Movement behaviours and habitat usage of West Kimberley dugongs: A community based approach

Final Report to the National Marine Mammal Centre

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EXECUTIVE SUMMARY

This project was funded by the Australian Marine Mammal Centre (AMMC) within the Australian Antarctic Division, a research division housed within the Department of Sustainability, Environment, Water, Population and Communities. The project contributed to the key need of development and application of integrated habitat studies using data from archival and telemetry tagging studies. It addressed the AMMC priority research area of ..“Quantifying the status, dynamics and forcing factors (physical, biological) of marine mammal population structure, distribution and abundance”. The projects aims were:

A-To build on past projects that developed and enhanced indigenous capacity to contribute to and conduct research on key species which will help in the development of sustainable management plans under the NAILSMA (Northern Australian Indigenous Land and Sea Management Alliance) dugong and turtle project.
B- To increase knowledge about the foraging behaviour and movement patterns of dugong in the west Kimberley region.

This program was a successful collaboration between the Bardi-Jawi community, Kimberley Land Council (KLC) and researchers from the Department of Environment and Conservation (DEC) and Edith Cowan University (ECU). Considerable knowledge was gained by both groups in this project and it should provide the basis for further research and learning opportunities for both parties. Data from this report will also contribute to the formulation of conservation management strategies by State and Federal bodies as well as contributing to local community-level sustainable hunting and management strategies. The data from this study shows that dugong can move extensive distances, thus crossing many jurisdictional and traditional boundaries, but that they also exhibit high levels of foraging site fidelity and small foraging ranges within embayments.

Dugong in the west Kimberley were tagged for this study in two locations on the Dampier Peninsula. These animals showed a variety of foraging behaviours and movement patterns, in some ways similar to other populations of dugong studied throughout Australia. Dugong were observed to move over large distances (100s of kms) but also to exhibit a high level of foraging site fidelity. Foraging ranges were similar in size to other areas around Australia but

appeared to be smaller within the Beagle Bay area than for other places along the Dampier Peninsula. Dugong in the west Kimberley travel along the sea bottom by preference and combine periods of foraging in restricted areas in between periods of migration/movement. Dugong utilised shallow water habitats (< 5metres) throughout the study area, but were observed to dive to maximum depths of approximately 20 metres. The tide and diel periods exerted a strong influence on the micro-scale patterns of habitat use, with use of the inter-tidal seagrass habitats only occurring at high waters periods during the night. These micro-scale patterns of habitat use may be influenced by avoidance of daytime predators, including traditional indigenous hunters. There was no systematic migration of animals from one area to another, however this may be due to the limited period of the deployments throughout the seasons. This study identified important foraging habitat within embayments but also along the open coastal margin of the Dampier Peninsula, suggesting that these habitats are important conservation areas for dugong. Further research to better understand the patterns of habitat use, the distribution of foraging effort and the patterns of seagrass distribution are needed to help design effective conservation programmes in this area. Studies designed to determine the seasonal migration patterns of this metapopulation of dugong are also important to understanding the links between populations of dugong throughout the north-west of WA. These data will also contribute to the development of community-led management plans for the sustainable use of dugong and the development of future research programmes to address knowledge gaps to achieve sustainable hunting outcomes. These data are also valuable in contributing to the knowledge and understanding of the likely impacts of large-scale industrial developments throughout areas identified as foraging locations for dugong in the West Kimberley.

INTRODUCTION

The dugong (*Dugong dugon*) is distributed throughout the Indo-Pacific tropical and subtropical areas. This species is the only herbivorous mammal species in the world that is exclusively marine, and as such is restricted to shallow coastal waters throughout its range (Heinsohn et al. 1997, Marsh et al. 2004, Holley et al. 2006). It has suffered range reductions and depletions in abundance due to habitat destruction, modification and incidental bycatch across its range. Australia represents one of the strongholds for this species with stable populations throughout Western Australia, Northern Territory, Queensland and in the Torres Strait (Marsh et al. 2004). This species is an important cultural and natural resource among many of the indigenous communities throughout northern Australia and very much so for the Bardi-Jawi saltwater people (Buchanan et al. 2010). The dugong is currently protected as a listed marine and migratory species under the Commonwealth EPBC Act (1999), and is considered vulnerable to extinction under the IUCN Red list based on reductions in abundance and destruction of habitat (IUCN 2009).

Dugong feed exclusively on seagrass species of the *Potamogetonaceae* and *Hydrocharitaceae* families (Heinsohn & Birch 1972, Marsh et al. 1982, Preen 1995), and their distribution and abundance is linked to the distribution of preferred forage species such as *Halophila sp.* and *Halodule* (Preen 1992, Holley et al. 2006, Sheppard et al. 2007, 2010). Dugong display varying geographic scales of site fidelity and movement, with short-medium term fidelity to small scale foraging sites (de Iongh et al. 1998, Sheppard et al. 2006, Sheppard et al. 2009) and seasonal movements based on sea temperature (Holley 2006). Dugong are also known to undertake large scale migrations and movements in response to perturbations such as cyclone activity and associated flooding and run-off events (Preen & Marsh 1995, Gales et al. 2004). The movement of dugong over large distances means that management of these animals involves many management authorities and communities that impact upon and utilise this resource.

Previous satellite tracking studies have shown that dugong often have relatively small core foraging areas, remaining with a small area (5-10km^2) for a period of months (Holley 2006, Sheppard et al. 2009), but they may undertake large unidirectional movements in relation to a variety of potential stimuli (Sheppard et al. 2006). The size of core foraging areas and the patterns of habitat utilization will depend upon the quality and abundance of the forage, which are often distributed patchily and can vary seasonally (Kirkman 1997). Factors such as tidal and diel cycles can cause micro-geographic scales of movement related to access to preferred forage (Sheppard et al. 2010) and avoidance of predation (Wirsing et al. 2007a). Understanding local-scale and wider-scale movement patterns of dugong are important for management purposes in terms of risk to exposure to interaction with commercial fishing operations and other industrial processes. The understanding of large scale movements (seasonal or intermittent) helps to define the management areas and links between regional sub-populations of animals. A better understanding of fine-scale movements and diving behavior will allow us to determine the habitat requirements of this species and the potential risk factors to dugong such as habitat disturbance (Preen & Marsh 1985) and vulnerability to boat strike whilst near the water surface (Hodgson & Marsh 2007). The intensity and patterns of dugong grazing can also have profound effects on the abundance and composition of seagrass communities, with early pioneer species being encouraged and somatic growth and seed production enhanced by grazing (Masini, et al. 2001, Aragones et al. 2006, de Iongh et al. 1995).

The Kimberley region of Western Australia represents an area where there are significant numbers of dugong, but information is scarce on distribution and behaviour of this species. Traditional usage of dugong is high and local communities have strong relationships with this species. The Bardi-Jawi people have a long history of hunting dugong (odorr) and have developed an extensive traditional ecological understanding of this species (Buchanan et al 2010).

The Bardi Jawi have been involved in numerous projects over the past decades to do with the management of marine species especially dugong and marine turtle. This has been evidenced by involvement in the West Australian Marine Turtle Project in the 1990's, turtle harvest surveys through the Department of CALM and most recently catch harvest data of both species collected by the Bardi Jawi Rangers established through the joint KLC/NAILSMA Dugong and Marine Turtle project, now funded by the Commonwealths' "Working on Country" Program.

This project will be the first examination of dugong foraging behaviour in the Kimberley using fine-scale resolution GPS tags and dive tags. This project will build capacity amongst local indigenous communities throughout the west Kimberley area to conduct research on dugong movements, behaviours and habitat requirements using GPS satellite telemetry. This project will also combine some of the traditional knowledge on the distribution and movement patterns of dugong in the west Kimberley area with the derived GPS satellite tag data. Information gathered will assist the local communities in the development of sustainable management of dugong as well as provide much needed input for the appropriate assessment of the impact of proposed large-scale industrial development within the region.

METHODS

Development of community capacity

The collaborative research program used in this study was developed over a number of years through contact between DEC research staff and the Bardi-Jawi ranger groups and representatives of the Kimberley Land Council. A previous collaborative programme between the Yadjala Corporation and one of the authors (D. Holley) on dugong foraging behaviour in Shark Bay (Holley 2006) was used as a basis for developing this program. There was also an important meeting and passing of information between Traditional Owners (TOs) of the Bardi-Jawi community and from the Yadjala group to develop this project. The programme was developed with input from the Bardi-Jawi community and the Nyul-Nyul people of Beagle Bay to provide relevant information for their ongoing management of dugong.

Throughout the programme, the participating ranger groups (Bardi-Jawi and Nyul-Nyul) were involved in the operational planning, field work and organised instrument retrieval. Whilst the data collection and analysis was primarily the task of the DEC scientists, the programme enabled the sea rangers to understand the principles behind the data collection techniques and the benefits of these data to indigenous peoples for their own management purposes.

Animal capture, deployment and tag protocols

All dugongs were caught using the rodeo technique described in Marsh and Rathbun (1990) with modifications for open water as defined by Lanyon et al. (2006). Using a harness attachment technique basically similar to that described by those authors, a floating transmitter package was tethered to a tailstock harness by a 3-m tether. The transmitter packages contained a very high-frequency (VHF) transmitter and a quick fix pseudo-range (QFP) GPS satellite tag (Telonics, Mesa, AZ). The instruments captured GPS positions within 5 seconds when at the surface. These tags were programmed to attempt to acquire a position every hour of the day and allowed X unsuccessful attempts for every acquisition. These GPS positions have an accuracy of $\leq$ 75 metres and a resolution of ± 1m. These tags also recorded PTT positions through the Argos satellite system which have an accuracy of $\leq$ 1.5 kms. The time-depth recorders TDRs (MK9, Wildlife Computers, Seattle, WA,) were attached just above the harness, i.e., effectively on the dorsal aspect of the dugong's tailstock. These were programmed to record time and depth every 2 seconds and had a depth resolution of 50 centimetres. These were archival instruments and had to be retrieved to collect the dive data. All harness attachments were designed to release automatically from the animals for retrieval via either a corrodible link or a remote radio-activated signal. This ensured that deployment time was no more than a maximum of 3 months.

Three separate deployments at two different locations were undertaken in this study between July 2009-September 2010. Traditional ecological knowledge on the spatial and temporal availability of dugong was provided by members of the Bardi-Jawi sea ranger group. Site selection was determined by aerial surveys of the coastal margin between Broome and One Arm Point. The aerial survey determined the availability of animals and confirmed the suitability of catching habitat (clear, shallow seagrass and sand bottom habitat). Deployments of tags occurred twice in Beagle Bay (4 tags in July 2009 and 2 tags in July 2010) and once in Pender Bay (2 tags in April 2010). There were limited opportunities to tag dugong in the west Kimberley area due to the temporal availability of animals and the limited number of suitable catching locations.

A pilot programme involving the capture and deployment of two dugong with Telonics PTT tags was performed in May 2008. The accuracy and frequency of positions provided by these types of tags are not comparable to the GPS units used. The data from one of these animals is presented in Appendix A and briefly discussed.

Spatial movement analysis

A percentage of PTT and GPS dugong locations were acquired remotely from the QFP satellite tags via the Argos system. The full GPS dataset and dive data from the TDRs were downloaded from tags recovered from the field. The GPS data were processed using dedicated Telonics software to provide GPS positions and diagnostic data.

Spatial data were analysed using the GIS programs ArcView 3.2 with the Animal Movement Extension (Hooge et al. 1997) used to define Home Range (Kernel 95and 50% contours with least squares cross validation smoothing function), minimum travel distances and minimum travel speeds.

Mean travel speeds were calculated for each individual. The mean number of daily locations were determined for each animal and plotted against mean travel speed as there is the potential for the GPS tag aerial to remain under the surface during higher speeds of travel and not transmit, reducing its efficacy.

Space use was determined by plotting all GPS derived positions from the tags for each individual. All parameters of movement were derived from GPS positions unless otherwise stated. Large distance movements (LSM) were determined from examination and extent of travel and minimum travel speed between successive GPS fixes. Analysis of space use was determined by performing kernel density estimates on clustered positions for each animal.

The clusters were defined by examining the range and minimum estimated speed of travel of each individual and defining the areas where individuals remained resident in an area. Clusters were defined for animals that remained in an area for at least 14 days (1 full tidal cycle) and did not display consistent unidirectional travel during that period. They also demonstrated relatively lower minimum travel speeds within clusters of positions, than during travel between clusters of positions. Clusters of positions were used to define kernel density estimates (50% and 95%) of temporal habitat use using the Animal Movement Program (Hooge et al. 1999) in Arcview 3.2 (ESRI, Remond, CA, USA). The KDEs should not be strictly interpreted as home ranges due to the short term nature of the deployments and the likelihood of large scale movements of dugong. Size of core foraging areas (KDE 50%) and the larger 95% KDE foraging area were plotted against length of animal and gender to determine the relationship with these factors. The corresponding KDE home ranges were calculated for one individual using the PTT derived positions to compare the sensitivity of the two systems of location acquisition.

The validity and sensitivity of estimating home ranges from the sample sizes of locations presented here were determined by bootstrap analysis of the minimum convex polygon estimated from randomly sampled locations for each deployed unit. This analysis was run with the function “MCP bootstrap analysis” in the Spatial Analyst extension to Arcview GIS 3.2. The minimum convex polygon estimate of home range was used as it is considered the most sensitive parameter to samples size (Seaman et al. 1999).

Dugong movement is known to be affected by tide and diel period (Sheppard et al. 2009). Analysis of variation in spatial behavior due to tide and diel cycle was compared by using definitions of these variables in Sheppard et al. (2009). They used a combination of diel period (day/night) and 3 tide height categories (high, medium, low) based on the height of water relative to tidal period means. This resulted in 6 tide-diel categories of high, medium and low water for both day and night. Water height (relative to Lowest Astronomical Tide) was determined using Seafarer software at the location as close as possible to the determined GPS position. Locations within all clusters identified in this study were defined as belonging to one of these 6 categories and plotted for visual determination. A minimum of 30 positions (preferably >50) are recommended for use of the kernel density estimate (Seaman et al. 1999, Kernohan et al. 2001). Kernel density estimates were determined for each tide-diel category for each animal, where sufficient numbers of positions were provided. The core foraging areas (KDE 50%) for each tide-diel category for each individual were plotted to determine the extent and the overlap of each defined KDE for each animal. Analysis of variation of the size of the 50% and 95% KDE among tide-diel categories and among individuals was performed using separate Kruskal-Wallis non-parametric tests.

Dive Data Analysis

Dive data were downloaded from retrieved tags and analysed using the computer programme Instrument Helper (v2.0, Wildlife Computers®). The location of the TDR tags on the tailstock, which is commonly higher than the rest of the body, particularly while the dugong is feeding (Anderson, 1998) means that there were fluctuations in the position of the tail as the dugong moves. Dives were defined as starting at a minimum depth of 1.5m as depths shallower than this could not be discriminated from surface activity due to the placement of the dive tag on the harness around the peduncle of the dugong. This was consistent with examination of diving behaviour in dugong in the literature (Chilvers et a. 2004). The tag also has a precision error estimated at 0.5m. The definition of the bottom phase of the dive was determined using the default setting in the Instrument Helper programme. Dives were classified according to a set of criteria regarding the dive length, dive depth and proportion of bottom time into 5 dive types as described in Chilvers et al. (2004). An additional dive type, deep erratic, was identified that was not represented by the criteria set out in Chilvers et al. (2004). The criteria for these dive profiles are listed in Table 1. Initial dive analysis using the 1.5 m minimum dive depth as per Chilvers et al. (2004) resulted in a large proportion of dives (>50% of total) of 1.5-2.0 metres. The vast majority of these (95%) were less than 30 seconds in duration and nearly three quarters were less than 10 seconds in duration. These data were very heavily skewed and not suitable for further analysis or comparison with previous studies. Re-analysis of diving activity with a minimum dive depth of 2.0 m was performed to give a more representative picture of diving activity and relative proportion of dive types during the deployment. Diving information recorded included the maximum depth of each dive, the duration of each dive and the surface time since the last dive, equivalent to the surface resting period between dives. A variety of other metrics were recorded but not analysed for this study.

Dive records were determined for 2 animals deployed in Beagle Bay in July 2009. No TDRs were recovered from the deployment in Pender Bay in April 2010 and data from the second Beagle Bay deployment were not recovered by the completion date of this report.

Variation in dive depth, dive duration and surface time since last dive (STSLD) was investigated with a general linear model using the predictive factors of categorical definition of tide height (high, medium, low) and diel period (day, night) with an interaction term. This model is consistent with the categories used in the analysis of spatial habitat use. Raw data were analysed except for the use of a transformation (ln +1) of STSLD to normalise data distribution. The most appropriate GLM for each of these variables was a full factorial model of tide height category and diel period (night/day). Analyses were performed separately for the two individuals due to the limited number of individuals (n=2) and the large level of difference among the two individuals.

Further descriptive statistical analyses of some of the dive characteristics across tidal and diel periods were examined for each individual to determine the possible behavioural traits or determinants for the variation in diving and foraging behavior. Tidal period was also examined as a categorical factor based on the four periods (high, ebb, low and flood) for the two tidal cycles of spring and neap tom produce 8 categories of tidal definition. These categories were based on the timing of the lunar cycle and estimated tidal heights for the area. The mean of dive characteristics (max depth, duration, STSLD) were also examined across the finer temporal scale of 1 hour blocks. This helps to determine if relationships are linear and whether there are more complex temporal patterns to dugong diving and foraging behavior.

Comparison of traditional knowledge and scientific instrument knowledge on dugong behaviours

A series of questions were posed to the Bardi-Jawi rangers, some of whom are traditional hunters of dugong in the area. The questions related to their understanding of dugong behaviour and movement from observation and knowledge passed down which could be compared with findings from the satellite and dive tag data. The survey was not an extensive investigation of knowledge of all traditional hunters in the Bardi-Jawi native title claimant area and did not include surveys of hunters from the Nyul Nyul area which includes Beagle Bay (study site).

RESULTS

Spatial habitat use and movement patterns

Deployments periods and information for the eight animals tagged are presented in Table 2. Two animals had very short deployment length (1 & 3 days) due to the detachment of the satellite unit from the tether around the animal. These animals were discarded from further analyses. Deployment length for the remainder of tags varied between 17*-49 days with a mean deployment length of 36.2 ± 17.2. This included one tag that was still deployed at the time of completion of this study. The average number of locations per day varied among animals from 13-22 with a mean of 18.02 (±3.08). The mean travel speed between successive locations for each animal was similar with a range of values of 0.5-0.75 kmh. There was no relationship between size of animal and either average number of locations per day or mean travel speed, nor any obvious gender differences in these two variables. The limited number of replicates however reduces the power to discriminate in these cases. There was a significant inverse relationship between the deployment length and the average number of locations received per day ($r=-0.96$). This suggests that efficacy of the tag is reduced with increasing deployment length which may be due to battery life and/or biofouling of the tag.

Large scale movements were evident for 3 of the remaining 6 animals (Figs. 2a-b, 3a-d). The greatest distance moved was over 400kms (BB03) over a period of 6 weeks (Fig. 2b). This animal left the tagging site, Beagle Bay, and undertook a series of large scale movements southwards parallel to the coast. During this movement there was one extended period of residency near James Price Point which represented a cluster of locations. There were large time gaps in reported positions from this animal after leaving this area with only a further 13 resolved GPS positions within the next 16 days. This may have been due to higher travel speeds or reduced tag functionality. The animal from Pender Bay, PB02, made a large scale movement to the south of the tagging location and then returned to Pender Bay over a period of 2 weeks (Fig. 2a, 3c). This may have been partly influenced by a post-capture behavioural response. The animal remained within the Pender Bay area upon return and these locations represented a cluster of locations which were used in the foraging range analysis. The other animal that displayed a LSM was BB05 (Fig. 2a, 3d), which was still deployed at the completion of the study. This animal moved soon after capture north to Perpendicular Point (at the head of Pender Bay) and then returned to Beagle Bay within a few days, a straight line at sea distance of approximately 25 kilometres. This is most likely to have been a post-capture response due to its occurrence shortly after release and the relatively short duration and distance of the move.

The spatial extent of minimum travel speed between successive locations is shown for all animals in Figs 3a-d. All dugong showed a similar range of rates of travel from 0.1-4.5 kmh. The animals that exhibited large scale movements (BB03, PB02, BB05) all displayed higher rates of travel between clusters of positions and lower rates of travel when resident in an area. The patterns of travel speed were used to help define the clusters of positions used in the estimates of foraging range by means of the kernel density estimates. Animals travelling between locations in a constant direction displayed varied minimum travel speeds from 0.5-4 kmh. Travel speeds between successive locations within clusters were much lower (< 2kmh) for the three animals that showed long distance movements (Figs 3a-c). Travel speeds of the three dugong that remained within Beagle Bay ranged from 0.1-4.5 kmh, similar to that of the animals that undertook large distance movements. Animal BB01showed a relatively large number of higher travel rates between locations than for the other dugong that remained resident within Beagle Bay. These rates of movement may be related to tide and diel effects and distinct foraging patches. These data are presented below.

The at sea locations and movement of one adult female animal from the pilot tagging program in 2008 showed a LSM from the capture location at Pender Bay southwards to an area near James Price Pt and Coulomb Pt (Appendix A). This pattern of movement was similar to that of animal PB02 (Figs. 2A, 3C)

Kernel density estimates and foraging range

Estimates of the core and 95% probability foraging ranges of the 6 dugong are presented in Figs. 4a-c. The four animals that foraged within Beagle Bay had similar sized foraging ranges (0.17-0.67 km2 50%KDE and 2.1-2.95kms 95% KDE, Table 2). There was no overlap of space use among these animals as shown by the extent of the 95% KDE. In most cases the two foraging range estimates were single, contiguous areas. The exception to this was BB02, which had four separate areas of 95% kde, suggesting distinct foraging sites. The KDE estimates for the 2 dugong which foraged outside of Beagle Bay (BB03, PB02) were of similar size but were considerably than for the dugong which remained inside of Beagle Bay (Table 2). There was no significant relationship between the size of the KDE and the number of locations suggesting that deployment length has no influence on the size of foraging area (r2=0.06). There was no relationship between the size of KDE and the length of the animal. The two female dugong that were tagged for this study displayed the largest KDE values, but were also foraging outside of Beagle Bay. There were insufficient numbers of animals tagged to statistically determine gender differences and site differences in foraging range estimation.

The distribution of GPS positions within clusters based on the 6 tide-diel periods and the 50% KDE ranges for each of the tide-diel periods are shown in Fig.5a-d. There appears to be two distinct patterns seen in the spatial patterns among tide-diel periods. Three of the animals tagged in Beagle

Bay (BB02, BB03, BB05) showed some variation in space use with different tide-diel periods as seen by the level of overlap of the KDE ranges 9Figs. 5a,c,d). In most cases, there were multiple core foraging areas identified for the night medium and high water tide times, however there were only single core foraging areas for day tidal categories. These animals used the shallow intertidal habitat more during the night high and medium water periods than the corresponding tidal levels during the day. These animals centred their core foraging areas during the day over similar areas independent of the tidal height. The other animal within Beagle Bay showed considerable overlap between all tide-diel categories, suggesting that foraging area was independent of tidal height and diel period.
The two dugong which foraged outside of Beagle Bay (BB03, PB02) did not show any marked difference in the distribution of the habitat use for the 6 tide-diel categories, as shown by the high level of overlap of the 50% KDE. There was some distinction between night medium and low water tidal core foraging areas and the rest of the tide-diel categories for animal BB03.

The mean size of the 50% and 95% KDE of foraging ranges among the six tide-diel categories were compared using the Kruskal-Wallis non parametric test of two samples. No significant differences were found among tide-diel categories for either 50% KDE ($p=0.71$) nor 95% KDE ($p=0.65$). Significant variability was found among individuals for both variables ($p<0.01$).

The bootstrap analysis of mean convex polygon size for increasing sample size showed that area reached an asymptote at around 50-150 locations (Appendix B). This suggests that kernel estimates used in this study for total deployment time and for each tidal-diel category were representative of the areas used by dugong as sample sizes in this study were equal to or exceed this number (Table 2).

Dive data analysis

The summary statistics of dive data for the two retrieved tags are shown in Table 4. These two animals had very different deployment lengths but showed similar rates of diving (14 & 16 dives/hr). Proportion of time spent near the surface was similar (0.28 & 0.36) and the maximum dive depth and maximum dive length were similar (18 & 20metres, 10.5 & 11.5 minutes respectively). There was a difference in mean and median dive depth between the two animals, with BB01 (resident within Beagle Bay) recording shallower diving activity than BB03, which undertook a LSM of over 400 kilometres. Mean dive duration was also longer for BB03 than for BB01. A representative sample of 1 hour diving time from animal BB03 is shown in Figure 6 and displays the typical square foraging dives and surface activity and shallow erratic dives as described in Table 1.Regression of dive duration on dive depth was positively significant for both individuals and line of best fit are shown in Figure. 7a-b.

The frequency of dive types was similar for both animals overall and there were no obvious differences in proportion of dive types among the 6 tide-diel periods for either dugong (Figs 8a-b.). The percentage of supposed foraging dives (square and U-shaped) was over 90% for the complete deployment and for each tide-diel category for both dugong. The two next most numerous dive types were erratic and deep erratic. There were negligible frequencies of resting (<0.1%) and V-shaped dives ($\leq$ 1%).

GLM univariate analysis of variation in mean dive depth, dive duration and surface time since last dive showed a significant effect of both tide height and diel period for both animals for all three parameters (Table 6 & 7). The interaction term (tide height*diel period) was significantly different for dive depth and dive duration but not for surface time since last dive. This suggests that dive depth and dive duration varies among tidal heights at a different rate for the two diel categories of night and day. This was supported by the spatial variation in core foraging areas for the 6 tide-diel categories (Figs. 5a-f). Post-hoc testing was performed for the tidal height category only as there were only 2 groups of diel period (day, night). Post-hoc comparisons were significantly different ($p<0.01$) in all comparisons for all three variables for animal BB01 but not for animal BB03. Mean dive depth for each tidal-diel category for each dugong is displayed in Figs. 9a-b.

Significant correlations among the 3 dependent variables may influence the outcome of the GLM analyses. Whilst dive depth and dive duration were positively correlated, there was no significant relationship between dive depth and surface time since last dive ($r=0.06$) nor dive duration and surface time since last dive ($r=0.04$).

Finer scale investigation of mean dive depth and mean surface time since last dive in hourly blocks showed the non-linear relationship between time and diving behaviour for dugong BB01. Dive depth was greatest during the middle of the day for low and medium tidal heights and there were two periods of low mean dive depth around dusk and dawn for these two tidal periods (Fig. 10a). Dive depth appeared independent of the hourly block during the high tidal waters. Similarly variation in the mean surface time in between dives occurred around the dusk and dawn periods for the low and medium tidal heights with the highest values recorded during low tide periods from 6pm to 10 pm (Fig. 11a). These patterns were not as evident for animal BB03 with dive depth and surface time in between dives appearing to be independent of hourly blocks for the three tidal height categories (Figs. 10b & 11b).

Diving parameters and behaviours

The definition of two behaviour types, foraging or travelling, was based on distribution of GPS positions for animal BB03. The minimum travel rate between successive GPS locations was significantly higher ($t=4.39$, d.f.=380, $p<0.001$) for travelling periods (0.88 ±0.66kmh) than for foraging periods (0.54±0.56 kmh) for the subset of the deployment of BB03. The mean dive depth was significantly greater for foraging dives than for travelling dives (Mann Whitney U-test, $p<0.001$), however there was no significant difference in the mean duration (Mann Whitney U-test, $p=0.74$), mean surface time between dives (Mann Whitney U-test, $p=0.99$) nor the mean bottom time (Mann Whitney U-test, $p=0.66$) for dives of the two behaviour types. Dive type frequency was very similar for the two behaviours (Fig. 12), with a slight increase in erratic dives during travelling periods. Square and U-shaped dives constituted over 90% of dives for both categories.

Comparison of traditional knowledge and scientific instrument knowledge on dugong behaviours

The following information came from some of the Bardi-Jawi rangers in response to questions on dugong movement and behaviour.

1. How do dugong patterns of habitat vary with the tide?
Mainly see dugong on hunting grounds[1] around big tides or when tides are building up. Rarely see dugong around neap tides
2. How does dugong patterns habitat vary between night and day?
Shallower waters at night time. More active at night time
3. What other things affect the behaviour and movements of dugong like the wind strength or direction?
Dugong come into shallow waters around strong easterly winds. May be more confident because no boats in water and generally around protected feeding grounds.
4. Do dugong feed whilst they are travelling or do they travel along the surface?
Both, they travel on surface and along bottom possibly feeding.
5. Are there any specific times of the day when they seem to rest or feed?
Generally rest out in deep water when tide is out (therefore not feeding)
6. What are the patterns of seasonal movement and what are the reasons or triggers for the movement?-

Dugong appear when south east winds start[1] and the water gets cooler, therefore when the water starts to warm up they must head south for cooler water. Dugong leave the hunting grounds when the humpback whales appear[2].

7. Any other observations on dugong biology and behaviour?

Appear to have calves in the season whilst around Bardi country. Female dugong have been seen with up to 3 calves but generally there will only be 1.

1. Hunting grounds are traditionally in shallow waters in embayments and protected areas, and not so much in open coastal waters.
2. South-east trade winds start around April every year (BOM website http://www.bom.gov.au/climate/averages/tables/cw_003004.shtml)
3. Humpback whales first appear in the Kimberley around July every year.

DISCUSSION

Community collaboration and capacity building

This research programme was a successful collaboration between the research organisation (DEC) and the sea ranger groups of the Kimberley Land Council. This resulted in the development of field research skills and knowledge of satellite-linked animal tracking systems within the Bardi-Jawi sea ranger group. It has also provided the researchers with an opportunity to hear some of the traditional ecological knowledge (TEK) concerning the marine environment of the area and relate this to the scientific data provided by the satellite tags. This "both ways" learning model, which recommends that all participants are teachers and learners, is recognised as providing beneficial outcomes in indigenous education (Lea et al. 2006). Natural resource management has been recommended as a key area of work for indigenous communities as it provides positive environmental outcomes (Wilson et al. 2010) as well as important outcomes for indigenous health (Burgess et al. 2009).

Output of the results back to the communities was facilitated through two workshops in Kooljamon and in Beagle Bay in November 2010. The B-J rangers organised and presented much of the data at the workshops to the community (see Figures below) as well as providing a resource handbook summarising the project's findings (see Appendix D).

The development of research capacity within the Bardi-Jawi sea ranger group has resulted in a subsequent sea turtle satellite tracking programme being developed and to be implemented by the group in the near future. This capacity building will lead to the development of further research programmes, in collaboration and independently, to address issues of sustainable wildlife management and conservation of marine resources in the Kimberley. The Bardi-Jawi group also now have the capacity to train and consult with other sea ranger groups in the Kimberley to design and implement research programmes to address issues of importance such as contained in the Saltwater Country Plan (Mayala Native Title Claim Group, Dambimangari Corporation,Wunambal-Gaambera Aboriginal Corporation, Balanggarra Native Title Claim Group and the Kimberley Land Council 2010).

Dugong Foraging Behaviour

The dugong tagged in the West Kimberley for this study displayed similar characteristics of movement, foraging ranges and diving characteristics to that of other dugong studied around Australia (Sheppard et al. 2006, Chilvers et. al. 2004, Holley 2006). There was considerable variation in spatial habitat use and movement patterns among the 6 dugong tagged for this study. Some individuals undertook large scale movements, either unidirectional or as a return journey to the original tagging site. Dugong in this region are capable of moving over relatively large distances with the maximum recorded movement of over 400 kilometres in around 40 days similar in range to that of dugong in other parts of Australia (Preen & Marsh 1995, Sheppard et al. 2006). However, patterns of movement were not consistent through time for all individuals with many animals remaining within small home ranges during the entirety of their deployment. It is not clear from this limited tagging what the potential cues may be for large scale movement of dugong in this area, though traditional owners and hunters state that seasonal movements occur in relation to the onset of warmer weather in September-October each year (P McCarthy, Kevin George,. Bardi-Jawi Rangers pers. comm.). The maximum extent of movement by one individual southward past Eighty Mile Beach towards the Pilbara region supports the beliefs of the local Bardi-Jawi people on the seasonal movement patterns of dugong between the west Kimberley and more southerly areas.

The estimated size of foraging ranges of dugong in the West Kimberley was similar to those from other studies of dugong. Foraging ranges (based on 95% KDE) of dugong in Hervey Bay were between 0.6-12 km^2 (based on GPS tags in Sheppard et al. 2008) and in Shark Bay seasonal foraging ranges were in the range of 5-20 km^2 (based on PTT tags in Holley 2006). Though the sample sizes were low in this study there was a definite pattern of smaller kernel density estimates of foraging ranges (50% and 95%) within Beagle Bay than outside this embayment in more open coastal waters. This may be a result of greater forage density of preferred species (in particular *Halophila sp.* and *Halodule sp.*) in Beagle Bay than in open coastal areas. This pattern is seen among east coast Australia tropical environments where abundance of seagrass in protected waters is higher than in open coastal habitats due to the greater protection and reduced sediment movement (Coles et al. 2000, Carruthers et al. 2002). The repeated use of areas near James Price Pt and Coulomb Pt for foraging by a number of individual dugong highlights the importance of this area as key foraging habitat. This suggests that certain areas of open coastal habitats support considerable stands of suitable seagrass forage for dugong over time despite the seasonal and annual changes in abundance and distribution of ephemeral seagrass species (Carruthers et al. 2002).

Tide and diel effects on the spatial aspects of foraging behaviour were apparent, especially for the animals foraging within Beagle Bay. Three out of the four dugong which foraged in Beagle Bay showed distinct differences in the location of the core foraging range for the day and night periods. Animals only moved into nearshore intertidal habitats during the night high and medium tidal water levels, and preferred deeper waters during corresponding tidal states in the daytime. This is consistent with foraging patterns of dugong in Hervey Bay (Sheppard et al 2010), where dugong accessed higher nutritive inter-tidal forage species mainly at night time. Dugong were also recorded to travel at higher speeds between foraging patches associated with different tide-diel periods, even on small geographic scales of 1-2 kilometres, suggesting that habitat use and resource varies on a fine spatial scale and is patchy within tropical embayments. The two dugong which foraged outside of Beagle Bay showed very little difference in their spatial foraging range among tide-diel categories, as did the remaining animal within Beagle Bay. This level of foraging site fidelity may have been due to preference for sub-tidal patches of forage and/or increased use of deeper water habitats to avoid the risk of predation by large sharks (Wirsing et al. 2007a).

The variation in habitat use in dugong in Hervey Bay among tide-diel conditions has been explained as a mechanism to avoid daytime boat traffic in these habitats (Sheppard et al. 2009, 2010). It also possible that this is a strategy to minimise the risk of interacting with day active predators such as tiger sharks, the main predator of dugong (Wirsing et al. 2007a, Heithaus et al. 2002). Deeper waters afford dugong a greater chance of escape from a predator (Wirsing et al. 2007a, Wirsing et al. 2007b). The level of boat traffic in this area is minimal compared to areas such as Hervey Bay, but there is a much higher level of daytime hunting activity by indigenous groups. This prevalence of hunting may be a driver for variation in tide-diel foraging behaviour in combination with avoidance of other daytime active predators (i.e large sharks).

Dugongs in this study displayed similar parameters of diving activity to those studied in other areas throughout Australia (Chilvers et a. 2004, Anderson 1998, Childwood 2001, Anderson

& Birtles 1978). They displayed similar levels of diving activity across depth with a majority of diving activity to less than 5 metres depth. They also displayed similar rates of diving (14-16 dives/hr) and maximum depths recorded (18-20m) to dugong from other locations. The proportion of time spent within 2 metres of the surface (0.28-0.36) is also similar to that seen among dugong in other areas and will provide important information to correct for sightability and availability biases in aerial survey estimates of abundance of dugong in the Kimberley waters (Marsh & Sinclair 1989a&b). Proportion of dive types displayed by these two animals varied from that in Chilvers et al. (2004). There were a greater proportion of square and U-shaped dives (assumed foraging) exhibited by the dugong in this study than from other populations of dugong throughout Australia. This may reflect a greater proportion of time spent foraging and less time spent resting, possibly due to availability of preferred forage, though this is not reflected in the size of home range from the kernel estimates.

Diving activity as determined by the use of the time depth recorders had limited application in this study due to the low retrieval rate of only 2 of the 6 tags deployed. This small sample size did not allow for comparisons of diving behaviour among gender or location or foraging behavioural differences. The two tags retrieved came from animals that showed different movement patterns during the deployment, one animal remained within Beagle Bay for the whole deployment and the other animal undertook the largest migration moving over 400 kilometres south from Beagle Bay. Mean depth, dive duration and surface time between dives varied considerably between the two animals, supporting previous summaries of dugong diving behaviour which found that the greatest variation in diving parameters occurred among individuals (Chilvers et al. 2004). Not surprisingly, dive depth and dive duration were positively correlated, a pattern seen in dugong (Chilvers et al. 004) and among other benthic foraging species (i.e. Australian sea lions, Goldsworthy et al. 2010). Maximum dive depth and dive duration varied significantly between tidal categories and diel categories and among the tidal categories between diel periods. This pattern was reflected in the variation in mean surface time between dives where significant differences were observed between tidal categories and diel periods but not within the interaction between the two dependent variables. The variation in mean dive depth is partly explained by the high level of foraging site fidelity and relative change in water depth at the preferred foraging site due to tidal fluctuation. The variation in dive depth among tidal categories across diel periods reflects the preferred use of shallow habitats during night periods as opposed to daytime periods independent of tidal height state. This was not reflected in the spatial discrimination of core foraging ranges for the different tidal-diel categories for the two dugong that provided both spatial location data and dive data. This shows that determining the fine-scale habitat preferences of dugong and the influence of various environmental factors may sometimes require a combination of diving and location data

Exploration of finer scale temporal variability in the patterns of mean dive depth and mean surface time between dives for each individual revealed a more complex relationship. There appears to be a non-linear relationship between dive depth and hourly period, especially for the animal that remained within Beagle Bay. A peak of maximum dive depth occurred in the middle of the day for this animal and relative minimums occurred at the dawn and dusk periods. There was also a very evident peak of mean surface time between dives occurring around dusk for this animal, probably reflective of a preferred period of resting. Mean surface time did not appear to vary across time for the other animal that undertook a large scale movement. This does not accord with estimates of timescales of foraging activity and resting activity in dugong from other studies. Anderson (1998) observed that resting took place mostly between 1000-1300 hours, which was not supported by our study, where a peak of resting activity took place around dusk from 1800-2200 hours. Foraging behaviours were evident at all hours and this supports the findings of Chilvers et al. (2004).

In this study, dugong that undertook large scale movements had periods of residency during the movement, indicating that periods of intensive foraging are required during migration movements. Analysis of the diving behaviour during periods of uni-directional travel and periods of residence for the dugong that undertook a migration showed that similar types and proportions of dives were exhibited in both cases, with a slight increase in erratic type dives when travelling. This animal moved at a faster rate between successive locations when travelling than when remaining resident, but performed over 90% of dives to the sea bottom during both periods. This supports the evidence that dugong travel along the sea bottom rather than along the sea surface when undertaking migrations (Sheppard et al. 2009, 2010). However, it does not support the use of dive shape alone to infer the activity undertaken in all cases (i.e. square and U-shaped dives are foraging dives), as travel rates of dugong at approximately 2-4 kmh are less likely to be foraging dives but more likely travelling dives. Further research, including the use of crittercams and/or gravitational sensors on the dugong jaw to discriminate behaviour among dive types and travel speeds may help us to understand the activity budget of dugong and their habitat requirements when undertaking large scale movements.

We are very limited in our application of these diving data due to the limited samples obtained, and there is a need for more detail and greater sampling in regards to dugong foraging behaviours and habitat requirements within the West Kimberley region. There is also a very limited understanding about the temporal variation in dugong distribution, habitat use and foraging behaviours and the temporal variability of their key resource, seagrass. A combination of spatial distribution and foraging data of dugong may be helpful in determining and prioritising key conservation areas (see Grech & Marsh 2010). These data will be useful in determining potential impacts of human activities and industrial development in critical dugong habitat, as well as contributing to the development of community-led management strategies for the sustainable use of dugong (NAILSMA-Saltwater People Network, Marsh et al. 2010).

Comparison of traditional knowledge and scientific instrument knowledge on dugong behaviours

The information gathered from traditional hunters of dugong in the area supported some of the data from the scientific investigation but also differed from it in other aspects. The observation of dugong mostly on the big tides or as the tides are on the make is partly supported by the distinct habitat use differences among tidal heights for some animals. There were cases of individual dugong foraging in the same area independent of tidal or diel condition. The greater use of shallow habitats during the night is supported by the tagging data in this study and in other studies (Sheppard et al. 2010). Whilst dugong were stated to be more active at night, we did not specifically investigate activity rates or movement rates among diel categories. The proportions of dive types (Figs. 8a-b) did not differ among tide-diel categories though it was noted in one animal in Beagle Bay that surface resting time occurred more frequently in the early evening hours than at other times of the day.

We made no investigation of the role of wind direction and strength in dugong movement and diving behaviour, this may be investigated in further analyses of these data.. It was stated that dugong come into the shallow waters, presumably for protection, during strong south-east offshore winds. These winds blow mostly in the mornings during the period April-August, which coincides with the *Bargana* season, a time of hunting for dugong (odorr), according to the local calendar of events (See Appendix C).

Further discussion with traditional hunters of dugong throughout the Kimberley region would be of great benefit in developing ecological knowledge of this species and how it varies in space and time across this area and in comparison to other dugong populations in Australia and across the Indo-Pacific. This knowledge would also assist in developing further research programmes with traditional owners and sea ranger groups to provide important information for sustainable management and natural resource management. This project supports the assertions of Wilson et al. (2010) that collaborative research programmes offer opportunities for knowledge transfer “both ways”

FUTURE DEVELOPMENTS

Subsequent analysis of quantitative habitat preferences will be performed using habitat quality data and information on seagrass distribution from industry surveys when available. This technique will employ the utilisation distribution function of relative space use derived from the GPS positions (e.g. Marzluff et al. 2004, Sheppard et al. 2010) and relate that to variation in habitat quality and forage resource availability. This analysis may provide us with a better understanding about habitat preferences and requirements for dugong and potential reference points for the carrying capacity of these habitats.

Development of further dugong foraging behaviour studies in other areas of the east Kimberley (i.e. Wanjina Wunggurr Uungguu Native Title claim area), where dugong are thought to be resident all year round, will provide a broader picture of dugong foraging behaviour throughout the Kimberley. These data will be incorporated into the development of community-based management plans designed to provide greater understanding and sustainable hunting of this important resource.

ACKNOWLEDGEMENTS

This project would not be possible without the cooperation and permission granted for access to traditional country of the Bardi-Jawi people and the Nyul-Nyul people of the Dampier Peninsula. The Kimberley Land Council was also integral in developing the proposal and coordinating field work and logistics. Many thanks to all the people who participated in the planning and fieldwork including Richard Meister, Daniel Oades, Todd Quartermaine, Kevin George and the entire Bardi-Jawi ranger group. The Nyul-Nyul ranger group were also an important part of all the field operations. Thanks to Steve Arrow for supporting the work in the Beagle Bay area and to the residents of Red Soil camp for housing and feeding us. Many thanks to the pilots of the King Leopold Air, in particular Jamie, whose keenness and observational powers were noted by all who endured long sessions in the spotter plane.

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TABLES AND FIGURES

Table 1 Characteristics of dive definitions for dugong in this study (modified from Chilvers et al. 2004).

Dive type	Min., max. depth (m)	Proportion of bottom time to total dive time	Dive contains wiggles*	Time spent <1.5m prior to dive
S-Square	>1.5	>0.65	no	n.a
U-shaped	>1.5	0.33≤ x ≤0.63	possible	n.a.
V-shaped	>3.0	0	no	n.a.
E-Erratic	1.5< x <3.0	<0.33	possible	n.a.
R-Erratic (resting)	1.5< x <3.0	<0.33	possible	>5 min
DE-deep erratic	<3.0	0<x<0.33	possible	n.a.

Table 2 Deployment information and travel characteristics for the 8 dugong tagged.

ID	Location	Depoyment	Sex	Length	Girth	Deployment length	No. Hits	Mean hits/day	Mean travel speed (sd)	50% KDE (km^2)	95% KDE (km^2)
BB01	Beagle Bay	16/07/2009	M	2.2		24	539	22.52	0.58 ± 0.50	0.4	2.95
BB02	Beagle Bay	16/07/2009	M	2.36	1.4	47	726	15.45	0.66 ± 0.60	0.17	2.58
BB03	Beagle Bay	17/07/2009	F-mature	2.36	1.78	49	637	13.08	0.63 ± 0.61	2.69	36.77
BB04	Beagle Bay	19/07/2009	M	2.38	1.58	43	646	15.11	0.51 ± 0.45	0.42	2.8
PB01	Pender Bay	22/04/2010	M	2.2	1.3	3	64	21.35	1.04 ± 0.67		
PB02	Pender Bay	26/05/2010	F-mature	2.3		38	635	16.84	0.75 ± 0.76	2.1	14.71
BB05	Beagle Bay	21/07/2010	M	2.36	1.63	17	370	21.77	0.22 ± 0.22	0.67	2.1
BB06	Beagle Bay	21/07/2010	M	2.58	1.75	2	0				

Table 3. Dive summary and characteristics for the two TDRs retrieved during the study

Animal ID	Location	Deployment length (hrs)	Dives/hr	Prop. of time <2m	Mean dive depth	Max depth	Median depth	Mean dive duration (mm:ss)	Max dive duration	Median dive duration (m:ss)	Max TSLD (h:mm)
BB01	Beagle Bay	573	15.9	0.36	4.0 ± 2.0	18	4	2:24 ± 1:37	10:32	2:10	6:33
BB03	Beagle Bay	1253	13.8	0.28	6.8 ±3.8	20	6	3.08 ± 2:11	11:36	3:20	3:23

* A wiggle refers to a >1 m discontinuity in water depth during the bottom phase of a dive.

Table 4 Summary of F values and significance of GLM analysis for the variation in dive depth, dive duration and STSLD for animal BB01.

Source	Dive depth		Dive duration		STSLD	
	F	P	*F*	P	*F*	P
Model	7384.034	.000	3756.056	.000	11058.44	0
Tidal height	333.614	.000	416.741	.000	186.187	0
Diel period	299.024	.000	7.549	.006	20.108	0
Tide*Diel	3.792	.023	5.738	.003	1.075	0.342

Table 5. Summary of F values and significance of GLM analysis for the variation in dive depth, dive duration and STSLD for animal BB03.

Source	Dive depth		Dive duration		STSLD	
	F	P	*F*	P	*F*	P
Model	9698.670	.000	6107.570	.000	24078.39	0
Tidal height	364.261	.000	97.197	.000	65.98505	2.83E-29
Diel period	46.033	.000	.190	.663	23.61024	1.19E-06
Tide*Diel	25.078	.000	20.146	.000	8.535402	0.000197

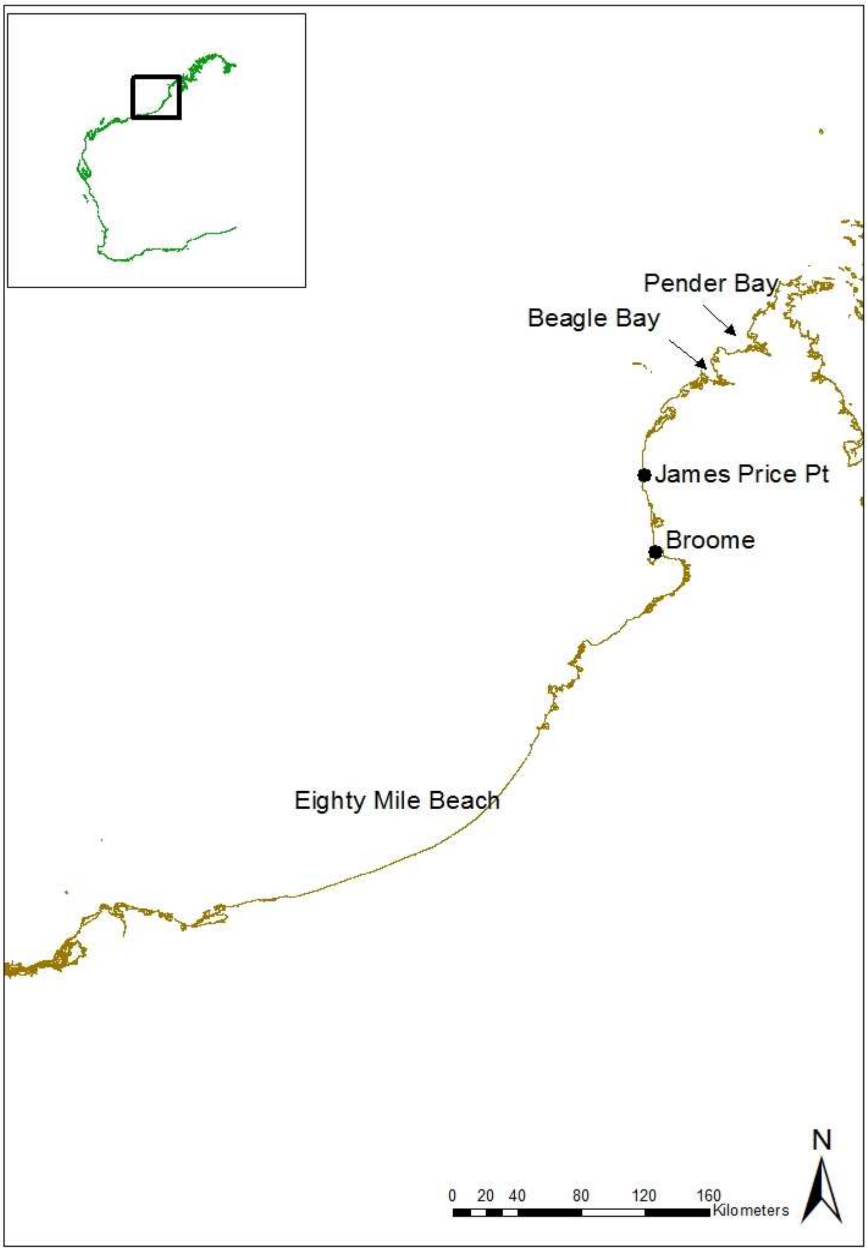


Figure 1. Study site in the north of Western Australia and relevant place names of locations mentioned in the report

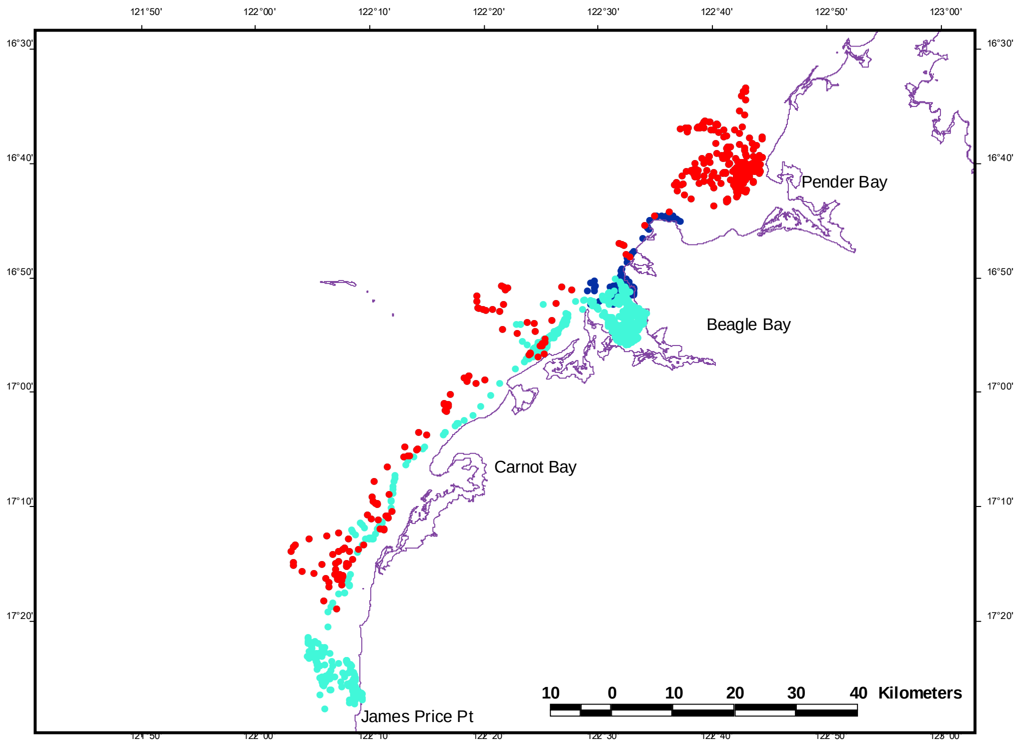


Figure 2a GPS locations of all tagged dugong in Beagle Bay (2009-light blue, 2010-dark blue) and Pender Bay (2010-red). Further extension to the travel of one of the dugong from the 2009 deployment in Beagle Bay is shown in Fig. 2b.

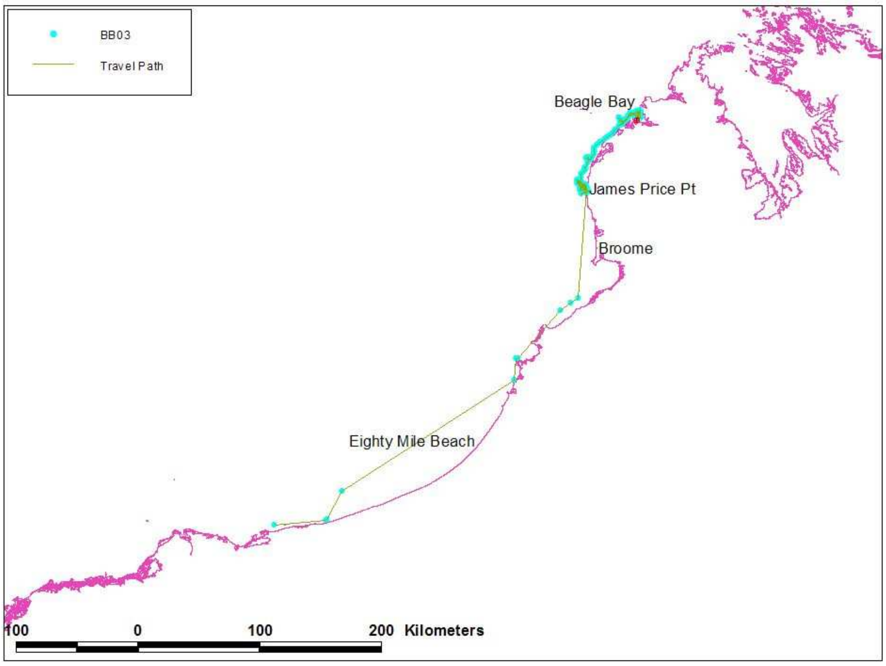


Figure 2b. Full extent of all GPS positions (blue) and travel path (green)of individual BB03 tagged in Beagle Bay in 2009. Note the large gaps in reported positions south of James Price Pt.

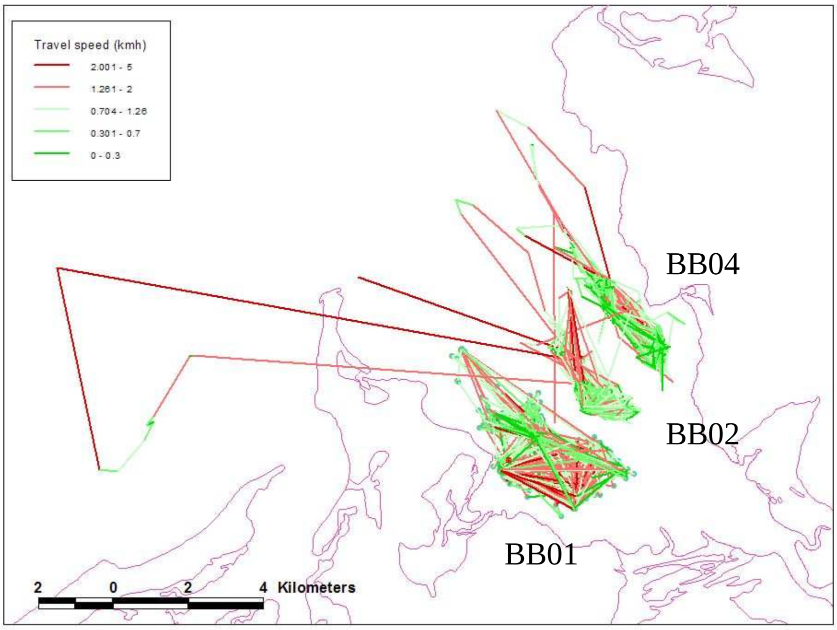


Figure 3a. Travel paths and minimum travel rates between GPS positions for animals BB01, BB02 & BB04 tagged in Beagle Bay in July 2009. Minimum travel rates are based on straight line travel between successive GPS positions. Note that travel paths across land represent gross under-estimates of minimum travel rate.

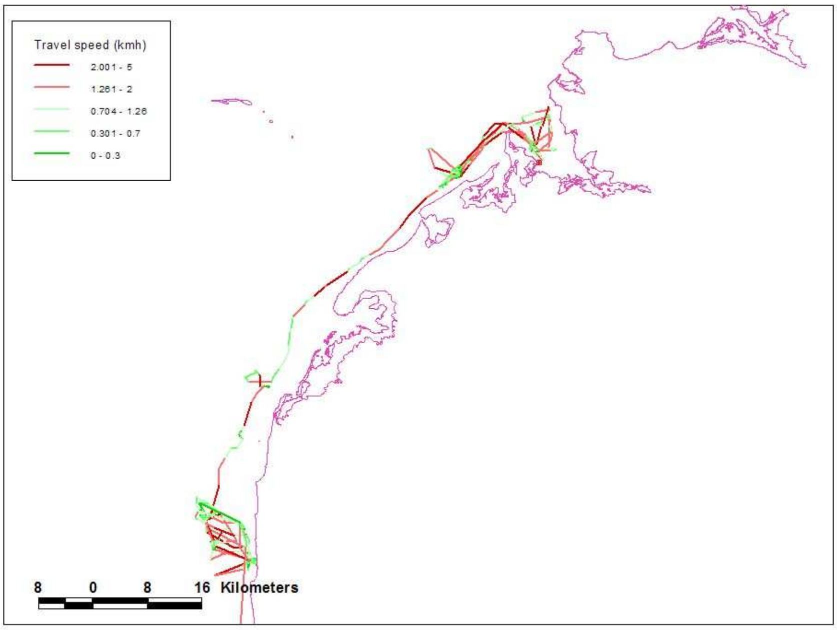


Figure 3b. Travel paths and minimum travel rates between GPS positions for dugong BB03 tagged in Beagle Bay in July 2009.The green lines suggest periods of residency and likely foraging and the red lines represent higher minimum travel rates most likely representing movement between foraging sites.

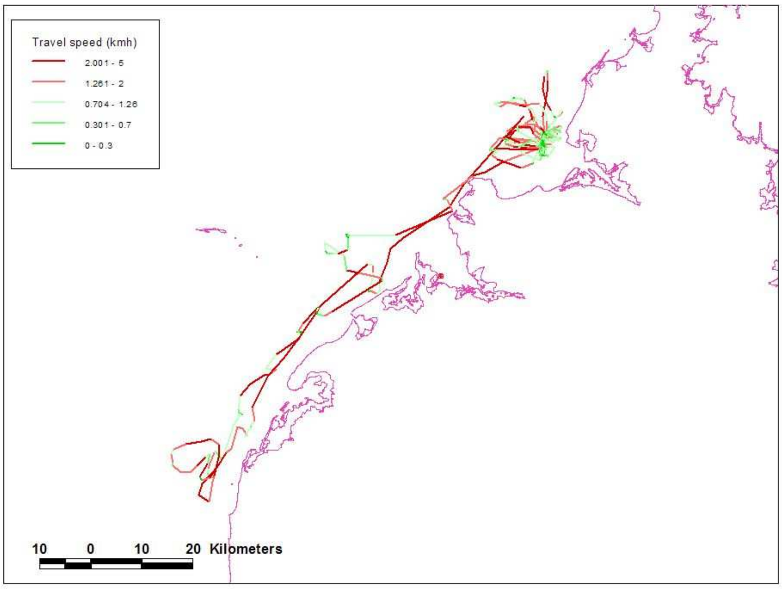


Figure 3c. Travel paths and minimum travel rates between GPS positions for dugong PB02, tagged in Pender Bay in April 2010. This animal undertook a return journey from the tagging site and displays higher rates of travel throughout the LSM than during the period of residency within Pender Bay as indicated by the colour of travel paths.

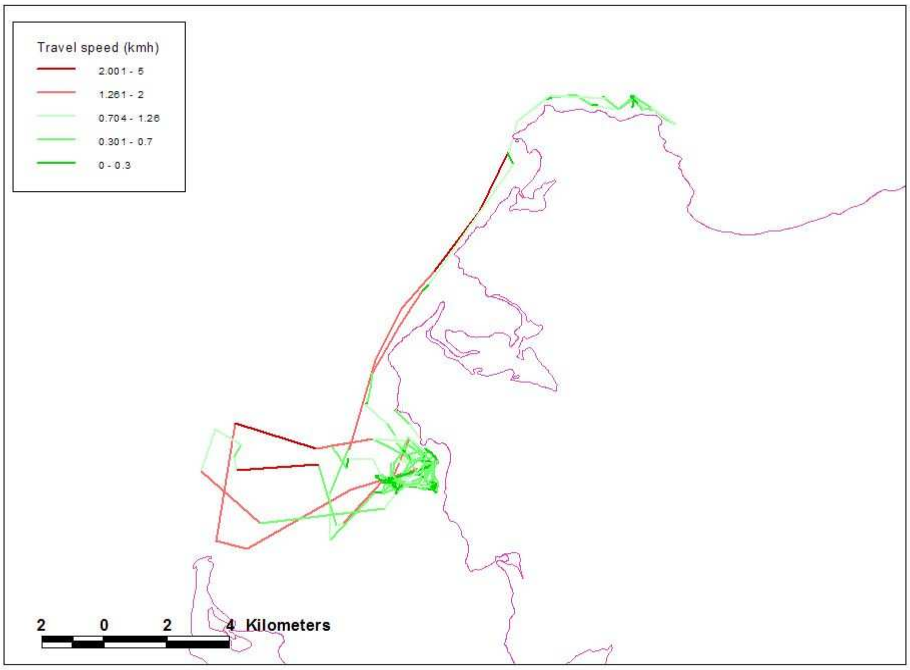


Figure 3d. Travel paths and minimum travel rates between GPS positions for dugong BB05 deployed in Beagle Bay in July 2010, which made a short loop movement out of Beagle Bay shortly after release. Consistent patterns of higher rates of travel are indicated by the red lines when moving versus the slower rates indicated by green lines when remaining in a restricted area.

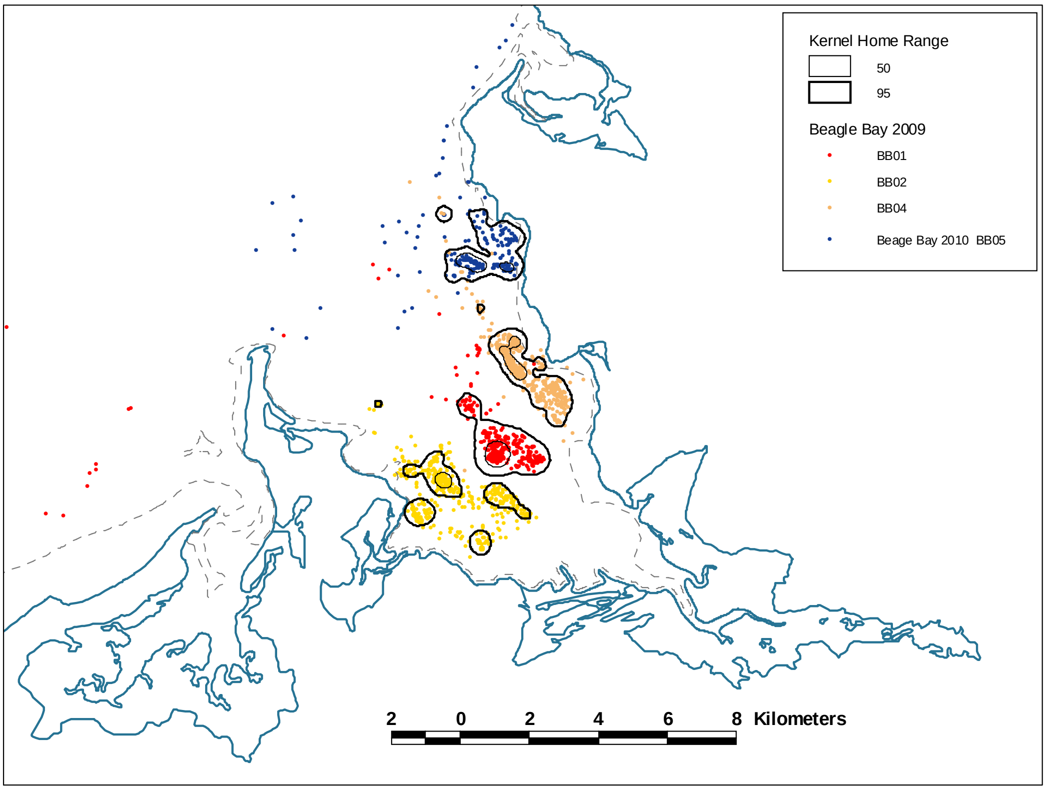


Figure 4a. Distribution of GPS positions for the four dugong that resided in Beagle Bay (BB01, BB02, BB04 & BB05) and the 50% and 95% kernel home range estimates. The dark band corresponds to the 95% KDE and lighter outline to the 50% KDE for each individual. Note the lack of overlap of home ranges of individuals within the bay. Dashed line represents the estimate of low water mark (DEC modelled data), which underestimates the extent of the inter-tidal zone within Beagle Bay.

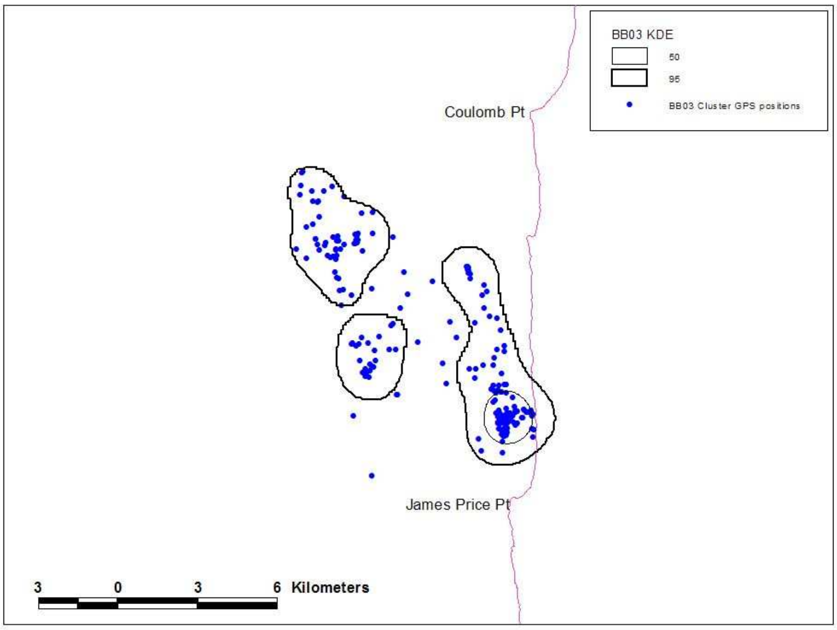


Figure 4b Kernel home range estimates from an identified cluster of positions near James Price Pt for animal BB03, tagged in Beagle Bay in 2009. Note that the 95% KDE overlaps with an area above the high water mark due to the algorithm of kernel density estimation.

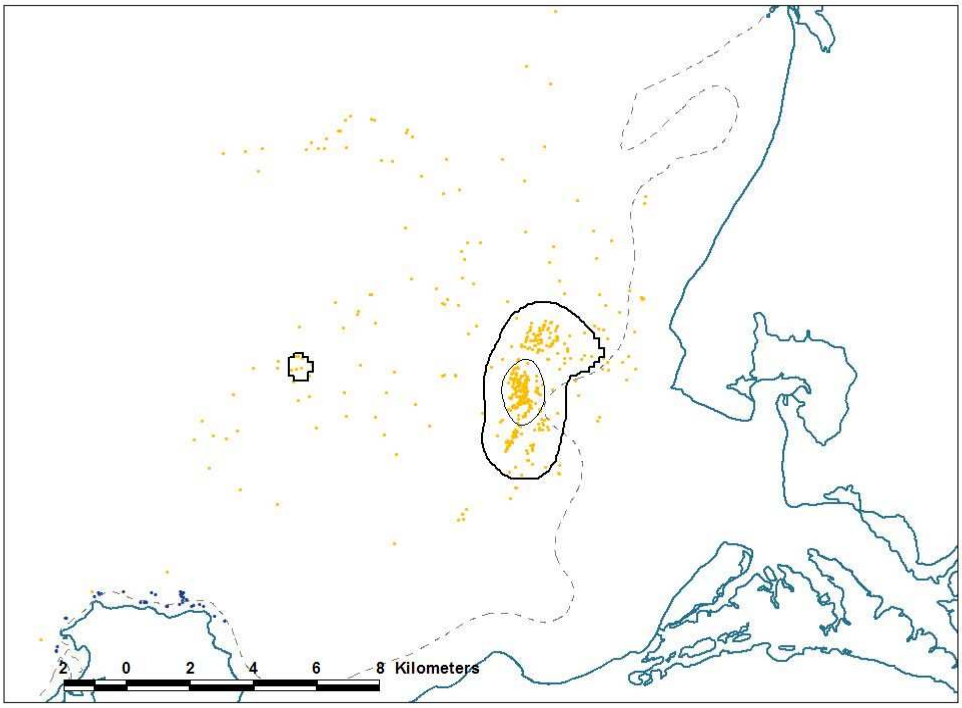
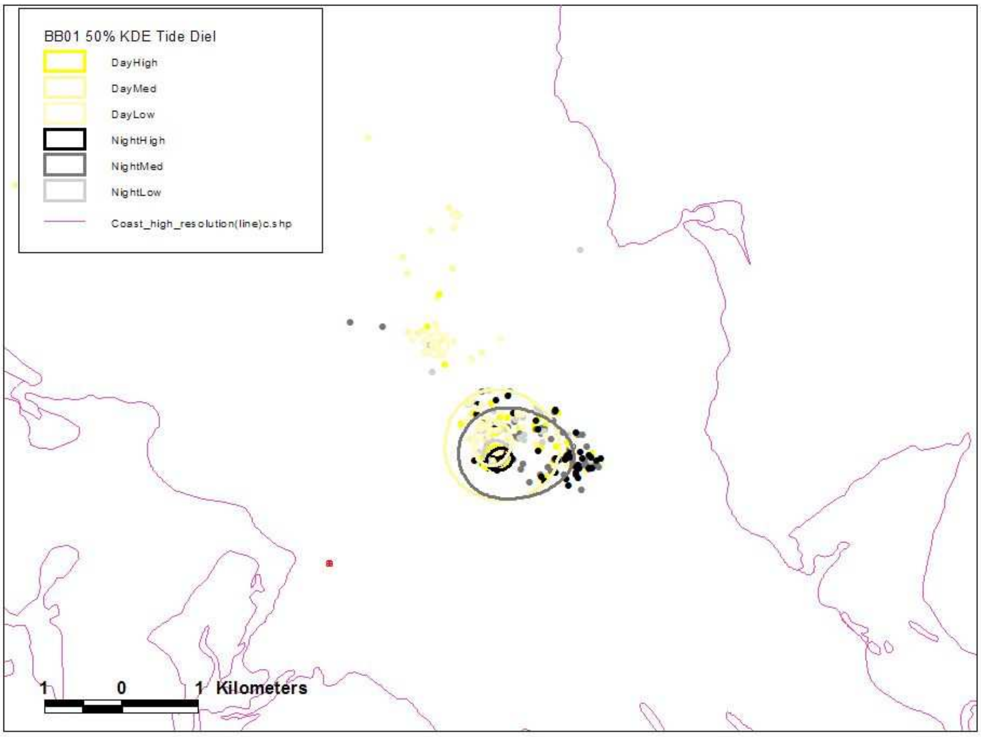


Figure 4c Kernel home range estimates (50%-light line, 95%-heavy line) from a cluster of positions within Pender Bay for individual PB02 tagged in Pender Bay in 2010. Estimated low water level is indicated by the dashed line, suggesting that the majority of GPS positions were in sub-tidal areas.



Figures 5a-d GPS positions and core foraging areas (50%KDE) for the 6 tide-diel categories for each individual dugong. GPS positions are identified by the same colour pattern as the 50%KDE shapes. Fig 5a-Core foraging areas among tide-diel categories for animal BB01 in Beagle Bay. There is a high degree of overlap among all 6 tide-diel categories, except for the day low tide estimate which is isolated from all other core foraging range estimates. GPS positions for night-high tide category appear to be further inshore and separate from other categories but this was not reflected in the location of the core foraging areas.

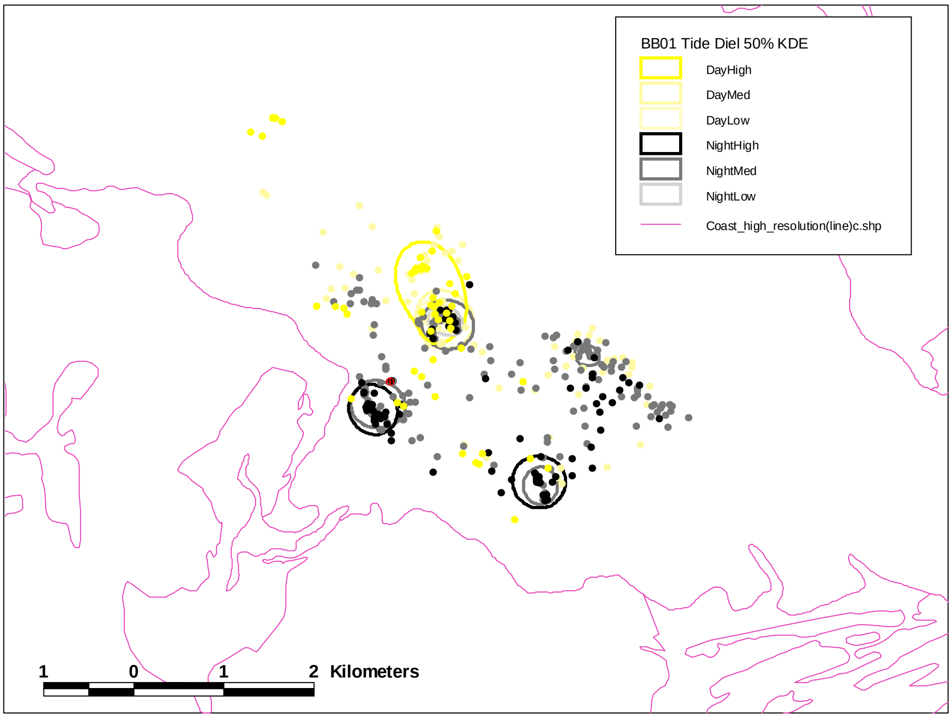


Figure 5b. Tide-diel category positions and core foraging areas for animal BB02. There are multiple core foraging areas for many of the night tide categories and considerable spatial separation of all core foraging areas. All daytime tide core foraging areas are centred over the same area.

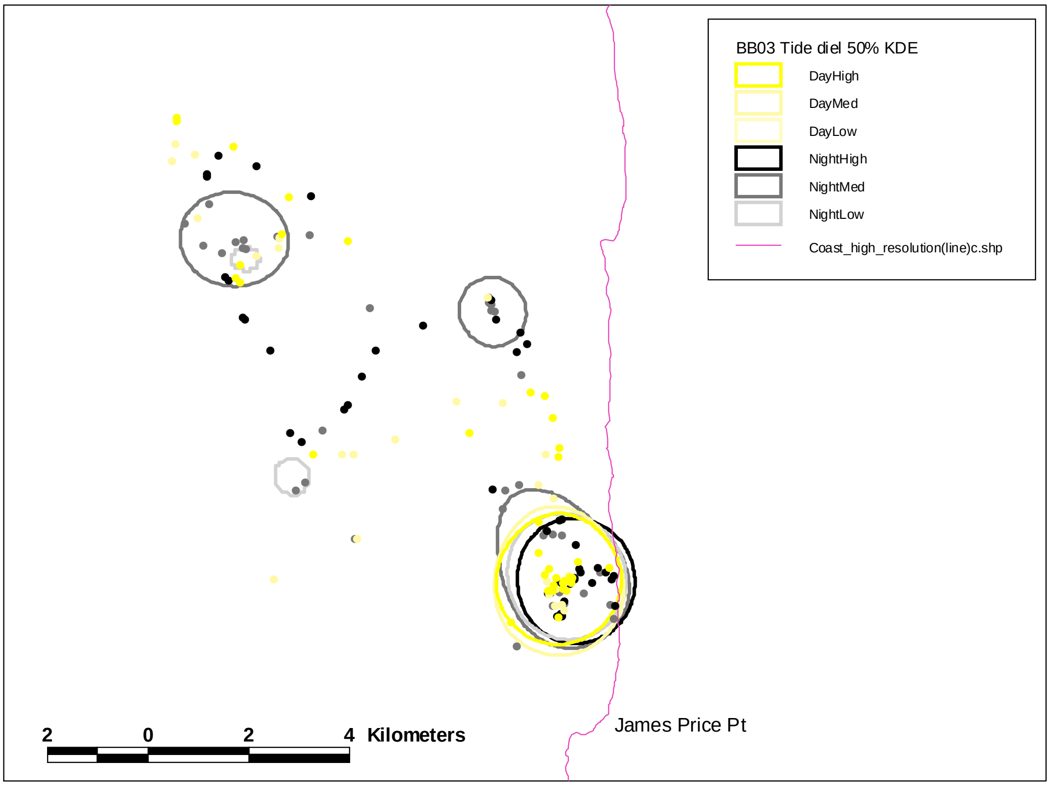


Figure 5c. Tide-diel category positions and core foraging areas for animal BB03. There were multiple core foraging areas for some of the night tide categories but all daytime tide categories were centred on the same location inshore. There was considerable distance separating the core foraging areas.

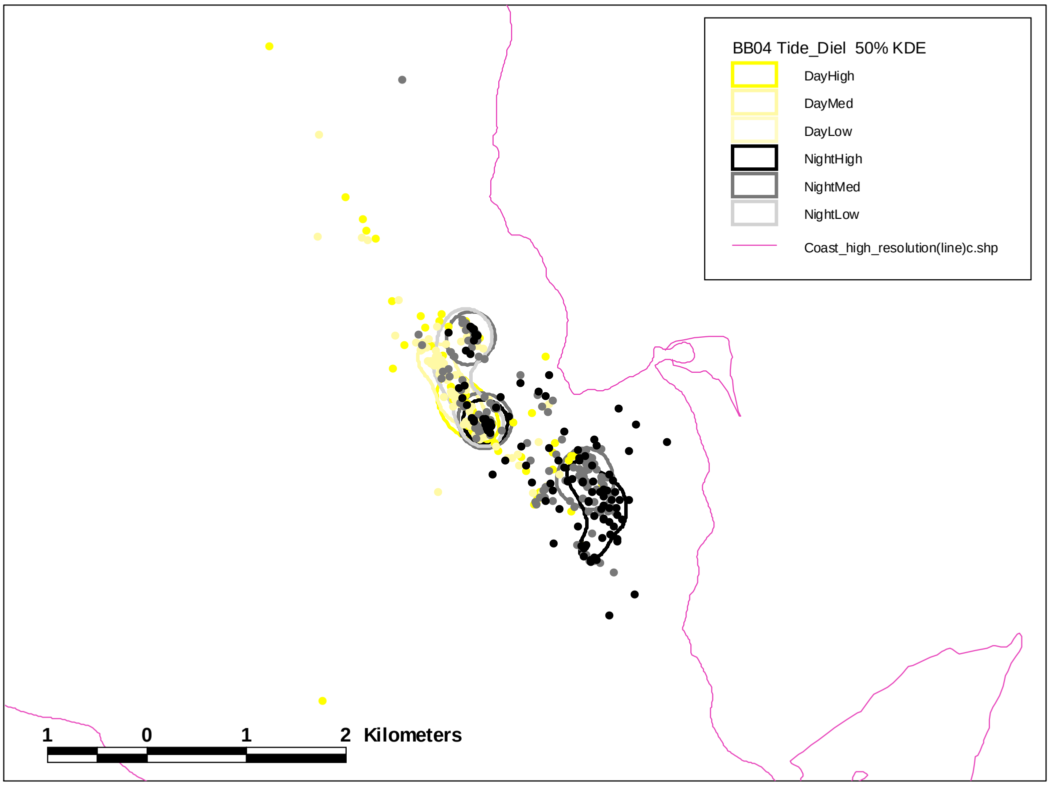


Figure5d. Core foraging areas and GPS positions for BB04 in Beagle Bay among the 6 tide-diel categories. Multiple core areas were identified for the medium and high night tide categories. All daytime tidal categories were centred over the same location. The animal appeared to forage closer to shore during the higher periods of water in the night time than for corresponding tidal heights in the day.

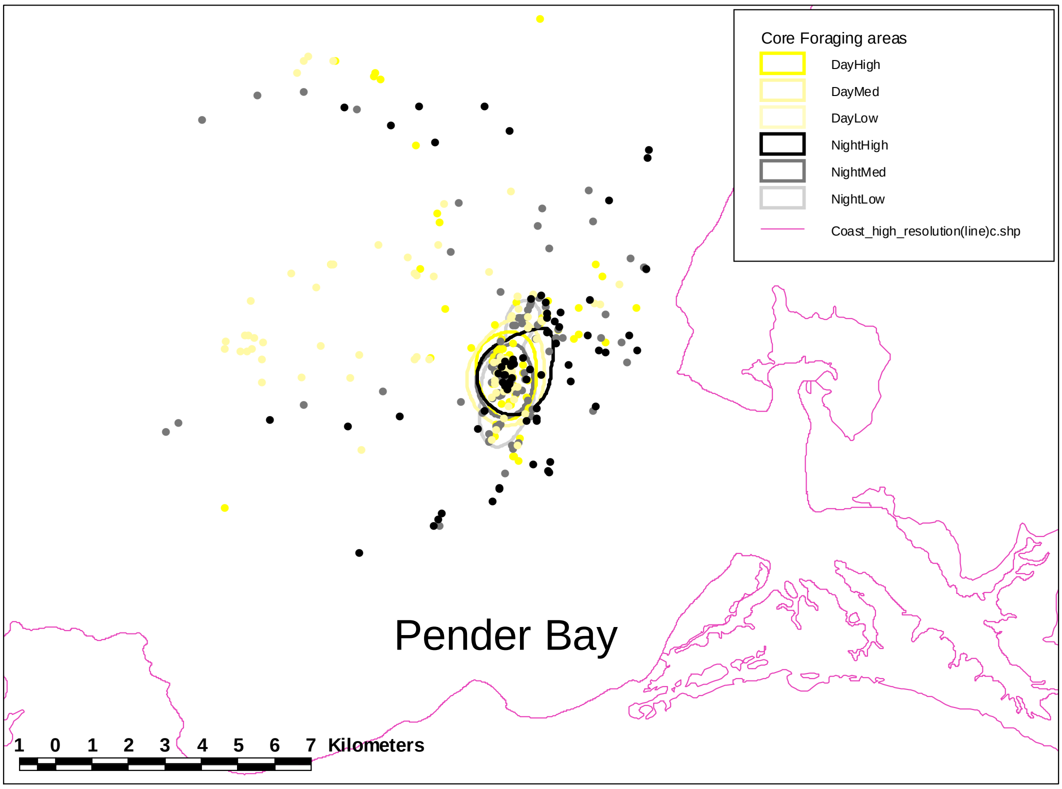


Figure 5e. Complete overlap of all core foraging areas of the 6 tide-diel categories for animal PB02 in Pender Bay.

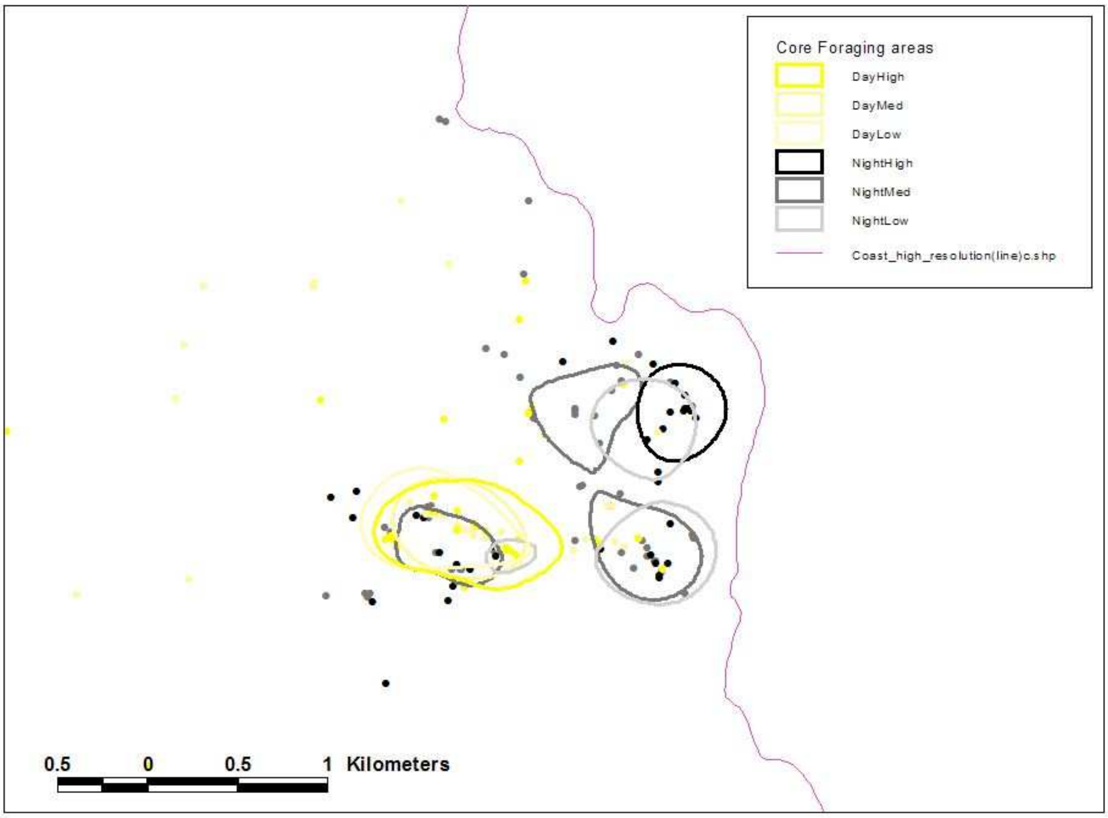


Figure 5f. Tidal-diel GPS positions and core foraging areas for animal BB05 in Beagle Bay. Note the multiple areas for some of the night tide periods and the overlap of all daytime tidal core foraging areas.

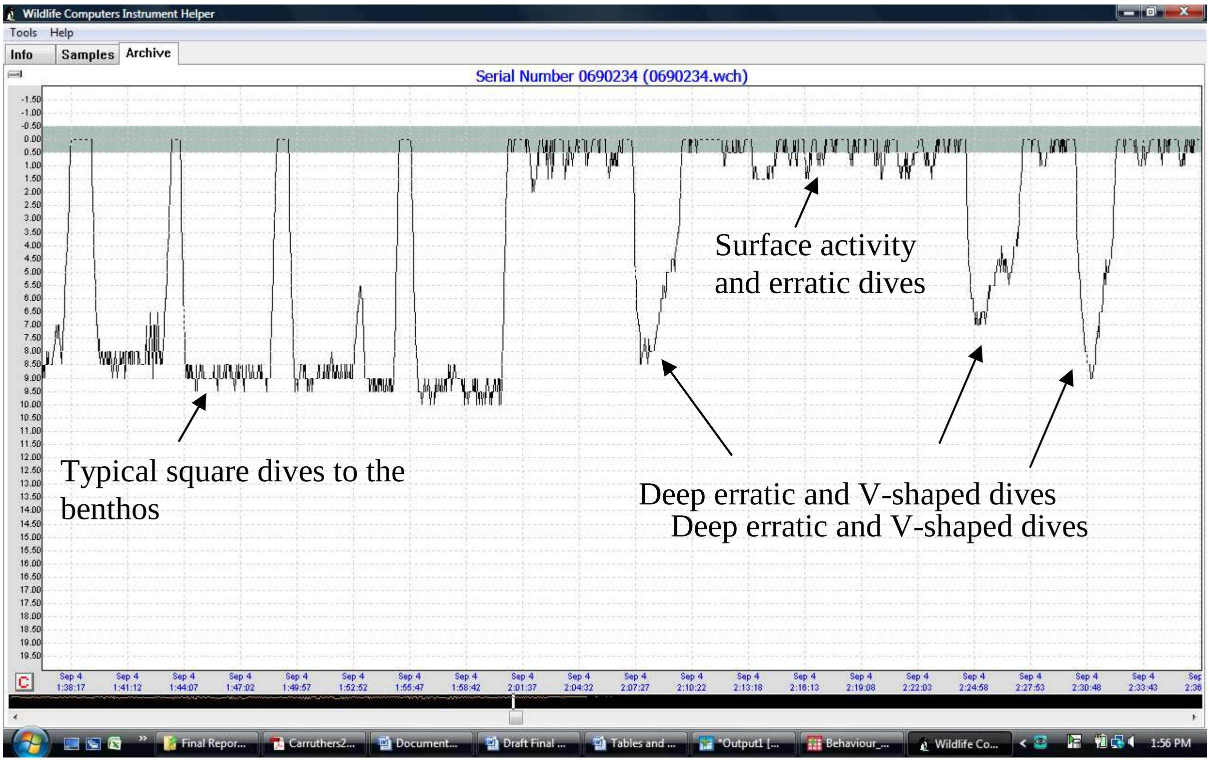


Figure 6. A 1 hour representative sample of diving activity of one of the dugong showing some of the dive types and behaviours exhibited by dugong. The grey area represents the surface with time along the x-axis and depth along the y-axis. Note the very short surface interval between square dives and rapid descent and ascent phase of the dives.

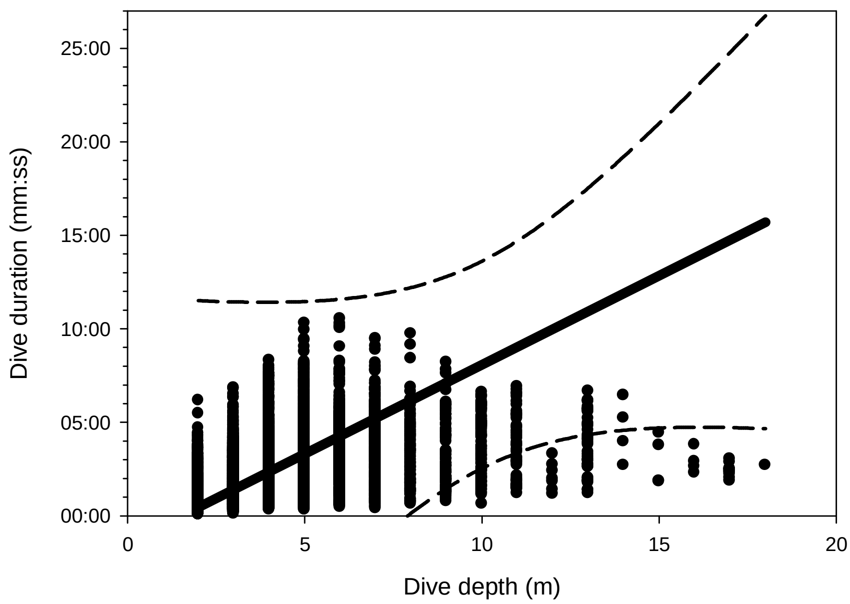


Figure 7a. Regression of dive duration on dive depth for animal BB01 (with 95% CI) which remained within Beagle Bay. The regression was significant (R^2=0.25,$F_{1,9134}$=7419, p<0.001).

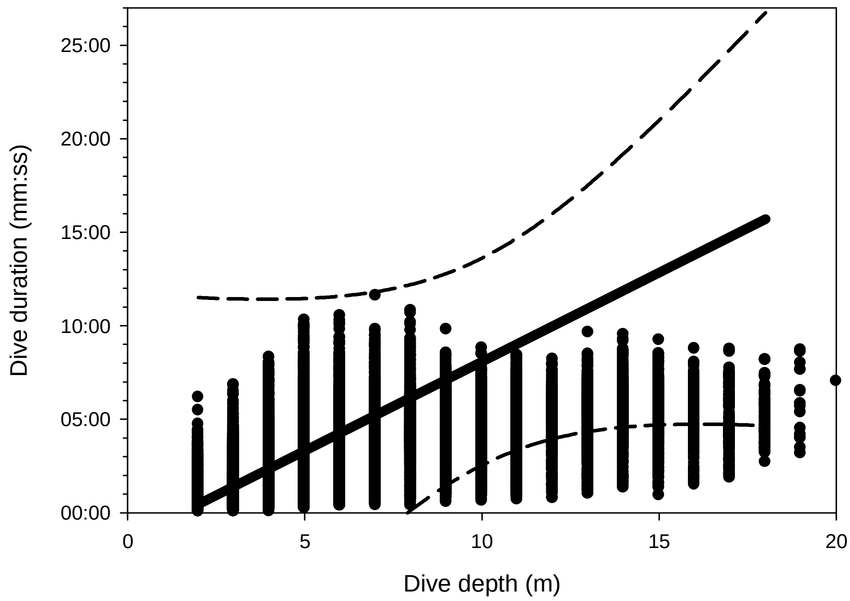


Figure 7b. Regression of dive duration on dive depth for animal BB03 which undertook a large scale movement of over 400kms from Beagle Bay. The regression was significant (r^2=0.51,$F_{1,17,358}$=18,005, p<0.001)

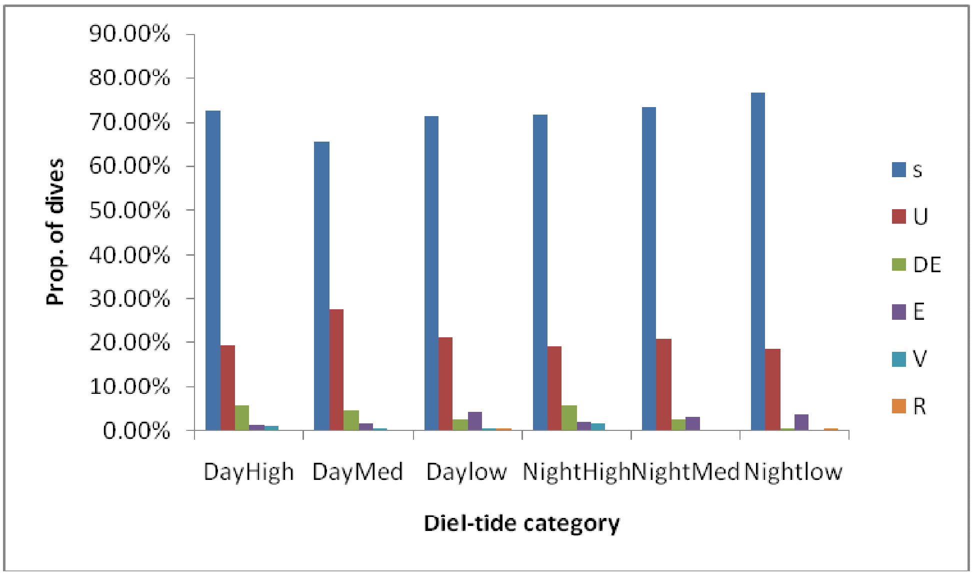


Figure 8a. Proportion of dive types for each animal for the 6 diel-tide categories (night & day) for BB01. Index for dive types are S-Square, U-U shaped, DE-Deep erratic, E-erratic, V-V shaped, R-Resting. See Table 1 for definitions.

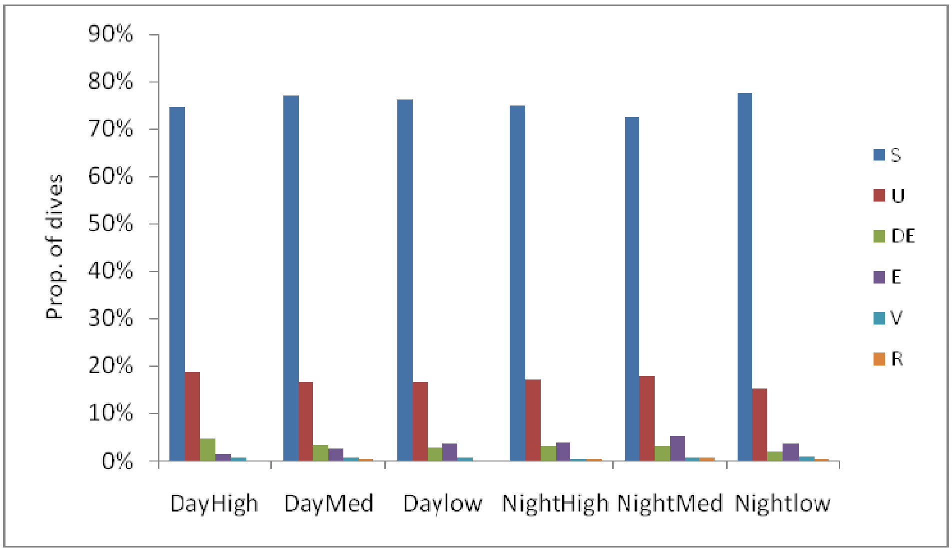


Figure 8b. Proportion of dive types for each animal for the 6 diel-tide categories (night & day) for BB03.

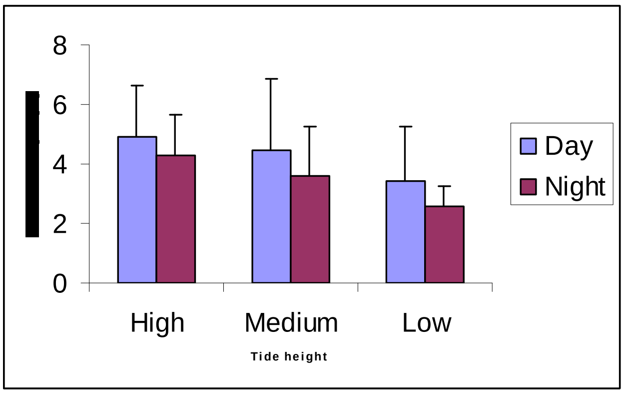


Figure 9a. Mean dive depth for animal BB01 by tide height category and diel period. Post-hoc testing revealed significant difference among all pairwise comparisons among tidal categories (p<0.05).

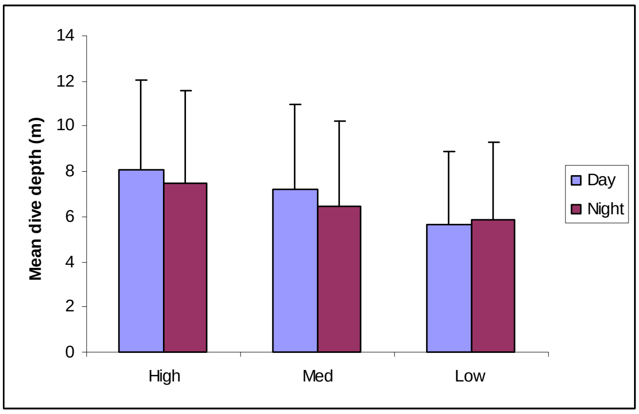


Figure 9b. Mean dive depth among tide and diel categories for animal BB03. Post-hoc testing revealed no significant differences among all pairwise comparison of tidal height categories.

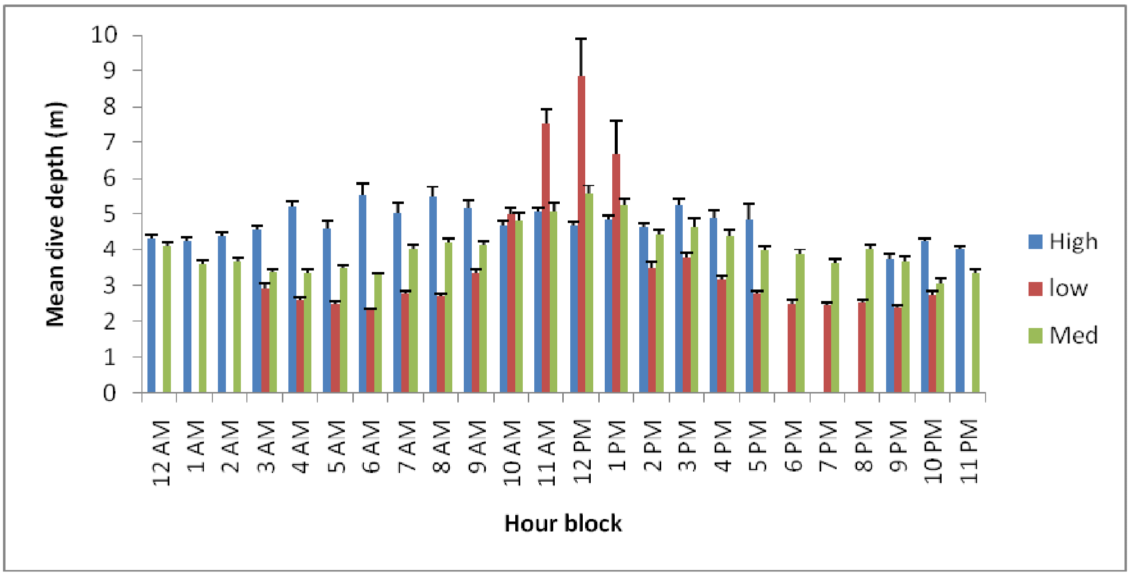


Figure 10a. Mean dive depth (±se) for all hourly blocks for each of the three tide height categories for animal BB01. There appears to be an increased mean dive depth during the middle of the day for the low and medium height tidal conditions and a corresponding decrease mean dive depth at the dawn and dusk periods for these two categories. Mean dive depth appeared independent of the time of day for the high tide level.

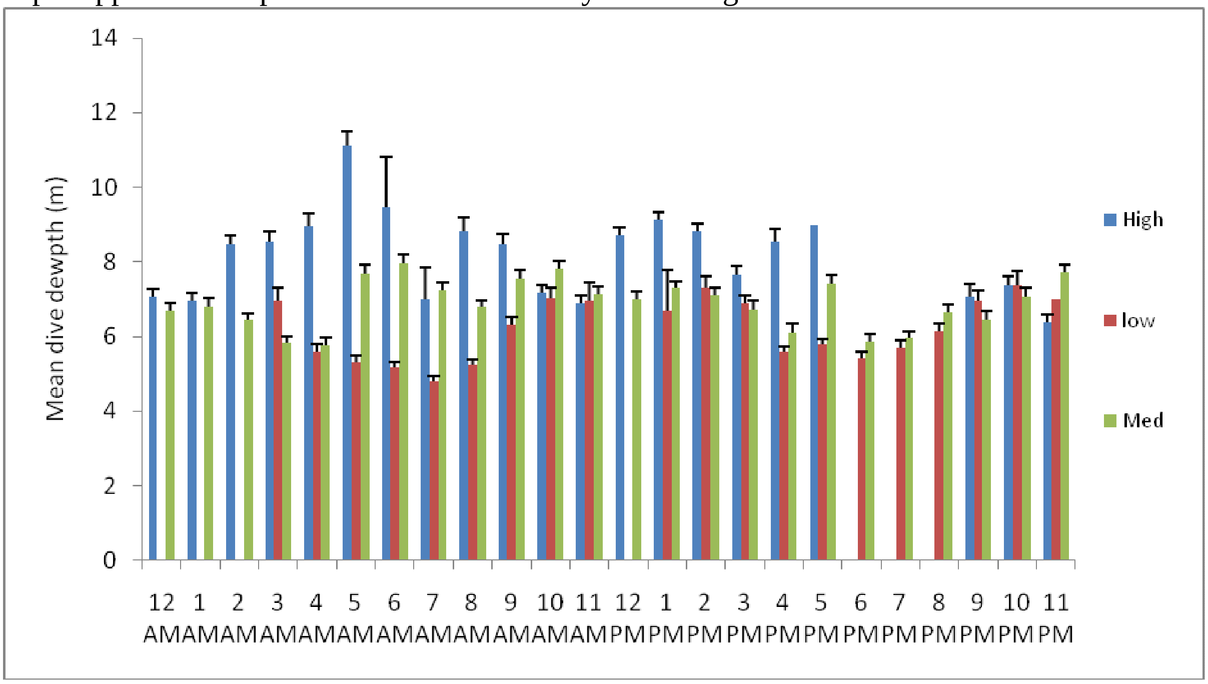


Figure 10b. Mean dive depth (±se) for all hourly blocks for each of the three tide height categories for animal BB03. Mean dive depth appeared independent of the time of day for all tide levels.

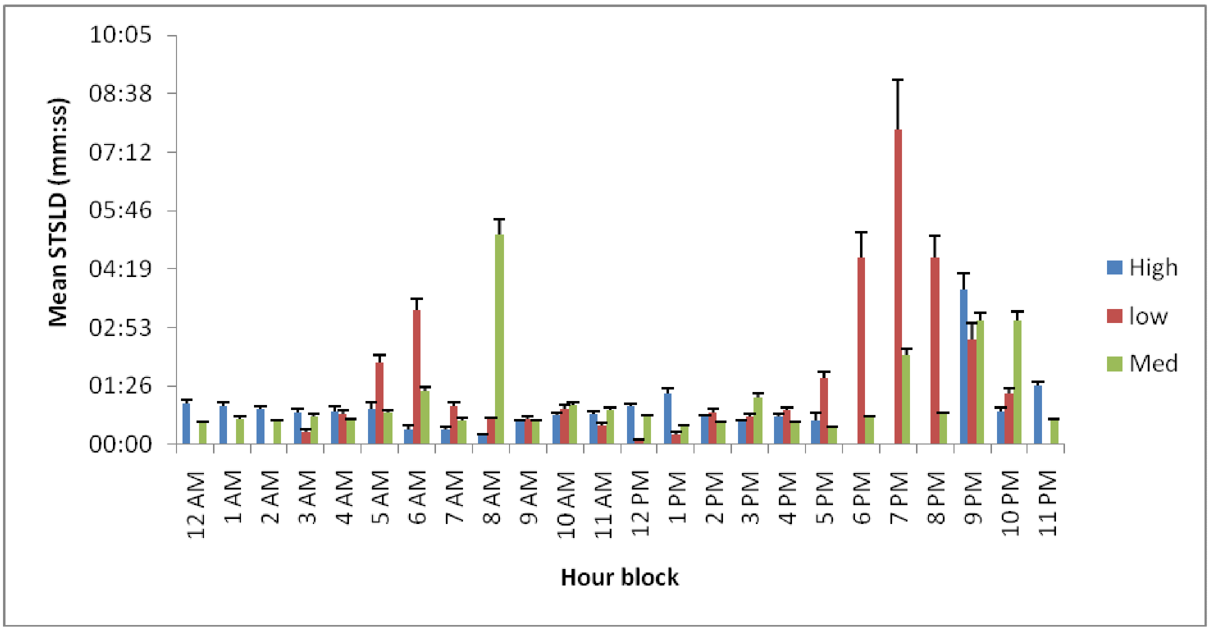


Figure11a. Mean surface time since last dive (STSLD, ± se) for hourly blocks among the three tide height categories for BB01 within Beagle Bay. There is a distinct peak of mean STSLD during the early evening hours and to lesser extent in the early morning period around 6am.

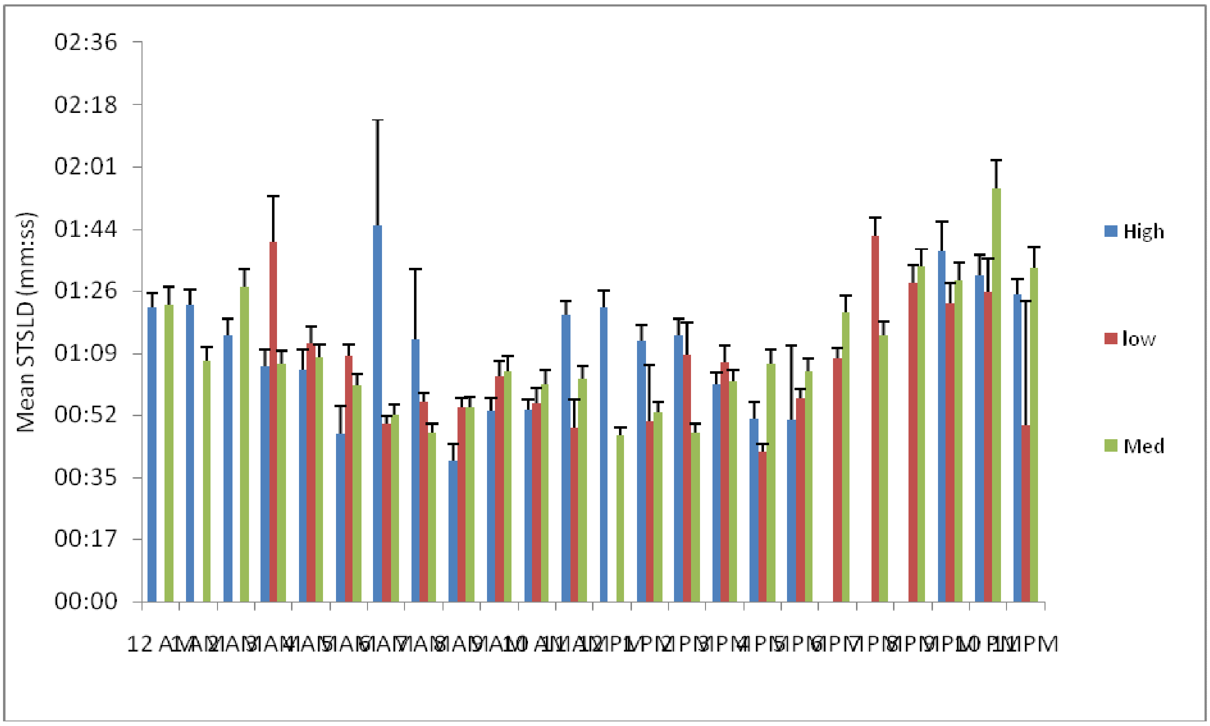


Figure 11b. Mean STSLD (± se) among hourly blocks for the three tide height categories for BB03. This variable appeared to be independent of time for all tide categories.

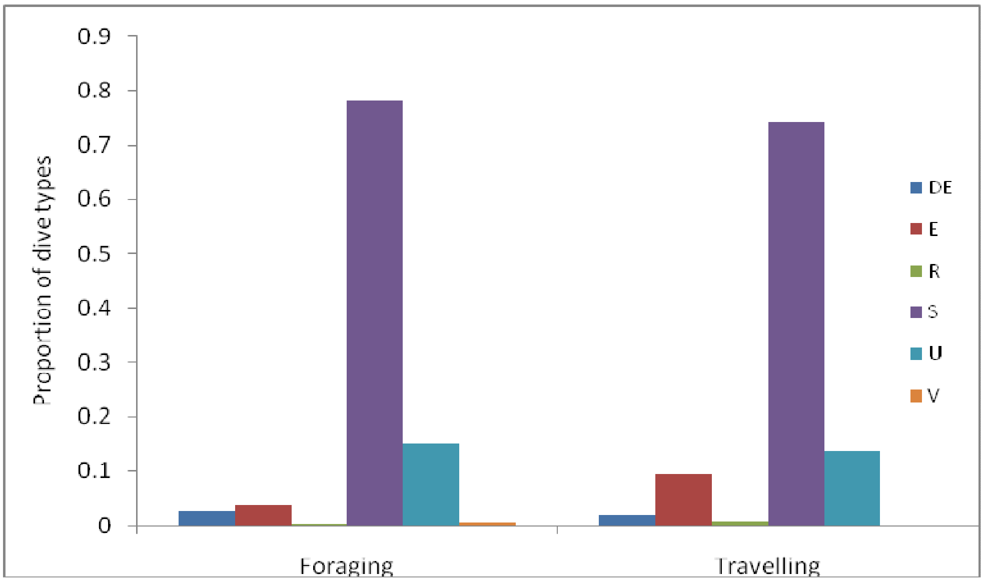


Figure 12. Proportion of dive types for a subset of dive data determined as foraging (n= 5435) or travelling (n=943) based on minimum travel rates for animal BB03. These data represented approximately 3 weeks of the total deployment period of 6 weeks for this animal.

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APPENDIX A

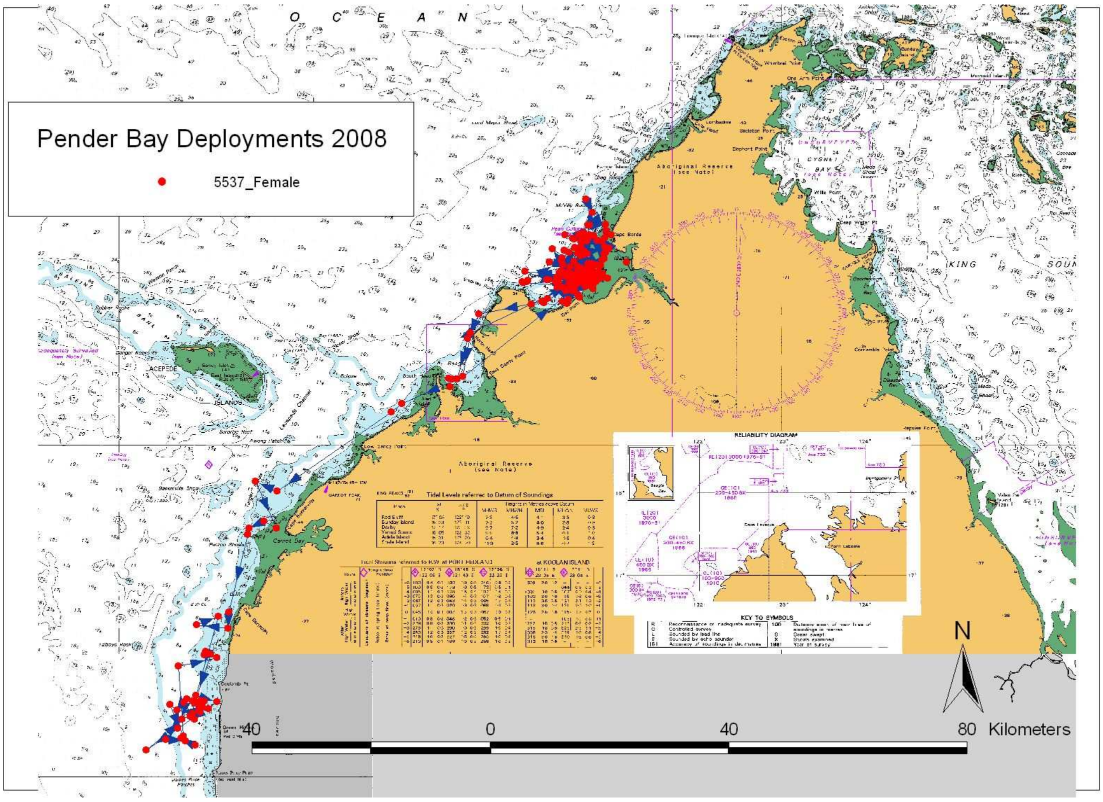

Figure A. Locations and track from satellite tag deployed on female dugong May 2008.

APPENDIX B

Minimum convex polygon bootstrapping analysis performed in the AM (Hooge & Eichenlaub 1997) extension for Arcview 3.2

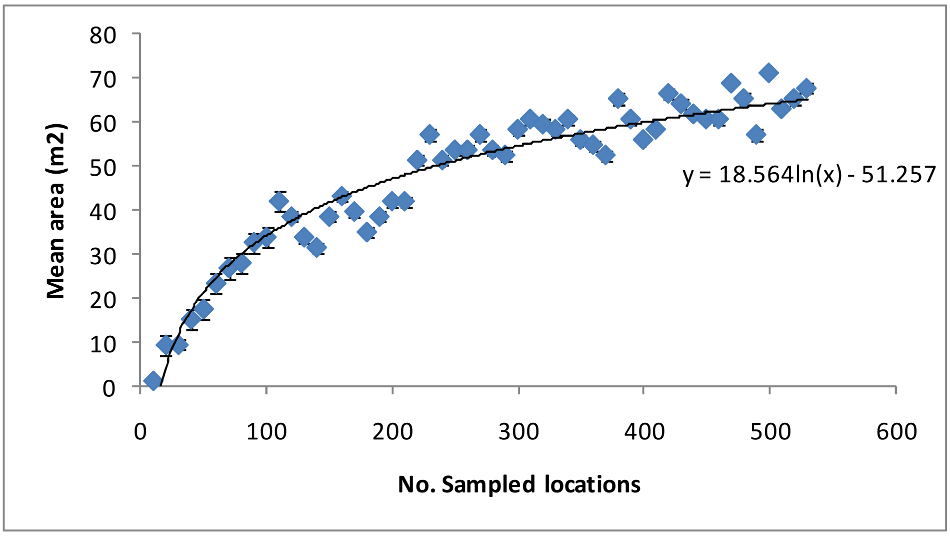

Figure A. MCP bootstrap analysis for BB01. Ten replicates of each bootstrap sampling with replacement were performed at increments 5 locations.

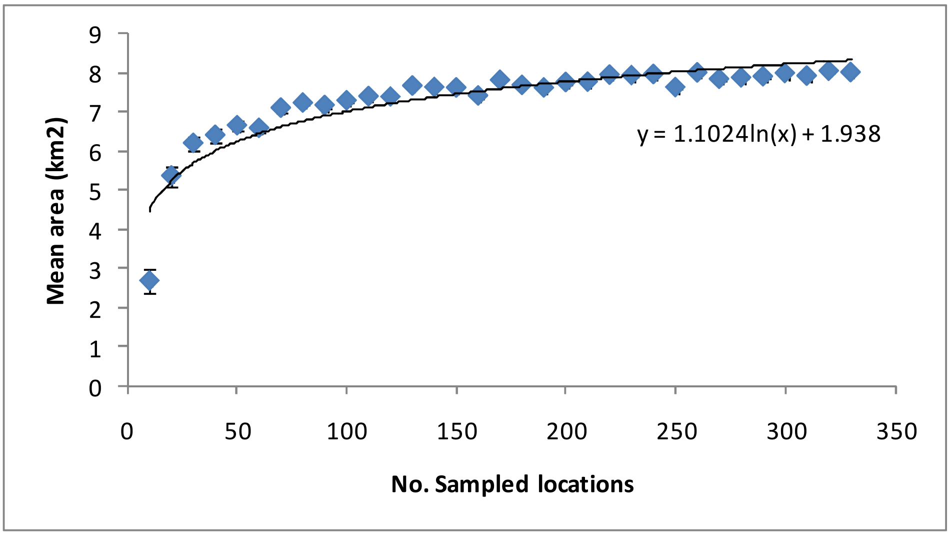

Figure B. MCP bootstrap analysis for BB02

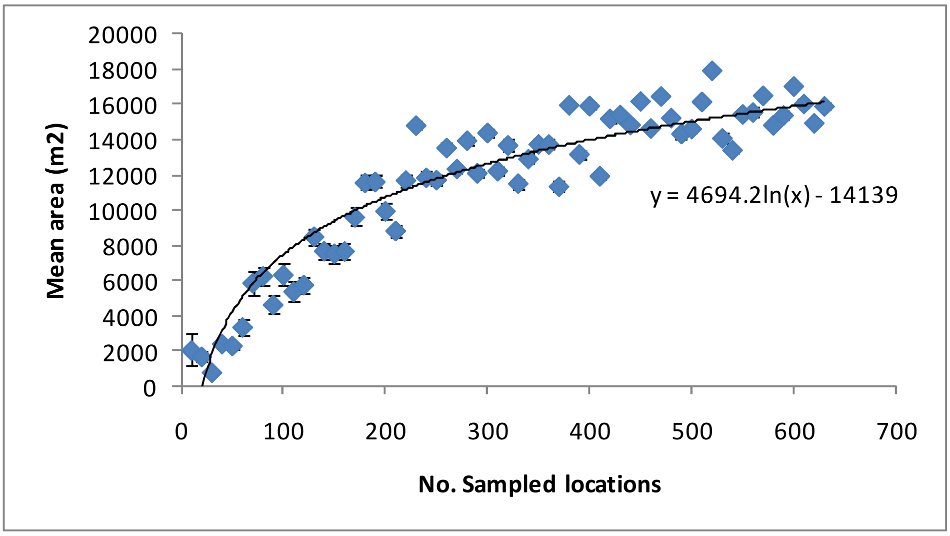

Figure C. MCP bootstrap analysis for BB03.

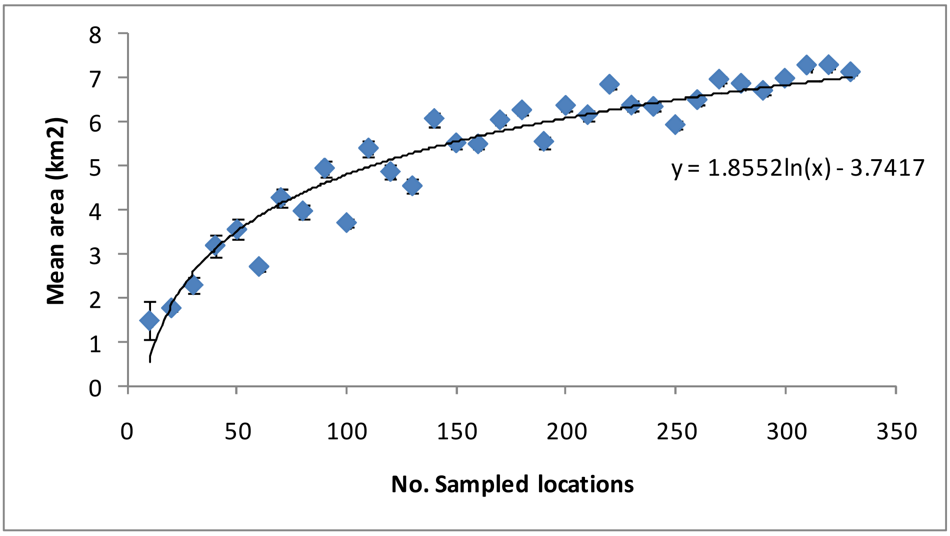

Figure D. MCP bootstrap analysis for BB04

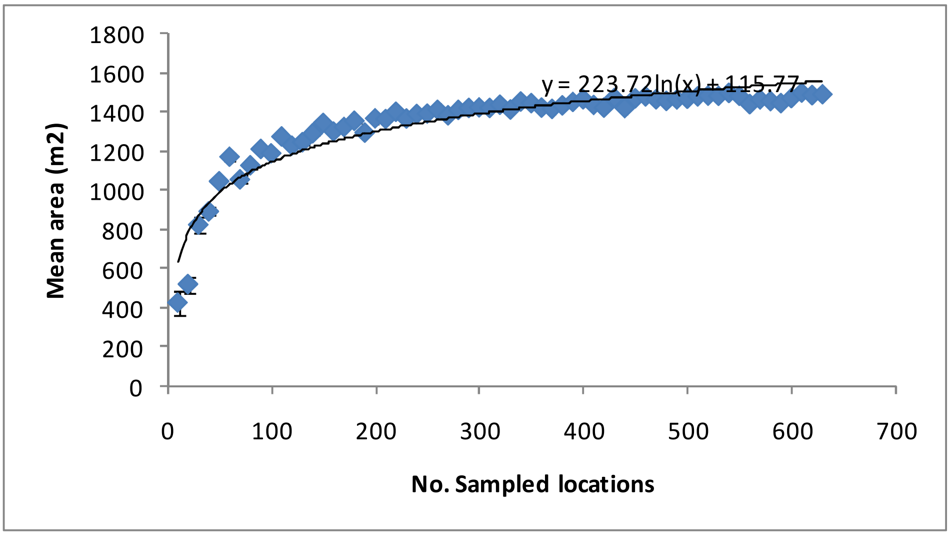

Figure E. MCP bootstrap analysis for PB02.

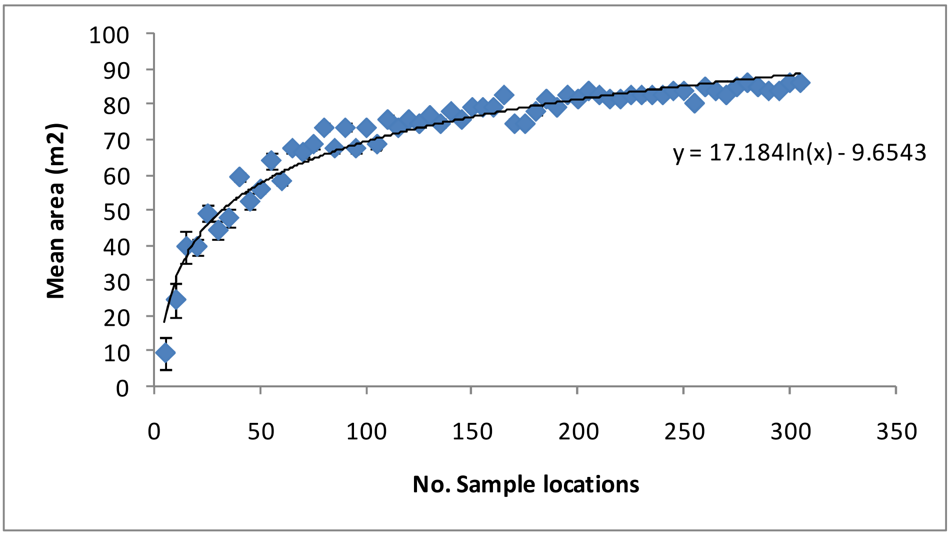

Figure F. Bootstrap analysis for animal BB05.

APPENDIX C

Depiction of the traditional seasons of the Bardi showing the appearance of dugong (odorr) and time of hunting during the *Bargana* season. Comparisons with the Roman calendar are shown. Image courtesy of the Bardi people and Geoff Buchanan.