PART 2.

BIOLOGY OF DUGONGS IN RELATION TO THEIR ENVIRONMENT

CHAPTER 5.

USE OF SPACE

5.1. Introduction

The way in which dugongs use space is a fundamental aspect of their ecology. Their local distribution, patterns of movement and the characteristics of their home ranges are manifestations of their relationships with their environment. Successful long-term conservation and management strategies must be based on a sound understanding of these relationships. An understanding of the bases of their selection of habitats is an implicit requirement.

Aerial surveys have documented the regional distribution of dugongs (see Table 7.4). The usefulness of these surveys for determining the habitat preferences of dugongs is limited by their low resolution, which at best, is commensurate with the scale of the visible landscape. These surveys have established that dugongs are most frequently found in bays, shallows and reef areas, which are usually protected from heavy seas and are known or are expected to contain extensive seagrass beds (Heinsohn et al., 1977; Marsh, 1989a; Nishiwaki and Marsh, 1985). In the absence of detailed ground-truthing, aerial surveys have been unable to resolve habitat preferences below the landscape level.

Our understanding of the movements and home range of dugongs is also incomplete. Six dugongs have been tracked for relatively short periods (five of them for < 100 days) in the inshore waters of north Queensland (Marsh and Rathbun, 1990). Five of the dugongs were relatively sedentary, moving less than 22 km from their site of capture, but one dugong made three trips of over 140 km between its capture site and another favoured feeding area. The only other information on movements of individual dugongs comes from Shark Bay in Western Australia (P. K. Anderson, 1982a), where 15 dugongs, identified by photographs and sketches, were resighted between 1 h and 15 days later as far as 19 km away.

Information on the geographic stability of dugong populations is even more scant. Few populations have been surveyed frequently or intensively enough to document movements of the dugongs adequately. In Shark Bay, Anderson (1986) inferred from seasonal changes in their distribution, that dugongs migrated seasonally across the Bay although other data suggest that only a small proportion of the population may undertake those movements (Marsh et al., 1991). The traditional inhabitants of Torres Strait believe that there is a seasonal movement of the dugong population in Torres Strait (Johannes and MacFarlane, 1991; Olewale and Sedu, 1982), although this is not supported by the limited aerial survey data (Marsh and Saalfeld, 1988).

By using a coordinated program of aerial surveys and satellite tracking of individual dugongs, I aimed to expand our limited understanding of the use of space and habitat selection by dugongs. These two approaches provide complementary information. The aerial surveys monitor the distribution of the population, while the tracking provides detailed information on the movements of individuals.

The principal aims of the aerial surveys were:

1. to document the fine scale distribution of dugongs in the study areas over a range of time scales
2. to relate the distribution of dugongs to habitat types
3. to relate the distribution of dugongs to other potentially influential features such as water temperature, water depth and boat traffic.

The principal aims of the satellite tracking were:

1. to document the home range of individual dugongs
2. to identify movement patterns within and beyond the Bay
3. to relate the distribution of individual dugongs to habitat types.

The methods and results of the aerial surveys and tracking are presented separately, although their findings are discussed together.

5.2. Aerial surveys

5.2.1. Methods

5.2.1.1. Surveys of the study areas

The distribution of dugongs within the East and West study areas was monitored by 28 standardised aerial surveys flown between July 1988 and February 1990 (Table 5.1). These 'standard' surveys were flown at approximately 3-week intervals (mean = 21.2 days, SE = 1.6). Surveys were flown at an altitude of 274 m and each flight averaged 75 minutes (SE = 1.4), excluding transit time (Table 5.1). All surveys were flown in the morning and were timed to cover the East study area within 1 h of high tide. Weather conditions for each survey were standardised as much as possible. Generally surveys were not flown unless the wind was ≤15 kt, sea surface was <3 (Beaufort scale) and cloud cover was minimal (no cloud, very sparse cumulus, or very thin stratus).

A principal objective of these surveys was to establish the distribution of dugongs relative to the seagrass and other habitats. Therefore, the flight path (Figure 5.1a) was selected to maximise the coverage of the study areas (particularly the East study area), while minimising navigation problems and, therefore, maximising repeatability. To assist the different pilots, the ends of the legs of the flight path (referred to as transects) were marked by navigation beacons or topographic features. At the flying altitude of 274 m, coverage of the banks in the East study area was high (>70%). The effect of the fall-off in the sightability of dugongs with increasing distance from the aircraft was minimised, in some parts of the survey area, by the closeness of the transects. Where overlap occurred between search areas of adjoining transects, double counting was avoided because sightings were recorded directly onto maps of the area (see below), so locations could be checked.

I chose the survey altitude of 274 m, rather than the lower altitude used for most strip-transect aerial surveys of dugongs (137-152 m; Bayliss and Freeland, 1989; Marsh and Saalfeld, 1988, 1989, 1990a, Marsh et al., 1990, 1991; Preen, 1989a) because of its cost effectiveness (the lower altitude would have required twice as many transects for the same coverage) and because it is easier to delineate natural groups of dugongs at the higher altitude. Furthermore, the greater the altitude, the more time is available for observers to count groups and record data. Marsh and Sinclair (1986) found that survey altitude (274 m or 137 m) had no significant effect on the sighting rate of dugongs in Moreton Bay.

The legs of the flight path that were located to the east of the Bay, outside South Passage (Figure 5.1), were flown during only 14 of the 28 surveys (Table 5.1). The first six flights (winter and spring 1988) included the area, but the outside transects were discontinued once the number of dugongs sighted there dropped to zero. These data, plus the results of satellite tracking of individual dugongs (below) indicated that the use of the area outside South Passage was largely restricted to the winter period (see below). Hence, the area was surveyed only twice during the summer of 1988-9. Surveys of the area recommenced the following autumn and continued through winter and spring until sightings again dropped to zero.

5.2.1.2. Surveys of other areas

Two additional surveys were flown around the perimeter of Moreton Bay, to estimate the relative proportion of dugongs occurring in seagrass areas outside the study areas. These so-called perimeter surveys (Figure 5.2) searched the known areas of seagrass in Moreton Bay that lay outside the study areas (see Hyland et al., 1989). One survey was flown in summer (7 March 1989) and one in winter (21 July 1989). The survey altitude and survey conditions were standardised, as for the 'standard' surveys.

5.2.1.3. Observation and data recording

A high-wing, four-seat aircraft (Cessna 172) was used for all surveys. The survey team comprised two observers (myself and one other) and a passenger. I sat on the right-hand side, next to the pilot. The passenger sat behind me, and observed when I needed to communicate with the pilot. Dawn Couchman was the principal left-hand observer, participating in 17 of the 28 'standard' and both of the perimeter surveys. A total of 5 other people acted as observers when Dawn was not available.

Each observer recorded sightings directly onto maps, which detailed the flight path and topographic and seagrass features. Observations from the following categories were recorded:

- dugongs: group size and calf count
- dolphins: species, group size and calf count
- sharks: >2 m long
- fishing nets (gill, seine or tunnel)
- boats: number of the following types:
  - speed boat or dinghy powered by an outboard motor
  - sailing boat
  - cruiser (displacement-hulled power boat)
  - professional fishing boat (displacement-hulled)
  - trawler
  - punt (un-powered tender)
  - barge
  - dredge
  - car ferry
  - tug boat

Calves were defined as individuals that were distinctly smaller than the animal with which they were closely associated. Groups were defined as subjectively discrete clusters. Groups of animals were circled, counted and photographed using slide film. Counts derived from a series of projected slides were usually accepted in preference to the real-time counts (with which there was good agreement on almost all occasions). The position of sightings were normally located on the maps within 500 m of their true position. In areas characterised by distinct patterns of seagrass and/or topographic features, I estimate that sightings were accurate to within 100-200 m.

5.2.1.4. Seasons

Seasonality was defined by water temperature, as discussed in section 2.2. Year 1 included four seasons commencing with winter 1988 while year 2 spanned three seasons, ending with summer 1990 (Table 5.1).

5.2.1.5. Habitat selection

To investigate habitat selection by dugongs, I examined the distribution of dugongs sighted during the aerial surveys in relation to environmental parameters that may affect their choice of habitat. Due to the virtual absence of dugongs in the West study area, only data from the East were included in the analyses.

To enable environmental parameters to be compared between areas used by or avoided by dugongs, the study area was divided into grids of 1 km^2 cells as follows: (1) 181 cells that were monitored during each survey and (2) an additional 21 cells, east of South Passage, that were surveyed on 14 occasions only. A 1 km grid was used so any grid cell would encompass the combined maximum errors of the seagrass and dugong mapping.

The density of dugongs was estimated in each grid cell for each aerial survey, along with the following environmental parameters:

- predominant habitat

  eight habitats were recognised:

  1. very low biomass seagrass communities dominated by H. ovalis (communities H4 and H5; Table 3.2)

2. other seagrass communities dominated by Halophila species (communities H1-H3 and H6)
3. seagrass communities dominated by Z. capricorni broad (community-group ZB)
4. seagrass communities dominated by Z. capricorni thin (community-group ZT)
5. sand
6. Rous and Rainbow Channels
7. deep water up to 1-2 km to the west of the main seagrass banks
8. deep water east of the Bay, outside South Passage

- distance to deep water

  distance from centre of grid cell to the nearest water $\geq$2.5 m deep leading directly to deep water (>5 m). My boat-based observations indicated that the behaviour of dugongs in water >5 m was usually perceived to be 'relaxed', while dugongs in water <2.5 m were easily disturbed (see Appendix 5.3).

- water depth

  approximate mean depth of grid cell (read from Figure 2.9b)

- water temperature during winter

  average estimated water temperature of each grid cell at high tide during winter (determined once from a series of five satellite images [8/7/88, 7/8/88, 11/6/89, 12/7/89, 1/8/89] as well as thermometer readings [24/7/89]: they were not determined for each survey)

- boats

  density of boats in each grid cell during each aerial survey.

Other variables were:

- year

  year 1: winter 1988-summer 1989; Year 2: winter 1989-summer 1990.

- season

  winter, spring or summer. Two surveys (# 15 and 16) were flown in autumn. Survey 15 was flown 18 days after the end of summer, and survey 16 was flown 7 days before winter. Therefore, for the purposes of these analyses, survey 15 was assumed to be a summer survey while survey 16 was regarded as a winter survey.

Dugongs tend to have preferred feeding areas, often returning to the same area for several weeks (see below). As a result, the density of dugongs seen in one grid cell was not independent of the density in adjoining cells, or in the same cell during a subsequent survey. Consequently, analyses assuming independence of sightings, such as multiple regression, were invalid. Instead, the analysis involved a series of log-linear models and logistic regressions. These analyses were performed by Glenn De'ath, a professional statistician from the Department of Tropical Veterinary Science and Agriculture at James Cook University, and he has detailed the analyses in Appendix 4. In summary, the quantitative variables were reduced to qualitative values for the log-linear analyses. Once the factors that account for the dugong distribution were identified, logistic regression was used to quantify their effects more precisely (Appendix 4).

The values of the qualitative variables were: water depth: 0 m (based on the facts that seagrass is most abundant between depths of -1 and +1 m relative to Datum [section 3.4.1] and the mean depth of feeding sites that were investigated was -0.1 m [section 6.2.2.1]); distance to deep water: 1.5 km [dictated partly by the resolution of the 1 km^2 grid size]; water temperature during winter: 19° C (on the basis that 18-19° C is suspected to be the threshold temperature, below which dugongs cannot maintain homeostasis indefinitely [section 5.4.2.2]); boats: presence/absence in grid cells; dugongs: 0, 1 or >1 in grid cells. It should be noted that the threshold values for depth, distance and temperature were largely subjectively assigned and not empirically derived. Further analyses may determine more appropriate cut-off values.

5.2.2. Results

A total of 10,326 dugongs was recorded in 1,197 groups during the 28 'standard' surveys. A further 24 dugongs were sighted on the two perimeter surveys.

5.2.2.1. Population size

On average, 368.8 (SE = 17.9) dugongs were counted on each of the 28 surveys. There was considerable variation in the number of dugongs counted on each survey: 201 to 569 dugongs (Figure 5.3, Table 5.1), but no seasonal or inter-year pattern was detected (Table 5.2). Possible explanations for the variation in counts between surveys are considered below.

1. Survey conditions
I ranked the survey conditions during each flight on a scale of 1 (very poor) to 5 (excellent), based on the amount of glare (surface reflection), cloud cover, water turbidity and the height of waves. This ranking also included a consideration of the apparent reliability of the left-hand observer, relative to Dawn Couchman, the regular left-hand observer (Table 5.1). The number of dugongs seen on each survey was significantly correlated with survey conditions (Spearman Rank correlation: $n = 28$, $r = 0.4098$, $p = 0.03033$), suggesting that a small part of the variation in counts may be explained by the variation in survey conditions.

2. Dugongs in the 'blind' zone
There is a 'blind' zone, 93 m wide beneath a Cessna 172 flown at an altitude of 275 m (P.K. Anderson, 1982a). When all the observations from the 28 surveys were plotted on the one map, the effect of the 'blind' zone was evidenced by the paucity of sightings along the flight path. As dugongs in Moreton Bay typically occur in large herds (section 7.3.1), the occasional location of single herds within the 'blind' zone beneath the aircraft could account for a substantial proportion of the variation in survey counts.

3. Dugongs missed in the area east of South Passage
The transects outside South Passage were flown on only 14 of the 28 surveys (Table 5.1). Although dugongs apparently use this area primarily during winter (see below), a small number of dugongs were found there at other times during the year as well. Therefore, some of the dugong population may have been missed because they were outside the Bay at times when this area was not searched.

Even in winter, when the area outside South Passage was surveyed, substantial numbers of dugongs may have been missed in the area. Moving eastwards from South Passage there is a progressive dilution of the density of dugongs, as they disperse over a wide area of deep water (up to 50 m). It was practicable to incorporate only a limited search effort of this area into the flight path (Figure 5.1a), so only the area close to South Passage was surveyed. But dugongs certainly disperse beyond this searched area. Each of the six dugongs tracked during winter (see below) were located, at some stage, beyond the searched area, sometimes as far as 9 km beyond South Passage (Figure 5.7a). Lear (1977) recorded dugongs beyond the searched area on 3 out of 15 surveys that included the eastern coastlines of Moreton and North Stradbroke Islands. An unknown number of dugongs may have been missed, therefore, even when the South Passage area was surveyed.

4. Dugongs outside the study areas

It is possible that substantial numbers of dugongs were missed on some of the 'standard' surveys because they were inside Moreton Bay, but outside of the study areas. However, the results of the perimeter surveys, the satellite tracking (below) and previous surveys (Table 5.3) suggest that this is unlikely. During the summer and winter perimeter surveys, only 19 dugongs and 5 dugongs, respectively, were sighted outside the East and West study areas (Figure 5.2). These figures represent 5.7% and 1.2% of the number of dugongs seen inside the study areas on the previous day (summer), or same day (winter).

Based on the highest counts made during the 28 surveys (569, 567, 510 dugongs; Table 5.1), and given that on those days, the substrate could be seen clearly on the banks where most dugongs occurred, I estimate that a population of approximately 600 dugongs lives in vicinity of the banks in the East study area. Given the results of the perimeter surveys, the satellite tracking and previous surveys (Table 5.3), this is probably a reasonable estimate for all of Moreton Bay.

5.2.2.2. Dispersion of dugongs

Typically the dugongs recorded on the 'standard' surveys were aggregated into at least two large groups (of about 100 dugongs) and numerous smaller groups (Figure 5.1b). On average, the dugongs were distributed in 42.7 groups (SE = 2.6), ranging in size from 1 dugong to 459 dugongs. On some occasions the population of dugongs was very dispersed (surveys 7, 10, 25, 26), while at other times they were highly aggregated (surveys 6, 13, 14, 28). On survey 25, 532 dugongs were recorded in 67 groups, while on survey 14, 569 dugongs were sighted in 12 groups in just two restricted areas (Figure 5.1b). Herd size will be considered more fully in Chapter 7.

5.2.2.3. Distribution of dugongs

Distribution in Moreton Bay

The locations of dugongs sighted during each of the 'standard' surveys are plotted in Figure 5.1b. Dugongs seen during the perimeter surveys are plotted in Figure 5.2.

The surveys undertaken during this study were inadequate to establish unequivocally the distribution of dugongs throughout Moreton Bay. However, Moreton Bay has been surveyed for dugongs on many previous occasions (Table 5.3), and these surveys all support the findings of this study.

The most striking aspect of the distribution of dugongs in Moreton Bay is their concentration in the area enclosed by the East study area, and their virtual absence from most other parts of the Bay. Every time Moreton Bay has been surveyed, 82-100% of all dugongs were seen within the boundaries of the East study area (Table 5.3). During the summer perimeter survey, only six dugongs were seen along the mainland shore (two each at Deception Bay, Wellington Point and Redland Bay), while during the winter survey, only one dugong was seen in the western Bay (Figure 5.2). During the 'standard' surveys, only 15 of the 10,326 sightings of dugongs (0.14%) were located in the West study area (Figure

5.1b).

The other conspicuous aspect of the dugongs' distribution was the seasonal use of the area outside Moreton Bay, to the east of South Passage. This area was surveyed six times during winter (ie. every winter survey) and eight times during other seasons (spring: 6; summer: 2; autumn: 1; Figure 5.4). During the winter months, an average of 25% (SE = 7.9) of the total number of dugongs counted on surveys was located outside South Passage. During those non-winter surveys that extended outside South Passage, only 3.6% (SE = 2.0) of dugongs occurred in this area, which is a significantly smaller proportion (one-way Anova: df = 1, 12, F = 13.60, p = 0.0031; proportions were arcsine transformed). The true seasonal differences are likely to be even greater than indicated. The non-winter counts are a biased estimate of the proportion of dugongs using this area during the non-winter period because most of these counts were made during months adjoining the winter period (Figure 5.4). Furthermore, although only 16 dugongs were seen outside the Bay during survey 10, in mid-summer, this represented a substantial proportion of the total count (7.9%), as that survey had the lowest total count of the 28 surveys (201 dugongs; Table 5.1; Figure 5.3).

The use of the area east of South Passage was clearly related to water temperature, and the colder the Bay temperature, the greater the use of the outside area. Water temperatures during the 1989 winter were significantly colder than during 1988 (section 2.2) and 33.9% (SE = 13.9) of dugongs sighted on aerial surveys in winter were outside the Bay in 1989, compared with 16.1% (SE = 6.2) during winter in 1988. Due to the large variation between surveys (Figure 5.4), this difference was not significant (one-way Anova: df = 1,4, F = 1.50, p = 0.2881; proportions arcsine transformed).

Distribution on the eastern banks

The distribution of dugongs on the seagrass beds of the East study area often varied substantially between surveys (Figure 5.1b), although some patterns were consistent. Groups of dugongs were almost always seen in some areas, such as the Turtle and Maroom Banks while other areas were never, or rarely used (eg.

Oyster Bank, Amity Shoals, Wanga Wallen Bank and the south east area of the Dunwich Banks). Still other areas were used periodically by large herds. For example, large herds were seen on the Warragamba Bank during surveys 5, 9 and 24 only. Similarly the Chain Bank was grazed by large herds during surveys 7, 8, 11, 12 and 25 (Figure 5.1b).

Distribution in relation to seagrass communities and biomass

In the East study area, dugongs were sighted on 13 of the 15 recognised seagrass communities. (The seagrass communities are defined in Table 3.2, and their distribution within the East study area is shown in Figure 3.1). No dugongs were seen on seagrass communities composed solely of C. serrulata (community C) or S. isoetifolium (community S).

Pooling across surveys, 63.3% of all dugongs were sighted in habitats dominated by species of Halophila. During all but two surveys (# 23 and 24), most dugongs were found in these habitats. Habitats dominated by Z. capricorni broad were used with the second greatest frequently, with 15.8% of all sightings. Other communities were relatively little used: sand (7.4%); outside South Passage (6.0%, based on all surveys, although not all flights covered this area); areas dominated by Z. capricorni thin (3.3%); mid-bay (2.3%); and channels (1.8%).

Of the 8,504 dugongs sighted in areas of seagrass, 76% were located in communities dominated by Halophila. Most were seen in communities H1, H2 and H5 (Figure 5.5). Because communities dominated by Halophila are characterised by low seagrass biomass (Figure 3.2), dugongs occurred mostly in areas with relatively little seagrass. A total of 81% of dugongs seen on seagrass occurred in areas with $\leq$50 g seagrass/m^2, even though only 67% of the total area of seagrass in the East study area (no dugongs were seen on seagrass in the West) was characterised by $\leq$50 g seagrass/m^2 (biomasses derived from sampling sites within tracts of seagrass in which dugongs were sighted; see Chapter 3). At the locations where dugong herds were seen on tracts dominated by Halophila, the mean biomass was 13.3 g/m^2 (SE = 0.4). This total was composed primarily of H. spinulosa (8.6 g/m^2, SE = 0.3), H. ovalis (4.4 g/m^2, SE = 0.1) and H.

uninervis thin (0.2 g/m², SE = 0.01).

The tracts of seagrass dominated by Z. capricorni broad accounted for 19% of all sightings on seagrass (Figure 5.5). These areas generally support seagrass biomasses of >100 g/m² (Figure 3.2). However, the dugongs may not be attracted to these areas by Z. capricorni broad per se. In the areas I inspected where dugongs had been feeding in a ZB community, they had selectively avoided much of the Z. capricorni broad and fed on patches of other species (sections 6.4.5 and 6.4.6). Excluding the Z. capricorni broad component, the average biomass at locations where dugong herds were seen was only 21.2 g/m² (SE = 2.9).

5.2.2.4. Habitat selection

As detailed in Appendix 4, hierarchical log-linear analyses with backward elimination identified the following variables as having a significant effect on the level of abundance of dugongs (0, 1, >1) in a grid cell: habitat, season and distance from deep water. The presence of boats, depth of the water and year were not included in the minimal model, suggesting that the distribution of dugongs did not vary between years, and that neither water depth not the presence of boats had a significant effect on their distribution. Boats, depth and year were excluded from the subsequent analyses. Water depth does influence the behaviour and distribution of dugongs, but this response is accounted for by the effect of distance to deep water. Most of the shallow areas that could be resolved by the 1 km grid were also far from deep water. Dugongs can also be sensitive to the presence of boats, under certain circumstances (Appendix 5.3; see section 5.4.6).

Subsequent analyses showed that distinguishing between the categories of one or more than one dugong per grid cell had a negligible effect on the results. It was therefore legitimate to treat dugong abundance as presence/absence data which allowed a simpler analysis (logistic regression), that was easier to interpret, to be used.

The hierarchical logistic regression analysis identified the factors that explained the proportion of survey grid-cells in which dugongs were present (response) over 28 surveys. (The grid cells outside South Passage were not surveyed on all of these surveys). The independent variables tested were season (winter, spring, summer), habitat (1-8), distance to deep water ($<$ or ≥ 1.5 km) and water temperature nested within the winter ($\leq$ or $> 19°$ C). The resultant model indicated that water temperature (in winter), distance to deep water and habitat type (which interacted with season) were the main determinants of habitat selection (Appendix 4). The analysis takes into account the relative abundance of each habitat, and therefore, the results indicate habitat preferences.

During winter, dugongs were 4.91 times (95% ci = 1.88, 12.81) more likely to be in areas with water $> 19°$ C than in areas with water $\leq 19°$ C. Dugongs were also 1.74 times (95% ci = 1.24, 2.45) more likely to be found in areas with good access to deep water (< 1.5 km away) than in areas further from deep water (≥ 1.5 km).

The interactions between habitats and seasons, after correction for distance from deep water, are graphed in Figure 5.6a. Two sets of data are presented for winter: the expected proportions of grid cells in each habitat occupied by dugongs under cold water conditions ($\leq 19°$ C), and the expected proportion after correction for the effect of temperature. During winter the dugongs obviously had a higher preference for all habitats, except the area west of the banks, under conditions of warm water than cold water. Comparing the relative difference between the warm and cold winter values with other seasons (spring, summer), it is apparent that water temperature had a greater influence on the dugongs' choice of some habitats than others. Areas of cold water in habitats dominated by Halophila and the area outside South Passage were used relatively little in winter, while the same habitats in areas of warm water were preferred habitats. The channels (Rous and Rainbow) were preferred more in winter than in other seasons, irrespective of water temperature.

After the winter values were corrected for temperature, there were significant seasonal differences in the dugongs' preferences for four habitats: those dominated by Z. capricorni broad and Z. capricorni thin, channels and the area outside South Passage (Table A.4.3). Each of these habitats was preferred in winter over the other seasons (Figure 5.6a).

Habitat preferences, after correction for water temperature and distance of habitats from deep water, are shown in Figure 5.6b and Table A.4.4. Despite the broad confidence intervals (resulting in part from the relatively coarse 1 km^2 grid), it is clear that habitats dominated by species of Halophila were preferred. The area outside South Passage also rated highly, although use of this area was primarily seasonal (Figures 5.4 and 5.6a). Seagrass areas dominated by either Z. capricorni broad, or Z. capricorni thin were not preferred over non-seagrass areas such as sandy areas, or channels. The mid-bay area west of the banks was the least preferred habitat.

The distribution of dugongs did not vary between years, and neither water depth nor the presence of boats had a significant influence on their distribution. Water depth does influence the behaviour and distribution of dugongs, but this response is accounted for by the effect of distance to deep water. Most shallow areas, that could be resolved by the 1 km grid, were also far from deep water. Dugongs can also be sensitive to the presence of boats, under particular circumstances (Appendix 5.3; see section 5.4.6).

5.2.2.5. Movement of herds

Herds of dugongs were frequently sighted at the same location on sequential aerial surveys. In some instances, boat-based observations confirmed the herd's continued presence at such sites between surveys. Table 5.4 details several examples of the feeding site fidelity of dugong herds. The estimates of the periods that herds used the same site are minimum values, as the dates when the dugongs commenced and finished using the sites were never determined. Herds of dugongs were confirmed to feed at the same location for periods of 17 to 31 days (Table 5.4). In case # 3, the locations of the herds on 17-8-89 and 4-9-89 were so close that the same seagrass patches could be identified on photographs taken to count the dugongs.

5.3. Satellite tracking

5.3.1. Methods

5.3.1.1. Capture and tagging

Dugongs were captured on the seagrass banks of the East study area using a hoop-net (Marsh and Rathbun, 1990) and fitted with satellite (UHF) and/or radio (VHF) monitored transmitters. Seven dugongs were tagged in the winter of 1988 (3 with UHF, 3 with UHF+VHF, 1 with VHF), five in the following spring (3 UHF, 1 UHF+VHF, 1 VHF) and three in the summer of 1988-89 (2 UHF, 1 UHF+VHF; Table 5.5).

The buoyant transmitters were attached by a 3 m flexible tether to an adjustable peduncle belt (see Rathbun et al., 1987 and Marsh and Rathbun, 1990 for details). Materials used in the parts of the belt and tether (wishbone, corrodible link and weak link) were modified for each tracking period in an effort to increase the length of the tracking period.

3.3.1.2. Data from the satellite transmitters

Details of the transmitters can be found in Marsh and Rathbun (1990). The satellite-monitored platform transmitter terminals (PTTs) broadcast information on location, activity and temperature at intervals of 60 seconds throughout their duty cycles.

Duty cycles

During the winter tracking period, the PTTs transmitted between the hours of 0100 and 0900, and 1400 and 2100 every second day (ie. on 8 h, off 5, on 7, off 4+24 h). This duty cycle was designed to maximise the number of satellite passes intercepted, while minimising battery drain. However with this duty cycle, the PTTs were transmitting during part of every Julian day, based on Zulu time (time in France, where the satellites are monitored and administered by Service

ARGOS). Because the fees for satellite usage are based on the number of Julian days of operation, the duty cycle was offset 11.5 h during the spring and summer tracking periods. The PTTs then transmitted every second day, based on Zulu time, and thus halved the cost of operation. Hence, during spring and summer, the PTTs operated for part of every day (local time), on a two day cycle: day 1, on between 0130 and 0830 h; day 2, on between 1230 to 2030 h (ie. on 7 h, off 4+24, on 8, off 5).

Quality of location records

Service ARGOS provides a quality rating for each PTT location. Quality 1 fixes are non-guaranteed, with 68% of fixes estimated to occur within a 1 km radius of the true location. Sixty eight percent of Quality 2 fixes are estimated to fall within 350 m radius of the true location, while this radius is reduced to 150 m for Quality 3 fixes.

Measures of activity

The PTTs transmitted two measures of activity, based on the frequency the transmitter tipped between a vertical orientation (dugong stationary, PTT floating) and a horizontal orientation (dugong moving, PTT towed). The short-term counter accumulated the number of minutes of the previous hour in which the PTT tipped through 90° to the vertical. The long-term counter recorded the number of actual tips (to a maximum of 1023) through 90° in the previous 12 h.

Non-location records

To derive a successful location, the orbiting satellite must receive a minimum of four signal transmissions during a suitable pass. Tip counter and temperature data can be received by the satellite from a single PTT transmission. Such messages are referred to as non-location records.

5.3.1.3. Home range estimation

To determine the most appropriate home range model for the PTT derived data, home range estimates derived from the following methods were compared (Appendix 6): (1) convex outer polygon, (2) multi-nuclear polygons by clustering, (3) harmonic mean (4) kernel and (5) Anderson's Fourier series. The kernel estimator was ultimately selected for use (Appendix 6.2). This model uses the bivariate normal kernel estimator to derive the fix density at each intersection of a notional grid laid across the range. The range is described in terms of a probabilistic model based on the density of fixes. Hence, the 50% isopleth of the kernel range encloses the densest 50% of fixes (Kenward, 1990). The default smoothing factor of 1.0 was used for all range analyses.

Marsh and Rathbun (1990) used Anderson's Fourier series to estimate the home ranges of five dugongs tagged with PTTs in tropical north Queensland. To allow comparison with the home ranges reported here, from sub-tropical Queensland, I re-analysed their data using the kernel estimator.

To determine whether the area over which a dugong foraged was related to the abundance of seagrass within that area, the size of home ranges were correlated with the biomass of nine species/morphs of seagrass. The biomass of seagrass within each home range was calculated by averaging the total biomass (above- plus below-ground parts) of each species of seagrass at each of the PTT fixes. Seagrass biomass at each location was assumed to be the same as the biomass of the tract of seagrass in which the location occurred. The seagrass was sampled in summer (section 3.2.3.4) so biomass estimates for the winter and spring tracking periods were adjusted to account for seasonal variation in the biomass of above- and below ground parts (correction factors derived from data in Chapter 4).

5.3.1.4. Habitat preferences

Log-linear analysis was used to examine the habitat preferences of the tracked dugongs. The response variable was the number of locations, with habitat (eight recognised habitats: see section 5.2.1.5), season of tracking (winter, spring and summer) and individual dugong (1-13), as qualitative explanatory variables. The logarithms of the areas of the habitats were used as offsets, on the assumption that the number of locations in each habitat was proportional to its area, if the dugong was not selecting for habitat. See Appendix 4 for more details of the methods.

5.3.2. Results

Two dugongs were tagged with VHF transmitters only. These transmitters provided very few locations. Boat-based tracking was restricted by the apparent diurnal activity of the dugongs (see Marsh and Rathbun, 1990 and below) which resulted in the near-constant submergence of the VHF transmitter housings, and thus attenuation of the signal. The absence of suitable elevated topography, and the distance from the coast to the dugongs (10-30 km) prevented night tracking. Hence, all the results presented are from the dugongs tagged with PTTs.

The 13 dugongs tracked in Moreton Bay included four males (two adults, two sub-adults) and nine females (five adults, four sub-adults; Table 5.5). Six dugongs were tracked through winter, four were tagged in spring and tracked through spring and summer (PTT # 234 was tracked through spring only) and three were tracked through summer (Table 5.5).

5.3.2.1. Factors affecting the number of locations received

Tracking period

The PTTs remained attached to the dugongs for an average of 50.2 days (SE = 5.7, range = 20 to 88 days; Table 5.5). There was no significant difference in the tracking period between the three tracking seasons (one-way ANOVA: df = 2, 10, $F = 1.74$, $p = 0.2249$), despite attempts to improve the retention of the PTTs. During the first deployment (winter 1988), four of the six PTTs were shed due to the premature decomposition of the corrodible link. The other two PTTs were never recovered, so the reasons for their early release could not be established. Two of the four PTTs deployed in spring 1988 detached due to the failure of the in-built weak link following attacks on the transmitter housings by sharks. The other two, which had also been attacked by sharks, as well as the three PTTs deployed the following summer, failed at an unknown part of the peduncle belt. There were no correlations between the average short- or long-term tip counts for each dugong and the number of days their PTTs remained attached: less active dugongs did not retain their PTTs for longer periods than more active dugongs (short-term tips: d.f. = 12, r = 0.2448, p = 0.4202; long-term tips: d.f. =12, r = 0.2641, p = 0.38326). This suggests that physical tensions from normal dugong activity were not responsible for attachment failures.

Duty Cycle

PTTs deployed in winter transmitted for 15 h every second day (15 h/48 h) while the spring and summer PTTs were on for seven and eight hours on alternate days (15 h/48 h). To compare the effect of this changed duty cycle, the number of locations received every two days has been halved as a measure of locations per day.

On average 1.4 (SE = 0.05) locations were received per day from all the PTTs (range: 0-4). Significantly more locations were received daily from the winter-deployed PTTs (operating on the original duty cycle; mean = 1.6) than the spring/summer PTTs (mean = 1.3; t-Test with unequal variance: df = 218.3, t = 3.23, p = 0.0016). This suggests that the change of duty cycle resulted in a 22% reduction in the number of daily locations, for a 50% saving in satellite charges. However, the reduction in location rate may also have been due to differential performance of the PTTs or to individual variation in the behaviour of the tagged dugongs. Limitations of the data (only one dugong tagged by each PTT under the original duty cycle) prevented a separation of the contributions of these potentially confounding factors.

Dugong activity

When swimming, tagged dugongs tow their PTTs below the surface and any transmissions are attenuated due to the high electrolyte content of the sea water. The PTTs float to the surface when the dugongs are resting or feeding in shallow water (Marsh and Rathbun, 1990; pers. obs.) Therefore, dugong activity affects the amount of time a PTT is at the surface, and consequently could influence the number of locations received.

The short-term tip counter records were significantly lower for location records than for non-location records, suggesting that the relatively inactive dugongs may generate more locations than more active individuals (Mann-Whitney U: location: U = 257100, n = 943; non-location: U = 387000, n = 683; p = 0.0000). However, other data suggest that this was not the case. Although some dugongs generated significantly higher average tip counts than others (parametric ANOVAs applied to ranks: Short-term counter: df = 12, 1613, F = 46.07, p = 0.0000; long-term counter: df = 12, 1613, F = 124.91, p = 0.0000), there was no correlation between average tip counts and the number of locations received per day, for the 13 tracked dugongs (short-term: d.f. = 12, r = -0.033, p = 0.91477; long-term: d.f. = 12, r = -0.0659, p = 0.83063).

5.3.2.2. Potential biases in the data

Diel pattern of habitat use

A bias in the spatial distribution of locations could develop if dugongs exhibit a diel pattern of habitat usage, that is, if they favour different habitats by day and night. Only 39.6% of locations were recorded during the day (night/day boundary based on civil twilight), despite 47.4% of sensor records (location and non-location records: an index of satellite passes) occurring during the day (this difference is significant: X^2 with Yate's correction: d.f. = 1, X^2 = 14.69, p = 0.0001). This bias in the timing of locations is due to the activity pattern of the dugongs. Based on the records from the short-term tip counter, the dugongs were significantly more active during the day than at night (Wilcoxon Signed Rank test: normal approximation with continuity correction = 6.939, p = 0.0000). Visual inspection of the plots of day and night locations, however, did not indicate any diel pattern of in habitat use.

Tidal height

At low tide the dugongs are forced off shallow seagrass banks and into deeper areas. Dugongs do not rest near the surface (pers. obs.), so when they are in deep water, their transmitters are likely to spend less time at the surface than when they are feeding in shallow (<3 m) water. More locations could therefore be expected during high tide than low tide, introducing a spatial bias in the distribution of home range fixes. However, there was no bias related to tidal height. The frequency histogram of the tidal height at the time of each location was not skewed (g_1 = 0.0734, t_s = 0.937, $p>0.2$) and there was no significant difference between the total number of locations, or the total number of non-location records received during high and low tides (top and bottom 30% of each tidal range) (X^2 contingency table with Yates correction: df = 1, X^2 = 0.41, p = 0.5195).

Lunar cycle

Activity appeared to be independent of lunar cycle. There was no correlation between tip counts and size of the tidal range (small during neap tides, large during spring tides) on the day of each tip count record (short-term: d.f. = 1627, r = 0.0028, p = 0.91012; long-term: d.f. = 1627, r = -0.0023, p = 0.92612).

5.3.2.3. Movements

Rates of movement

The maximum distance between two sequential locations, within an 8 h period was 14.5 km. The maximum rate of movement was 4.7 km/h (14.3 km over 3.05 h). Most of the large movements (13 of 14 movements over 15 km and four of five movements over 10 km in less then 8 h) occurred during winter, and all these involved travel between Moreton Bay and the adjacent ocean outside South Passage.

Winter movements out of Moreton Bay

During the period of winter tracking all the tagged dugongs left Moreton Bay and spent some time in the oceanic waters east of South Passage. The location data suggests that none of the tracked dugongs left the Bay during spring or summer. As there is no known seagrass outside the Bay, these movements were probably in response to cold water temperatures. During the period of winter tracking, water temperature (measured by sensors in the PTTs) averaged 18.2° C (SE = 0.06) compared with 23.9° C (SE = 0.06) during the spring and 25° C (SE = 0.07) during the summer tracking periods.

By periodically moving out of the Bay, the dugongs were able to reduce their exposure to cold temperatures, as water temperatures up to 10 km outside the Bay were up to 5° C higher than on the seagrass beds inside the Bay (section 2.2). During the winter period of tracking, PTT temperatures at locations inside Moreton Bay averaged 17.7° C (SE = 0.07). PTT temperatures at locations seaward of the Bay were significantly higher, averaging 19.4° C (SE = 0.23; t-Test: df = 391, t = -5.35, p = 0.0000).

A total of 24 locations were received from the area east of South Passage. Using PTT temperatures from sequential non-location records, it was possible to partially reconstruct the timing of these movements. The resolution of the reconstructions is restricted by the limited number of non-location records. The 24 locations represent at least 17 separate movements out of the Bay. On four occasions, the dugongs stayed outside the Bay for a single low tide. On six occasions, the dugongs were outside for at least a single low tide. Three dugongs stayed out for at least one high tide and four dugongs were out for at least one high tide plus the adjoining low tides.

The winter duty cycle of the PTTs restricted transmissions to every second day. Only when the PTT locations were supplemented by VHF locations from the intervening days was it possible to extend the reconstructions beyond 24 h. Dugongs were located outside the Bay, using the VHF signals from the appropriately configured PTTs, on six occasions. In four cases, the dugongs were located outside the Bay on two consecutive days. In the other instance, the dugong was located outside the Bay on three consecutive days, but this animal made at least one trip back into the Bay during this period.

5.3.2.4. Home range

Factors that affect the estimates of home range characteristics are considered in Appendix 6. As a result of those analyses, I concluded that:

1. Quality 1 locations (non-guaranteed) could be included in all home range calculations.

2. Home ranges should be based on the 95% probability isopleth. As the dugongs' ranges did not display core areas, ranges were also calculated using the 50% isopleth to allow comparisons of areas of intensive use. Selection of this value was arbitrary as it has no special biological significance.

3. The number of locations did not significantly affect the estimate of home range area, within the range of locations (30-100) that could be tested. Hence, as more than 30 locations were received from each dugong (mean = 75.1, SE = 11.3; Table 5.5), the ranges of the 13 dugongs could be compared.

4. Although the dugongs were tracked for periods ranging from 20 to 88 days (mean = 50.2, SE = 5.7; Table 5.5), there was no significant increase in the 95% home range with increasing tracking period, indicating that the ranges of all the tracked dugongs could be compared.

Size of home ranges

During the period of tracking, dugongs occupied ranges of 28-123 km^2 (Table 5.5), with an average home range size of 63.6 km^2 (SE = 8.1). 'Core areas' (arbitrarily based on the 50% isopleth) ranged from 2-22 km^2 and averaged 9.7 km^2 (SE = 1.6) during the periods of tracking (Table 5.6). The estimated home ranges of the tracked dugongs are plotted in Figure 5.7.

Due to the small sample size, it is not possible to unambiguously separate the various factors that may determine the size of the dugongs' home ranges. Analysis of variance was used to examine the effects of sex and age, together with isopleth (95% and 50%). The effect of season had to be examined separately, as only one male and one sub-adult were tracked in winter.

Males tended to maintain smaller ranges than females ($p = 0.0515$; Table 5.7). Age (adult or sub-adult) had no significant effect on home range size (Table 5.7).

During winter, the dugongs ranged over larger areas than during spring and summer combined (one-way Anova: $df = 1, 11$, $F = 5.07$, $p = 0.0458$; Table 5.6; compare Figures 5.7a, b and c). However, there was no significant difference when the three seasons were examined separately, perhaps because of the small sample sizes (3 and 4 in summer and spring respectively; one-way Anova: $df = 2, 10$, $F = 2.30$, $p = 0.1505$).

Home range size was significantly correlated with the biomass of only one species of seagrass, Z. capricorni broad ($r = 0.6331$, $df = 12$, $p = 0.0202$). Females did not have significantly higher biomasses of Z. capricorni broad in their ranges than males (one-way Anova: $df = 1, 11$, $F = 3.37$, $p = 0.0937$), but winter ranges did contain significantly more Z. capricorni broad than ranges in the other seasons (one-way Anova: $df = 1,11$, $F = 10.68$, $p = 0.0075$). A cautious summary of these results is: dugongs have larger home ranges in winter, when (or because) the ranges contain more Z. capricorni broad, and male dugongs may range over smaller areas than females.

Comparison with home ranges of tropical dugongs

The dugongs tracked by Marsh and Rathbun (1990) in north Queensland had average ranges, based on 95% and 50% of fixes, of 29.6 km^2 (SE = 9.2) and 4.1 km^2 (SE = 0.9), respectively (Table 5.8). The characteristics of these five dugongs prohibited an examination of age, sex or season effects (all were male, four were tracked in summer and four were adults; Table 5.8).

There was a significant difference in average home range size between north Queensland and Moreton Bay dugongs when all animals were included (t-Tests: 95%: d.f. = 16, t = -2.36, p = 0.0312; 50%: d.f. = 16, t = -2.89, p = 0.0106). However, when females were excluded from the Moreton Bay sample, the difference was not significant (t-Tests: 95%: d.f. = 7, t = -1.15, p = 0.2874; 50%: d.f. = 7, t = 0.02, p = 0.9842). However, this latter test has very low power.

Overlap of home ranges

The Moreton Bay dugongs were tracked for relatively short periods (20-88 days), and although home range size was not correlated with tracking duration (correlations: 95%: d.f. = 12, r = -0.0866, p = 0.7785; 50%: d.f. = 12, r = 0.0818, p = 0.7905) it must be assumed that this study did not identify the dugongs' annual ranges. Aerial survey and boat-based observations suggest that the locations of the grazing areas of dugong herds vary throughout the year, suggesting that the ranges occupied by individual dugongs may vary similarly. For this reason, dugongs tracked in different seasons cannot be compared for range overlap.

The average overlap of home ranges (mean of overlap matrices calculated for each season) was 55.4% (SE = 3.8) for the 95% ranges and 25.3% (SE = 4.6) for 50% ranges (Table 5.9). There was no significant difference between the extent of overlap between dugongs tracked during the same season (1-way ANOVAs: 95%: d.f. = 2, 45, F = 1.92, p = 0.1587; 50%: d.f. = 2, 45, F = 0.19, p = 0.8285). Limited sample sizes prevented comparisons of sex and age between seasons.

Movement of home ranges

Sequential plots of the fixes from individual dugongs indicated that some dugongs used discrete areas for periods of up to 35 days before moving their (presumed) feeding area to a different location. I refer to these temporarily preferred areas as sub-ranges. Three dugongs (# 136, 139, 236) demonstrated this pattern clearly

(Figure 5.8), while most tracked dugongs displayed no detectable pattern of sub-range use during the period of tracking. To examine the pattern of range use, data files of locations from dugongs 136, 139 and 236 were subdivided based on the timing of the change in feeding site, and separate home ranges calculated. For comparison, files of dugongs which did not use sub-ranges were subdivided into equal sized files of sequential records and ranges calculated. Locations seaward of Moreton Bay represent seasonal use of a warm water refuge, rather than a feeding area, and so were excluded from these analyses.

Dugongs 136, 139 and 236 each occupied two to four sub-ranges sequentially over four periods (Table 5.10). The four sub-ranges of dugong 136 (sub-adult female) were separate and non-overlapping (Figure 5.8, Table 5.10). Dugong 139 (adult female) used two sub-ranges which did not overlap. Each sub-range was occupied twice in turn during the period of tracking (Figure 5.8; Table 5.10). Dugong 236 (sub-adult female) displayed a similar pattern, except the third sub-range encompassed a period of apparent exploratory behaviour. The average inter-fix distance in this sub-range was 2.3 km, which is significantly greater than the mean inter-fix distance in its other three sub-ranges (1.4 km; t-Test: df = 160, t = -3.27, p = 0.0013). Sub-range three also overlapped the other sub-ranges extensively (mean = 32.7%, SE = 0.32; Table 5.10, Figure 5.8).

Sub-ranges were occupied for approximately 1-5 weeks before the dugongs moved to a different site (Table 5.10).

The pattern of range use exhibited by most of the other dugongs, within the period of tracking, is demonstrated by dugong 235 (sub-adult female). Each of the ranges, which were based on sequential sub-sets of that dugong's fixes, occupied a very similar location, with an average overlap of 77% (SE = 5.3) between ranges (Table 5.10, Figure 5.8).

5.3.2.5. Distribution of locations in relation to seagrass communities and biomass

Dugongs were located on 13 of the 15 seagrass communities recognised from the

East study area. No locations came from seagrass communities S or C: those communities composed solely of C. serrulata and S. isoetifolium respectively.

Pooling across dugongs to assess the overall proportion of fixes from different seagrass communities introduces some biases. The proportion of fixes from each community varied considerably between dugongs, depending on the focus of their activities during the period of tracking. In addition, some dugongs generated substantially more locations that others. However, the general patterns are so strong, that I consider these biases do not lead to invalid conclusions.

Of the 773 PTT locations from seagrass habitats, 81% occurred on tracts with ≤50 g seagrass/m². The mean biomass was 41.2 g/m² (SE = 2.6), although the distribution was skewed, with a median of 12.3 g/m². Excluding the biomass of Z. capricorni broad (which may not always be consumed; section 6.4.6), the mean biomass was 15.3 g/m² (SE = 0.9) with a median of 8.9 g/m². A total of 75% (580) of all the PTT locations on seagrass habitats were from communities dominated by Halophila. In those areas, the mean biomass of seagrass was 13.6 g/m² (SE = 0.4), which, on average, was comprised of H. spinulosa (9.1 g/m², SE = 0.3), H. ovalis (4.2 g/m², SE = 0.1), H. uninervis thin (0.11 g/m², SE = 0.01) and H. decipiens (0.03 g/m², SE = 0.01).

5.3.2.6. Habitat preferences

The final model from the log-linear analysis indicated that the distribution of fixes was determined by habitat, and that this relationship varied between seasons and individual dugongs (Appendix 4). The output is in the form of expected density of locations, and therefore provides a measure of habitat preference that accounts for the relative abundance of each habitat.

The dugongs' habitat preferences during each season are graphed in Figure 5.9a. Despite the broad confidence intervals (due to the small number of dugongs tracked and the considerable variation between individuals), some patterns are apparent. There was substantially greater selection of habitats dominated by Halophila, except during winter, when the use of those habitats was much reduced. This result, in part, is due to a bias in the locations of dugong captures in winter. None of the dugongs was caught on the Moreton Banks, the area that contained the greatest area of low biomass Halophila beds (Turtle Bank). Hence, few dugongs spent time in this area in winter.

There may have been a winter preference for habitats dominated by Z. capricorni broad, and a spring preference for Z. capricorni thin dominated areas. The dugongs showed relatively low preference for channel areas, the area west of the banks, or the area outside South Passage in any season. The latter area was not used at all during spring or summer.

The effect of habitat was much stronger than the interaction of habitat and season (Appendix 4), and the density of locations from each community is plotted in Figure 5.9b. The most preferred habitats were those dominated by Halophila, the low mean number of locations in low biomass Halophila notwithstanding. There was very broad overlap between habitats dominated by Z. capricorni broad and Z. capricorni thin and sand areas, while there was very little use of channels, the area west of the banks and the area outside the Bay.

5.4. Discussion

5.4.1. Size and dispersion of the dugong population

The perimeter surveys, supported by previous surveys of Moreton Bay demonstrate that the overwhelming majority of dugongs live in the vicinity of the banks of the East study area (Figure 5.2; Table 5.3). My population estimate of 600 dugongs for this area, therefore, is probably realistic for the whole of Moreton Bay. Only Marsh et al. (1990) have attempted to estimate the dugong population of Moreton Bay (other surveys have determined distribution and derived minimum counts). They estimated a minimum population of 458 dugongs (95% CI = 313-603).

Most of the dugongs in Moreton Bay typically aggregate into a small number of large herds, and in this regard, they may be unusual (section 7.4.4). Surveying such a contagiously distributed population is difficult because a substantial proportion of the population is easily missed. During one survey, for example, 569 dugongs (all that were located) were in two restricted areas (survey 25, Figure 5.1). No large herds were seen on the strip transect survey of Marsh et al. (1990), and the population estimate relies on the inclusion of a herd of 140 dugongs found during a deliberate search. This is despite a sampling fraction of 17%, which is relatively high for such surveys. Despite the high sampling intensity of my 'standard' surveys (about 70% coverage) over half the estimated population was missed on some surveys (Table 1). The herding of dugongs in Moreton Bay is considered in Chapter 7.

Aerial surveys of dugongs in Moreton Bay have spanned 14 years (Table 5.3). However, due to different aims and methodologies of the surveys, and the typically low precision of estimates of dugong populations, it is not possible to determine whether, or not, the population is stable. Welsby (1905) indicated that 300-400 dugongs lived in Moreton Bay in the late 1800's, when commercial dugong 'fishing' was practiced (Lack, 1968). However, as it is impossible to estimate accurately the size of a dugong population from boats (pers. obs.), it is not even possible to comment on any change in dugong status over the past century, except to state the obvious: there is still a substantial dugong population in Moreton Bay despite the period of past exploitation.

5.4.2. Movements

5.4.2.1. Scale of movements

The dugongs tagged in Moreton Bay were sedentary during the period of tracking. No large inter-bay movements were detected. The maximum distance between consecutive locations, within an 8 h period was 14.5 km and only five movements of more than 10 km were recorded for the same period. The maximum rate of movement was 4.7 km/h (14.3 km over 3.05 h). A dugong tracked by Marsh and Rathbun (1990) demonstrated the scale of movements dugongs may undertake. Their dugong D1 moved a minimum distance of 143 km immediately after it was tagged. Six weeks later, D1 returned to its area of capture, travelling for two days at an average speed of 3 km/h. After a further two days D1 returned to his former range. At the other extreme, Marsh and Rathbun (1990) also tracked a dugong (using a VHF transmitter) that was particularly sedentary, apparently staying within 3 km of its capture site for 16 months.

Dugong D1 was the only dugong out of the 19 tracked in north Queensland and Moreton Bay that undertook large movements within the periods of tracking. The speed with which D1 travelled between areas, and his apparent familiarity with his destinations (no exploratory movements) suggests his long movements were not aberrant, and that his home range was in fact split between areas 140 km apart. The other 18 dugongs so far tracked occupied single ranges and did not undertake any large movements, during the periods of tracking. Some Florida manatees undertake large movements, in excess of 500 km, between areas, but these movements are associated with seasonal migrations (Reid et al., 1991).

5.4.2.2. Migratory movements

Six percent of PTT fixes received during the winter tracking (1988) came from the oceanic waters east of Moreton Bay. This figure underestimates the amount of time dugongs spend in this area, as the dugongs rest below the surface (pers. obs.), so few transmissions are received by the satellites. On the aerial surveys conducted during the winter (1988) tracking, 16.1% (SE = 6.2) of dugongs sighted were outside South Passage. This is likely to be a considerable underestimate because the surveys were conducted at high tide, when the dugongs were more likely to be in the Bay feeding, and because the dugongs dispersed well beyond the area searched. In contrast, no tracked dugongs were recorded outside the Bay during spring or summer. On the non-winter surveys that searched outside South Passage, only 3.7% (SE = 2.0) of dugongs were outside the Bay. This compares with 25.0% (SE = 7.9) in winter (1988 plus 1989).

Temperature appears to be responsible for the dugongs' movements out of the Bay in winter. Winter water temperatures on the seagrass banks can be 5°C colder than the oceanic water within 10 km of the South Passage entrance to

Moreton Bay (section 2.2). During 1989, winter temperatures were significantly colder than during 1988 (section 2.2), and a substantially larger proportion of the number of dugongs seen during the winter aerial surveys were in the warm water east of the Bay (33.9%, SE = 13.9 in 1989 compared to 16.1%, SE = 6.2 in 1988; Figure 5.4).

Manatees, and presumably dugongs, have low metabolic rates, high thermal conductivities and limited thermoregulatory abilities (Irvine, 1983; Gallivan and Best, 1980; Gallivan et al., 1983). The lower critical temperature for the Amazonian manatee is 22-23°C (Gallivan et al., 1983). The Florida manatee seeks warm water refugia when water temperatures drop to 20-21°C (Bengtson, 1981; Hartman, 1979), which is the minimum water temperature at which the species can remain unstressed indefinitely (Irvine, 1983). On the basis of aerial survey data, Anderson (1986) infers a seasonal migration of dugongs in Shark Bay, that is apparently induced by water temperature. When water temperatures in the eastern part of the Bay fall below about 19°C, the dugong density in an area flushed with relatively warm oceanic water rises. Less than 4% of dugongs ($n = 437$) sighted during a winter aerial survey of Shark Bay were in water <18°C (Marsh et al., 1991). The Florida manatees also undertake seasonal migrations related to water temperature. During winter, they congregate in the warmer southern parts of the State, or around point-source warm water refugia, and during summer they disperse northwards (Lefebvre et al., 1989; Packard, 1981; Rathbun and O'Shea, 1984; Reid et al., 1991).

Moreton Bay is the southern limit of dugong distribution in eastern Australia. During winter, I have recorded water temperatures on the seagrass banks in the eastern part of the Bay as low as 14.7°C, although they probably average between 16 and 19°C during this season (Figure 2.3b). The coldest water in which I encountered dugongs was 16.0°C (24 July 1989). Irvine (1983) suggests that manatees can forage in cold water (≤16° C) if they can later digest in warmer water. By travelling outside the Bay, dugongs can raise their ambient temperature by up to 5° C. The average water temperature recorded by the PTTs from inside the Bay during the 1988 winter was 17.7°C (SE = 0.07), which was significantly colder than the records from outside the Bay (19.4°C; SE = 0.23).

Observations during the aerial surveys and from boats indicate that during cold periods in winter, movements in and out of the Bay coincide with the flow of tides in and out of South Passage. During the surveys in winter, dugongs were frequently seen swimming into the Bay on rising tides and out on falling tides. This synchrony allows the dugongs to ride the flush of warm water that enters the Bay as the flood tide, to access the seagrass beds during the high tide and, if necessary, to leave the Bay with the ebb current. This coordination presumably makes the 15-40 km round trip between feeding areas and the warm water refuge energetically sustainable. The timing of the dugongs' movements, relative to the tides, suggests that the dugongs may spend as little as 1-1.5 h foraging per tide cycle (low tide to low tide), assuming they remained in the Bay during high tide only. In one instance (survey 18, Figure 5.1b) I observed a herd of about 250 dugongs which had recently departed the Bay. Just 1.3 hours after the top of the tide (at South Passage) they were 5 km east of South Passage and still purposefully swimming out to sea. The further west from South Passage, the later the tide, so if those dugongs had been feeding on the Maroom Bank, they would have had to commence their exodus before the top of the high tide. This suggests that those dugongs had already been in the Bay before high tide, or that they had been feeding in an area close to South Passage. All dugongs tracked in winter had centres of activity close to South Passage (Figure 5.7b).

None of the areas of seagrass near South Passage was commonly used as feeding sites (Figure 5.1b and pers. obs.), although I found one area, which is the closest seagrass to South Passage, that was heavily grazed during the winter of 1989. The 51 ha patch of Z. capricorni thin and H. ovalis (community ZT2) was so heavily grazed during the 1989 winter that the aerial photographs taken on 2 September 1989 (for seagrass mapping) indicated the area was virtually bare sand. When the patch was sampled in December 1989, the remnants of feeding trails were obvious, but the seagrass had recovered to a biomass of 202.7 (SE = 80.2) g/m^2.

The periodicity of movements of individual dugongs in and out of the Bay during winter is not clear, due to the constraints imposed by the winter duty cycle of the PTTs. The limited data indicate that individual dugongs may stay outside the Bay for up to several days at a time, and that they make brief (high tide) feeding sorties into the Bay during that period. Much of the time the dugongs stayed out of the Bay only during low tide, returning regularly to feed. When necessary, Florida manatees can stay in their warm water refuges without feeding for up to a week (Bengtson, 1981), and under different circumstances, Amazonian manatees may fast for months (Best, 1983).

The area outside Moreton Bay would normally be considered unfavourable dugong habitat. It is deep (sloping to over 50 m), exposed to high energy wave action, and supports no seagrass. Furthermore, because the dugongs do not stay near the bottom, where their relatively soft under-belly can be protected, they are potentially more vulnerable to predation by sharks. Although South Passage is characterised by an extensive area of breaking surf, it is no obstacle to the dugongs, which were frequently seen in the surf zone.

The only obvious resource provided by the area outside the Bay is refuge from the cold water temperatures. In this regard, the dugongs behave like Florida manatees, which aggregate at warm-water refuges in winter, despite a paucity of food nearby (Packard, 1981).

If the water temperatures inside the Bay are below the dugong's tolerable threshold, access to the warm oceanic waters may be essential for their year-round occupation of Moreton Bay. If the dugongs were not able to move rapidly between feeding areas and the warm water refuge, they would be forced to migrate to warmer areas. Hervey Bay, 250 km to the north, is the nearest large area of suitable habitat. Although dugongs are occasionally caught in shark nets along the coast between Moreton Bay and Hervey Bay (Paterson, 1979, 1990), there is no evidence of any migratory movements between them.

The movement of dugongs between the seagrass banks of Moreton Bay and the nearby warm water refuge is functionally equivalent to a migration. Although there is no universally accepted definition of migration (see Baker, 1978; Taylor and Taylor, 1983; and Kenney, 1985), the movements described for the Moreton Bay dugongs comply in most respects with most definitions. In particular, the movements are seasonal in occurrence and involve travel between two distinct habitats to maximise resource utilisation. The movements also have a pronounced direction ratio (Baker, 1978). Although the scale of the migratory movements is small, relative to the dugong's capacity for travel, small movements of comparable animals are also considered to be migrations. For example impala (Aepyceros melampus) use open woodland during the wet season but migrate a few hundred metres in the dry season to habitats close to rivers (Sinclair, 1983). The regular (sometimes daily) nature of the dugongs' movements between the two habitats may be seen as a contradiction of the concept of migration. This periodicity of movements is a function of the proximity of the two essential habitats. If the dugongs could not move between habitats so efficiently they would probably be forced to make a single, large seasonal migration. Irrespective of the periodicity of the movements, the ecological purpose of the migration is fulfilled (Taylor and Taylor, 1983).

5.4.3. Home range

5.4.3.1. Home range form

The dugongs exhibited a variety of home range shapes, including circular, dumb-bell and irregular (Figure 5.7). Each dugong had at least one area of concentrated use within its range. These areas, arbitrarily defined as containing 50% of fixes, occupied an average of just 15.4% (SE = 1.9) of the area of home ranges (based on 95% of fixes). The areas of concentrated use were not obvious and easily delineated, as are core areas of species that use home sites or where shelter and food resources are patchily distributed (eg. Springer, 1982; Clutton-Brock et al., 1982; Samuel et al., 1985). The absence of distinct core areas in the ranges of dugongs in Moreton Bay suggests that feeding and resting areas are not spatially restricted. Similarly, some African ungulates, unrestrained by patchy resources, do not have core areas within their home ranges (Leuthold, 1977).

5.4.3.2. Home range size

The dugongs were tracked for an average of 50.2 days, just 0.27% of their life spans (assuming a life span of 50 years; see Marsh, 1980). As time scale is an important component of home range (Spencer et al., 1990), the estimates do not represent the life-time or even annual ranges of these animals. During the periods of tracking, the dugongs occupied home ranges averaging 63.6 km^2.

The home ranges were significantly larger in winter than during the other seasons. This difference is probably due to the pronounced seasonality of the Moreton Bay environment (section 2.2). The standing crop of most seagrasses declines through winter and spring (section 4.3.2.2), so the dugongs may need to forage over a larger area to meet their nutritional requirements. Furthermore, the low temperatures during winter force the dugongs periodically to leave Moreton Bay to seek refuge in the nearby warm oceanic waters, so they must move over larger areas.

The winter expansion of the home ranges was greater than the estimates of home range indicate. This is because relatively few fixes were received from outside South Passage, where the dugongs tend to stay well below the surface. Moreover, the winter locations from outside Moreton Bay were the fixes most distant from the range centers (Figure 5.7), so they were the first fixes to be rejected when probability contours (less than 100%) were calculated. Consequently, the 95% home ranges of only three of the six dugongs tracked during winter actually included habitat outside of Moreton Bay (Figure 5.7a), even though all the dugongs spent some time outside the Bay.

There was also a tendency (although the sample is small), for male dugongs to have smaller ranges than females. This contrasts with Florida manatees, where adult males maintain larger home ranges than females, at least during the period of mating. In summer, the adult male manatees patrol large ranges in search of oestrous females, while females and young males appear to occupy relatively small home ranges along specific stretches of river. During spring there is no sex- or age-based difference in range use, and in winter, most manatees are confined to small warm water refugia (Bengtson, 1981). Aspects of the mating behaviour of dugongs in Moreton Bay are similar to those of Florida manatees (Preen, 1989b), and differences in habitat and herding behaviour may account for the difference in the males' home ranges. In Florida, manatees tend to be solitary (outside their refuges) and spend much of their time in linear, sometimes inter-connected coastal waterways (Bengtson, 1981). In Moreton Bay, dugongs tend to occur in herds (Chapter 7) in a large, relatively uniform area. Therefore, male dugongs could monitor large numbers of females without requiring a range larger than the females.

The home ranges of the Moreton Bay dugongs, from sub-tropical Queensland, on average, were more than twice the size of the ranges of dugongs from tropical Queensland (mean = 63.6 km^2, SE = 8.1, compared with 29.6 km^2, SE = 9.2). When only male dugongs were considered (no females were tracked in north Queensland) the Moreton Bay ranges were still larger, but the statistical significance was lost due to reduced sample size. In many African ungulates, home range size is highly flexible, adapting to varying environmental conditions (Leuthold, 1977). For example, the home ranges of African buffalos (Syncerus caffer) vary greatly between regions: estimates from different locations include 10, 80, 222, 250 and 700 km^2 (Taylor, 1989 and references therein).

Virtually nothing is known of the seagrasses or the physical environment in the home ranges of the dugongs tracked in north Queensland, so it is difficult to explain this disparity between regions on the basis of environmental differences. An alternative explanation may be found in the herding tendencies of the dugongs in the two areas. The more conspecifics that share an individual's home range and consume its resources, the larger that home range must be (Damuth, 1981). In Moreton Bay, most dugongs occur in herds of more than 140 animals (section 7.3.1), and home ranges of individuals overlap extensively (as is normal for large, herding species; Damuth, 1981). In tropical Queensland, dugongs typically occur in groups of much less than 10 (section 7.4.4), and home ranges are relatively small.

5.4.3.3. Movement of herds and home ranges

Some of the tracked dugongs had distinct sub-ranges, within their home ranges. They concentrated their activities in these temporarily favoured areas for periods of up to 35 days, before moving their centre of activity to another sub-range (Figure 5.8, Table 5.10). Similarly, herds of grazing dugongs showed short-term site fidelity. Herds were seen to return to feed at the same location for periods of up to at least 31 days (Table 5.4). Because recognition of individual dugongs is generally not reliable, only once was I able to confirm the presence of the same individuals (two distinctly scarred dugongs) in the same herd on different days. It seems probable, however, that the stable feeding sites of herds correspond to sub-ranges within the range of each dugong in the herd. The fluctuations in the number of dugongs seen in herds at the same location (Table 5.4), however, indicate that the membership of the herds was fluid. Counts from the air (boat-based estimates are unreliable) show that the number of dugongs at a feeding site could vary by a factor of five in a month (case 4, Table 5.4). Hence, the movements among sub-ranges may have been linked only weakly with the movements among feeding sites by herds. On one occasion a satellite tagged dugong (PTT 136) moved between two geographically stable herds.

The sub-ranges of tracked dugongs tended to be small (average of 23.8% (SE = 7.2) of range based on all fixes). However, one sub-range of one dugong (# 236: sub-adult female; Figure 5.8) covered a large area (103% of home range estimated from all fixes). This sub-range apparently encompassed a period of exploratory behaviour. The average distance between locations within this sub-range was significantly greater than within its other three sub-ranges, and it overlapped extensively with the other sub-ranges. This behaviour may allow the dugong to locate new areas of seagrass that are at a favourable growth phase. Herbivores need to sample a variety of feeding areas in order to keep track of the current quality rankings of the vegetation (Owen-Smith and Novellie, 1982), even though they may spend most of their foraging time in areas where food acquisition is most profitable (Ellis et al., 1976). In moose (Alces alces; Addison et al., 1980) and Black bear (Ursus americanus; Klenner, 1987) occupancy of restricted areas, for up to several weeks, is followed by a period of extensive movements before localised activity in a favourable feeding area is resumed. Herds of African buffalo often remain in one locality for 4-10 days before moving several kilometres to a new locality (Taylor, 1989; Sinclair,1977), although this behaviour is not necessarily related to food.

Although most of the dugongs tracked did not exhibit unambiguous sub-ranges, the impression gained from the aerial surveys was that most of the dugong population concentrated their activity in small areas for days to weeks, before moving to another location. The fact that this behaviour was only detected in three tracked dugongs may have been an artefact of the short tracking periods (20-88 days).

5.4.4. Distribution of dugongs in relation to seagrass communities and biomass

Some areas of the eastern banks, such as the Turtle and Maroom Banks (Figure 2.2), were used consistently by the dugongs, large herds being seen on parts of these areas during virtually all surveys (Figure 5.1b). Other areas, such as the Oyster, Wanga Wallen and Dunwich Banks were rarely, if ever, seen to be used by dugongs. Some of these latter areas were relatively shallow (see Figure 2.9), however, all were covered by at least 1 m of water during most high tides, and hence were accessible to the dugongs at the times of the aerial surveys. Those vegetated banks not used by dugongs were dominated by Z. capricorni broad (see Figure 3.1) or rarely by S. isoetifolium or C. serrulata (on the deeper parts of the Wanga Wallen Bank).

The areas where dugongs were most frequently seen were dominated by species of Halophila (community-group H). Seventy-six percent of all dugongs sighted on seagrass banks, and 75% of all PTT locations on seagrass banks were on seagrass communities dominated by Halophila species.

The areas favoured by dugongs were also characterised by low seagrass biomass. A total of 81% of dugongs sighted on the seagrass beds, and 81% of all the PTT fixes on seagrass beds were on tracts of seagrass with mean biomasses of <50 g/m². Excluding the contribution of Z. capricorni broad, the mean biomass of seagrass at the locations of sighted dugongs was 21.2 g/m², compared to 15.3 g/m² at the locations of PTT fixes.

The mean biomass of seagrass at the sites where dugong herds were seen on tracts dominated by Halophila (76% of sightings) and where PTT locations occurred on tracts dominated by Halophila (75% of total) was 13.3 g/m² (SE = 0.4) and 13.6 g/m² (SE = 0.4), respectively.

In contrast, areas dominated by Z. capricorni, S. isoetifolium or C. serrulata had biomass values of greater than 100 g/m² (mostly greater than 200 g/m², Figure 3.2), and accounted for only 23% of aerial survey sightings and 25% of PTT fixes.

5.4.5. Habitat selection

During winter, the distribution of the dugongs is strongly influenced by water temperature. Dugongs were 4.91 times more likely to be found in areas warmer than 19° C than in cooler areas, even after adjustment for the relative size of these areas. Across all seasons, dugongs were also more likely to be found in areas with relatively close access to deep water (<1.5 km).

Habitat type was another major determinant of dugong distribution. The separate analyses of the aerial survey and satellite tracking data resulted in broadly similar season by habitat interactions that accounted for the distribution of the dugongs (Figures 5.6, 5.9 and 5.10). The similarity of these results is perhaps surprising, given the different biases in the two data sets. The aerial surveys were all conducted around high tide, while the timing of fixes had a slight day-night bias (section 5.3.2.2). The biases inherent in the two methods may also account for some of the differences between their results. For example, the aerial surveys indicated that the dugongs had a relatively high preference for channels and the area outside South Passage, especially in winter (Figure 5.6), but this pattern was not supported by the tracking data (Figure 5.10). The low number of locations received from these areas was probably due to their depth (>3 m), and the relatively small amount of time the PTTs would have spent at the surface. The outside area was used as a warm water refuge, while the channels were the pathways used by the dugongs as they travelled in and out of the Bay. The Rous Channel may also have been used as a specialised feeding area (section 6.4.1.2).

Taking into account the relative areas of different habitats, the effect of water temperature (in winter), and the different location of habitats relative to deep water, both analyses confirmed that the dugongs had a strong preference for habitats dominated by Halophila species (Figure 5.10). This community-group was preferred over other seagrasses during all seasons, although some seasonal changes in seagrass preference were apparent (Figures 5.6 and 5.9). The dugongs used the low-biomass seagrass communities dominated by H. ovalis less during winter than other seasons. During this time they spent more time in the warm waters east of the Bay. Seagrass areas dominated by Z. capricorni broad were used most in winter, while areas dominated by Z. capricorni thin were preferred in spring.

The dugongs displayed a relatively high preference for sandy areas devoid of seagrass (Figure 5.10). The dugongs may feed in these areas. The stomach of one dugong that had been feeding in a predominantly sandy area contained a large number of colonial polychaetes (see section 6.4.2.2). In comparison, the area to the west of the Banks was little used by the dugongs, especially in winter, when it is colder than other areas of the East study area.

Selection for seagrass communities does not necessarily imply selection for all the seagrasses in those communities. For example, selection for communities dominated by Z. capricorni broad does not necessarily reflect a preference for Z. capricorni broad per se. Community ZB4 is composed of similar volumes of Z. capricorni broad and H. spinulosa (Table 3.2) and has a localised distribution (the western half of the Warragamba Bank; Figure 3.1). It was noted during aerial surveys of this area during the winter of 1988 that the seagrass was particularly patchy. Subsequent underwater inspection revealed that the dugongs had grazed the area selectively, removing the patches of H. spinulosa and largely avoiding the Z. capricorni broad. I documented similar feeding behaviour in other areas (section 6.4.5).

5.4.6. Boats and dugongs

The presence of boats was not a significant determinant of dugong distribution in the East study area (Appendix 4). My observations, however, establish that dugongs are sensitive to boats under particular circumstances (Appendix 5.3). When dugongs are in shallow water and/or are distant from deep water, they strongly avoid boats. When they are in deep water, they are often quite tolerant of boats. Due to the variable bathymetry that can occur within a grid cell, these interactions can occur on a scale that would rarely be detected by the resolution of the 1 km^2 grid. It should also be noted, that because of the virtual absence of dugongs from the West study area, this area, which had a high density of boats, was not included in the analyses.

Boats were most abundant in the inshore area. The West study area contained approximately 25% of the total survey area, but accounted for 46% of the number of boats recorded (Appendix 5). The same surveys demonstrated that the West study area contained only a small proportion of the dugongs in the study areas: just 15 of the 10,326 sightings occurred in the West study area. The perimeter surveys indicated that this low density of dugongs is typical of the western and southern parts of the Bay, where urban development and boat traffic are greatest.

The reciprocity of distributions of dugongs and boats in the East and West study areas suggests possible avoidance of areas of high boat use by dugongs. Certainly within the East study area, dugongs in shallow water, or far from deep water actively avoid boats (Appendix 5). Marsh (1989b) plotted the density of dugongs against the approximate area of seagrass in 23 areas along the central and north Queensland coast and found that five of the six sites with the lowest dugong density were characterised by high boat traffic. Anecdotal evidence supports the suggestion that dugongs have been displaced from the inshore areas in Moreton Bay by boat traffic. Although dugongs are now virtually absent from the West study area, which includes Fisherman Islands and St. Helena Island, this has not always been the situation. Within the last century, Aborigines hunted dugongs at Fisherman and St. Helena Islands (Alfredson, 1984; Petrie, 1932), and a dugong oil industry was established on St. Helena (Lack, 1968; Welsby, 1905). A professional bait-worm collector that I interviewed (14 January 1990) on Fisherman Islands maintained that dugongs were common in that area when he was young (25-30 years ago) and speculated that their present absence was due to the high level of boat traffic. Similarly, in a discussion on dugongs in Moreton

Bay in the late 1800's, Welsby (1905, p. 99) stated "In former days they could be found in summer in Redland Bay, but the traffic of steamers has driven them out of that.". Only three dugongs were seen in the Redland Bay area on the two perimeter surveys (Figure 5.2), yet four of the 10 dugong deaths I documented during this study came from this area, and at least two of these resulted from boat strikes. In Florida, where boat traffic is intense, boat strikes are the major identifiable cause of mortality in manatees, (Lefebvre et al., 1989; O'Shea et al., 1985), accounting for 25% of all known deaths (Wright et al., 1992). Packard (1984) noted that Florida manatees avoided feeding in areas that were very shallow, or that were regularly occupied by fishers.

5.4.7. Dietary preferences

Observations from the aircraft and from my boat confirmed that when dugongs are on the seagrass banks they spend much of their time feeding. Consequently, the distribution of dugongs, in relation to the seagrass communities, and the habitat preferences illustrated in Figures 5.6 and 5.9, provide an indication of the dietary preferences of the dugongs. The dugongs select for seagrass in areas dominated by Halophila species, even though the biomass of seagrass in these areas is relatively low. The most favoured species appear to be H. ovalis, H. spinulosa and H. uninervis thin. The dugongs generally avoid the high biomass species (Z. capricorni, S. isoetifolium and C. serrulata), but they may feed on Z. capricorni broad and Z. capricorni thin seasonally. Observations of feeding sites in areas dominated by Z. capricorni broad, however, indicate that the dugongs often feed selectively, avoiding the Z. capricorni and removing the patches of H. ovalis, H. spinulosa, H. uninervis or S. isoetifolium. Dugongs were not recorded on areas of C. serrulata, but this species has a restricted distribution in Moreton Bay (Figure 3.1), so no conclusions about preference can be drawn. The food preferences of dugongs in Moreton Bay are considered in more detail in the next chapter.

Table 5.1. Details of the 'standard' aerial surveys of the study areas in Moreton Bay.

Survey #	Date	Day of week	Season	Duration of survey (minutes)	Survey conditions[1]	Surveyed outside South Passage	Dugongs counted
1	15-7-88	Fri	winter	89	4	Yes	329
2	13-8-88	Sat	winter	87	3	Yes	295
3	29-8-88	Mon	winter	75	5	Yes	389
4	16-9-88	Fri	spring	82	2	Yes	381
5	9-10-88	Sun	spring	90	2	Yes	382
6	26-10-88	Wed	spring	79	2	Yes	432
7	15-11-88	Tue	summer	65	5	-	386
8	28-11-88	Mon	summer	70	5	-	361
9	21-12-88	Wed	summer	71	5	-	369
10	3-1-89	Tue	summer	69	4	Yes	201
11	9-2-89	Thu	summer	75	3	Yes	269
12	21-2-89	Tue	summer	75	4	-	300
13	6-3-89	Mon	summer	63	1	-	332
14	21-3-89	Tue	summer	77	4	-	569
15	18-4-89	Tue	autumn	81	4	-	366
16	24-5-89	Wed	autumn	72	3	Yes	219
17	19-6-89	Mon	winter	75	3	Yes	250
18	21-7-89	Fri	winter	66	5	Yes	415
19	17-8-89	Thu	winter	74	5	Yes	367
20	4-9-89	Mon	spring	71	5	Yes	510
21	17-9-89	Sun	spring	76	5	Yes	567
22	2-10-89	Mon	spring	87	3	-	492
23	16-10-89	Mon	spring	72	1	-	306
24	31-10-89	Tue	spring	74	2	-	368
25	15-11-89	Wed	spring	72	5	-	532
26	29-11-89	Wed	spring	80	1	-	342
27	2-1-90	Tue	summer	70	4	-	313
28	9-2-90	Fri	summer	63	1	-	284
Overall (SE)				75 (1.4)			368.8 (17.9)

[1] 1: Very poor; 2: Poor; 3: Fair; 4: Good; 5: Excellent

Table 5.2. Result of analysis of variance testing for year and seasonal differences in the number of dugongs counted during 'standard' aerial surveys of the study areas in Moreton Bay.

Factor	df	MS	F	p
Year[1]	1	6.580	0.00	0.9780
Season[1 2]	3	15812.1	1.87	0.1662
Yr*Season	2	4257.8	0.50	0.6121
Error	21	84712.0		
Total	27			

[1] Fixed factors
[2] 1988: winter, spring, summer, autumn; 1989: winter, spring, summer

Table 5.3. Results of previous aerial surveys of Moreton Bay, as well as surveys from this study, demonstrating the relative importance of the habitats in the East study area for dugongs in Moreton Bay.

Date	Flight path/survey area	Total dugongs	% in East study area	Reference
May 1977	24 transects traversed all Bay between Peel and Bribie Islands	210	95	Heinsohn, 1977
May 1976	Western edge of Moreton and North Stradbroke Islands plus additional trasects over the eastern banks. Included area east of South Passage	283	97.8	Lear, 1977
September 1976		184	98.4	"
October 1976		148	98.6	"
December 1976		118	100	"
January 1977		268	99.1	"
August 1979	Perimeter survey plus additional transects over eastern banks	307	82	Heinsohn and Marsh, 1980
July 1988	Strip-transect survey of entire Bay. Included area east of South Passage	168	98.8	Marsh et al., 1990
March 1989	Perimeter survey plus standard survey	351	94.6	This study
July 1989	Perimeter survey plus standard survey. Included area east of South Passage	420	98.8	This study

Table 5.4. Evidence of feeding site fidelity. Examples of dugong herds feeding in the same location for extended periods. All sightings were made around high tide, when there was sufficient water on the banks (> 1.5 m) for the dugongs to be present. Sightings from the air were made during 'standard' aerial surveys and the locations of the herds are plotted in Figure 5.1b. Each Case refers to a separate feeding site.

Case	Apparent minimum period of usage (days)	When sighted (date)	Sighted from	Estimated number of dugongs
1	17	6-3-89	air	223
		7-3-89	air[1]	not counted
		8-3-89	boat	~70
		9-3-89	boat	'large herd'
		10-3-89	boat	~50
		12-3-89	boat	~100
		21-3-89	air	459
		23-3-89	boat	~100
2	21	3-6-89	boat	~50
		19-6-89	air	22
		23-6-89	boat	30-50
3	31	17-8-89	air	153
		22-8-89	boat	~100
		31-8-89	boat	~100
		2-9-89	boat	~150
		4-9-89	air	187
		17-9-89	air	219
4	31	17-8-89	air	54
		4-9-89	air	133
		17-9-89	air	302

[1] Perimeter aerial survey.

Table 5.5. Details of 13 dugongs tracked by satellite telemetry in Moreton Bay.

	Dugong Number												
	134	135	136	137	138	139	234	235	236	239	334	335	339
PTT number	5534	5535	5536	5537	5538	5539	5534	5535	5536	5539	5534	5535	5539
VHF transponder	-	-	-	Yes	Yes	Yes	-	-	-	Yes	-	-	Yes
Body length (m)	2.8	2.96	2.23	2.8	2.6	2.98	2.6	2.28	2.27	2.18	2.48	2.39	2.8
Age class[1]	Adult	Adult	Sub-adult	Adult	Adult	Adult	Adult	Sub- adult	Sub- adult	Sub- adult	Sub- adult	Sub-adult	Adult
Sex	Male	Female	Female	Female	Female	Female	Male	Female	Female	Male	Female	Male	Female
Capture date	14-6-88	14-6-88	14-6-88	13-6-88	13-6-88	12-6-88	14-10-88	12-10-88	12-10-88	11-10-88	10-1-89	7-1-89	10-1-89
Tracking season	Winter	Winter	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Summer	Summer	Summer
Tracking period (days)	48	70	30	29	29	32	20	57	88	62	63	66	59
Number of locs.	105	112	71	37	32	60	31	115	166	50	43	96	59
Mean locations per day	2.08	1.54	2.19	1.21	0.97	1.68	1.36	1.95	1.81	0.75	0.66	1.40	0.97
Home range: 95%[2] (km^2)	49.2	122.6	79.0	99.6	91.8	41.1	46.9	28.4	56.0	33.6	86.8	39.1	52.9
Home range: 50%[2] (km^2)	4.1	18.6	22.4	12.7	8.6	7.0	2.0	5.4	11.6	5.1	10.0	5.1	13.1

[1] Based on age-length relationship of Marsh (1980).
[2] Based on the densest 95% and 50% of fixes, using the kernel estimator.

Table 5.6. Average areas of the home ranges[1] of 13 dugongs tracked in Moreton Bay, calculated for each sex, age class, season and for all animals.

			Home Range (km^2)			
			95% isopleth		50% isopleth	
		n	Mean	SE	Mean	SE
Total		13	63.6	8.1	9.7	1.6
Sex	Female	9	73.1	10.2	12.1	1.8
	Male	4	42.2	3.6	4.1	0.7
Age	Sub-adult	6	53.8	10.0	9.9	2.7
	Adult	7	72.0	12.1	9.4	2.2
Season	Winter	6	80.5	12.6	12.2	2.9
	Spring	4	41.2	6.3	6.0	2.0
	Summer	3	59.6	14.1	9.4	2.3

[1] Based on the kernel estimator, see Appendix 5.

Table 5.7. Results of analysis of variance testing the effect of home-range isopleth, dugong sex and dugong age on the home range of 13 dugongs in Moreton Bay.

Factor	df	MS	F	p
Isopleth (Iso)[1 2]	1	8649	21.00	0.0002
Sex[1]	1	1791	4.35	0.0515
Age[1 3]	1	209	0.51	0.4852
Iso*Sex	1	548	1.33	0.2636
Iso*Age	1	294	0.72	0.4088
Sex*Age	1	283	0.69	0.4175
Iso*Sex*Age	1	359	0.87	0.3627
Error	18	412		
Total	25			

[1] Fixed factors
[2] 50% and 95%
[3] Adult and sub-adult

Table 5.8. Details of 5 dugongs tracked by satellite telemetry in north Queensland. Further details are presented in Marsh and Rathbun (1990).[1]

	Dugong Number						
	D1	D3	D4	D5	D6	Mean	SE
Body length (m)	2.30	2.52	2.53	2.73	2.42		
Age class	Sub-adult	Adult	Adult	Adult	Adult		
Sex	Male	Male	Male	Male	Male		
Tracking season	Spring	Summer	Summer	Summer	Summer		
Tracking period (days)	63	47	94	64	32	48	15
Number of locations	142	88	170	87	92	115	17
Home range (km^2) 95%[2]	26.8	7.3	18.2	33.9	62.0	29.6	9.2
50%[2]	4.9	1.5	2.2	5.0	6.9	4.1	0.9

[1] Marsh and Rathbun (1990) estimated home ranges using Anderson's Fourier series.
[2] Based on kernel estimator.

Table 5.9. Percentage overlap of home ranges of 13 dugongs tracked in Moreton Bay. Home range areas are based on the densest 95% and 50% of fixes, corresponding to the home range boundary and the area of concentrated use.

		# of	# of	Home Range Overlap (%)			
				95% HR[1]		50% HR	
		dugongs	overlaps	Mean	SE	Mean	SE
Overall		13	156	41.0	2.2	15.8	2.1
Both Sexes	Winter	6	30	59.6	3.9	24.6	5.9
	Spring	4	12	42.8	9.8	29.7	9.5
	Summer	3	6	59.7	8.3	20.1	10.4
	Average		48	55.4	3.8	25.3	4.6
Females	Winter	5	20	66.0	4.7	50.0	8.3
	Spring	2	2	74.1	17.5	51.6	13.2
	Summer	2	2	55.4	8.8	9.2	1.1
	Average		24	65.8	4.3	35.8	6.6
Males	Spring	2	2	15.4	1.7	0.0	0.0

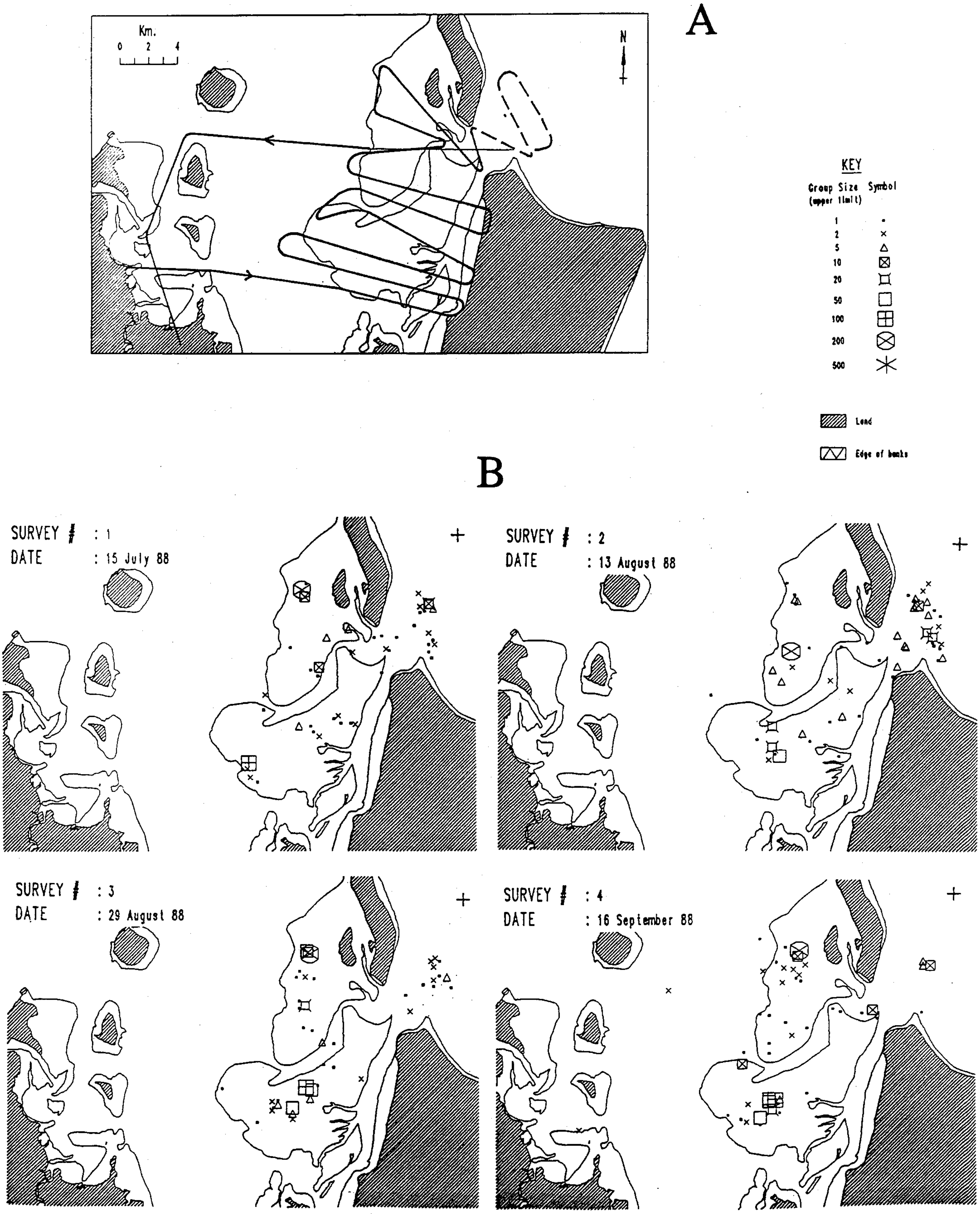
[1] Home Range calculated using kernel estimator.

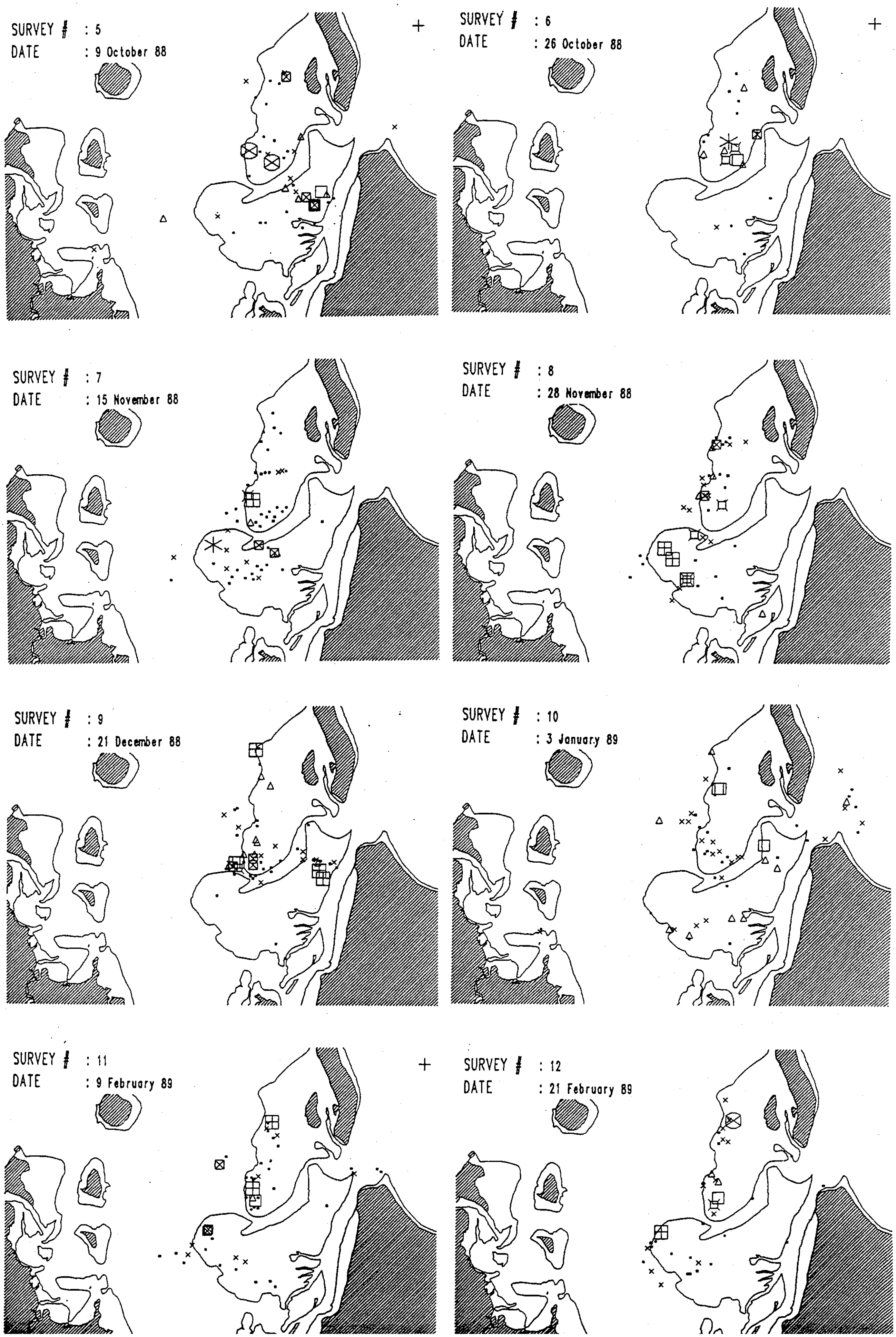
Table 5.10. **Pattern of range use exhibited by selected dugongs tracked in Moreton Bay. Dugongs 136, 139 and 236 sequentially utilized a series of sub-ranges, which are numbered by order of use.** For comparison, **the range of dugong 235 is divided into four periods comprising equal numbers of sequential locations.**

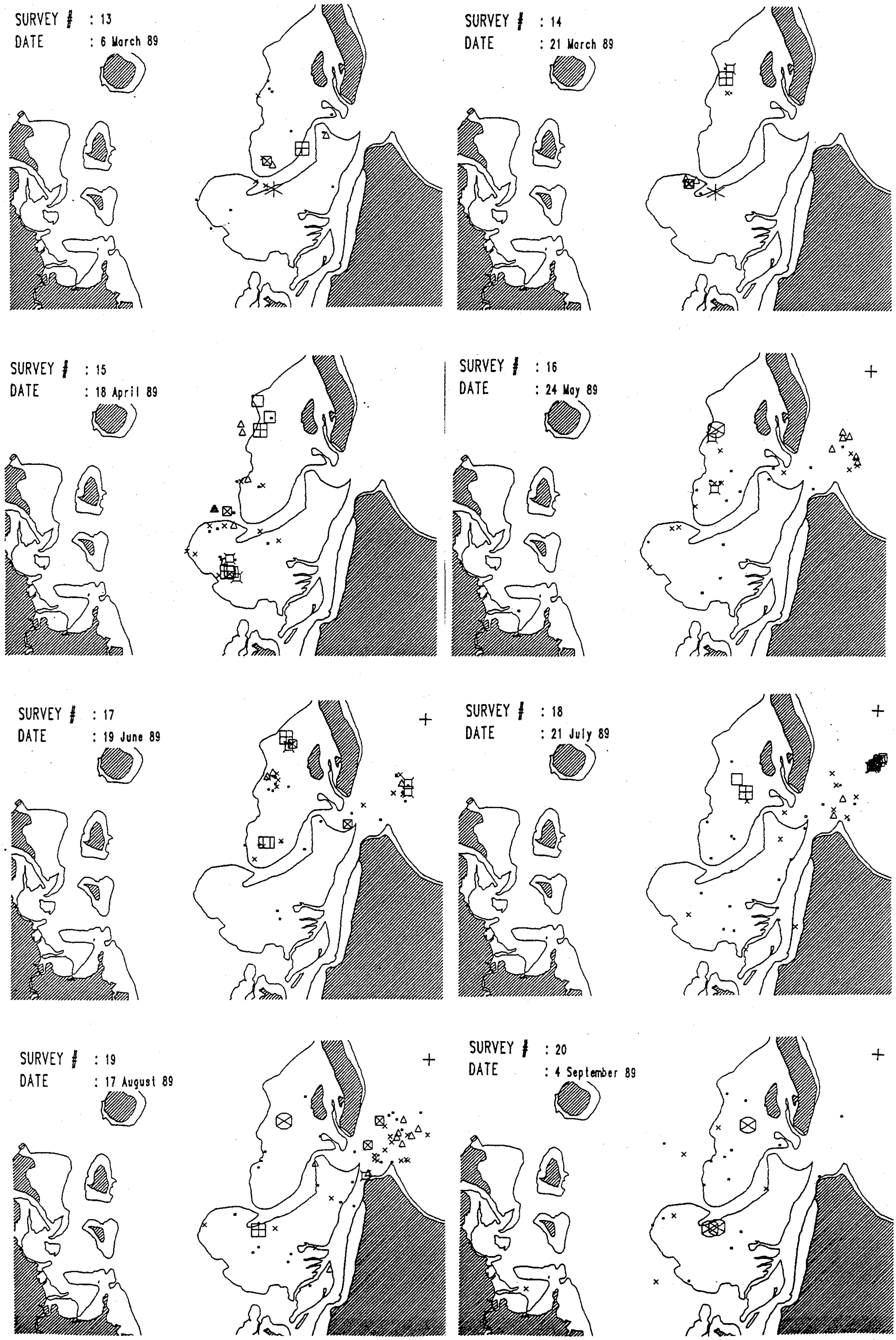
Dugong number	Sub-range number	Days of usage	95% area (km^2)[1]	% overlap of other sub-ranges		
136	1	≥9	14.7	2: 0.02[2]	3: 0.0	4: 0.0
	2	11	9.1	1: 0.0	3: 0.0	4: 0.0
	3	9	11.0	1: 0.0	2: 0.0	4: 0.0
	4	≥5	1.8	1: 0.0	2: 0.0	3: 0.0
139	1	≥16	8.9	2: 0.0	3: 90.4	4: 0.0
	2	11	10.3	1: 0.0	3: 0.0	4: 100
	3	3	9.2	1: 89.5	2: 0.0	4: 0.0
	4	≥5	1.1	1: 0.0	2: 10.7	3: 0.0
236	1	≥4	10.9	2: 2.0	3: 6.6	4: 83.7
	2	35	16.3	1: 2.8	3: 9.4	4: 0.0
	3	27	57.5	1: 33.3	2: 32.3	4: 32.4
	4	≥26	9.4	1: 73.2	2: 0.0	3: 5.6
235	1	≥15	18.3	2: 92.5	3: 75.3	4: 50.9
	2	15	14.4	1: 72.8	3: 65.9	4: 43.3
	3	13	21.2	1: 88.1	2: 97.9	4: 56.9
	4	≥17	33.5	1: 92.8	2: 99.9	3: 88.0

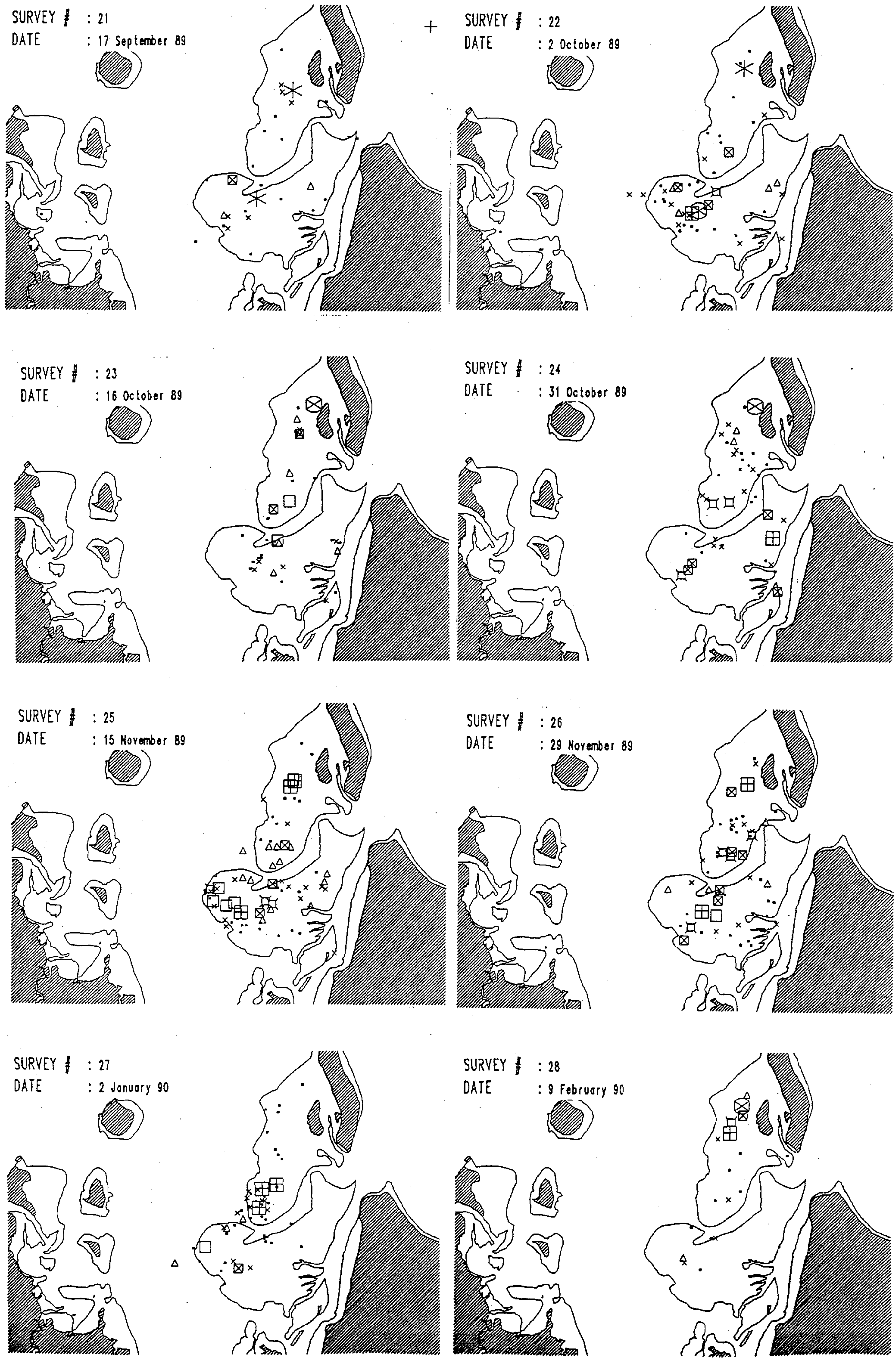
[1] Based on kernel estimator
[2] eg. sub-range 1 of dugong # 136 overlaped 0.0% of sub-range 2

Figure 5.1. 'Standard' surveys of the East and West study areas in Moreton Bay. (A) Flight path. (B) Location of dugong groups recorded on each survey. + indicates the surveys that included the transects east of South Passage (dashed line on flight path map).




SURVEY # : 5
DATE : 9 October 88
SURVEY # : 6
DATE : 26 October 88
SURVEY # : 7
DATE : 15 November 88
SURVEY # : 8
DATE : 28 November 88
SURVEY # : 9
DATE : 21 December 88
SURVEY # : 10
DATE : 3 January 89
SURVEY # : 11
DATE : 9 February 89
SURVEY # : 12
DATE : 21 February 89


SURVEY # : 13
DATE : 6 March 89
SURVEY # : 14
DATE : 21 March 89
SURVEY # : 15
DATE : 18 April 89
SURVEY # : 16
DATE : 24 May 89
SURVEY # : 17
DATE : 19 June 89
SURVEY # : 18
DATE : 21 July 89
SURVEY # : 19
DATE : 17 August 89
SURVEY # : 20
DATE : 4 September 89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DATE : 17 September 89
SURVEY # : 22
DATE : 2 October 89
SURVEY # : 23
DATE : 16 October 89
SURVEY # : 24
DATE : 31 October 89
SURVEY # : 25
DATE : 15 November 89
SURVEY # : 26
DATE : 29 November 89
SURVEY # : 27
DATE : 2 January 90
SURVEY # : 28
DATE : 9 February 90

Figure 5.2. Flight path of perimeter surveys of Moreton Bay and the location and number of dugongs (and calves) sighted. Circles: summer survey (7 March 1989); triangles: winter survey (21 July 1989).

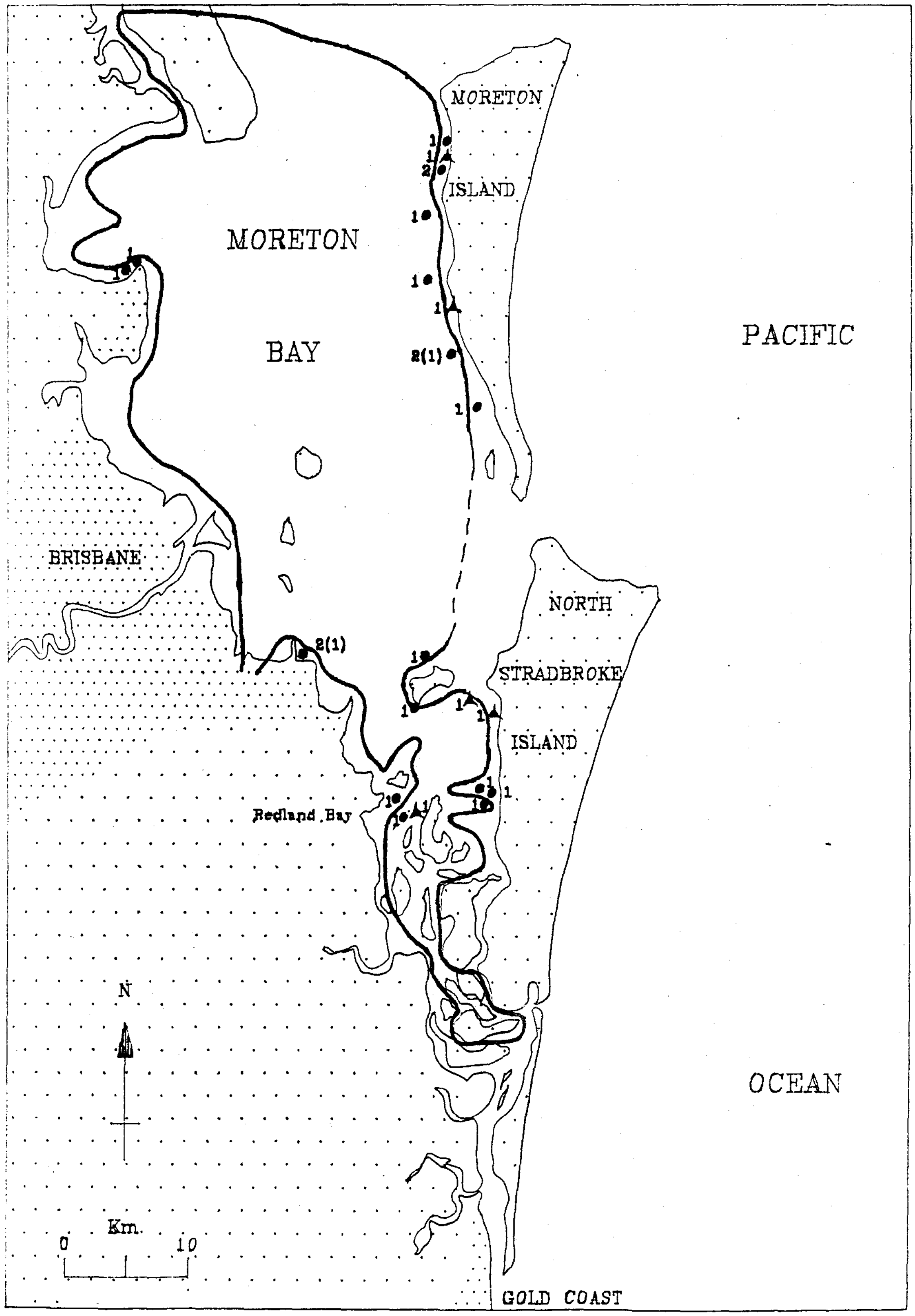


Figure 5.3. The total number of dugongs recorded during each of the 'standard' aerial surveys of the Moreton Bay study areas. * indicates surveys that did not search the area outside South Passage.

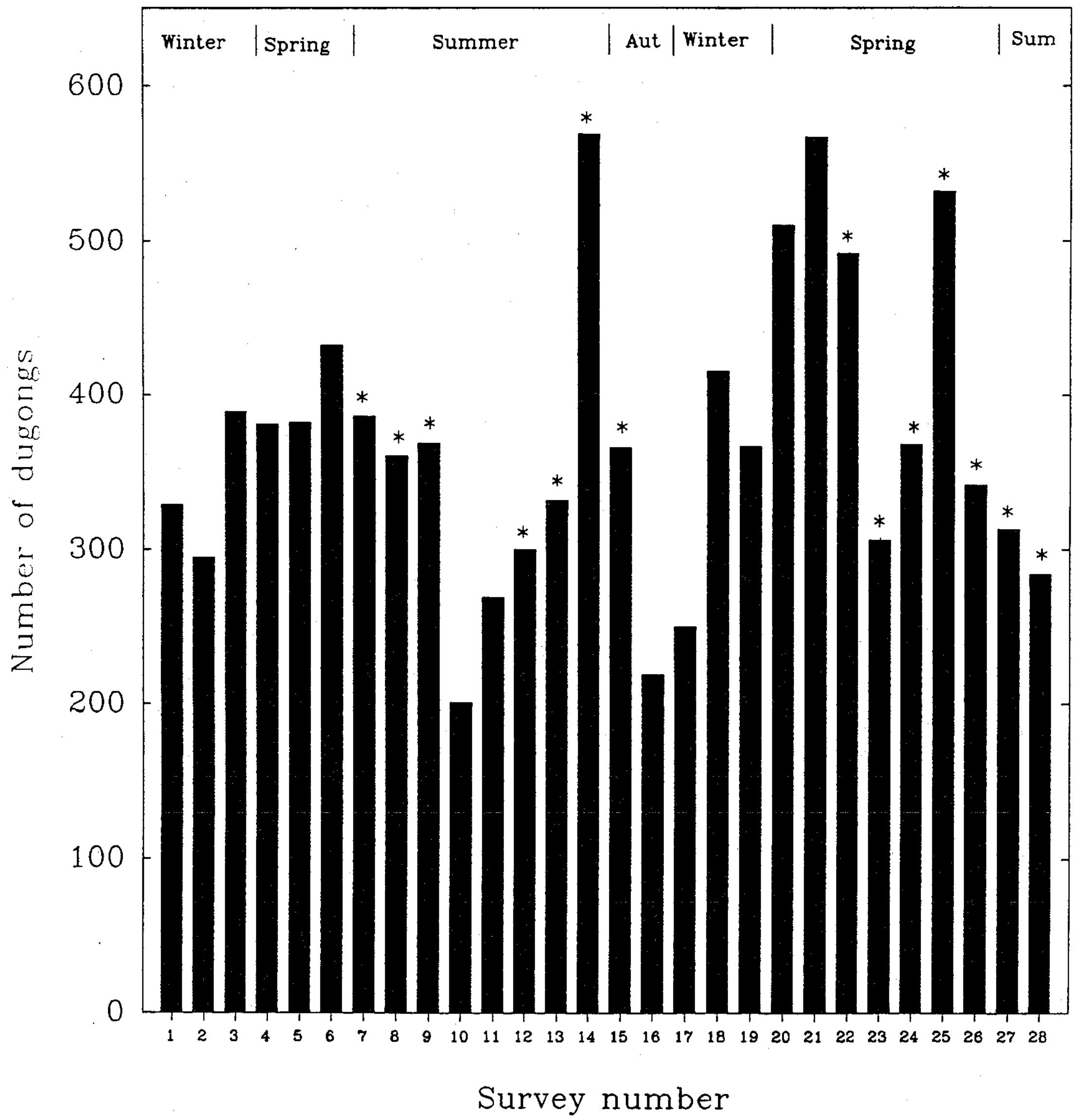


Figure 5.4. Number of dugongs counted outside Moreton Bay as a proportion of the total count during 14 of 28 'standard'. aerial surveys. The actual number of dugongs seen is indicated on the top of each bar.
* indicates the 14 flights that did not survey the area east of South Passage. Solid bars indicate winter surveys.

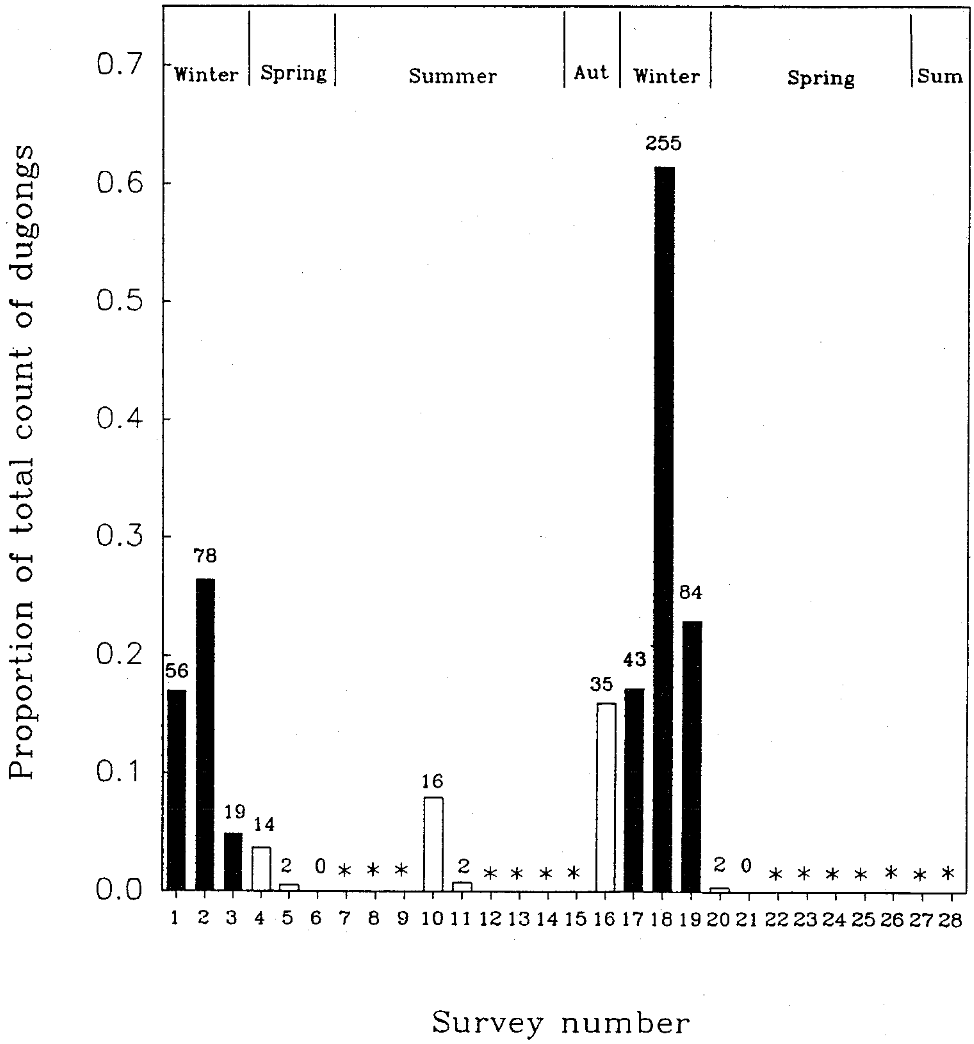


Figure 5.5. Percentage of dugongs seen in each seagrass community during 28 'standard' surveys of the East study area (n = 8,504 dugongs seen on seagrass).

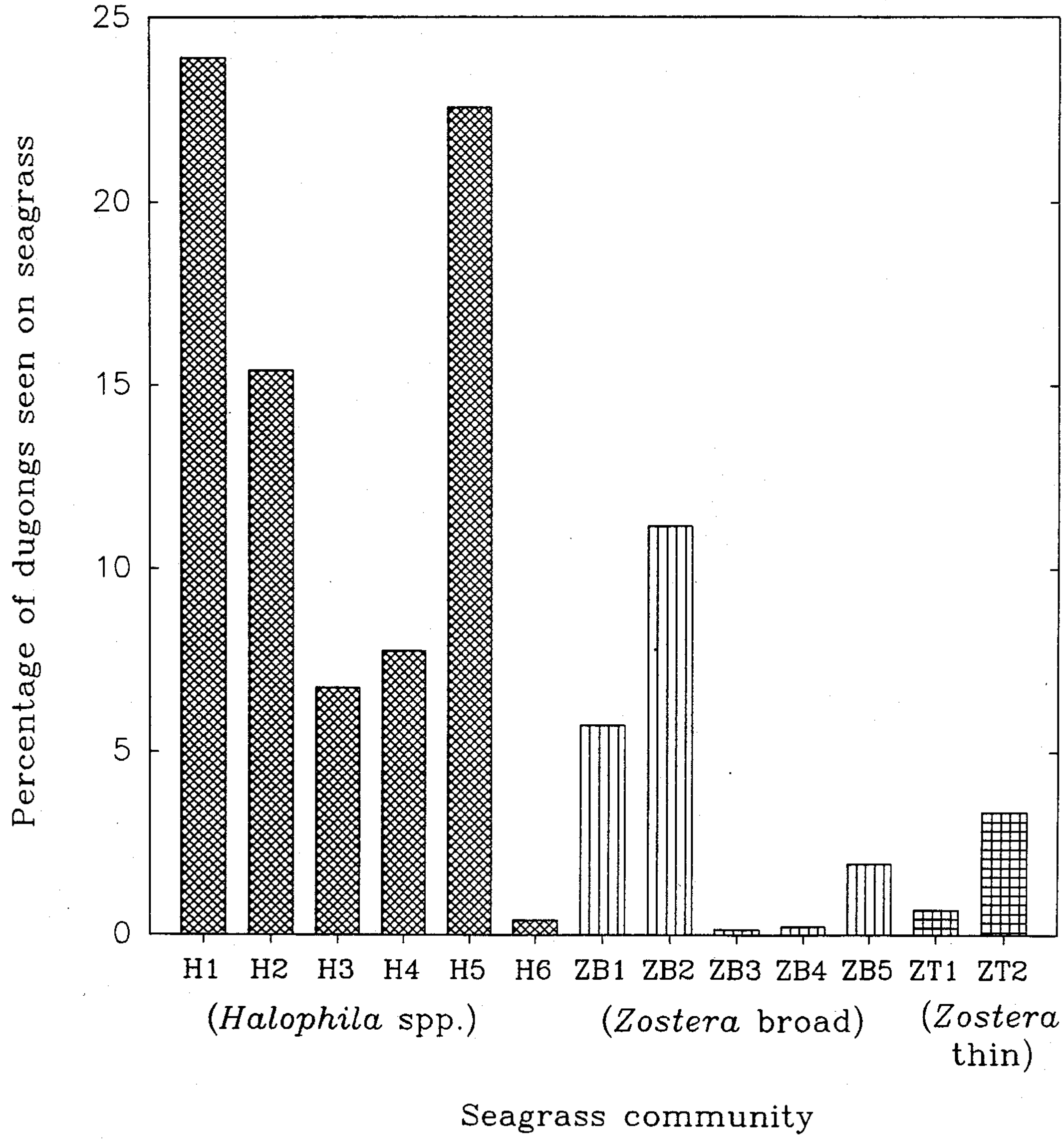


Figure 5.6. Habitat preferences of dugongs observed during aerial surveys in Moreton Bay. Estimated proportion (plus 95% confidence interval) of grid cells in each habitat occupied by dugongs (A) during each season (corrected for distance from deep water) and (B) during all seasons (corrected for distance and water temperature). Winter cold areas are $\leq 19^0C$ and winter warm areas are $>19^0C$.

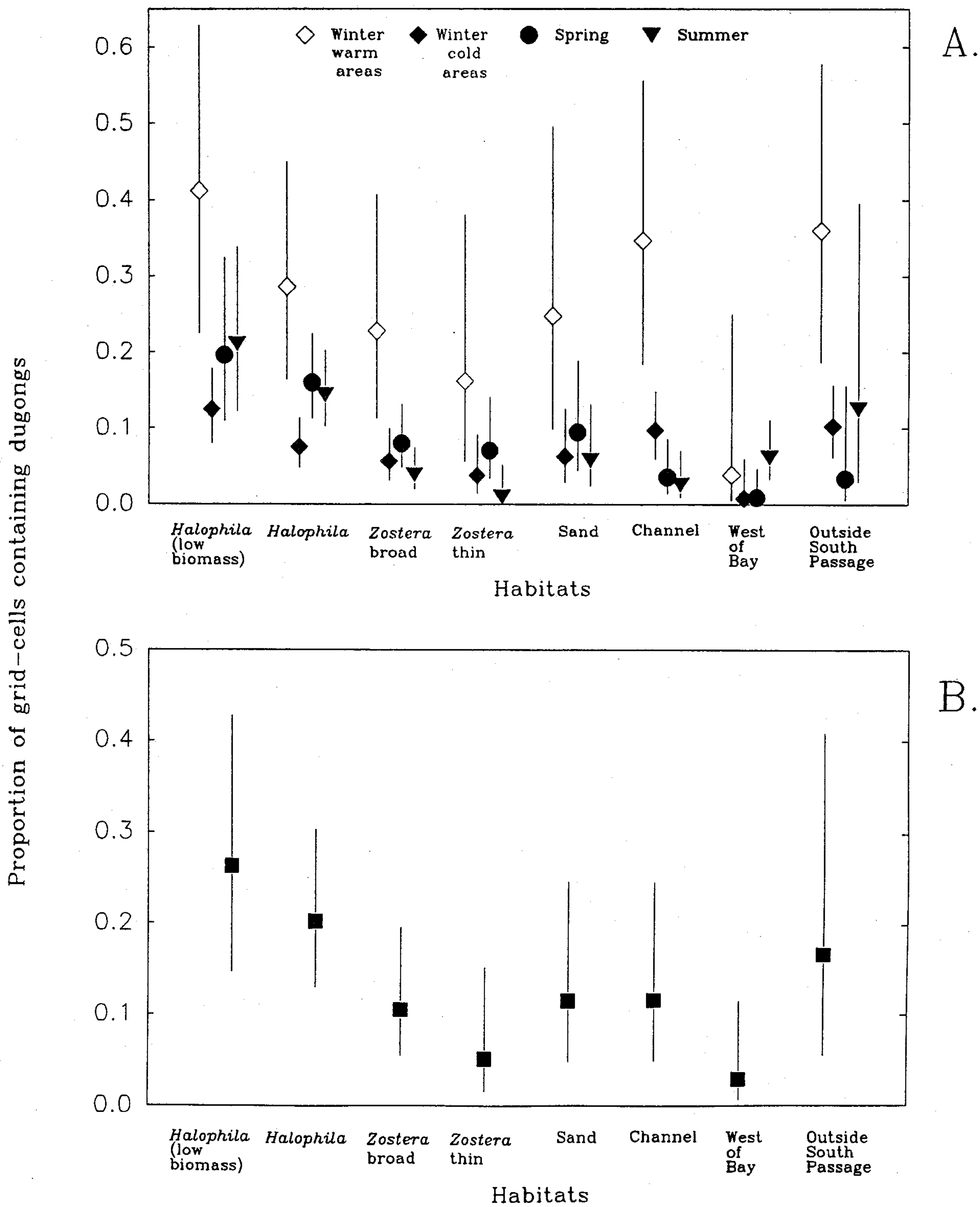
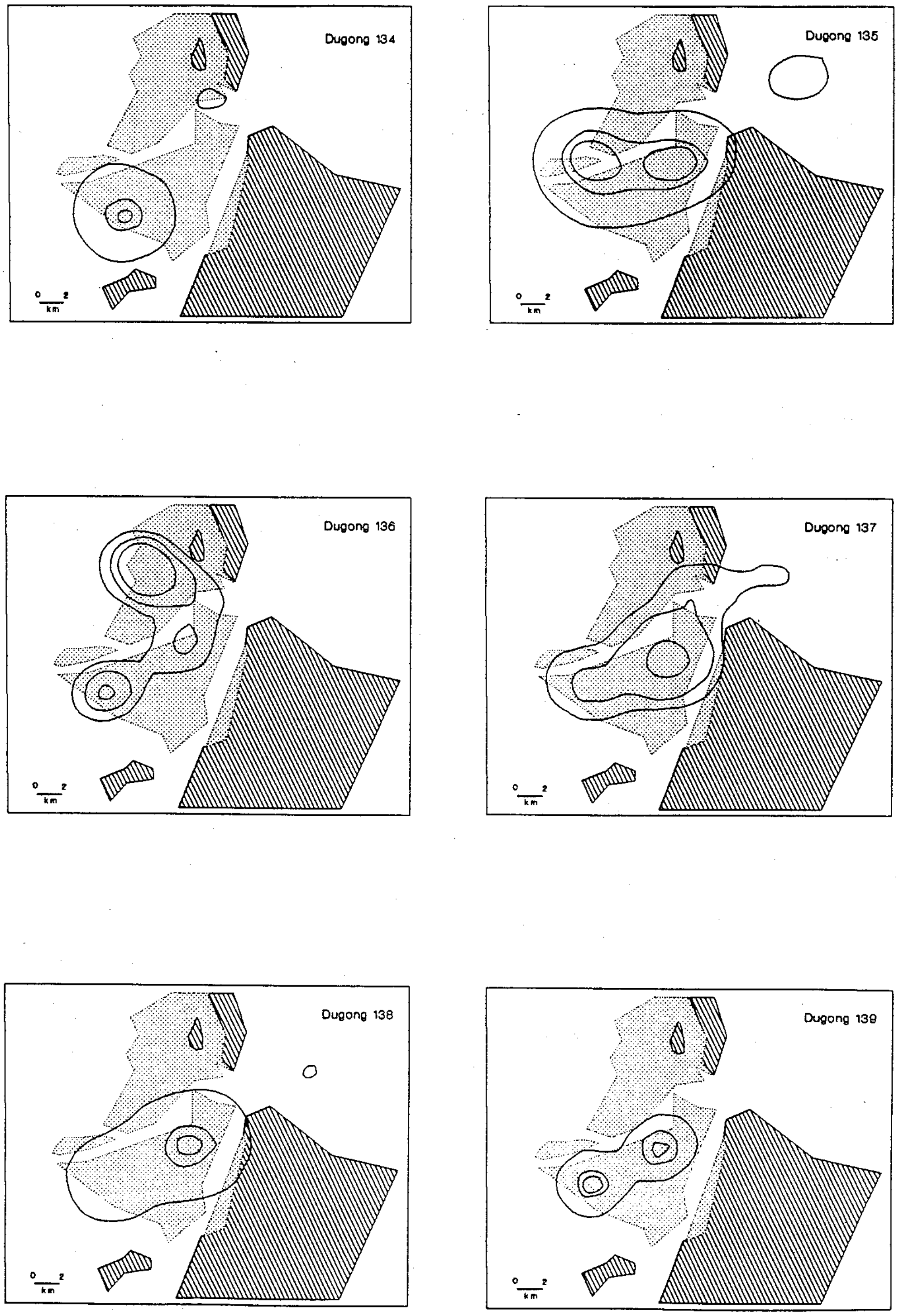
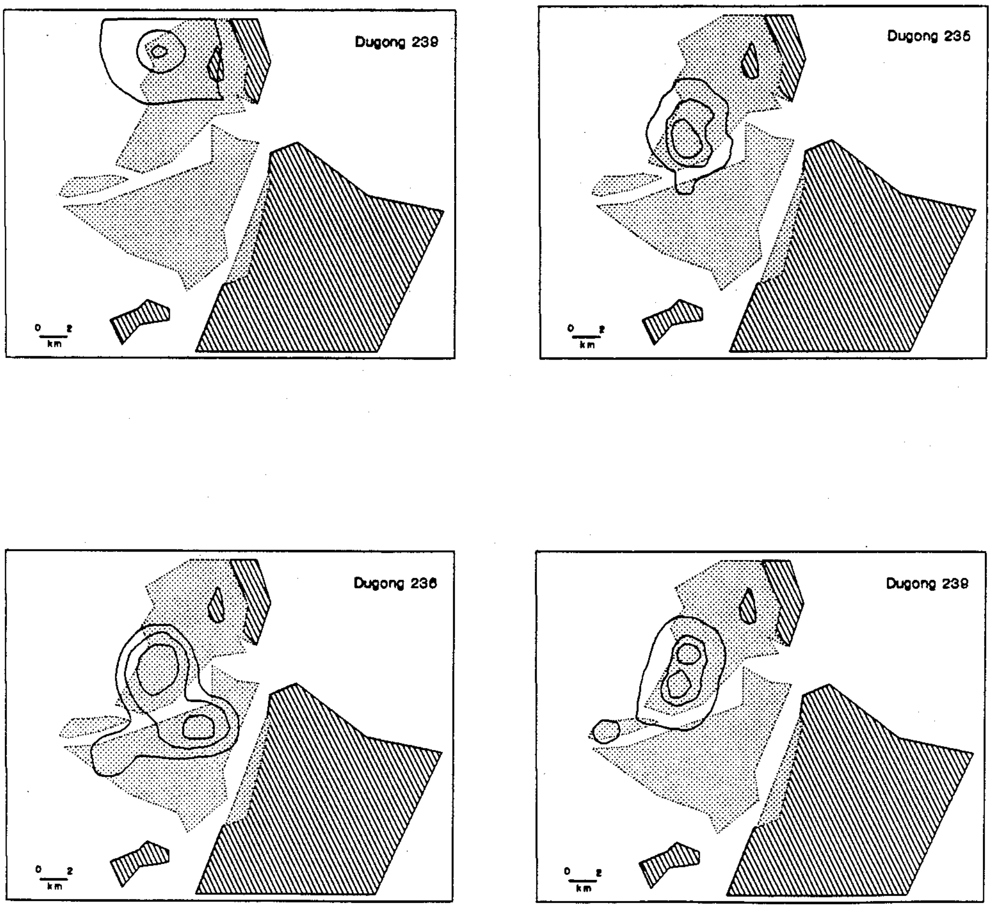


Figure 5.7. Home ranges of dugongs tracked in Moreton Bay. Isopleths show the densest 50%, 75% and 95% of fixes based on the kernel estimator. Stipple indicates the seagrass and sand banks of the East study area, and the hatch indicates islands.

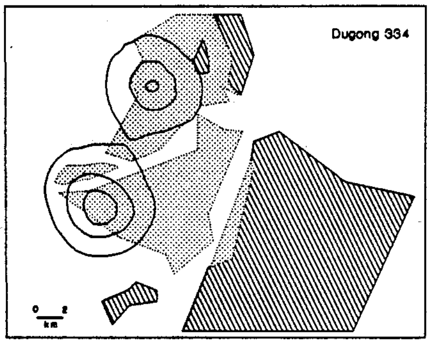
A. Dugongs tagged in winter.

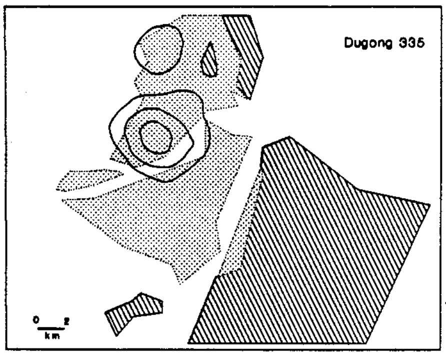


B. Dugongs tagged in spring.



C. Dugongs tagged in summer.





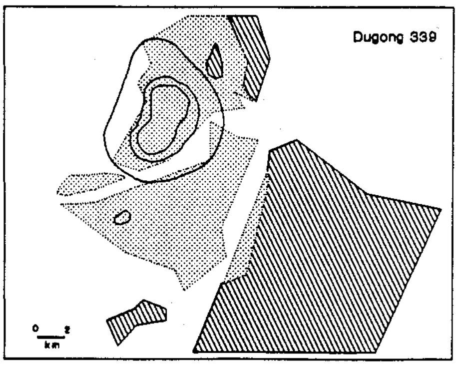


Figure 5.8. Sub-ranges sequentially occupied by dugongs 136, 139, and 236, as well as home ranges calculated from four sequential series of locations from dugong 235. Dugong 235 did not occupy sub-ranges during the period of tracking. Numbers indicate sequence of use.

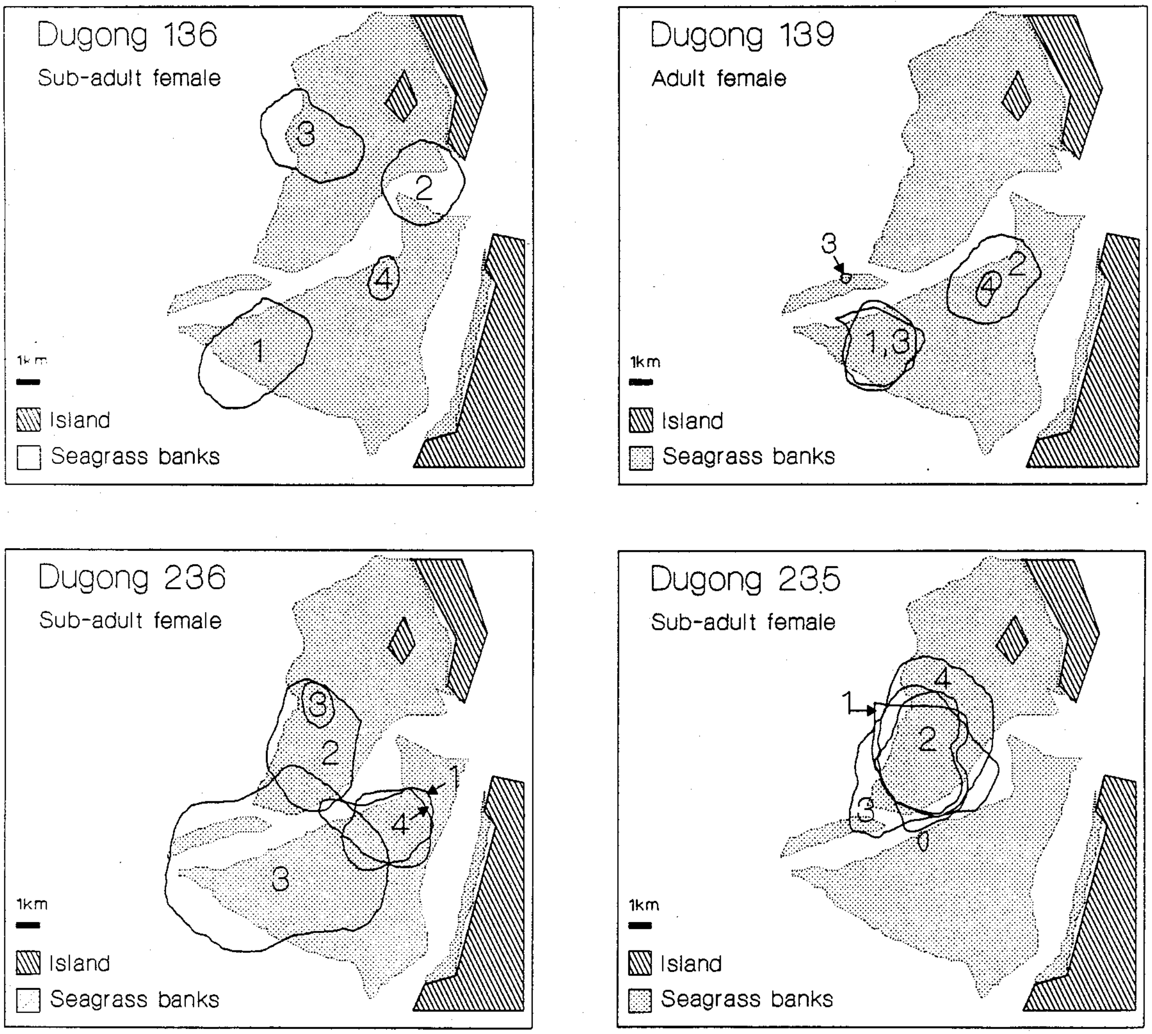


Figure 5.9. Habitat preferences of dugongs tracked in Moreton Bay. Estimated mean number of locations (plus 95% confidence interval) per km^2 from each habitat (A) during each season and (B) during all seasons.

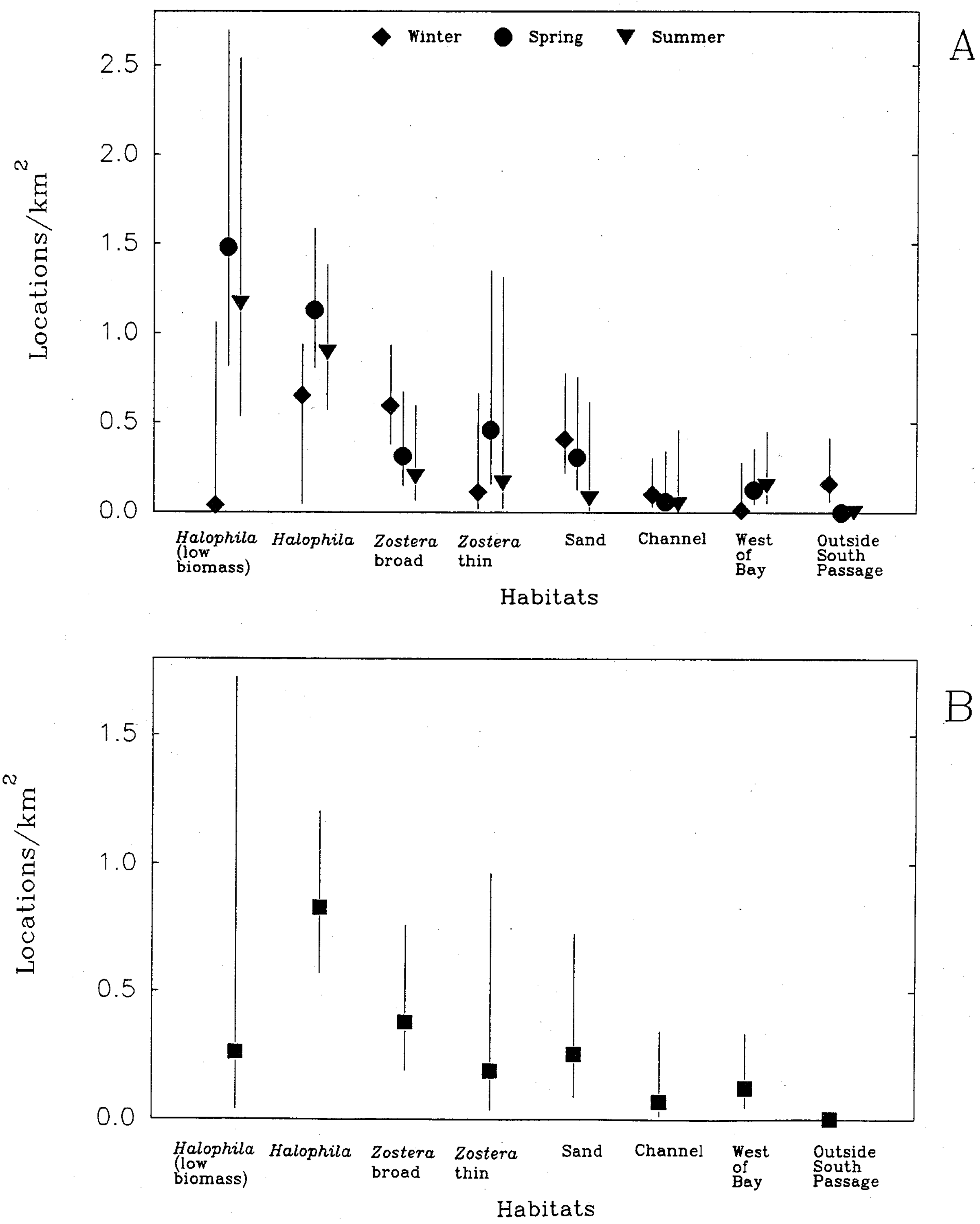


Figure 5.10. Comparison of the ranked habitat preferences of Moreton Bay dugongs determined by aerial survey and satellite tracking. Data are from Tables A.4.4 and A.4.6.