DUGONGS (*DUGONG DUGON*) OF THE BAZARUTO ARCHIPELAGO, MOZAMBIQUE

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1. EXECUTIVE SUMMARY

Historically, dugongs occurred in almost all coastal areas from southern Mozambique in the west to Australia in the east, including many of the island States in the Indian and Pacific Oceans between. However, through much of this range, dugongs have all but disappeared and where they occur, are represented by relict populations. This is especially true for Eastern Africa and the Indian Ocean and Mascerine Islands. In most areas dugongs have been extirpated and only in southern, central Mozambique, the Bazaruto Archipelago, does a relatively large number still survive.

Between April 2006 and December 2007 a series of 27 aerial surveys was flown over the Bazaruto Bay region, from Cabo Sao Sebastio in the south to north of the Save River Mouth in the north and between the coast and the 30 m isobath (extending to eastwards of the Bazaruto Archipelago islands in the south). A total of 9052 nautical miles of survey was flown during the 27 surveys. During these, 355 sightings of an estimated 760 dugongs were made.

Two core areas of distribution were apparent; a northern core region, between the Save River Mouth and 21°24' S, and a southern core region aligned with the shallow sandbanks to the north and south of Santa Carolina Island. The mean group size of dugongs encountered was 2.22 and comparable to mean group sizes observed elsewhere. However, the maximum group size observed was considerably smaller than those observed in other areas of dugong abundance. Likewise, calculated dugong densities were substantially lower in the Bazaruto area than they are in the Arabian Gulf or Australia. There was no evidence of any seasonal variation in occurrence, group size, density or proportion of calves. The proportion of calves was similar to that in other areas surveyed for dugongs.

Statistical manipulation of the data from aerial surveys suggests that the dugong population inhabiting the area surveyed is around 250 animals.

The extent of dugong habitat was gauged by mapping seagrass occurrence, diversity and distribution. Mapping was accomplished through extensive dive sampling of 982 stations within the surveyed area, within 5m to about 25 m depth. Five species of seagrass were identified within the area. These covered some 4.68 % of the area and occurred generally in the north and close to the shore in waters less than 8 m deep. In the north, the areas of greatest seagrass abundance and diversity coincide with the areas of greatest dugong abundance. However, in the area to the north and south of Santa Carolina, seagresses were almost absent, suggesting that this area is used by dugongs for reasons other than feeding.

Population Viability Analysis (PVA) modelling was used to assess the viability of the dugong population in the Bazaruto Archipelago under various scenarios. PVA is a statistical method of understanding the influence of a species' natural history, in combination with demographic, environmental, and random genetic (stochastic) events, on the dynamics of its future. The species' population dynamics is modelled as a set of discrete, sequential events (e.g., births, deaths, catastrophes, etc.), which occur according to defined probabilities. Population dynamics models provide a predictive tool, where the impacts of variables (threats), in this instance – environmental threats (cyclones, floods); hydrocarbon exploration and incidental fishing catch, can be theoretically modelled.

Overall, the PVA models suggest strongly that the dugongs inhabiting Bazaruto Bay are in a precarious position and face extirpation. The models suggest that dugongs are particularly susceptible to long term stressors that might reduce overall reproductive success. Further, the analyses clearly show that regular deaths, from anthropogenic sources, are the major cause of dugong decline.

A number of scenarios, covering options for hydrocarbon exploration and exploitation, are presented and discussed, in terms of their potential impacts on the dugongs inhabiting the Bazaruto area.

1.1 INTRODUCTION

The dugong is the one extant species member of the family Dugongidae of the mammalian order Sirenia. As the only true marine mammal that is herbivorous, dugongs are strongly associated with seagrasses (Heinsohn and Birch, 1972; Marsh et al., 1982; Preen, 1995, Lanyon et al., 1989; Aragones and Marsh, 2000), feeding almost exclusively on phanerogram seagrasses (the families Potamogetonaceae and Hydrocharitaceae) (Kingdon, 1971; Heinsohn and Birch, 1972; Husar, 1978; Marsh et al., 1982; Preen, 1995). Tropical seagrass beds are consequently critical habitat for dugongs, particularly seagrass beds that occur within water depths of less than 10 m deep (UNEP, 2002).. Such seagrass habitat is often under pressure from various anthropogenic activities, including commercial and artisinal fishing, vessel traffic (including tourism), coastal development and degradation of coastal zones.

Dugongs range across nearshore tropical and subtropical coastal and island waters (between approximately 27 degrees north and south of the equator) of the Indo-Pacific between southern Mozambique / northern KwaZulu Natal, South Africa (although records in South Africa may have been historical vagrant records) in the west and Vanuatu to Japan in the east (UNEP, 2002). The range is extensive spanning some 140 000 kilometres of coastline of approximately 40 coastal and island states within this region. It has been suggested that the limits of this range are defined by water temperatures of less than about 18° C (Preen, 1992; Marsh et al., 1994). Although Australian waters contain the world's largest dugong population (Marsh et al., 2002), Preen (2004) has reported that the Arabian Gulf is the most important area for dugongs in the western half of their range, and the most important area outside Australia.

Dugongs are currently listed globally as vulnerable to extinction under the 1996 World Conservation Union (IUCN) Red List of Threatened Species, being threatened worldwide due to loss and degradation of coastal zone habitat (especially seagrass beds), fishing pressure (including indigenous fishing pressure through hunting), and coastal pollution. Many of the local populations over the extensive range are thought to be heavily depleted, particularly so within the coastal waters of African range states and within the Western Indian Ocean (WIO). The United Nations Environment Programme’s Dugong Status Report and Action Plans for Countries and Territories (UNEP, 2002) states that

‘throughout much of its range, the dugong is represented by relict populations separated by large areas where its numbers have been greatly reduced or it is already extirpated. The dugong is still present at the historical limits of its global range, although there is evidence of a reduction in its area of occupancy within its range. In most parts of its range, the anecdotal evidence suggests that dugong numbers are declining’.

Quantitative population estimates have only been made in three areas, Australia; the eastern Red Sea; and the Arabian Gulf (Bayliss and Freeland, 1989; Preen, 1989; Marsh and Saalfeld, 1990; Marsh et al., 1996; Preen et al., 1997; Marsh and Lawler, 2001). Although over approximately 75% of the world’s dugongs are found in Australia, recent evidence has suggested that certain components of the Australian populations are in decline (Marsh et al., 2005).

1.2 WESTERN INDIAN OCEAN REGIONAL DISTRIBUTION

Historically dugong distribution range within the African region of the Western Indian Ocean (WIO) extended from Somalia in the north, through Kenya, Tanzania, Mozambique and further east off the islands of the Comoros, Seychelles, Madagascar and Mauritius. However current information on the status of dugongs in the WIO is sparse. Historical data indicate that most dugong populations in the region have suffered a steep decline in since the 1960s.

Current information from qualitative and quantitative surveys show that dugongs may now only remain in small numbers in a few areas in Kenya, Tanzania, Mozambique, Madagascar, Seychelles and the Comoros archipelago (Moheli and Mayotte islands). Distribution may be summarized as patchy across areas including in

- Kenya, where small populations still persist off the Lamu-Kiunga coast and at Gazi in the south near the Tanzanian border. Muir et al. (2003) noted that although herds of up to 80 were recorded in Manda Bay in 1996, recent aerial surveys suggest a strong decline in numbers.
- Tanzania, in the region of the Rufiji Delta and Mafia Island , although infrequent sightings also occur in the north (these animals probably form part of the southern Kenyan population). Muir et al (2003) noted that of the 11 records between Mafia and Rufiji between 2000 and 2003, 9 were captured or killed, while only two ere sightings. Muir et al (2003) reported that dugongs, once common along Tanzania's 900 km coast, dugong populations are now so rare that their status is no longer known. They noted further that population levels have reached levels where the species may no longer recover.
- Madagascar, where the most important dugong areas are the islets of Andavadoaka - Morombe; at Ambararata – Courrier and Diego Bay; the bays and estuaries of Sakoany - Bombetoka; Ambavarano - Vohémar; and Sainte-Marie Island.
- The Seychelles, where regular dugong sightings in the sheltered lagoon at Aldabra Atoll indicate a resident population of 3 dugongs: 2 adults and 1 juvenile.
- Mayotte, where groups of 5-7 dugongs have been sighted in the lagoon during 2002 and 2003 (including two mother and calf pairs) and one was caught accidentally in a net in September 2003.
- Mozambique, where the largest population and possibly the only viable population within the Western Indian Ocean occurs within the Bazaruto Archipelago. Sparse records occur from elsewhere on the Mozambique coast, although no sightings are believed to have been made within the Quirimbas region since 2003.

Dugongs possibly still occur in the Comoros (at Moheli Island) and off the Somalian coast, but their current status is unknown. They are believed to have become extinct from Mauritius in the early 20th century, and never to have occurred in Reunion. Their status at other WIO islands remains unknown. Although dugongs are protected across the range of all the above states, enforcement is limited by both human capacity and resources.

WWF (2004) noted that current information from the WIO region suggests that dugong populations have been declining sharply since the 1960s and 70s. A recent UNEP/IUCN (UNEP, 2002) report on the global status of dugongs suggested that extinction of the dugong in the WIO region was considered inevitable without immediate and effective conservation measures.

1.3 DUGONGS IN MOZAMBIQUE AND THE BAZARUTO BAY REGION

Based on a survey along the Mozambican coastline in 1969, Hughes (1971) reported that dugongs were common at Maputo Bay, Chidenguele, Inhambane Bay, Bazaruto Bay, Mozambique Island and Pemba Bay. Hughes also speculated (based on the existence of suitable habitat) that dugongs might occur in the Quirimba Archipelago, but their status in this area was unknown (Hughes, 1971; Smithers & Lobão Tello, 1976). Smithers & Lobão Tello (1976) observed dugongs in Maputo Bay (8 -10 animals), Inhambane Bay (2 - 4 animals), Ponta Bartolomeu Dias (20 animals seen in 1974) and along the coast between Bazaruto Bay and Save River where they were reported to be common. Elsewhere, smaller groups were observed at Angoche, Mozambique Island, Matimbane Bay and Pemba where they were said to be abundant until 1970. These reports suggest a hiatus in the distribution of dugongs between the Save River mouth and Angoche (Hughes and Oxley Oxland, 1971), although the lack of survey effort within this region (coupled with the general high water turbidity resulting from river discharge in this region) must be noted.

Results of 114 questionnaire surveys on dugong occurrence in Inhambane Province and the Quirimbas region suggested that dugongs occurred in or near Maputo Bay, Zavora, Inhambane Bay, Bazaruto Bay and the Bartolomeu Dias region in Inhambane Province, while in the Quirimba Archipelago, dugongs were reported to occur in the shallow southern areas between the mainland coast and the southern islands (Guissamulo, unpub. data).

The status and distribution dugongs are believed to have altered significantly since Hughes (1969) conducted the survey along the Mozambique coast (UNEP, 2002), in that he concluded that dugongs were relatively common. However, recent aerial and vessel based surveys have suggested a considerable decline in dugong abundance across Mozambique waters.

- In the mid 1970s, dugong herd sizes of eight to ten individuals were reported for Inhaca Island (Guissamulo & Cockcroft 1997). Guissamulo & Cockcroft (1997) assessed the distribution and relative abundance of dugongs in Maputo Bay during 1992. Dugongs were sighted in the eastern quarter of the Bay, in the vicinity of Inhaca Island. This area is now thought to support only 2 or 3 individuals (Cockcroft & Young, 1998). Two individuals were sighted in Maputo Bay in 2007 (Rabe, in litt to VCG).
- During a boat survey in Inhambane Bay in October 1994, dugongs were observed throughout the bay (ATG, unpub. data), although a more recent aerial survey in 2001 recorded only a single dugong outside the bay, during a low spring tide (Mackie, 2001).
- The Bazaruto Archipelago region is reported to support the largest dugong population along the east African coast (Dutton, 1994). Estimates based on strip transect sightings suggested a local population of 130 dugongs in the Bay (Guissamulo & Cockcroft 1997). However, aerial surveys by Dutton (1998) suggest that the dugong population is declining rapidly as maximum counts suggested approximately 21 dugongs per survey (Dutton 1998). An aerial census of the Bazaruto National Park (including the Bazaruto National Park (Bazaruto, Santa Carolina, Benguerra, Magaruque and Bangue) conducted by WWF in May 2001 found dugongs distributed throughout the northern, central and south central areas of the Archipelago between Bazaruto Island and the mainland. However, WWF (2004) suggested from aerial counts (of between 25 and 130 individuals) between 1990 and 2002, that this population is declining (Mackie, 1999).
- No dugongs were recorded in aerial surveys of the Pemba to Mtwara region of northern Mozambique (Cabo Delgado Province) in 2007 (ATG, unpub. data). No dugongs appear to have been reported from this region since an individual drowned in a net in the Quirimbas National Park in November 2003 (WWF 2004). Prior to this a local fisherman reported seeing a lone dugong in 2001 near Quilalea Island in the Quirimbas National Park (Motta, 2001).

The intensification of large mesh gill netting from 1976 onwards (often directed at dugongs), coupled with lack of law enforcement, is thought to have been the principal cause of the decline of the dugong population in Mozambique. However, seine netting, commercial trawl operations and palisade fish traps are believed to compound the fishing pressure on dugongs in Mozambique. WWF (2004) suggested that habitat destruction of seagrass beds (through increased levels of riverine sedimentation and through natural cyclone and flood events), and increased anthropogenic disturbance through exposure to vessel noise (particularly tourism vessels) are further threats to dugong populations in Mozambique.

Box 1. Recent Convention on Migratory Species Memorandum of Understanding on Conservation of Dugongs and their Habitats signed by Mozambique.

A Memorandum of Understanding (MoU) concerning the conservation of dugongs in the Indian Ocean was signed and entered into force on 31 October 2007 in Abu Dhabi under the auspices of Convention on Migratory Species.

The agreement is designed to facilitate national level and transboundary actions to conserve Dugong populations and their habitats. Dugongs are vulnerable to anthropogenic influences due to their life history (they are late and slow breeders), their extensive range and their distribution along rapidly changing coastal habitats throughout several countries. Given the dugong's migrations across borders, coordinating management initiatives across these boundaries will be crucial to its long-term survival. Without a multilateral approach and internationally cooperative decision-making, the future of the dugong looks bleak.

Dugongs are hunted for food, usually for their meat and blubber, throughout their range. Also, the sea grass beds which the dugong depends on are threatened by eutrophication caused by agricultural and industrial runoff. Due to their feeding habits, dugongs are frequently injured or killed by collisions with motor vessels.

The dugong's current distribution is reduced and scattered, and many populations are close to extinction. The World Conservation Union (IUCN) classifies the dugong as "Vulnerable", meaning that it is threatened by extinction. The Convention on International Trade in Endangered Species limits or bans the trade of derived products based on the species. Despite being legally protected in many countries throughout their range, the main causes of decline of dugong population remain manmade.

The associated Conservation and Management Plan (CMP) to the new agreement concluded under CMS lists nine objectives and an annex containing examples of specific activities to protect the species. International cooperation within a legal framework and educational activities to create understanding for long-term conservation needs will promote the agreement's implementation.

1.4 STUDY CONTEXT

Recently the Government of Mozambique signed an Exploration and Production Concession Contract (EPC) was with Sasol Petroleum Sofala Limitada (Sasol) and Empresa Nacional de Hidrocarbonetos, E.P. (ENH). The contract gives Sasol and ENH the rights to conduct hydrocarbon exploration and production activities in the Blocks 16 and 19, Mozambique (see Figure 1), located to the east and north east, north and north west of Bazaruto Archipelago National Park (BANP), Inhambane Province, Mozambique.

Despite the reported decline in dugongs in the Bazaruto Bay region (Dutton, 1994; WWF, 2004), it is apparent that the area must be considered one of the last strongholds (if not the last stronghold) of dugongs in the Western Indian Ocean. Blocks 16 and 19 include this dugong habitat and the impacts of exploration to the local dugong population were identified as of concern in the EIA for exploration (ERM, 2007). Due to this concern and the lack of information on dugong biology (including distribution and abundance, behaviour and life history parameters) Sasol Petroleum Sofala Limitada (Sasol) committed to an investigation of aspects of the biology of the species in the region.

The importance of the Bazaruto Bay region to dugongs is particularly evident in the context of the limited dugong populations within the Western Indian Ocean. The Bazaruto population probably represents the most viable (and possibly the only viable) population of dugongs in the Western Indian Ocean south of the Arabian Gulf. The long-term conservation and recovery of this species within the Western Indian Ocean may well be dependent on the “seeding” of the region by individuals from the Bazaruto population (and their subsequent survival within regions which have shown recent population declines).

METHODOLOGY

1.5 THE STUDY AREA

The coast of Mozambique extends from approximately 10°20’ S to 26°50’ S, over a distance of 2750 km. Three geographical regions can be identified within coast of Mozambique (Tinley, 1971; Rodrigues et al. , 1999; Motta, 2001) including:

1. a coral coast of 770 km extending from the Rio Rovuma southwards to Pebane at approximately 17°20’S;
2. a swamp coast of 950 km from Pebane southwards to Bazaruto Island at 21°10’ S, and
3. a dune coast extending from Bazaruto southwards for 850 km to Ponto do Ouro.

The Bazaruto Archipelago is a series of five islands (Bazaruto, Benguerra, Margaruque, Bangue and Santa Carolina) situated in a general north - south linear orientation in the region of 21° S on the central coastline of Mozambique (Figure 1), although Santa Carolina, lies to the west of the others, having formed during separately from the other four. Bazaruto Bay lies between the Archipelago and the mainland. Bazaruto Bay is a shallow (generally less than 30 m deep) protected bay of some 1000 $km^{2,}$ lying between the four outer islands of the Bazaruto Archipelago and the mainland (latitudes 21°10' to 22°10' S; longitudes 35°22' to 35°30' E). This large bay has extensive seagrass beds and consequently provides excellent habitat for dugongs.

Two distinct basins can be found in this bay, one to the north of Santa Carolina Island (maximum depth 33 m) and in the middle section of the bay, west of the southern end of Bazaruto and northern end of Benguerra Islands (maximum depth 24 m). The northern basin is the main connection of the bay to the open sea and is the deepest area of the bay. The southern section of the bay is comprised of vast areas of tidal flat areas often drying-out during spring low tides.

The main feature of circulation within the bay is the strong tidal currents during the flood and ebb phases. Wave action is restricted to the seaward side of the islands. The mean spring tidal range is approximately 3 m during normal spring tides, increasing to approximately 4.4 m during equinoctial spring tides. Strong tidal flows maintain the deep channels on the landward side of the islands and transport sand across the tidal flats.

The physical and chemical characteristics of water masses of Bazaruto Bay exhibit spatial and temporal variability by season as rainfall is highly variable both within and between years. December to February are the wettest months (140 mm to 170 mm), while the months from July to October are the driest (typically < 40 mm).In the dry season, the Bay has a marine character, with a uniform salinity ranging from 35 to 36 PSU. In the wet season the bay becomes more estuarine, exhibiting a lower overall average salinity (33 to 35 PSU) compared to dry season. However a stable West-East increasing salinity gradient can be found throughout the rainy season.

The Bazaruto Archipelago area is a high risk region for tropical cyclones.

As a shallow tropical bay, Bazaruto Bay contains a number of important seagrass meadows or beds. Prior to this project, the information on seagrass species composition, extent and distribution was only known for the southern Bazaruto Bay, between Inhassoro and Cabo Sao Sebastiao. Within this region seagrass covers an area of approximately 88km^2 of the shallow intertidal and subtidal waters inside the 5m isobath. Nine species of seagrass were recorded at Bazaruto Bay area, namely: *Thalassondendron ciliatum, Cymodocea rotundata, Cymodocea serrulata, Thalassia hemprinchii, Halophila ovalis, Nanozostera capensis, Halodule uninervis, Halodule wrightii,* and *Siringodium isoetifolium*. The most extensive seagrass communities are those dominated by *Thalassondendron ciliatum* (45.5 % of area) and Cymodocea (32.6 %) of area.

Seagrass meadows also occur north of Inhassoro and off the Govuro River estuary and westward of the Bartolomeu Dias area, where it is suspected that *Nanozostera capensis*, *Halodule uninvervis* and *Cymodocea rotundanta* dominate the meadows.

Two major marine protected areas occur in the Bazaruto Archipelago region.

1. Bazaruto Archipelago National Park

The Bazaruto National Park (BNP) was created in 1971 with an aim to protect the marine fauna, specifically dugongs and sea turtles, and the area covered the three Islands of the Bangue, Margaruque and Benguerra Islands in the district of Vilankulo. Dutton (1994) suggested that the establishement odf the BNP had little success in protecting the dugongs. In 2001, new boundaries of the Bazaruto National Park (BNP) were defined through the Decree Nº 39/2001. With the implementation of the new boundaries, the Bazaruto and the Santa Carolina Islands in the Inhassoro district have been incorporated and the Park was then designated the Bazaruto Archipelago National Park (BANP), managed by the Park Administration, under the jurisdiction of the Tourism Ministry.

2. Protected Area of São Sebastião

The Total Protection Zone of the Cabo de São Sebastião was created under the Decree Nº 18/2003, with an objective to protect the natural resources of the São Sebastião Peninsula. The “Vilanculos Coastal Wildlife Sanctuary” Project has a concession of approximately 25,500 hectares designated to the establishment of a Private Natural Reserve in the area.

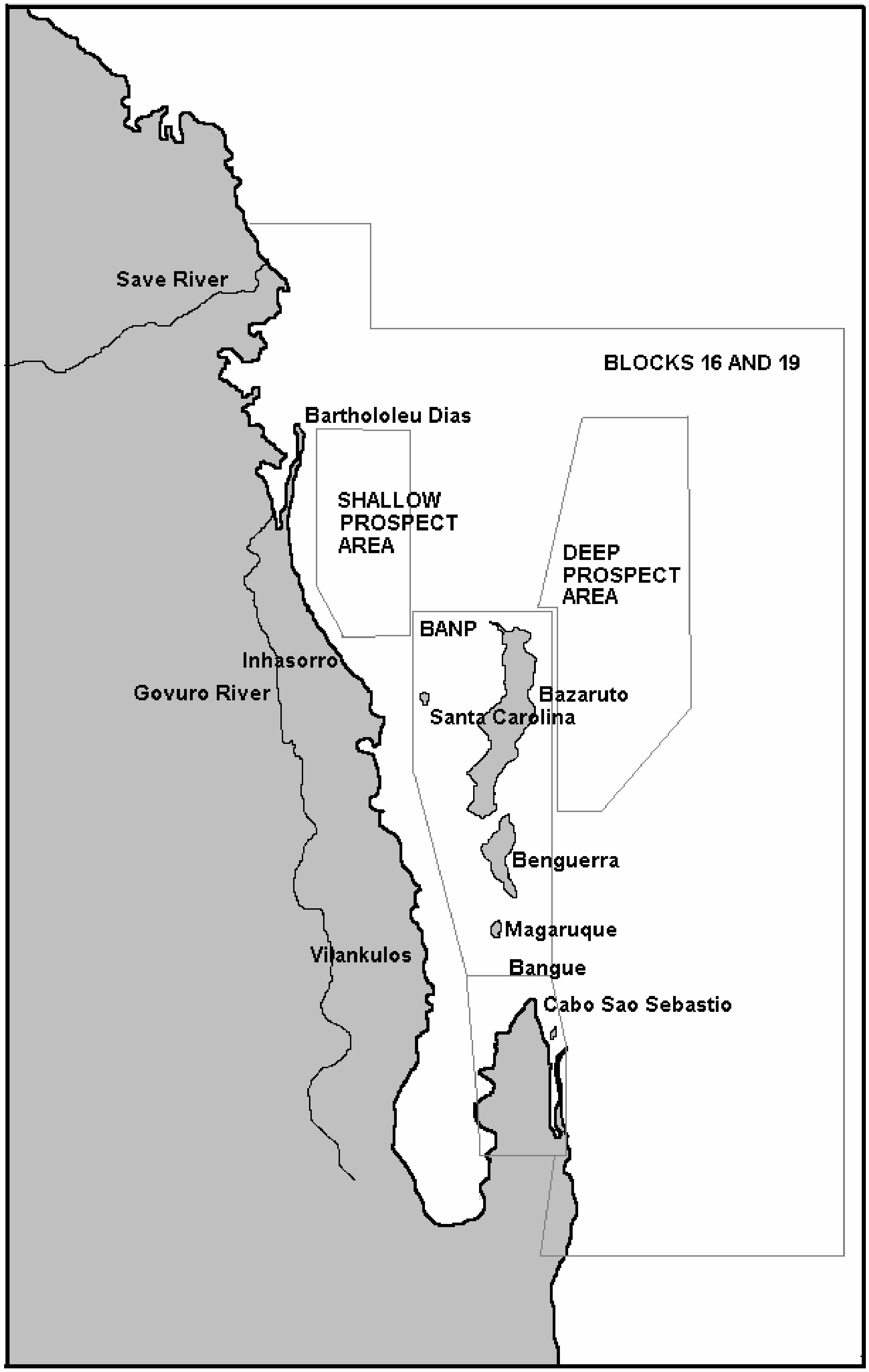

Figure 1. The Bazaruto Archipelago, showing positions of locations mentioned in the text.

1.6 AERIAL SIGHTING SURVEYS

1.6.1 Field Methodology

Aerial surveys were flown over the Bazaruto Bay region from Cabo Sao Sebastio in the south to north of the Save River Mouth in the north and between the coast and the 30 m isobath (extending to eastwards of the Bazaruto Archipelago islands in the south).

Each aerial survey has comprised a series of east – west / west – east transects flown at an altitude of 450 ft (137 m) and speed of approximately 80 knots in two aircraft types; a Cessna 210, with 6 seats and high wing configuration (ZS SPV) was used in the flight of 18 November 2006, while four different single - engined Cessna 182 or 185 aircraft were used for the remainder of the surveys (ZS IGR; ZS EPO; D-EOVC and C9 JSH). The number of transects flown per survey was not constant, being influenced by fuel capacity, available observer time or weather conditions. As surveys were generally flown from north to south, such limitations precluded the southern end of the survey area being covered on all occasions. However the shallow nature of this southern region of the bay resulted in no dugongs being sighted on survey transects that were flown in this region.

Survey plans comprised of 22 transects/legs (March 2006 to Aril 2006), 30 legs (November 2006 to 13-14 January 2007) or 36 legs (after 15th January 2007), each being flown east west or west east and generally perpendicular to the coast. However, the actual number of transects flown on each survey was dependent on available time and fuel constraints and prevailing wind and sea conditions. The survey carried out in December 2006, used a 6 km spacing between the survey legs and consisted of 19 survey legs. In other aerial surveys, the spacing between transects was 2 nautical miles. The lengths of the transects were variable depending on the coastal orientation and water depth; in the northern area, between Inhassoro and the Save river, the eastern limit of the survey was limited by the 20 m isobath, while within the Bazaruto National Park, surveys were carried out between the islands and the mainland, although surveys extended beyond the islands in the southern area where shallow banks extended to the east of the islands. All survey transects were flown following the aircraft Garmin Global Positioning System.

The survey crew consisted of a pilot, two observers and a data recorder. A single observer searched the entire visual observation area (outwards from as far below the aircraft as possible) from the rear seats on each side of the aircraft, while a data recorder logged flight paths and altitude, survey effort, sighting parameters and weather conditions, from the forward starboard seat position, while also directing the pilot. On making a sighting, the observer measured the abeam distance perpendicular from the survey track line to the dugong sighting using an inclinometer to measure the dip azimuth angle to the group (surveys after 16 December 2006) or by assigning sightings to distance bins marked by tape on the aircraft wingstrut (surveys prior to and including 16 December 2006). All information on the dugong sighting (including the number of animals, occurrence of calves in groups, and the sighting angles) were relayed to the data recorder.

The majority of survey was carried out in passing mode. However, when large groups were observed or suspected, or in cases where identification or group size estimation was not certain, the aircraft diverted from the survey track line for confirmation of the sighting. Other sightings of dugongs made during confirmation were considered secondary sightings and recorded, but not used for estimation of dugong numbers. Positions of effort and sightings were recorded using a hand held Garmin III Plus Global Positioning System.

1.6.2 Analyses

On completion of the surveys, data were entered into Microsoft Excel spreadsheets for analyses. GPS data captured during the survey were downloaded using DNR Garmin Arc

View Extension. The distribution of sightings and transects were sketch plotted using Microsoft Excel, for initial verification. Thereafter, the data on group size and location were plotted in Arc View 3.2 (ESRI), and the distribution of sightings was extracted.

Perpendicular distances were calculated for sightings as d.tan(θ), where d is the aircraft altitude and θ is 90 minus the dip azimuth angle of the sighting from the horizon (measured at the time of sighting abeam by hand – held inclinometer).

The density of observed groups (D) can be defined as

$$D = n/Lw \qquad \text{(Eqn 1)}$$

where n is the number of groups sighted during search effort, L is the length of the search track or transect, while w is the effective detection area (defined as the Effective Search Width (ESW)). Substitution of w by 2a (where a is half the ESW) gives

$$D = n/2La \qquad \text{(Eqn 2)}$$

The parameter a is the total area under the detection function with distance g(x). The distribution of detection distances may be defined by a probability density function f(x) where

$$f(x) = g(x)/a \qquad \text{(Eqn 3)}$$

so that with the assumption that g(0) is one (that all groups on the trackline are detected), a may be defined as

$$a = 1/f(0) \qquad \text{(Eqn 4)}$$

The Distance software programme (Thomas et al., 2006) was utilised to fit a hazard-rate model (Buckland, 1985),

$$g(y) = 1 - \exp[-(y/a)^{1-b}] \quad \text{(Eqn 5)}$$

to the perpendicular distances grouped into 0.05 n. mile intervals to give the sighting probability density function f(0) and its variance V[f(0)]. Two different analyses have been carried out using Distance to determine the sighting probability density function f(0) as the distribution of sightings with distance from the trackline suggests that observers could not detect animals under the aircraft. The first analysis utilised all the perpendicular distances of sightings from the trackline outwards, while the second analysis left truncated the perpendicular distances at 0.1 n. mile due to the difficulty of detecting groups directly under the aircraft.

The abundance estimate (N) of dugongs in the area surveyed (A) is given by

$$N = [A.n.s.f(0)]/[2L.g(0)] \qquad \text{(Eqn 6)}$$

where n is the total number of groups sighted during effort, s is the mean size of groups, and L is the total length of the search track or transects. The g(0) parameter here is assumed to be 1.

The variance on this estimate (V(N)) is calculated using the delta method,

$$V(N) = [V[f(0)/[f(0)]^2 + V[s]/s^2 + V[n_i/l_i]/[n/L]^2] \qquad \text{(Eqn 7)}$$

where V[ni/li] is the variance on transect sighting rates, where n_i and l_i are the number of sightings and the search effort of transect (i) respectively.

The area of the entire survey region was calculated from as the extent of the area between the coastline and the eastern limit of the survey transects, and excluding the land area of islands (which may have been flown over during survey) or the shallow sandbank region in the south of Bazaruto Bay (where no dugong groups were encountered).

1.6.3 Assumptions of the analyses

Estimates of animal abundance across a region requires a number of assumptions, including:

1. The area surveyed represents the entire range of the population.

The current limital range of the Bazaruto Archipelago dugong population is unknown. Anecdotal reports of individuals within the Pomene Estuary and published historic records of individuals in Inhambane Bay suggest a possible broader range than the area surveyed. However the association of these animals with the Bazaruto Archipelago population is unknown and it is assumed for the purpose of this report that these groups are discrete and no migration occurs in and out of the region. For the purposes of this report it is further assumed that the entire Bazaruto Archipelago population is found within the area surveyed. This assumption may bias the abundance estimate downwards if animals are present outside of the area surveyed (e.g. to the south of Cabo Sao Sebastio or to the north of the Save River Mouth).

2. The probability of detection of groups of animals on the track line g(0) is 1 (that all groups distributed on the track line will be detected with certainty) and that the probability of detection decreases with distance from the survey trackline.

A number of authors (Marsh and Sinclair, 1989a; 1989b; Gales et al., 2004; Preen, 2004) have reported on detection bias of animals which are missed by observers in strip transect surveys. Such bias may result from a) availability bias where animals are not near the surface and consequently not available to observers as potential sightings; and b) perception bias results from visible animals being missed by the observers.

The assumption that all groups on the trackline will be detected with certainty is unlikely to be met and will bias the abundance estimate downwards in that not all groups will be detected. However, the proportion of groups missed on the trackline (through either perception or availability bias) may be estimated using a capture – recapture analysis of sightings from independent sighting platforms. An estimate of the number of groups available as potential sightings may be carried out by analysis of the sightings using a capture – recapture Petersen model (sometimes referred to as the Lincoln – Petersen model). Here the available groups have been determined using the Chapman (1951, in Seber, 1982)) modified Petersen model.

$$N = (n_1 +1) (n_2+1)/(m +1) -1 \quad \text{(Eqn 8)}$$

Where n_1 is the number of sightings made from the primary aircraft; n_2 is the number of sightings made independently from the second aircraft and m is the number of sightings made by both aircraft. However a number of assumptions are required to be met for this model to be valid. Such assumptions include:

a) the population of groups is closed (that no immigration or emigration of groups, or splitting or merging of groups occurs between the two independent surveys);

b) all groups are equally likely to be sighted in each survey, and;

c) all, and only resighted groups, are recognised as such.

A twin platform survey was carried out on 29 October 2007, when two aircraft surveyed the area independently. The standard survey aircraft (the primary aircraft) completed the survey followed by an independent second survey aircraft flying the same transects some five to seven minutes behind the primary aircraft.

3. The entire surveyed area represents dugong habitat and that dugongs are randomly distributed throughout this habitat with respect to survey transects. Two aspects of this assumption require consideration:

a) Uneven distribution of survey effort in relation to animal distribution is likely to bias results if density estimates from high or low density areas are spread across the entire survey area,

b) Dugong habitat within the survey area is likely to be fragmented by shallow sandbanks, with such fragmentation varying by tidal cycle.

1.7 SEA GRASS STUDIES

Seagrass studies were carried out through scuba diving for collection of data on seagrass cover and species diversity in the inshore area between Inhassoro and Bartolomeu Dias. Because sampling was carried out parallel to the coast and the spacing of survey lines was approximately 1 km, we carried out 2 perpendicular transects. In addition, seagrass growth experiments were also carried out.

Seagrass sampling stations were sampled at 500m intervals along lines parallel to the coast in the area. These lines were surveyed from a twin 60 hp semi-rigid inflatable boat. A Garmin GPS was used to plan the survey stations and for navigation to the sampling stations. At the sampling stations, we recorded the GPS position, then we searched initially for the presence of any vegetation using a transparent glass bottom bucket inserted in the water. If any type of vegetation was observed in the bottom, then scuba diving was carried out to descent to the sea bottom and collect the seagrass data. Seagrass cover was measured using a 1x1 m quadrat frame, with 10 quadrats, each quadrat consisted of a 10% cover. This frame was laid in the bottom and then seagrass cover measured. Then, species of seagrass and other marine vegetation (seaweed) were described and samples collected for later confirmation of identification. The identification of seagrass and seaweed species was performed with help of Richmond (1997) and Branch and Branch et al. (1994).

Nutrition content

Three samples of seagrass species were collected for lab measurements of dry weight, percent of organic matter, nitrogen and protein content, neutral fibers and ashes. The sampling area was isolated using a stainless steel quadrat of 25 cm x 25 cm area (625 cm^2) and inserted in the sea bottom to a depth of 10 cm. The sand was dug to the depth of 10 cm to remove the roots and rhizomes. Samples of each species were sorted in the following categories: above ground (leaves and stems) and below ground plant parts (roots and rhizomes). These lab analyses are being performed at the lab of the Faculty of Veterinary, Universidade Eduardo Mondlane.

For dry matter, samples of seagrass species were maintained in a stove at 70º C for 48 hours. The content of ashes and organic matter in the seagrass species were obtained by burning a known quantity in the muffle at 600ºC for 3 hours and subsequent measurements of ashes.

1.7.1 Data analysis

Data collected during the surveys were tabulated in the excel files and included date, latitude, longitude, time of the sampling, seagrass cover and species present per sampling station. These files were converted to DBASE IV format and imported into Arcview 3.2. They were then matched with the electronic chart of the Bazaruto area.

Data from nutrient analyses of seagrass species were entered into SPSS version 11.5 and charts of means and one standard error about the mean produced. The data on dry matter, organic matter, protein was clustered into above ground parts (ACS) and bellow ground parts (ABS).

1.8 BEHAVIOURAL OBSERVATIONS

1.8.1 Platform – based Visual Behavioural Observations

A 6 x 6 m floating platform was constructed and positioned within the southern core dugong distribution area just to the north of Santa Carolina Island for visual observations of dugong behaviour, including diving and surfacing behaviour. On two different occasions of both anchor lines and floatation drums from the platform were stolen while it was moored at the study site. This meant that the risk of the platform sinking or breaking its moorings and becoming a navigational hazard became high and the platform was recovered. As a consequence, behavioural observations were not undertaken.

1.9 POPULATION VIABILITY ANALYSES

Population viability analysis (PVA) is a statistical method of understanding the influence of a species' natural history, in combination with demographic, environmental, and random genetic (stochastic) events, on the dynamics of its future. The species' population dynamics is modelled as a set of discrete, sequential events (e.g., births, deaths, catastrophes, etc.), which occur according to defined probabilities. The goal of these analyses is to determine, given as much information as is known, whether the population will survive, under a defined scenario of events.

PVA was used to assess the viability of the dugong population in the Bazaruto Archipelago under various scenarios. The need for this approach arises because Bazaruto's dugongs are, to all intents, isolated and they are under threat from continued incidental capture and increasing, rapid habitat loss. Two decades of research off East Africa and the Indian Ocean Islands, suggest that these are the last viable population off East Africa and that their situation is tenuous – they are on the brink of extirpation.

Population dynamics models provide a predictive tool, where the impacts of variables (threats), in this instance – environmental threats (cyclones); hydrocarbon exploration and incidental fishing catch, can be theoretically assessed. These threats can impact dugongs in a number of ways, including:

1. Complete habitat loss, causing dugong extirpation.

2. Fragmentation of the habitat, causing a decrease in numbers, or outright extirpation.

3. A decrease in reproductive success, through stress (seismic sound, increased competition for food), or even death of reproductive females.

4. A decrease in the number of dugongs, beyond that sustainable (especially reproductively active females).

The simulations run included all the above variables, alone and in various combinations and used the software, VORTEX 9.72.

However, it is important to remember that these manipulations are models only and all models have inherent biases and inaccuracies, especially when:

There is little or no knowledge of many of the finer details of the variables, or the animal's natural history. For example, the number of dugongs taken form the Bazaruto Archipelago by fishers annually is unknown, yet these data are required to 'accurately' model.

Populations, and the age and sex classes within them, are small. Unfortunately, this is true for Bazaruto's dugongs. When numbers are low (a population of around 250 animals) and the animals are long lived (up to 70 years) and slow breeding, the number of animals in any year cohort (group of animals of the same age) will be low. (For example, a population of 250 dugongs will be divided in two sex groups - male and female - of 125 individuals each. Then, each sex group is further divided into 70 age cohorts. The maximum number of dugongs in any age cohort would be about five or six, in the zero to one year cohort)! As a result, population models, by virtue of the mathematics used, tend to inflate the survival potential of such populations.

*All the results given here must be viewed in this context.

Parameters that the model requires include:

1. Reproductive parameters

- Reproductive System, such as monogamous or polygamous
- Age of first reproduction of males and females
- Maximum age of reproduction
- Maximum number of progeny per year
- Sex Ratio of the population
- Reproductive Rates
- Number of Adult Females Breeding / year
- Number of Adult Males in Breeding Pool

2. Survival Parameters

- Mortality of Females per age cohort
- Mortality of Males per age cohort

3. Catastrophic Events

- Define Catastrophic events – such as cyclones, hydrocarbon exploration, incidental take
- Are catastrophes global – do they effect all animals equally?
- What are the likely impacts of each catastrophic event on the reproductive rates and survival rates or mortality?

4, Population Parameters

- Initial Population Size
- Stable (normal) age distribution
- What is the Specific age distribution of males and females
- Estimation of the carrying capacity of the habitat
- Density Dependence - Does the reproductive rate increase or decrease as density increases?

5. Harvest Information

- Is there any harvest of the population?
- How many animals (males and females) are harvested annually?
- When harvest started?
- When harvest ended?

6. Emigration/Immigration:

- The extent of emigration and immigration of males and females in the population?

7. Genetic Management

- The genetic composition and diversity of the Bazaruto Archipelago dugong population is totally unknown and has been excluded from the model.

As much of the information for the above variables is not available for dugongs of the Bazaruto Archipelago, these were estimated using ‘normal’ large mammal values. Some dugong information is available from Australia, where dugongs are plentiful and have been extensively studied, while other information is derived, by comparison of what is known for Australia and what is known for Bazaruto. Other information, such as the impacts of hydrocarbon exploration, or the level of incidental take, is the result of ‘educated guess work’.

Variables that were ‘fixed’, such as initial population size and the extent of Emigration / Immigration were not changed when the model was run. Variables that were ‘flexible‘, such as age at first reproduction, were manipulated within ‘reasonable’ levels during modelling. Lastly, other variables, which were environmental and anthropogenic in nature – hydrocarbon exploration, incidental catches and catastrophic cyclones - were also manipulated within what was thought to be reasonable levels.

To overcome as many of the shortcomings of the model as possible, all scenarios were run using ‘liberal’ scenario variables and ‘conservative’ scenario variables, or combinations thereof:

<u>‘Liberal’ scenario variables:</u>

Initial Population Size = 250

Age at first calving = 10 years

Proportion of females breeding = 25%

Maximum age of reproduction = 70 years

Seismic exploration occurring once only, causing a 10% reduction in reproductive success for that year and the death of 5 dugongs

A catastrophic event (such as a cyclone) every 10 years, causing a 10% reduction in reproductive success and the death of 5 dugongs

The number of deaths and any decline in reproductive success caused by anthropogenic causes was varied.

<u>‘Conservative’ scenario variables:</u>

Initial Population Size = 220

Age at first calving = 15 years

Proportion of females breeding = 20%

Maximum age of reproduction = 55 years

Seismic exploration occurring once only, causing a 10% reduction in reproductive success for that year and the death of 5 dugongs

A catastrophic event (such as a cyclone) every 10 years, causing a 10% reduction in reproductive success and the death of 5 dugongs

The number of deaths and any decline in reproductive success caused by anthropogenic causes was varied.

For each variable, or combination of variables, the model was run several hundred times, to give a ‘population viability’ after 200 years. In other words, after several hundred iterations, the model gave a ‘mean’ scenario for the Bazaruto dugong population after 200 years – how many there would be.

RESULTS

1.10AERIAL SIGHTING SURVEYS

A total of 27 surveys were flown during this study, including three surveys flown as a component of the original EIA carried out in March and April 2006. These surveys exclude the one survey flown on 15 November 2007. Particulars of each of flown surveys are presented in Table 1, while positions of track lines and sightings are presented in Appendix I. The distribution of total survey effort and primary and secondary sightings are presented in Figure 1. No surveys were flown between 15 February and 15 April due to the extensive damage to the chartered aircraft (ZS IGR) during Cyclone Favio on 22 February 2007, and delays encountered in sourcing a replacement aircraft. No surveys were attempted on 5 May; 25 May; 25 July; 26 August and 5 September due to inclement weather, while on 14 January, 26 August and 17 September surveys were abandoned due to high winds and sea state and poor sighting conditions.

Surveys were flown as a series of east to west or west to east transects in a progressive north to south direction. All flight time en route from Vilankulos airport to the start of survey in the north, between transects and en route from the end of survey to Vilankulos airport was carried out in transit (off effort). All sightings made during on effort transects have been recorded as primary sightings, while all sightings made during transit or during confirmation of primary sightings have been recorded as secondary sightings. While secondary sightings have been utilised in analyses of biological parameters such as group size or distribution, they have been excluded from abundance estimation or density analyses. A total of 9052 nautical miles of survey effort was flown during the 26 surveys, during which 355 sightings of an estimated 760 dugongs were made. Totals of 331 primary and 24 secondary sightings of 718 and 42 respectively were made during the flights (Table 1).

1.10.1 Distribution and Group Size and Composition

The distribution of dugong sightings occurred across the region of flown transects, apart from a lack of sightings south of a line drawn southeastwards from Vilankulos to Cabo Sao Sebastio. This region appears to comprise a number of tidally inundated sandbanks and is possibly too shallow to be utilised by dugongs. Consequently the southern region (the light grey shaded area in Figure 2) was excluded from analyses of abundance (see Section 3.1.2). Within the surveyed area, two core areas of distribution are apparent from Figure 2. A northern core region of distribution appears spread across the inshore and offshore region to approximately the 10 m isobath between the Save River Mouth and 21°24’ S, while the southern core region lies within Bazaruto Bay and inshore of Bazaruto, Benguerra and Magaruque Islands, and appears aligned with the shallow sandbanks to the north and south of Santa Carolina Island. These core regions become even more obvious when the distribution of individuals rather than groups is reviewed.

Figure 3 shows the frequency of group sizes of all groups sighted during surveys. The mean group size of groups (primary sightings made during full survey effort) was 2.22 (se 0.191). Group sizes recorded in the Bazaruto Archipelago were comparable to group sizes recorded in other regions of dugong abundance. However, few large groups of dugongs were seen in the Bazaruto Archipelago. For example, Preen (2004) records a maximum group size of 674 dugongs in the Arabian Gulf.

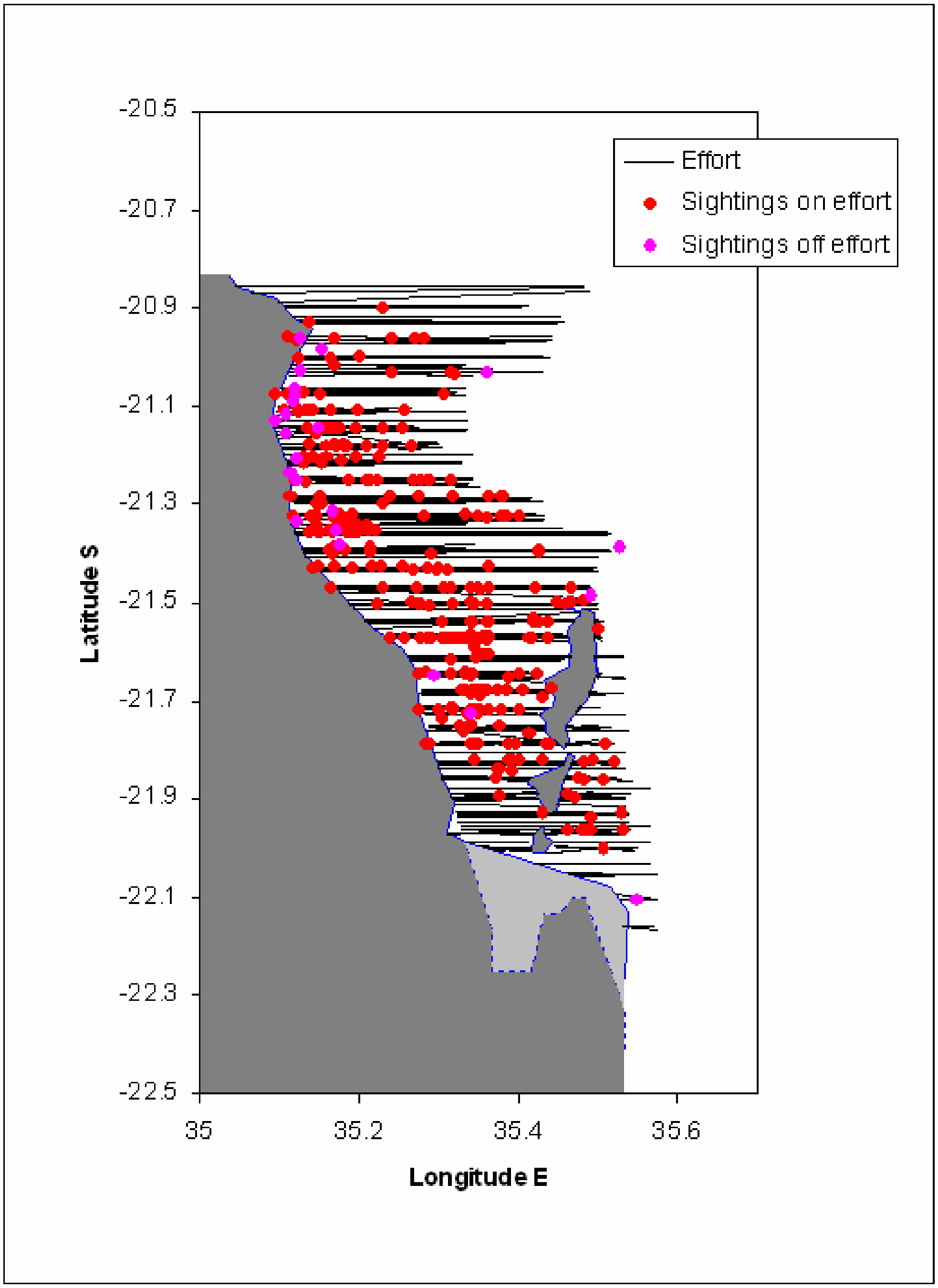

Figure 2. The distribution of aerial survey search effort (transects) and of primary and secondary sightings of dugongs observed during this study (November 2007 data excluded). Although transects were flown over the light grey shaded area in the region of Cabo Sao Sebastio, no dugongs were observed in this region of shallow sandbanks and the survey effort has been excluded from analyses.

Table 1. Survey effort and sightings made during aerial surveys carried out during this study.

Date	*Aircraft*	*Transects Flown*	*Distance Surveyed*	*Groups Sighted*	*Animals Sighted*	*Primary Groups*	*Primary Animals*	*Second. Groups*	*Second. Animals*	*Comment*
31 Mar 2006		22	282.36	12	22	12	22			EIA Survey
01 Apr 2006		22	282.36	13	18	11	16	2	2	EIA Survey
02 Apr 2006		22	282.36	15	45	12	41	3	4	EIA Survey
18 Nov 2006	ZS SPV	17	225.07	8	18	8	18			
16 Dec 2006	C9 JSH	20	222.15	10	18	8	9	2	9	
13 Jan 2007	ZS IGR	25	333.85	18	65	15	61	3	4	
14 Jan 2007	ZS IGR	3	5.33	2	2	2	2			Survey aborted due to weather
28 Jan 2007	ZS IGR	36	455.39	15	24	14	22	1	2	
06 Feb 2007	ZS IGR	36	424.14	32	54	31	53	1	1	
15 Feb 2007	ZS IGR	32	366.34	15	35	13	28	2	7	
15 Apr 2007	D-EOVC	26	337.75	21	30	21	30			
26 Apr 2007	D-EOVC	30	420.35	21	40	21	40			
17 May 2007	D-EOVC	31	432.33	29	53	28	52	1	1	
09 Jun 2007	D-EOVC	32	408.41	25	42	19	34	6	8	
19 Jun 2007	D-EOVC	32	405.01	12	20	12	20			
26 Jun 2007	D-EOVC	32	410.03	16	21	15	19	1	2	
08 Jul 2007	D-EOVC	34	420.73	12	42	12	42			
17 Jul 2007	D-EOVC	32	402.39	11	30	11	30			
04 Aug 2007	D-EOVC	32	407.98	3	3	3	3			
20 Aug 2007	D-EOVC	32	408.05	15	69	14	68	1	1	
26 Aug 2007	D-EOVC	0								Survey aborted due to weather
17 Sept 2007	D-EOVC	26	129.95	2	3	2	3			Survey aborted due to weather
20 Sept 2007	D-EOVC	30	385.65	9	25	8	24	1	1	
06 Oct 2007	D-EOVC	32	402.71	5	8	5	8			
14 Oct 2007	D-EOVC	32	398.33	8	33	8	33			
29 Oct 2007	D-EOVC	31	406.15	11	16	11	16			Twin platform survey
29 Oct 2007	ZS EPO	30	396.83	15	24	15	24			Twin platform survey
TOTAL		729	9052.01	355	760	331	718	24	42	

Figure 4 shows the distribution of groups stratified by group size. Once again the two core regions are clearly evident in these distribution plots, particularly when the distributions of individuals within groups of dugongs are considered. The distribution of mean group size by season (Figure 5) shows no significant difference in observed group size by season (single factor anova $F = 0.4895$; $p = 0.6897$; $df = 354$).

The distribution of groups of dugongs containing a calf observed during aerial surveys is shown in Figure 6. As with the distribution of all groups, the distribution of calves appears to be centred on the two core areas, While the high density within Bazaruto Bay is more or less expected in terms of water clarity, decreased exposure to predation and water movement, the high density of calf sightings in the northern core region is unexpected given the poor water clarity often encountered in this area. The apparent hiatus in calf distribution between these two regions is unknown, but may be related to water movement in and out of the Bay, the distribution of suitable calf habitat or to anthropogenic influences of seine net fishing in the region (and the impact this may have on habitat). Surprising two calf groups were sighted offshore of the islands, where both wave action and exposure to potential shark predation may be higher.

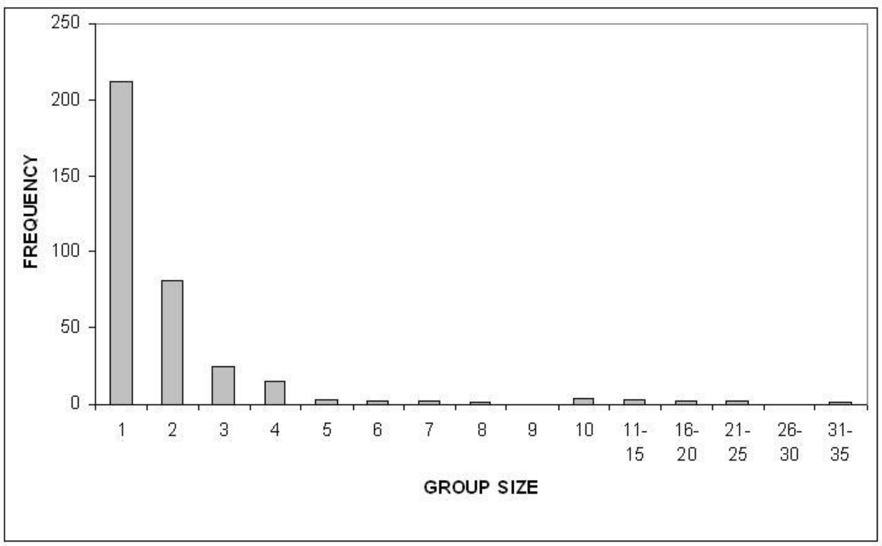

Figure 3. The frequency of dugong group sizes recorded during aerial surveys carried out during this study.

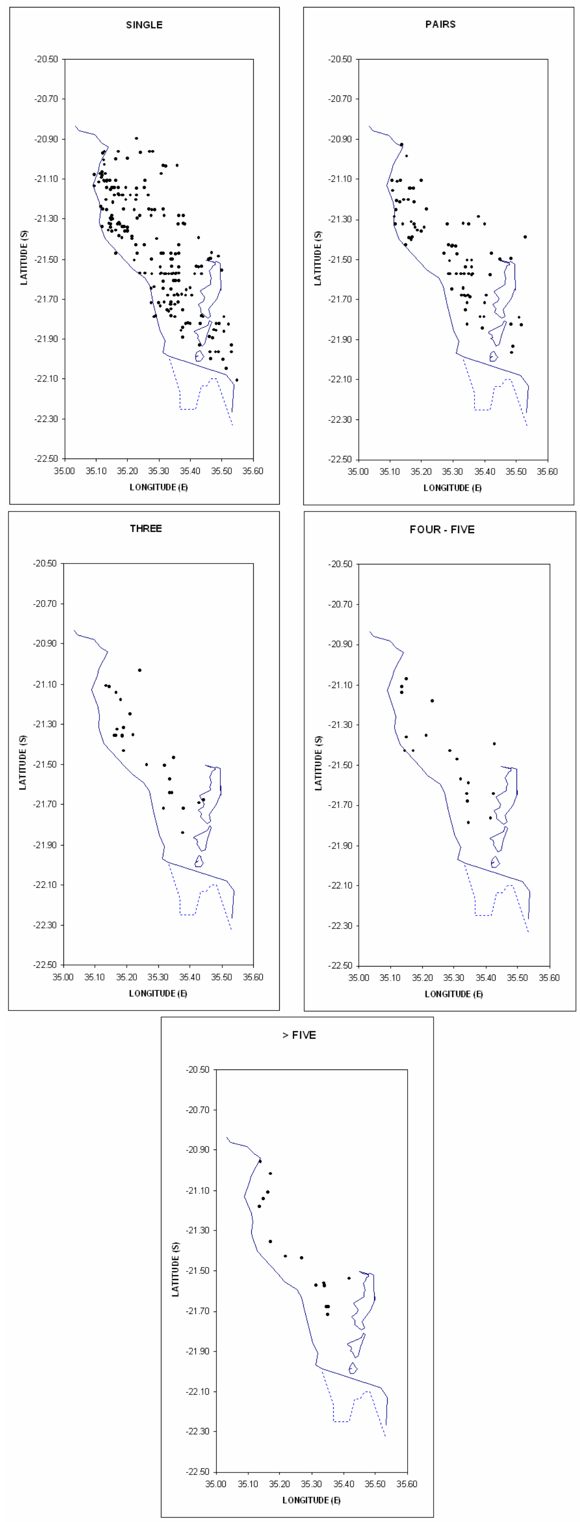

Figure 4. The distribution of groups of dugongs observed during aerial surveys during this study stratified by group size.

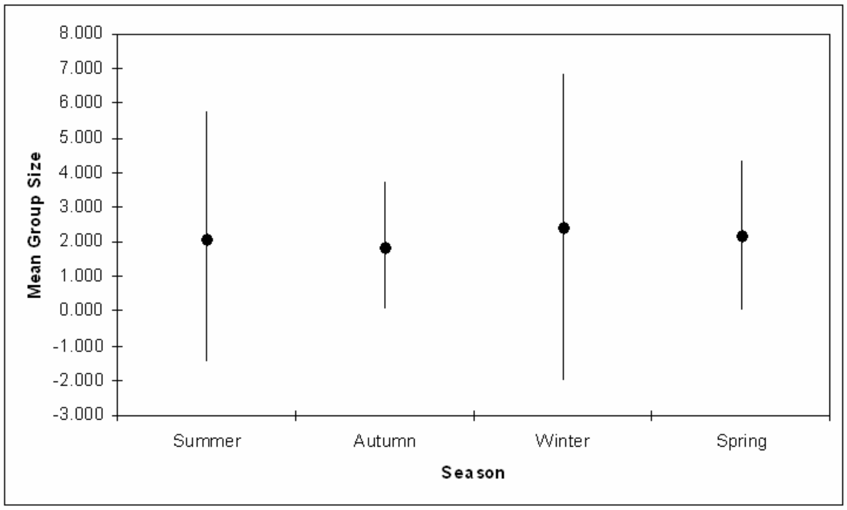

Figure 5. Then mean group sizes of dugongs observed on aerial surveys in the Bazaruto Archipelago by season.

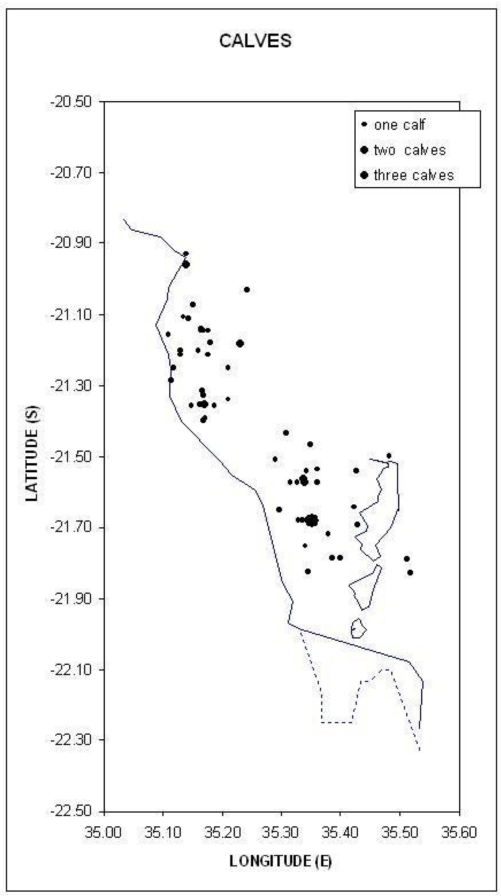

Figure 6. The distribution of dugong groups containing one or more calves observed during aerial surveys carried out during this study.

1.10.2 Density

The density of dugongs recorded on each of the aerial surveys in the Bazaruto Archipelago ranged between 0.004 and 0.15 dugongs per square km using the effective strip width calculated with truncated distance data and between 0.004 and 0.09 per km2 using the effective strip width calculated with no left truncation of the perpendicular distance data (Figure 5). Preen (2004) noted that the densities of dugongs observed from aerial strip surveys ranged from 0.21/km^2 ± 0.05 in 1986 in the southern Arabian Gulf, 0.08 in the eastern Red Sea (Preen, 1989) to 0.71/km^2 in Shark Bay, Australia (Preen et al., 1997), with most recorded densities between 0.26 and 0.62/km^2 (Marsh et al., 1994, in Preen 2004). Although such densities from aerial strip surveys and aerial line transect surveys may not be directly comparable, the data suggest low densities for the Bazaruto Archipelago population.

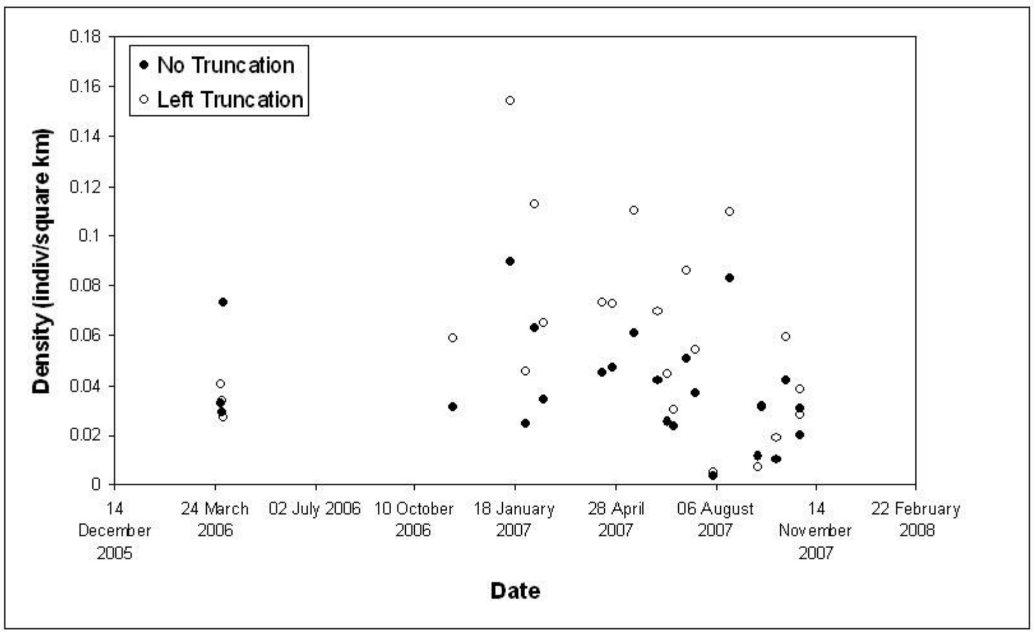

Figure 7. Densities of individual dugongs as individuals per square kilometre calculated from the effective search widths truncated and with no truncation on each aerial survey flown during this study.

No significant differences in seasonal density of dugongs calculated from the non truncated distance data (single factor anova F = 1.9839; p = 0.148, df = 23) or truncated distance data (single factor anova F = 2.7675; p = 0.0684, df = 23) were recorded over the entire research area suggesting no season movement in or out of the area surveyed (Figure 6).

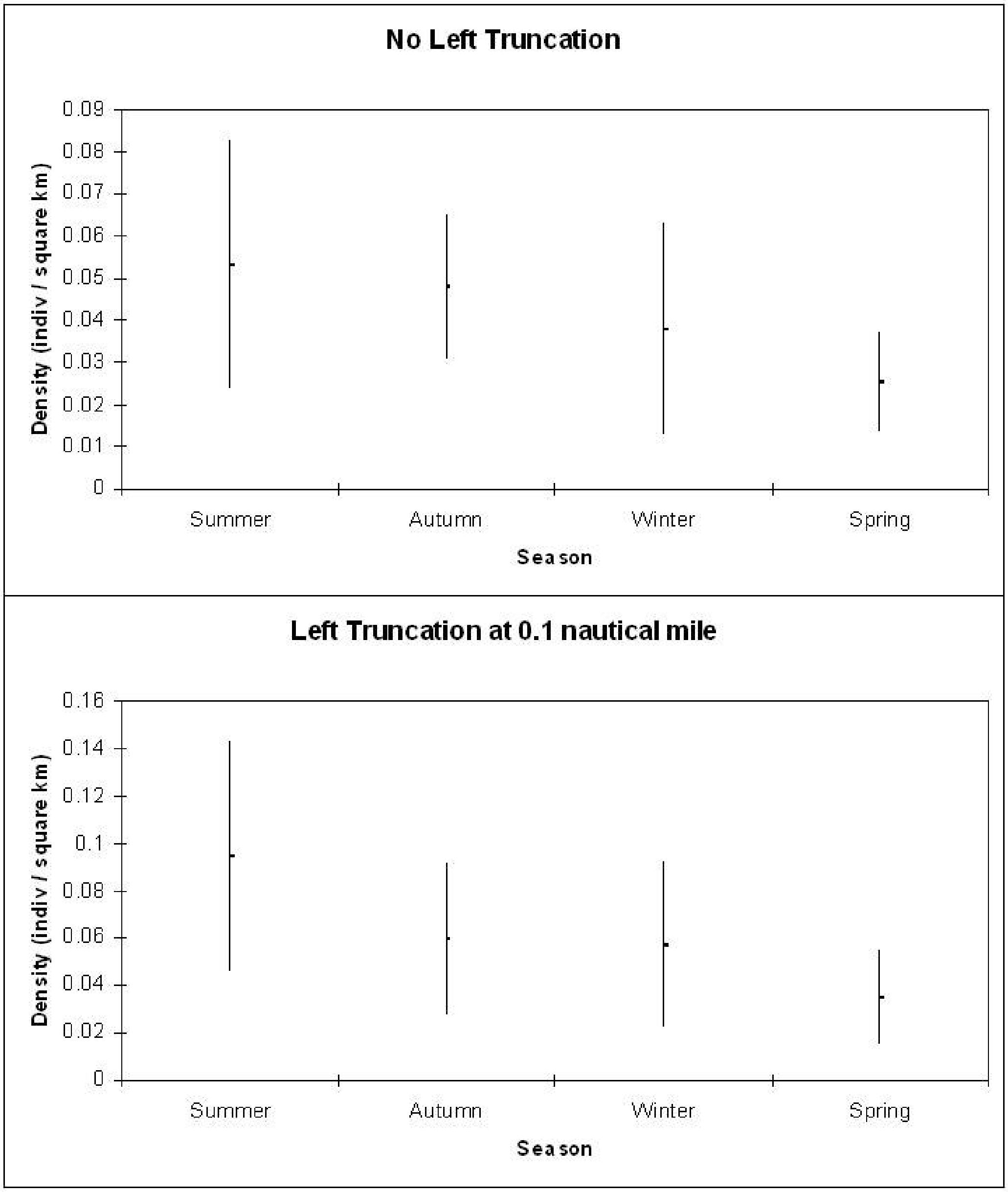

Figure 8. Mean seasonal densities of dugongs observed during aerial surveys in summer, autumn, winter and spring calculated from the untruncated distance data and 0.1 nm truncated distance data. Bars represent standard errors of mean densities.

A total 62 of the 760 (8.1%) sighted dugongs of sighted dugongs in the Bazaruto Archipelago were calves. The proportion of calves per survey ranged between 0 (December; April; June and August) and 22.2 % (November) (Table 2). Preen (2004) reported proportions of dugong calves in the western and southern Arabian Gulf in 1986 as 14.5%, compared with 18.7% in the southern Gulf in 1999, and noted that these figures were typical of the proportions recorded on other surveys (Marsh et al., 1994, in Preen, 2004).

Table 2. Proportions of calves sighted on each aerial survey during this study.

Date	Number of sightings		Proportion of calves
	All Dugongs	Dugong calves	
31 March 2006	22	3	0.136364
01 April 2006	18	2	0.111111
02 April 2006	45	1	0.022222
18 November 2006	18	4	0.222222
16 December 2006	18	0	0
13 January 2007	65	5	0.076923
14 January 2007	2	0	0
28 January 2007	24	2	0.083333
06 February 2007	54	4	0.074074
15 February 2007	35	5	0.142857
15 April 2007	30	2	0.066667
26 April 2007	40	0	0
17 May 2007	53	5	0.09434
09 June 2007	42	5	0.119048
19 June 2007	20	2	0.1
26 June 2007	21	0	0
08 July 2007	42	1	0.02381
17 July 2007	30	2	0.066667
04 August 2007	3	0	0
20 August 2007	69	5	0.072464
17 September 2007	3	0	0
20 September 2007	25	3	0.12
06 October 2007	8	1	0.125
14 October 2007	33	3	0.090909
29 October 2007	16	3	0.1875
29 October 2007	24	4	0.166667
	760	62	

The seasonal densities of calves (as proportions of all sighted individuals) are presented in Figure 7. Despite higher proportions of calves being observed in Spring (September to November), no significant difference in the proportion of calves in the population were observed between seasons (single factor anova $F = 2.11634$; $p = 0.128597$; $df = 24$).

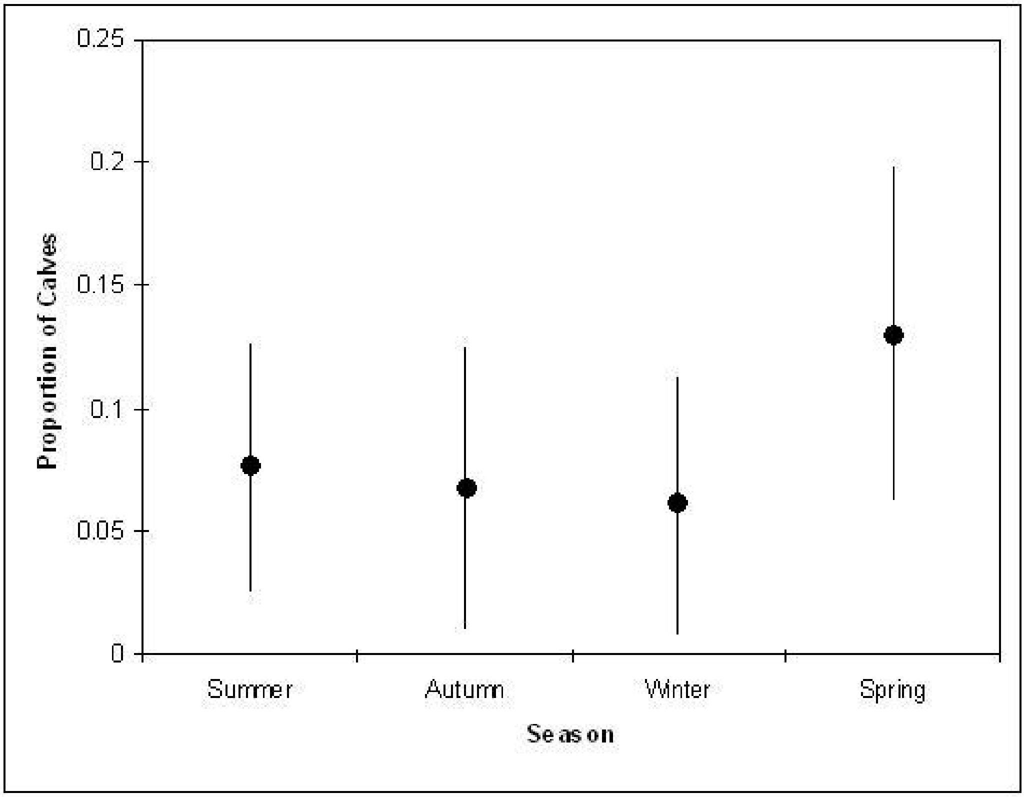

Figure 9. The seasonal densities of dugong calves as proportions of all individuals sighted during aerial surveys carried out during this study.

1.10.3 Abundance Estimation

Data from 23 survey flights were utilised for dugong abundance estimation. The two aborted flights on 14 January 2007 and 17 September 2007 were excluded due to incomplete coverage, while the survey carried out on 16 December 2006 was excluded due to uncertainty in the recorded positions of the track-lines and sightings (which were recorded to the aircraft Global Positioning System and appear to be in error). All of the remaining flights have been assumed to be of equal sighting probability with respect to environmental conditions.

A total of 8824 nautical miles of survey effort were flown during the 23 survey flights, during which 321 primary sightings were made (see Table 2). Nine sightings have no associated distance data and have been excluded from analyses. Such exclusion has been identified as bracketed data in Table 2.

The area of the survey coverage has been calculated at 1211 square nautical miles. This area was defined as the coast in the west and the outer limits of the transect lines in the east. The shallow sandbank region to the south of Vilankulos was excluded from the survey area as it is believed to be too shallow for dugong habitat (no dugong sightings were made in this region during surveys). All survey effort within this shallow region was excluded from analyses. The landward areas of islands were obviously excluded from this area of survey region and as were any flight paths over land.

Abundance estimation has been carried out as two analyses; firstly as a global estimate treating all 929 transects and their associated observation data within one stratum, and secondly as treating each survey as a replicate separate stratum (of equal area) and pooling the resulting survey estimates as a mean. In order to increase sample size, estimation of the sighting probability density function f(0) in the second analyses have utilised data from all surveys, so that only the encounter rate (n/L) and mean group size (s) has differed between these surveys.

Figure 10 shows the distribution of sightings with perpendicular distance from the trackline. The inability of observers to detect dugong groups below the aircraft is clearly apparent from these data, as the distribution should exhibit a shoulder at zero distance. Two analyses options of the sighting probability density function have consequently been carried out; the first option using all sightings to define the sighting probability density function; and the second option utilising a left truncation at 0.1 nautical miles so that only sightings seen outside of a distance of 0.1 nautical miles are used. Figures 11 and 12 show the hazard rate modelled f(0) to each of these options respectively. Given the lack of sightings below the aircraft, the truncated distance model has been selected as more robust, with the non – truncated distance model being presented for comparative purposes.

Table 3 lists parameters of the sighting probability density functions calculated using the hazard rate model specified under Equation 5 above.

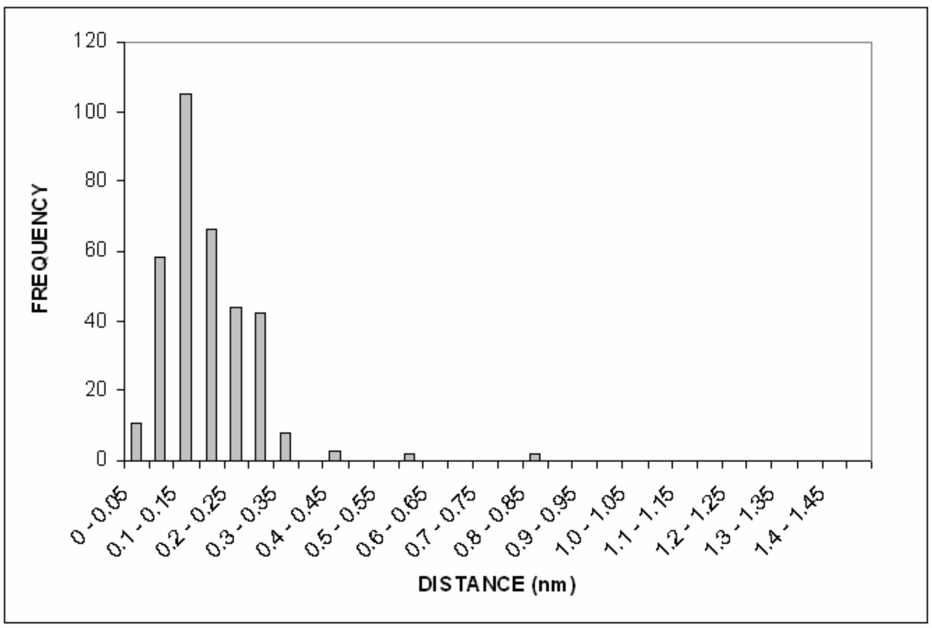

Figure 10. The distribution of all primary sightings with perpendicular distance from the trackline.

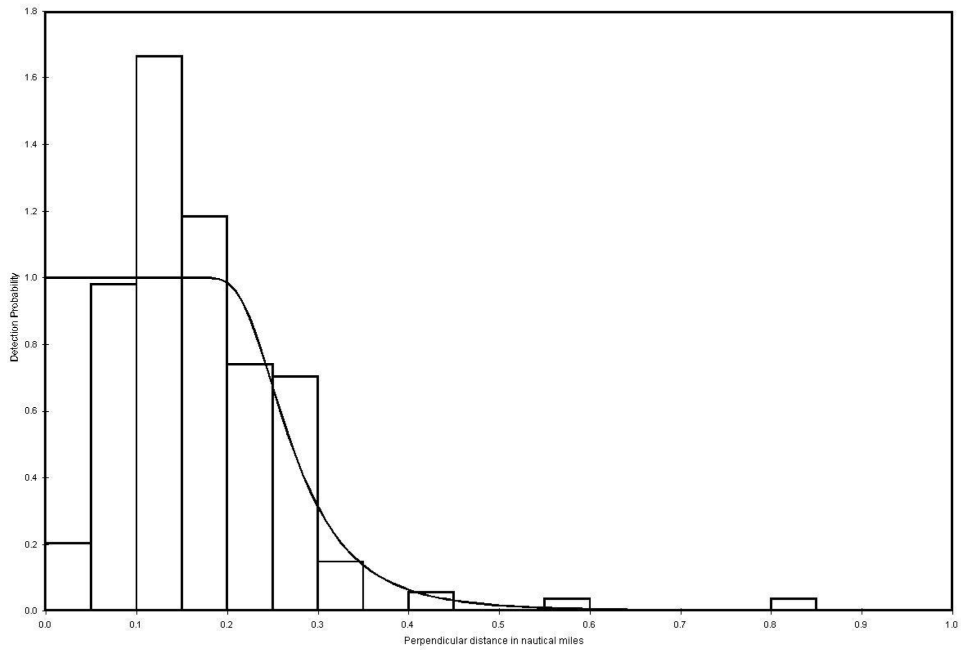

Figure 11. The detection probability function fitted to the frequencies of perpendicular distances of all primary sightings in 0.05 nautical mile distance bins.

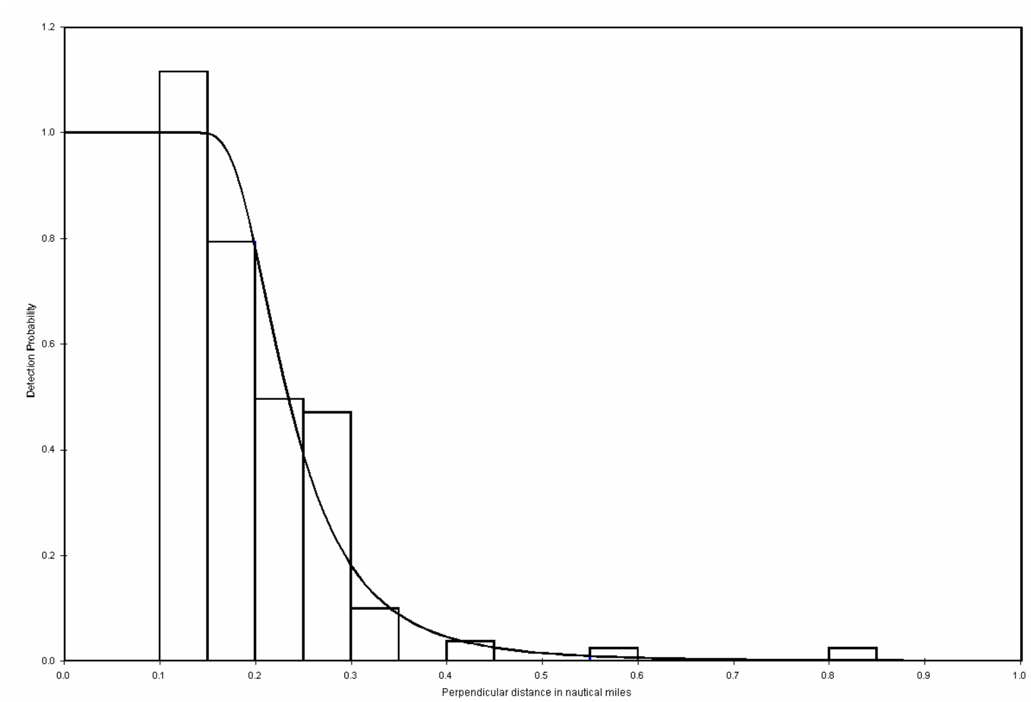

Figure 12. The detection probability function fitted to the frequencies of perpendicular distances of all primary sightings in 0.05 nautical mile distance bins outside of 0.01 nautical miles.

Table 3. ESW and f(0) parameters of the sighting probability density functions calculated using the hazard rate model. These parameters are used as common parameters in calculation of population estimates in Table 4 and 5 respectively.

Perpendicular Distance Distribution	f(0)		ESW	
	Value	Std Error	Value	Std Error
No Left Truncation	3.4788	0.12171	0.28746	0.010057
Left Truncation at 0.1 nautical miles	6.5375	0.44743	0.15296	0.01045

The abundance estimation of all surveys combined has utilised this mean group size calculated from all surveys, while the individual surveys have utilised the mean group size observed during that survey. No correlation was found between sighting distance and group size (Figure 13) which suggests detection was independent of group size.

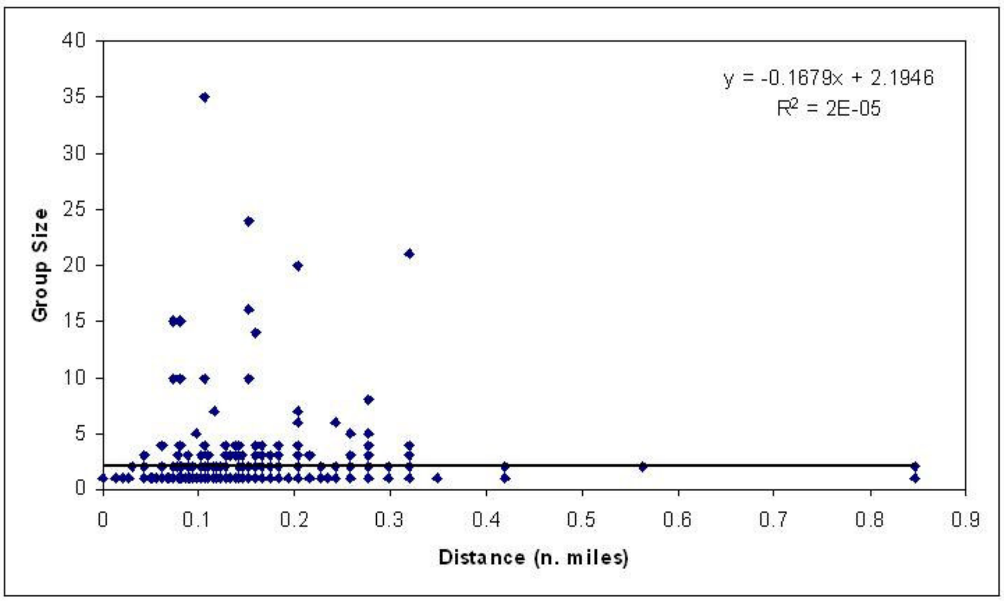

Figure 13. The distribution of group sizes sighted with perpendicular distance from the trackline during aerial surveys carried out during this study.

Table 4 shows the results of the global abundance estimation analyses utilising data from all surveys combined under both the truncated and non truncated perpendicular distance options. Given the lack of detection of sightings below the aircraft the resulting population abundance estimate (N) from the truncated data is believed to be the more robust of the two estimates.

Table 4. Parameters utilised in the global population estimate for the survey region for both left truncated perpendicular distances and no left truncation of perpendicular distance.

Parameter	No Left Truncation		Left Truncation at 0.1 nautical miles	
	Value	Std Error	Value	Std Error
n	311		247	
L	8824.56		8824.56	
f(0)	3.4788	0.12171	6.5375	0.44743
ESW	0.28746	0.010057	0.15296	0.010469
s	2.2219	0.19150	2.2267	0.22269
DS	0.061301	0.042143	0.091492	0.0086836
D	0.13620	0.15016	0.20373	0.28089
N	165.00	18.191	247.00	34.056

Table 6 and 7 show the results of the abundance estimation of each of the flown aerial surveys (albeit utilising the detection probability function from all surveys (truncated and non – truncated as per the global abundance estimates)). The pooled abundances from the individual surveys correspond to the global abundance estimates presented in Table 4, as a common detection function was utilised across all surveys.

The population abundances estimated on each survey and survey sighting conditions (mean wind speed, Beaufort state and sightability) of the survey are presented in Table 5, while Figure 14 shows the regression of the population abundance estimates against these environmental variable. The results suggest a strong negative environmental bias in the estimated population abundances, with lower estimates being recorded under poorer sighting conditions.

Table 5. The population abundances estimated on each survey and survey sighting conditions of that survey.

Date	Pop Abundance	Mean Wind Speed (	Mean Beaufort State	Mean Sightability
18 November 2006	246	5	1.5	3
13 January 2007	640	5	1	1
28 January 2007	191	13.5	3	3.7
06 February 2007	467	7.8	1.4	2
15 February 2007	270	6	1.8	3
15 April 2007	305	5.3	1.5	3
26 April 2007	301	10	2.5	3.5
17 May 2007	458	6	0.5	2.5
09 June 2007	291	2.4	1	3
19 June 2007	186	9	2.8	3.75
26 June 2007	126	6.93	1.4	3
08 July 2007	358	8.87	2.3	3.142857
17 July 2007	226	6.857	1.7	3
04 August 2007	19	10.727	2.5	4
20 August 2007	456	3.143	1	1
17 September 2007	30	18.5	3	3
20 September 2007	133	8.85	2.6	3.857143
06 October 2007	79	5.428	1.7	2.785714
14 October 2007	248	4.714	1.1	2.285714
29 October 2007	117	6.428	2.8	4
29 October 2007	160	7.857	3.1	3

Table 6. Dugong group sighting and effort survey data within the Bazaruto Archipelago region and associated estimated dugong abundance (with no left truncation of perpendicular distances).

Survey Date	n	L (nm)	Group Size (s)		Density of Groups		Density of Animals		Abundance	
			Mean	Std Error	Value	Std Error	Value	Std Error	Value	Std Error
31 March 2006	12 (10)	282.36	1.8	0.3266	0.061603	0.023520	0.11089	0.046874	134.00	56.645
01 April 2006	11	282.36	1.45	0.2073	0.067763	0.021477	0.098565	0.034253	119.00	41.354
02 April 2006	12	282.36	3.42	1.2878	0.073923	0.016200	0.25257	0.11012	306.00	133.41
18 November 2006	8 (7)	225.07	2.33	0.9545	0.046369	0.020445	0.10820	0.065076	131.00	78.792
13 January 2007	15 (13)	333.85	4.38	2.2206	0.067732	0.019565	0.30740	0.17466	372.00	211.36
28 January 2007	14	455.39	1.57	0.2912	0.053475	0.014527	0.084032	0.027633	102.00	33.541
06 February 2007	31	424.14	1.71	0.4824	0.12713	00.21018	0.21735	0.071074	263.00	86.004
15 February 2007	13 (12)	366.34	2.08	0.3362	0.056976	0.012731	0.11870	0.032715	144.00	39.688
15 April 2007	21	337.75	1.43	0.1898	0.10815	0.020552	0.15450	0.035829	187.00	43.366
26 April 2007	21 (20)	420.35	1.95	0.3118	0.082758	0.019423	0.16138	0.045831	195.00	55.380
17 May 2007	28	432.33	1.86	0.2284	0.11265	0.021044	0.20921	0.046789	253.00	56.582
09 June 2007	19	408.41	1.79	0.2240	0.080920	0.017727	0.14480	0.036535	175.00	44.154
19 June 2007	12	405.01	1.67	0.3553	0.051536	0.015429	0.085893	0.031568	104.00	38.223
26 June 2007	15	410.03	1.27	0.1182	0.063632	0.019065	0.080600	0.025293	98.000	30.754
08 July 2007	12	420.73	3.50	1.5739	0.049611	0.014888	0.17364	0.093874	210.00	113.53
17 July 2007	11 (10)	402.39	2.90	1.2512	0.043227	0.014007	0.12536	0.067641	152.00	82.017
04 August 2007	3	407.98	1		0.012790	0.0067960	0.012790	0.0067960	15.000	7.9701
20 August 2007	14 (13)	408.05	5.15	2.703	0.055415	0.015584	0.28560	0.16996	346.00	205.90
17 September 2007	2	129.95	1.5	0.5	0.026770	0.028039	0.040155	0.044137	49.000	53.859
20 September 2007	8	385.65	3.0	1.069	0.036082	0.015304	0.10825	0.059966	131.00	72.571
06 October 2007	5	402.71	1.60	0.245	0.021596	0.010356	0.034554	0.017394	42.000	21.142
14 October 2007	8	398.33	4.12	1.3153	0.034934	0.014073	0.14410	0.074035	175.00	89.909
29 October 2007	11	406.15	1.45	0.2073	0.407109	0.019416	0.068522	0.029882	83.000	36.196
29 October 2007	15	396.83	1.60	0.2895	0.065749	0.020466	0.10520	0.037876	127.00	45.726
TOTAL / POOLED MEAN	312	8824.56							165	19.14

Table 7. Dugong group sighting and effort survey data within the Bazaruto Archipelago region and associated estimated dugong abundance (with left truncation of perpendicular distances at 0.1 nm).

Survey Date	n	L	Mean Group Size (s)		Density of Groups		Density of Animals		Abundance	
			Mean	Std Error	Value	Std Error	Value	Std Error	Value	Std Error
31 March 2006	5	282.36	2.40	0.5090	0.057883	0.031487	0.13892	0.81129	168.00	98.113
01 April 2006	7	282.36	1.43	0.2974	0.081036	0.032168	0.11577	0.51890	140.00	62.753
02 April 2006	6	282.36	1.33	0.2108	0.069459	0.028102	0.09261	0.40230	112.00	48.651
18 November 2006	6	225.07	2.33	0.9545	0.087139	0.038762	0.20332	0.12288	246.00	148.67
13 January 2007	8	333.85	6.75	3.4525	0.078328	0.025493	0.52871	0.32053	640.00	388.00
28 January 2007	14	455.39	1.57	0.2911	0.10049	0.027933	0.15791	0.52752	191.00	63.805
06 February 2007	28	424.14	1.78	0.5329	0.21578	0.040384	0.38532	0.13574	467.00	164.51
15 February 2007	12	366.34	2.08	0.3361	0.10707	0.024739	0.22306	0.62864	270.00	76.091
15 April 2007	18	337.75	1.44	0.2172	0.17420	0.035817	0.25162	0.64101	305.00	77.699
26 April 2007	15	420.35	2.13	0.3887	0.11664	0.035344	0.24883	0.87983	301.00	106.43
17 May 2007	26	432.33	1.92	0.2413	0.19658	0.039577	0.37804	0.89681	458.00	108.65
09 June 2007	17	408.41	1.76	0.2353	0.13606	0.0031371	0.24010	0.63950	291.00	77.506
19 June 2007	11	405.01	1.73	0.3835	0.088777	0.27453	0.15334	0.58378	186.00	70.811
26 June 2007	11	410.03	1.18	0.1220	0.087691	0.028864	0.10363	0.03575	126.00	43.465
08 July 2007	10	420.73	3.80	1.8903	0.077692	0.025595	0.29523	0.17615	358.00	213.60
17 July 2007	7	402.39	3.28	1.7957	0.056863	0.021321	0.18684	0.12383	226.00	149.79
04 August 2007	2	407.98	1.00		0.016024	0.011001	0.01602	0.011001	19.000	13.044
20 August 2007	8	408.05	5.87	4.1766	0.064084	0.027133	0.37650	0.31153	456.00	377.32
17 September 2007	1	129.95	1.00		0.025153	0.047452	0.02515	0.047452	30.000	56.595
20 September 2007	6	385.65	2.17	0.4773	0.050855	0.024960	0.11019	0.059278	133.00	71.550
06 October 2007	5	402.71	1.60	0.2449	0.040584	0.019607	0.064934	0.032909	79.000	40.038
14 October 2007	5	398.33	5.00	2.0494	0.041030	0.016357	0.20515	0.11730	248.00	141.80
29 October 2007	8	406.15	1.50	0.2673	0.064384	0.027345	0.09658	0.044481	117.00	53.888
29 October 2007	11	396.83	1.45	0.2073	0.090608	0.033708	0.13179	0.052504	160.00	63.741
TOTAL / POOLED MEAN	247	8824.56							247.00	35.024

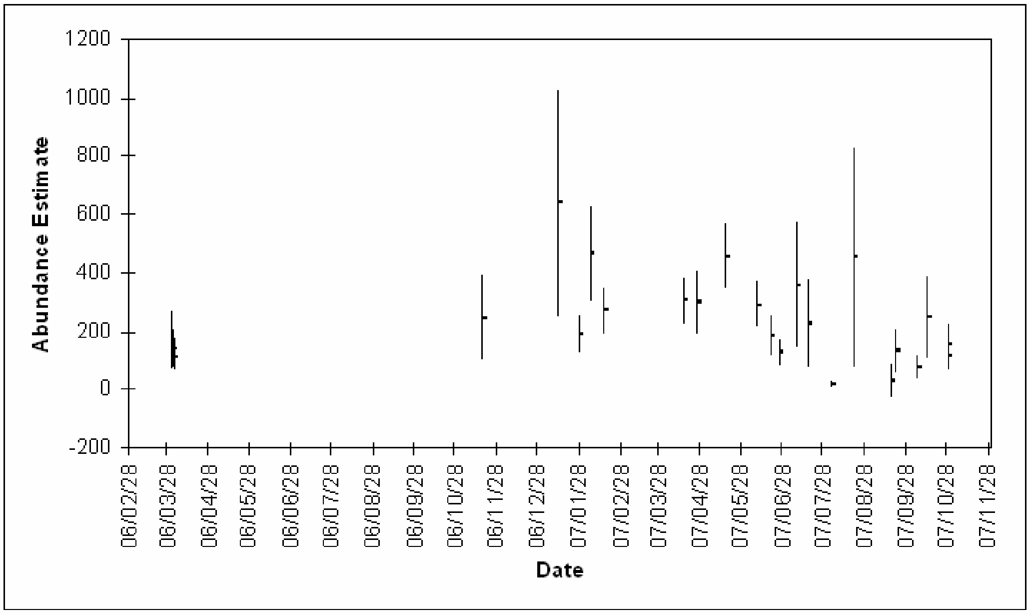

Figure 14. Population estimates of dugongs of the Bazaruto Archipelago and their standard errors calculated from aerial line transect surveys carried out during this study (April 2006 to November 2007).

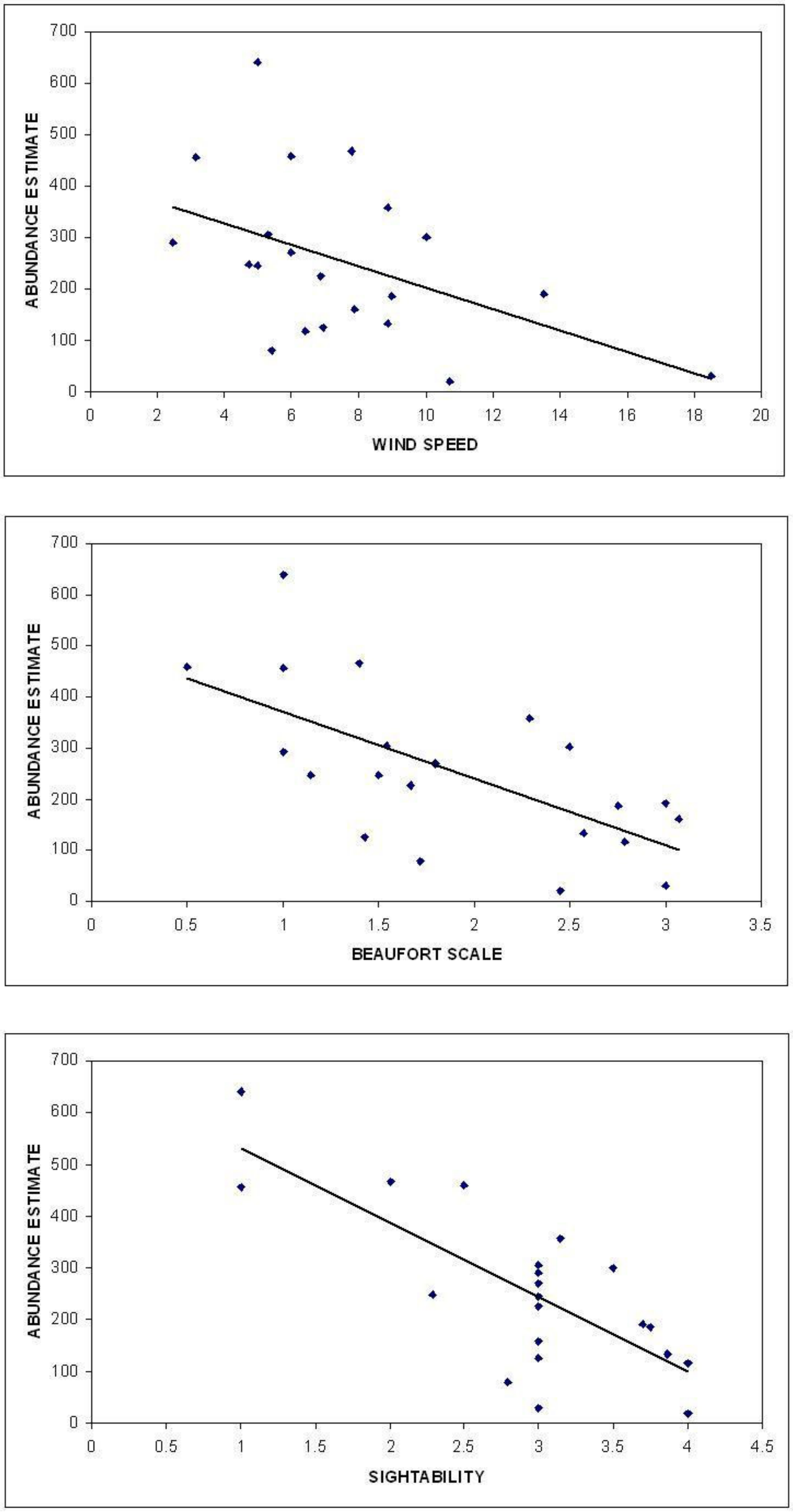

Figure 15. The interrelationship between the abundance population estimated on each survey and the sighting conditions (as described by wind speed, Beaufort State and a general index of sightability) during which the survey was carried out.

1.10.4 Independent twin platform survey

Results of the independent twin platform aerial survey are presented in Table 8 and Figure 16. During this survey the primary aircraft (D-EOVC) made 11 sightings of dugongs on effort, while the secondary aircraft (ZS EPO) made 15 sightings of dugongs on effort. Five sightings were matched by eye as common to both platforms on the basis of their positions and the time of sighting.

The capture – recapture Petersen model estimates a total "population" of 31 groups available for sighting within the search width during this survey. Sightings of 11 groups by the primary observation platform and 15 groups by the secondary observation platform suggest that 35.5 % and 48.4 % of dugong groups were sighted by the primary and secondary platforms respectively. These results suggest a mean sighting efficiency of 42 % across both sighting platforms.

The high proportion missed during the twin platform survey probably result from the poor sighting conditions under which the twin platform survey was carried out (see Table 5 for 29 October 2007).

Nevertheless, this approach is worth pursuing. Repeating this methodology in better weather would provide a more precise measure of sightability, providing a more realistic abundance estimate.

Table 8. Results of the independent twin platform aerial survey carried out on 29 October 2007.

Platform	Model Parameter	Primary Sightings
D-EOVC	Capture (n_1)	11
ZS EPO	Recapture (n_2)	15
D-EOVC & ZS EPO	Common Sightings (m)	5
	N	31
D-EOVC	Proportion sighted	35.4 %
ZS EPO	Proportion sighted	48.4 %

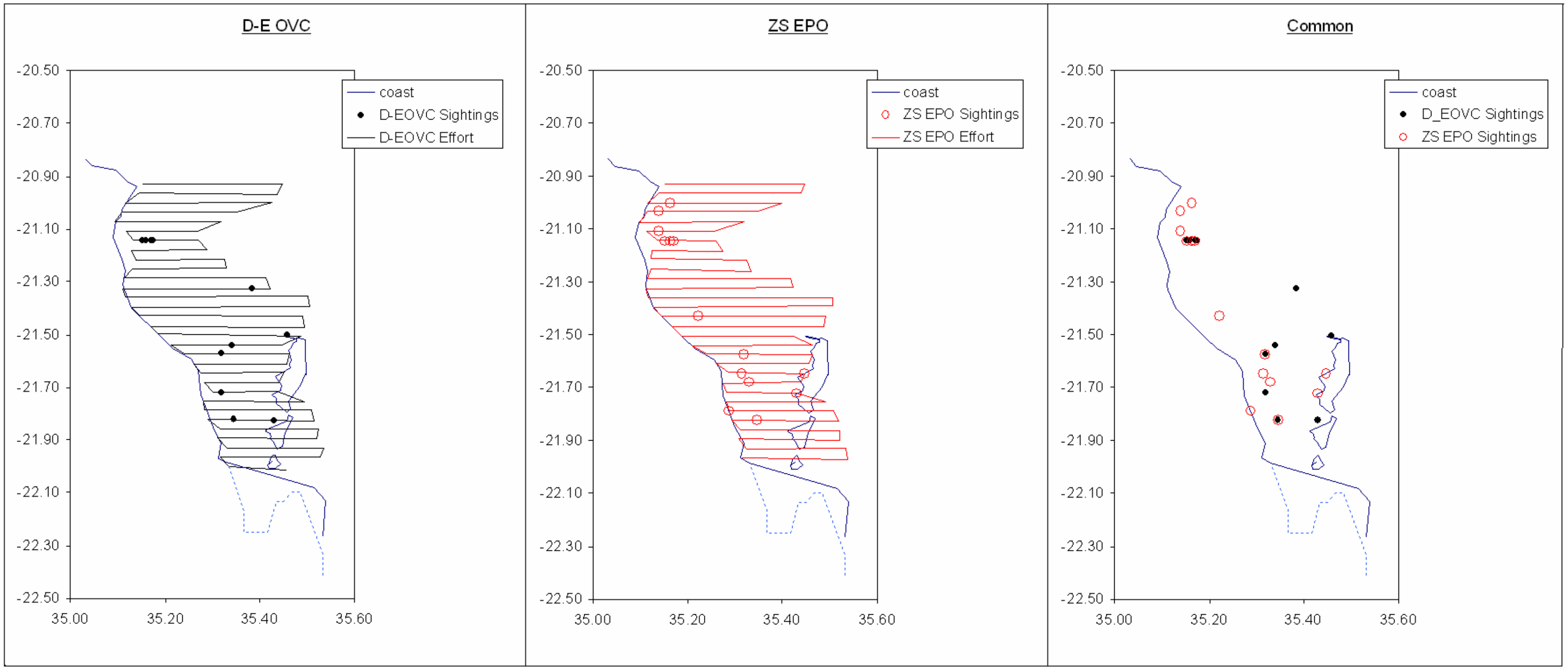

Figure 16. Survey tracks and sightings made from the two platforms (the Aircrafts ZS EPO and D-EOVC) during the win platform survey carried out on 29 October 2007. Sightings made by both platforms are identified in the right chart by black dots encircled with red.

1.11SEA GRASS STUDIES

1.11.1 Depth of sampling station

The sampling of seagrass took place within a depth range of >5 to about 25 m. Most of the sampling stations were shallow in the south of the study area (11 to 15 m) and within 8 km of the shore. The northern section was deeper than the southern section. Inside Bazaruto Bay, the depth at any sampling station did not exceed 10 m (Figure 17). The maximum depth was observed in the north eastern limit of the study area.

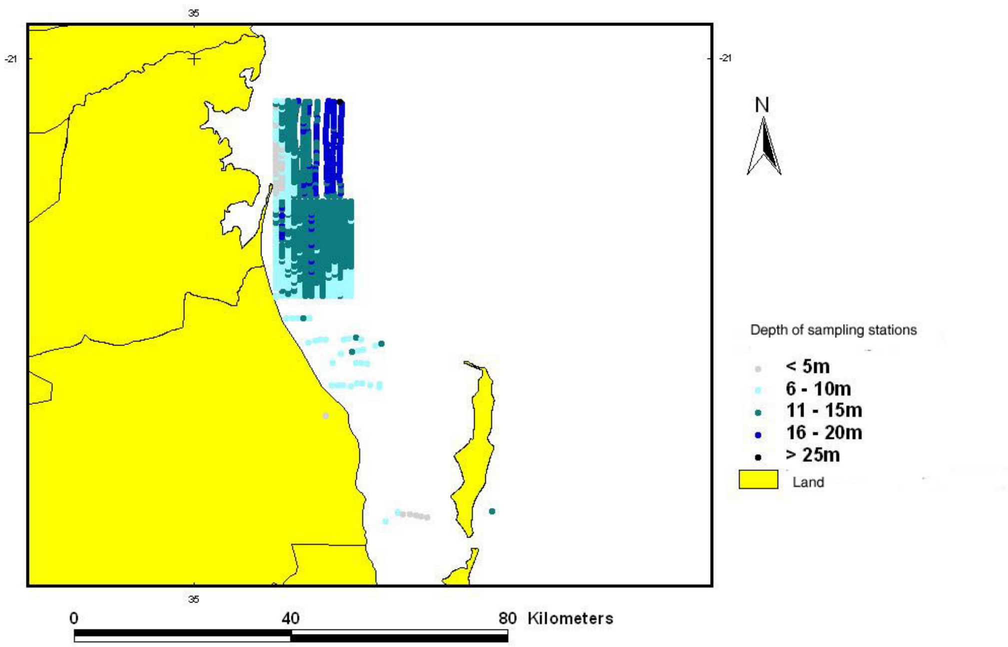

Figure 17. Depth of the seagrass sampling stations between Inhassoro and Save River.

1.11.2 Seagrass species occurrence.

Five species of seagrass were mapped in the area. *Thalassodendron ciliatum, Halophila ovalis, Halodule uninervis, Halodule wrightii and Cymodocea rotundata.*

Seagrass occurred in 46 of the 982 stations searched and covered 4.68% of the area surveyed. Within each survey line, seagrass occurrence varied in coverage from 0 to 70% (Table 9). In general, occurrence was low and limited to lines near the coast. The most frequent species is *Thalasodenron ciliatum. Halodule uninervis* and *Cymodocea rotudanta* had similar proportion of occurrence. *Halophila ovalis* was the species with the lowest frequency of occurrence. The largest cover occurs at some distance from shore, indicating that there is a preferred depth.

Table 9. Number of sampling stations and frequencies of occurrence of seagrass and other substrates per survey line. Lines 20, 19, 26, 18 and 17 are perpendicular to shore and have the same number as those flown by the aerial survey. The remaining lines are parallel to shore and the numbers indicate distance from shore. N1 is closer to the shore and N10 the most distant.

	Sampling stations			**Frequencies of occurrence of seagrass species**				**Frequencies of other substrates**		
Line	**Number of samples**	**Samples with seagrass**	**Percent of occurrence**	***Thalassodendron ciliatum***	***Halophila ovalis***	***Halodule uninervis***	***Cymodocea rotundanta***	**Rock/coral**	**Sand**	**Seaweed**
20	10	3	30.0	16	0	0	0	1	6	22
19	7	2	28.6	9	0	0	0	0	5	8
26	10	0	0.0	0	0	0	0	0	10	0
18	10	7	70.0	51	0	14	10	0	7	35
17	9	4	44.4	34	0	10	23	0	45	10
N1	36	22	61.1	5	5	11	1	3	20	0
N2	36	6	16.7	2	0	3	1	0	30	0
N3	36	2	5.6	2	0	0	0	0	0	0
N4	36	0	0.0	0	0	0	0	5	31	0
N5	36	0	0.0	0	0	0	0	0	36	6
N6	36	0	0.0	0	0	0	0	0	36	2
N7	36	0	0.0	0	0	0	0	2	36	0
N8	36	0	0.0	0	0	0	0	0	36	0
N9	36	0	0.0	0	0	0	0	0	36	0
N10	36	0	0.0	0	0	0	0	0	36	0
N11	36	0	0.0	0	0	0		0	36	1
N12	36	0	0.0	0	0	0	0	0	36	5

	Sampling stations			Frequencies of occurrence of seagrass species				Frequencies of other substrates		
Line	**Number of sample**	**samples with seagrass**	**Percent of occurrence**	***Thalassodendron ciliatum***	***Halophila ovalis***	***Halodule uninervis***	***Cymodocea rotundanta***	**Rock/coral**	**Sand**	**Seaweed**
N13	36	0	0.0	0	0	0	0	0	36	3
N14	36	0	0.0	0	0	0	0	0	36	3
M1	36	0	0.0	0	0	0	0	0	36	0
M2	36	0	0.0	0	0	0	0	0	36	0
M3	36	0	0.0	0	0	0	0	0	36	0
M4	36	0	0.0	0	0	0	0	0	36	0
M5	36	0	0.0	0	0	0	0	0	36	0
M6	36	0	0.0	0	0	0	0	0	36	0
M7	36	0	0.0	0	0	0	0	0	36	0
M8	36	0	0.0	0	0	0	0	0	36	0
M9	36	0	0.0	0	0	0	0	0	36	0
M10	36	0	0.0	0	0	0	0	0	36	0
M11	36	0	0.0	0	0	0	0	0	36	0
M12	36	0	0.0	0	0	0	0	0	36	0
Total	982	46		119	5	38	35	11	946	95
Percent of occurrence	100	4.68		12.12	0.51	3.87	3.56	1.12	96.33	9.67

1.11.3 Distribution of each species

Thalassondendron ciliatum

Thalassondedron ciliatum occurred along the coast of the Inhassoro district close to the mainland. Its widest occurrence was observed inside the Bay than in the north offshore are exposed to ocean waves. The species distribution when matched with the depth contour indicate its occurrence within 0-10 m (Figure 18).

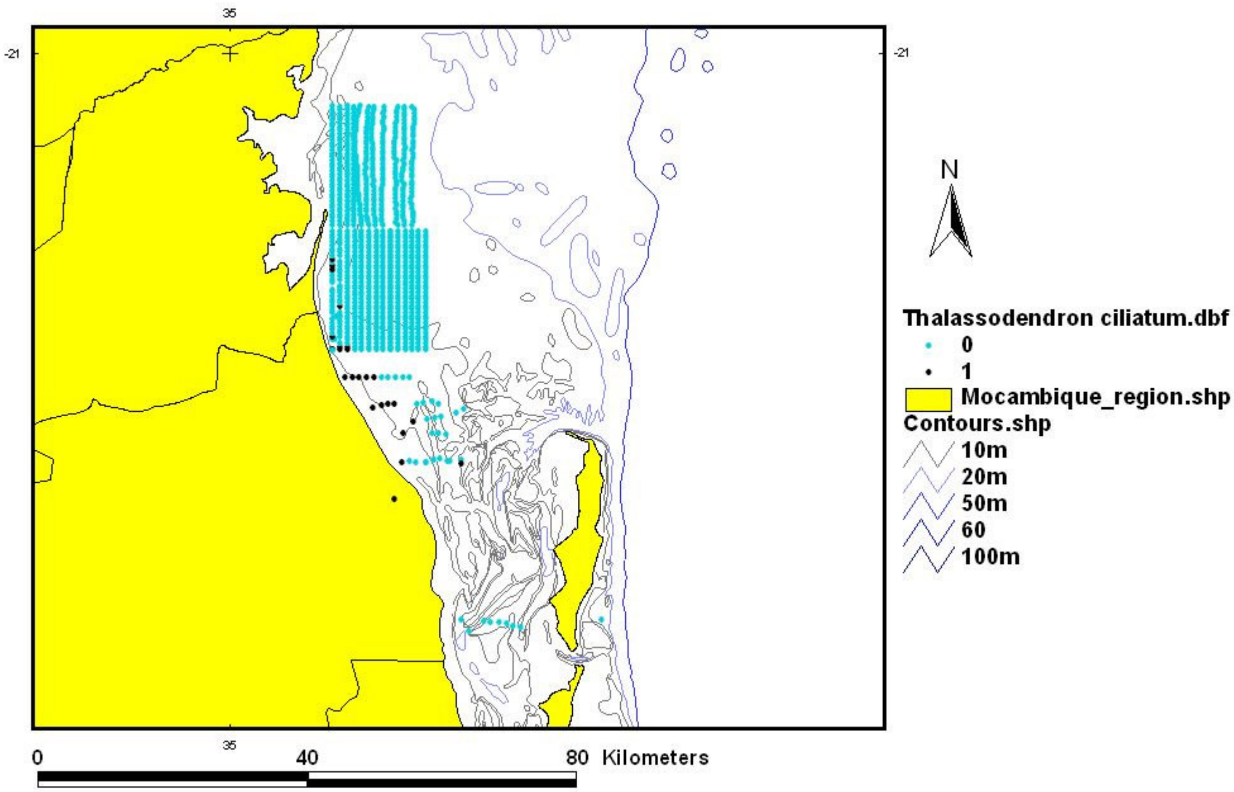

Figure 18. Distribution of *Thalassondedron ciliatum* at the sampling stations of Bazaruto- Save area (in the picture blue dots – 0 indicate absence of species and black dots indicate species presence

Halodule uninervis

This species occurred mainly in along the coast of Inhassoro village and south of the Ponta Nhamabue at Govuro River mouth. It was found near shore. It was also observed to have wider distribution off Inhassoro Vilage. It did not occur in the southern transect lines (Figure 19).

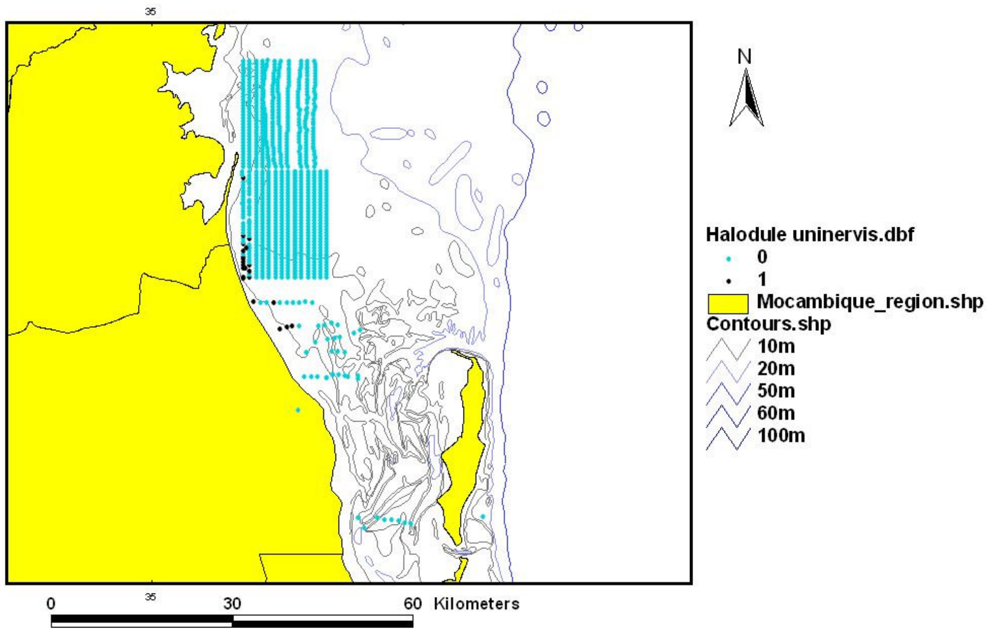

Figure 19. Distribution of *Halodule uninervis* at the sampling stations of Bazaruto- Save area (in the picture blue dots – 0 indicate absence of species and black dots indicate species presence

Cymodocea rotundata

The species had similar distribution as *Halodule uninervis*, but its occurrence was more sparse. It did not occur near the Govuro River mouth, suggesting that it forms isolated patches (Figure 20)

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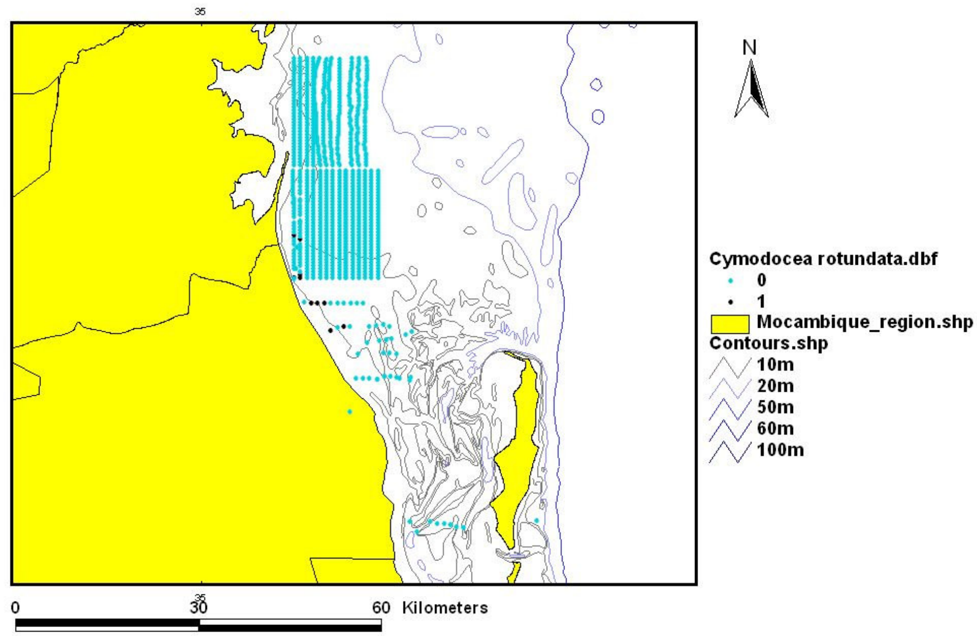


Figure 20. Distribution of *Cymodocea rotundanta* at the sampling stations of Bazaruto-Save area (in the picture blue dots – 0 indicate absence of species and black dots indicate species presence.

*Halophila ovali*s

This species had its occurrence limited to the coastline of Inhassoro area, in a continuous narrow patch (Figure 21).

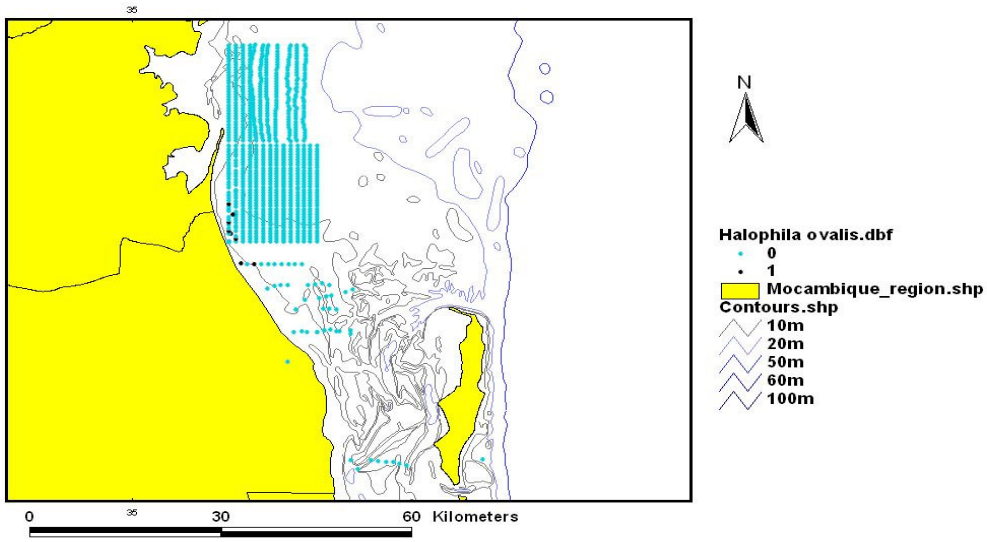


Figure 21. Distribution of *Halophila ovalis* in the sampling stations of Bazaruto- Save area (in the picture blue dots – 0 indicate absence of species and black dots indicate species presence.

Halodule wrightii

This species was only identified at the end of the study on a shallow sand bank located north of Santa Carolina Island. There, seagrass cover was very low and it appeared that after the cyclone in February 2007 the seagrss beds were damaged. *Halodule* is known as a pioneer species and is one of the species preferred by dugongs. Due to low coverage of seagrass and the opportunistic nature of our sampling, we do not present a chart of the species distribution.

1.11.4 Vertical distribution of seagrasses (Zonation of seagrass species)

Zonation of seagrasses from shore along the coast of Inhassoro was measured at two locations. One location was inside the Bay (within a sheltered area) (Table 10) and the second was outside the Bay , in the area exposed to ocean wave action (Table 11).

In the transect line carried out at line 20, adjacent to Inhassoro Village, the seagrass cover peaked at distance between 600 and 1700 km from shore. The seagrass cover is low nearshore and increased between 100 to 500 m from shore. Two species were both frequent *Thalassodendron ciliatum* and *Halodule uninervis*. *Halophila ovalis* and *Cymodocea rotundata occurred* close inshore and also offshore, but was not common In the second transect carried out inside the Bay.

The second transect line (carried out north of Inhassoro Village) at line 16 used a broad scale, was carried out inside the Bay. The seagrass cover was high in between 500 and 2500 m from shore and decreased slightly afterwards (Table C). In this transect *Thalassodendron ciliatum* dominated. *Cymodocea rotudanta* only occurred at 3500 and 4000 m from shore at places were *T. ciliatum* was present, but did not dominate. Seaweed occurred within 500 m, associated with seagrass.

Table 10. Zonation of seagrass species, seagrass cover and other bottom features along a transect in the transect line 20 - Latitude S 21º 35.528' (abundance of seagrass in stations : * = frequent, **= very frequent, * =dominant)**

	Distance of sampling stations in the transect (m)																	
Type of bottom	0	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700
Seagrass cover (%)	0	11	10	45	12	12	85	76	85	80	61	83	62	60	71	73	63	63
Thalassodendron ciliatum		*			*	*	*	*	*	*	*	*	*	*	*	*		
Halodule uninervis			*	*		*	*	**	**	**	**	**	**	**	**	**	**	**
Halophila ovalis					*	*							*					*
Cymodocea rotundata				*	*	*			*									*
Rock/coral																		
Sand																		
Seaweed																		

Table 11. Zonation of seagrass species, seagrass cover and occurrence of other bottom features in the transect line 16 – Latitude S 16 – Latitude S21º23,638'(Abundance of seagrass species was classified into * frequent, ** very frequent, * dominant)**

	Distance of sampling stations in the transect (m)									
Type of bottom	0	500	1000	1500	2000	2500	3000	3500	4000	4500
Seagrass cover (%)	0	80	70	85	70	70	50	65	20	60
Thalassodendron ciliatum		***	***	***	***	***	***	*	*	***
Halodule uninervis										
Halophila ovalis										
Cymodocea rotundata								*	*	
Rock/coral										
Sand										
Seaweed		*								

1.11.5 Occurence of Seaweed (algae)

3 seaweed species were recorded in the area, namely *Sargassum* spp., *Dyctiopeltis ligulata* and *Caulerpa serrulata*. The frequency of seaweed . They occurred in association with seagrass species and their overall frequency was larger than the seagrass occurrence (9.7%) (Table 9).

Sargassum sp.

Samples of sargassum were only collected inside the Bay beyond the depth of 10 m. It did not occur outside the Bay (Figure 22).

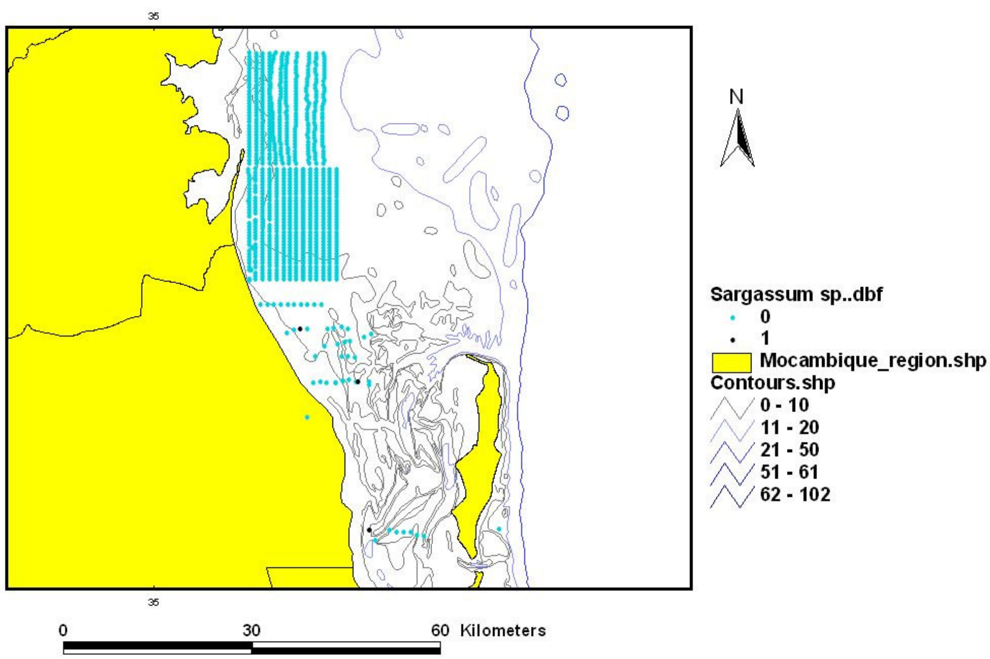


Figure 22. Distribution of the seaweed Sargassum sp. in the study area. (Blue dots or Zero denotes absence and black dots represent presence).

Dyctiopteris ligulata

The species was sampled also inside the Bay but its distribution is wider than Sargassum and it was found from the shore line to the 10 m depth countour line (Figure 23). It did not occur outside the Bay in the northern area.

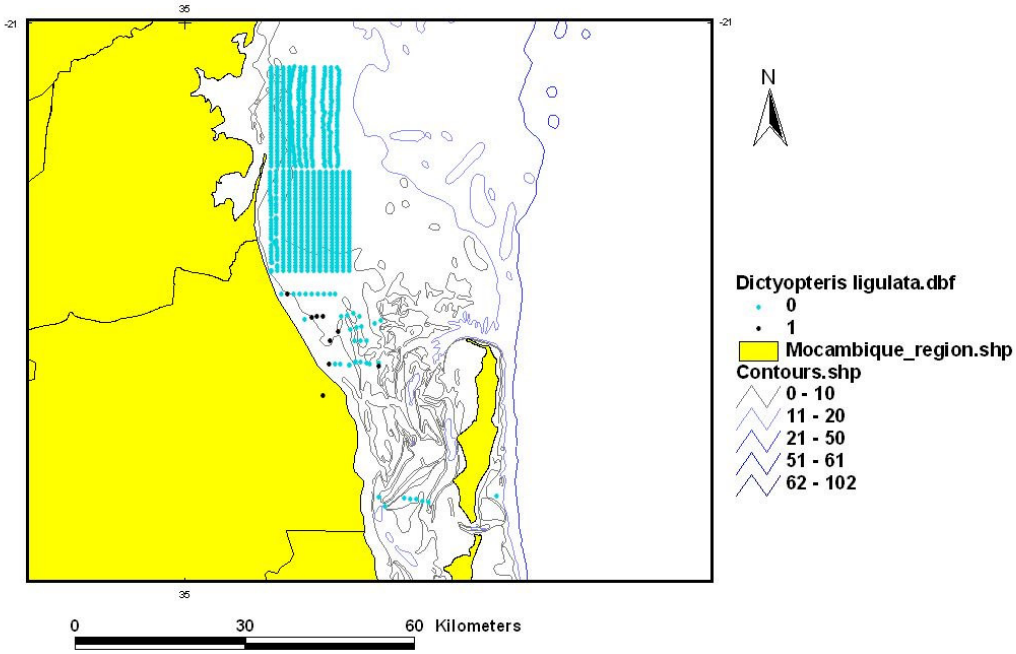


Figure 23. Distribution of the seaweed *Dictyopteris ligulata* in the study area. (Blue dots or Zero denotes absence and black dots represent presence

Caulerpa serrulata

The species was also observed inside the Bazaruto Bay area in a very few stations, near the 10 m isobath (Figure 24).

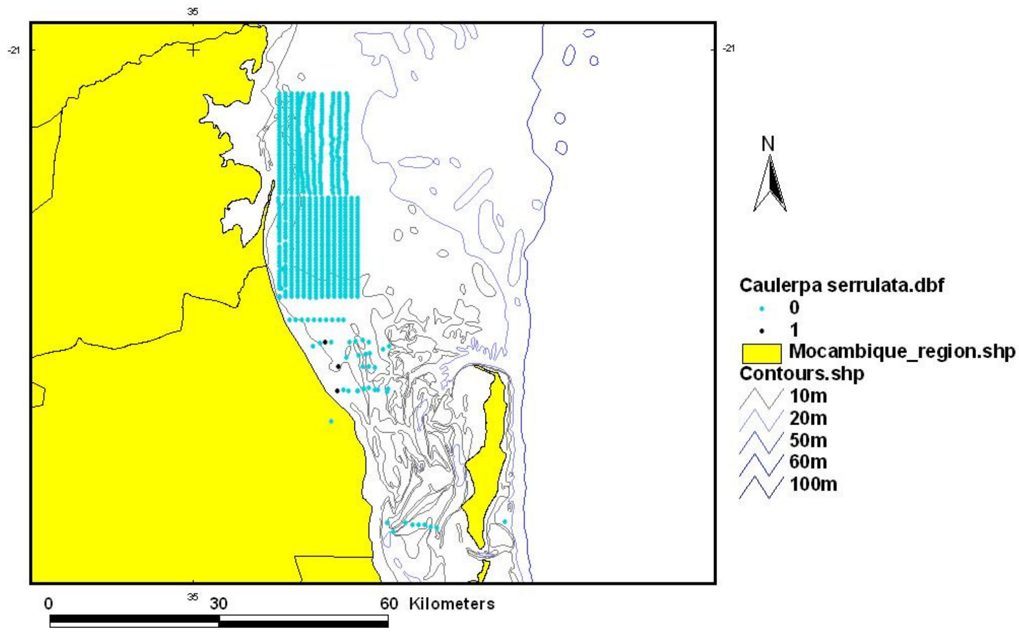


Figure 24. Distribution of the seaweed *Caulerpa serrulata* in the study area. (Blue dots or zero denotes absence and black dots represent presence.

1.11.6 Seagrass cover

Seagrass cover ranged between 0 and 100% (Figure 25). At most of the offshore sampling stations seagrass cover was 0%. Only in a small strip of coast seagrass cover occurred. Cover was high in the survey lines sampled inside the Bay. Seagrass cover decreased from south to north of the study area. The largest cover occurred near the coast at Inhassoro Village and towards south. When matched with the depth contour line, the greatest seagrass species cover occurs within 0-10 m of depth.

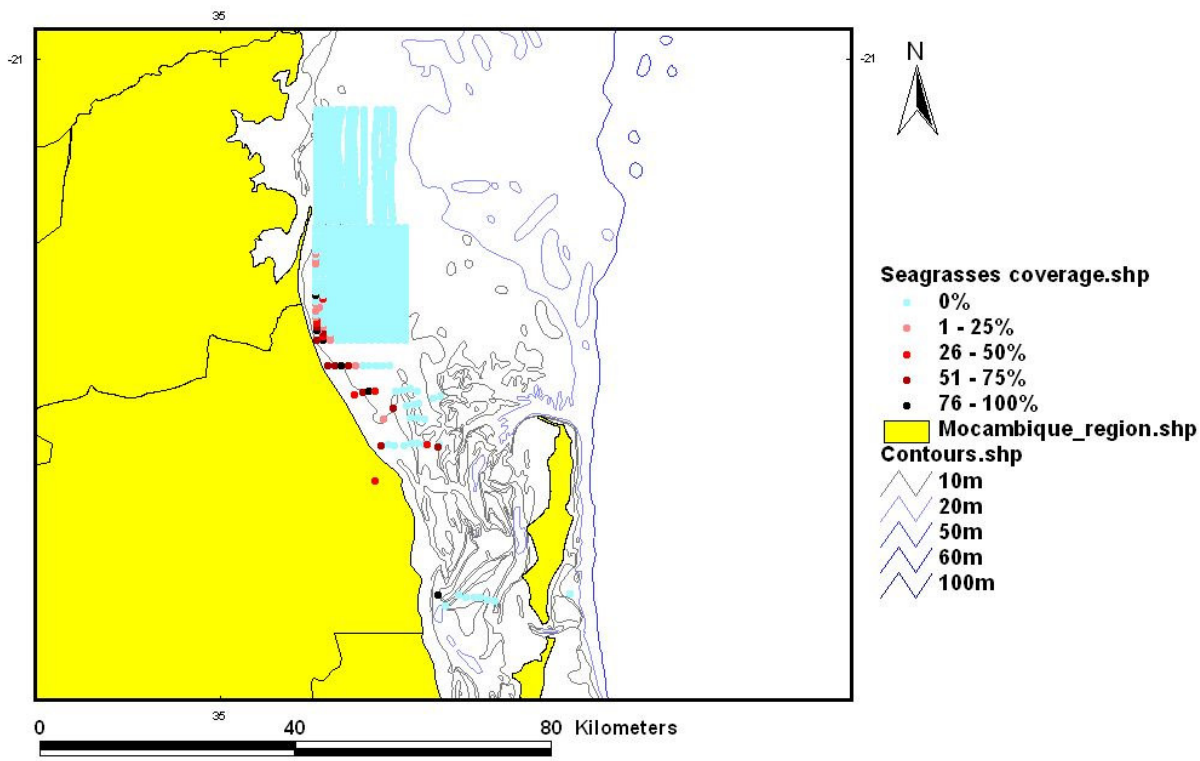


Figure 25. Distribution of the percentage of seagrass cover per sampling station in the surveyed area. Contours means depth contour.

1.11.7 Nutritional value of seagrass species

For this study we included the species *Nanozostera capensis*, collected at Bazaruto Island, near Sitone.

Overall, the percent of dry matter in the seagrass varied between 84 to 90% (Figure 26). *Halophila ovalis* was the species with high dry matter for above ground and below ground plant parts. *Cymodocea rotundata* , *Nanozostera capensis* and *Halodule uninervis* had the lowest percentage of dry matter both for above and below ground plant parts. *Thalassondedron ciliatum* had large content of below ground dry matter, but low content of above ground biomass.

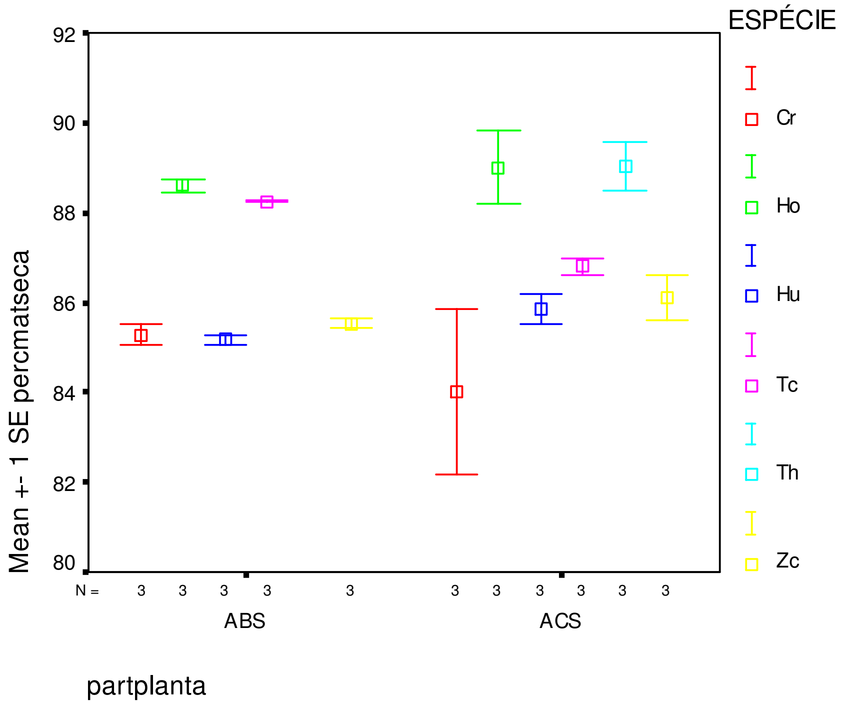


Figure 26. Percent of dry matter of samples of seagrass species collected at Bazaruto area (ABS means below ground parts and ACS means above ground parts). (Cr = *Cymodocea rotudanta*, Ho = *Halophila ovalis*, Hu = *Halodule uninervis*, TC = *Thalassondedron ciliatum*, Th = *Thalassia hemprinchii*, Zc = *Nanozostera capensis*)

Nitrogen content is an indication of the quality of forage for dugongs. In general, nitrogen content is low in the plant parts below ground when compared with the above ground plant parts, for all species. *Thalassodendton ciliatum* and *Cymodocea rotundata* had lower nitrogen content below ground, than other species. Large variability in the above ground parts was observed for *Cymodocea rotundanta* and *Halodule uninervis*. However, is lower than above ground plant (Figure 27).

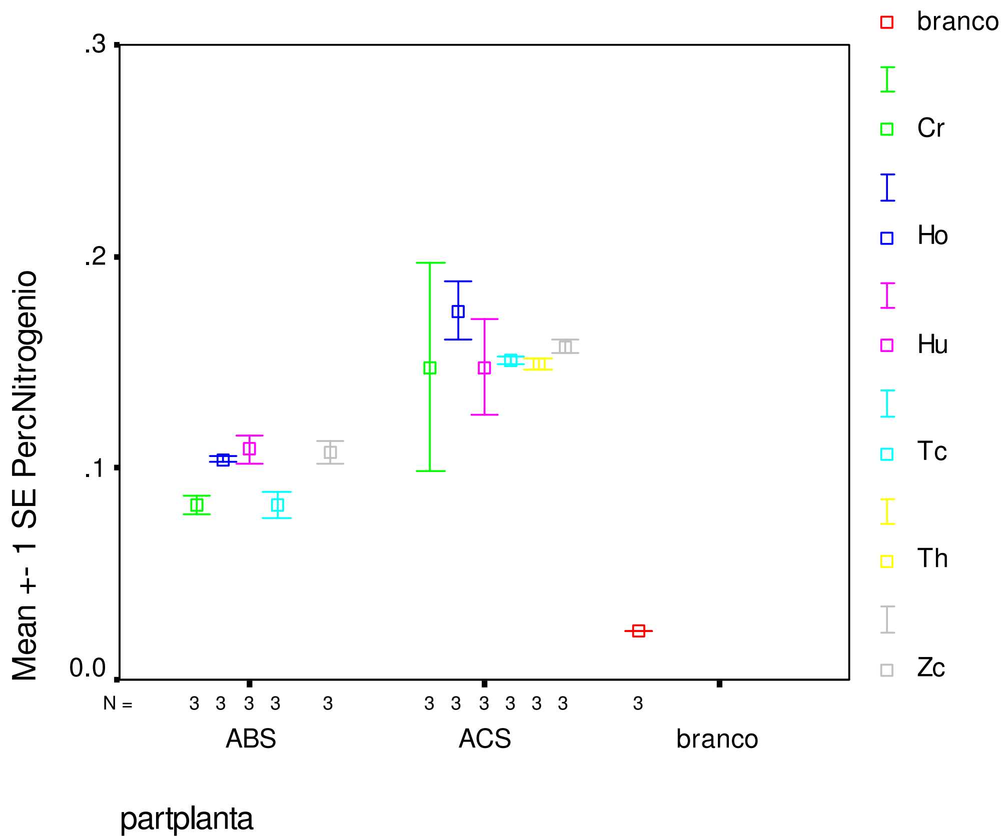


Figure 27. Percent of nitrogen content of samples of seagrass species collected at Bazaruto area (ABS means below ground parts and ACS means above ground parts). (Cr = *Cymodocea rotudanta*, Ho = *Halophila ovalis*, Hu = *Halodule uninervis*, TC = *Thalassondedron ciliatum*, Th = *Thalassia hemprinchii*, Zc = *Nanozostera capensis*, branco – means blanc test)

Species with high percent of organic matter were *Thalassodendron ciliatum* and *Cymodocea rotudanta*. *Halophila ovalis* had the lowest organic matter content at the above ground plant parts (Figure 28).

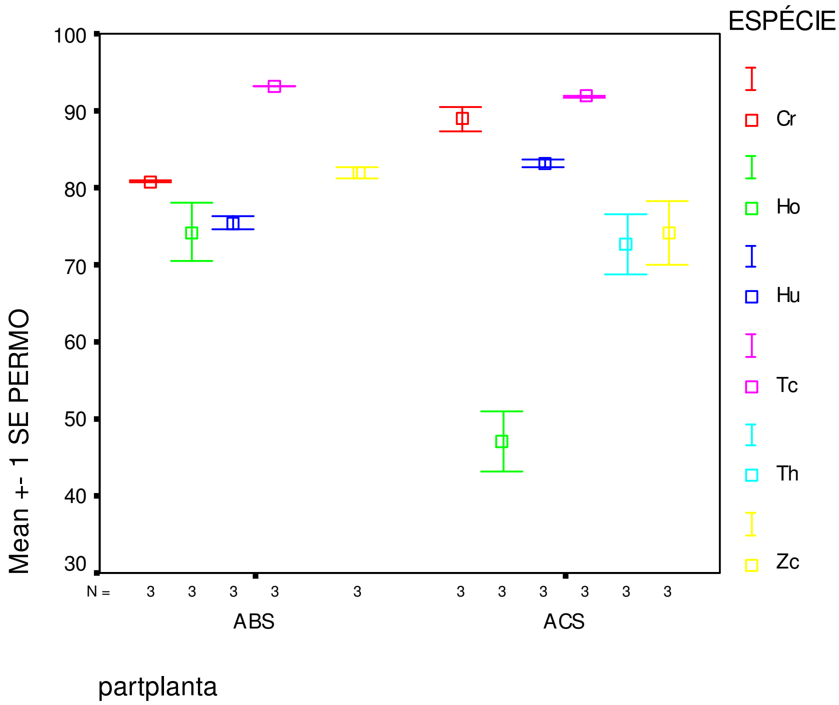


Figure 28. Percent of organic matter content of samples of seagrass species collected at Bazaruto area (ABS means below ground parts and ACS means above ground parts). (Cr = *Cymodocea rotudanta*, Ho = *Halophila ovalis*, Hu = *Halodule uninervis*, TC = *Thalassondedron ciliatum*, Th = *Thalassia hemprinchii*, Zc = *Nanozostera capensis*)

1.12BEHAVIOURAL OBSERVATIONS

Over the final three months of the project, an inordinate amount of time was spent determining seagrass coverage. This left little time for dugong observational work. In addition, repeated theft from the observation platform and the risk of the platform being cast adrift led to its removal and, consequently, Visual Behavioural Observations were not undertaken.

1.13POPULATION VIABILITY ANALYSES

Given the inaccuracies and biases of stochastic models, the results for Bazaruto's dugongs were interesting and surprising. Despite the wide range of scenarios available and run, six scenarios summarise the prognosis for Bazaruto's dugongs.

1. Catastrophic Event Model

In this model, other than a catastrophic event resulting in a direct mass mortality of dugongs, or an indirect impact through destruction of their entire habitat, the population is likely to recover over time.

2. Hydrocarbon Exploration Model

As seismic exploration will take place only once, one year in the 200 modelled, the model suggests that it is almost immaterial (provided not all are killed) how many dugongs are killed, whether they be reproductively active females or not!

As an expansion of this model, exploratory well drilling was added. Under this scenario, six exploratory wells were drilled, two in each year, for three years, in addition to seismic exploration. Other than a catastrophic event resulting from the drilling, such as a blow out, causing massive habitat destruction, impact scenarios were restricted to being local and up to three dugong deaths annually. Under these circumstances, the model predicts results similar to those above, but, obviously, slightly more serious in the short term. Nevertheless, under almost all 'reasonable' scenarios of possible impacts on reproductive success and mortality, the population is predicted to survive and increase.

Under this scenario, even using the most conservative variable values, if 50% of dugongs are killed, including half the reproductively active females, the population will probably survive. Only if a catastrophic event, one that removes almost all the animals and reproductive females, does the model predict extirpation.

3. Combined Hydrocarbon Exploration and Cyclone Model

Again, the results are almost intuitive. Because both events are infrequent, unless both events remove half of the reproductively active females and more than 45% of other animals, the population will recover, though slowly.

It is important to note that the latter three models assume that there are no other negative affects on survival or birth rates through natural or anthropogenic pressures. Under such an assumption the population can probably withstand any one off mortality, provided it is not a totally devastating mass mortality..

4. Incidental Capture Model

With all other catastrophic variables excluded – hydrocarbon exploration operations, environmental (cyclones) or anthropogenic calamities– and the flexible variables manipulated, the model was run using levels of incidental capture, for various age groups and sexes. When female age at first breeding was at it's highest known (17 years), the loss of even one breeding female and four, non-breeding, animals every year, dooms the Bazaruto dugongs to slow decline and extirpation sometime around 2500. Even when dugong females breed at their earliest, from 10 years, as few as an average of three caught per year, and two other non-breeding dugongs, relegates this population to extirpation by the next millennium. Obviously, with higher catch levels of breeding females at more than three a year, under any manipulation of the other variables, extirpation of the population is within tens and hundreds of years.

The model is very sensitive to the proportion of breeding females caught (or in the population as a whole). If the proportion of females breeding increases to 22% (per annum), the population will survive. However, if the numbers of reproductive female captured increases also, the extirpation scenario remains.

The salient point of this model is that even if all other pressures are excluded and a 'liberal' scenario is used, the loss of as few as nine animals per year, including two reproductively active females, through incidental catch, dooms Bazaruto's dugongs to extirpation. Any regular and consistent stressor, in this instance incidental capture, places enormous pressure on the survivability of the population, especially if this stressor is on reproductively active females.

5. Incidental Capture and Catastrophic Event Model

This model assumes that incidental capture is five dugongs annually, with ONLY one reproductively active female captured every second year.

Under this scenario, and assuming catastrophic events occur once every 10 years and no reproductive females die as a result, but as few as three other dugongs die, incidental catch need only be one reproductively active female every third year to send the population to extirpation.

Obviously, if no dugongs die, or reproduction is not disturbed, the result is the same as that for the Incidental Capture Model.

The important result of this model is that the synergistic impacts of only one more pressure, albeit natural, exponentially increases the probability of extirpation of this population.

6. All Inclusive Model

Given the evidence of the models above, it seems intuitive that with a combination of pressures, the survival of the dugongs in Bazaruto is balanced on a knife edge!

Using the 'liberal' scenario, the number of dugongs increases over the next decades, even if the negative impacts of hydrocarbon exploration and cyclones are increased substantially. But, if the incidence of anthropogenic impact increases to eight dugongs annually, including two breeding females, the model predicts extirpation within 250 years.

Using the 'conservative' scenario, the model suggests that with as few as an annual average of three deaths from anthropogenic causes (not even a breeding female), Bazaruto's dugong numbers show a gradual decline over the next century, but then recover. However, if one breeding female is captured in addition, the model predicts a slow slide to extirpation. Any further catches of non-breeding animals hastens extirpation, as does the increased capture of breeding females. If seven dugongs are captured annually and an average of two of these is female, the model predicts extirpation within 120 years.

DISCUSSION

1.14 DISTRIBUTION

The aerial survey flights identified that dugongs occur throughout the shallow region inshore of the 20 m isobath from the Save River mouth to Cabo Sao Sebastio. However the region south of a line extending from Vilankulos to Cabo Sao Sebatio appears too shallow for dugongs as no individuals were sighted over this large area of shallow sandbanks separated by channels.

Two distinct core areas of abundance are apparent from the distribution records. The northern core area offshore of the Govuro River Mouth and the Bartholomeu Dias Spit lies directly inshore of the possible Shallow Water Prospect Area, while the second core area lies in the vicinity of Santa Carolina Island, where a number of large groups of dugong were seen during aerial surveys. This second core area shows little seagrass cover and it appears that animals utilise this area for other reasons than feeding. UNEP (2002) suggested there is some evidence that dugongs use specialized habitats for various activities, as shallow waters, such as tidal sandbanks (Marsh et al. 1984c) and estuaries (Hughes & Oxley-Oxland 1971), have been reported as sites for calving, which Anderson (1981) noted may be a strategy to minimise the risk of shark predation to calves. Wirsing et al. (2006) suggested that dugongs manage their probability of death by allocating more time to safe but lower-quality feeding microhabitats when the likelihood of encountering sharks is elevated.

1.15 POPULATION ABUNDANCE

The Global abundance estimate (247 – SE 34.09) of the Bazaruto Archipelago dugong population calculated for this study is probably the most robust population estimate of this population to date. Abundance estimates from previous surveys have suggested slightly lower population estimates that those recorded in this study, although it should be noted that the estimates are not directly comparable due to different survey methodology and survey area limits.

Guissamulo & Cockcroft (1997) estimated a local population of 130 dugongs in the Bay based on strip transect sightings. The survey area covered by Guissamulo & Cockcroft (1997) is smaller than that covered in this survey so that a smaller proportion of the local population was surveyed.

Aerial counts by Dutton (1998) suggested to him that the dugong population is declining rapidly as maximum counts amounted to approximately 21 dugongs per survey (Dutton 1998). However it appears that these counts are raw counts only and no survey methodology was applied in results analysis.

An aerial census of the Bazaruto National Park (including the Bazaruto National Park (Bazaruto, Santa Carolina, Benguerua, Magaruque and Bangue) conducted by WWF in May 2001 found dugongs distributed throughout the northern, central and south central areas of the Archipelago between Bazaruto Island and the mainland. However, WWF (2004) suggested from aerial counts (of between 25 and 130 individuals) between 1990 and 2002, that this population is declining (Mackie, 1999).

A single survey carried out by VGC and ATG in 1990 counted 92 dugongs in the area between Bazaruto, Benguerra and Magaruque Islands and the mainland and from the northern tip of Bazaruto to Vilankulos (VGC and ATG, unpub. data). Although these data remain unanalysed they suggest higher densities than those recorded during the surveys carried out in this study.

1.16 POPULATION TREND

A single point estimate of population abundance is difficult to evaluate without information on the dynamics or change in the population (whether the population is increasing or decreasing). it is believed that the local Bazaruto dugong population must be viewed in the context of the status of the population within the Western Indian Ocean, which has clearly declined over the last thirty to forty years. Preen (2004) has suggested that the long – term survival of the dugong in the Western Indian Ocean, will depend on the establishment of an adequate network of protected areas where the impacts of human activities can be minimised. Although populations elsewhere across the range appear to be in better health, Marsh *et al*., (1996, 2001) has identified an apparent decline in dugong numbers within parts of the Great Barrier Reef Marine Park in Australia.

No trend in abundance can be seen in the data over the year of surveys. Each abundance estimate obviously has an associated coefficient of variation, and the year time period of survey is too short in terms of data contrast for any trends in abundance to be detected over the coefficient of variation. Marsh and Saalfeld (1989) recommend a five year gap between surveys for trends to be identified, as endorsed by CALM (1996, in Holley et al., 2006).

Even given continued and regular aerial surveys, these are unlikely to provide the precision necessary to identify any change (decline) in the dugong population (Taylor & Gerrodette, 1993). As a consequence, it is imperative that conservation efforts are not reliant on further aerial estimates. It’s important to base conservation on Educational & Awareness programmes, aimed at reducing or negating anthropogenic impacts, particularly hunting and incidental captures.

Simplistically, the dynamics of a population within an area are governed by four factors, namely Natality (birth rate), Mortality (death rate – usually measured as adult and juvenile survival parameters), Emigration (movement out of the area) and Immigration (movement into the area). A population within an unoccupied niche or habitat will fill that niche to carrying capacity through immigration or population increase (where Natality exceeds Mortality). Carrying capacity is determined by the available environmental resources limiting further growth and is reached when the population is in dynamic equilibrium through Natality equalling Mortality or Emigration equalling Immigration. Equilibrium of an increasing population may be attained by the limitation of resources increasing Morality (through direct vectors such as starvation, or indirect vectors such as reduced fitness tolerance to disease) or decreasing Natality (through a decrease in reproductive rates through reduced fitness). Furthermore, equilibrium may be attained by emigration of individuals to new areas or habitat. Anthropogenic activities have the potential to impact populations by increasing Mortality (decreasing survival) or deceasing Natality (alteration or slowing of reproductive rates).

Increasing evidence of synergistic effects compounding impacts on population dynamics in populations has recently come to light (Peres, 2001; Zanette et al 2003). Synergistic effects on populations occur through non – linear processes so that the resulting impact of two synergistic effects may be exponentially greater than the linear additive effects. Such synergistic effects could be important in two natural aspects that are critical in the evaluation of impacts to dugong populations.

1. The inherently low reproductive rates of dugongs

Life-history parameters are summarized in Marsh (1995a, 1999). Marsh (1999) noted that dugongs are long-lived with a low reproductive rate, long generation time, and a high investment in each offspring. The gestation period is relatively long at between 13-15 months, with usually one calf per pregnancy. Nursing continues for 14 to 18 months, while inter-calving intervals have been estimated at between 2.4 and seven years (UNEP, 2002), although may increase in relation to resource limitation. Such life history parameters suggest a low reproductive rate and a correspondingly high adult survival (at 95% or greater per annum (Bryden et al., 1998)) if populations are to maintain equilibrium. Population model simulations suggest that a dugong population is unlikely to increase more than 5% per year (Marsh 1995a, 1999).

2. The role played by stochastic or episodic events such as the impacts of tropical cyclones or floods on seagrass bed habitat.

Impacts to the Bazaruto Archipelago dugong population could manifest at a number of different levels:

1. direct impacts (such as vessel strikes or pollution loading) leading to injury or mortality at an individual or mass population level (it should be noted that at critically low population levels, individual level impacts may manifest at a population level).

2. direct impacts leading to a decrease in the birth rate (e.g. decreased reproductive fitness arising from stress or pollution loading, or through disturbance of reproductive behaviour)

3. direct impacts leading to emigration (avoidance of the area)

4. indirect impact (e.g. habitat loss) leading to mortality (e.g. through starvation or reduced fitness and disease tolerance) or to reduced birth rates (through decreased reproductive fitness)

6. indirect impact (e.g. habitat loss) leading to emigration.

UNEP (2002) has suggested that the rate of change of dugong populations is most sensitive to decreases in adult survivorship, and that a minor decrease in adult survivorship as a result of habitat loss, susceptibility to disease, direct hunting mortality or indirect fishing mortality can have chronic impacts on dugong populations. UNEP (2002) suggested the following factors to contribute to declines in dugongs across their range:

1. Habitat degradation

a) Anthropogenic habitat degradation. Little is known of the dynamics or changes in the habitat of dugongs over the last 40 years, although increased anthropogenic activities (including increased vessel traffic and associated noise and potential vessel strike effects; and increased beach seine net fishing which may heavily alter seagrass structure through disturbance) suggest that habitat must have declined over this time.

b) Natural habitat degradation.

No information appears available on changes in the dugong habitat of the Bazaruto Archipelago as a result of natural causes. However Preen and March (1995) report on more than 1000 square km of seagrass being lost from Hervey Bay, Queensland in 1992, with an associated decline in the dugong population about 1753 in 1988 to about 71. A total of 99 carcasses was recovered, with the majority dying six to eight months after the event, with most being emaciated as a result of starvation. The authors estimate that full recovery of the 1988 population may take more than 25 years. Heinsohn and Spain (1974) report of impacts of a cyclone on dugongs of the tropical coast of Queensland (both changes in diet and distribution are reported).

Although Cyclone Favio struck the Study Area on 22 February 2007 no dugong deaths were recorded from the area.

2. Indirect fishing pressure

The commercial fishery for sharks in the Bazaruto Archipelago uses 40cm stretch size gill nets set for extended periods in known dugong habitats and resulted in many dugong mortalities (Dutton 1994; Cockcroft et al. 1994; Guissamulo & Cockcroft 1997). There is also evidence that the catch of dugongs has developed into a directed fishery in Bazaruto Bay (Guissamulo & Cockcroft 1997; Cockcroft & Young 1998), where nets are set at night. Fishers do not openly admit to taking dugongs however, dugong meat is prized (Cockcroft et al.

1994).

3. Indigenous use and hunting

The extent of mortality to the Bazaruto Archipelago dugong population from hunting remains unknown due to the illegal nature of the activity. However it is believed to be in the order of four to six individuals per year (VGC pers obs).

Other anthropogenic and natural stressors to the population include vessel activity (including strikes) and ecotourism (largely through vessel noise and possible harassment as informal dugong watching (though to be low, although numerous tourism concerns utilise dugongs within their marketing campaigns)), chemical pollutants (thought to be low due to the limited input of chemical pollutants in the area) and disease (which may be related to anthropogenic influences on water quality). There is little or no information on the extent of these other stressors on the Bazaruto dugong population.

The effects of immigration and emigration are as important in assessing population dynamics as changes in survival or birth rate. Dugongs may move considerable distances, and the best information on dugong movement arises from tracking using VHF and satellite telemetry equipment within Australian waters (Marsh and Rathbun, 1990; Gales et al, 2004; Sheppard et al. 2006).

UNEP (2002) suggest that daily movements of dugongs are dependent on tidal amplitude. At localities in which there are large tidal ranges, dugongs can gain access to their inshore feeding areas only when water depth is 1m or more. In areas of low tidal amplitude and in areas where seagrass grows subtidally, daily movements are not dictated by tides.

Sheppard et al. (2006) reported on the movements of 70 dugongs fitted with tracking devices (VHF and satellite telemetry equipment). Noting that dugongs often use multiple and distinct core habitats separated by transit areas, they divided movements into a number of types

- microscale movement of less than 15 km occurring as tidally-driven foraging and commuting movements between and within seagrass beds
- large scale movement (LSM) as any displacement that was greater than 15 km between two consecutive stopping points during the entire tracked animal path where, a stopping point was designated when an animal paused at a previously identified core habitat or remained stationary for longer than 5 hours. LSMs were further divided into into meso-scale movements (of 15–100 km) and macro-scale movements (of >100 km).

Of the 70 tracked individuals, 26 individuals were relatively sedentary while 44 moved distances of up to 625 km from their original capture sites. Animals from all age–sex classes including cows with calves undertook these large-scale movements. At least some of the movements were return movements, suggesting that such movements were ranging rather than dispersal movements. Seven dugongs moved over 200 km, while 14 moved over 100 km and more than 50% moved over 50 km. During such LSMs, dugongs rarely travelled further than 15 km from the coast. The authors suggested that dugongs apparently do not feed or rest for significant periods while on these LSMs, despite passing areas where significant seagrass resources are available.

Stimuli for movement was suggested by Sheppard et al (2006) to include

1. Thermoregulatory stimulus

Sheppard *et al* (2006) reported that dugongs in Moreton Bay, Australia, undertake meso-scale thermoregulatory movements in response to low winter water temperatures. Such movements are in the region of 8–20 km to an area outside the bay where local oceanographic conditions are 5° C warmer than inside the bay. Preen (2004) suggested that dugongs may aggregate around thermal springs in winter, approximately 400 km from the summer habitats. A number of authors have reported that dugongs in Hervey Bay and Moreton Bay in Queensland, Australia (Sheppard et al., 2006; Preen, 1992; 2004), as well as Shark Bay in Western Australia (Anderson, 1986; Marsh et al., 1994), appear to move seasonally (or in winter at minimum) in response to water temperature thresholds of 17–19°C. Similar movements of sirenians in response to water temperatures has been recorded in Florida (Deutsch et al., 2003a, b). Sheppard et al (2006) suggested that both meso-scale and macro-scale movements are utilised by dugongs to avoid cool winter water temperatures in the higher latitude extents of their ranges.

2. Spatio - temporal heterogeneity of seagrass food resources

Dugong distribution is associated with the availability of suitable seagrass beds, and such beds vary across spatio - temporal bathymetric, nutritional and seasonal gradients. Sheppard et al. (2006) suggested that dugongs maintain a spatial memory of areas of quality seagrass food resources, which they may visit periodically.

3. Extreme episodic weather events such as cyclone and floods, which can result in the loss of hundreds of square kilometres of seagrass.

Extreme weather events such as cyclones, hurricanes and floods can cause extensive damage to seagrass communities (Poiner & Peterken, 1996) through severe wave action and siltation and sedimentation of shifting sand and silt loads, and changes in water visibility and consequently light reduction (Preen & Marsh, 1995; Preen et al. 1995). Preen & Marsh (1995) reported that an unusual flood and cyclone event resulted in the near total loss of 1000 sq km of seagrass meadows in Hervey Bay, in eastern Australia, and that as a consequence, many dugongs starved and eventually died, while some individuals emigrated as far as 900km. Sheppard et al. noted that the changes in dugong population and distribution observed from aerial surveys in the 1987, 1991, 1996 and 2001 Torres Strait and 2000 northern Great Barrier Reef cannot be attributed to natural increase in the absence of immigration, and appear linked in part with large-scale episodic disturbance to habitat by cyclones and floods (Marsh and Lawler, 2002; Marsh et al., 2002, 2004).

In the context of Bazaruto Archipelago dugongs, movements into or out of the area appear minimal. Exploratory flights northwards up the coast as far as Sofala and southwards to Inhambane suggest that the dugongs inhabiting the Bazaruto area are probably entirely isolated.

North of the Chiloane Islands, the water visibility is often extremely poor, even in the ‘dry’ season, when rain has not fallen for some months. This poor visibility extends out to at least 15 nm, as far as the aircraft was permitted to fly. Such poor visibility indicates poor seagrass coverage, as seagrasses require sunlight for photosynthesis. Although areas north of Sofala were not explored, a preliminary examination of satellite photographs suggests that there is little dugong habitat between the Chiloane Islands and somewhere north of the Zambesi River, some 600 km. Although dugongs are known to move as far as 650 km, intuitively, it is difficult to imagine a regular immigration or emigration route involving these movements. Such a hiatus in distribution was suggested by Hughes (1971).

South of Cabo Sao Sebastio the continental shelf is narrow and probably does not provide habitat for more than transient dugongs. Inhambane, which some 10 years ago was known to accommodate at least 16 dugongs, appears now to be over exploited by human activity. Dugongs were not seen during an exploratory survey and the density of fishing boats and fish traps, suggests that dugongs may well have been all, but, extirpated from the area.

1.17 DENSITIES OF SIGHTINGS

The densities of sightings recorded during this study although high compared with the rest of East Africa are low throughout the Bazaruto Archipelago area, especially in comparison with

Australia and the Arabian Gulf. While such densities may not be directly comparable as the quality or extent of habitat within the areas is expected to vary, the fact that Australian or Arabian Gulf densities are some four to eight times higher suggest that the Bazaruto Archipelago population may be at a level well below carrying capacity.

No seasonal differences in dugong densities were apparent from the aerial surveys flown in this study. There is considerable evidence that dugongs at the higher latitude extent of their range may move seasonally in relation to water temperatures, and a number of authors have suggested that dugong distribution limits may be set by tolerance to lower water temperatures of between 17 and 19℃. ERM (2007) suggests that the water temperatures of the region range from 23ºC in winter to 27ºC in summer (Dutton and Zolho, 1990, in ERM, 2007). Furthermore the latitude of the Bazaruto Archipelago region at approximately 21º S lies well to the north of the latitudinal distribution limits of the species which is defined by UNEP (2002) at between approximately 26° and 27° north and south of the equator (Nishiwaki & Marsh 1985).

1.18 SEAGRASS STUDIES

Seagrass occupy a very narrow strip of coast line varying between 2000 and 4500 km along the coast between Inhassoro Village and Save River. Seagrass was not found during sampling absent in the coast in the region north of Ponta Nhamabue, indicating that the food available for dugongs outside the Bazaruto Bay is limited to a narrow extent between Inhassoro Village and Ponta Nhamabue. This is of very significant value, because large offshore aggregations have been observed in these areas, and appear to have access to a relatively scarce forage area.

The distribution of cover, show that seagrass cover is high within a very narrow area nearshore and that in other areas seagrass is absent or their cover is sparse. It is still not possible to provide an indication of the importance of such low seagrass cover, but it may suggest that seagrass forage for dugongs is not common, provided that the area occupied is limited. The distribution of species requires a more detailed sampling, as the 1 km spacing between survey lines (oriented north south) is a large gap between sampling stations, and an increase sampling intensity is necessary to produce a more accurate picture of seagrass. However, it is already sufficient to provide the dominant / frequent species, the landward and seaward species range.

The available Landsat 5 satellite image of the area between Inhassoro and Save River is not good for mapping of seagrass patches in the area. In addition, there are no aerial photographs available for this section of the coast that would help improve the mapping of seagrass. It is suggested that a very detailed (high resolution) satellite image of the area is obtained for a more precision of mapping of vegetation.

Four species were recorded in this part of the area, despite that another two species (*Nanozostera capensis* and *Thalassia hemprinchii*) also occur in the area. These two species are found along the the west coast of Bazaruto Island. Another two species *Halodule wrightii* and *Cymodocea serrulata* also occur in the shallow submersed sandbanks in the middle of the Bazaruto Bay at locations of high water transparency. Despite the lack of measurements, the inshore water of the coast of Inhassoro to Save is relatively turbid, usually green, showing the presence of suspended matter. These conditions may not favour the species that were not recorded along shore of Inhassoro- Save area.

Zonation of seagrass carried out at lines 16 and 20 (same as lines flown during the aerial survey design) indicate that the species grazed by dugongs (*Halodule uninervis* and *Halophila ovalis*) occur and are more frequent in the south to the offshore area (line 20) Outside the Bay (line 16) , the seagrass beds are dominated by *Thalassodendrom ciliatum* and there is a presence of *Cymodocea rotundata*. There is need to carry out more perpendicular transects from the shore to improve the data on distribution of seagrass. The procedure of north-south oriented transects was adopted because it was cost effective (given the limited time available to produce a detailed seagrass chart) for boat maneuvering and to reduce time to transit to the sampling stations.

Nutrient analysis carried out was very preliminary and based on a small sample size. However, it provides an indication of the value of seagrass forage. The content of dry matter requires improvements. This was measured between sun dried seagrass weight (ambient temperature varying between 25 and 35) and the seagrass weight after 48 hours in a stove 70ºC. Therefore, this indicates that the species that retain more water are *T. ciliatum* and *Halophila ovalis*, especially in the parts below ground.

The content of organic matter, measured as the difference between dry matter and the ashes after burning the seagrass at 600º show that the species that are potentially preferred by dugongs (*Halodule uninervis* and *Halophila ovalis*) have intermediate or low organic matter content, but that *T. ciliatum* and *C. rotundata*, the most frequent species in the area have large organic matter content. This is of high significance because, it tells that dugongs are already foraging in species that contribute will less organic matter. This indicates that they need to collect large quantities of forage.

The nitrogen content was low in general among the seagrass species. However, lower values were found in the parts below ground than in those above ground. As dugongs eat more roots and these are the most abundant than the above ground parts, they may need to graze in large quantities to obtain the necessary amount of nitrogen required. This again is critical, when considering the limited distribution and low seagrass cover observed in the studied area.

1.19 POPULATION VIABILITY

Overall, the application of Population Viability Analysis reinforces the perception that the dugongs inhabiting Bazaruto Bay are in a precarious and precipitous position. Modelling strongly suggests that they are particularly susceptible to long term stressors that might reduce overall reproductive success. Further, the models clearly show that regular deaths from anthropogenic sources, are the major cause of their decline.

Any attempt at conservation and management of these animals needs to address this issue. In this context, it is imperative that some form of incidental catch reduction be pursued. It is beyond the scope of this report to explore this further, other than to suggest suitable conservation strategies, some of which are discussed in section 5.

RECOMMENDATIONS

As a point of departure in making recommendations it is re-iterated that the Bazaruto Archipelago dugong population probably represents the last viable dugong population within the Western Indian Ocean. Thus, the conservation of the species within this ocean basin is probably dependent on the survival of this local population (and the successful re - colonisation of other areas by individuals from this population). Dugongs are known to re-colonise shallow seagrass habitat through deep ocean migration pathways. For example, reports in 2001 of dugongs at Aldabra Atoll in the southern Seychelles (Chong-Seng pers comm. 2001, in UNEP, 2002) over 400km from Madagascar confirm their ability to disperse through open ocean as dugongs had not been recorded at Aldabra for many years prior to this (Cockcroft et al. 1994; Cockcroft & Young 1998).

In this light it is strongly recommended that a moratorium be placed on any anthropogenic activities which could result in a) a decline in the dugong population (through increased mortality / decreased survival) or b) a decline or slowing of an increase in the population (as ocean – basin survival of the species may be dependent on emigration of surplus individuals from this local population).

1.20 POTENTIAL HYDROCARBON EXPLORATION SCENARIOS

Hydrocarbon exploration activities within the shallow regions of Block 16 and 19 could follow one of five potential scenarios. These five scenarios are discussed below with reference to dugong conservation. However, as current contractual exploration and legal obligations are unknown, these have not been considered in the discussion of these scenarios.

1. A No Exploration Option with relinquishment of the rights to the Blocks

This option would see the relinquishment of the hydrocarbon exploration rights to the shallow inshore region by the project proponent. However, the position of the Mozambique Government and Hydrocarbon Licencing Authority remains unknown and could follow one of two avenues:

a) The reissue of the rights to other parties.

It is assumed that this option would require a further EIA process during which the impacts of exploration on dugongs would require further assessment. This option is **not recommended**, as it does little more than prolong potential threats to the dugong population (it should be noted that such re – issue of rights to a less environmentally responsible proponent could see an increase exploration activities within dugong habitat).

b) The freezing of hydrocarbon exploration rights within the shallow nearshore region co-incident with dugong habitat. Such an option could co-incide with an extension of Bazaruto Archipelago National Park boundaries to include a greater area of dugong habitat, or management of anthropogenic activities in the region so as to limit impacts to the dugong population and associated seagrass habitat. This option is **recommended** subject to the development and initiation of an integrated (and Strategic Environmental Assessment (SEA) based) management plan for dugong conservation across all industry sectors, including fishing (commercial and subsistence, and aquaculture); tourism (including infrastructural development) and mining.

2. No Exploration Option with retention of the exploration rights to the Block

This option would see the project proponent retain the rights to explore in the shallow inshore area along with the exploration rights to offshore prospect area, but commitment by the proponent to place a moratorium on exploration activities within the dugong inshore dugong habitat. It is envisaged that such an option would include operation of the inshore shallow region as a “private park” initiative and co – management of the area with the Bazaruto Archipelago National Park Authority; a private ‘conservation’ entity, or both. While an indefinite moratorium on exploration activities may be preferable for dugong conservation, such a moratorium may be reviewed after a set period. This option is **highly recommended** in terms of dugong conservation and provides an exceptional opportunity for associated conservation branding by the proponent company. The costs of this option would be considerably outweighed by the ‘advertising / marketing’ benefit achieved – Buy a Species campaign.

3. Land – Based Exploration Only Option

This option would see exploration activities occurring within the shallow water prospect area, but being limited to land based activities as directional drilling or seismic surveys only. Such activities would not impact on the marine environment and would preferably see the inshore shallow marine environment co – managed with the Bazaruto Archipelago National Park Authority. As with option 2, this option is **highly recommended** in terms of dugong conservation and again provides opportunity for conservation branding. As individuals intimately involved with making television documentaries and generally advertising conservation, the principal investigators would strongly encourage the project proponent to explore this with their marketing and advertising departments.

4. Limited Marine Exploration Option

This option would see limited hydrocarbon exploration within the marine environment. Such activities would need to be heavily dependent on impacts to the dugong population, and the mitigation thereof. The extent of exploration activities and their mitigation measures would be dependent on the type of activities proposed. Co – management of the dugong population within the shallow inshore prospect region with the Bazaruto Archipelago National Park Authority would form a component of this option. The outcome of this option in terms of dugong conservation will depend on the extent and duration of the proposed activities, and the environmental management thereof on two levels, namely:

a) an operational level (for example the selection of drilling fluids, or disposal of drill cuttings), and

b) an event risk management level (for example, the risk of a blow-out or spill and its impact on dugongs, or more importantly, on dugong habitat).

Recommendations for this option will depend entirely on the proposed exploration activities, and the implementation of effective mitigation measures.

5. Full Marine Exploration Option

The Full Exploration Option would result in seismic surveys and exploration well drilling within the shallow inshore region of Blocks 16 and 19. Apart from possible negative impacts to dugong conservation, this option is likely to result in international outcry and very negative publicity and press. This option is **not recommended**.

LITERATURE CITED

Anderson, P.K. 1981. The behaviour of the dugong (Dugong dugon) in relation to conservation and management. Bulletin of Marine Science 31: 640-647.

Aragones, L.V. and Marsh, H.D., 2000. Impact of Dugong grazing and turtle cropping on tropical seagrass communities. Pacific Conservation Biology 5: 277-288.

Bayliss, P., Freeland, W.J., 1989. Seasonal distribution and abundance of dugongs in the western Gulf of Carpentaria. Australian Wildlife Research 16, 141–149.

Chilvers, B.L., Delean, S., Gales, N.J., Holley, D.K., Lawler, I.R., Marsh, H. and Preen, A.R., 2004. Diving behaviour of dugongs, Dugong dugon. J. Exp. Mar. Biol. Ecol. 304, 203–224.

Cockcroft, V.G. 1993. A preliminary assessment of the status of Madagascar's coastal resources, with special reference to marine mammals and reptiles. Final report for United Nations Environment Programme, South African Department of Foreign Affairs and African Wildlife. December 1993. 16pp.

Cockcroft, V.G. 1995. Aerial survey in Kenya finds few dugongs. Sirenews: Newsletter of the IUCN/SSC Sirenia Specialist Group 24: 8.

Cockcroft, V.G., R.V. Salm and T.P. Dutton. 1994. The status of dugongs in the western Indian Ocean. First International Manatee and Dugong Research Conference. March 11-13. Gainesville, Florida.

Cockcroft,V.C. & Young, D.D. 1998. An investigation of the status of coastal marine resources along the west coast of Madagascar. Unpublished report.Worldwide Fund for Nature (WWF), Gland, Switzerland, 121 pp.

Dutton, P. 1994. Past and present status of dugong Dugong dugon in the Bazaruto Archipelago and other known habitats on the Mozambique Coast. First International Manatee and Dugong Research Conference. March 11-13. Gainesville, Florida.

Dutton, P. 1998. East African dugongs disappearing. Sirenews: Newsletter of the IUCN/SSC Sirenia Specialist Group, 29: 4.

Dutton, T.P. and R. Zolho (1990) Conservation Master Plan for sustainable development of the Bazaruto Archipelago, Republic of Moçambique. WWF/SANF Report, 75pp.

ERM, 2007

Gales, N.J., McCauley, R.D., Lanyon, J., Holley, D.K., 2004. Changes in abundance of dugongs in Shark Bay, Ningaloo and Exmouth Gulf, Western Australia: evidence for large-scale migration. Wildl. Res. 31, 283–290.

Guissamulo, A. and V. G. Cockcroft 1996. Current state of investigations on sea mammals in Mozambique. In: Workshop Proceedings 'The role of the Investigation in the Coastal Zone Management' Department of Biological Sciences, UEM, 24-25th April 1996.

Guissamulo, A.T. (1993) Dolphins and dugongs distribution in Maputo and Bazaruto Bays: An assessment of interaction with artisanal and semiindustrial trawling fisheries. Unpublished report to UNEP, July 1993.

Guissamulo, A.T. and V.G. Cockcroft 1997. Dolphin and dugong occurrence and distribution and fisheries interactions in Maputo and Bazaruto Bays, Mozambique. Paper SC/49/SM24 presented at the 49 meeting of the International Whaling Commission, London September 1998.

Heinsohn, G.E. 1972. A study of dugongs (Dugong dugon) in Northern Queensland, Australia. Biological Conservation 4(3): 205-213.

Heinsohn, G.E. 1981. The dugong in the seagrass system. In: The Dugong: Proceedings of a seminar/workshop held at James Cook University, 8-13 May 1979, Ed. H. March. James Cook University of North Queensland, Townsville. 92 pp.

Heinsohn, G.E. and Spain, A.V., 1974. Effects of a tropical cyclone on littoral and sub-littoral biotic communities and on a population of dugongs (Dugong dugon (Muller)). Biol. Conserv. 6, 143–152.

Heinsohn, G.E. and W.R. Birch. 1972. Foods and feeding habits of the dugong, Dugong dugon (Erxleben), in northern Queensland, Australia. Mammalia 36: 414-422.

Holley, D. K., Lawler, I.R. and Gales, N.J. 2006. Summer survey of dugong distribution and abundance in Shark Bay reveals additional key habitat area. Wildlife Research, 33, 243–250

Hughes, G. 1971. Preliminary report on the sea turtles and dugongs of Mozambique.Veterin. Moçamb. 4 (2). P. 45-62.

Hughes, G.R. 1969. Dugong status survey in Mozambique. World Wildlife Yearbook. World Wildlife Fund, Switzerland. pp. 137-139.

Hughes, G.R. and R. Oxley-Oxland. 1971. A survey of dugongs (Dugong dugon) in and around António Enes, Northern Moçambique. Biological Conservation.Vol. 3 (4): 299-301.

Husar, S. 1978. Dugong dugon. Mammalian Species 88: 1-7

Kingdon, J., 1971. Dugong. In: Kingdon, J. (Ed.), East-African Mammals. An Atlas of Evolution in Africa, vol. 1. Academic Press, London, pp. 390-399.

Lacy, R.C., M. Borbat, and J.P. Pollak. 2005. VORTEX: A Stochastic Simulation of the Extinction Process.Version 9.50. Brookfield, IL: Chicago Zoological Society.

Lanyon, J.M., Limpus, C. andMarsh, H., 1989. Dugongs and turtles: grazers in the seagrass system. In: Larkum, A.W.D., McComb, A. J., Shepherd, S.A. (Eds.), Biology of Australian Seagrasses, An Australian Perspective. Elsevier, Amsterdam.

Mackie, C. 2001.Aerial census of dugongs, dolphins and turtles in the Bazaruto National Park, WWF Eastern African Marine Ecoregion Programme. Report to the Directorate of Forestry and Wildlife, Ministry of Agriculture, Mozambique. 11pp.

Mackie, C. S. (1999), Aerial Census of Dugongs, Dolphins and Turtles in Bazaruto National Park, Mozambique: May 1999.WWF Project Paper, 16pp.

Marsh, H and Rathbun G. B. 1990. Development and application of conventional and satellite radio tracking techniques for studying dugong movements and habitat use. Australian Wildlife Research. 17: 83-100.

Marsh, H and Saalfeld,W. K. 1989. The distribution and abundance of dugongs in the northern Great Barrier Reef Marine Park. Australian Wildlife Research 16 : 429-440.

Marsh, H, Heinsohn, G E and Marsh, L M. 1984. Breeding cycle, life history and population dynamics of the dugong, Dugong dugon (Sirenia: Dugongidae). Australian Journal of Zoology. 32: 767-88.

Marsh, H. 1995. The life history, pattern of breeding, and population dynamics of the dugong. In: O'Shea, T.J. (ed). Proceedings of a workshop on manatee population biology. US Fish and Wildlife. Service Technical Report.

Marsh, H. 1999. Reproduction in sirenians. In: Boyd, I.L., C. Lockyer and H.D. Marsh. Chapter 6: Reproduction in Marine Mammals. In: Reynolds, J.E. and J.R. Twiss (eds). Marine Mammals. Smithsonian Institute Press, Washington DC. pp. 243-256.

Marsh, H. and Lawler, I., 2001. Dugong distribution and abundance in the southern Great Barrier Reef Marine Park and Hervey Bay: results of an aerial survey in October–December

1999. Research Publication No. 70. Great Barrier Reef Marine Park Authority, Townsville.

Marsh, H. and Sinclair, D.F. 1989a. Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. Journal of Wildlife Management 53: 1017-1024.

Marsh, H., Corkeron, P., Morissette, N & Preen, A. R. 1995. The status of the dugong in the southern Great Barrier Reef Marine Park. Great Barrier Reef Marine Park Authority Research Publication. 41 80pp.

Marsh, H., De'ath, G., Gribble, N. and Lane, B. 2005. Historical marine population estimates: Triggers or targets for conservation? The dugong case study. Ecological Applications, 15(2): 481-492.

Marsh, H., Heinsohn, G.E. and Marsh, L.M., 1984. Breeding cycle, life history and population dynamics of the dugong, Dugong dugon (Sirenia: Dugongidae). Australian Journal of Zoology 32, 767–788.

Marsh, H., Lawler, I.R., Kwan, D., Delean, S., Pollock, K., Alldredge, M., 2004. Aerial surveys and the potential biological removal techniques indicate that the Torres Strait dugong fishery is unsustainable. Anim. Conserv. 7, 435–443.

Marsh, H., Prince, R.I.T., Saalfeld, W.K. and Shepherd, R., 1994. The distribution and abundance of the dugong in Shark Bay, Western Australia. Wildlife Research 21, 149–161.

Marsh, H.D. and Saalfeld, W.K., 1990. The distribution and abundance of dugongs in the Great Barrier Reef Marine Park south of Cape Bedford. Australian Wildlife Research 17, 511–524.

Motta, H. (2001).Análise do FOFA (forças e fraquezas) de Implementação do Parque Nacional das Quirimbas. Draft Document.WWF.

Muir, C.E., Sallema, A., Abdallah, O., De Luca, D.W. and Davenport, T.R.B. 2003. The dugong (Dugong dugon) in Tanzania: A national assessment of status, distribution and threat. Wildlife Conservation Society. pp 31.

Nishiwaki, M. & Marsh, H. 1985.The dugong. In: Ridgway, S. H. & R.J. Harrison (eds). Handbook of Marine Mammals Vol. 3.Academic Press, London: 1-31.

Nishiwaki, M., Kasuya, T., Miyazaki, N., Tobayama, T. and Kataoka, T., 1979. Present distribution of the dugong in the world. Scientific Reports of the Whales Research Institute 31, 133–141.

Peres, C.A. 2001; Synergistic Effects of Subsistence Hunting and Habitat Fragmentation on Amazonian Forest Vertebrates. Conservation Biology, 15(6): 1490-1505.

Poiner, I.R., and C. Peterken. 1996. Seagrasses. In: Zann, L.P. and P. Kailola (eds). The State of the Marine Environment Report for Australia. Technical Annex:1. Great Barrier Reef Marine Park Authority, Townsville, Australia. pp. 40-45.

Preen, A. and H. Marsh. 1995. Response of dugongs to large-scale loss of seagrass from Hervey Bay, Queensland, Australia. Wildlife Research 22: 507-519.

Preen, A.R. 2004. Distribution, abundance and conservation status of dugongs and dolphins in the southern and western Arabian Gulf. Biological Conservation 118 (2004) 205–218.

Preen, A.R., Marsh, H., Lawler, I.R., Prince, R.I.T., Shepherd, R., 1997. Distribution and abundance of dugongs, turtles, dolphins and other megafauna in Shark Bay, Ningaloo Reef and Exmouth Gulf, Western Australia. Wildlife Research 24, 185–209.

Rodrigues, M.J., Motta,H., Pereira,M.A.M., Gonçalves, M., Carvalho, M and Schleyer, M. 1999. Reef Monitoring in Mozambique I: The Monitoring Programme and 1999 Report. MICOA/IIP/CORDIO/ORI. 57pp.

Seber, G.A.F. 1982. The estimation of animal abundance. Macmillan Publishing, New York.

Sheppard J. K. Preen, A.R., Marsh, H., Lawler, I., Whiting, S.D and Jones, R. Movement heterogeneity of dugongs, Dugong dugon (Müller), over large spatial scales. J. Exp. Mar. Biol. Ecol. 334: 64–83.

Sirenews. 2001. Dugongs at Aldabra. Sirenews: Newsletter of the IUCN/SSC Sirenia Specialist Group Number 36.

Smithers, R.H.N. and J.L.P. Lobão Tello. 1976. Checklist and Atlas of the Mammals of Mozambique. Museum Memoir No. 8,Trustees of the National Museums and Monuments of Rhodesia, Salisbury, p.184.

Spain, A.V. and Heinsohn, G.E. 1973. Cyclone associated feeding changes in the dugong (Mammalia: Sirenia). Mammalia, 37: 678-680.

Taylor, B.L. & Gerrodette, T. (1993) The uses of statistical power in conservation biology: the vaquita and northern spotted owl. *Conservation Biology*, **7**, 489–500.

Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H., Bishop, J.R.B. and Marques, T.A. 2006. Distance 5.0. Release "x"1. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/

Tinley, 1971, Determinants of Coastal Conservation Dynamics and Diversity of the Environment as Exemplified by the Mozambican Coast, in Proceedings of the Symposium on Nature Conservation as a Form of Land Use, Gorongosa National Park, Sarcus, Pretoria, 125:153.

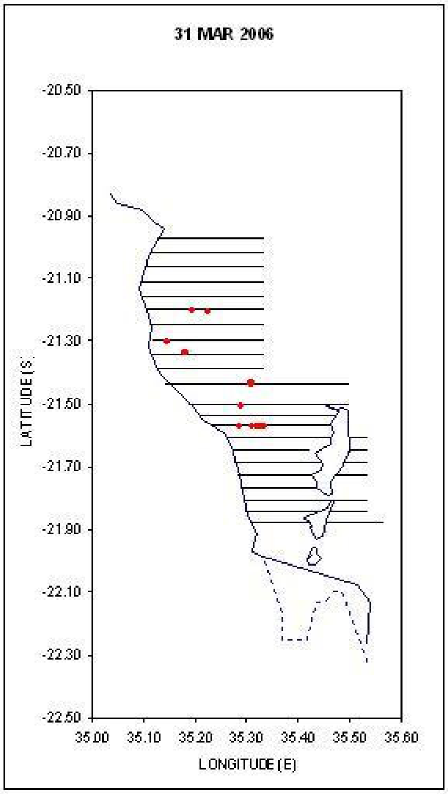
UNEP, 2002. Dugong Status Reports and Actions Plans for Countries and Territories. Marsh, H., Penrose, H., Eros, C., Hugues, J. (eds) UNEP, Nairobi. 162 pp.

Wirsing, A.A. Heithaus, M.R. and Dill, L.M. 2006. Living on the edge: dugongs prefer to forage in microhabitats that allow escape from rather than avoidance of predators. Animal Behaviour, 2007, 74, 93e101

WWF East African Marine Ecoregion 2004. Towards a Western Indian Ocean Dugong Conservation Strategy. The status of dugongs in the Western Indian Ocean Region and Priority Conservation Actions. Dar es Salaam, Tanzania.

Zanette, L., Smith, J. N. M., van Oort, H. and Clinchy, M. 2003. Synergistic effects of food and predators on annual reproductive success in song sparrows. Proc. R. Soc. Lond. B 270, 799–803.

Appendix 1 SURVEY TRACKS AND SIGHTINGS OF EACH AERIAL SURVEY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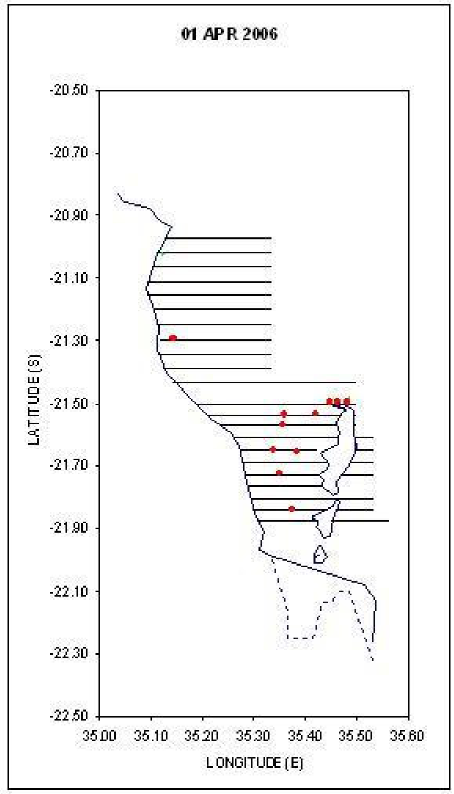
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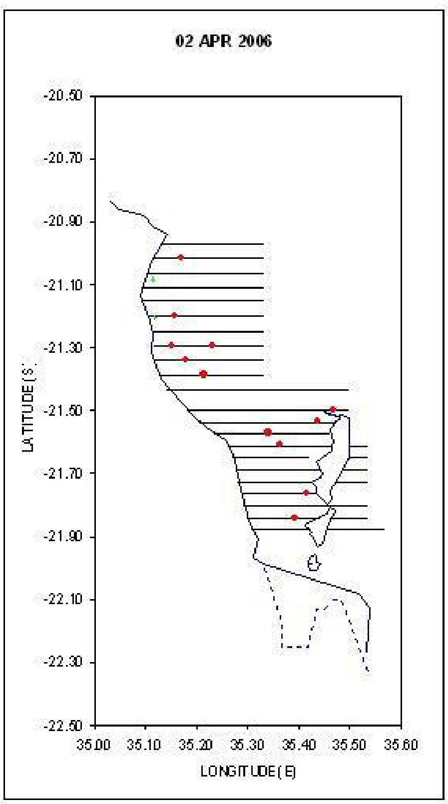
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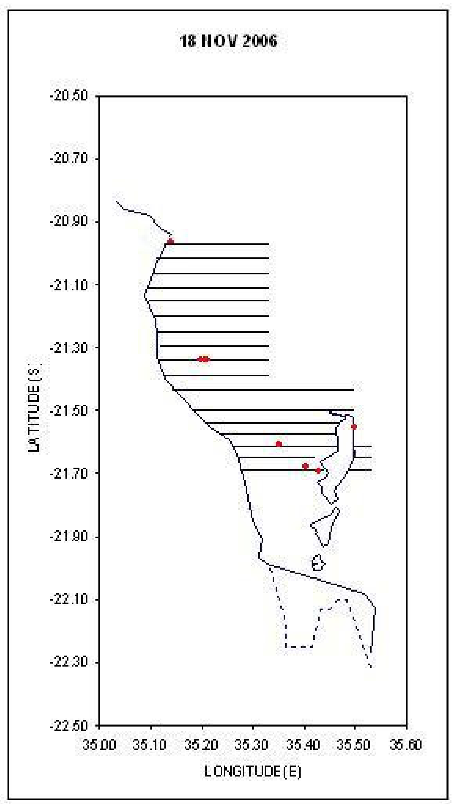
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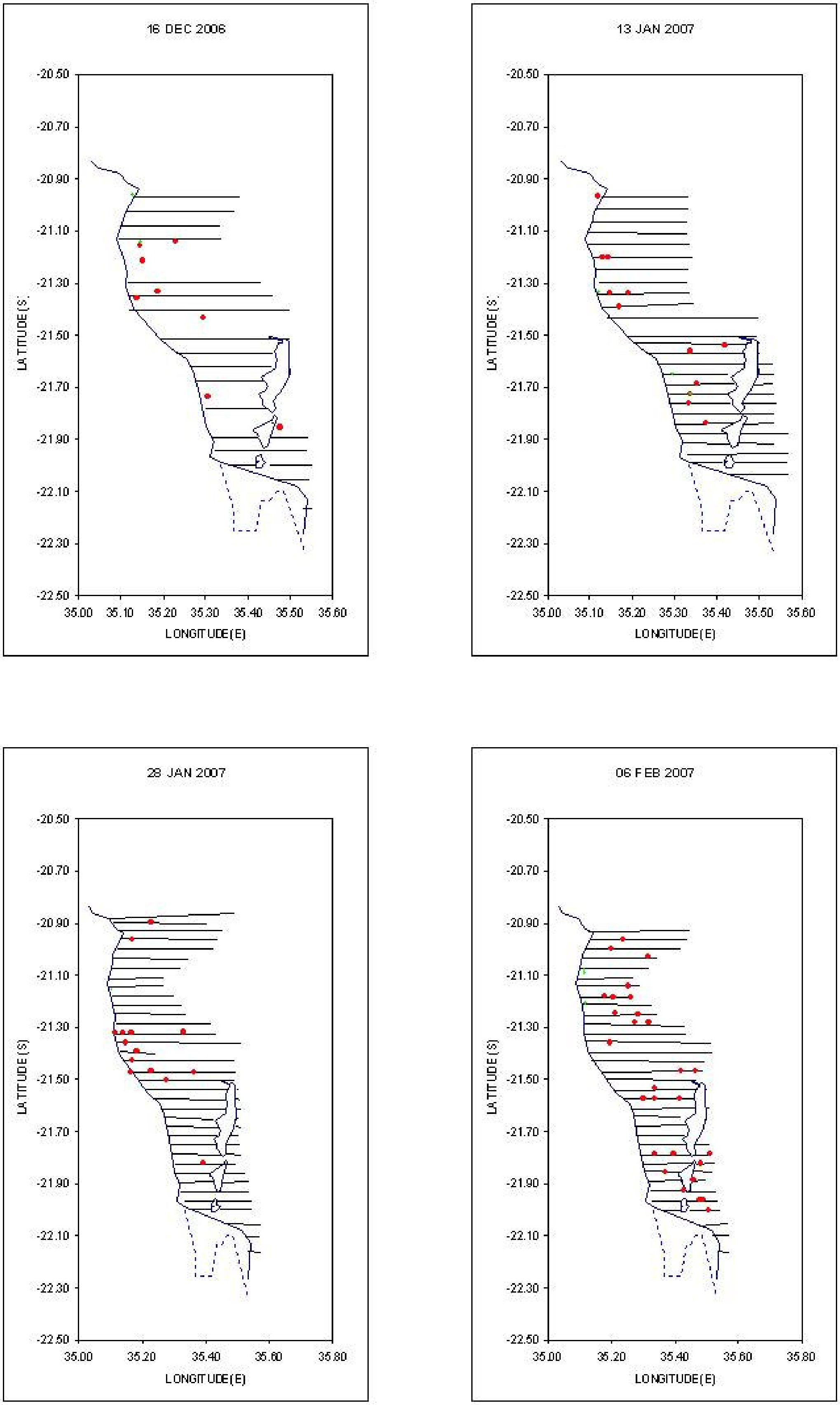
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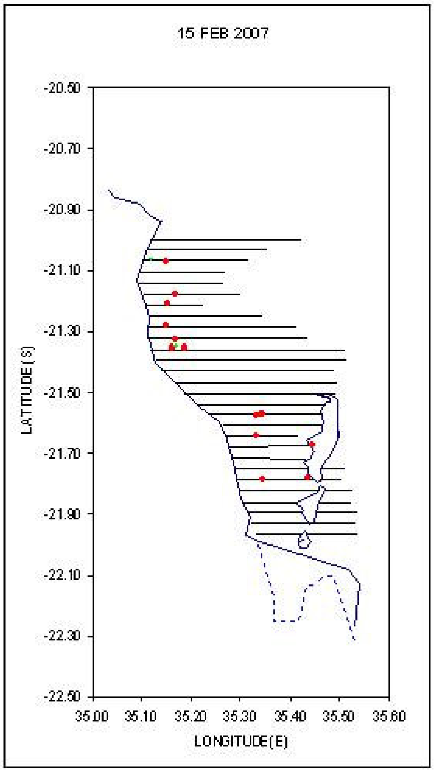
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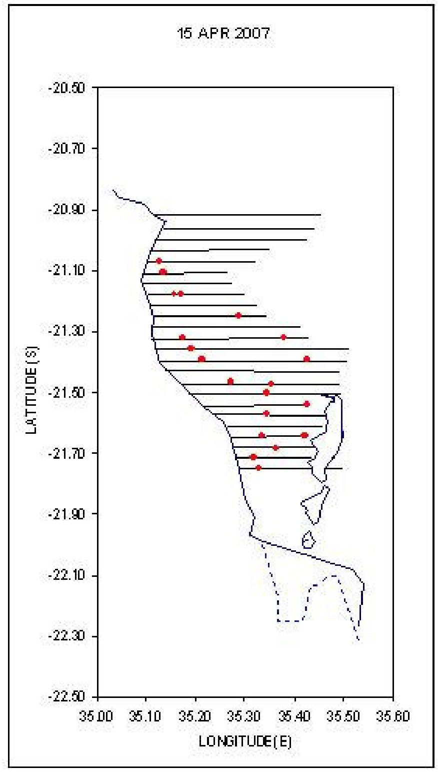
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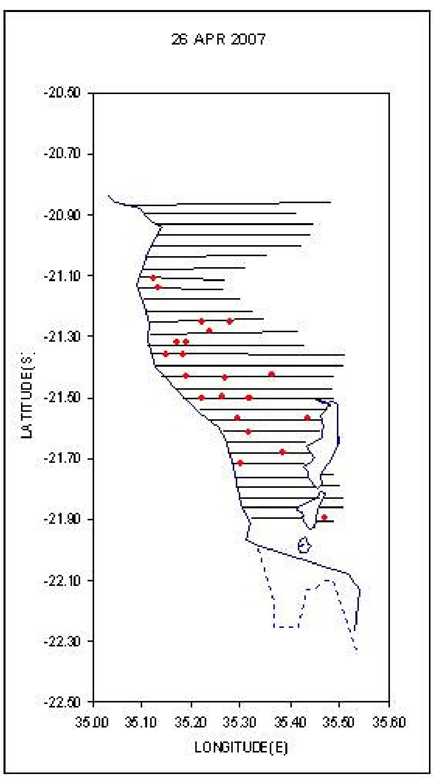
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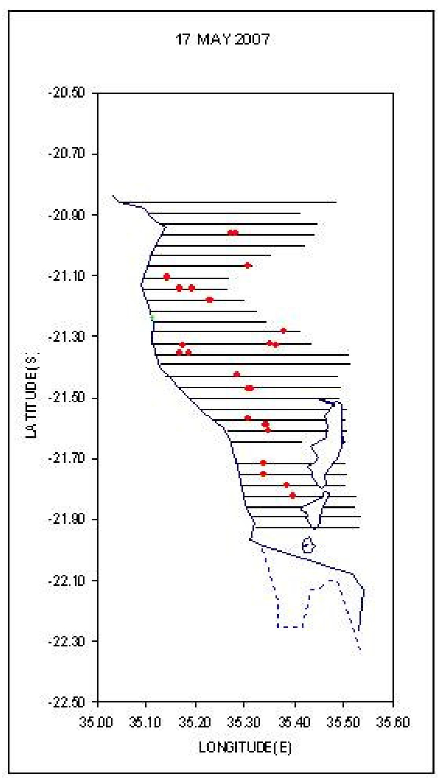
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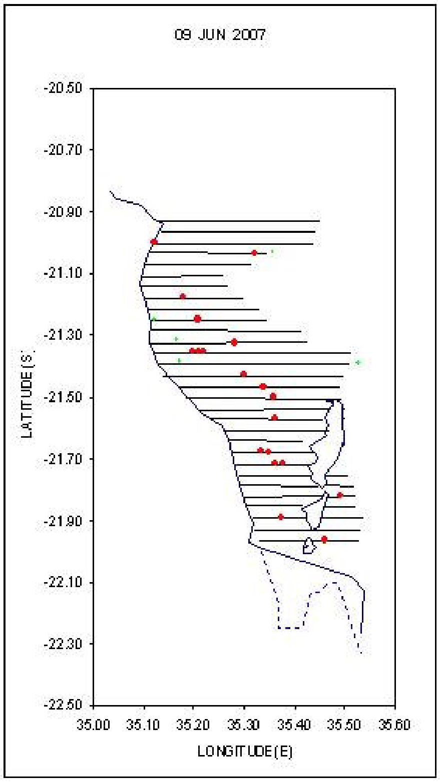
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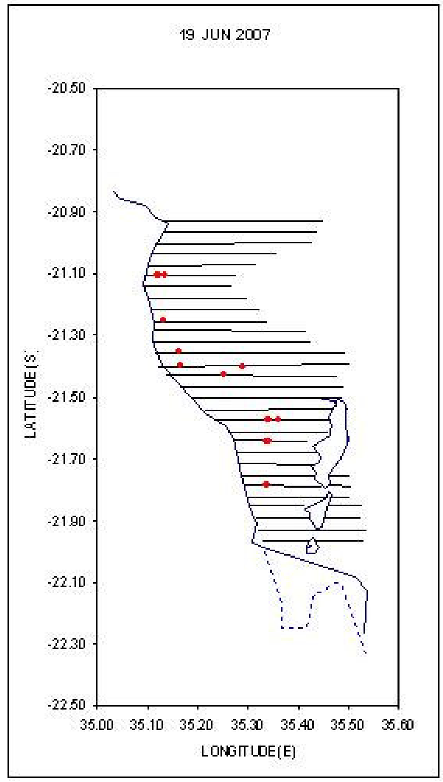
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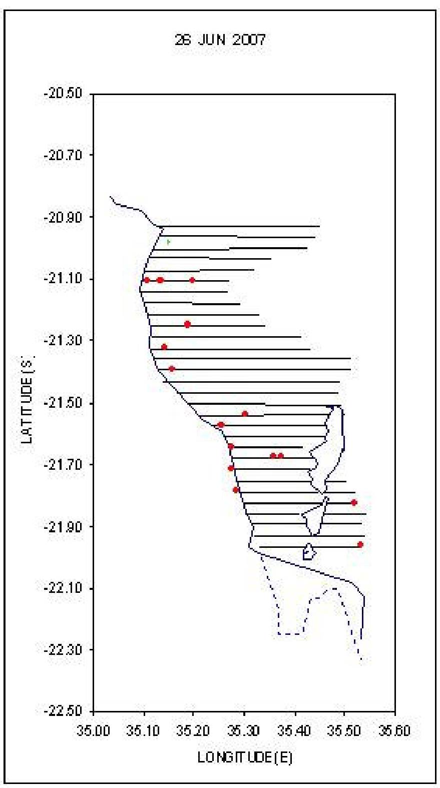
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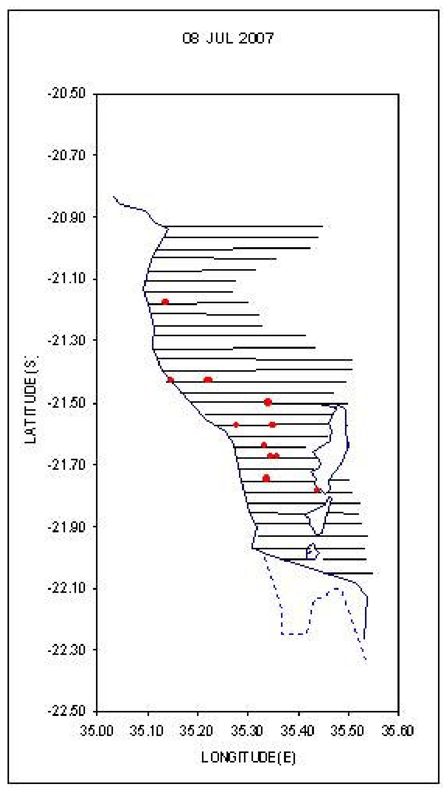
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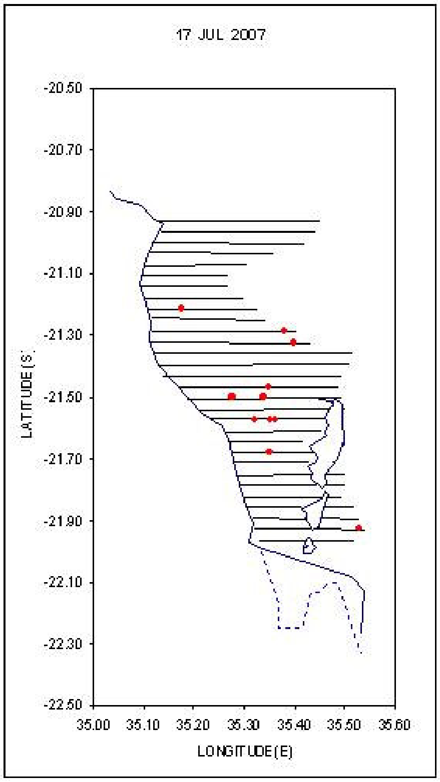
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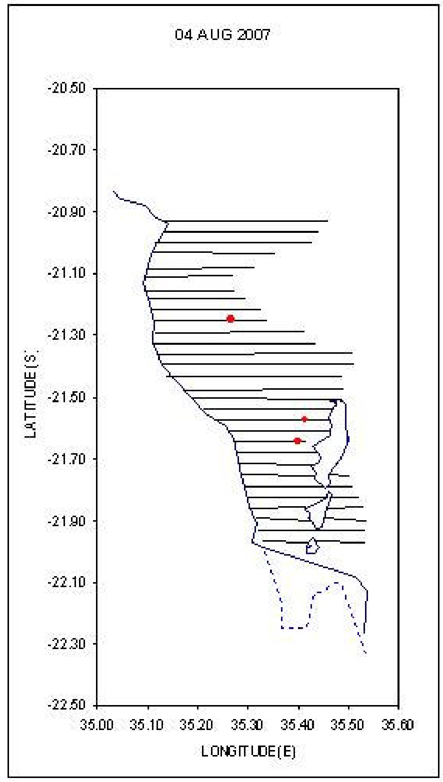
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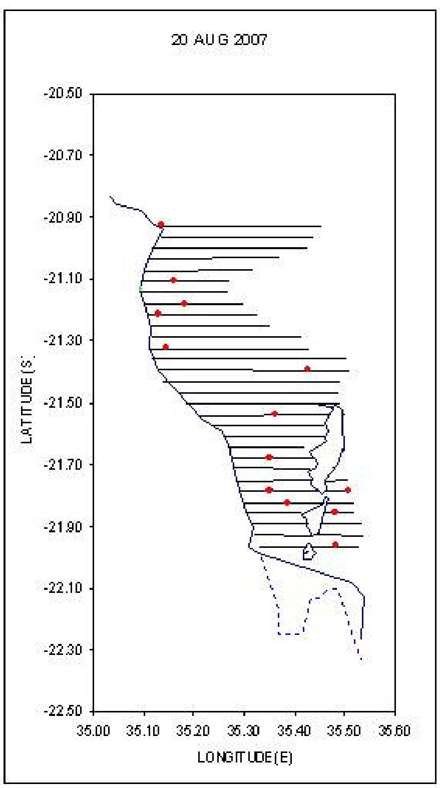
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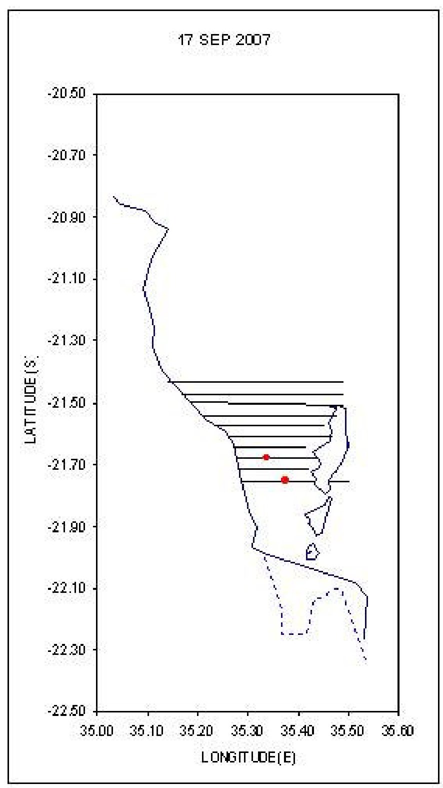
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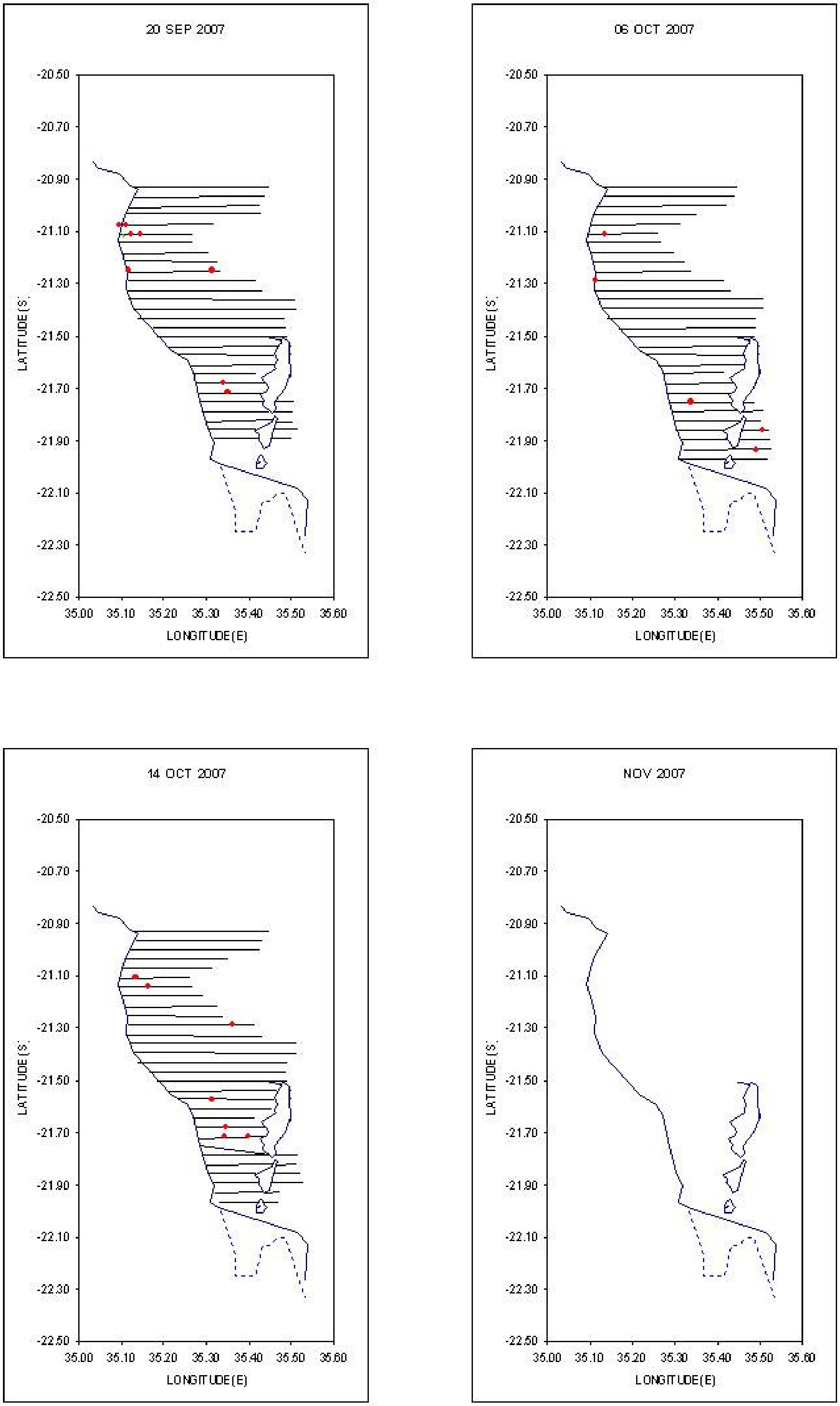
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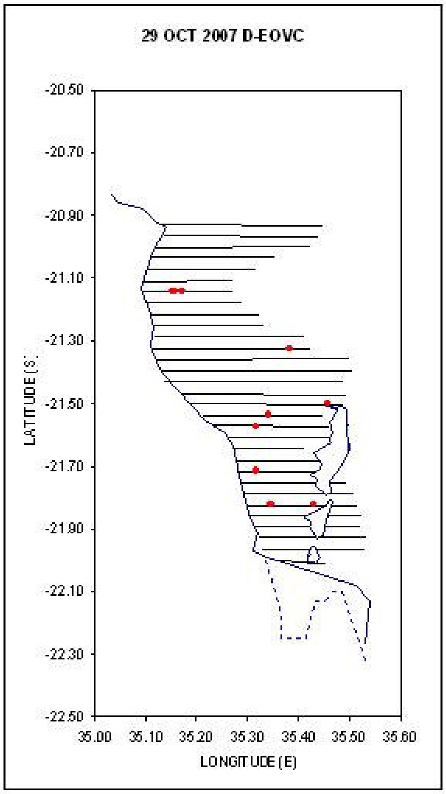
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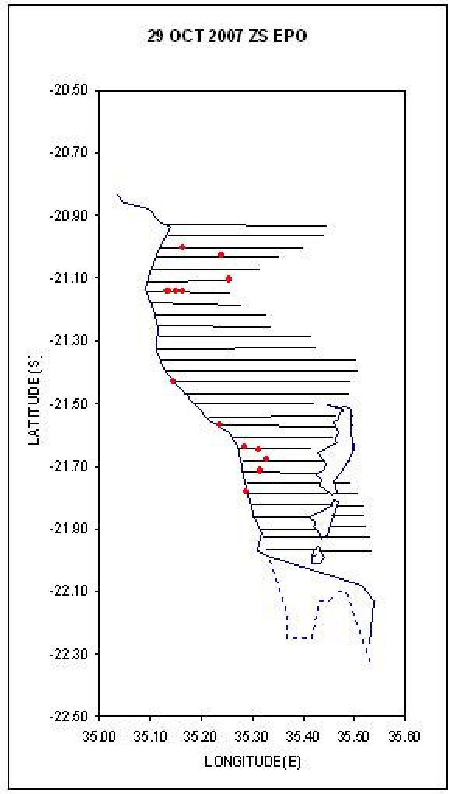
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