substantial increases and decreases over time scale too short to allow reproduction to be an appropriate explanation. In the southern Great Barrier Reef, surveys in 1986-87, 1994 and 1999 returned estimates of 3479, 1682 and 3993 respectively (Marsh and Lawler 2001). Similarly, estimates in Torres Strait ranged from 13300 in 1987 up to nearly 28000 in 1996 and down again to approximately 14000 in 2001 (Marsh et al. 2004).

Unfortunately an estimate of the corresponding dugong population of Exmouth and Ningaloo cannot be given here as such a survey was beyond the scope of this study. While no dedicated dugong survey has been conducted during the period of this survey, dugongs have been sighted in increasing numbers within the Gulf over the previous two years. Benthic surveys of Exmouth Gulf conducted for the assessment of enhancing Panaeid prawn stocks, have noted a general increase in dugong presence since the cyclone as well as quantifying the re-establishment of seagrass communities. Seagrass species identified as returning include *Halodule uninervis*, *Halophila spinulosa* and *H. ovalis* (Longeran et al. 2003), all species known to be consumed by dugongs.
4.5 Conclusions and Management Implications.

The outcomes from this summer aerial survey have confirmed and quantified a distinct seasonal shift in the distribution of the Shark Bay dugong population suspected by previous authors and suggested by remote instrumentation (Chapter 3). The abundance estimates obtained from this survey suggest that the size of this population continues to remain at a consistent level indicating that the Shark Bay ecosystem continues to be able to support and maintain one of the highest densities of dugongs in the World. This population and the condition of Shark Bay may become increasingly important, with recent studies showing that indigenous harvest of dugongs in Torres Strait and Cape York Peninsula, the two other most important dugong populations in Australia, are unsustainable (Heinsohn et al. 2004; Marsh et al. 2004).

The use of aerial surveys as a tool in determining the status of this dugong population has to date been particularly relevant. The results for the winter surveys have been informative for measuring fluctuations in this population and providing regular population estimates. With the completion of this most recent survey, which has given a snapshot of the population during a summer period, we are detecting general population trends over time and gaining an understanding of how this population utilises Shark Bay throughout the year.

The importance of these surveys is also highlighted through hypothesised and measured large scale movements. For example, the impact of large scale catastrophic events to the north indicates that the Shark Bay dugong population should not be considered in isolation. Discussions have been held with managers (including the Great Barrier Reef Marine Park Authority and the Australian Fish Management Authority) and researchers on the east coast about how to deal with the issue of large-scale movements of dugongs in the context of monitoring programs (Marsh and Lawler 2004; Stokes 2004). As these refinements are developed, the local managers may wish to consider them in the light of connections between dugong populations in Shark Bay and the Pilbara region.
CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

The results achieved from this study contribute to a greater understanding of the ecology of the dugong within the Shark Bay World Heritage Area. This population of dugongs, as shown from aerial surveys in this and previous work, is large and stable, with consistently high abundance estimates. These surveys have also shown a population density higher in Shark Bay than any other location where similar surveys have been conducted. Maintenance of these estimates is partially attributed to the low level of threatening activity to which dugongs and dugong habitat are exposed within Shark Bay. The significance of this population for global dugong conservation, therefore, cannot be underestimated, not only because of this species’ high biodiversity value but also as a reference population for remaining populations elsewhere (Marsh et al. 2002).

This study shows the distribution of dugongs in Shark Bay on both an individual level and population level and throughout the year. It has also identified high use locations and provides both fine- and large-scale habitat descriptions. The study has also identified critical pathways and movement behaviours utilising new technologies and techniques in a manner that minimised the impact on target and non-target animals. Some impact was expected, however, and the degree and extent of these impacts were measured as part of the study.
5.1 Scope

The major findings of the research, as detailed throughout the dissertation, are given below in the context of the major objectives of the research, as described in chapter 1.

1. Develop methods and techniques associated with the attachment, application and release of remote transmitting and logging platforms to allow finer scale resolution of dugong distribution (Chapter 2).

Prior to this study the application of remote recording and transmitting devices had never been applied to measure dugong distribution and behaviour or to define habitat usage within Shark Bay. Therefore, a critical first step in this process was the development of attachment and release mechanisms for the units, as well as appropriate capture and holding techniques for conditions in Shark Bay. In order to understand the movements of animals over a large scale, PTT units (satellite transmitting only), which had been successfully deployed on dugongs in Queensland (Marsh and Rathbun 1990), were reused in this study. No changes were made to the attachment or release mechanisms used in these units. These tags were effective in measuring individual dugong movement patterns at low resolution but the release mechanism, which consisted of a corroducible link within each tag, was inhibited by the salinity regime in Shark Bay resulting in tags remaining attached for extended periods.

The use of GPS to measure fine scale movement pattern was the first application for this type of instrument on this species. As the tags used in this study were data loggers, compared with the PTT’s which remotely transmit location and behaviour data, it was necessary to develop a release mechanism to allow for tag retrieval in order to access data. This remote release mechanism, located in the harness and triggered remotely, involved an electrolytic reaction dissolving a wire trace and resulting in the harness detaching from the animal’s tail. As the GPS units had previously been untested
on dugongs in Shark Bay, a pilot study was undertaken to determine the effectiveness of
the release mechanism, as well as the units’ ability to effectively record an animal’s
position. This study showed that the units accurately recorded an animal’s position and
that tags could be retrieved remotely without creating any further disturbance to the
dugong. Both tag types were attached to dugongs using the same method that is by a
harness and three metre tether with the tag floating at the end. As the tags are only
capable of transmitting or logging a location when above the water surface, there was an
inherent bias towards shallow water distribution of recorded locations.

2. **Apply these methods in the field as well as develop and refine
techniques for the appropriate ethical approach to the chase, capture and handling
of dugongs within the waters of Shark Bay (Chapter 2).**

The capture method adopted for use in this study, termed the ‘chase and grab’ or
‘rodeo’ method (Lanyon *et al.* 2002), was appropriate for the waters of Shark Bay with
average chase to release times of 12 minutes throughout the year. Whilst it was the most
appropriate technique, there is no doubt that there was an impact upon the dugong from
this type of intensive activity. At the least, it should be anticipated that the chase and
capture procedure may alter an animal’s behaviour resulting in location shifts in the
immediate aftermath of capture, and possibly up to a few days after. It is therefore
critical that the information gathered during each chase and grab be maximised to
warrant the stresses placed upon the animal.

From a total of 18 successful deployments a combined dataset of approximately
10,000 locations from a 2 year period was generated. From the tag data the PTT
deployments were successful in determining the large scale movements of four animals
over a period of up to 11 months, whilst the GPS units functioned effectively in
recording fine scale movements over smaller temporal scales, but with greater
resolution and a higher recording rate than that of the PTT units. The number of study
animals and recorded locations from all tags are comparable from previous intensive
tracking studies performed on dugongs elsewhere within their range.
3. By use of developed remote recording techniques define large scale seasonal movement pathways and fine scale critical habitat areas for individual dugongs within the Shark Bay World Heritage Property (Chapter 3).

The effectiveness of remote recording devices being used to measure the distribution and behaviour of species such as the dugong, which are by nature difficult to observe, is shown in the large-scale distribution of animals over the seasonal year. While a seasonal movement pattern had previously been determined in response to shifts in water temperature (Prince et al. 1981; Anderson 1982a, 1986, 1998; Marsh et al. 1994) the true extent of this pattern and the movement pathways have never been fully understood.

From the PTT deployments four animals retained tags for periods long enough to show a significant shift from core areas in the summer to a separate winter distribution pattern. Whilst this distribution was within the confines of Shark Bay, three of the four animals travelled up to 150km between each centre of seasonal activity. This seasonal shift resulted in these animals, tagged within the eastern gulf, leaving the lower reaches of this gulf coincident with a reduction in SST. Upon increase in SST all three animals returned to the eastern gulf. In addition, the home ranges of these animals overlapped. The fourth animal that retained a tag long enough to discern a seasonal pattern was a female who remained within the confines of the eastern gulf though there was a distinct shift to the north and into deeper waters, again coincident with a shift in SST.

This seasonal shift in distribution for all tagged animals resulted in an average increase in water depth in additional to the changes in SST. Although well within the diving capability of dugongs (Chilvers et al., 2004), there is a clear change from an average depth during summer of 3-5 m to an average depth of 5-10m during winter. It was shown that in addition to this direct movement between seasonal centres of activity, these animals also undertook exploratory return movements, possibly in search of alternate forage sources.
Fine scale movements as determined from the GPS deployments showed that within core centres of activity dugong movements are highly individualistic. These movements also showed the importance of sheltered regions for dugong distribution, with animals clearly spending the majority of time within those protected areas and avoiding areas subject to high wind and fetch conditions. These deployments also identified critical habitats outside of the preferred winter and summer core areas, such as the Guischenault Point region.

Analysis of pathways showed that the Peron Peninsula is the dominant feature governing the movement of animals between the two gulfs. Additionally, dugongs tend to use the edges of seagrass banks when travelling within core areas, while travel between core areas requires a direct route through the deeper areas in the centre of each gulf. No tagged animal left the Shark Bay area as defined by the SBWHP boundary during the course of this study. While some animals travelled considerable distances between recorded locations, they were smaller than the maximum distances travelled by dugongs tagged in Queensland and Indonesia, while average speeds of dugongs within Shark Bay as determined from these deployments were comparable with speeds travelled by other tagged dugongs at these other locations (De Iongh et al. 1998, Preen 1992, 1995a; Marsh and Rathbun 1990).

4. Through the use of ground-truthing and existing GIS datasets, characterise the benthic habitat at those locations deemed to be of significance as established through remote recording devices (Chapter 3).

The characterisation of habitat for dugongs within those areas determined as high use from tag deployments could only be undertaken within the autumn-winter-spring distribution pattern of the animals. These habitat surveys showed that the benthic habitat at preferred locations differed markedly from that in locations animals were moving through. The predominant species available for dugong forage at these times of the year is the perennial species Amphibolis antarctica. It appears that the preferred areas for forage is where this species occurs with a percentage cover of 30-80%, an above ground biomass of 110-360 g m\(^{-2}\) in waters <5 m. These preferred forage sites
also occurred within 1000m of areas of deeper water. Coarser analysis of PTT distribution against the GIS datasets showed that distribution was skewed towards areas of dense perennial seagrass species.

5. Using established aerial survey techniques determine the summer distribution pattern and abundance estimates for the entire Shark Bay population. Compare with previous winter survey distribution patterns (Chapter 4).

The undertaking of a comprehensive aerial survey of dugongs during the summer in Shark Bay had never previously been fully achieved. The results from this survey, when compared with previous winter aerial surveys, confirmed that the Shark Bay dugong population undertake a seasonal migration pattern consistent with that exhibited by individual tagged animals. The total abundance estimate of 11 021 +/- 1 357(se), with a density of 0.74 dugongs km$^{-2}$ represented a decrease of 30% since the previous survey conducted in the winter of 1999 (Gales et al. 2004). That previous survey gave an estimate 40% higher than the previous survey in 1994 (Preen et al. 1997), possibly the result of immigration of animals into Shark Bay from regions further to the north in response to a cyclonic event. The subsequent decline from the 1999 survey to this survey may be as a direct consequence of these animals returning to those regions further to the north.

The survey also showed a significant shift in distribution compared with the results from the previous winter survey, again demonstrating that dugongs face changes in sea surface temperature and depth in response to seasonal cues and consistent with the result from tag deployments. In addition, the survey highlighted the importance of the lower reaches of the western gulf of the Bay for animals during the summer and suggests that during summer the entire population is split between the two gulfs.
6. Undertake this research within a framework for management purposes, and establish relationships and foster ownership of results with traditional Indigenous owners of Shark Bay (Chapter 5).

The key findings as summarised above were gathered in the context of providing this information in a manner that may be directly utilised in a management framework for dugong conservation within Shark Bay. The existing Shark Bay Marine Reserves Management Plan (CALM, 1996) is due for a required 10-year review in 2006. The review process will determine the level to which management objectives set out in the plan have been achieved, and will assess any new information that may affect management activities. In line with this process, results from this project should be assessed and incorporated into the review. In addition information gained from this study has been and should continue to be viewed in the assessment of proposed development activities such as aquaculture applications.

The strategies, in order of priority, as listed in the current plan (CALM, 1996) are to:

1. Control activities that may adversely impact on dugongs;
2. Encourage further research on dugong distribution, abundance, biology and behaviour in the reserves;
3. Implement a long term monitoring program for dugongs;
4. Investigate and report on any observed cases of dugong breeding or calving in the reserves; and
5. Encourage the wise management of important dugong habitats outside the reserves.

The outcomes from this study have made significant progress to achieving a number of the strategies as outlined above. By determining distribution patterns, core areas of activity and habitat composition at areas significant to dugongs, a
comprehensive knowledge base now exists with which to make more informed decisions regarding strategies 1 and 5. The undertaking of this program has been driven by strategy 2 and the findings have, and will continue to, generate further applied research that will provide ongoing effective conservation of the Shark Bay dugong population.

5.2 Discussion and Recommendations

5.2.1 Seasonal Movements

The confinement of dugong movements to areas within Shark Bay over the time frame of this study illustrates the importance of the entire SBWHP for the continued conservation of this large and relatively stable population. However as postulated, there may be movements on a large scale into and out of the Bay in response to large scale disturbances such as cyclones and this has implications for dugong conservation, not only within Shark Bay but the entire Pilbara region and given the significance of this population, on a global scale. This seasonal pattern, as shown by remote monitoring of individual animals and a thorough population survey during the summer months, is triggered by fluctuation in water temperature. It could be that a reduction in the availability of ephemeral species of seagrass is also a further trigger.

A drop in temperature below the dugong’s perceived thermal threshold of 18°C, identified by Anderson (1986), appears to be the major trigger for the majority of animals to undertake this migration pattern, with animals migrating from the inner regions of both gulfs to the outer areas of the Bay. However readings from a number of GPS tag deployments and remotely sensed SST at those times and locations consistent with PTT tag distribution would suggest that animals can remain in waters between 15-18°C for weeks at a time, and may actively search cooler waters for preferred forage.

The seasonal fluctuation in water temperature throughout Shark Bay results in limited production, distribution and abundance of those species of ephemeral seagrasses that form a significant component of dugong diet during the warmer summer months. In
a tropical environment in North Queensland it was shown that as the temperature drops production of these species diminishes (Lanyon and Marsh 1995), so reducing the availability of that forage type. Although, as has been shown in this study, dugongs feed on the perennial species such as *A. antarctica*, particular during the winter months, they appear to prefer the ephemeral species. If the ephemeral species are not available in cooler waters, it appears to be more energetically beneficial for the dugongs to forage upon the perennial species in warmer waters.

The distribution of animals during the winter months reflects the influx of warmer waters associated with the southward flowing Leeuwin current. Associated with this shift to the warmer oceanic waters is an increase in the average depth of water, and the availability of only one species of seagrass, *A. antarctica*, for forage. It was previously suggested that a deeper-water ephemeral species, *Halophila spinulosa*, (Anderson, 1998) might be available during the winter periods. However this species was not located in heavily foraged locations during this study. Surveys conducted for Paneid prawns in Exmouth Gulf identified large areas of *H. spinulosa* where none had been observed prior to cyclone Vance (Lonergan *et al* 2003). While dugongs may selectively forage on *H. spinulosa* when available, it would not appear to be a consistently reliable forage source from one winter to the next.

In a management context this seasonal pattern has implications for how human based activity within the Bay is controlled throughout the year to avoid adverse impacts upon the dugong population. Currently, boating activity peaks during the winter months when lighter winds and cooler temperatures attract greater numbers of people to the Bay, both recreationally and commercially. Among those activities that may directly impact upon animals are boat strikes from recreational and commercial vessels, with numerous vessels travelling at high speeds over shallow seagrass banks particularly surrounding Dirk Hartog Island. While there are recorded incidents of boat strike as a source of dugong mortality in Egypt, South East Asia and Australia (Marsh *et al* 2002) there is no direct evidence of strikes occurring within Shark Bay. However from interviews with local recreational fishers and assessment of 2 early-released GPS tags, boat strikes appear to occur within the Bay, albeit infrequently. Currently there are pamphlets and warning brochures advising boat operators to exercise caution when
travelling throughout the Bay (CALM 1996) and while these publications do provide some guidance in operating vessels near dugongs they do not adequately give details on those areas where the likelihood of encountering large numbers of animals at particular times of the year. It is where these large herds are encountered over shallow banks that the potential for strike is high.

While this level of disturbance is currently regarded as low, establishing education programs highlighting the seasonal movement pattern and the dugong’s utilisation of distinct areas throughout the year would provide users of the marine park with a more intimate knowledge on dugong movements and locations throughout the year, highlighting areas where caution should be exercised and contribute to lower levels of vessel and other types of disturbance. This would effectively facilitate conservation of the population, as would the associated increase in the local community and general public’s appreciation and awareness of dugong ecology within the Bay.

The major seasonal dugong migration pattern within Shark Bay can therefore be used as a platform for education and interpretation programs focusing on dugongs and dugong habitat within the SBWHP. An example of a seasonal movement or migration pattern of another marine mammal in Western Australia that is highly publicised and forms an existing education program is that focussing on the movements along the West Australian coastline of the Humpback Whale (*Megaptera novaeangliae*). Although on a significantly larger spatial scale than the movements of dugongs within Shark Bay, the Humpback migration caters to a large tourism industry, which in turn fosters a greater understanding and appreciation of this species’ ecology.

### 5.2.2 Defined Critical Habitat Areas

While the core areas of activity (Figures 3.5) were defined on the basis of tracking data from a small proportion of the Shark Bay dugong population, there was overlap in usage of areas amongst even this small sample. Anecdotal information from a number of sources also indicates that these core areas of activity regularly contain large
numbers of dugongs. In addition there are likely to be other areas not identified within this study that would regularly contain large numbers of animals for extended periods of time. These core areas of activity are should be key focal points for managing human activities, since inappropriate activity may impact on their availability to dugongs throughout the year.

Working aquaculture leases, such as pearl and fish-farms, can reduce the availability of these areas through direct exclusion, by placement of nets and lines associated with lease production or through indirect exclusion by generation of noise and vessel activity. Currently there are 15 licensed aquaculture leases within the SBWHP with a further 5 in application (WA Dept of Fisheries 2002). The majority of leases operate as pearl farms or grow out farms for tuna. Given the economic importance of these activities not only to the region but to the state as a whole there is serious consideration given to the all the likely impacts upon any of the listed criteria on the Shark Bay World Heritage register before any lease application is declined. However, in respect to dugong conservation, future granting of leaseholds may contribute to the exclusion of dugongs from habitats that are just as desirable to aquaculture activities as they are to dugongs.

A suggested management measure based on the results of this study would be through the definition of these identified core areas as important dugong conservation zones. By undertaking this step, greater protection can be afforded to dugongs by ensuring that activities likely to impact directly on animals or indirectly through habitat disturbance are minimised. In addition the measured habitat variables of these core areas could form the basis for research into similar areas within the Bay. Through the identification of additional sites and through the creation of further conservation zones, based on the variables as shown to be of significance to dugongs within this study, greater certainty in providing adequate dugong conservation could be achieved for this population within Shark Bay.
5.2.3 Winter Habitat Resources

The habitat surveys demonstrate that in the winter distribution pattern the predominant forage available for dugongs is the seagrass Amphibolis antarctica (Table 3.3). As discussed previously, Anderson (1994) suggested that dugongs may also forage on deep-water Halophila spinulosa during the winter, but this species was not recorded at winter usage site in this study, highlighting the significance of A. antarctica for dugong forage requirements in Shark Bay. Effective conservation of this population of dugongs requires ongoing access by dugongs to the forage areas identified within this study as well as similar habitats throughout the bay. Hence, an appropriate management measure would be the recognition and protection of A. antarctica beds within the dugongs winter distribution range. Through the application of these protective measures in the light of these Amphibolis antarctica meadows providing critical forage requirements for dugongs, again further certainty would be provided for the long term maintenance of this critical global dugong population.

5.2.4 Dugong Distribution Outside of the Shark Bay Marine Park

The movement data from this study indicates that significant numbers of dugongs move through areas outside the marine reserve boundaries. The Shark Bay Marine Park is an effective conservation mechanism for dugongs and habitat within its boundaries. Outside the marine park dugongs are subject to the same level of protection both under the Wildlife Conservation Act 1950, but certain activities can occur outside the existing marine park structure which may indirectly impact on dugongs.

The major threats to dugongs in Shark Bay outside of the marine reserves are likely to derive from activities such as trawling, which can disturb seagrass habitat, and seismic exploration, which can generation excessive noise levels to which dugongs may react adversely. In addition, shipping movements and dredging activities are also likely to impact indirectly upon dugongs outside of the reserve through the generation of noise and habitat modification. The main application of the results of this study in terms of
revealing the wide ranging movement patterns of dugongs in the Bay is to illustrate that appropriate conservation of this population requires protection measures that reflect the dugong’s entire spatial distribution, and not just within the marine reserve boundaries.

The distribution of dugongs outside of this reserve structure was first identified during the winter aerial surveys of 1994 and 1997. These surveys showed that during these periods more than half of all observed dugongs occurred outside of the existing Marine Park boundary (Preen et al. 1997). It was identified that because of the importance of the Shark Bay dugong population consideration needed to be given to the extension of the existing Shark Bay Marine Park boundary to match that of the Shark Bay World Heritage Boundary, to adequately encompass all dugong distribution and migration movements within the Bay (Preen et al. 1997). The existing reserve structures for this population and that for dugongs to the north in Ningaloo Marine Park are considered to be inadequate for the management of dugongs along Australia’s Indian Ocean Coast (Preen 1998). In the light of these previous findings and those on the distribution of individual animals (this study) and the dugong population (this study and Gales et al., 2004), further consideration should be given to the extension of existing reserve structure and the management of the Shark Bay and Exmouth/Ningaloo dugongs as a single unit.

5.2.5 Future Intensive Dugong Research Programs

The capture and deployment procedure employed in tagging dugongs for this program, as well as previous programs within Shark Bay, followed strict protocols (Lawler et al. 2000; Gales and Holley, in prep.) to ensure the potential of injury or death to the dugong was minimised. The chase and catch procedure employed during this program is believed to represent the safest option for dugong capture (Lawler et al. 2000, Lanyon et al. 2002). Nevertheless it can be reasoned that the disturbance created by this activity is probably acute. Although no dugong mortality events are known to have occurred from the tagging procedures during this or previous programs in Shark Bay, very little is known about the susceptibility of dugongs to mortality after capture.
Aside from the direct impact upon dugongs that were tagged, there were likely to be other animals in the vicinity that may have been disturbed by this activity. The combined disturbances created from the catch process on non-target as well as target animals, particularly at identified catch locations over an extended period, may increase this population’s susceptibility to mortality. Considered opinion amongst researchers involved in this project, as well as similar projects elsewhere within the dugongs range, is that the number of dugongs captured within discrete populations should be minimised to reflect the size of that population. Management agencies and institutions involved in dugong research within Shark Bay and elsewhere, should give greater consideration to ethical issues in their permit approval for programs involving intensive chase and catch procedures. Guidelines and protocols similar to those described in this study should be rigorously adhered to.

5.2.6 Indigenous Collaboration and Global Implications

A critical component of the study was the collaboration with the local Indigenous organisation, the Yadgalah Aboriginal Corporation (Inc.) (YAC). Members of this group were actively involved throughout the study program, from initial discussions on objectives and direction through to the studies conclusion. For Yadgalah an important role was that played by the elder members of the community in relaying information on where and when dugongs would occur. In many instances, the measured dugong distribution pattern mirrored this anecdotal evidence. The presentation of the movement data of individual animals to the community as the data were retrieved was an important step in this collaboration.

The YAC identified the dugong project as important at both a community level and in a broader Indigenous context. They see the project as a vehicle for increasing the involvement of Indigenous communities in similar research programs that have broad conservation and management objectives, particularly involving species such as dugongs that have both high biodiversity and cultural values. The success of this
collaboration was most recently highlighted with the YAC winning the Indigenous category of the National Landcare Awards (2004) for their involvement in the study.

This collaborative effort has implications for studies in other regions of Western Australia, particularly the Kimberley region which was identified in the Status Report for Countries and Territories (Marsh et al. 2002) as an area in which little is known about dugong distribution and abundance and the impact of anthropogenic activities such as traditional hunting upon these populations. The report states that detailed studies, carried out in conjunction with local Indigenous communities, on the extent and range of dugong movements should be undertaken as a high priority within this region. The results achieved, and relationships established, as part of this study in Shark Bay, would form an ideal foundation with which to develop a similar project in conjunction with local indigenous groups within the Kimberley region of Western Australia.

Results from this study also have implications for dugong populations in regions outside of Shark Bay and Australia. As shown, significant environmental events such as cyclones may have consequences for dugong populations in addition to the impact from day to day anthropogenic activities. Given the encroachment of humans into the coastal zone in Australia and globally, as well as the unknown implications of changing climatic regimes, species such as dugongs are facing greater threats to survival than at any time previously. The costs of this study associated with remote tracking of dugongs are out the realms of many governments and institutions throughout the dugongs range. However the findings of habitat use and movement patterns based on variables such as temperature and forage composition and distribution may be useful for identification and delineation of dugong protection zones particularly at those locations at the latitudinal limits of the dugong’s range.
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(2006). Movement heterogeneity of dugongs, Dugong dugon (Müller) over large


## APPENDIX

1.1 Metadata statement for combined PTT and GPS acquired positions.

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</table>
PTT's are transmitter platforms which transmit signals at regular intervals which are received by Service Argos receivers aboard NOAA polar-orbiting environmental satellites. At least two satellites are simultaneously in service on sun-synchronous, polar, circular orbits at 850 km altitude, providing full global coverage. Locational accuracy is dependant on signal strength and satellite coverage.

Attributes recorded from the PTT units include: Location class, date, time-Western Standard Time and Lat/Long in milliseconds.

The GPS units each with an eight channel receiver, log a units position from pulses received from the navstar series of satellites. The GPS units can be user programmed to obtain a position at a rate of between 5min-6hours.

Attributes recorded on the Lotek GPS units include: Lat/Long-in milliseconds, Date, Time-Western Standard Time, Temperature- Degrees Celsius. Attributes on the Telonics Gen II units include; Lat/Long-in milliseconds, date, Time-Western Standard Time, Temperature- Degrees Celsius.

An accuracy attribute is recorded against each location.

Deployment and retrieval dates for each unit type are listed below:

<table>
<thead>
<tr>
<th>PTT UNIT</th>
<th>DATE DEPLOYED</th>
<th>DATE RETRIEVED</th>
</tr>
</thead>
<tbody>
<tr>
<td>5519</td>
<td>22/03/2000</td>
<td>11/12/2000</td>
</tr>
<tr>
<td>5065</td>
<td>22/03/2000</td>
<td>05/04/2000</td>
</tr>
<tr>
<td>5534</td>
<td>23/03/2000</td>
<td>25/10/2000</td>
</tr>
<tr>
<td>5536(1)</td>
<td>23/03/2000</td>
<td>04/04/2000</td>
</tr>
<tr>
<td>5536(2)</td>
<td>06/04/2000</td>
<td>28/05/2000</td>
</tr>
<tr>
<td>5535</td>
<td>23/03/2000</td>
<td>23/10/2000</td>
</tr>
<tr>
<td>5537</td>
<td>22/03/2000</td>
<td>16/08/2000</td>
</tr>
<tr>
<td>1311</td>
<td>16/05/2001</td>
<td>01/07/2001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GPS UNIT</th>
<th>DATE DEPLOYED</th>
<th>DATE RETRIEVED</th>
<th>FIX ACQUISITION RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>8001</td>
<td>15/08/2000</td>
<td>05/10/2000</td>
<td>15 MINUTES</td>
</tr>
<tr>
<td>8002</td>
<td>16/08/2000</td>
<td>04/10/2000</td>
<td>15 MINUTES</td>
</tr>
<tr>
<td>8003</td>
<td>16/08/2000</td>
<td>03/10/2000</td>
<td>15 MINUTES</td>
</tr>
<tr>
<td>8004</td>
<td>17/08/2000</td>
<td>21/09/2000</td>
<td>15 MINUTES</td>
</tr>
<tr>
<td>8005</td>
<td>17/08/2000</td>
<td>01/10/2000</td>
<td>15 MINUTES</td>
</tr>
<tr>
<td>7301</td>
<td>18/09/2001</td>
<td>28/09/2000</td>
<td>20 MINUTES</td>
</tr>
<tr>
<td>7001</td>
<td>20/09/2001</td>
<td>28/09/2001</td>
<td>20 MINUTES</td>
</tr>
<tr>
<td>0803</td>
<td>21/03/2002</td>
<td>11/05/2002</td>
<td>15 MINUTES</td>
</tr>
<tr>
<td>0807</td>
<td>17/06/2002</td>
<td>25/07/2002</td>
<td>15 MINUTES</td>
</tr>
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<td>0606</td>
<td>18/06/2002</td>
<td>09/08/2002</td>
<td>15 MINUTES</td>
</tr>
<tr>
<td>0602</td>
<td>19/06/2002</td>
<td>04/07/2002</td>
<td>15 MINUTES</td>
</tr>
<tr>
<td>0603</td>
<td>20/06/2002</td>
<td>02/07/2002</td>
<td>15 MINUTES</td>
</tr>
</tbody>
</table>

1. Data are downloaded from the GPS tags in the datum WGS 1984 via a link unit, in a comma delimited file (.csv) Data are then converted into a text delimited file (.txt) and imported in Arcview and converted into shapefiles (.shp). For the PTT units, data are retrieved from service Argos in a spreadsheet format in the datum WGS 1984, then imported into Arcview in the same manner and converted into shapefiles.

Positional Assessment of the closeness of the location of spatial objects in the dataset in relation to their true positions on the earth's surface after all transformations have been carried out.
1. The two unit types used in determining dugong locations have a varying degree of spatial resolution. PTT units have a degree of error dependant upon satellite strength and location. For PTT location accuracy, service Argos has a location class attribute. The resolution associated with each class is listed below.

<table>
<thead>
<tr>
<th>CLASS</th>
<th>ESTIMATED ACCURACY IN LATITUDE AND LONGITUDE.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>&lt;150m</td>
</tr>
<tr>
<td>2</td>
<td>150m - 350m</td>
</tr>
<tr>
<td>1</td>
<td>350m - 1000m</td>
</tr>
<tr>
<td>0</td>
<td>&gt;1000m</td>
</tr>
</tbody>
</table>

2. With the removal of Selective Availability the GPS units’ positional accuracy is now estimated at <10.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attributes for this dataset are consistent with CALMs Marine Information System standards and values are drawn directly from original download files (see additional metadata).</td>
<td></td>
</tr>
</tbody>
</table>

| Logical Consistency | All points are labelled correctly with values drawn from the original download files (see additional metadata). |

| Completeness | The data set will be upgraded as more units are deployed and retrieved. |

**CONTACT INFORMATION**

<table>
<thead>
<tr>
<th>Contact Organisation</th>
<th>Department of Conservation and Land Management, Marine Conservation Branch.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact Position</td>
<td>Marine Zoologist.</td>
</tr>
<tr>
<td>Mail Address</td>
<td>1</td>
</tr>
<tr>
<td>Mail Address 2</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>---</td>
</tr>
<tr>
<td>Suburb or Place or Locality</td>
<td></td>
</tr>
<tr>
<td>State or Locality 2</td>
<td>WA</td>
</tr>
<tr>
<td>Country</td>
<td>Australia</td>
</tr>
<tr>
<td>Postcode</td>
<td></td>
</tr>
<tr>
<td>Telephone</td>
<td></td>
</tr>
<tr>
<td>Facsimile</td>
<td></td>
</tr>
<tr>
<td>Electronic Mail Address</td>
<td></td>
</tr>
</tbody>
</table>

**METADATA DATE**

| Metadata Date | January 2003 |

**ADDITIONAL METADATA**

| Additional Metadata | Original download files have been burnt to CD and are held in the CALM\MCB\MIS CD library, 47 Henry street Fremantle, Western Australia, 6160
1.2 Metadata statement for dugong sightings acquired during aerial survey.

<table>
<thead>
<tr>
<th>DATASET</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Title</strong></td>
</tr>
<tr>
<td><strong>Custodian</strong></td>
</tr>
<tr>
<td><strong>Jurisdiction</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abstract</strong></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Search Word(s)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Geographic Extent Name(s) or Geographic Extent Polygon(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Shark Bay (SBY) and Zuytdorp (ZUY) IMCRA Regions</em></td>
</tr>
</tbody>
</table>
### DATA CURRENCY

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Begin Date</td>
<td>4/2/2002</td>
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<tr>
<td>End Date</td>
<td>15/2/2002</td>
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</table>

### DATASET STATUS

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Details</th>
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</thead>
<tbody>
<tr>
<td>Progress</td>
<td>Completed</td>
</tr>
<tr>
<td>Maintenance &amp; Update Frequency</td>
<td>As required</td>
</tr>
</tbody>
</table>

### ACCESS

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available Format Type</td>
<td>DIGITAL ArcView 3.2 shapefile</td>
</tr>
<tr>
<td>Access Constraint</td>
<td>Data available for external use subject to transfer fee and licence conditions. Data is not to be distributed without authorisation from CALM. Contact CALM's database administrator for further details.</td>
</tr>
</tbody>
</table>

### DATA QUALITY

#### Lineage

1. Location data for all sightings of megafauna observed during the 2002 summer aerial survey of Shark Bay recorded as waypoints within aircrafts GPS system in the datum WGS84.

2. Combined location data for all megafauna over entire survey period entered into Excel, then imported into ArcView 3.2 and converted to three point shapefiles representing dugongs, cetaceans and turtles.

3. Polylines representing transects and survey blocks were also imported into each active theme.

4. Data datum transferred from WGS84 to AGD84 then to GDA 94 using the change datum functionality of the extension 'CALM Added Functionality v 2001' in ArcView 3.2.

#### Positional

The locations of all sightings as recorded from this survey represent the summer distribution patterns of marine megafauna within the SBWHP. All sightings were recorded from an aircraft flying at a nominal height of 137m and a ground speed of 100 knots along...
Accuracy: Predetermined transects. Observations of animals were recorded if they occurred in relation to transect markers attached to the plane. The equivalent transect width on the water at the flying height is 200m either side of the aircraft. Sighting locations are therefore approximate only and represent an animal’s position at during the flight period.

Attribute Accuracy: Methods used in the collection of this dataset are consistent with data collected from previous aerial surveys conducted in the Shark Bay World Heritage Property. Flight paths were flown as close as possible to marked transects, however turbulence may have resulted in slight variations along each transect.

Logical Consistency: Attribute values have been checked and validated for consistency, and checked for logic in relation to attribute names. All attributes that require values have been assigned values.

Completeness: The dataset is complete as at the date of this metadata statement.

<table>
<thead>
<tr>
<th>Contact Organisation</th>
<th>Department of Conservation and Land Management, Marine Conservation Branch.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact Position</td>
<td>Marine Zoologist</td>
</tr>
<tr>
<td>Mail Address 1</td>
<td>47 Henry Street</td>
</tr>
<tr>
<td>Mail Address 2</td>
<td>Optional element where mailing address of contact position is longer than that which would ordinarily go on one line.</td>
</tr>
<tr>
<td>Suburb or Place or Locality</td>
<td>Fremantle</td>
</tr>
<tr>
<td>State or Locality 2</td>
<td>Western Australia</td>
</tr>
<tr>
<td>Country</td>
<td>Australia</td>
</tr>
<tr>
<td>Postcode</td>
<td>6160</td>
</tr>
<tr>
<td>Telephone</td>
<td>08 9336 0121</td>
</tr>
<tr>
<td>Facsimile</td>
<td>08 9430 5408</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Electronic Mail Address</td>
<td><a href="mailto:davidho@calm.wa.gov.au">davidho@calm.wa.gov.au</a></td>
</tr>
</tbody>
</table>

**METADATA DATE**

<table>
<thead>
<tr>
<th>Metadata Date</th>
<th>12/08/2002</th>
</tr>
</thead>
</table>

**ADDITIONAL METADATA**