Wildl. Res., 1995, **22**, 507–19

Response of Dugongs to Large-scale Loss of Seagrass from Hervey Bay, Queensland, Australia

Anthony Preen and Helene Marsh

Department of Tropical Environment Studies and Geography,
James Cook University, Townsville, Qld 4811, Australia.

Abstract

In August 1988, southern Hervey Bay contained an estimated 1753 (± 388, s.e.) dugongs, and the regional (Hervey Bay plus Great Sandy Strait) population was estimated to be 2206 (± 420). Following two floods and a cyclone in early 1992, more than 1000 km^2 of seagrass were lost from Hervey Bay. Approximately eight months later (November 1992), southern Hervey Bay contained only 71 (± 40) dugongs. In December 1993, 21 months after the floods, the regional dugong population was estimated to be 600 (± 126). The proportion of calves in the population declined from 22% seen in 1988 and 1992, to only 2·2% in 1993. A total of 99 dugong carcasses was recovered. Most dugongs died 6–8 months after the floods, and most were emaciated as a result of starvation. Some dugongs travelled up to 900 km south of Hervey Bay before dying, although some animals successfully relocated to other areas. Full recovery (to the 1988 population level) of the Hervey Bay dugong population may take more than 25 years. This event demonstrates the need to consider the potential impacts of habitat loss or modification, as well as the influence of traditional hunting and incidental mortality in gill nets, when managing for the conservation of dugong populations.

Introduction

Dugongs (*Dugong dugon*) are seagrass-dependent foragers of the near-shore waters of the tropical and subtropical Indian and western Pacific oceans (Nishiwaki and Marsh 1985). They have a relatively low reproductive potential (Marsh *et al.,* 1984) and are subjected to a variety of anthropogenic impacts, including hunting and incidental drowning in nets. Dugongs have been exterminated from some parts of their former range and may be seriously threatened in others (Husar 1978; Marsh *et al.,* 1995). For these reasons dugongs are regarded as being vulnerable to extinction (IUCN 1990). Habitat loss or modification has not yet been demonstrated to be a threat to dugong populations, although there is some indirect evidence of impacts from cyclone-related damage to seagrass beds (Heinsohn and Spain 1974; Jones 1980).

Aerial surveys conducted through the 1970s and 1980s established that dugongs occur along the entire eastern coastline of Queensland, with the largest populations in the Starcke River area off Cape York Peninsula, and in Hervey Bay and the adjoining Great Sandy Strait in southern Queensland (Heinsohn *et al.* 1976; Marsh and Saalfeld 1989, 1990; Marsh *et al.* 1990). During the same period, a series of broad-scale seagrass surveys along the Queensland coast established that these two areas were also remarkable for their extent of seagrass: approximately 1200 km^2 in the Starcke River area and 1000 km^2 in Hervey Bay (Lee Long *et al.* 1993).

In August 1992, dead and dying dugongs began to strand in unprecedented numbers along the shores of Hervey Bay and the Great Sandy Strait. A subsequent survey of Hervey Bay found that virtually all the known seagrasses had disappeared, apparently as a result of an unusual combination of floods and a cyclone (Preen *et al.,* 1995). This paper describes the response of the dugongs to this major perturbation. Perhaps as many as 1000 dugongs left the region and 99 carcasses were recorded. Most animals died apparently of starvation. We estimate that it will take more than 25 years for dugong numbers in Hervey Bay to recover.

1037-3512/95/040507$05.00

Methods

Study Area

Hervey Bay (25°S, 152°45′E) is a large (3800 km^2), U-shaped embayment formed by Fraser Island, off the central coast of eastern Australia (Fig. 1). Although the northern side of the Bay is open to the Coral Sea, it is partly protected from oceanic swells by the southern extension of the Great Barrier Reef. The Great Sandy Strait is a connection 70 km long and 2–14 km wide, between the bottom (south) of Hervey Bay and the Pacific Ocean, at the southern end of Fraser Island (Fig. 1). The Great Sandy Strait receives the waters of the Mary River (annual discharge of 2 300 000 ML: Queensland Department of Primary Industries 1993).

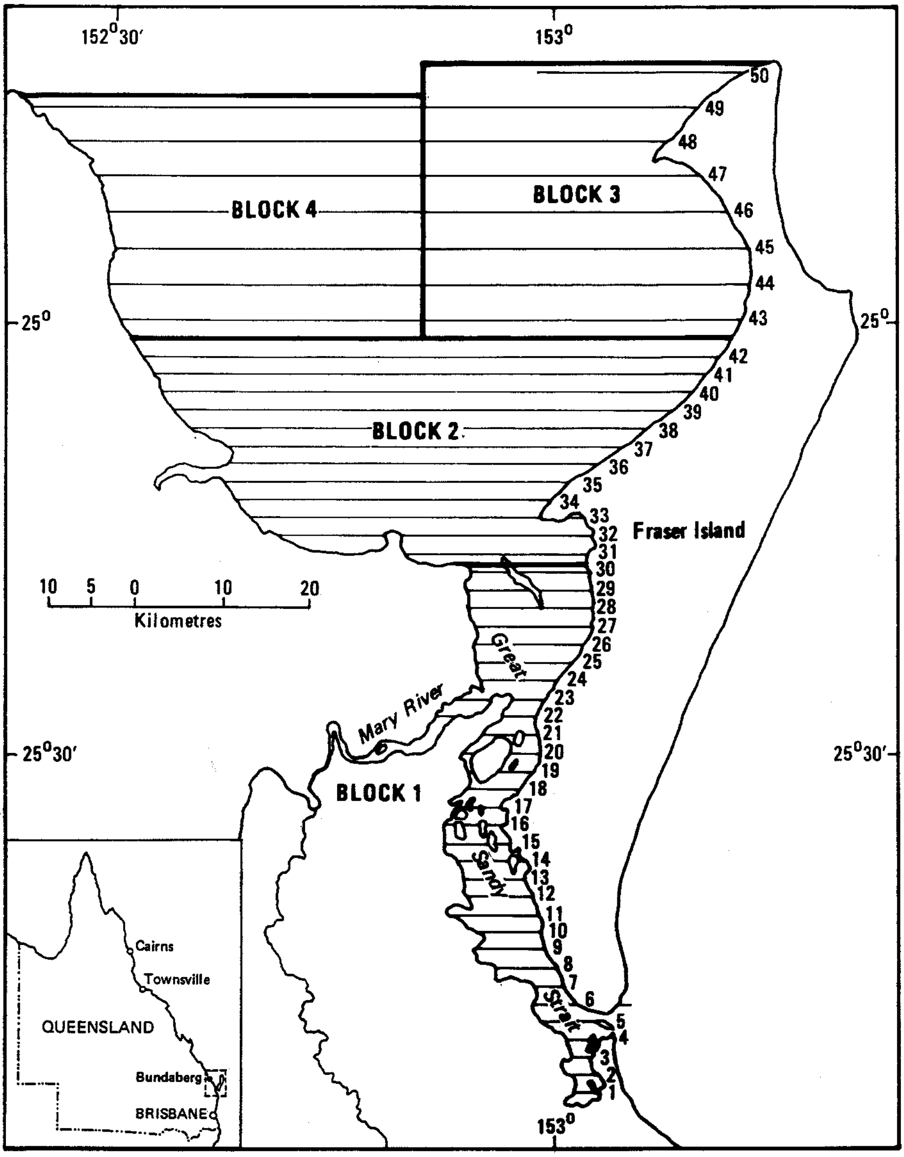

Fig. 1. The transect lines and survey blocks of the dugong survey of Hervey Bay and the Great Sandy Strait. In 1988, only even-numbered transects were flown in Block 1.

Aerial Surveys

Hervey Bay

Dedicated dugong surveys. We conducted dedicated aerial surveys to determine the distribution and abundance of dugongs in Hervey Bay and the Great Sandy Strait in August 1988, November 1992 and December 1993. The methods followed those of Marsh and Sinclair (1989*a*, 1989*b*) and Marsh and Saalfeld (1989). Sightings were recorded in a strip 200 m wide on each side of the aircraft, from an altitude of 137 m. Two isolated, independent observers were used on each side of the aircraft so factors could be derived to correct for the dugongs visible, but missed by observers [based on a mark–recapture analysis of sightings (perception-bias correction factor: Marsh and Saalfeld 1989)]. Results were standardised to correct for dugongs not at the surface at the time the plane passed over (availability-bias correction factor; Marsh and Sinclair 1989*b*). The same parallel, east–west-oriented transects were flown on each survey, except that the number of transects in Block 1 (Great Sandy Strait) was doubled for 1992 and 1993. This increased the survey intensity in this block from 9·6% in 1988 to 17% and 16·4% in 1992 and 1993, respectively (Fig. 1, Table 1). Surveys were conducted only under good weather conditions (Beaufort sea state ≤ 3) (Table 2), and we avoided flying during periods of severe glare (early morning, late afternoon and midday). The 1992 and 1993 surveys of the Great Sandy Strait were timed to coincide with high tide over most of the area. 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 standard errors were adjusted to incorporate the error associated with each correction factor (Table 3), as outlined in Marsh and Sinclair (1989*a*).

The significance of the differences between the dedicated dugong surveys of Hervey Bay conducted in 1988, 1992 and 1993 was tested by ANOVA 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 km^{-2}, based on mean group sizes and the estimates of the correction factors for perception and availability bias, each line contributing one density per survey based on the combined corrected counts of both tandem observer teams. The densities were transformed [$\log_{10}(x+1)$] for analysis, to equalise the error variances.

Whale surveys. The distribution of dugongs in Hervey Bay was recorded during 7–17 surveys for humpback whales (*Megaptera novaeangliae*) conducted each year between 1989 and 1992. Although the surveys were flown by different organisations, using different methods, they were all conducted during winter and spring (August–October) using a strip-transect design (see Corkeron *et al.* 1994). These whale surveys differed from the dedicated dugong surveys in that they were flown at higher altitudes (457 m in 1989–90, 305 m in 1991, and 250 m in 1992), used two observers, used a lower survey intensity, and excluded the west of the bay and all of the Great Sandy Strait.

Table 1. Areas of survey blocks and sampling intensities in the Great Sandy Strait and Hervey Bay

Block	Area (km^2)	Survey intensity (%)		
		1988	1992	1993
1 (Great Sandy Strait)	512	9·6	17·0	16·4
2 (S Hervey Bay)	1402	16·0	12·2	15·8
3 (NE Hervey Bay)	1222	9·5	9·0	8·5
4 (NW Hervey Bay)	1235	8·7	8·7	8·7

Table 2. Weather conditions during aerial surveys of Hervey Bay and the Great Sandy Strait
Values for Beaufort sea state and glare are the mean of the modes for each transect, with the range in parentheses. Glare: 0, none; 1, less than 25% of field affected; 2, 25–50%; 3, more than 50%

Conditions	1988	1992	1993
Wind speed at take-off ($km\ h^{-1}$)	<28	<20	<20
Cloud cover at take-off (octas)	1–6	0–5	1–4
Minimum cloud height (m)	610–2400	300–760	460–1800
Beaufort sea state	2·1 (0–4)	2·0 (0–3·5)	1·2 (0–3)
Glare	0·9 (0–3)	1·6 (0–3)	1·4 (0–3)

Table 3. Details of mean group sizes, correction factors and their coefficients of variation (c.v.) used for the population estimates of dugongs in Hervey Bay and the Great Sandy Strait

Survey	Mean group size (c.v.)	Correction factors		
		Perception (c.v.)		Availability (c.v.)
		Port	Starboard	
1988	1·692 (0·120)	1·032 (0·008)	1·035 (0·010)	1·636 (0·154)
1992	1·534 (0·174)	1·289 (0·096)	1·049 (0·018)	1·146 (0·241)
1993	1·184 (0·091)	1·000 (0·000)	1·036 (0·016)	1·600 (0·267)

Moreton Bay

In response to a large increase in dugong sightings reported by the public in Moreton Bay (>150 km south of the Great Sandy Strait), a survey of the main dugong habitat (east–central area of the bay) was flown on 7 April 1993 following the methods used on 28 occasions between July 1988 and February 1990 by Preen (1993). A shoreline survey (*sensu* Heinsohn *et al.* 1979) covering the other areas of seagrass in Moreton Bay was flown the following day to determine whether there had been a major redistribution of dugongs following the possible immigration. These surveys were flown at an altitude of 274 m and used three observers, who recorded sightings directly onto maps. Details of the flight paths are provided in Preen (1993). The standardised surveys covered more than 70% of the area of dugong habitat in Moreton Bay, and the data are presented as uncorrected counts.

Carcass Salvage

Reports of dead or moribund dugongs were received from April 1992. Where practicable, fresh carcasses were examined by personnel experienced with dugongs or cetaceans, preferably by a veterinarian. The skull, stomach contents, gonads and tissue samples were collected whenever possible.

Results

Dugong Population of the Hervey Bay Region Prior to the Loss of Seagrass

In August 1988, Hervey Bay and the Great Sandy Strait contained an estimated population of 2206 dugongs (± 420, s.e.) (Table 4). Most (80%) of these dugongs occurred in the southern half of Hervey Bay (Block 2) (Table 4; Fig. 2*a*), corresponding with the distribution of seagrasses at the time (Preen *et al.*, in press).

Although the 31 whale surveys (1989–91) covered the eastern half of the bay only, the distribution of dugong sightings accorded with the pattern indicated by the 1988 dugong survey. In the second half of 1991, for example, 71% of all dugongs sighted on nine surveys were seen on the southern two transects, and 76% of these were towards the centre, or west of the bay (along the western half of these transects: Fig. 2*b*). This pattern was typical of the whale surveys from the other years, although there was also a concentration of sightings in the north-east of the bay in 1989 (M. Brown, personal communication).

Dugong Population of the Hervey Bay Region After the Loss of Seagrass

The 17 whale surveys conducted in 1992 occurred 5–7 months after the cyclone and floods that probably killed the seagrasses in Hervey Bay. The distribution of dugong sightings differed from the pattern in 1991, with very few dugongs seen in the areas where they were previously most abundant. Most sightings were in the north-east of the bay. By November 1992, eight months after the floods, the estimated population of the southern half of Hervey Bay was only 71 (± 40, s.e.) dugongs (compared with 1753 ± 388 in 1988). At this time the number of dugongs in the southern part of the Great Sandy Strait had increased (Fig. 2*c*; Table 4), suggesting that many of the dugongs had moved into this area, where the seagrasses remained intact (A. Preen, unpublished data). In December 1993, 13 months after the 1992 dugong survey, and 21 months after the floods and cyclone, the estimated population of Hervey Bay and

Table 4. Estimates of dugong populations and population densities (± s.e.) in Hervey Bay and the Great Sandy Strait in August 1988, November 1992 and December 1993

Block	Numbers			Density (dugongs km^{-2})		
	1988	1992	1993	1988	1992	1993
1 (Great Sandy Strait)	269 ± 147	943 ± 377	168–218 ± 52[A]	0·53 ± 0·29	1·84 ± 0·74	0·33-0·43 ± 0·1
2 (S Hervey Bay)	1753 ± 388[B]	71 ± 40	257 ± 85	1·25 ± 0·28	0·05 ± 0·03	0·18 ± 0·06
3 (NE Hervey Bay)	151 ± 55	21 ± 22	22 ± 21	0·12 ± 0·05	0·02 ± 0·02	0·02 ± 0·02
4 (NW Hervey Bay)	33 ± 32	74 ± 50	132 ± 74	0·03 ± 0·03	0·06 ± 0·04	0·11 ± 0·06
Total	2206 ± 420	1109 ± 383	579–629 ± 126	0·50 ± 0·28	0·25 ± 0·05	0·13-0·14 ± 0·13
Precision	0·19	0·35	0·22-0·20			

[A]Includes a group of 50–100 dugongs. [B]Includes a group of 22 dugongs.

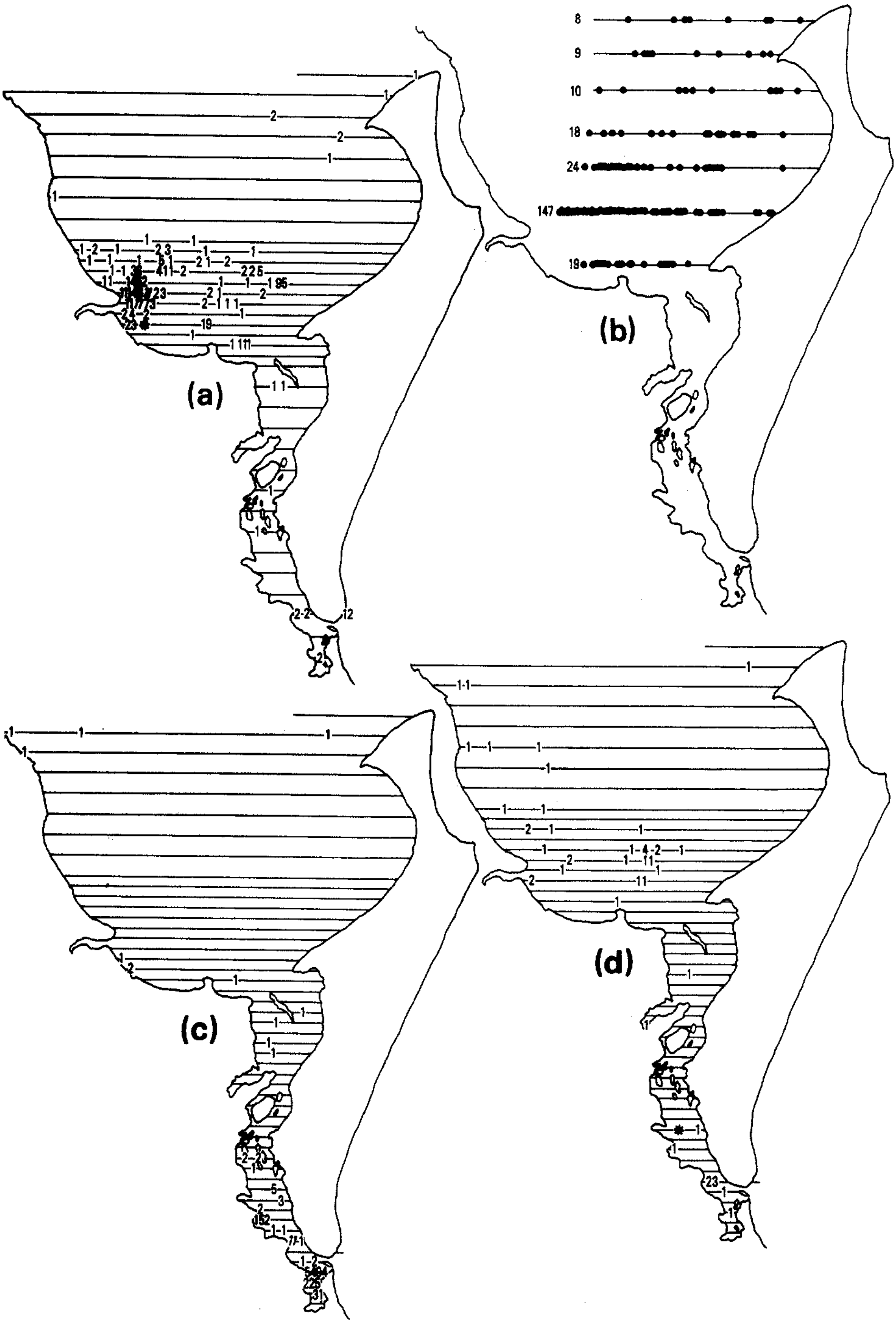

Fig. 2 . The distribution of dugongs sighted during (*a*) the August 1988 survey, (*b*) 13 whale surveys in August–October 1991, (*c*) the November 1992 survey and (*d*) the December 1993 survey. In *a*, *c* and *d*, numbers refer to the total number of dugongs seen at each location, not necessarily group size. Numbers greater than nine are italicised. In *b*, numbers refer to the total number dugong groups seen along each transect. * indicates the location of a herd of at least 22 dugongs in 1988 and a herd of 50–100 dugongs in 1993.

the Great Sandy Strait was only 579–629 (± 126). Most of the dugongs occurred in Hervey Bay (Fig. 2*d*; Table 4).

Both an ANOVA that compared the density of dugongs along transects between the three surveys, and an analysis of covariance that included Beaufort sea state as a covariate in the analysis, identified a significant time × block interaction (Table 5). These results were primarily caused by the loss of dugongs from the southern bay (Block 2) in 1992 concurrent with the movement of dugongs into the Great Sandy Strait (Block 1), followed by the general return to the initial pattern in 1993 (albeit at a much lower population level: Fig. 3).

Carcasses

At least 99 dugongs died in Hervey Bay and the adjacent areas to the north and south following the loss of seagrass (Fig. 4). Most (at least 74) died during 1992, although dugongs continued to die at a higher-than-normal rate through most of 1993 (Fig. 5). The temporal pattern of dugong deaths fitted a normal probability distribution, with most animals dying 6–8 months after the floods and cyclone (Fig. 5). A secondary peak in September 1993 may represent animals that succumbed to the cumulative effects of winter water temperatures, especially in New South Wales, which is outside the normal range of dugongs (Fig. 4).

Most carcasses were in poor condition by the time they were reported. During 1992, 17 fresh carcasses were reported. Ten of the 11 carcasses that we inspected or viewed photos of were clearly emaciated. Autopsies were performed on eight dugongs in 1992, and revealed a variety of symptoms that indicated that, although the proximal cause of death varied, starvation was probably the ultimate cause in most cases. The stomachs of dead dugongs often contained unusual material, including algae, dead seagrass rhizomes and anoxic sediment. Interestingly, some dugongs that moved into areas with seagrass continued to starve. While catching dugongs to tag with satellite transmitters in November 1992, chases were initiated on 11 dugongs in a seagrassed area at the northern end of the Great Sandy Strait. Of these dugongs, two were extremely emaciated and lethargic.

The distribution of dugong carcasses north and south of Hervey Bay (Fig. 4) suggests that there was an exodus of dugongs from that area following the loss of seagrass. The aerial survey of Moreton Bay in April 1993 suggests that some dugongs successfully relocated to nearby areas. A total of 664 dugongs was counted on the standardised survey of the central bay. This was substantially greater than the maximum count recorded during 28 previous surveys (569 dugongs), and exceeded the upper 95% confidence limit (608) of the mean (556) of the three highest counts previously recorded. The count of dugongs recorded during the shoreline survey (24) was in accord with previous surveys of this type and other surveys of the bay (see Preen 1993).

Table 5. Results of ANOVAs comparing dugong density in Hervey Bay and the Great Sandy Strait in 1988, 1992 and 1993, without covariates (1) and with Beaufort sea state as a covariate (2)

Data were transformed by $\log_{10}(x+1)$

Source of variation	d.f.		*F*		*P* (Significance of *F*)	
	1	2	1	2	1	2
Block[A]	3	3	3·37	1·39	0·0289	0·2617
Time[B]	2	2	1·62	2·45	0·2054	0·0936
Transect nested in block[B]	36	36	1·54	1·58	0·0602	0·0505
Block × time[B]	6	6	3·65	3·63	0·0032	0·0034
Residual	72	71				
Regression[B]				2·12		0·0020

[A]Tested against transect nested in block. [B] Tested against residual.

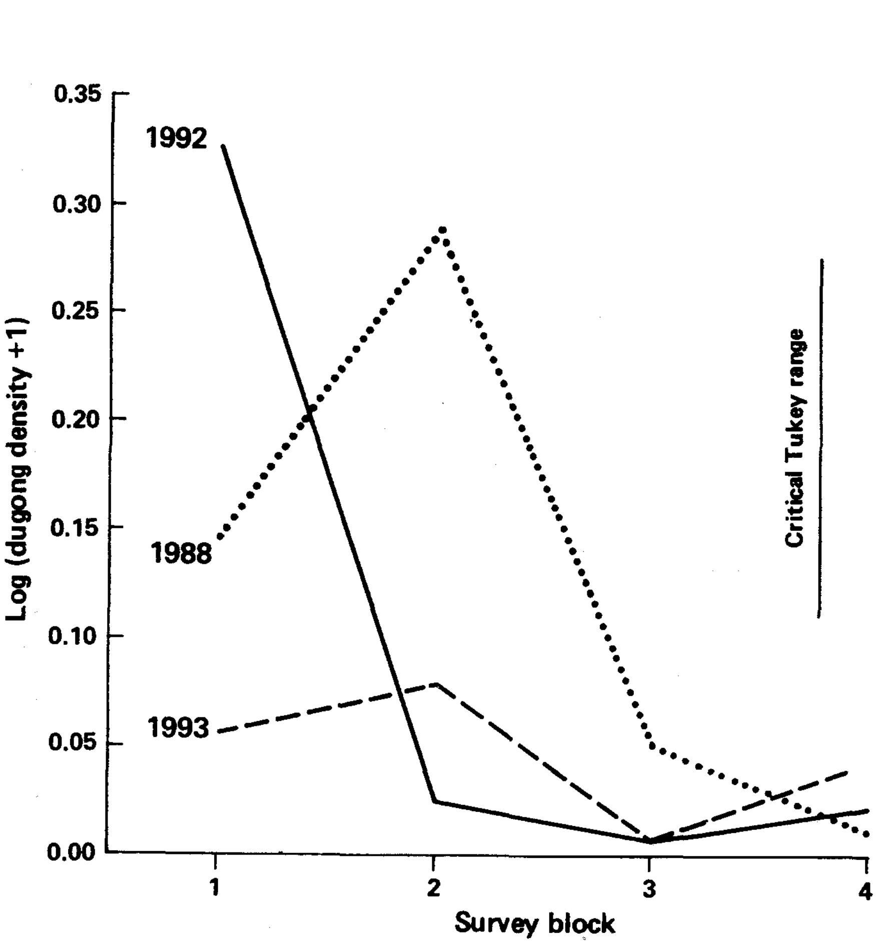

Fig. 3. Result of an ANOVA comparing dugong population estimates in 1988, 1992 and 1993. Graph shows dugong density [$\log_{10}(x+1)$] by survey block for each time. Locations of survey blocks are shown in Fig. 1.

Discussion

The Exodus of Dugongs from Hervey Bay

The sudden loss of more than 1000 km^2 of seagrass forced dugongs to leave Hervey Bay. An estimated 1753 (± 388, s.e.) dugongs occurred in southern Hervey Bay (Survey Block 2) before the loss of seagrass (Table 4). Eight months after the floods and cyclone, the estimated population of this area was only 71 dugongs (± 40) (Table 4). Many of the displaced dugongs moved into the adjoining Great Sandy Strait. The estimated population of the Great Sandy Strait increased from 269 (± 147) in August 1988 to 943 (± 377) in November 1992.

The distribution of carcasses during the period following the seagrass loss (Fig. 4) suggests that many dugongs moved to other areas. Some dugongs travelled at least 900 km before they died, and dead dugongs occurred along 1500 km of coastline. An unknown number of dugongs successfully established in new areas. At least four dugongs survived in estuaries in New South Wales, well outside their normal range, before succumbing to the cold water temperatures of the 1993 winter (Fig. 5) (A. Preen and H. Marsh, unpublished data). The survey of Moreton Bay suggests that emigration from Hervey Bay may have boosted the local dugong population by 100–200. This increase could potentially be accounted for by natural increase since the previous

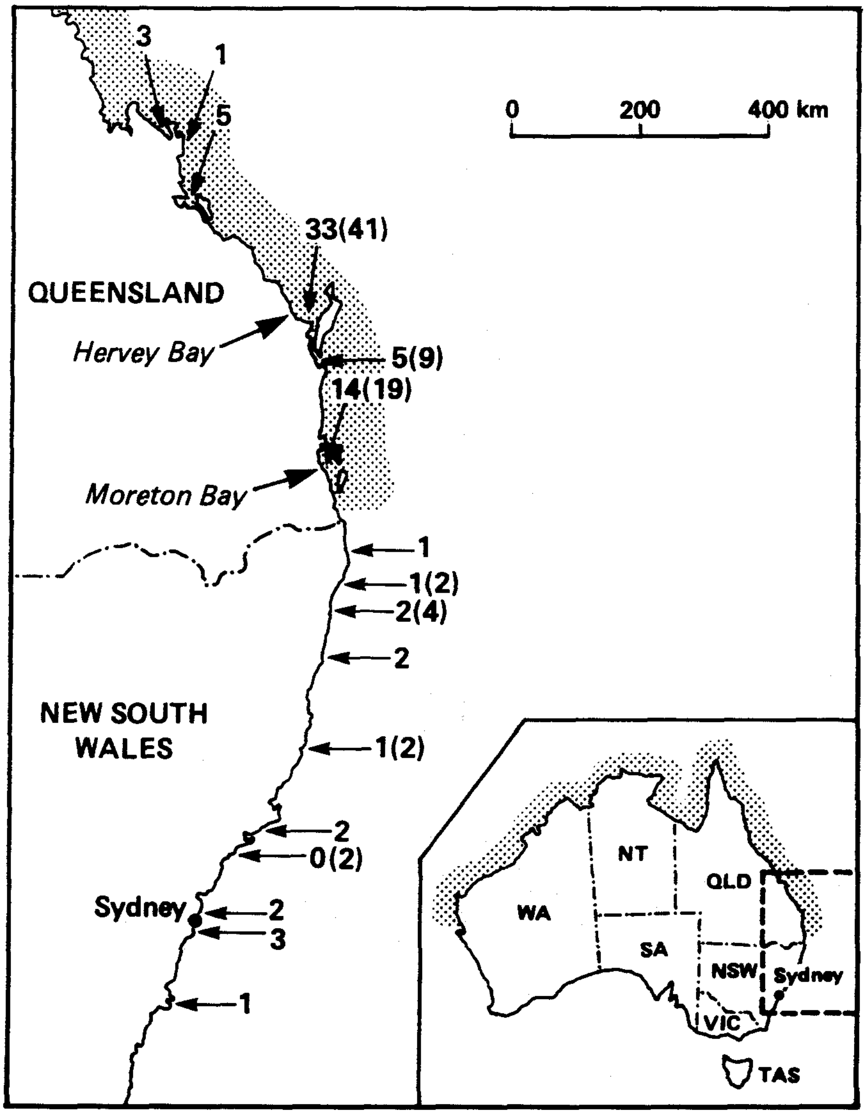

Fig. 4. Distribution of stranded dugong carcasses recorded during 1992 (and 1992–93). Stippling shows the normal distribution of dugongs along the Australian coast.

surveys (assuming maximum rates of increase: Marsh *et al.* 1984); however, no increase was detected during two years of monitoring in the late 1980s (Preen 1993). We consider it likely that the detected increase between 1990 and 1993 was primarily due to immigration.

The December 1993 survey of Hervey Bay and the Great Sandy Strait indicates that the dugong population continued to decline after the known pulse of deaths. Relatively few carcasses were recorded during this latter period, suggesting that dugongs continued to emigrate.

The dramatic differences in the estimates of the dugong population between surveys warrants a close examination of factors, other than population decline, that may have contributed to the

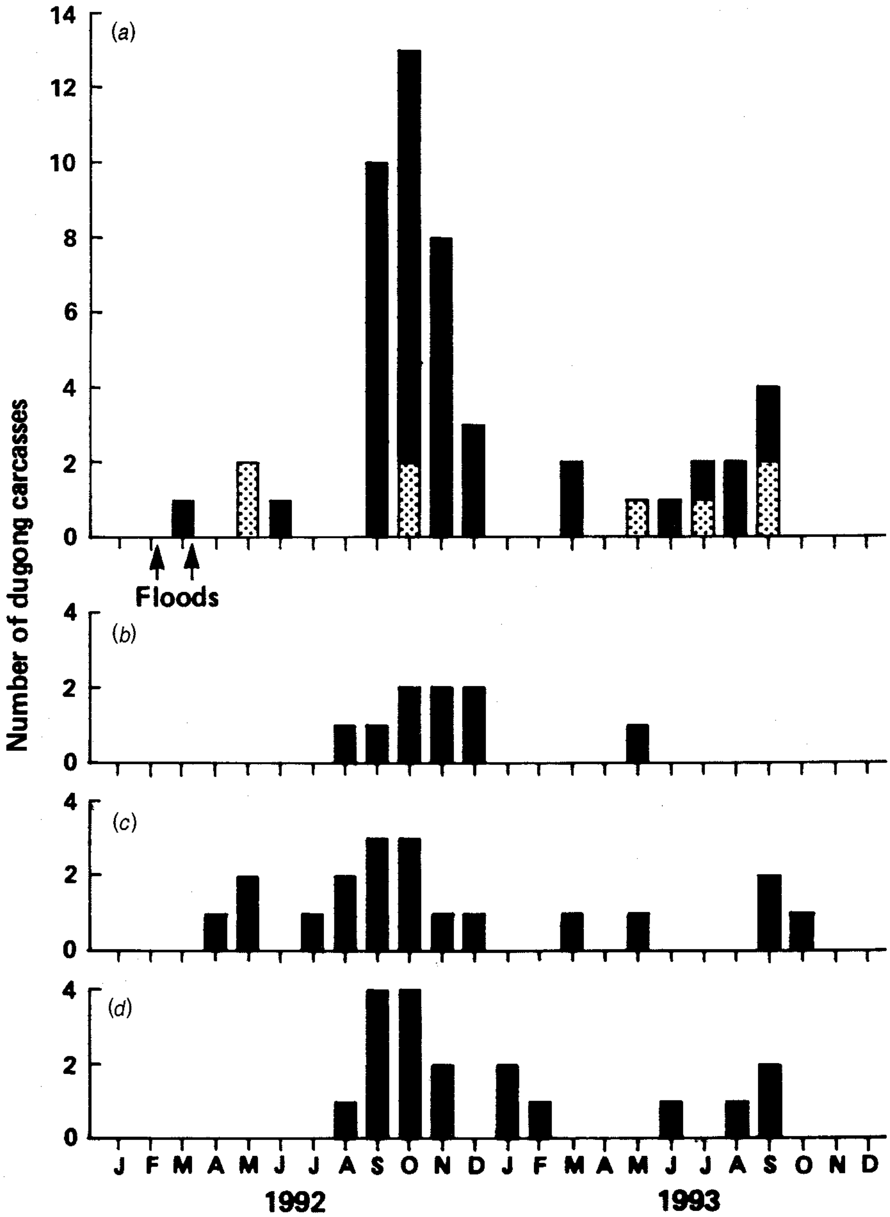

Fig. 5. Frequency of reported dugong strandings during 1990–93: (*a*) in Hervey Bay and the Great Sandy Strait, including dugongs that apparently drowned in gill nets (stippled); (*b*) along the coast immediately north of Hervey Bay; (*c*) in Moreton Bay; and (*d*) along the coast of New South Wales.

results. Weather conditions during the three surveys were comparable, with the best conditions experienced in 1993, and little difference between the 1992 and 1988 surveys (Table 2). Indeed, the difference in Beaufort sea state made no substantial difference to the comparisons between surveys (Table 5).

Although the perception and availability correction factors and mean group sizes were similar across surveys (Table 3), these similarities may mask a change in the biases between surveys that would affect the dugong population estimates. In 1988, most dugongs were seen in relatively deep water in southern Hervey Bay. In this area, dugongs are not visible when they are grazing and, except near the shore, are recorded only when they are near the surface. An attempt was made to correct this bias with the availability correction factor (Marsh and Sinclair 1989*a*), which operates by comparing the number of dugongs seen at the surface with the proportion of dugongs at the surface in 2–3 m of clear water in Moreton Bay (derived from aerial photographs taken vertically). This correction may not be ideal when dugongs are feeding in deeper water, such as southern Hervey Bay (5–15 m). Preliminary evidence suggests that dugongs spend a smaller proportion of time near the surface when feeding in deeper water (A. Preen and H. Marsh, unpublished data). If this is correct, then the availability correction factor will lead to an underestimate of the dugong population in such areas. Hence, it is probable that the 1988, and to a lesser extent the 1993, population estimates are underestimates relative to 1992 when most (85%) dugongs were in relatively clear, shallow (<3 m) water in the Great Sandy Strait, a situation similar to Moreton Bay.

It is also likely that differences in the pattern of dispersion of dugongs between surveys affected the precision of the population estimates and hence the capacity of the surveys to reflect temporal trends in dugong numbers. As outlined in Marsh and Saalfeld (1989), herds of more than nine dugongs are excluded from the calculation of population estimates for each block in order to reduce the sampling error. The total counts of these large herds are subsequently added to the population estimate for the appropriate block as a separate stratum *sensu* Norton-Griffiths (1978). The efficacy of this approach relies on the capacity of observers to recognise large herds. However, these may be missed if observers see only the outlying animals on either side of the aircraft. Few large herds were identified on the transect surveys (Fig. 2); however, we know from a shoreline survey flown at an altitude of 274 m that many of the dugongs in the Great Sandy Strait were aggregated into large herds one month after the November 1992 transect survey. Similar data are not available for the 1988 or 1993 transect surveys.

Dugong Mortality

The tally of carcasses is undoubtedly an underestimate of the number of dugongs that died during this period. For example, while five carcasses were documented in the Great Sandy Strait in 1992, at least three more went unreported (J. McLeod, personal communication). Furthermore, much of the coastline north of Hervey Bay has a sparse human population, and this probably accounts for the low incidence of reported carcasses in this area (Fig. 4). Three dead dugongs that were not recorded are known from one location along this coast (Port Curtis: J. McLeod, personal communication). Dugongs that may have travelled east, rather than north or south, are unaccounted for, as are the carcasses that sunk or were consumed by scavengers before they beached.

Most dugongs died 6–8 months after the loss of seagrass (Fig. 5) despite the apparent death of most of the seagrass soon after the floods and cyclone (Preen *et al.,* in press). During this period, dugongs continued to feed, albeit suboptimally, as evidenced by the presence of algae, dead seagrass rhizomes and anoxic sediment in some stomachs. Dugongs eat large amounts of algae only under exceptional circumstances (Spain and Heinsohn 1973; Marsh *et al.* 1982; Preen 1995), and the absence of sediment is normally a feature of dugong stomach contents. The low metabolic rate of sirenians [the rate for manatees is 17–36% of predicted levels (Gallivan and Best 1980; Irvine 1983)] may allow extended starvation. Amazonian manatees (*Trichechus inunguis*) that survive in seasonally isolated lakes may have to fast for up to seven months between substantial meals of their preferred foods (Best 1983). They seem to survive on fat reserves and by eating dead plant matter and sediments.

Some dugongs that moved into areas with seagrass also starved, as evidenced by our observations of emaciated and lethargic dugongs among healthy animals at the northern end of

Great Sandy Strait in November 1992. Dugongs have distinct seagrass preferences (Preen 1993), which seem to be based on their nutritional quality (Lanyon 1991). It is possible that refugee dugongs were actively excluded from the areas of better-quality seagrasses by the resident animals, and, unable to meet metabolic needs, they slowly deteriorated.

Recovery?

By the end of 1993, many of the remaining dugongs had moved back into Hervey Bay from the Great Sandy Strait (Table 4). This relocation corresponds with a recovery of the seagrasses in deep water in the bay (Preen *et al.*, in press). On the basis of the 1993 population estimate, and assuming that the 1988 estimate represents the 'normal' population, a full recovery of the regional dugong population will take at least 25 years (assuming a maximum rate of increase of 5%: Marsh *et al.* 1984). The recovery may be even slower than this as the seagrasses in waters less than 10 m deep, which represent 25% of the bay, are showing little sign of recovery (Preen *et al.*, in press). Furthermore, the rate of dugong reproduction may take some years to reach maximum levels. Calves represented 22% of all dugongs seen during both the 1988 and 1992 surveys. By 1993, however, calves represented just 2·2% of the population, presumably reflecting the energetic trauma associated with the period of starvation following the loss of seagrass.

Implications for Conservation

The events of 1992 were unusual. Anecdotal evidence suggests that the loss of seagrass and dugongs from Hervey Bay is unprecedented in the past 100 years (Preen *et al.*, in press). Nevertheless, these events have significant implications for the conservation of dugongs. Habitat loss or modification resulting from a natural disturbance, in this case exacerbated by poor catchment management (Preen *et al.* 1995), can have a massive impact even on a very large dugong population. Previous concern about dugong conservation has tended to focus on traditional hunting and incidental drowning in gill nets. It is apparent that effective conservation management must address all impacts, including habitat loss and modification.

Acknowledgments

The dugong surveys were funded by the Queensland Department of Primary Industries (1988) and the Queensland Department of Environment and Heritage (QDEH; 1992 and 1993). Information on dugong sightings and carcasses was provided mainly by the Queensland Boating and Fisheries Patrol, the New South Wales National Parks and Wildlife Service, the Organisation for the Rescue and Research of Cetaceans in Australia (ORRCA) and B. Thompson. M. Cohen performed most of the autopsies. Information on dugongs recorded during whale surveys was provided by M. Brown and P. Corkeron (1989, 1990), QDEH (1991) and the Pacific Whale Foundation (1992). B. Breen assisted with statistics and N. Morrisette conducted the GIS analyses. A. Preen was funded by an Australian Research Council Postdoctoral Fellowship.

References

Best, R. C. (1983). Apparent dry-season fasting in Amazonian manatees (Mammalia : Sirenia). *Biotropica* **15**, 61–4.

Corkeron, P. J., Brown, M., Slade, R. W., and Bryden, M. M. (1994). Humpback whales, *Megaptera novaeangliae* (Cetacea : Balaenopteridae), in Hervey Bay, Queensland. *Wildlife Research* **21**, 293–305.

Gallivan, G. J., and Best, R. C. (1980). Metabolism and respiration of the Amazonian manatee (*Trichechus inunguis*). *Physiological Zoology* **53**, 245–53.

Heinsohn, G. E., and Spain, A. V. (1974). Effects of a tropical cyclone on littoral and sub-littoral biotic communities and on a population of dugongs (*Dugong dugon* (Müller)). *Biological Conservation* **6**, 143–52.
Heinsohn, G. E., Spain, A. V., and Anderson, P. K. (1976). Populations of dugong (Mammalia : Sirenia): aerial survey over the inshore waters of tropical Australia. *Biological Conservation* **9**, 21–3.
Heinsohn, G. E., Marsh, H., Gardner, B. R., Spain, A. V., and Anderson, P. K. (1979). Aerial surveys of dugongs. Australian National Parks and Wildlife Service Special Publication No. 1, pp. 85–95.
Husar, S. L. (1978). *Dugong dugon. Mammalian Species* **88**, 1–7.
Irvine, A. B. (1983). Manatee metabolism and its influence on distribution in Florida. *Biological Conservation* **25**, 315–34.
IUCN (1990). '1990 IUCN Red List of Threatened Animals.' (IUCN–World Conservation Union: Gland.)
Jones, S. (1980). The dugong or the so-called mermaid, *Dugong dugon* (Müller) of the Indo–Sri Lankan waters – problems of research and conservation. *Spolia Zeylanica* **35**, 223–60.
Lanyon, J. (1991). The nutritional ecology of the dugong (*Dugong dugon*) in tropical north Queensland. Ph. D. Thesis, Monash University, Melbourne.
Lee Long, W. J., Mellors, J. E., and Coles, R. G. (1993). Seagrasses between Cape York and Hervey Bay, Queensland, Australia. *Australian Journal of Marine and Freshwater Research* **44**, 19–32.
Marsh, H., and Saalfeld, W. K. (1989). Distribution and abundance of dugongs in the northern Great Barrier Reef Marine Park. *Australian Wildlife Research* **16**, 429–40.
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**, 511–24.
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**, 1017–24.
Marsh, H., and Sinclair, D. F. (1989*b*). An experimental evaluation of dugong and sea turtle aerial survey techniques. *Australian Wildlife Research* **16**, 639–50.
Marsh, H., Chanells, P. W., Heinsohn, G. E., and Morrissey, J. (1982). Analysis of stomach contents of dugongs from Queensland. *Australian Wildlife Research* **9**, 55–67.
Marsh, H., Heinsohn, G. E., and Marsh, L. M. (1984). Breeding cycle, life history and population dynamics of the dugong, *Dugong dugon* (Sirenia : Dugongidae). *Australian Journal of Zoology* **32**, 767–88.
Marsh, H., Saalfeld, W. K., and Preen, A. (1990). The distribution and abundance of dugongs in southern Queensland waters: implications for management. Report to the Queensland Department of Primary Industries.
Marsh, H., Rathbun, G. B., O'Shea, T. J., and Preen, A. R. (1995). Can dugongs survive in Palau? *Biological Conservation* **72**, 85–9.
Nishiwaki, M., and Marsh, H. (1985). Dugong: *Dugong dugon* (Muller, 1776). In 'Handbook of Marine Mammals. Vol. 3'. (Eds S. H. Ridgway and S. R. Harrison.) pp. 1–31. (Academic Press: London.)
Norton-Griffiths, M. (1978). Counting animals handbook No. 1. Serengeti Biological Monitoring Programme, African Wildlife Leadership Foundation, Kenya.
Preen, A. R. (1993). Interactions between dugongs and seagrasses in a subtropical environment. Ph. D. Thesis, James Cook University of North Queensland, Townsville.
Preen, A. R. (1995). Diet of dugongs: are they omnivores? *Journal of Mammalogy* **76**, 163–71.
Preen, A. R., Lee Long, W. J., and Coles, R. G. (1995). Flood and cyclone related loss, and partial recovery, of more than 1000 km^2 of seagrass in Hervey Bay, Queensland, Australia. *Aquatic Botany* **52**, in press.
Queensland Department of Primary Industries, (1993). The condition of river catchments in Queensland. Queensland Department of Primary Industries, Brisbane.
Spain, A. V., and Heinsohn, G. E. (1973). Cyclone associated feeding changes in the dugong (Mammalia : Sirenia). *Mammalia* **37**, 678–80.

Manuscript received 5 September 1994; revised and accepted 3 March 1995