Winter distribution and abundance of dugongs, turtles, dolphins and other large vertebrate fauna in Shark Bay, Ningaloo Reef and Exmouth Gulf, Western Australia

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Executive Summary

Strip-transect aerial surveys of Shark Bay, Ningaloo Reef and Exmouth Gulf were conducted during the winters of 1989 and 1994. While these surveys were designed primarily to estimate the abundance and distribution of dugongs, they also allowed sea turtles and dolphins, and to a lesser extent, whales, manta rays and whale sharks to be surveyed.

Shark Bay contains a large population of dugongs that is of international significance. Estimates of approximately 10000 dugongs resulted from both surveys. Exmouth Gulf and Ningaloo Reef are also important dugong habitats, each supporting in the order of 1,000 dugongs.

The estimated number of turtles in Shark Bay is comparable to the number in Exmouth Gulf plus Ningaloo Reef (7000-9000). The density of turtles in Ningaloo Reef, and to a lesser extent Exmouth Gulf is exceptionally high, when compared with most other areas that have been surveyed by the same technique.

Shark Bay supports a substantial population of bottlenose dolphins (2000-3000 uncorrected for availability bias). Exmouth Gulf and Ningaloo Reef were not significant habitats for dolphins during the winter surveys.

Northern Shark Bay is once again becoming an important area for whales (primarily humpbacks) during winter months. Northern and western Shark Bay, and Ningaloo Reef support substantial numbers of manta rays in winter. Ningaloo Reef is an important area for whale sharks in autumn.

The Shark Bay Marine Park excludes much of the winter habitats of the large vertebrate fauna of Shark Bay. In 1989 and 1994, more than half of all the dugongs were seen outside the Marine Park (57.4% and 50.7%, respectively). Between one third and one half of turtles and dolphins were seen outside the Marine Park (turtles: 43% and 27%, respectively; dolphins: 47% and 32%, respectively). Almost all the whales and most of the manta rays were outside the Marine Park.

Recommendations

- The boundaries of the Shark Bay marine protected areas should be reviewed to ensure the adequate protection of the bay's large vertebrate fauna, especially the dugong, which is recognised as one of the important World Heritage values of Shark Bay. It is recommended that the boundary of the Marine Park should shadow the marine boundary of the World Heritage Area. It is noted that trawling is already permitted in the Marine Park.
- The deep-water seagrass beds of Shark Bay should be mapped. The effects of trawling on these meadows should be investigated.
- The summer distribution of the large vertebrate fauna in Shark Bay is not known. A summer survey should be conducted.
- Exmouth Gulf is an important habitat for turtles and dugongs and should be afforded protected area status.
- The seagrasses of the Exmouth Gulf-Ningaloo Reef region are poorly known and should be investigated further.
- The coastal waters of northern Western Australia (north from Exmouth Gulf) should be surveyed to establish the distribution of dugong, turtle and cetacean populations, before marine protected areas are established in this vast area.

Introduction

The coast of Western Australia is over 12500 km long, and spans 21° of latitude between 14° and 35°S. The southern and western coastal waters are relatively well known (Wilson *et al.* 1979; Pearce and Walker 1991), but knowledge of the habitats and marine fauna decreases northwards from the populated south-west. The central western coast, between 22° and 27°S, includes a number of areas of high conservation status, including the Shark Bay World Heritage Area and Ningaloo Marine Park. Effective management of these areas requires sound knowledge of their environments, including the distribution and abundance of high conservation status. We used aerial surveys in the winters of 1989 and 1994 to determine this information for dugongs, cetaceans, and turtles in Shark Bay, Ningaloo Reef and the adjacent Exmouth Gulf (Fig. 1). The 1989 data on dugongs in Shark Bay have been presented previously (Marsh *et al.* 1994). Here we document the winter distribution and abundance of dugongs, turtles and dolphins in these three areas, and examine differences between the 1989 and 1994 surveys. We also provide information on the distribution of whales, manta rays and whale sharks obtained during these surveys.

Shark Bay supports a dugong population of international significance, a large turtle population, and is again becoming important for whales in winter. While the Shark Bay World Heritage Area encompasses virtually all the important habitat for these species in this region, the Shark Bay Marine Park does not. This anomaly has the potential for confusion and conflict due to the different management regimes that may be expected by State and Federal agencies in the World Heritage Area outside the marine park.

Ningaloo Reef and Exmouth Gulf support important populations of turtles and are significant habitats for dugongs. Manta rays and whale sharks are relatively common off the Ningaloo Reef in winter. Ningaloo Reef is well protected in the Ningaloo Marine Park, but Exmouth Gulf, which sustains an important trawl fishery and is covered by petroleum exploration permits, currently has no special conservation status.

Methods

Study areas

Shark Bay is a 13000 km² embayment complex on the central Western Australian coast (25.5° S, 113.5° E). It experiences a semi-arid to arid climate and precipitation (200-400 mm/y) is greatly exceeded by evaporation (2000-3000 mm/y). Consequently, enclosed parts of the bay, particularly Hamelin Pool are hypersaline (>42$^0/_{00}$). About half the bay is metahaline (38-42$^0/_{00}$), while the remainder, primarily the western and northern areas has oceanic salinities (35-40$^0/_{00}$; Fig. 1; Logan and Cebulski 1970).

Shark Bay has been inscribed on the World Heritage List in recognition of its outstanding universal natural values (DASETT 1990; DEST 1995). Seagrass meadows cover more than 4000 km² and are reported to be the largest in the world (Walker 1989). These meadows are composed predominantly of the temperate species *Amphibolis antarctica*, although there is recent evidence of large deep-water meadows dominated by the tropical species *Halophila spinulosa* (Anderson 1994). The bay supports a population of approximately 10000 dugongs (*Dugong dugon*), making it a habitat of international significance for this species (Marsh *et al.* 1994). Nesting beaches at the northern tip of Dirk Hartog Island are used annually by as many as 800-1000 female loggerhead turtles (*Caretta caretta*), which may represent 70% of the Western Australian breeding population (Prince 1994). Monkey Mia, on the eastern coast of the Peron Peninsula, is renowned for the contact between humans and some members of the local population of bottlenose dolphins (*Tursiops truncatus*; Smolker *et al.* 1992). The World Heritage Area includes the entire bay complex, excluding nearshore waters around Carnarvon (Fig. 1). The southern and eastern areas of the bay are included in the Shark Bay Marine Park and the Hamelin Pool Marine Nature Reserve (Department of Conservation and Land Management 1994; Fig. 1)

Ningaloo Reef (22.5°S, 113.8°E) is the largest fringing barrier reef in Australia and extends 260 km north-south along the western shore of the Cape Range Peninsula (Department of Conservation and Land Management 1989). It is mostly enclosed by Ningaloo Marine Park (Marine Parks and Reserves Selection Working Group 1994). Unlike most other coral reef systems in Australia, Ningaloo Reef is a near-shore barrier reef. Its enclosed lagoon varies in width from as little as 200 m up to 6 km, with an average depth of 4 m (Department of Conservation and Land Management 1989). Because of the aridity of the hinterland, and consequent low run-off of water, the lagoon waters are particularly clear (May *et al.* 1983), especially when compared with most inshore reef waters in Australia. Ningaloo Reef is contiguous to Exmouth Gulf (22.0°S, 114.4°E), which lies on the east side of the Cape Range Peninsula (Fig. 1). In contrast to the clear waters of Ningaloo Reef, Exmouth Gulf is a relatively turbid environment, characterised by areas of fringing mangroves, mudflats, rock pavements and soft bottom habitats. It supports a major trawled-prawn fishery (Marine Parks and Reserves Selection Working Group 1994). Early aerial surveys indicated that Exmouth Gulf was an important habitat for dugongs (Prince *et al.* 1981). The Muiron Islands, at the northern edge of the Gulf are an important nesting area for loggerhead and green (*Chelonia mydas*) turtles (Prince 1993).

Aerial surveys

We conducted strip-transect aerial surveys of Shark Bay, Ningaloo Reef and Exmouth Gulf between 4 and 13 July 1989 and between 21 and 30 June 1994. The surveys were conducted during winter to take advantage of the relatively light winds, and hence better observation conditions. The Shark Bay surveys encompassed the entire World Heritage Area, except for the western shorelines of the barrier islands (Fig. 2). The Ningaloo-Exmouth surveys covered all of Exmouth Gulf, as defined by an east-west line through the tip of North West Cape (Fig. 2) and the full length of Ningaloo Marine Park (in 1994 only).

The methods followed those of Marsh and Sinclair (1989*a.*, 1989*b.*) and are detailed for the 1989 Shark Bay survey in Marsh *et al.* (1994). To calculate regional densities of fauna, Shark Bay was divided into eight survey blocks (Fig. 2). Ningaloo Reef and Exmouth Gulf were treated as single blocks, with a small part of Ningaloo Marine Park included in the Exmouth block (Figs. 1 and 2). The parallel east-west oriented transects were 4.65 km apart (2.5' latitude), resulting in a coverage of 8.9% to 9.9%, except in Shark Bay blocks 0 and 2, where transects were 9.3 km apart, and coverage was 4.1%. The same transects were flown on each survey, except for Ningaloo Reef. In 1989, 19 transects, covering only the northern half of Ningaloo Marine Park were surveyed (Fig. 2). In 1994, 43 transects (including the original 19), covering the full length of Ningaloo Marine Park were flown. The 1994 transects extended approximately 200 m seaward of the fringing reef, while the 1989 transects extended 0.8 to 4.5 km ($\bar{x}$ = 2.3 km) further.

Surveys were conducted only under good weather conditions (Beaufort sea state ≤ 3; Table 1), and we avoided flying during periods of severe glare (early morning, late afternoon and mid-day). Sightings were recorded in a 200 m wide strip on each side of the aircraft, from an altitude of 137 m.

Two isolated, independent observers were used on each side of the aircraft. From a mark-recapture analysis of sightings, perception-bias correction factors were derived to adjust the results to allow for the animals visible, but missed by observers (Marsh and Saalfeld 1989*a*.; see Table 2). Separate perception-bias correction factors were calculated for each side of the aircraft for dugongs and turtles for Shark Bay and for the combined Ningaloo-Exmouth blocks. Due to the low number of dolphins recorded in Exmouth Gulf, the Shark Bay correction factor was used. Insufficient dolphins were seen in Ningaloo to derive population estimates, so no correction factors were needed.

Availability correction factors were derived to correct for the number of animals not at the surface, and hence, less likely to be available to observers, at the time the plane passed over (Marsh and Sinclair 1989*b*.; see Table 2). For dugongs, the proportion of sightings at the surface was standardised to the proportion at the surface in Moreton Bay, Queensland, where all dugongs feeding in 3 m of water were visible. That proportion was determined from vertical aerial photographs. The availability correction factor makes the untested assumption that the proportion of dugongs at the surface is constant across depths, time and activities. Although this is improbable, this correction factor is likely to be conservative and provides a means of standardising for repeat surveys of the same area. The availability correction factors for turtles were calculated by standardising against the number of turtles seen at the surface in a survey of the northern Great Barrier Reef (blocks 8-13; Marsh and Saalfeld 1989*b*.). The proportion of turtles sighted at the surface on that survey was the lowest of any survey we have undertaken. The availability correction factor for turtles is likely to be a considerable underestimate because (i) the availability correction factor does not fully account for turtles not visible below the surface, (ii) small turtles are very difficult to see at the survey altitude, and (iii) turtle sightings are particularly dependent on sea surface conditions (Marsh and Sinclair 1989*a*.).

The availability correction factors for dugongs were calculated separately for Shark Bay and Ningaloo-Exmouth combined (the proportion of dugongs at the surface did not vary significantly between Ningaloo and Exmouth; Chi-square: $\chi^2 = 0.046$, df = 1, p = 0.829). Large numbers of turtle sightings allowed availability correction factors to be calculated separately for Shark Bay, Ningaloo and Exmouth. Availability bias was not corrected for dolphins due to the lack of suitable data to use as a standard.

The surveys were designed primarily to census dugongs. Within that constraint, it was normally not possible to circle to positively identify small cetaceans, so they have been analysed as a single group. Similarly, it is difficult to reliably separate green, loggerhead and other turtles at the survey altitude, so they too have been grouped together.

As the transects were of variable length, the Ratio Method was used to estimate the density, population size and associated standard errors for each block. The population estimates were based on the estimated number of animals of each group of fewer than 10 animals for each tandem team per transect, calculated using the appropriate corrections for perception and availability bias and mean group size. The standard errors were adjusted to incorporate the error associated with each correction factor (Table 2), as outlined in Marsh and Sinclair (1989*a*.). Herds of ≥10 dugongs are excluded from the calculation of population estimates, and added to the population estimate as a separate stratum, as suggested by Norton-Griffiths (1978).

The significance of the differences between the abundance of dugongs, dolphins and turtles in Shark Bay in 1989 and 1994 were tested using analysis of variance, both with, and without the modal Beaufort sea state for each transect as the covariate. Blocks and times were treated as fixed factors and transect as a random factor nested within block. Input data for all analyses were corrected densities per square kilometre, with each transect contributing one density per survey, based on the combined corrected counts of both tandem observer teams. The densities were transformed ($\log_{10}(x+1)$) to equalise the error variances. The differences between surveys of the Exmouth Gulf were examined using two-way analysis of variance with transect as the blocking factor. The differences between surveys of Ningaloo Reef were not compared statistically due to the differences in the number and lengths of transects.

Sea surface temperatures

Satellite images of the sea surface temperatures in the survey areas were obtained for 6 July 1989 (1520 h, local time) and 23 June 1994 (0717 h). Temperatures of the sea surface were derived from AVHRR bands 4 and 5 using an algorithm by McMillin and Crosby (1984) and were correct to approximately 0.5°C. Because the sea-surface skin is measured, temperature could vary with the time of day that the images were acquired.

Results

Weather conditions encountered during the surveys are summarised in Table 1. The values for the mean group sizes, and the correction factors used in the population estimates are shown in Table 2. The size and sampling coverage of the survey blocks are presented in Table 3.

Shark Bay

Dugongs

During the 1989 survey 297 dugongs were seen in herds of <10. Two large herds (>40 and >100 dugongs) were also recorded. The mean group size (for herds <10) was 1.48 (± s.e. = 0.04). The estimated population was 10146 (± s.e. 1665), with an average population density of 0.71 (± 0.12) dugongs/km² (Table 3). Calves made up 19% of sighted dugongs.

In the winter of 1994, we counted 290 dugongs on transects, of which 16.6% were calves. The mean group size was 1.45 (± 0.08; Table 2), and the maximum group comprised only seven dugongs. A 'herd' of at least 200 dugongs was encountered just north-west of Denham, but the dugongs were dispersed over approximately 10 km², so this aggregation was not treated separately. The estimated population of 10529 (± 1464), and the average density of 0.71 (± 0.10) were very similar to the 1989 estimates (Table 3).

Comparing the two surveys, there was a significant year by block interaction, although inclusion of Beaufort sea state as a covariate suggests that this effect was marginal (Table 4). In 1989 most dugongs were seen in blocks 4 and 5 (Fig. 3), and the greatest density

(5.1/km²) was in block 5 (Table 3). In 1994, most dugongs, and the greatest density of dugongs (2.8/km²) occurred in block 4 (Fig. 3, Table 3).

In 1989, the distribution of dugongs appeared to be partly determined by water temperature, with <4% of dugongs seen in water <18°C. This pattern was maintained in 1994, but not as strongly, as 13.8% of dugongs were in water <18°C (Fig. 3).

Turtles

Three hundred and twenty six turtles were seen on transect in 1989, compared to 365 in 1994. The identity of the turtles that could be confidently identified suggests that the great majority sighted each survey were green turtles.

The 1989 population estimate was 6373 (± 710) turtles at an average density of 0.43/km². In 1994, the population estimate was 8431 (± 758), at an overall density of 0.57 turtles/km² (Table 3). Comparing surveys, there were significant effects of year and year by block, with or without the inclusion of Beaufort sea state as a covariate. This suggests that the different distribution of turtles between years is not accountable to a difference in observation conditions.

In 1989 most turtles were seen in the relatively deep water of blocks 3, 5 and 6 (east side). In 1994, however, far fewer turtles were seen in these locations. Instead, most were seen in the shallow waters of the Wooramel Bank and Faure Sill, to the east and south of this area (Figs. 2 and 4).

The 1989 distribution of turtles tends to match the pattern in surface water temperature (Fig. 4), with 31.3% of turtles sighted in water <18°C. In 1994, however, more than half (50.6%) of turtles were seen in water <18°C. It is unlikely that these differences are due to major changes in the bay's thermal patterns between the time of image capture and aerial survey. The 1994 image was taken just 2 days before the blocks 6, 5 and 3 were flown, while in 1989 these blocks were surveyed 4-6 days after the image was captured.

Dolphins

Two hundred and twelve dolphins in 85 groups were seen during the 1989 survey. The largest group comprised 15 animals. In 1994, 185 dolphins were sighted in 91 groups, the largest being 10. Calves represented 8.1% of sightings in 1989 and 10.4% in 1994.

In 1989, 8% of dolphins were of unknown identity while 92% were identified as bottlenose dolphins. Seventy-five percent of these identifications were described as 'certain'. In 1994, 80% of dolphins were identified as bottlenose (66% with certainty). Seventeen percent were unidentified, while 3 dolphins (1.6%) were believed to be *Stenella* species or *Delphinus delphis* and one (0.5%) was thought to be *Sousa chinensis*.

The estimated population of dolphins varied from 2888 (± 434) in 1989 to 2063 (± 267) in 1994 (Table 3). The overall density of dolphins was 0.19/km² in 1989 and 0.14/km² in 1994 (Table 3). No correction has been made for availability bias, so these are underestimates.

Comparing surveys, there were no significant effects or interactions (Table 4), reflecting the broadly similar distribution of sightings during each survey (Fig. 5). In 1994 there was a concentration of dolphins around the tip of Peron Peninsula (particularly block 5) and an absence of sightings from block 0. This lack of sightings is most probably due to the poor sighting conditions that developed during the 1994 survey of this block.

Other taxa

Whales and manta rays (*Manta birostris*) were frequently seen during the aerial surveys (Fig. 6). The 1994 plot of whales includes whales that were not on transect. The six whales (three groups) that occurred within transects were all identified as humpbacks (*Megaptera novaengliae*). In 1989, none of the seven sighted whales were within transects. Six of these whales were identified as humpbacks. Population estimates have not been calculated for whales or manta rays. These species occurred primarily in the deeper waters of oceanic salinity (Figs. 1 and 6).

Ningaloo Reef and Exmouth Gulf

Dugongs

In 1989, 57 dugongs were seen on transects in the Ningaloo and Exmouth blocks, compared to 40 in 1994, when an extra 24 transects were flown in the southern part of Ningaloo Marine Park. A very dispersed herd of about 50 dugongs was seen near North West Cape in 1989. This herd was stratified out of the population model and later added to the population estimate. The population and density estimates for Exmouth Gulf changed very little between years: 1062 (± 321) dugongs at a density of 0.33 (± 0.10)/km² in 1989, compared with 1006 (± 494) and 0.32 (±0.16)/km² in 1994 (Table 3). The difference between surveys was significant when Beaufort seas state was included as a covariate (Table 4). The significant transect effect indicates a different distribution pattern between years, but the marginally significant year effect also suggests a change in abundance (survey conditions were better in 1994, when fewer dugongs were seen). This could be due to dugongs moving across the arbitrary northern boundary of the Exmouth survey block.

Ningaloo Marine Park contained an estimated 968 (± 320) dugongs in 1994, while there were 634 (± 127) dugongs in the northern half of the Marine Park in 1989. The density of dugongs was very similar for each survey (1.14 ± 0.23 in 1989 and 1.11 ± 0.37 in 1994; Table 3). Because of the differences in survey design, the Ningaloo results have not been compared statistically.

The distributions of dugongs in Ningaloo Reef and Exmouth Gulf showed a broadly similar pattern between surveys, with most groups being sighted in the eastern half of Exmouth Gulf (Fig. 7). In 1989, 24% of dugongs were calves, compared with 20% in 1994. During both surveys, virtually all the waters in Ningaloo Reef and Exmouth Gulf were >18°C, and most were >20°C, and water temperature did not appear to account for the distribution of animals.

Turtles

In 1989, 262 turtles were seen in Exmouth Gulf, compared with only 115 turtles in 1994. The resulting population estimates were 4512 (± 877) in 1989 and 3252 (± 684) in 1994. The density of turtles was 1.4 (± 0.28) turtles/km² in 1989, compared with 1.0 (± 0.22)/km² in 1994 (Table 3). These differences were not significant (Table 4). One hundred and sixty-two turtles were seen in northern Ningaloo Reef in 1989. This translated to a population estimate of 2503 (±261) at a density of 4.51 (±0.47) turtles/km². In 1994, 119 turtles were seen over the full length of Ningaloo Marine Park. This represents a population estimate of 4260 (±724) and a density of 4.90 (±0.83) turtles/km² (Table 3). The distribution of turtles was broadly similar between years, although few turtles were seen in the deeper waters of central and western Exmouth Gulf in 1989 (Fig. 8).

Dolphins

Fifty-nine dolphins were seen in 1989, compared with 24 in 1994. Bottlenose dolphins made up 76% of sightings in 1989 (82% called as 'certain'), while 22% were unidentified, and one dolphin (1.7%) was identified as a *S. chinensis*. In 1994, 33% of sightings were thought to be bottlenose (82% 'certain'), while 42% were unidentified and 25% were *S. chinensis*. The estimated populations and densities are shown in Table 3. The difference between surveys was not significant (Table 4). Very few dolphins were seen in Ningaloo on either survey (Fig. 9) and no population estimates have been calculated.

Other taxa

Manta rays were common in the northern half of Ningaloo Marine Park during both surveys (Fig. 10). In 1989, whale sharks (*Rhinodon typus*) were also common in the north of the Marine Park. No whale sharks were seen in 1994. A group of three humpback whales and a group of two unidentified whales were seen in the north of Ningaloo Marine Park in 1989 and 1994, respectively (Fig. 10).

DISCUSSION

Shark Bay

Dugongs

The consistency of results between the winter surveys of 1989 and 1994 confirms that Shark Bay supports a large population of dugongs, at a density (0.71/km²) that is notably higher than for other areas around Australia and the Middle-East that have been surveyed using this method (see Table 4 in Marsh *et al.* 1994). The only exception is Torres Strait, where two surveys returned density estimates of 0.44 ± 0.07 and 0.79 ± 0.11 dugongs/km² in 1987 and 1991, respectively (Marsh *et al.* in press).

The main difference between the results of the two surveys of Shark Bay was the change in dugong distribution. In 1989 dugongs were concentrated to the north-east of the Peron Peninsula, and along the eastern shore of northern Dirk Hartog Island (Fig. 3). In 1994, the dugongs were located primarily around the edge of Denham Sound: off the western side of northern Peron Peninsula and off the eastern shore of central Dirk Hartog Island (Fig. 3). This difference may be of little significance, as the distance between the 1989 and 1994 areas of concentration (75-100 km) is well within the scale of movements regularly undertaken by dugongs (Marsh and Rathbun 1990; Preen, unpublished data). It should be noted, however, that in late 1995 the seagrass in the vicinity of the 1989 concentration of dugongs in the east of the bay had disappeared (P.K. Anderson, personal communication). The timing of this seagrass loss is unknown, but could potentially account for the differences in dugong distribution during the two surveys.

The 1989 and 1994 surveys provide a good indication of the distribution of dugongs in Shark Bay in winter. Comparable data are not available for summer. The Faure Sill (in the centre of block 3; Fig. 1 and 2), is known to be an important summer feeding area (Anderson 1986). Between one third and one half of the Shark Bay dugong population was using this area when it was surveyed twice in the summer of 1990-91 (Marsh *et al.* 1994). The summer distribution of the total Shark Bay dugong population, however, is not known as the entire bay has not been surveyed during this season.

Anderson (1982, 1986) noted that the distribution of dugongs in Shark Bay varied seasonally; the dugongs being driven from their preferred feeding grounds in the east of the bay by cold water temperatures in winter. The dugongs were thought to take refuge in the warmer waters of the western bay, particularly along the eastern shores of Dirk Hartog Island (Anderson 1982). The winter survey of 1989 (the first to cover all the bay) found that many of the dugongs actually remained in the east of the bay (Fig. 3). This area had relatively warm water, and 96% of dugongs were sighted in areas $\geq$18°C. Indirect evidence suggests that 18-19°C is a critical temperature for dugong thermoregulation (Anderson 1986; Preen 1989, 1993). In 1994, 86% of dugongs seen were in water $\geq$18°C, but very few dugongs were found in the east of the bay (Fig. 3). Taken together, these data (in the absence of a complete summer survey of the bay) suggest that the seasonal movement of the majority of dugongs in Shark Bay is from the shallow, tropical-seagrass dominated banks in the east (Faure Sill) and southern (Henri Frecinet Harbour) parts of the bay in summer into deeper, relatively warmer waters in winter.

A subsequent seagrass survey of the area north-east of the Peron Peninsula, where dugongs were aggregated in the winter of 1989 discovered a large, previously unknown meadow of the tropical seagrass *Halophila spinulosa* (Anderson 1994). This genus is a preferred food of dugongs (Preen 1993). The 1994 concentration of dugongs in relatively deep water (Figs. 2 and 3) around the perimeter of the Denham Sound suggests the presence of another deep water meadow of *Halophila* species.

The proportion of the dugong population that was calves (19% in 1989 and 16.6% in 1994) is relatively high compared with surveys done in other areas (Table 4 in Marsh *et al.* 1994). The difference between surveys probably reflects the imprecision of the definition of a calf: 'a substantially smaller animal in close association with another'. Previous shore-line surveys in Shark Bay have returned calf counts of 11-12% (Anderson 1982) and 10.4% (Anderson 1986). These estimates differ substantially from our estimates, but it is not possible to determine whether the disparity is due to definitional differences or whether they reflect temporal variation in reproductive success.

Turtles

While turtles were abundant in Shark Bay (in excess of 8400 in 1994), and their density (0.57/km^2) was comparable to densities recorded from areas of similar latitude in south-east Queensland, they occurred at a lower density than in more tropical areas of Queensland and the Torres Strait (Table 5). Turtle density, at least in eastern Australia, appears to correlate with latitude (Table 5).

Green turtles are the most common species in Shark Bay (Department of Conservation and

Land Management 1994), and the identifications made during the 1994 survey support this assessment. A few loggerhead turtles were also seen. The proportion of loggerheads would probably increase in summer, when breeding turtles arrive from other areas to nest at the rookery at the northern tip of Dirk Hartog Island (Prince 1994), and when resident green turtles are expected to migrate out of the bay to breed.

The 1989 distribution of turtles in Shark Bay corresponds with the pattern of surface water temperatures, with most turtles clearly avoiding water colder than about 18°C (Fig. 4). This pattern appears to break down in 1994, as a considerable concentration of turtles occurred in the cool waters close to shore along the Wooramel Bank (Fig. 4). This apparent anomaly may be explained by the timing of the capture of the satellite image used to derive water temperatures. At 0717 h, when the 1994 image was captured, the shallow waters where these turtles occurred (33% of turtles east of the Peron Peninsula were in water <3 m deep) would have been cold from the previous night. But under suitable conditions of light breezes and clear skies (as experienced during the aerial survey) shallow waters heat up to be considerably warmer than nearby deeper waters. As all the Wooramel Bank was surveyed in the afternoon in 1994, it is probable that at least the surface waters in this area were warmer than indicated by the early morning satellite image, so the distribution of turtles was probably not anomalous. The 1989 image was captured in the afternoon.

Dolphins

The 1989 and 1994 surveys indicate a population of 2000-3000 dolphins in Shark Bay. The great majority were bottlenose. The real number is likely to be higher, as these estimates make no correction for availability bias. The density of dolphins (0.14-0.19/km^2) is comparable with densities estimated for the Great Barrier Reef Marine Park, and greater than for Torres Strait and the Mornington Island area in the Gulf of Carpentaria (Table 5).

The 1994 survey detected a concentration of dolphins around the tip of Peron Peninsula (Fig. 5). This area is well known for its high density of dolphins (Department of Conservation and Land Management 1994).

Other taxa

Post-war whaling occurred in northern Shark Bay between 1950 and 1962, by which time the population of humpback whales had been reduced from about 10000 to no more than 800 (Chittleborough 1965). The number of whales using the area is now increasing, reflecting the recovery of populations of the Area IV stock (Bannister 1994). Sightings of humpback and Southern Right whales (*Eubalaena australis*) in Shark Bay embayments have increased in recent years (Department of Conservation and Land Management 1994), and humpback whales were common in the northern part of the bay in 1994. Manta rays were common in the Denham Sound area. Both these taxa appeared to be restricted to the areas of oceanic salinities.

Ningaloo and Exmouth

Dugongs

The density of dugongs in Ningaloo Reef and Exmouth Gulf was about half that of Shark

Bay, but was comparable to the densities of dugongs recorded in other significant dugong habitats in northern Australia (Table 4 in Marsh *et al.* 1994), excluding the Torres Strait where densities are similar to Shark Bay (Marsh *et al.*, *in press*). The Ningaloo-Exmouth population (approximately 2000 dugongs; Table 3) is substantial, being comparable to that of much larger areas, such as the central plus southern sections of the Great Barrier Reef Marine Park (Marsh and Saalfeld 1990; Marsh and others, unpublished data) and the eastern coast of the Red Sea (Preen 1989).

Although the Ningaloo and Exmouth marine habitats differ markedly (oceanic, reefal, calcareous sediments, compared with turbid inshore waters with terrigenous sediments), the dugongs could be expected to move freely between the adjoining areas. Such exchanges, if they occur, are of relevance to management as the Ningaloo habitats are protected in the Marine Park, while Exmouth Gulf has no special protection.

It is likely that the aerial surveys have inadequately sampled the dugong population in this region, as suitable habitat extends well beyond the northern boundary of the Exmouth survey block. The significant difference between Exmouth surveys may well be due to a net movement of dugongs across that northern boundary. The nature of the seagrass communities in this region is poorly understood (Walker and Prince 1987), but seagrasses appear to be abundant just north of Exmouth Gulf (Bowman Bishaw Gorham 1995), but uncommon in the southeast of the gulf (McCook *et al.*, in press).

Turtles

The density of turtles in Ningaloo Marine Park (4.9 ± 0.8/km^2) exceeds the highest densities of turtles recorded in any survey block throughout the Great Barrier Reef Marine Park (Marsh and others, unpublished data). Only one survey block, during one of two surveys of Torres Strait had a higher density of turtles (5.1 ± 0.7/km^2; Marsh, unpublished data). The very high density of turtles in Ningaloo Marine Park may, in part, be an artefact of the particularly clear waters of the reef and lagoon. Conversely, the turbid water in much of Exmouth Gulf may account for the apparently lower density of turtles in this area. However, the density of turtles in Exmouth Gulf (1.0-1.4/km^2) is still twice the value for Shark Bay, and comparable to the density of turtles in Torres Strait, the northern section of the Great Barrier Reef Marine Park (Table 5), and the best embayments in the central and southern sections of the Great Barrier Reef Marine Park (Marsh and others, unpublished data).

Our surveys were conducted outside the breeding season for sea turtles in this region (Prince, unpublished data), so we surveyed resident turtles. Differences in species composition between Ningaloo Marine Park and Exmouth Gulf are unknown, but the different habitats may support different species. Green turtles are the most abundant species in Ningaloo Marine Park and Hawksbill turtles (*Eretmochelys imbricata*) are also present (May *et al.* 1983). This latter species is rarely detected during our aerial surveys because of its small size and close association with coral. At the bottom end of Exmouth Gulf, 566 turtles have been tagged in recent years after being stranded behind tunnel or trap nets. Green turtles were the most common (86 %) followed by loggerheads (11%) and hawksbills (3%; Prince, unpublished data). Little is known of the movements of turtles between Exmouth Gulf and Ningaloo Reef, as only three tag returns have been obtained from these turtles. One was from the southern end of Ningaloo Marine Park, one from the north-west of the gulf and one from the south-west of the gulf (Prince, unpublished data).

Dolphins

Dolphins were not common in Ningaloo Marine Park or Exmouth Gulf on either survey. However, the densities of dolphins in these areas (0.09-0.18/km^2; Table 3) are comparable with densities estimated for the Great Barrier Reef Marine Park and Torres Strait (Table 5).

The species composition of dolphins varied substantially between surveys, although with 'unidentified' dolphins making up 22%-42% of sightings, such apparent change may be an artefact. Like Shark Bay, bottlenose dolphins were the most common, although *S. chinensis* is relatively more common in this more tropical area.

Other taxa

Ningaloo Marine Park, at least the northern half, is an important feeding area for whale sharks (Taylor 1989, 1994*a*., 1994*b*.) and manta rays (Fig. 10). A tourist industry, based out of Exmouth, has developed around the whale sharks since 1989. The presence of the whale sharks is apparently seasonal, although the end of the season is variable. Whale sharks were common during the 13 July survey in 1989, but absent during the 22-23 June survey in 1994. Although it is possible that this difference was due to the shorter transects in 1994, local tourist operators reported that the whale sharks had left the area three weeks before the 1994 survey.

Humpback whales migrate through the waters immediately adjacent to Ningaloo Reef and sometimes aggregate adjacent to the reef (May *et al*. 1983). Whaling operations commenced at this location in 1913 (May *et al*. 1983) and occurred on a large scale (up to 600 taken annually) between 1949 and 1955 (Chittleborough 1965).

Management considerations

Shark Bay

The dugong population ranges over a large part of the bay. In summer, block 3 (Marsh *et al*. 1994) and possibly block 0 (Anderson 1986), are important habitats. In winter, blocks 4, 5 and 6 are of critical importance. Most of blocks 4 and 6, some of block 5, and all of block 7 are excluded from the Shark Bay Marine Park (Fig. 1 and 2). In June 1994, 50.7% of dugongs were sighted outside the Marine Park. In 1989, 57.4% were outside the park boundaries. Given the international significance of the Shark Bay dugong population, it would seem appropriate that its major habitat areas are protected within the Shark Bay Marine Park.

In 1989 and 1994, respectively 43% and 27% of the sighted turtles were outside the Marine Park. At the same times, 48.6% and 32.4% of dolphins occurred outside the current boundaries of the Marine Park. Similarly, nearly all the whales and most of the manta rays were outside the Marine Park. Taken together, the winter distribution of large vertebrates in Shark Bay presents a strong case for the extension of the Marine Park boundary to include the northern and western areas of the bay. The current boundary of the Shark Bay Marine Park was substantially determined by the distribution of existing trawling grounds (Department of Conservation and Land Management 1994), the apparent aim being to avoid conflicts over resource use by locating the boundary outside trawling areas. In using this criterion, however, the habitats of many important species have been deprived of protection, and the Marine Park has a complicated boundary that would be difficult to police. The Marine Park should be expanded to enclose all of Shark Bay. To meet the requirements of the *World Heritage Properties Conservation Act 1983* (Commonwealth), and to simplify State-Commonwealth collaboration under this act, it would be appropriate for the Marine Park boundary to shadow the marine boundary of the World Heritage Area (Fig. 1). The difference in the World Heritage and Marine Park boundaries of the Great Barrier Reef in Queensland is an ongoing problem for management agencies (H. Marsh, personal communication).

Expansion of the Shark Bay Marine Park to the World Heritage Area boundary would not exclude trawling, as the General Use Zone, which is currently applied to the vast majority of the Marine Park, allows trawling (Department of Conservation and Land Management 1994). Inclusion of trawl grounds within the park may facilitate investigations into the effects of trawling on benthic communities, with the aim of ensuring that the fishing practices are ecologically sustainable.

It has been suggested that waters around Bernier and Dorre Islands should be included in the Shark Bay Marine Park (Marine Parks and Reserves Selection Working Group (1994). This would protect a representative selection of rocky shore habitats and some seagrass beds. However, this proposal would still exclude most of the dugong habitat that is not currently in the Marine Park, and would do little to conserve the whales, turtles and dolphins that use the rest of Shark Bay.

The abundance of whales in the Carnarvon area in the north of Shark Bay highlights the potential for this former whaling town to develop a whale-watching industry. This has occurred in other areas in Australia, including the Perth and Albany in Western Australia, and Hervey Bay, Moreton Bay and the Whitsunday Islands in eastern Australia (Postle and Simmons 1994). Experience from some of these areas suggests that management agencies need to anticipate such developments and be pro-active in their planning if the industry is to develop without impacting on the whale population. Inclusion of this area in the Shark Bay Marine Park would allow Special Purpose Zones to be established, specifically to manage whale watching activities (Government of Western Australia 1994).

The distribution of dugongs in block 4, and to a lesser extent block 6, in both 1989 and 1994 suggests the presence of more deep-water seagrass meadows, similar to those recently discovered (as a result of the 1989 dugong survey) in block 5 (Anderson 1994). These areas are clearly important winter, and possibly summer, habitats for dugongs. The mapping of deep-water seagrass meadows, therefore, should be a high priority. The effects of trawling on seagrass meadows, especially those characterised by fragile species such as *H. spinulosa*, are poorly understood, and should be investigated in Shark Bay.

The summer distributions of most of the dugong population and the resident turtles and cetaceans are unknown. A summer survey of Shark Bay should be undertaken to determine the location of the most important habitats.

Ningaloo Reef and Exmouth Gulf

Ningaloo Reef is substantially enclosed within the Ningaloo Marine Park, which affords considerable protection to habitats and many species. A substantial tourism industry has recently developed around providing visitors with opportunities to snorkel with whale sharks in the Marine Park. This intrusive form of tourism developed rapidly, in the absence of a management plan. Licences for tour operators were introduced in 1993. There are currently 13 licensed operators in the north of the Marine Park, with a further two licences being issued for the southern area. Each boat can carry up to 20 snorkellers, and up to 10 snorkellers are allowed in the water with a whale shark at any one time, although they are not meant to approach closer than 1 m of its head (Coughran 1994). Virtually nothing is known of the biology of whale sharks or the importance of the Ningaloo area for this species. The extent to which individuals move throughout the Park, and the effects of boats and divers on the whale sharks are unknown. Such information, however, is critical for the effective management of the industry and the conservation of the species.

In response to the growing tourist industry, a large resort and marina has been proposed for the Ningaloo Marine Park. If approved, the 45 ha marina will be adjacent to a sanctuary zone within the marine park (Anon. 1995; Backhouse 1995). Leachates from anti-fouling paints used on boats are a serious source of pollution, causing reduced growth of algae, and sterility and deformities in molluscs (Evens *et al.* 1994; Stewart and Thompson 1994). This is particularly a problem around marinas, despite the partial ban on the use of tributyltin (TBT) in these paints (Stewart and Thompson 1994). Butyltin compounds have also been detected in the blubber of a wide variety of marine mammals (Iwata *et al.* 1994). The herbicide used to replace TBT in anti-fouling paints has now been detected in significant levels around marinas (Gough *et al.* 1994). Increased boat traffic associated with a marina may also impact on the dugong (Preen 1993) and turtle populations as a result of direct strikes and noise pollution.

Exmouth Gulf, in contrast to Ningaloo and Shark Bay has no protection status. This is surprising given its importance as a habitat for dugongs and turtles. The Muiron Islands, just outside the gulf have the second most important loggerhead turtle rookery in Western Australia (Prince 1993). Almost all of Exmouth Gulf is covered by petroleum exploration permits, and it is also the focus of a major prawn trawl fishery. A recent report recommends that the eastern side of the gulf (roughly corresponding to the existing seasonal trawling closure) be considered for reservation as a marine protected area (Marine Parks and Reserves Selection Working Group 1994).

There are reports of extensive seagrass meadows on the eastern side of Exmouth Gulf (Bowman Bishaw Gorham 1995), although a recent survey found the cental- and south-eastern areas of the gulf to be largely devoid of seagrass (McCook *et al.* in press). That survey did not investigate the north-eastern area of the gulf. Extensive deep water (12-18 m) seagrass meadows, dominated by *H. spinulosa*, have been located immediately to the north of Exmouth Gulf (between Sunday and Threvenard Islands; Bowman Bishaw Gorham 1995). These data suggest that the area to the north of the gulf may be important dugong habitat. The delineation of Exmouth Gulf used in these surveys was determined by logistical constraints, rather than ecological boundaries. The coastal waters north of the surveyed area are comparatively unknown, but there is every likelihood that they support important habitats and populations of dugongs, dolphins and turtles (Prince *et al.* 1981). Surveys of fauna and seagrasses in this area are required. The development of the oil and gas extraction industry in these coastal waters (Department of Minerals and Energy 1994) and the incipient eco-tourism industry highlight the need for this information.

Concluding comment

Shark Bay and Ningaloo-Exmouth support an abundant and diverse assemblage of large marine vertebrates. In addition to the wildlife reported here, Southern right whales, minke whales (*Balaenoptera acutorostrata*), killer whales (*Orcinus orca*) and Australian sea lions (*Neophoca cinerea*) and Southern elephant seals (*Mirounga leonina*) are known to occur in these areas, at least irregularly (May *et al.* 1983; Anderson and Prince 1985; Department of Conservation and Land Management 1994; unpublished data). However, two species, dugongs and whale sharks, stand out as symbols of these respective areas, and their futures will be a test of our ability to manage these, and other, marine habitats.

The seasonal aggregation of whale sharks in the waters of Ningaloo Marine Park may be unique, with as many as 200 of these normally solitary fish using the area during the peak of the season (Taylor 1994*b*.). Although the significance of the Ningaloo area for this species is yet to be determined, these numbers suggest that it is important. In this context it is logical to assume that uncontrolled interactions between the whale sharks and humans could have a detrimental effect on these animals. Controlling an established industry that relies on this interaction, however, may be difficult.

The population of dugongs in Shark Bay is unusual and of considerable international significance because of its large size and because of the low level of human predation and incidental mortality, and presumed low level of habitat disturbance. With conservative management, this population has an almost uniquely stable future. As such, it will be a valuable reference point against which to compare through time, other important populations that are subjected to greater levels of hunting, fishing net entanglements and habitat disturbance.

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References

Anderson, P. K. (1982). Studies of dugongs at Shark Bay, Western Australia I. Analysis of population size, composition, dispersion and habitat use on the basis of aerial survey. *Australian Wildlife Research* **9**, 69-84.

Anderson, P. K. (1986). Dugongs of Shark Bay, Australia - seasonal migration, water temperature, and forage. *National Geographic Research* **2**, 473-490.

Anderson, P. K. (1994). Dugong distribution, the seagrass *Halophila spinulosa*, and the thermal environment in winter in deeper waters of eastern Shark Bay, Western Australia. *Wildlife Research* **21**, 381-388.

Anderson, P. K., and Prince, R. I. T. (1985). Predation on dugongs: attacks by killer whales. *Journal of Mammalogy* **66**, 554-556.

Anon. (1995). Coral Coast Marina Proposal. *The Greener Times (Conservation Council of Western Australia)* March, 6.

Backhouse, D. (1995). Coral Coast Resort: a threat to Australia's "other" barrier reef. *Bulletin of the Australian Marine Conservation Society* **18**(2), 6.

Bannister, J. L. (1994). Continued increase in Humpback whales off Western Australia.

Reports of the International Whaling Commission **44**, 309-10.

Bowman Bishaw Gorham (1995). North West Shelf Environmental Resource Atlas. Report prepared for BHP Petroleum Pty. Ltd.

Chittleborough, R. G. (1965). Dynamics of two populations of the Humpback whale *Megaptera novaeangliae* (Borowski). *Australian Journal of Marine and Freshwater Research* **16**, 33-128.

Coughran, D. (1994). An overview of the whale watching industry in Western Australia 1989-1992. In 'Encounters with Whales '93. A conference to further explore the management issues relating to human/whale interactions'. (Eds Postle, D. and Simmons, M.) pp. 45-74. (Great Barrier Reef Marine Park Authority: Townsville.)

DASETT (1990). Nomination of Shark Bay, Western Australia by the Government of Australia for inclusion in the World Heritage List. Prepared by the Department of Arts, Sport, the Environment, Tourism and Territories. 40 pp.

Department of Conservation and Land Management. (1989). Ningaloo Marine Park (State waters) Management Plan 1989-1999. Department of Conservation and Land Management. 75 pp.

Department of Conservation and Land Management. (1994). Shark Bay Marine Reserves Draft Management Plan. National Parks and Nature Conservation Authority. 156 pp.

Department of Minerals and Energy (1994). North West Shelf, Oil and Gas. Petroleum Operations Division, Western Australian Department of Minerals and Energy.

DEST (1995). World Heritage Information Kit. Shark Bay, Western Australia. Department of Environment, Sport and Territories, Canberra.

Evans, S. M., Leksono, T. and McKinnell, P. D. (1995). Tributyltin pollution: a diminishing problem following legislation limiting the use of TBT-based anti-fouling paints. *Marine Pollution Bulletin* **30**, 14-21.

Gough, M. A., Fothergill, J. and Hendrie, J. D. (1994). A survey of southern England coastal waters for the s-Triazine antifouling compound Irgarlo 1051. *Marine Pollution Bulletin* **28**, 603-20.

Government of Western Australia (1994). New Horizons in Marine Management. Published by the Government of Western Australia.

Iwata, H., Tanabe, S., Miyazaki, N. and Tatsukawa, R. (1994). Detection of butyltin compound residues in the blubber of marine mammals. *Marine Pollution Bulletin* **28**, 607-12.

Logan, S. H., and Cebulski, D. E. (1970). Sedimentary environments of Shark Bay, Western Australia. *Memoirs of the American Association of Petroleum Geologists* **13**, 1-37.

Marine Parks and Reserves Selection Working Group (1994). A representative marine reserve system for Western Australia. Report of the Marine Parks and Reserves Selection Working Group. Published by the Department of Conservation and Land Management.

Marsh, H., Harris, A. N. B., and Lawler, I. R. (in press). Is the dugong fishery in Torres Strait sustainable at current harvest levels. *Biological Conservation*

Marsh, H., Prince, R. I. T., Saalfeld, W. K., and Shepherd, R. (1994). The distribution and abundance of the dugong in Shark Bay, Western Australia. *Wildlife Research* **21**, 149-61.

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

Marsh, H., and Saalfeld, W. K. (1989*a*). Distribution and abundance of dugongs in the northern Great Barrier Reef Marine Park. *Australian Wildlife Research* **16**, 429-40.

Marsh, H., and Saalfeld, W. K. (1989*b*). Aerial surveys of sea turtles in the northern Great Barrier Reef Marine Park. *Australian Wildlife Research* **16**, 239-49.

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

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

Marsh, H., and Sinclair, D. F. (1989*b*). An experimental evaluation of dugong and sea turtle aerial survey techniques. *Australian Wildlife Research* **16**, 639-650.

May, R. F., Lenanton, R. C. J., and Berry, P. F. (1983). Ningaloo Marine Park. Report and recommendations to the Marine Park Working Group. National Parks Authority, Report 1. 67 pp.

McCook, L. J., Klumpp, D. W. and McKinnon, A. D. (in press). Seagrass communities in Exmouth Gulf, Western Australia: a preliminary survey. *Journal of the Royal Society of Western Australia.*

McMillin, L. M., and Crosby, D. S. (1984). Theory and validation of the multiple window sea surface temperature technique. *Journal of Geophysical Research* **89**, 3655-61.

Norton-Griffiths, M. (1978). `Counting animals Handbook No. 1'. (Serengeti Biological Monitoring Programme African Wildlife Leadership Foundation: Kenya).

Pearce, A. F. and Walker, D. I., Eds. (1991). 'The Leeuwin Current: an influence on the coastal climate and marine life of Western Australia.'. *Journal of the Royal Society of Western Australia* 74.

Postle, D. and Simmonds, M., Eds. (1994). 'Encounters with Whales '93. A conference to further explore the management issues relating to human/whale interactions.', Workshop Series No 20. (Great Barrier Reef Marine Park Authority: Townsville.)

Preen, A. (1989). Dugongs. Volume 1. The status and conservation of dugongs in the Arabian Region. Meteorology and Environmental Protection Administration Coastal and Marine Management Series. Report No. 10. 200 pp.

Preen, A. R. (1993). Interactions between dugongs and seagrasses in a subtropical environment. PhD Thesis, James Cook University of North Queensland. 392 pp.

Prince, R. I. T. (1993). Western Australian marine turtle conservation project: an outline of scope and an invitation to participate. *Marine Turtle Newsletter* **60**, 8-14.

Prince, R. I. T. (1994). Shark Bay World Heritage Area: An important Loggerhead nesting site. *Marine Turtle Newsletter* 67, 5-6.

Prince, R. I. T., Anderson, P. K., and Blackman, D. (1981). Status and distribution of dugongs in Western Australia. In `The Dugong: Proceedings of a seminar/workshop held at James Cook University 8-13 May, 1979'. (Ed. H. Marsh.) pp. 67-87. (James Cook University of North Queensland, Townsville).

Smolker, R. A., Richards, A. F., Conner, R. C. and Pepper, J. W. (1992). Sex differences in patterns of association among Indian Ocean bottlenose dolphins. *Behaviour* **123**, 38-69.

Stewart, C. and Thompson, J. A. J. (1994). Extensive butyltin contamination in southwestern coastal British Columbia, Canada. *Marine Pollution Bulletin* **28**, 601-6.

Taylor, G. (1989). Whale Sharks of Ningaloo Reef, Western Australia: A preliminary study. *Western Australian Naturalist* **18**, 7-12.

Taylor, G. (1994*a*). Gentle giants of the deep. *Australian Geographic* **34**, 93-103.

Taylor, G. (1994*b*). 'Whale Sharks. The Giants of Ningaloo Reef.'. (Angus & Robertson: Sydney.)

Walker, D. I. (1989). Regional studies - Seagrass in Shark Bay, the foundation of an ecosystem. In 'Biology of seagrasses. A treatise on the biology of seagrasses with special reference to the Australian region'. (Eds Larkum, A. W. D., McComb, A. J. and Shepherd, S. A.) pp. 182-210. (Elsevier: Amsterdam.)

Walker, D. I., and Prince, R. I. T. (1987). Distribution and biogeography of seagrass species on the northwest coast of Australia. *Aquatic Botany* **29**, 19-32.

Wilson, B. R., Hancock, D. A. and Chittleborough, R. G. (1979). The Sea. In 'Environment and Science'. (Eds O'Brien, B. J.) pp. 146-82. (University of Western Australia Press: Perth.)

Table 1. Weather conditions encountered during aerial surveys of Shark Bay and Ningaloo Reef/Exmouth Gulf in 1989 and 1994

Values for wind speed, cloud cover and cloud height are the range of values recorded at the start of each flying session. Values for Beaufort sea state and glare are the mean of the modes for each transect with range in parentheses. Glare is measured as: 0, none; 1, <25% of field of view affected; 2, 25-50%; 3, > 50%.

	Shark Bay		Ningaloo/Exmouth	
Variable	1989	1994	1989	1994
Wind speed (km h-1)	0-37	0-28	0-10	0-33
Cloud cover (oktas)	0-8	0-6	0	0-1
Minimum cloud height (m)	750-3650	1000-8000	-	300
Beaufort sea state	1.66 (0-4)	0.99 (0-3)	1.54 (0-3)	1.37 (0.5-2.0)
Glare North	1.43 (0-3)	1.25 (0-3.0)	1.69 (0-3)	1.65 (0-3.0)
South	0.01 (0-3)	0.03 (0-0.5)	0	0.07 (0-1.0)

Table 2. Details of group size estimates and correction factors used to derive the population estimates for dugongs, turtles and dolphins in Shark Bay, Ningaloo Reef and Exmouth Gulf in the winters of 1989 and 1994

Taxa	Area	Year	Group size (C.V.)	Perception correction factor (C.V.)		Availability correction factor (C.V.)
				Port	Starboard	
Dugong	Shark Bay	1989	1.48 (0.03)	1.03 (0.01)	1.04 (0.01)	2.45 (0.12)
		1994	1.45 (0.06)	1.04 (0.01)	1.09 (0.02)	3.35 (0.12)
	Exmouth	1989	1.48 (0.03)	1.03 (0.01)	1.04 (0.01)	2.45 (0.12)
		1994	1.48 (0.14)	1.11 (0.09)	1.19 (0.11)	3.90 (0.15)
	Ningaloo	1989	1.48 (0.03)	1.03 (0.01)	1.04 (0.01)	2.45 (0.12)
		1994	1.48 (0.14)	1.11 (0.09)	1.19 (0.11)	3.90 (0.15)
Turtles	Shark Bay	1989	1.10 (0.02)	1.12 (0.01)	1.11 (0.01)	1.39 (0.08)
		1994	1.10 (0.03)	1.13 (0.02)	1.14 (0.04)	1.98 (0.09)
	Exmouth	1989	1.10 (0.02)	1.12 (0.01)	1.11 (0.01)	1.39 (0.08)
		1994	1.11 (0.04)	1.67 (0.10)	1.62 (0.09)	1.59 (0.14)
	Ningaloo	1989	1.10 (0.02)	1.12 (0.01)	1.11 (0.01)	1.39 (0.08)
		1994	1.12 (0.05)	1.67 (0.10)	1.62 (0.09)	1.93 (0.12)
Dolphins	Shark Bay	1989	2.57 (0.10)	1.05 (0.02)	1.04 (0.01)	1.00 (0.00)
		1994	2.00 (0.18)	1.06 (0.02)	1.14 (0.04)	1.00 (0.00)
	Exmouth	1989	2.57 (0.10)	1.05 (0.02)	1.04 (0.01)	1.00 (0.00)
		1994	2.00 (0.18)	1.06 (0.02)	1.14 (0.04)	1.00 (0.00)

Table 3. Block areas, survey intensity (cover) and population estimates of dugongs, turtles and dolphins in Shark Bay, Ningaloo Reef and Exmouth Gulf
Only the northern half of Ningaloo Reef was surveyed in 1989. Too few dolphins were sighted in Ningaloo Reef in 1994 to calculate population estimates.

Block	Area (km²)	Cover (%)	Dugong				Turtles				Dolphins			
			Density (km^{-2})		Numbers		Density (km^{-2})		Numbers		Density (km^{-2})		Numbers	
			1989	1994	1989	1994	1989	1994	1989	1994	1989	1994	1989	1994
SB-0	1198	4.24	0	0	0	0	0.20±0.08	0.10±0.11	242±95	116±134	0.27±0.18	0	319±216	0
SB-1	1160	9.78	0	0.09±0.06	0	106±66	0.45±0.13	0.32±0.08	523±152	376±89	0.26±0.10	0.20±0.04	296±116	229±42
SB-2	1631	4.05	0	0	0	0	0	0	0	0	0	0	0	0
SB-3	2389	9.46	0.07±0.03	0.30±0.12	170±68	710±288	0.46±0.15	1.00±0.23	1105±351	2380±559	0.25±0.07	0.22±0.06	593±162	530±146
SB-4	2726	9.93	1.69±0.31	2.78±0.51	4467±819	7582±1401	0.64±0.12	0.79±0.12	1745±339	2146±324	0.26±0.08	0.22±0.07	700±215	613±192
SB-5	812	9.41	5.11±1.50	0.74±0.13	4040±1171	599±109	1.04±0.21	0.77±0.21	848±166	624±167	0.24±0.04	0.49±0.09	198±35	398±72
SB-6	2243	9.82	0.60±0.17	0.36±0.08	1293±847	798±181	0.64±0.19	0.89±0.10	1433±437	1997±223	0.26±0.10	0.06±0.02	587±221	138±34
SB-7	2747	9.90	0.07±0.03	0.27±0.08	176±90	734±222	0.17±0.05	0.29±0.09	477±127	792±233	0.07±0.03	0.06±0.03	195±77	157±72
Total	14906	8.69	0.71±0.12	0.71±0.10	10146±1665	10529±1464	0.43±0.05	0.57±0.05	6373±710	8431±758	0.19±0.03	0.14±0.02	2888±434	2064±267
Exmouth	3180	9.2	0.33±0.10	0.32±0.16	1062±321	1006±494	1.42±0.28	1.02±0.22	4512±877	3252±684	0.16±0.04	0.09±0.03	496±123	283±93
Ningaloo														
1989	555	8.3	1.14±0.23		634±127		4.51±0.47		2503±261		0.18±0.06		97±30	
1994	869	8.9		1.11±0.37		968±320		4.90±0.83		4260±724				
Total														
1989	3735	9.1	0.45±0.09		1696±345		1.88±0.25		7015±915		0.16±0.03		593±127	
1994	4049	9.2		0.49±0.40		1974±588		1.86±0.25		7512±996				

Table 4. Results of analyses of variance comparing the 1989 and 1994 densities of dugongs, turtles and dolphins in Shark Bay and Exmouth Gulf
Results are presented without covariates (1) and with Beaufort sea state as a covariate (2).

Source of variation	Dugongs						Turtles						Dolphins					
	d.f.		F		Significance		d.f.		F		Significance		d.f.		F		Significance	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Shark Bay																		
Transect nested in block[A]	59	59	2.00	2.04	0.004	0.004	74	74	2.35	2.73	0.000	0.000	71	71	1.77	1.71	0.009	0.013
Block[B]	4[C]	4[C]	17.74	21.98	0.000	0.000	6	6	3.77	3.50	0.002	0.004	5[D]	5[D]	1.95	2.34	0.097	0.050
Year[A]	1	1	0.55	0.57	0.461	0.453	1	1	7.55	0.16	0.008	0.694	1	1	1.86	0.36	0.177	0.552
Block by year[A]	4	4	3.06	2.50	0.023	0.052	6	6	2.40	2.77	0.036	0.018	5	5	1.21	1.22	0.315	0.309
Residual	59	58					74	73					71	70				
Regression[A]				3.33		0.073				14.61		0.000				0.27		0.603
Exmouth																		
Year	1	1	0.75	4.26	0.39	0.056	1	1	0.83	0.28	0.376	0.605						
Transect	17	17	1.70	2.61	0.141	0.031	17	17	1.36	0.82	0.265	0.652						
Residual	17	16					17	16										
Regression		1		6.51		0.21		1		0.32		0.579						

[A] Tested against residual. [B] Tested against transect nested in block. [C] Excludes blocks 0 and 2 where no dugongs were seen. [D] Excludes block 2 where no dolphins were seen.

Table 5. Densities of turtles and dolphins recorded during aerial surveys of other areas using the same technique

Location (Latitude)	Date	Area (km^{-2})	Density (km^{-2}) ± s.e. Turtles	Density (km^{-2}) ± s.e. Dolphins	Reference
South-east Queensland (25-27° S)	1988	9170	0.32±0.04	-	Marsh, Saalfeld and Preen, unpublished data
Southern Great Barrier Reef	1986/7	39396	0.64±0.04	0.17±0.01	Marsh, Breen and Preen, unpublished data
(15-25° S)	1992	39396	0.85±0.13	0.30±0.04	Marsh, Breen and Preen, unpublished data
Northern Great Barrier Reef (11-15° S)	1985	31288	1.03±0.08[1]	0.21±0.08[2]	[1] Marsh and Saalfeld 1989*b*, [2] Marsh, Kwan and Lawler, unpublished data
	1990	31288	1.46±0.11	0.16±0.02	Marsh, Kwan and Lawler, unpublished data
Mornington Island area (17° S)	1991	8848	0.95±0.15	0.09±0.02	Marsh and Lawler, unpublished data
Torres Strait (9-11° S)	1987	30533	1.43±0.16	-	Marsh and Saalfeld, unpublished data
	1991	30560	2.13±0.17	0.07±0.02	Marsh *et al.* in press
Shark Bay	1989	14906	0.43±0.05	0.19±0.03	this study
(25-27° S)	1994	14906	0.57±0.05	0.14±0.02	this study
Exmouth	1989	3180	1.42±0.28	0.16±0.04	this study
(22° S)	1994	3180	1.02±0.22	0.09±0.03	this study
Ningaloo	1989	555	4.51±0.47	0.18±0.06	this study
(22-23° S)	1994	869	4.90±0.83	-	this study

Figure Captions

Fig. 1. Location of Shark Bay, Ningaloo Reef and Exmouth Gulf showing the boundaries of the Shark Bay World Heritage Area, Shark Bay Marine Park and Ningaloo Marine Park. Hatching indicates the salinity regime of Shark Bay.

Fig. 2. Survey blocks and flight transects used for the 1989 and 1994 aerial surveys of Shark Bay, Ningaloo Reef and Exmouth Gulf. Fewer transects were flown over Ningaloo Reef in 1989, but they were longer (not indicated).

Fig. 3. Dugong sightings in Shark Bay in relation to water temperature in 1989 and 1994. Circles indicate the number of animals seen along 1 km of transect, and do not necessarily reflect group size.

Fig. 4. Turtle sightings in Shark Bay in relation to water temperature in 1989 and 1994. Circles indicate the number of animals seen along 1 km of transect, and do not necessarily reflect group size.

Fig. 5. Dolphin sightings in Shark Bay in relation to water temperature in 1989 and 1994. Circles indicate the number of animals seen along 1 km of transect, and do not necessarily reflect group size.

Fig. 6. Bathymetry of Shark Bay and the distribution of whale and manta ray sightings in 1989 and 1994. These maps include whales that were not on transects. Numbers indicate the size of groups (>1).

Fig. 7. Dugong sightings in Ningaloo Reef and Exmouth Gulf in 1989 and 1994. Circles indicate the number of animals seen along 1 km of transect, and do not necessarily reflect group size. The 1989 transects over Ningaloo Reef were longer than those of 1994.

Fig. 8. Turtle sightings in Ningaloo Reef and Exmouth Gulf in 1989 and 1994. Circles indicate the number of animals seen along 1 km of transect, and do not necessarily reflect group size. The 1989 transects over Ningaloo Reef were longer than those of 1994.

Fig. 9. Dolphin sightings in Ningaloo Reef and Exmouth Gulf in 1989 and 1994. Circles indicate the number of animals seen along 1 km of transect, and do not necessarily reflect group size. The 1989 transects over Ningaloo Reef were longer than those of 1994.

Fig. 10. Bathymetry and the distribution of whale, whale shark and manta ray sightings in Ningaloo Reef and Exmouth Gulf in 1989 and 1994. The 1989 transects over Ningaloo Reef were longer than those of 1994.

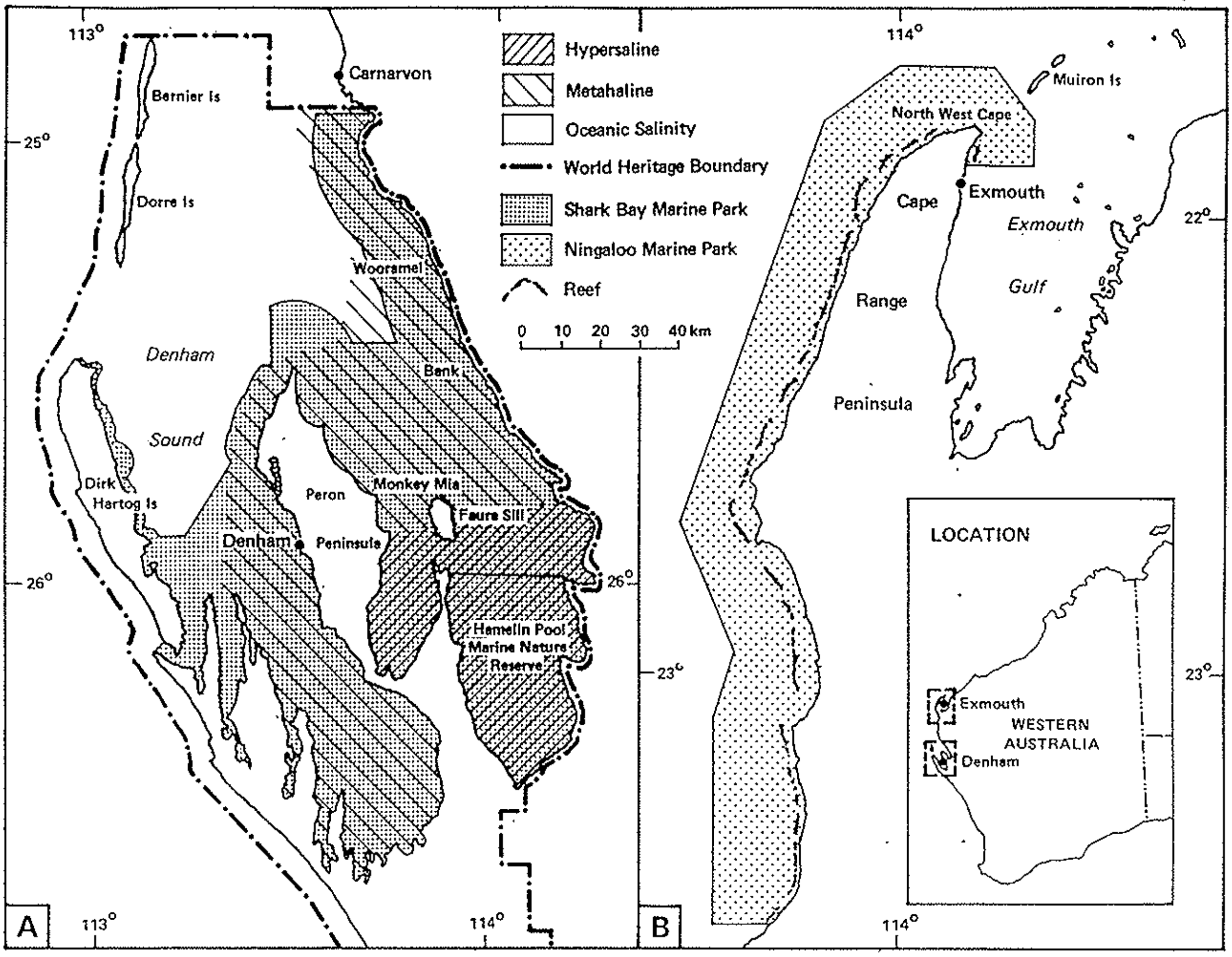
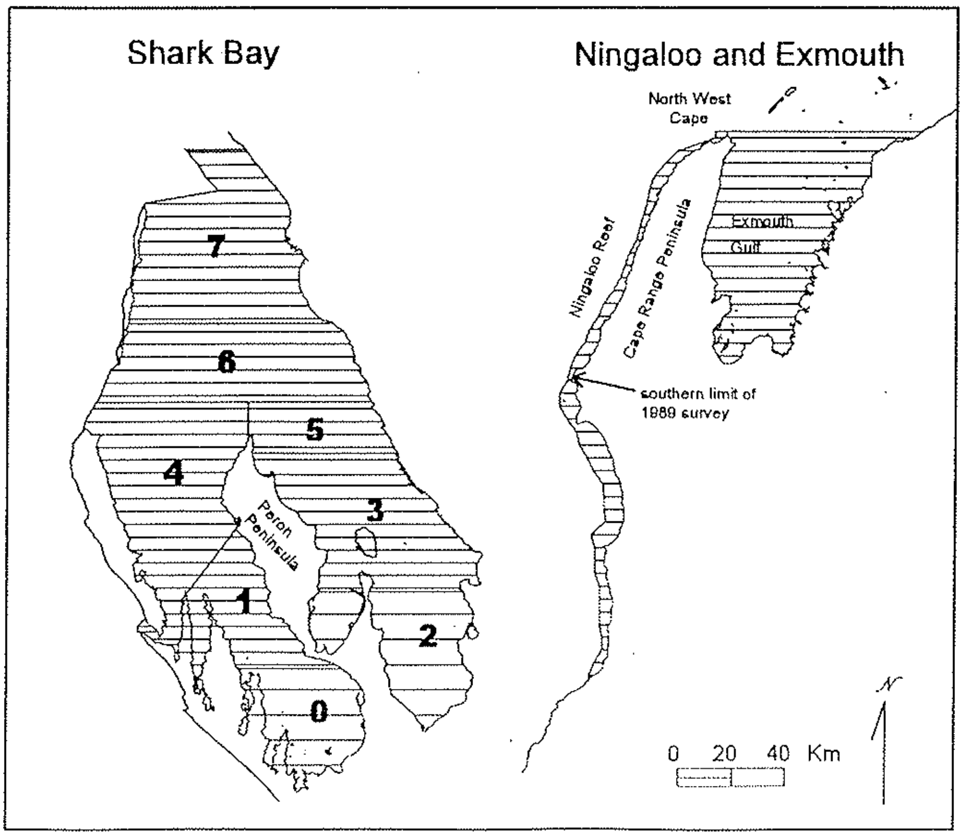


Figure 1.



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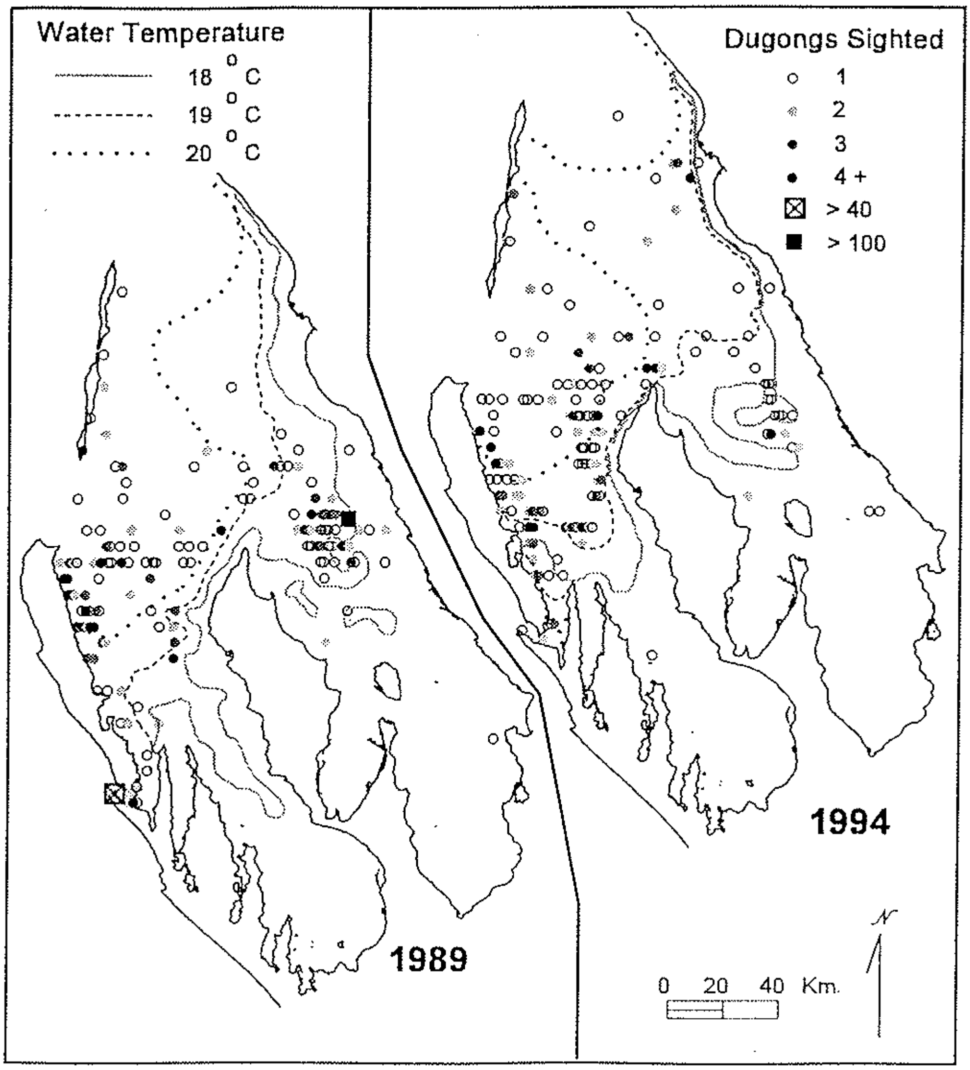

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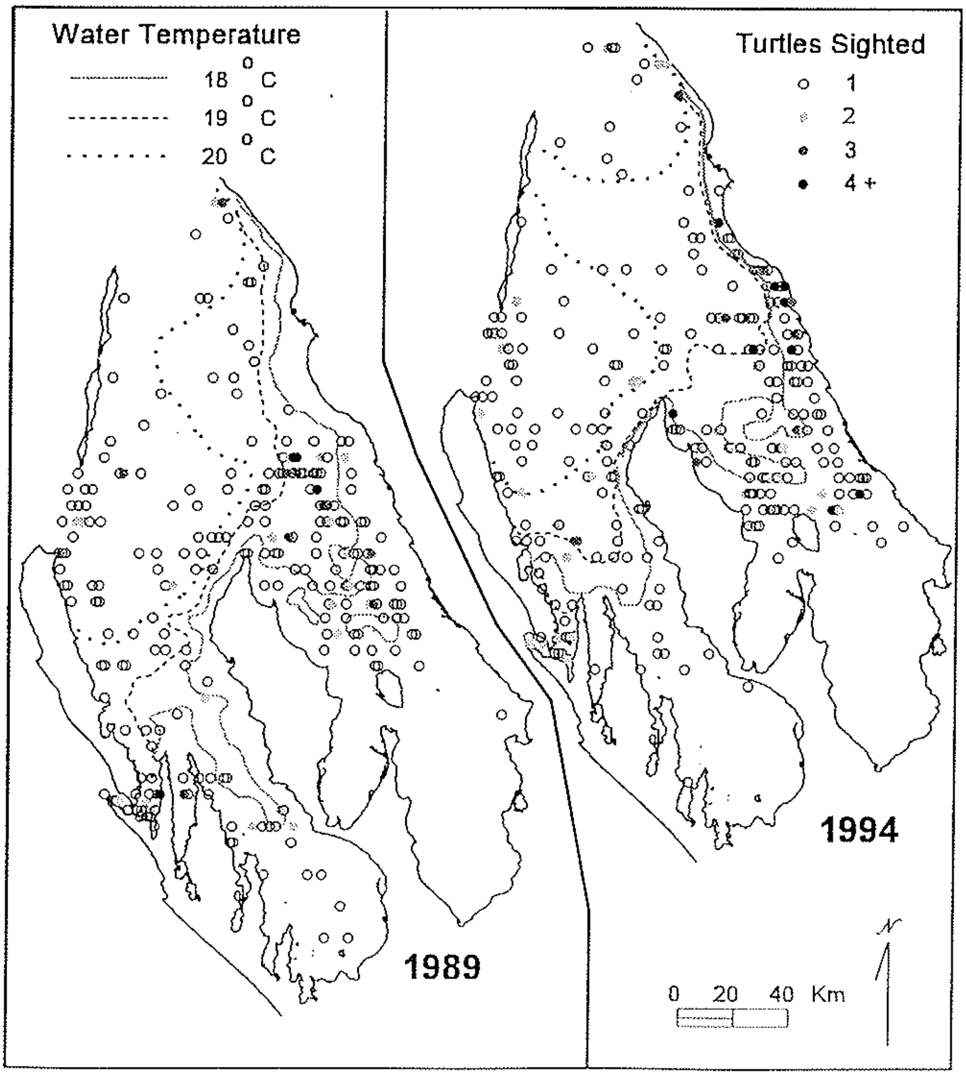

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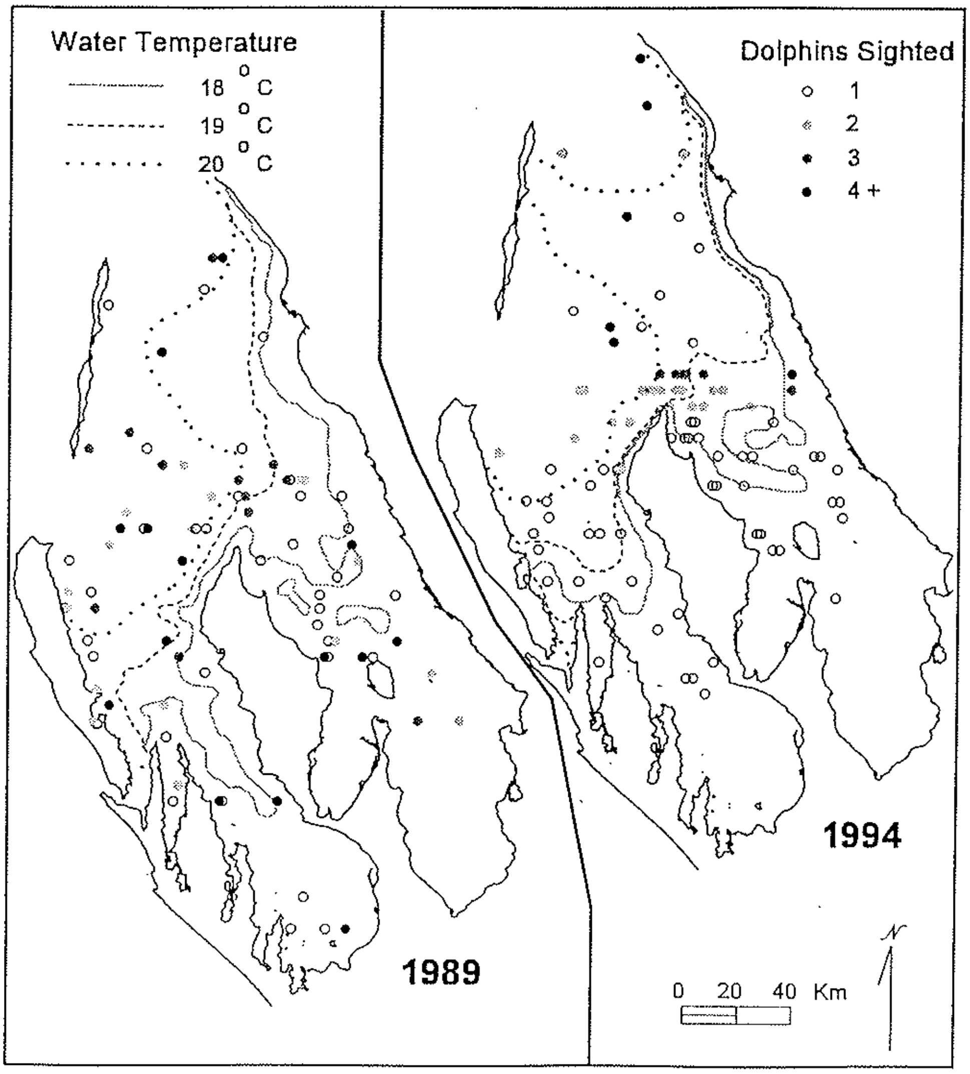

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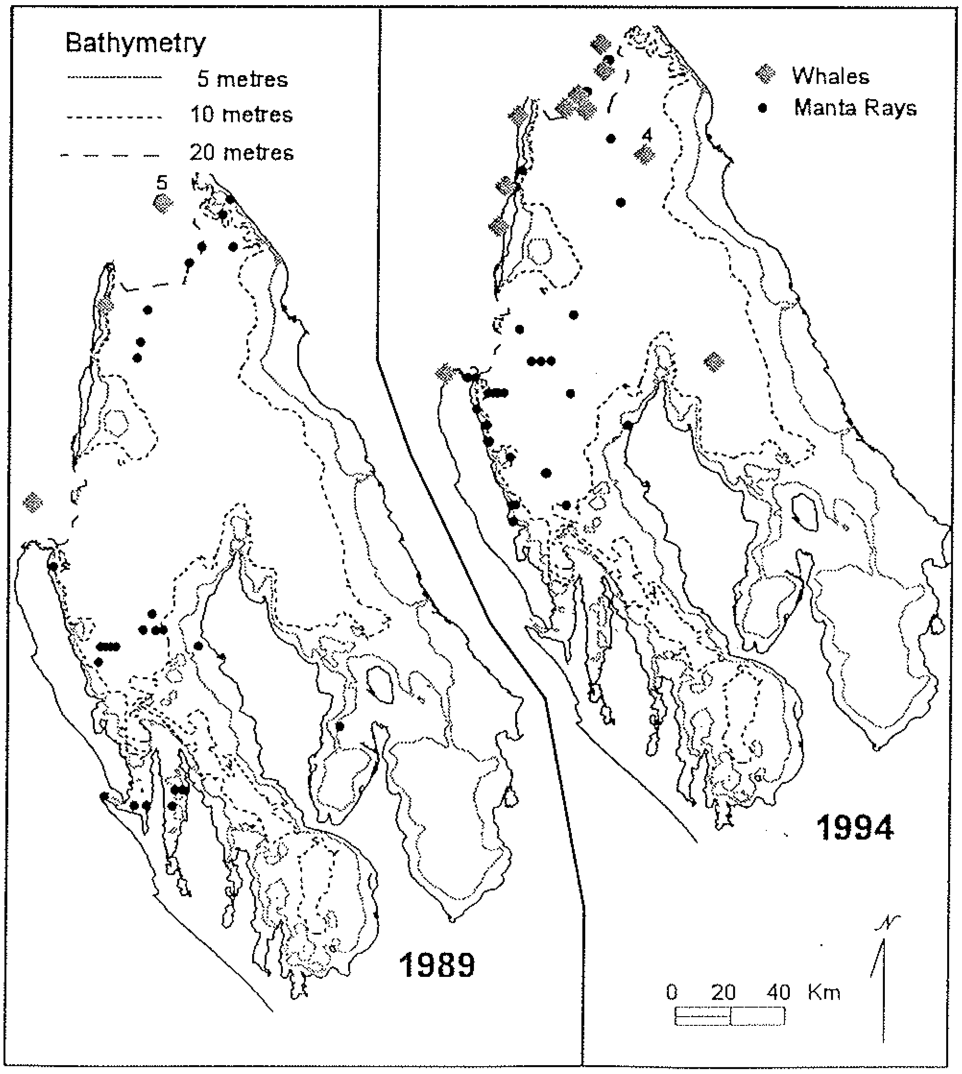

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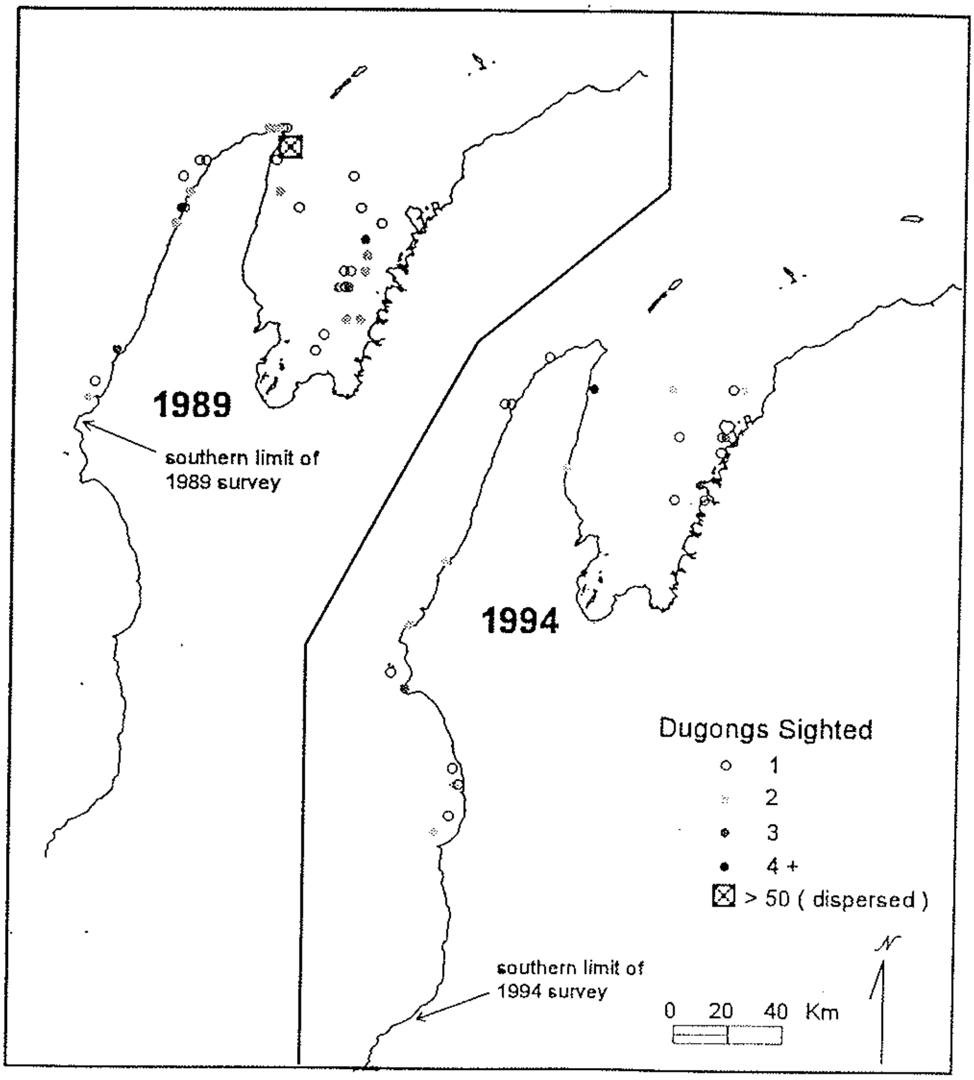

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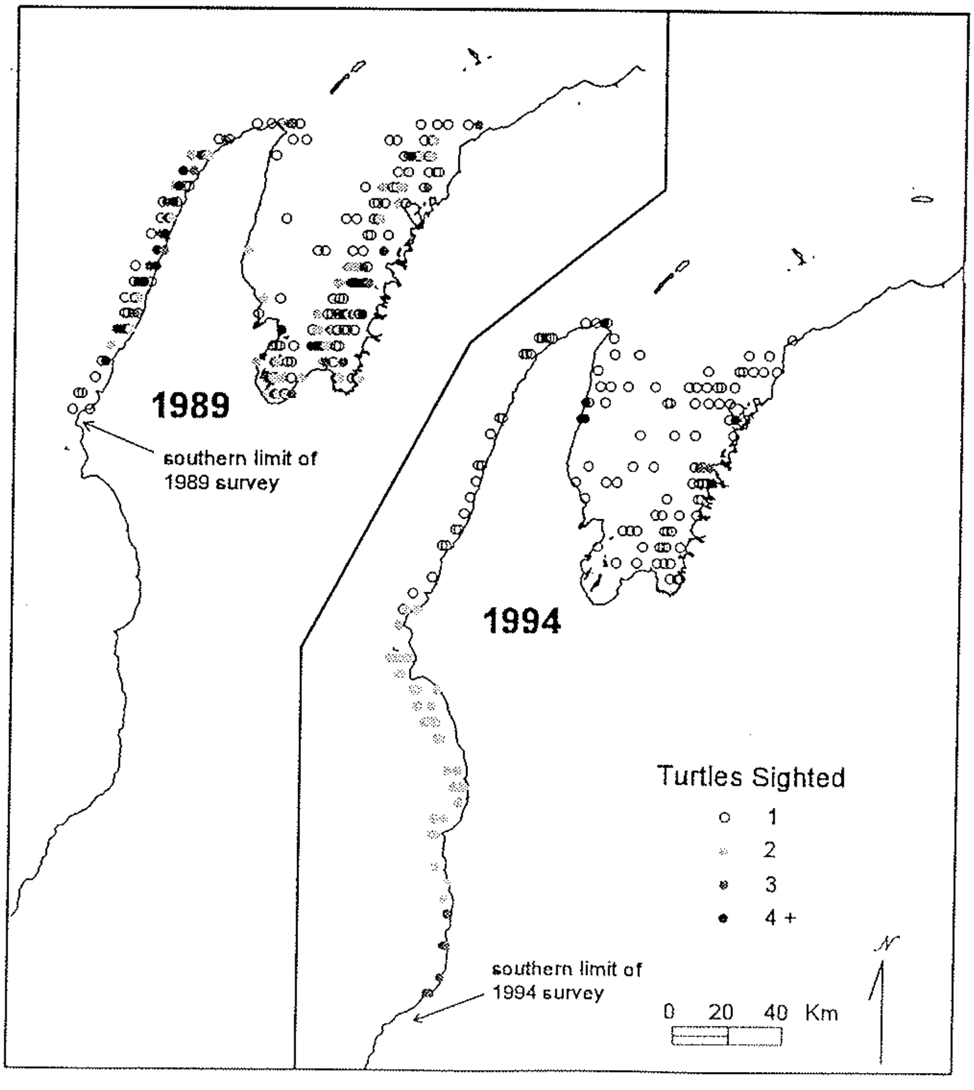

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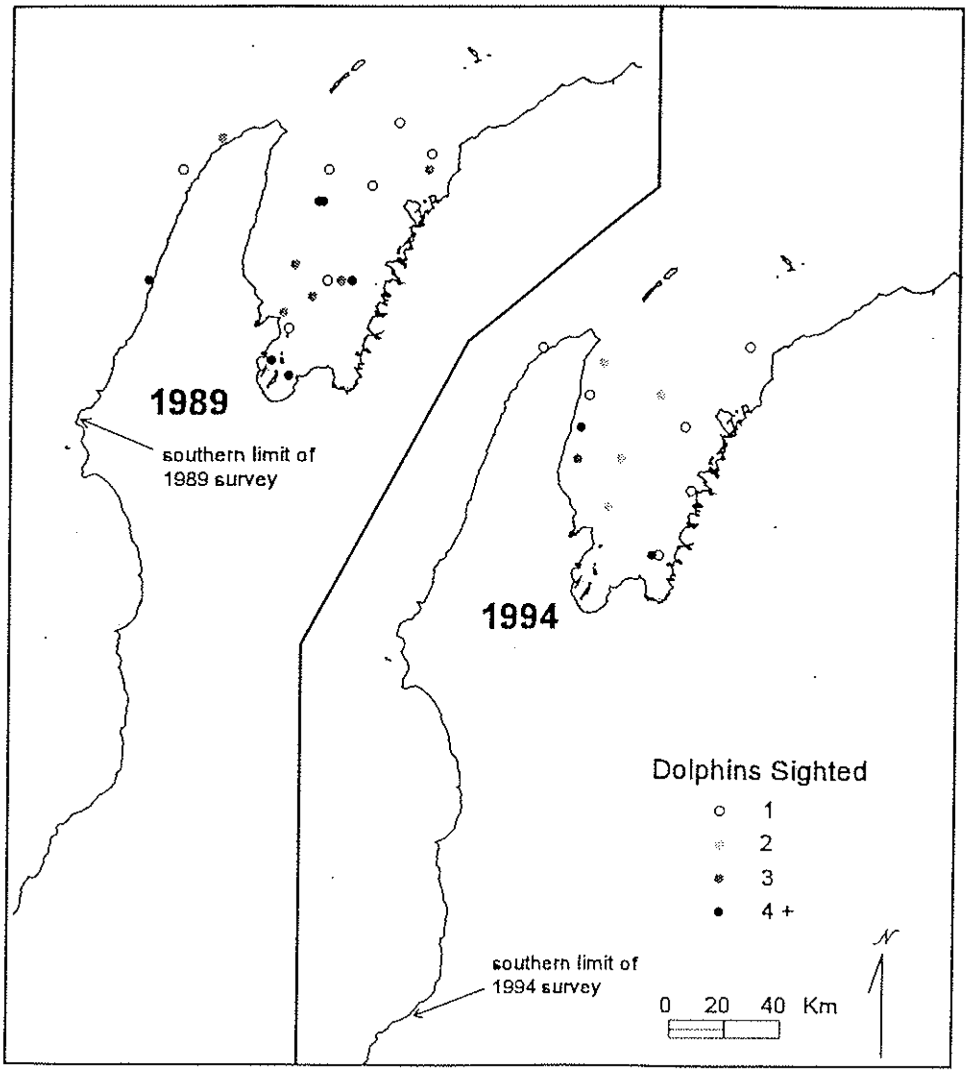

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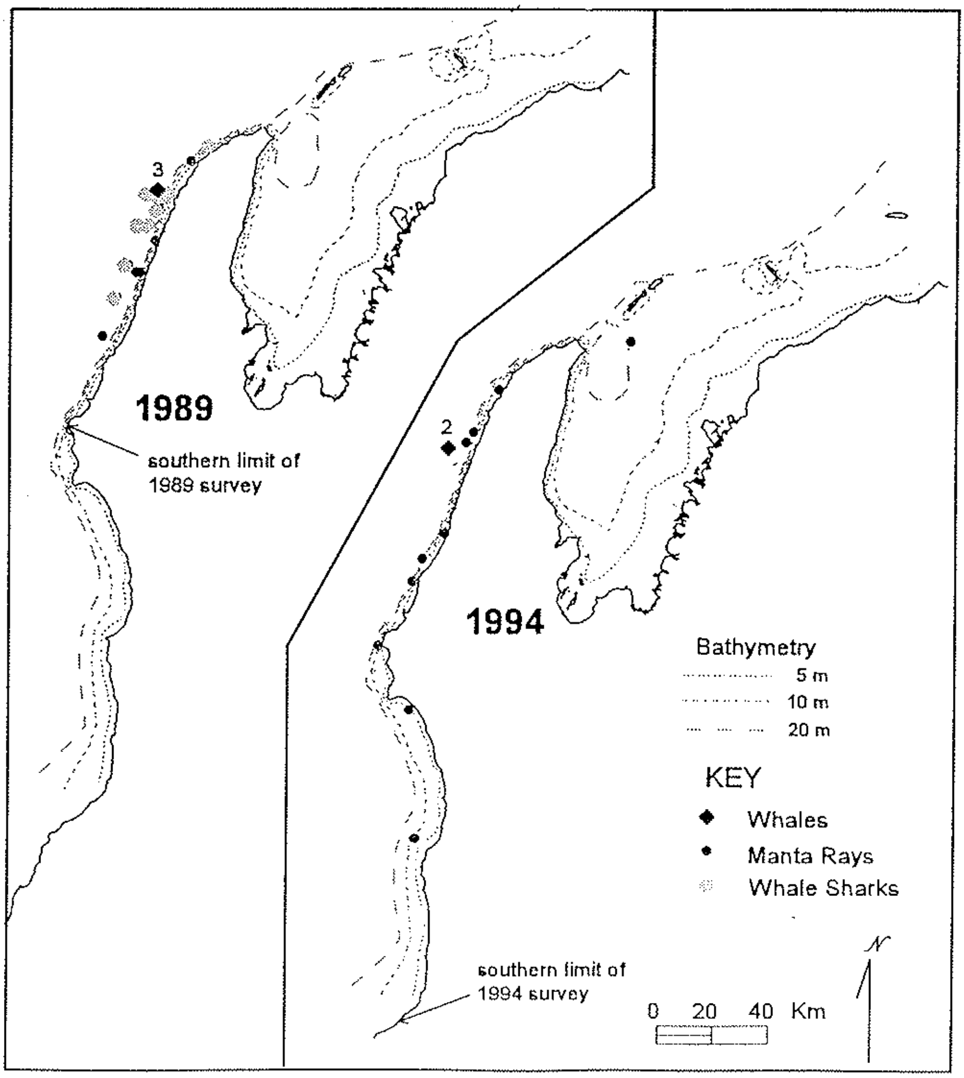

Figure 10.