FINAL

Dugong Aerial Survey Report

May 25-29, 2008

Bazaruto Archipelago National Park
Inhambane Province, Mozambique

World Wide Fund for Nature

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Introduction:

The World Wide Fund for Nature is actively involved with stakeholders in the conservation planning and implementation for the Bazaruto Archipelago National Marine Park in the Inhambane province of Mozambique, east Africa. Several species of regional and global importance are known to inhabit this area including dugongs (*Dugong dugon*). These marine mammals are members of the order Sirenia (manatees and dugongs) all species of which are listed by the IUCN as either threatened or endangered. Dugongs are represented by only one species and while they are abundant along the coasts of Indonesia and Australia they are in apparent decline along the east African coast. Various reports have lead to the suggestion that Western Indian Ocean dugongs may now remain in only small numbers in areas of Kenya, Tanzania, Mozambique, Madagascar, Seychelles, and the Comoros archipelago. Dugongs found in the Bazaruto Archipelago, Mozambique are considered to be the only viable dugong population within the entire Western Indian Ocean (Marsh et al. 2006, Dutton 1994). Cockcroft et al. (2008) reviewed recent records and indicated that few dugongs occur elsewhere on the Mozambique coast. An aerial census in May 2001 of the Bazaruto National Park and the eastern islands conducted by (Mackie/WWF 2001) found dugongs distributed throughout the northern, central and south areas of the Archipelago between Bazaruto Island and the mainland.

Reports of dugong abundance vary widely for this area. Dutton (1998) conducted aerial surveys that yielded only 21 dugongs and he suggested dugongs were rapidly declining based in these low counts. Guissamulo & Cockcroft (1997) estimated a total local population of 130 dugongs in the Bay based on strip transect aerial surveys. WWF (2004) reviewed various aerial counts with estimates of 20 to 130 individuals between 1990 and 2002, and also suggested that the population is in decline (Mackie, 1999). Unfortunately details of some of the surveys are not clear in terms of methods, areal extent and conditions, making comparison of animal numbers or trends very difficult and in some cases impossible. In May 2008, WWF initiated what would be an annual systematic dugong monitoring program for the BANP to assess general distribution and use within and nearby the park. This effort also involved training Park and WWF staff to begin the regular aerial monitoring program for Mozambique's dugongs. This report describes the methods and outcome of the 2008 WWF surveys.

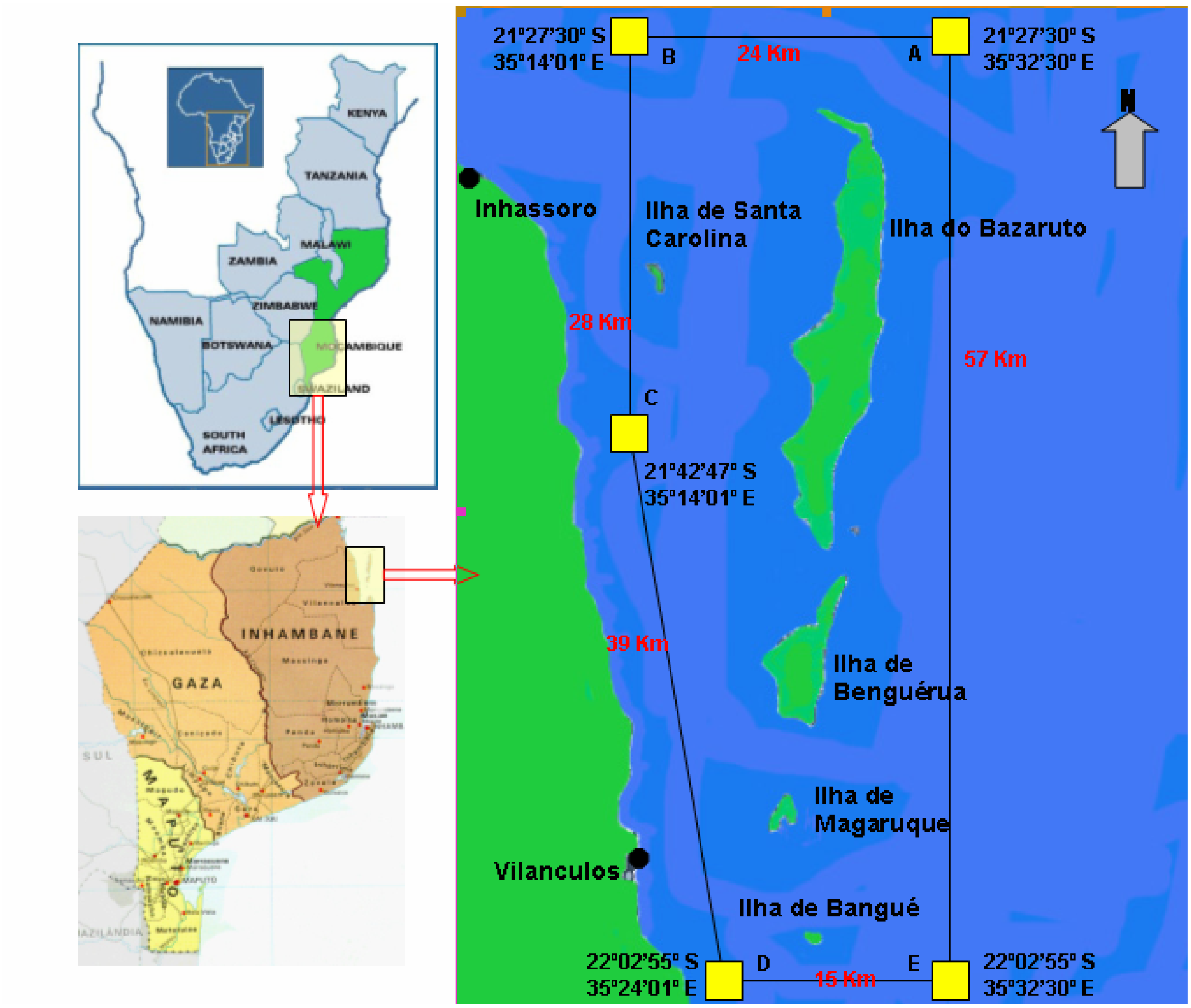

Figure 1. Bazaruto Archipelago National Park vicinity map with the park boundaries highlighted with yellow squares. (courtesy BANP Integrated Management Plan, 2006).

Methods

Systematic aerial surveys were performed utilizing standard techniques including a trained survey team familiar with dugongs and other species common to the Bazaruto region. The principal investigator (Provancha) has over 25 years experience in aerial surveys for manatees, sea turtles and dolphins in estuarine and marine systems. Initial reconnaissance surveys and team training were performed from 23 – 25 May which allowed for familiarization of conditions in the area, determination of realistic survey flight path and time periods, preparation of observers, and recorder for efficient data communication. Timing considerations included a variety of environmental variables, including tides, sunlight penetration of the waters, cloud cover, wind, etc. Winds greater than 15-18 kts, creating high sea-states were considered unacceptable conditions for surveys.

A Cessna 206 aircraft provided the aerial platform for the dugong surveys and included a pilot experienced in many hours of animal surveys the southeastern region of Africa. The aircraft seated seven and included communication system (headsets) to enhance communication efficiencies between the pilot and all team members. It was also outfitted with standard GPS systems and a PDA loaded with ESRI Arcpad to log the flightpath associated with each survey.

Study area and design

Based on reports of numerous dugong sightings north of the BANP, the surveys included the Indian Ocean waters east of Bartolomeu Dias (S 21 º deg 09``) and south through the BANP to Cabo S. Sebastião ( S22º 13``). The southern section originally included the shallow bay south of Vilanculos to Cabo S. Sebastião. Cockroft et al. (2008) performed flights over this bay but did not observe any dugongs there, however, Guissamulo (April 2008, pers. comm.) suggested many of those flights were aborted due to aircraft control issues at the nearby Vilankulos airport. The quiet waters of this bay were of interest to the management of the population of dugongs as a whole therefore, transects for this subsection were planned and oriented to accommodate airport traffic concerns by reducing time passing over this airspace.

After reviewing the study area, distance between transects was set at 4 km in order to yield reasonable observation coverage from an altitude of 500 feet (152m). The transect lines generally oriented east and west and could be considered one continuous flight track as we also searched for dugongs along the north south legs connecting the transects, Figure 2. This design involved 26 east-west transects and 25 north-south legs. The total original flight path was over 640km with transect spacing intended to allow for survey completion within a four and a half hour period. The initial design was considered tentative depending on actual effort (air time, observer fatigue, etc.) experienced in the preliminary reconnaissance and training flights.

Bazaruto Bay and vicinity waters were described by Cockcroft and Guissamulo (2008) as three distinct basins including one to the north of Santa Carolina Island with a maximum depth 33 m. This very broad and deepest basin is the main connection of the bay to the open sea. In the middle section, west of the southern end of Bazaruto Island and northern end of Benguerra Island, there is a variety of relief with shallow shoals and deeper areas with maximum depths of about 24 m. The southern bay is comprised of vast areas of tidal flat areas often totally exposed during spring low tides. These flats do not support the large expanses of seagrasses or algae found in slightly deeper areas that are not so consistently exposed.

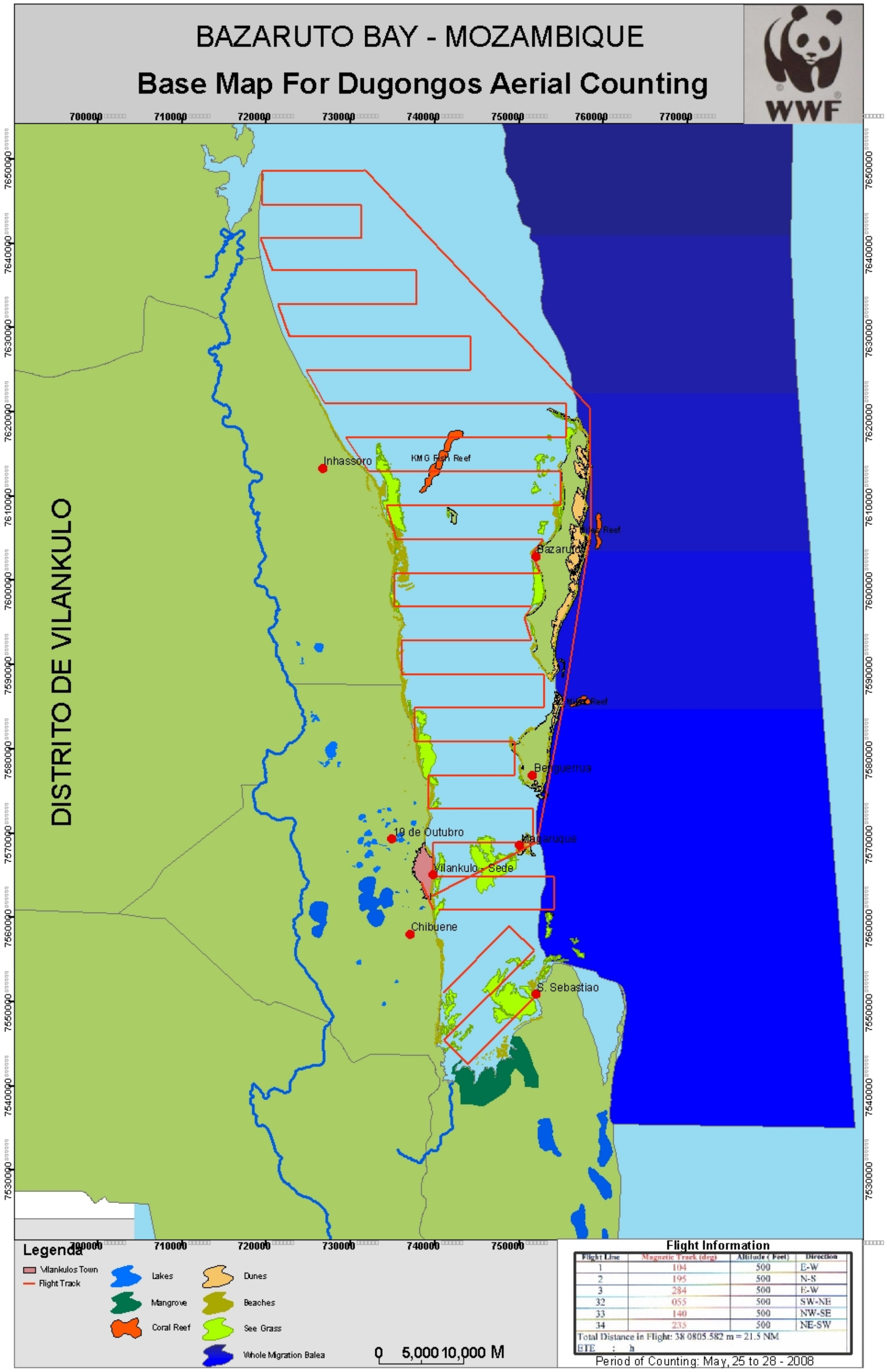

Figure 2. Study area with original flight path over Bazaruto Bay for May 2008 WWF flights

The pilot was familiar with flight lines based on preflight briefings and utilized the PDA with GPS and ArcPAD display for navigation along the predetermined flightpath. Survey data were recorded using ArcPad also running on an 8 x 11 inch Scribbler (Compaq) computer tablet with a Bluetooth GPS and a customized survey program (NASA/KSC manatee surveys). The BANP area GIS shapefiles were compiled and loaded in ArcPad including bathymetric and seagrass layers for viewing during survey operations. This “manatee entry form” eased the real time recording of multiple sighting records. Start time, aircraft identification number, fuel level, and tach-hours were recorded at the outset of each flight. Begin and end time of the actual survey track was also recorded. Observers were positioned in the two back seats and the recorder sat in front next to the pilot. For fuel efficiency the aircraft carried only 4 people during the surveys.

The observers were the official data collectors due to their consistent, diligence in searching the waters. Rare sighting events announced by the pilot or recorder were verified by an observer and only included in the output if the observer was confident he or she would have seen the animal without the initial notification by the non-observer. The level of effort by the pilot and recorder are typically highly variable and may bias the count/ index with numbers that would not normally be attained upon repeated surveys. However, for this sparsely distributed, important species, we captured all verified observations, as records of nonconforming data points were considered important.

Observers searched out the window between the bottom of the plane out to the edge of their ability to perceive dugongs or signatures of dugongs (i.e. fluke splash, feeding plumes, etc.). They also reported the sighting angle of the initial observation using an Asuunto clinometer. These records allowed for sample distance calculations of each sighting and the estimated swath width of the observation strip on the sea surface. Water and sighting conditions were recorded at the beginning of the flight and updated as needed: (turbidity, sea-state, etc.). Observers informed the recorder of dugong sightings and included number of adults, calves, behavior (traveling, feeding, surface rest, etc.).

The project effort focused on enumeration of dugongs but other information useful to Park management and dugong conservation were also collected as appropriate. These included numbers and locations of sea turtles, dolphins, and boats. The turtles and dolphins were not recorded to the level of species although some were identifiable. Number of individuals per event and sighting angle were collected for turtles and dolphins. Additionally calves accompanying dolphins were recorded. Boat categories included sailboats (touristic), motor power boat (touristic), local fishing/seining boats, and fish traps (gamboas) were also enumerated.

In the event the computer recording system failed (i.e. low battery, etc.), back up paper maps were onboard for scribing sightings. In this case, the recorder used the maps and coordinates from the GPS.

Analyses

Automated data were downloaded and quality screened as well as compared to paper maps as necessary. Outputs of all sighting distributions for each flight were placed on maps and tables. Data were also analyzed using program DISTANCE version 5.0, release 2 (Thomas et al. 2006). The general logic of the analysis was to first estimate the density of dugong clusters by modeling the detection rates for sightings as a function of distance. Abundance was calculated by multiplying the estimated cluster density by the expected cluster size and the area of the study site. Observers suggested that the assumed detectability of surfacing turtles, dugongs, and dolphins were similar given the water clarity conditions within the study area and the surfacing requirements of these species. The analysis assumes the observers were able to detect all large surface-breathing marine vertebrates on the transect center line, thus all estimation followed the assumption that g(0)=1 was met. Data were pooled over the 3 official survey days (27-29 May). Following data screening, we right truncated detection distances at 5% of the data (400m). We next evaluated several different models of the detection function using program DISTANCE version 5.0, following methods described by Buckland et al. (2001). We selected an individual model or set of best models based on the relative Akaike's Information Criterion (AIC) value (Burnham and Anderson 1998) and analysis of the model fit. The expected cluster size was estimated two ways: 1) using a size-biased regression method and 2) as the mean cluster size for all groups seen within 400m of the adjusted centerline. The regression method is recommended to correct for size-bias in estimation of cluster size, because larger clusters may be more easily detected at greater distances than are smaller clusters (Buckland et al. 2001). Expected cluster size and abundance was estimated as the total number of animals which included adults and calves.

Because the number of observations of dugongs were limited during this survey, we combined dugong sightings with sightings of sea turtles and dolphins, and used these data when fitting detection functions. Dugongs, adult sea turtles, and dolphins are all of similar size, and during preliminary surveys observers noted that all three appeared to be equally visible in these waters**.** Differences in the detectability between dugongs, dolphins and sea turtles were investigated by incorporating the animal type as a covariate into models of detection function (Marques and Buckland 2004). We also investigated the potential effects of survey day, observer and cluster size using covariates in models of the detection function. Following selection of the best model for the detection function using the combined animal data, we calculated the density of dugongs only, using the formula $\hat{D} = \frac{n \cdot \hat{f}(0) \cdot \hat{E}(s)}{2 \cdot L}$, where n = the number of dugong clusters observed within the truncation distance, $\hat{f}(0)$ = the value of the probability density function of perpendicular distances evaluated at zero distance (obtained from the detection function fit to data for all animals), $\hat{E}(s)$ = the expected cluster size for dugongs, estimated from the observed clusters within the truncation distance, and L = the total combined length of all transects. Variance in $\hat{D}$ was calculated using the delta method, as recommended by Buckland et al. (p. 52, 2001). Abundance was calculated as $\hat{D} \cdot A$, where A = area of study site (174,900 ha).

Due to the aircraft design, there was an area beneath the plane that was not visible to the observers. Based on measurements on the ground and examination of sighting data, it was determined that objects with sighting angles greater than 42 degrees from the horizon were not consistently visible during flight. At the designated survey altitude of 152m, this equated to a distance of 169 m from the centerline on each side. During analysis of the data, we adjusted observed distance by subtracting 169 m from all calculated distance, in effect moving the centerline over to the closest position reliably observed during flight. During surveys, observers recorded some observations with sighting distances closer to the centerline (e.g. sighting angles greater than 42 degrees), but we later discarded all observations with sighting angles greater than 42 degrees. This method is recommended to avoid introducing more uncertainty (Buckland et al. 2001).

RESULTS

Ground based training sessions occurred on May 23 and 24 incorporating clinometer readings, observation callouts, and computer program operation. The reconnaissance survey with experienced personnel occurred on 25 May and included full data collection along the entire study area. The remaining survey crew (new trainees) flew on surveys and became acclimated by performing observations and data entry over the survey area on 26 May. Training flights totaled 7.56 hours of search time. The subsequent surveys, utilizing the experienced and trained observers, occurred on 27-29 May and these official surveys resulted in a total search effort of 10.57 hours.

The 25 May reconnaissance flight included the collection of observations along the seaward edge of the islands for whale sharks and the bay of Cabo S. Sebastião for dugongs on a low tide. The flight track along outer- ocean was dropped from subsequent surveys due to effort (time) required. Cabo S. Sebastião bay was surveyed again on a high tide on 26 May with no dugongs sighted on either flight. Therefore the area was considered too labor and fuel intensive and so was also cut from subsequent flight paths. The flight line on Figure 2 that runs parallel and east of the islands and the 3 lines near Cabo Sebastião were eliminated from the study for the official surveys. This resulted in the survey totaling 23 east-west transects with 22 north south legs and yielding 521 km flightpath. Sighting events from the aerial surveys are displayed on figures 3 through 7, and in the Appendix.

Dugong sightings were highly variable with a total of 46 dugong groups comprising 218 dugongs during the five day period. The dugong counts for the three “official” surveys were: 9, 22, and 135 for each respective day from May 27 through May 29 (30 sighting events). Table 1a shows the counts and densities (animals/km2) of dugongs associated with each survey day. Note that on 25-26 May, full surveys were performed, but with crews “in-training” and so are highlighted in the table but were eliminated from the population and distance analyses.

Table 1a. Total effort and counts of dugongs each survey day, including training days which are highlighted in grey.

DATE	**Hours**	**Length (Lineark m)**	**Count**	**Dugong /Linaer km**	**Observed Density- (416km^2)**	**Area**
May 25*	4.1	700	4(1)	0.006	NA	BD-Vil, plus SS & Sea
May 26*	3.5	626	48(1)	0.08	NA	BD-Vil, plus SS
May 27	3.2	521	9(1)	0.02	0.02	BD-Vil
May 28	4.1	521	22 (2)	0.04	0.05	BD-Vil
May 29	3.4	521	135 (6)	0.26	0.32	BD-Vil

The distribution of dugongs for the five survey days is shown in figure 3, and while statistical comparisons of data for 25 and 26 May were not made, the distribution of dugongs sighted those days is considered important. About 38% of the dugong sightings were outside of the park boundaries. The largest single dugong group (over 70) was sighted in the northern end near the Govuro and Inhassoro boundaries (see the map for May 29 on figure 7). This group was sighted within 500 meters of a fishing boat that was tending what appeared to be a shark net. These nets are large mesh tanglenets capable of drowning dugongs and other air breathers.

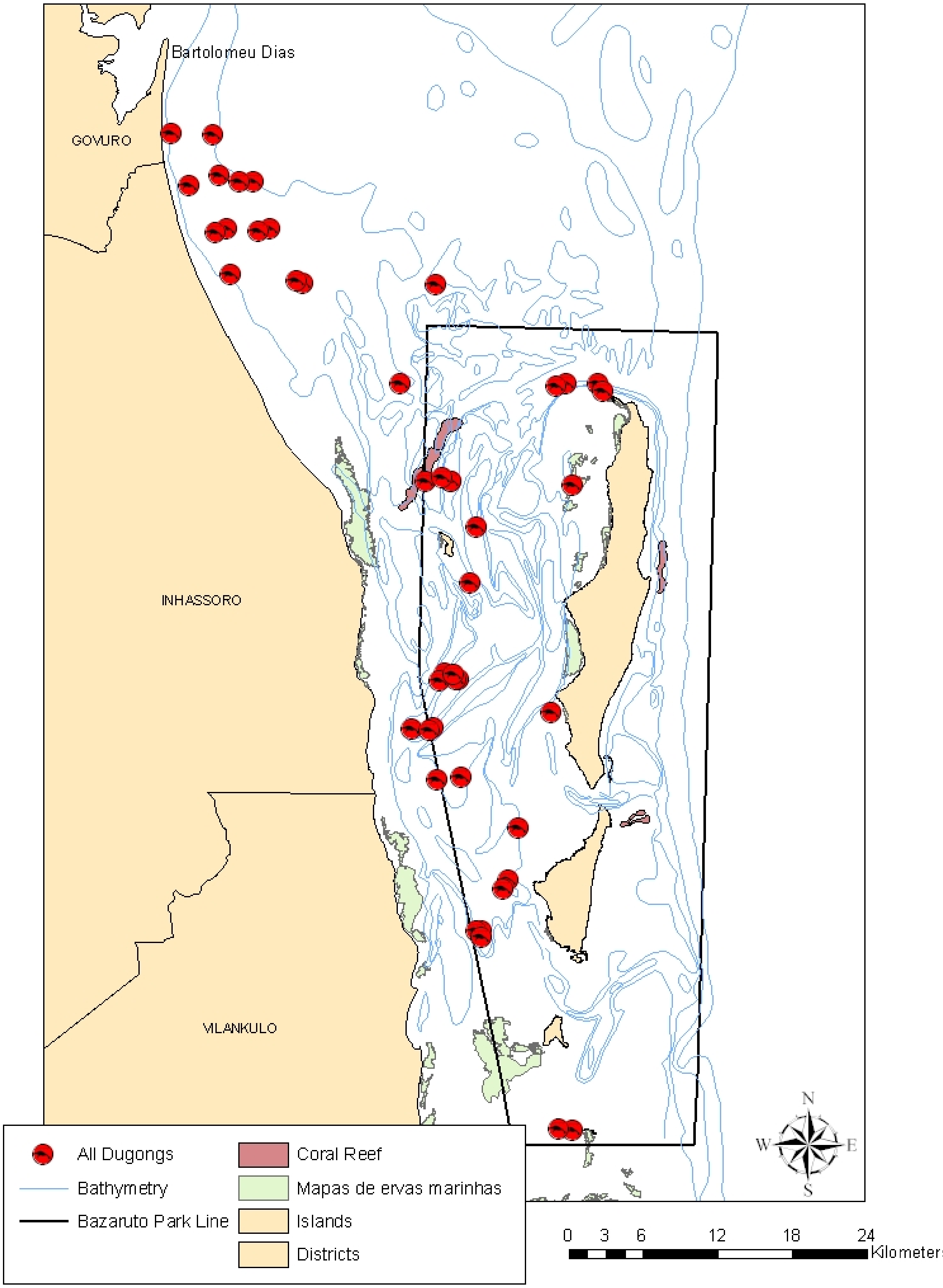

Figure 3. Map of dugong distribution within and the vicinity of BANP for all five days combined (May 25- May 29, 2008).

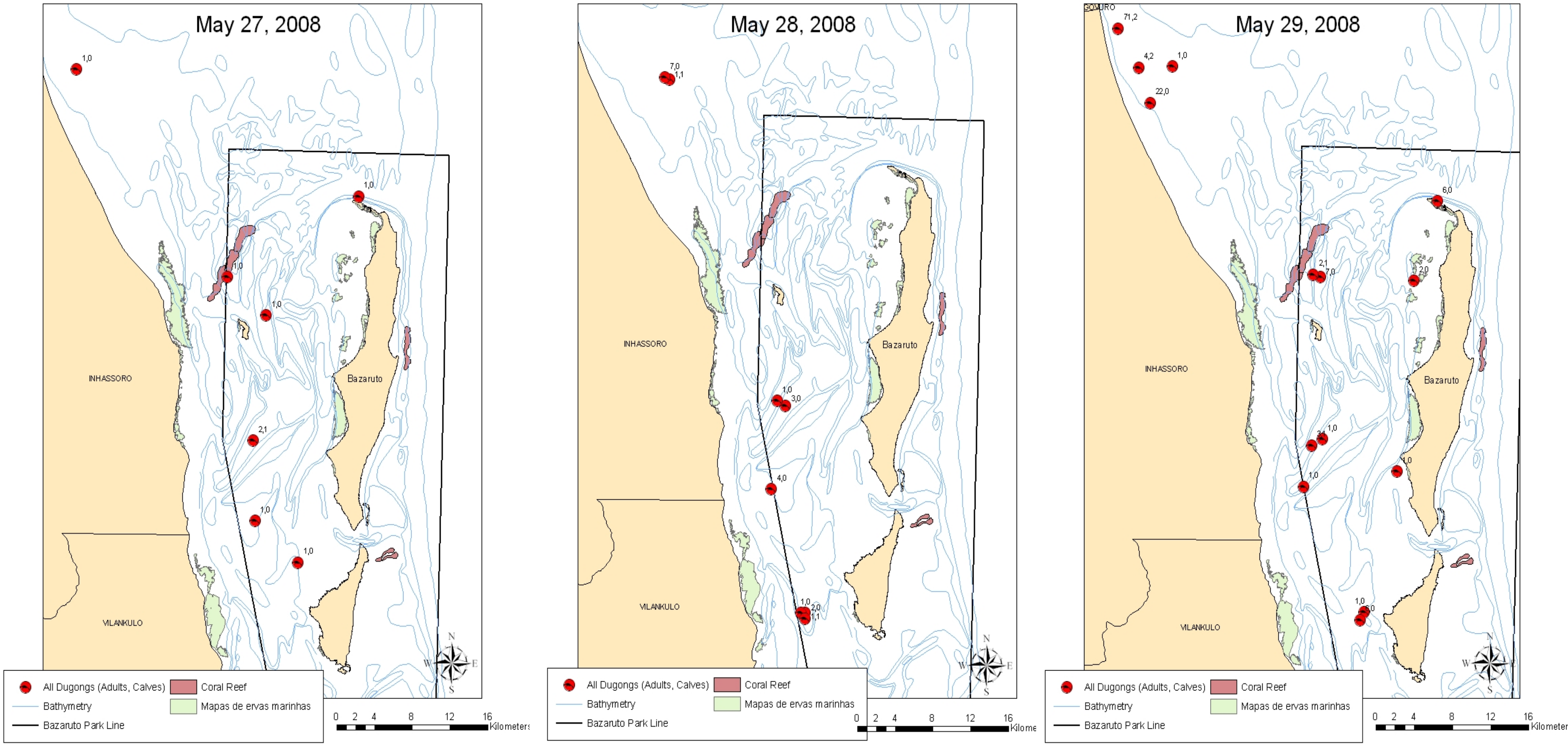

Figure 4. Daily distributions of dugongs within the 2008 dugong aerial survey area in BANP. Numbers indicate counts of adults ollowed by counts of calves.

Sighting distributions of fishing boats for all five flights combined are shown in Figure 5. Fishing boats were the dominant vessels observed and were distributed throughout the region with a minor break in densities near the northernmost end of the Inhassoro district. The distribution of the other boats for the same period is shown in Figure 6.

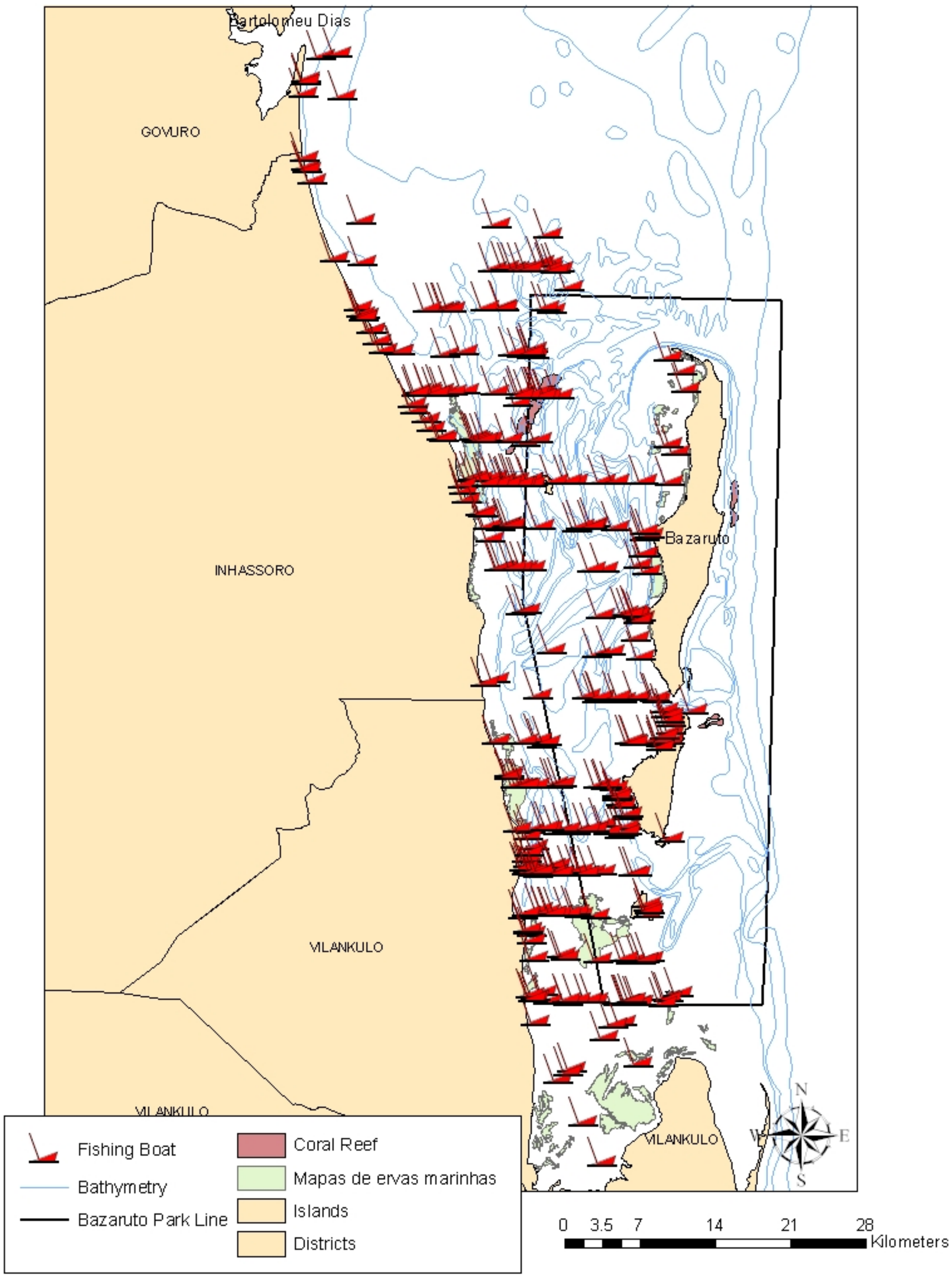

Figure 5. Map of the combined distribution of fishing boats during the five flights from May 25-29, 2008.

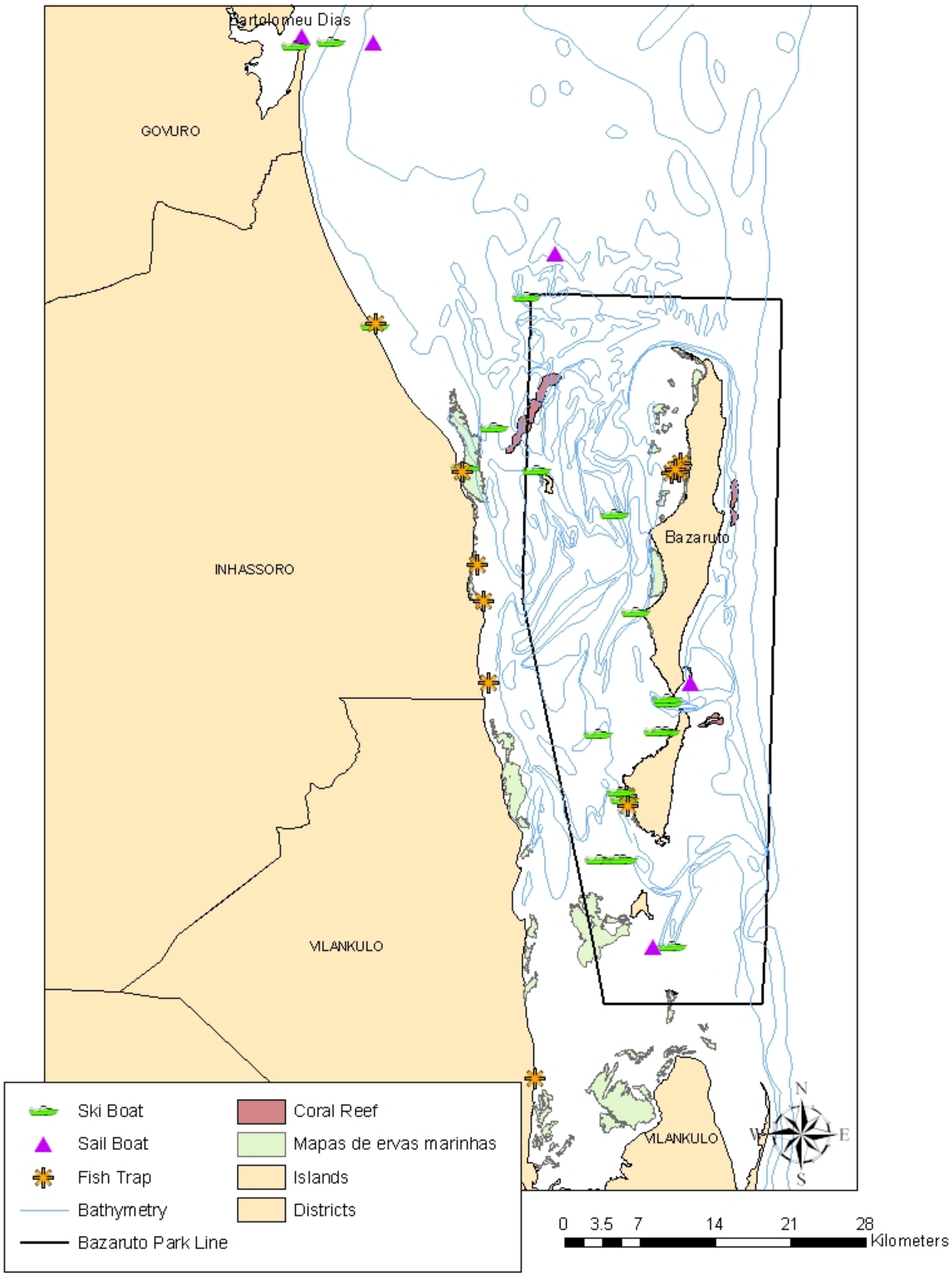

Figure 6. Map of the combined distribution of other boats (power or ski boats and touristic sail boats) during the five flights from May 25-29, 2008.

A total of 154 turtles were sighted during the surveys (Table 1b) with sightings distributed across the entire study area and as shown in Figure 7, most animals were found in the north half between Bazaruto Island up to Bartolomeu Dias. The individual turtle sighting events ranged from 36 to 54 for each survey day and are displayed in

Figure A-1. The majority of the turtles appeared to be Green turtles (Chelonia mydas) and at least three Leatherbacks (Dermochelys coriacea) were also recognized.

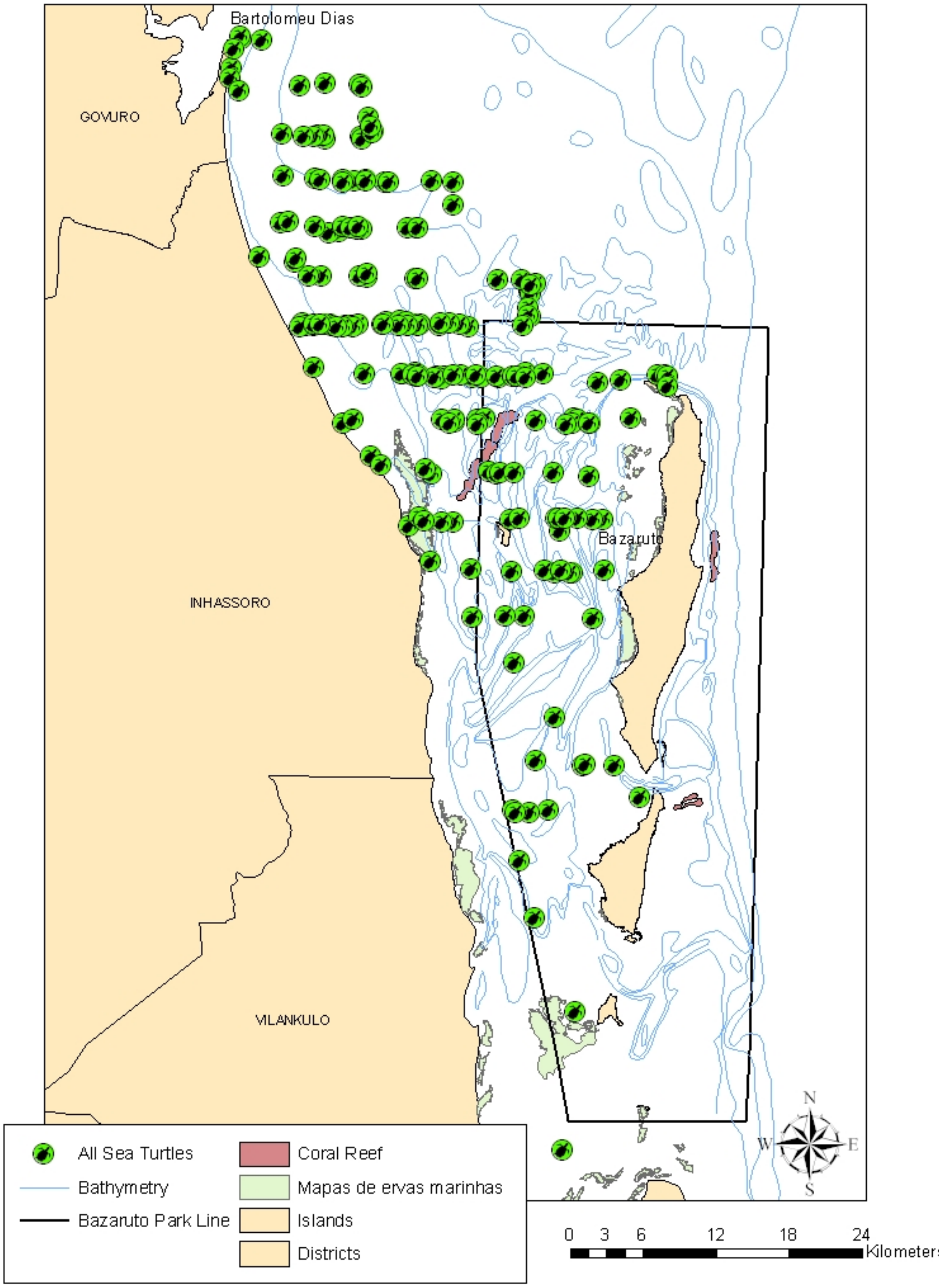

Figure 7. Map of sea turtle distribution within and near the BANP for all days combined from 25-29 May, 2008.

Dolphins were observed each day but in lower numbers than expected with totals ranging from 5 to 13. Table 1b indicates the counts for each flight for dolphins.

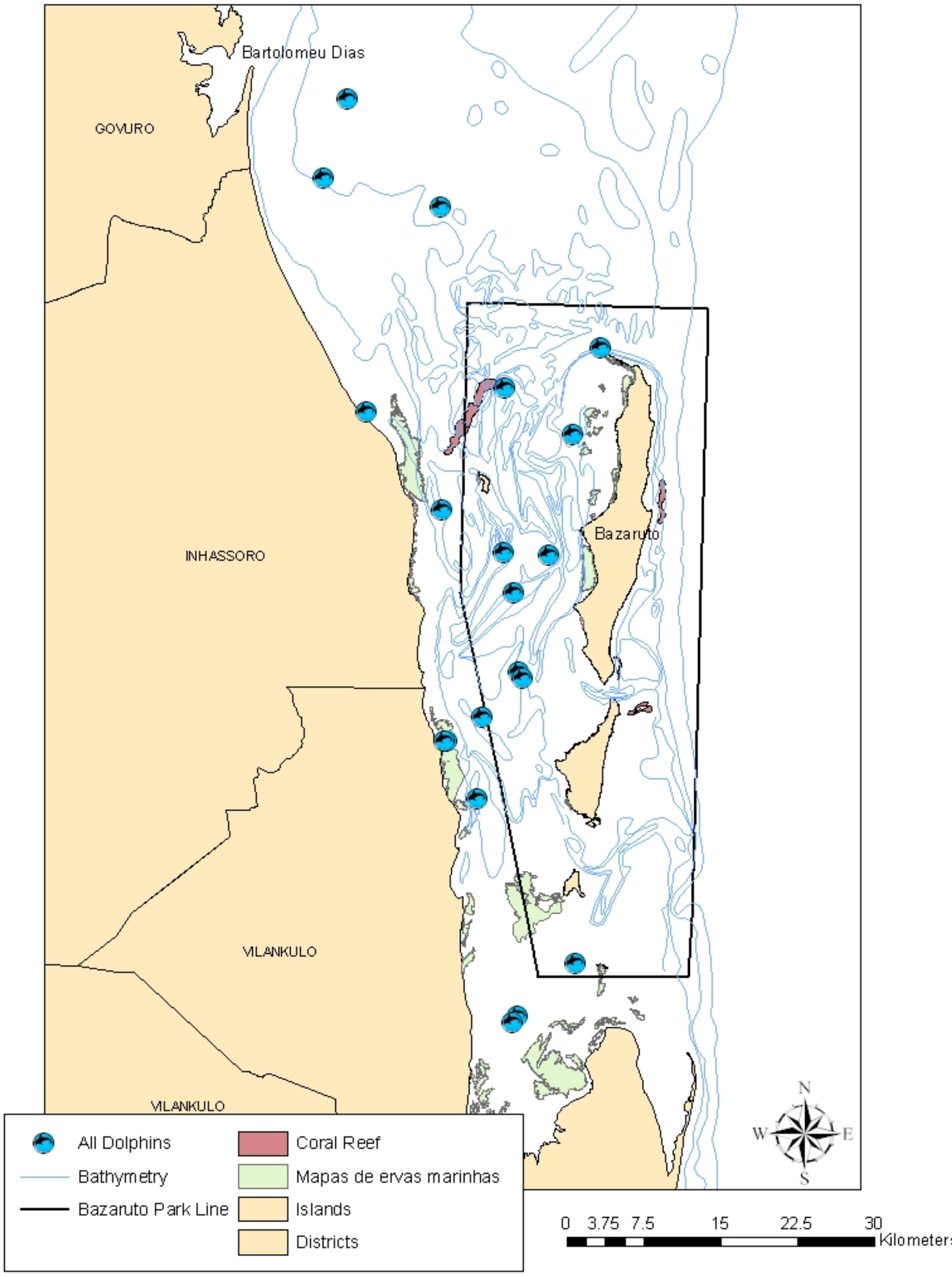

Figure 8. Map of dolphin distribution from aerial surveys conducted for five days from 25-29 May, 2008.

Table 1b. Daily counts for turtles, dolphins, boats and fish traps during the 2008 dugong surveys.

DATE	Turtle	Dolphin	Sail boat	Power boat	Artisanal Fish boat	Fish trap / Gamboas
May 25	39		NA	NA	NA	NA
May 26	36		NA	NA	NA	NA
May 27	54	13				
May 28	44	8				
May 29	48	5				

Power and sail boats were associated with tourism and, although infrequently seen, were observed in very localized areas within the park or mainland near tourist businesses.

Artisanal fishing boats, most under sail power, were scattered throughout the bay. Many were supporting shore based net seining operations. The vessels were often observed many hundreds of meters offshore of the mainland, shoals, or islands with seine haulers back on shore with lines for each net end (5 or 6 people per end). These hauls were reported to require about 5 hours of effort (L. Muaves/ WWF, pers. comm. May 2008). It is obvious from the map distributions (Figures 4, A-2, and A-3) that fishers are spread well beyond the shallow nearshore seining sites. Many of these sightings could have been traveling boats as we did not record whether a boat was actively fishing or travelling.

Shore based fish traps, or gamboas were historically set up for long term use and were seen in a few specific spots but were not consistently reported by the aerial observers. We noticed that none of them appeared to be tended and most did not have nets attached to the structure. There are reports that they are seldom used any more in this region (H. Motta / WWF, May 2008, pers. comm.).

Transects: With a 521 km flight path and 800 m search zone below the aircraft (400 m per side), an estimated 416 km^2 were searched by observers which represents 24% of the 1749 km^2 total area.

Data screening indicated that 400m was an appropriate distance for right-truncation of the data; this eliminated about 5% of the sightings from the analysis. Although there was evidence of heaping at angles that were multiples of 5, grouping the data did not improve the apparent fit of detection functions, so exact distances were used. Model selection resulted in a model with the hazard rate key function with no series expansion term. Models which included covariates for animal type, observer, survey day, and cluster size were not improvements over the simpler model with only distance. Figure 9 shows a histogram of the observed detection distances with a plot of the detection function superimposed.

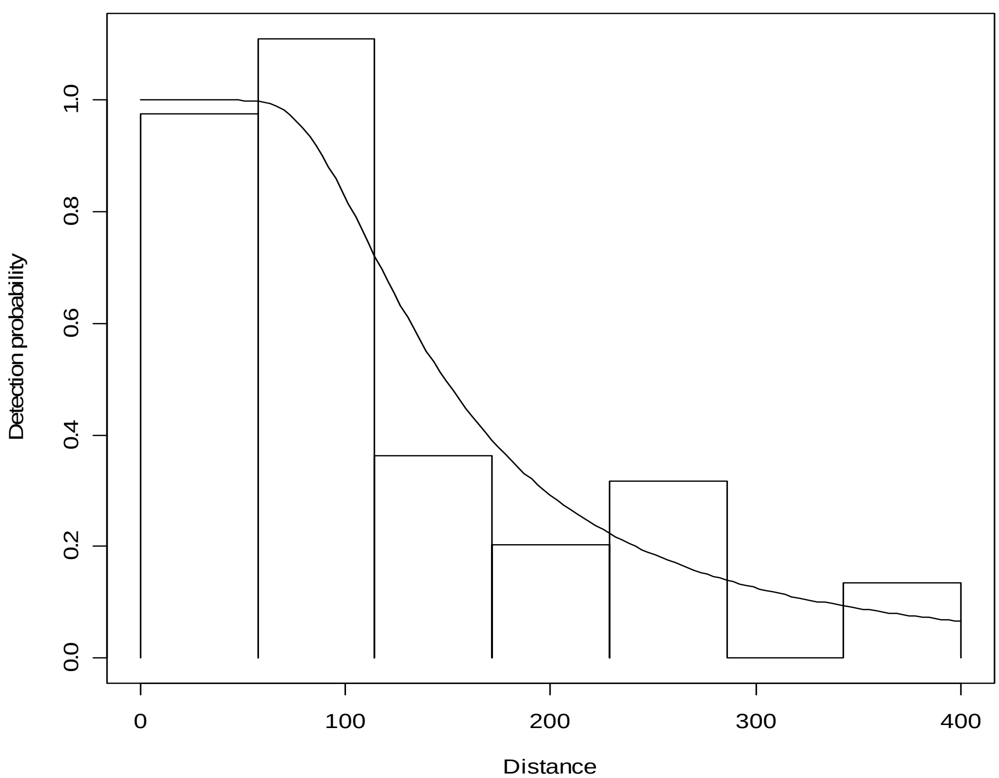

Figure 9. Histogram of detection frequencies as a function of distance for combined sightings of dugongs, sea turtles and dolphins, rescaled so that. A plot of the detection function fitted to the data is superimposed.

The expected cluster size was estimated two ways; a size-biased regression method and as the mean cluster size for all groups seen within 400m of the adjusted centerline. Although there was support for use of the regression to correct the expected group size for size-bias, the small sample size (17 clusters) reduced confidence in the regression results and made decision difficult. Further, the percent of the overall coefficient of variation of the density estimate due to cluster size estimation component was over 50% for both methods. Thus, we present abundance estimates incorporating both methods of estimation of cluster size. For the size-biased regression method, $\hat{E}(s)$ = 1.85 (se=0.600) and the resulting abundance estimate for the study site was 112 dugongs, with a 95% confidence interval of (53,237). For the mean cluster size for all groups seen within 400m of the adjusted centerline, $\hat{E}(s)$ = 7.65 (se=0.4.27) and the resulting abundance estimate for the study site was 463 dugongs with a 95% confidence interval of (155, 1378).

Abundance Size Biased Cluster Method	**Density (size biased) (Area =1749km^2)**	**Abundance Mean Cluster Size**	**Density (mean cluster) (Area =1749km^2)**
112	0.06	463	0.264

DISCUSSION

Several dugong aerial surveys have been conducted over the Bazaruto Bay area but have varied in one degree or another in terms of flight path, transect spacing, frequency etc., (Cockcroft et al. 2008; Mackie 1999, 2001; Dutton 1998).

Generally the surveys performed by Cockcroft and Guissamolo in 2006 and 2007 were similar to the 2008 surveys reported here. Their area of coverage was smaller but closer in extent to the 2008 work and included spacing between transects of almost 4 km (2 nautical miles). The lengths of transects varied depending on the coastal orientation and water depth, etc. as did ours. They flew 24 surveys over about 1.5 years with flight paths ranging from 222 km to 450 km. The total counts of dugongs from their surveys showed the high variability we experienced and ranged from 3 to 69 dugongs, the maximum well below our maximum count of 135. Their more extensive dataset resulted in an estimate of about 250 dugongs (global abundance of 247) which is within the range of our two estimates of 112 and 463. Their densities using truncated distance data ranged from 0.004 to 0.09 dugongs/ km^2 as compared to our two methods for the three survey days yielding 0.06 and 0.26 dugongs / km^2.

Given that aerial surveys previous to 2006 were of varying methods, spatial scales, and timing, combined with the reality of the high variability in dugong sightings between days in the BANP region, we cannot state that dugongs are increasing but that there are numbers higher than previously reported in the literature. In addition to current ecosystem stewardship policies, these recent observations should provide significant motivation for Mozambique to continue implementation of protection for these animals and their habitats. Our sighting of one large group of over 70 dugongs within close proximity of a local shark fishing net (outside of the BANP) emphasized a current fishery related threat to local dugongs.

Dutton (2004) described what he believed to be a decline in dugongs in Mozambique. He reported that the southernmost population of Africa's dugong at Inhaca, once numbering about 20 is extinct, with small numbers being reported at Inhambane. He also stated that the based on interviews and visits that the dugong was extinct on Mozambique's northern coast. He stated that an intensification of large mesh gill-netting from 1976, coupled with lack of law enforcement, was the principal cause of the decline of dugongs in Mozambique.

WWF has also expressed concerns of this species and associated habitats within the region. They have particular concerns regarding a predicted fisheries collapse due to overharvesting within in the region. Several corresponding problems can result from this including a) destruction of seagrass beds underlying netting areas, reducing forage available to dugongs and turtles; b) direct entanglement of dugongs by netting operations; and c) anticipated collapse of fishery with reduced productivity (catch) resulting in a revival of human harvest of dugongs and sea turtles for local subsistence.

Recommendations for future data collection efforts

The distance sampling method proved to work well in this application with a reasonable amount of survey effort. However, there are a few key assumptions that should be tested in the future if resources become available. The first among these is the assumption that all animals are seen on the survey line (g(0) = 1). This is a well-known problem in distance sampling of marine mammals that occurs when animals that are present are sometimes not available for observation during the period when the observer passes a given point on the line (termed visibility bias, Pollock and Kendall 1987). Current investigations are exploring ways to correct distance sampling results for this problem (e.g., Pollock et al. 2006). It would also be useful to explore the assumption that combined sightings of dugongs, dolphins and sea turtles provides a good approximation of the detectability of dugongs alone. An alternative would be to increase the survey effort to the point where dugong sightings alone could be used to model the detection function; 60-80 detections (of clusters, not individual dugongs) is recommended as the minimum for reliable fitting of detection functions (Buckland et al. 2001). If future survey effort is available, repeated surveys should be conducted close together in time to allow pooling of data for analysis.

Finally, because the estimation of expected cluster size has a large effect on the abundance estimate obtained from distance sampling, and because of the large amount of uncertainty due to this component, it may be optimal to put more effort into obtaining a better estimation of cluster size. One method of doing this might be to routinely collect cluster size data whenever dugong groups are observed by WWF scientists or BANP rangers during boating transits in the bay. However, it is important to make sure that size-bias is not creeping into the estimate (for example, if larger groups were more likely to be encountered than smaller groups). Covariates such as distance of group when first detected, sighting cues, season and geographic location should also be recorded. These data would then be available to refine future dugong abundance estimates based on distance sampling.

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Appendix – Additional Distribution Maps

Figure A-1. Daily distribution of marine turtles sighted during the official survey dates of 27- 29 May 2008.

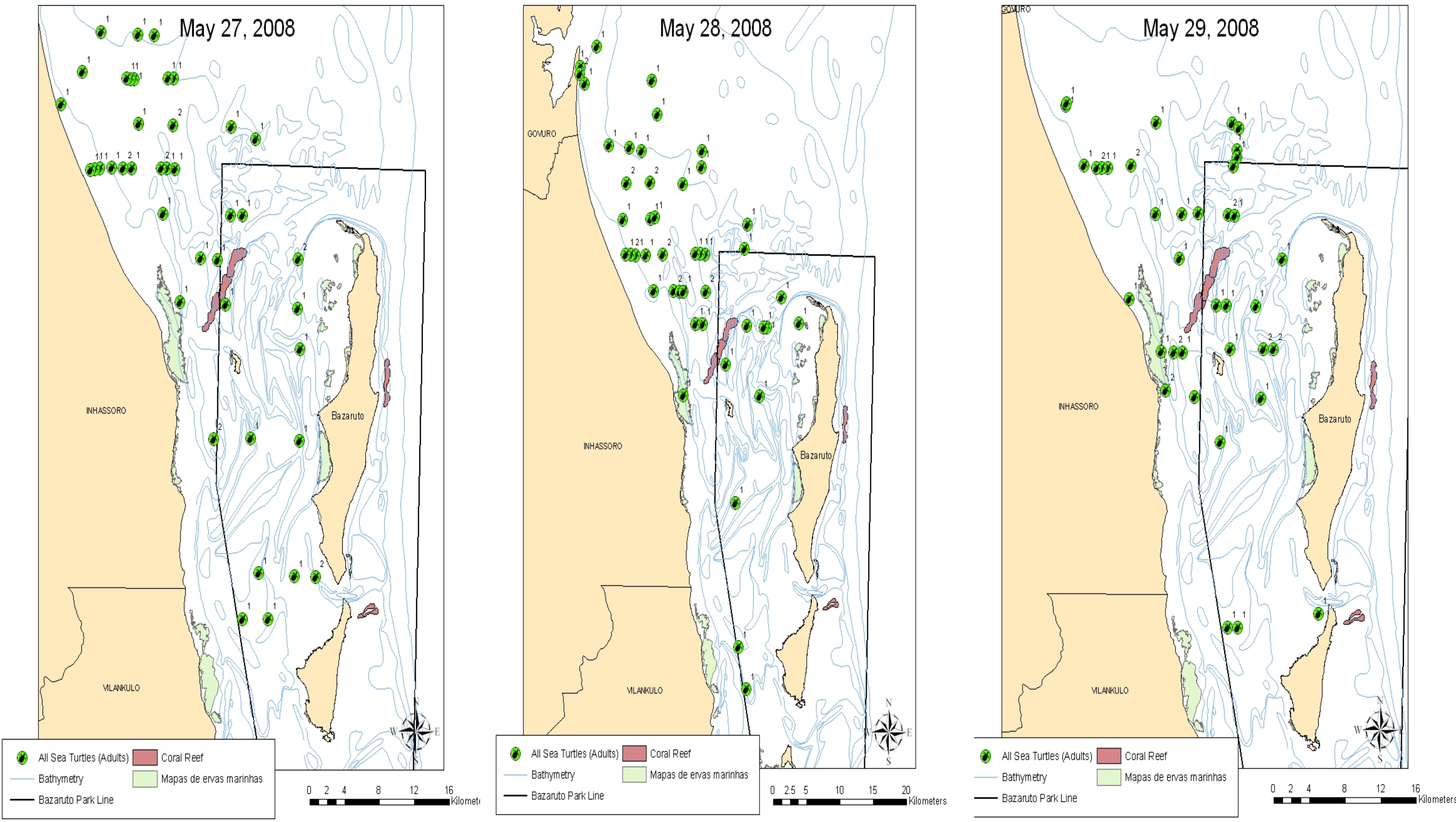

Figure A-3. Daily distributions of only artisanal fishing boats during official aerial surveys conducted 27-29 May

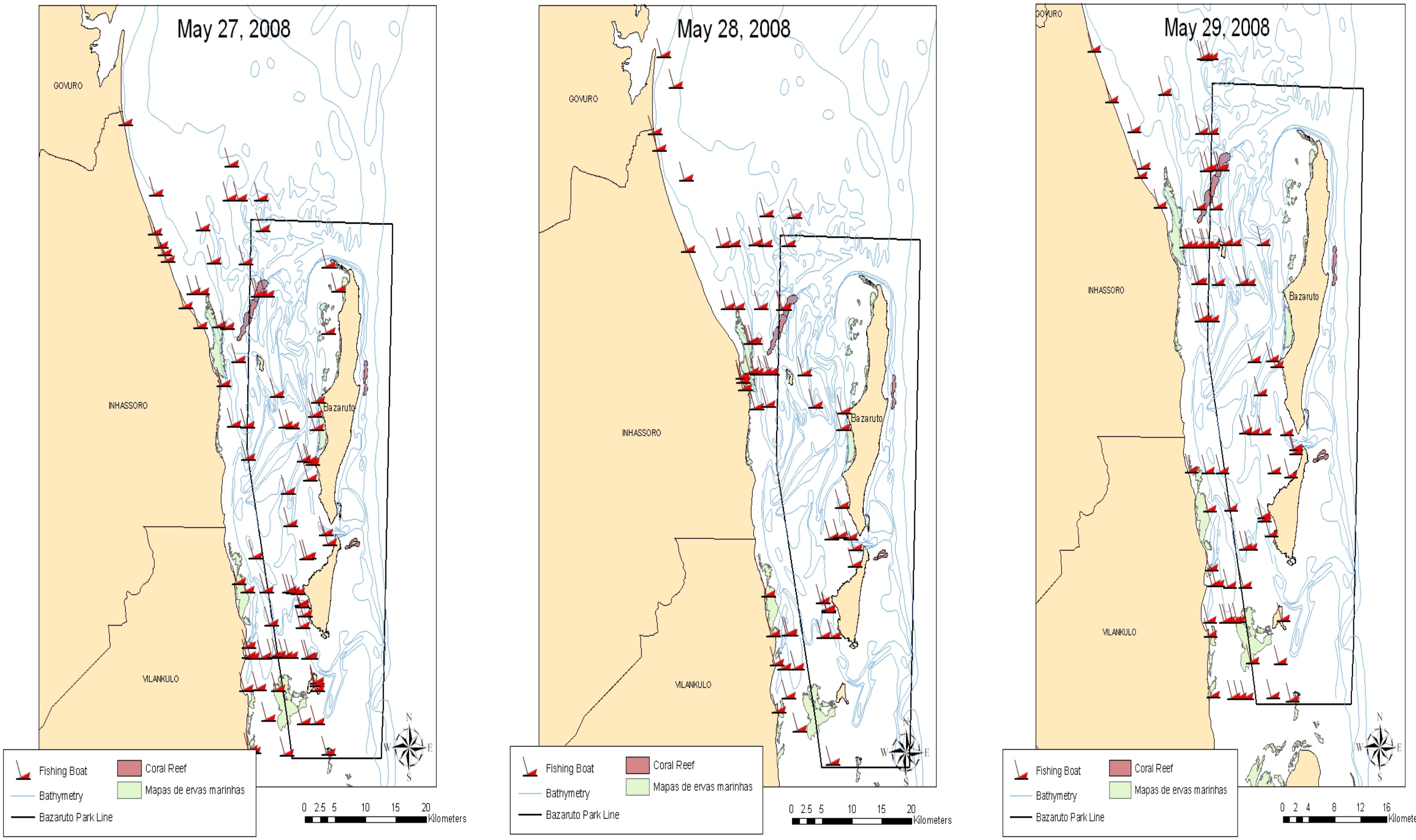

Figure A-4. Daily dolphin distributions during official aerial surveys conducted 27-29 May 2008.

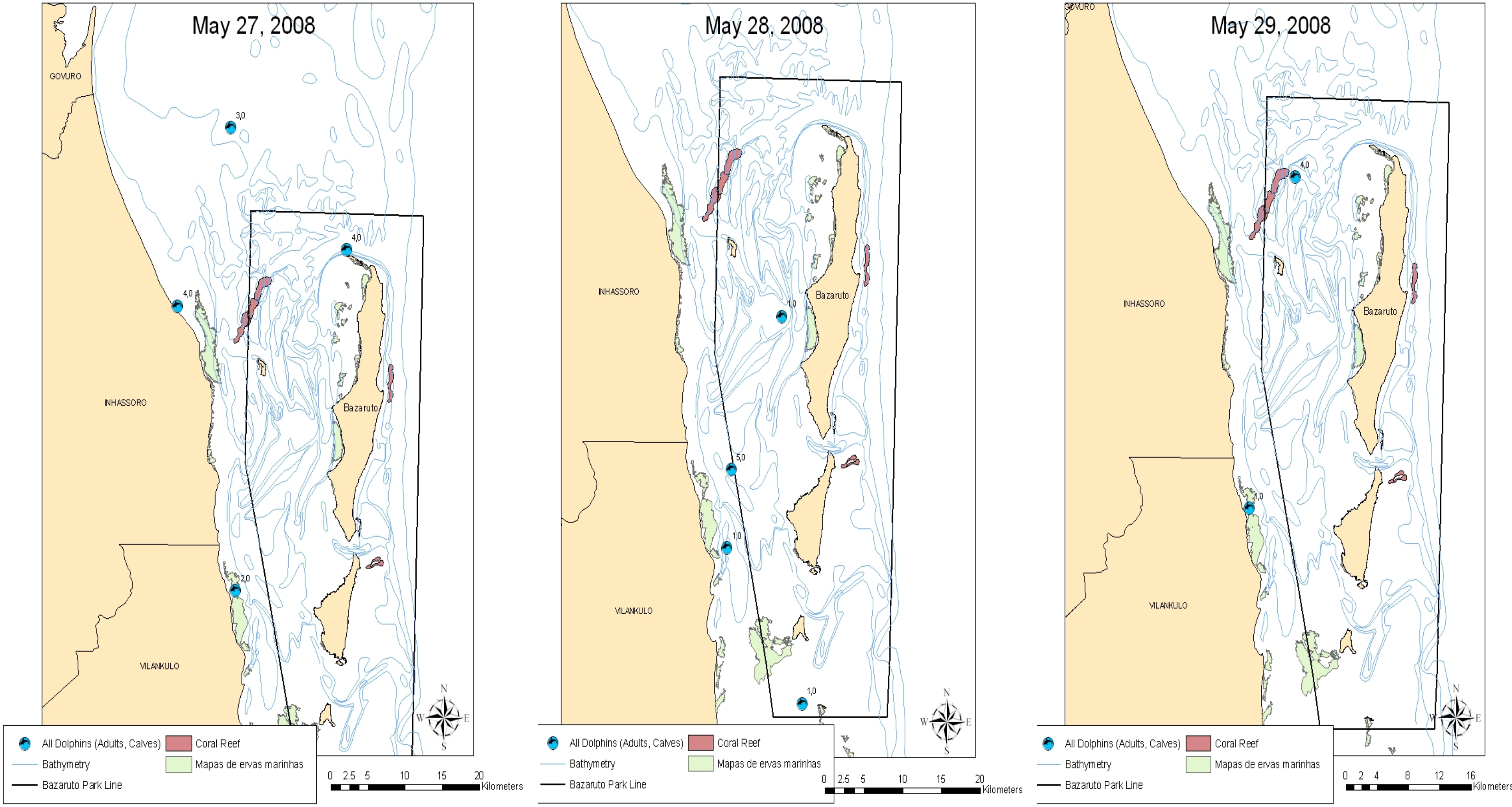

Figure A-5. Example of summary sheet for each aerial survey.

BNMP Dugong Surveys

DATE __________________________________Flight No ___________________

Aircraft Type ___________________________Aircraft Tail No _____________

GPS Test check_____________________________________

Observers____________________________________ Pilot ______________________

Weather ____
Wind __________________________________
Water Surface (seastate): ____
Turbidity notes:____

Start Survey Time _________________
Stop Survey Time _________________
Total Survey Time_____________________

Total Flight Time___________________

Condtions Summary (Excellent, good, fair, poor):_____________________________
____
Average Altitude _______________________
Average Speed __________________________
Flight Route: __________________________

Flight Summary:
Total Dugongs
Total Turtles

NOTES:

____
____
____
____
____

Data entry date_________________
Initials_______________

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