DISCUSSION

Temporal Changes in Dugong Distribution and Abundance

The aerial survey estimate of the dugong population in the GBR region in October–December 1999 was 3993 (± 641 s.e), which is significantly higher than the corresponding estimate in 1994 (1682 ± 236 s.e) but not significantly different from that obtained in 1986–1987 of 3479 (± 459 s.e) (Marsh & Saalfeld 1990). Most of the increase was in the northern part of the survey region (the Central Section of the GBR region) (table 5, figure 2a).

The aerial survey estimate of the dugong population in the Hervey Bay-Great Sandy Strait region in November 1999 was 1654 (± 248 s.e), also significantly higher than the corresponding estimate in 1994 (807 ± 151 s.e). It was however, lower than the 1988 estimate of 2206 (± 420 s.e), which was recorded prior to the significant dugong mortality and emigration from the region following the 1992 floods (Preen & Marsh 1995). Hervey Bay again experienced significant flooding in February 1999, with substantial loss of intertidal seagrasses in the northern Great Sandy Straits and of shallow subtidal seagrasses in the Bay itself (McKenzie et al. 2000). At the time of the aerial survey, the shallow water seagrasses showed little evidence of recovery (McKenzie et al. 2000). This was reflected in a change in the dugong distribution in Hervey Bay with more sightings occurring in deeper water than recorded in 1994. McKenzie et al. (2000) suggest that sufficient seagrasses remain to support the current dugong population but that some individuals may experience stress due to reduced food availability. The future of dugongs in Hervey Bay probably depends on both the intensity and frequency of major cyclone and flood events in the catchments feeding in to the Bay.

It is impossible that the differences between the 1994 and 1999 dugong population estimates for the southern GBR and Hervey Bay are the result of natural increase in the absence of immigration. The dugong is a long-lived species with an estimated maximum rate of increase of the order of 5% p.a. or 27.6% over five years (Marsh 1995a; Boyd et al. 1999). The rate of increase required to produce the effect recorded in this survey would need to be much greater than this because the controls on major Indigenous hunting and commercial net fishing, were not introduced until 1997.

An Evaluation of Explanations for the Observed Changes in Dugong Distribution and Abundance

Each of the large-scale aerial surveys conducted in the southern GBR-Hervey Bay region has provided a snapshot of the pattern of dugong distribution and abundance in the survey region at the time of the survey. Considerable effort is spent in attempting to facilitate between survey comparisons using the following techniques (Marsh & Sinclair 1989a):

1. Surveying over a large area and completing the survey as quickly as possible to minimise the likely effects of local scale dugong movements;
2. Surveying at the same time of year (October-early December) to maximise the likelihood of suitable weather and minimise the effect of any seasonal changes in dugong distribution;
3. Using a consistent survey design (transects and blocks for each survey);
4. Using consistent survey methodology: flying the aircraft at a constant height and speed, using the same transect width;
5. Imposing a strict ceiling on acceptable weather conditions, ideally Beaufort Sea State ≤ 3, cloud cover ≤ 4 oktas;
6. Using a tandem team of trained observers on either side of the aircraft;
7. Using mathematical and statistical techniques to correct for differences in perception

and availability biases and survey conditions.

Despite our efforts, some of these conditions are impossible to achieve in practice, usually for logistical reasons. Thus, the differences between the results of different aerial surveys are not solely the result of changes in dugong distribution and abundance, but may reflect differences in survey conditions. In addition, as explained above, changes in dugong distribution and abundance can result from a change in the overall size of the dugong population and/or migration into or out of the survey area. In assessing the observed temporal changes in dugong distribution and abundance revealed by the aerial surveys conducted between 1986 and 1999, we have critically evaluated several possible explanations for the changes we observed, and these are discussed below.

Sighting Conditions

As explained above we endeavour to impose a strict ceiling on weather conditions acceptable for survey. Two important dugong areas, Hervey Bay and Hinchinbrook were surveyed under near perfect conditions. This may partially explain the high population estimate for Hervey Bay. Even though the number of dugongs actually sighted on transect was similar (130 in 1994, 161 in 1999), the availability correction factor was much higher in 1999 (1.930 ± 0.170s.e.) than in 1994 (0.8903 ± 0.2178s.e.). The change in availability correction factor is counter-intuitive; we expect to see relatively more dugongs below the surface in good conditions. We offer two possible explanations for this discrepancy: (1) in exceptionally calm conditions such as those encountered in 1999, a higher proportion of dugongs may rest at the surface than when the sea is rougher; (2) in smooth water it may be harder to distinguish animals at the surface from those near the surface. The change in the availability correction factor is the major reason for the observed increase in the dugong population estimate for Hervey Bay between 1994 and 1999. We are less certain of an actual population increase in Hervey Bay than in the Hinchinbrook region (see below).

In the Hinchinbrook region, the estimated population increased from 377 (± 154s.e.) to 748 (± 432s.e.) from 1994 to 1999. The availability correction factor was significantly larger in 1999 (3.216 ± 0.139) than in 1994 (2.4706 ± 0.156), but even if all differences in correction factors and mean groups size are taken into account, there were still approximately 50% more animals actually sighted on transect in 1999.

We conclude that better survey conditions are unlikely to provide an explanation for the observed increase in the number of dugongs in the southern GBR region *per se*. Some important areas, such as Shoalwater Bay were surveyed under marginal survey conditions (table 2). Importantly, the initial model for testing the difference between years included Beaufort Sea State as a surrogate for weather conditions. The effect of this parameter was weak (presumably because we put a ceiling on the sea surface conditions on which we surveyed) and it was omitted from the final analyses.

Experience of Observers

The crew for a dugong survey comprises the pilot, the survey leader and four observers. The dugong group at James Cook University contains two experienced survey leaders (Marsh and Lawler). We found it difficult to obtain eight observers experienced in dugong surveys who could also be on continuous call for up to six weeks as required for this survey, which was unusually protracted because of unsuitable weather. Our difficulties were exacerbated by several additional factors in 1999:

1. the last-minute withdrawal of a third experienced survey leader, and an observer with some experience from Malaysia who was participating as a result of an exchange

agreement;
2. the unavailability of several experienced observers who were attending the Biennial International Marine Mammal Conference in Hawaii;
3. the reluctance of some sections of the relevant management agencies (QPWS and GBRMPA) to allow staff with prior experience to participate in the project.

The final crews comprised only two observers with prior dugong survey experience plus another four people with professional expertise in marine wildlife. All crew members were trained by working in tandem with experienced observers. The perception bias correction factors were all of similar magnitude to those estimated in previous surveys, and hence do not explain the results observed here. We conclude that the additional dugongs sighted in 1999 are not attributable to observer inexperience, especially as inexperienced observers are more likely to miss dugongs than to overcount them.

Changes in Dugong Fecundity

As explained above, it is impossible for the differences between the 1994 and 1999 surveys to be solely the result of natural increase in the absence of immigration. Nonetheless, the data on the percentages of calves in the population suggest that at least part of the increase resulted from increased fecundity. The proportion of calves in the Central Section of the GBR region (where most of the increase occurred) is nearly twice as high as in the Southern Section (where there has been little change in dugong abundance). This result suggests that food availability had improved in the Central Section since the early 1990s. Dugongs appear to vary their reproductive rates in response to resource availability (Marsh 1995a; Boyd et al. 1999). It is plausible that some of the increase in dugong abundance in the Central Section is the result of improved fecundity.

Dugong Movements

Satellite tracking studies show that individual dugongs are very variable in their movements and individuals can move hundreds of kilometres in a few days. There is however, no evidence of large-scale coordinated movements such as the migrations of some species of baleen whales between their feeding and breeding grounds (Boyd et al. 1999). Some individual dugongs are relatively sedentary while others caught at the same site at the same time may move hundreds of kilometres in a few days (Marsh & Rathbun 1990; Marsh et al. 1999; Preen 2001). However, relatively large-scale movements are common. For example, recent analysis of Dr Tony Preen's data shows that more than half of all tagged dugongs moved over 80 km in a couple of months, with one moving over a total of more than 800 km of coastline. Similarly, four of five dugongs tagged in Shark Bay Western Australia in 2000 have moved distances of over 120 km (Lawler unpublished data).

Within Surveys

Given that the survey was conducted over a period spanning six weeks due to difficulties with weather, it is possible that dugongs moved between survey blocks during the survey period. We have no data to reject or accept this hypothesis.

Between Surveys

The dugongs’ range in Australia spans some 15 000 km of coast from Moreton Bay in the east to Shark Bay in the west and adjoins habitat in Papua New Guinea and Irian Jaya. It is clearly logistically impossible to survey this vast area in one survey season. Thus, it will

always be impossible to guarantee that the difference between dugong surveys is not the result of some animals moving into or out of a survey area no matter how large (absence bias *sensu* Lefebvre et al. 1995).

Aerial survey data from Western Australia (Anderson 1986; Marsh et al. 1994b; Nick Gales unpublished), Torres Strait (Marsh et al. 1997a), the northern GBR region (Lawler & Marsh unpublished), the southern GBR (this report) and Hervey Bay (Preen & Marsh 1995; this report) suggest that much of the variation in the patterns of dugong distribution and abundance reflects movements of dugongs between surveys over large spatial scales. This conclusion is supported by the recent data on dugong movements outlined above, as well as data on the impact of extreme weather events on dugong habitats.

The reasons for the patterns of dugong movements are poorly understood, especially in lower latitudes when temperature changes are not likely to be a major influence. The seagrasses preferred by dugongs tend to be ephemeral and we suspect that many movements are in response to the destruction and development of seagrass beds caused by extreme weather events. *Halophila*, one of the genera that are the preferred foods of dugongs, appears to be particularly sensitive to light reduction. The duration and frequency (and possibly timing) of light-deprivation events such as plumes of muddy freshwater, appear to be the primary factors affecting the survival of seagrasses in this genus in environments that experience transient light deprivation (Longstaff et al. 1999). Members of the genus *Halophila* occur at greater depths than other species of tropical seagrasses. This sensitivity to light reduction is a plausible explanation for the large-scale loss of deep-water seagrasses in Torres Strait (Poiner & Peterken 1996) and Hervey Bay (Preen & Marsh 1995; McKenzie et al. 2000) after floods. The losses in Hervey Bay were still significant nine months after the flood in February 1999, when floating filamentous algae was evident at deepwater sites, possibly because of the unusually high nutrient loads in Hervey Bay waters and sediments (McKenzie et al. 2000). A spot check of seagrasses in February 2000 found no evidence of seagrasses in shallow sub-tidal waters in the path of the plume. We sighted most dugongs in Hervey Bay in deeper water (10–16 m) (figure 3f), a result consistent with the pattern of seagrass distribution in November 1999 (McKenzie et al. 2000).

We consider it plausible that the increase in dugong abundance in the Central Section of the GBR is the result of dugongs immigrating there from outside the region in search of higher quality habitat. In this case, the source population is most likely to be in the northern GBR. Such movements are well within the capacity of dugongs (one individual was recorded moving between Princess Charlotte Bay and Cleveland Bay by Preen (2001)). However, there are few current data on either the dugong populations or the habitat quality in the northern GBR to confirm this hypothesis.

Nonetheless, we conclude that the responses of dugongs and their seagrass habitats to extreme weather events is complex, and a major influence on dugong distribution. The nature of these impacts is poorly understood at present and difficult to predict. It is a plausible explanation for some of the major differences between surveys in the distribution and abundance of dugongs.

Implications for Dugong Management: the Effectiveness of DPAs

The satellite tracking data indicate that individual dugongs move in and out of the DPAs. The rationale for this strategy of dugong protection in the southern GBR and Hervey Bay is not that they provide lifetime protection for individual dugongs. Rather, they provide

increased protection to dugongs in areas that consistently support a significant proportion of the dugongs in the region. The positions of the DPAs and their boundaries were based on the analysis of all available dugong distribution data presented by Preen and Morissette (1997) and are supported by the results of this survey (tables 7 and 8, figure 3a-f). The one region in the southern GBR where significant numbers of dugongs were sighted in 1999 (but not in 1986–1987, 1992 or 1994) and where there is no DPA is the Whitsundays (figures 2a, 3b). We suggest that consideration be given to increasing the level of dugong protection in this area.

Given the severe and unpredictable impacts of extreme weather events on dugong habitats, the present strategy of having a large number of DPAs is justified. The DPAs consistently support a high proportion of the dugongs in the southern GBR at least between October–December, the time of year when the large-scale surveys have been conducted (tables 7 and 8).

The information on the likely effectiveness of the DPAs at other times of the year is limited. Marsh and Penrose (2000) conducted a desk-top study to compile information on the distribution and abundance of dugongs in the inshore waters of the southern GBR, using a range of sources including both dedicated surveys and incidental sightings. They concluded that the available data are generally inadequate to evaluate the seasonality of the distribution and abundance of dugongs in six of the DPA As and all eight of the DPA Bs. However, they found no evidence of seasonal use for the Hinchinbrook and Cleveland Bay DPA As, where the information is more comprehensive.

We suggest that the likely large-scale temporal variation in the distribution and abundance of seagrass meadows in the inshore waters of the GBR region should be taken into account when developing strategies for dugong conservation. The activities of 'Seagrass Watch', the community-based seagrass monitoring program coordinated by the Queensland Department of Primary Industries, will be crucial to provide information on changes in the distribution and abundance of seagrasses. The efficacy of the DPA Bs in reducing dugong mortality in commercial gill nets is uncertain (Marsh 2000). Given this uncertainty, it would be prudent for the managing agencies to have the capacity to: (1) alter the zoning status of selected DPA Bs quickly in the event of widespread destruction of the seagrass in the two key DPA As - Hinchinbrook and Shoalwater–Port Clinton, and (2) change the boundaries of the Hervey Bay DPA in the event of significant localised seagrass loss in this region.

Implications for the Future of Dugong Surveys

Most dugong management in Australia has been based on information obtained from aerial surveys. The surveys have been used to fulfil several objectives:

- To provide information on dugong spatial distribution and relative abundance as a basis for developing the spatial boundaries of conservation controls (e.g. some marine park zoning especially in the Far Northern Section of the GBRMP, Dugong Protection Areas);
- To provide estimates of minimum population size as a basis for evaluating the sustainability of Indigenous hunting (e.g. Smith & Marsh 1990; Marsh et al. 1997b); and
- To detect temporal trends in dugong abundance in a survey area (e.g. Marsh et al. 1995, 1997a).

As outlined above, the results of this survey and others suggest that the capacity of aerial surveys to detect trends in dugong numbers over large spatial scales is confounded by the dugongs' tendency to undertake large-scale movements. We suggest that a workshop be

held to review the arrangements for aerial surveys for dugongs including their objectives, methodology, spatial scale and the need for maintaining a pool of trained observers who are available for the extended periods required to complete the surveys in appropriate weather conditions. The workshop should involve representatives from the scientists who conduct the surveys, independent experts and the agencies that commission such surveys (AFMA, CALMWA, PAWCNT, GBRMPA and QPWS). It would be ideal if the review could be timed to coincide with the planned visit to James Cook University in early 2002 of Professor Ken Pollock from the University of Northern Carolina, a mathematician with expertise in wildlife surveys.

Marsh (1995b) used power analysis to demonstrate the difficulty in detecting trends in dugong populations, particularly small populations at local scales. If, as it now appears, the capacity to detect trends in dugong numbers even over large spatial scales is confounded by large-scale dugong movements (Preen & Marsh 1995; Marsh et al. 1997a; Gales unpublished; Marsh & Lawler unpublished; this report), the rationale for using time-series of aerial surveys as the major grounds for dugong management initiatives should also be reviewed. Because of such difficulties in detecting trends in abundance, the United States have employed management actions related to human-caused mortality of marine mammals that no longer rely on detecting depletion, but rather, on detecting a mortality rate that will lead to depletion. Wade (1998) describes a methodology for identifying populations of marine mammals with levels of human-caused mortality that could lead to depletion, taking account of the uncertainty of available information. Research is in progress to develop methodology to estimate the absolute abundance of dugongs using aerial surveys, and we are optimistic that this new methodology will overcome many of the problems with the present availability correction factor. Once we have achieved this we will be able to estimate the level of mortality that will lead to depletion of dugongs. However, deciding on the appropriate spatial scale over which to make such calculations will be difficult and will depend on determining stock boundaries.

This approach will be important given the legal difficulties in maintaining the restriction on permits for Indigenous hunting, and the anecdotal evidence that suggests that a decline in dugong numbers in the southern GBR and Hervey Bay has been going on for decades (Marsh et al. 1995). This conclusion is supported by the analysis of the temporal changes in the number of dugongs caught in shark nets set for bather protection since the 1960s (Marsh et al. 2001). It is important to appreciate that the dugong numbers recorded in 1986–1987 and 1999 almost certainly reflect population numbers far below those at the time of European settlement along the east Queensland coast. Thus, the most salient question to be determined by management agencies and stakeholders is the target level of recovery of dugong populations in this region. The management actions to achieve this target will need to be developed in the context of: (1) the aspirations and rights of the Indigenous communities in the region, and (2) the likelihood of a change in the frequency of extreme weather events as a result of climate change.