GREAT BARRIER REEF
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RESEARCH PUBLICATION NO. 70

Shark Control Records Hindcast Serious Decline in Dugong Numbers off the Urban Coast of Queensland

Helene Marsh, Glenn De'ath,
Neil Gribble and Baden Lane

AND

Dugong Distribution and Abundance in the Southern Great Barrier Reef Marine Park and Hervey Bay: Results of an Aerial Survey in October–December 1999

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Rey

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Helene Marsh[1], Glenn De'ath[1], Neil Gribble[2] and Baden Lane[3]

[1]School of Tropical Environment Studies and Geography, James Cook University, Townsville Qld 4811, Australia,
[2]Northern Fisheries Centre, PO Box 5396, Cairns, Qld 4870, Australia,
[3]Queensland Shark Control Program, Mineral House, George Street, Brisbane Qld 4000, Australia

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

GREAT BARRIER REEF
MARINE PARK AUTHORITY

PO Box 1379
Townsville Qld 4810

Telephone: (07) 4750 0700
Fax: (07) 4772 6093
Email: INFO@gbrmpa.gov.au
www.gbrmpa.gov.au

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GREAT BARRIER REEF
MARINE PARK AUTHORITY

PO Box 1379
Townsville Qld 4810
Telephone (07) 4750 0700

FOREWORD

The Great Barrier Reef Marine Park Authority is pleased to publish the results of an analysis of dugong by-catch data from the Queensland Shark Control Program and of the 1999 aerial survey of dugongs in the southern Great Barrier Reef and Hervey Bay.

Since the 1980s the Authority has committed a large amount of money researching the biology and conservation status of dugongs on the Great Barrier Reef. The results of aerial surveys in 1987, 1992 and 1994 suggested that a decline by over 50% in the number of dugongs south of Cooktown had occurred between the first survey in 1987 and 1994. This information was pivotal in the momentous 1997 decisions by the Great Barrier Reef Ministerial Council, comprising Commonwealth and Queensland Government Ministers, to initiate a number of new actions for the conservation dugongs on the Reef. In particular, 16 Dugong Protection Areas (DPAs) were established in the southern Great Barrier Reef and a restructure of net fishing occurred in the Areas. Ministerial Council is committed to ongoing review of its decisions regarding dugong and in 1999 and 2001 decided, among other things, to:

- introduce additional restrictions on the use of commercial nets;
- review the effectiveness of rules and level of compliance in relation to Zone B DPAs;
- move to develop co-operative agreements with Indigenous peoples;
- minimise risks to DPAs from on-land activities;
- upgrade procedures and give high priority to dealing with dugong strandings; and
- review the implications of the findings in the reports in this Research Publication for future research and monitoring of dugong populations and report back to Council.

In 1999 the Authority published a *Dugong Research Strategy for the Great Barrier Reef World Heritage Area and Hervey Bay* which was endorsed by the Ministerial Council as a guide for setting priorities, allocating funds and assessing performance of the dugong recovery and conservation actions. One of the recommended projects involved an investigation of factors influencing the mortality of dugongs in shark nets. Subsequently the Authority funded the study and it has resulted in the first report in this publication.

The results of the shark net study demonstrate that a dramatic decline in dugong numbers south of Cooktown has occurred since 1962, and that the current population is about 3% of its former level. In addition, the results of the 1999 aerial survey indicate that there has been a small increase in dugong numbers in the southern Great Barrier Reef, south of Cooktown. It is clear, since dugongs cannot breed rapidly, that the increase since the 1994 survey must be due to a movement of the animals into the southern Great Barrier Reef and Hervey Bay from other areas.

Variations in the dugong population south of Cooktown may be clarified later in 2001 when the results are known of an aerial survey of populations in the northern Great Barrier Reef that was funded by the Authority. In the meantime, it seems unequivocal that the surveys from 1987 to the present represent a relatively small fluctuation in the number of dugongs in a regional population that is at a much lower level than previously. As such, the reports comprehensively vindicate the actions for dugong conservation that have so far been taken by Governments through the Ministerial Council.

The Great Barrier Reef Marine Park Authority is pleased to make these reports generally available.

Hon Virginia Chadwick
Chair, Great Barrier Reef Marine Park Authority

August 2001

PREFACE

Dugongs are of significant biodiversity value as the only extant species in the Family Dugongidae and one of only four species in the Order Sirenia, all of which are listed as vulnerable to extinction by the IUCN-the World Conservation Union. Australia has international responsibilities for dugong conservation, particularly in the Great Barrier Reef (GBR) region, where the dugong's feeding grounds are listed as one of the World Heritage values of the region. As a result the Great Barrier Reef Marine Park Authority has funded a program of dugong research since the early 1980s.

This technical report consists of the reports of two of the studies commissioned by the Great Barrier Reef Marine Park Authority:

1. *Shark control records hindcast serious decline in dugong numbers off the urban coast of Queensland* by Helene Marsh, Glenn De'ath, Neil Gribble and Baden Lane.
2. *Dugong distribution and abundance in the southern Great Barrier Reef Marine Park and Hervey Bay: results of an aerial survey in October-December 1999* by Helene Marsh and Ivan Lawler.

Both reports present the results of studies aimed at monitoring changes in dugong distribution and abundance on most of the eastern coast of Queensland from Cairns south. The results of the two studies are published together because the first report provides a long-term context for the interpretation of the second.

In the first report, we used the 38-year data set collected by the Queensland State Government Shark Control Program to provide information on the status of dugongs between Cairns and the Gold Coast, additional to information provided by anecdotal reports and dedicated monitoring. We admit there are potential problems with observational data such as the shark control records. If a change is observed it may result from the influence of uncontrolled and unmeasured concomitant variables unrelated to changes in dugong numbers. Nonetheless, we believe that it is important to take serendipitous advantage of the information provided by the shark control records, because of the difficulty of detecting trends in dugong numbers using dedicated surveys, especially if population sizes are relatively small and the period covered by dedicated monitoring is relatively short.

Our analysis indicated that the numbers of dugongs caught in shark nets at eight shark contract areas between latitudes 17° and 28°S declined from the inception of the Queensland Shark Control Program in 1962. The estimated rate of decline in dugongs caught per beach per year for a balanced data set from the 31 beaches in six localities averaged 8.7% per year [95% CI = (7.1, 10.6)]. This represents a decline to 3.1% (1.4, 6.1) of initial catch rates over the 38-year sampling period (1962–1999). For the full data set from 47 beaches in eight localities, the overall capture rates were 8.2% per year (6.8, 9.7), only marginally lower than for the reduced data set.

This estimated decline in the by-catch of dugongs in shark nets can be taken as an estimate of decline in the dugong populations **from all causes** averaged over the areas where nets were deployed, provided that: (1) the catch of dugongs was dependent on dugong population density in the contract area, (2) dugongs did not learn to avoid the nets, or (3) dugongs had not been alienated from the contract areas by increased human use of the beaches. We regard the first two potentially confounding factors as unlikely and have no data to reject or support the third factor. We conclude that, at the very least, the netting data suggest a substantial depletion in dugong numbers along the urban coast of

Queensland since the early 1960s. This result accords with anecdotal reports by long-term residents including Indigenous peoples of a decline in dugong numbers. If the by-catch of dugongs in shark nets is a reliable index of changes in dugong abundance, our results suggest that by 1999, dugong numbers in the local regions of the shark nets had declined to about 3% of 1960 values, reinforcing concern for the status of the dugong along the urban coast of Queensland based on other evidence.

Our second report provides the results of another standardised aerial survey in the time series that my group have conducted since the mid-1980s to monitor the status of the dugong along the Queensland coast south of Cooktown. The survey was conducted in 1999, five years after the last survey. This is the first estimate of dugong abundance in the region since the establishment of the Dugong Protected Areas, a ban on Indigenous hunting of dugongs south of Cooktown, and other recent dugong conservation initiatives instituted by the Great Barrier Reef Ministerial Council. The survey period was characterised by unseasonally poor weather, and opportunities to survey under suitable conditions were limited. For this reason, the survey coverage was incomplete, with the focus directed towards high quality habitats at the expense of regions where few or no dugongs have been recorded in previous surveys. This resulted in the omission of the region between Cape Bedford and Innisfail, part of the coastline south of Mackay, including Broad Sound, the coast between Hervey Bay and Moreton Bay, and three of six blocks in Moreton Bay. Our statistical comparisons of the results of this survey with those of previous surveys were adjusted for these omissions which we expect to have a minimal impact on our overall assessment of the situation in the southern Great Barrier Reef region and Hervey Bay. Unfortunately, we were unable to make an assessment of dugong numbers in Moreton Bay as we were unable to survey the most important dugong area in that Bay.

The results of the 1999 survey indicate that dugong numbers in both the southern Great Barrier Reef region and Hervey Bay regions in October–December 1999 were significantly higher than the corresponding estimates in 1994, but not significantly different from that obtained for the southern Great Barrier Reef in 1986–1987. Most of the increase from 1994 was in the northern part of the survey region (the Central Section of the Great Barrier Reef Marine Park).

We consider that the observed increase is unlikely to be explainable solely by changes in dugong sighting conditions. It is also not possible for the differences between the 1994 and 1999 dugong population estimates to be solely the result of natural increase in the absence of immigration. We consider that the most plausible explanation for most of the increase observed is movement of substantial numbers of dugongs into the survey area, probably from the region north of Cooktown. In addition, northerly movement of dugongs from Moreton Bay cannot be ruled out because the survey of Moreton Bay was incomplete. Our conclusion that large-scale movements of dugongs into the survey area is the most likely reason for the change in dugong abundance in the southern Great Barrier Reef region has been supported by three independent expert reviewers. While there is no direct evidence for such movements, there is increasing evidence that seagrass abundance fluctuates over spatial scales on hundreds of kilometres in response to extreme weather events. Satellite tracking of dugongs has also proven that dugongs commonly move over large distances. For example, one animal has been tracked moving between Princess Charlotte Bay in the northern Great Barrier Reef and Cleveland Bay near Townsville.

The data from this survey support the location of the Dugong Protection Areas (DPAs) as areas which provide increased protection to a significant proportion of the dugongs in the region. As for previous surveys, in the southern Great Barrier Reef over 50% of all dugongs were in Zone A DPAs (10% of the 1999 survey area in this region). In addition, a further 22% were in Zone B DPAs (9.3% of the survey area in the southern Great Barrier Reef). In Hervey Bay/Great Sandy Straits 72.5% of dugongs were in the Zone A DPA (18.3% of the survey area in this region). Over the entire region and based on mean population estimates, 58% of the estimated dugong population was in the Zone A DPAs and 16% in Zone B DPAs.

The analysis of the dugong by-catch in the shark nets suggest that the aerial surveys between 1986–1987 and 1999 monitor fluctuations in population numbers far below those in the 1960s, which in turn probably reflect numbers far below those at the time of European settlement.

Helene Marsh
School of Tropical Environment Studies and Geography
James Cook University, Townsville

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Shark Control Records Hindcast Serious Decline in Dugong Numbers off the Urban Coast of Queensland

Helene Marsh, Glenn De'ath, Neil Gribble and Baden Lane

SUMMARY

- We used the 38-year data set collected by a government program to provide information on the status of dugongs on the urban coast of Queensland, Australia, additional to information provided by anecdotal reports and dedicated monitoring. There are potential problems with observational data such as the shark control records. If a change is observed it may result from the influence of uncontrolled and unmeasured concomitant variables unrelated to changes in dugong population numbers. Admitting this deficiency, we believe it is important to take serendipitous advantage of all information on the status of a dugong population, because of the difficulty of detecting trends using dedicated surveys, especially if population sizes are relatively small and the period covered by dedicated monitoring relatively short.
- The State Government conducted the 'Queensland Shark Control Program' by progressively introducing anti-shark measures at popular coastal resorts from 1962. This Program aims to protect swimmers in 10 districts (known as contract areas) on the east coast of Queensland between Cairns (16.5°S) and the Gold Coast (28°S). Six of these contract areas are in the Great Barrier Reef World Heritage Area. Each contract area consists of a number of beaches where gear is deployed to reduce the number of large sharks in the local area.
- Since its inception, the Program has deployed shark nets and baited drum lines in a 'mixed gear strategy' that adapts the type of gear to the characteristics of each beach. In addition to sharks, these nets also catch a variety of non-target species including marine mammals such as dugongs and sea turtles. Contractors employed by the Program have to record this by-catch as a condition of their contracts.
- We analysed the dugong by-catch data with two objectives: (1) to investigate factors affecting dugong mortality in nets, and (2) to use the change in catch of dugongs in shark nets as an index of the change in the status of the dugong population in the region between 1962 and 1999.
- The analysis indicated that the numbers of dugongs caught in shark nets set adjacent to the urban coast of Queensland at shark contract areas between latitudes 16.5° and 27°S declined from the inception of the Queensland Shark Control Program in the 1960s. The estimated rate of decline for a balanced data set from six contract areas averaged 8.7% per year [95% CI = (7.1, 10.6)]. This represents a decline to 3.1% (1.4, 6.1) of initial catch rates over the 38-year sampling period (1962–1999). For the full data set from eight areas, the overall capture rates were 8.2% per year (6.8, 9.7), only marginally lower than for the reduced data set. The rate of decline also increased over time, starting at about 6% in 1962, and increasing to 14% in 1999. This analysis is conservative, especially with respect to dugong mortality in the early years of the Queensland Shark Control Program. It is likely that the actual decline in the number of dugongs caught is greater than that reported here.
- The catch rates varied strongly between contract areas, and to a lesser degree between beaches within areas. Four of the six contract areas in the reduced data set showed severe declines, with two areas showing a modal distribution of catches, with higher catches centred around 1980–1982.
- There was weak monthly variation in catch rates, with catches significantly higher in the second half of the year than the first half.
- The number of nets at a beach and the number of fishing days per month did not appear to influence catch rates, however, the power of these tests are weak because of the confounding effects of beach and year on these parameters.
- Dugong catch rates did not change following the annual removal of nets at beaches for periods of 1–2 months.

- The estimated decline in the by-catch of dugongs in shark nets can be taken as an estimate of decline in the dugong populations **from all causes** averaged over the areas where nets were deployed, provided that: (1) the catch of dugongs is dependent on dugong population density in the contract area, (2) dugongs have not learned to avoid the nets, or (3) dugongs have not been alienated from the contract areas by increased human use of the beaches. We regard the first two potentially confounding factors as unlikely and have no data to reject or support the third factor. We conclude that, at the very least, the netting data suggest a substantial depletion in dugong numbers along the urban coast of Queensland since the early 1960s.
- If the by-catch of dugongs in shark nets is a reliable index of changes in dugong abundance, our results suggest that by 1999, dugong numbers in the local regions of the shark nets had declined to about 3% of their 1960 value, reinforcing concern for the status of the dugong along the urban coast of Queensland based on other evidence. The spatial scale over which any depletion has occurred is unknown. However, the extensive movements monitored by satellite-tracking individual dugongs suggest that any decline is likely to have occurred at regional rather than local scales.
- The likely reasons for any decline are complex and include habitat loss, traditional hunting and incidental drowning in commercial gill and mesh nets, as well as the Shark Control Program *per se.*
- The most salient questions to be determined by management agencies and stakeholders is the target level of recovery for dugong populations in this region and the time frame to achieve this target.

INTRODUCTION

One of the criteria used by the IUCN (2000) for evaluating the extinction probability of a species is evidence for reduction in population size over a time frame appropriate for that species (10 years or three generations, whichever is the longer). Obtaining the evidence relevant to this criterion is generally very difficult for species which are not harvested commercially, particularly for long-lived species such as the dugong, *Dugong dugon* (Marsh et al. 1999), which can live for over 70 years (Marsh 1980). If dedicated monitoring programs exist at all for such species, they have generally been introduced relatively recently, e.g. mid-1980s for dugongs along the urban coast of Queensland (Marsh & Saalfeld 1990). In addition, low-level chronic declines are very difficult to detect even by dedicated surveys, especially if population sizes are small (Taylor & Gerrodette 1993; Marsh 1995). These difficulties reinforce the importance of taking serendipitous advantage of all information on the status of a population. Indeed the IUCN criteria (2000) allow for the reduction in population size to be 'observed, estimated, inferred or suspected'. In this paper, we use data on dugong by-catch, collected by a government program designed to protect bathers from sharks, to provide information on the status of the dugong on the urban coast of Queensland, Australia. This information is additional to that provided by dedicated monitoring (Marsh & Saalfeld 1990; Marsh et al. 1994, 1996; Marsh & Lawler 2001) and anecdotal reports (see Marsh et al. 1996 for details).

The State Government has conducted the 'Queensland Shark Control Program' by progressively introducing anti-shark measures at popular coastal resort areas from 1962. This program aims to protect swimmers in 10 districts (known as contract areas; figure 1) on the east coast of Queensland between Cairns (16.5°S) and the Gold Coast (28°S) (Paterson 1979, 1986, 1990; Gribble et al. 1998; McPherson et al. 1998). Six of these contract areas are in the Great Barrier Reef World Heritage Area. Each contract area consists of a number of beaches where gear is deployed to reduce the number of large sharks in the local area. Since its inception, the Program has deployed shark nets and baited drum lines in a 'mixed gear strategy' that adapts the type of gear to the characteristics of each beach. There have been numerous temporal changes in the number of contract areas and beaches where the gear is deployed and the number of nets set per beach since the inception of the Program.

In addition to sharks, these nets also catch a variety of non-target species including marine mammals such as dugongs and sea turtles. There has been concern about the ecological sustainability of this by-catch since the early 1970s (Heinsohn 1972; Paterson 1979, 1990). In response to a ministerial Committee of Enquiry (*Review of the operation and maintenance of shark meshing equipment in Queensland waters*, 1992), initiatives were begun in 1992 (Gribble et al. 1998) to reduce the capture of non-target species. Nonetheless, concern over the by-catch increased in the mid-1990s as a result of aerial survey evidence of a decline in the dugong population in the Great Barrier Reef World Heritage Area between the mid-1980s and 1994 (Marsh et al. 1996). The likely reasons for this decline are complex and include habitat loss, traditional hunting and incidental drowning in commercial gill and mesh nets, as well as the Shark Control Program *per se* (Marsh et al. 1999). This concern led to a second inquiry in 1996–1997 which investigated the effect of the Queensland Shark Control Program on vulnerable and endangered species and the outcomes of the initiatives proposed in 1992–1993 (Gribble et al. 1998). Gribble et al. (1998) analysed the shark meshing records and concluded that, on average, the annual mortality of dugongs in shark nets in the southern Great Barrier Reef region represented 0.5% of the estimated dugong population of that region, based on the 1986 aerial survey (Marsh et al. 1996). Their analysis averages dugong mortality over the spatial scale of the entire region and the temporal scale of 1962–1999.

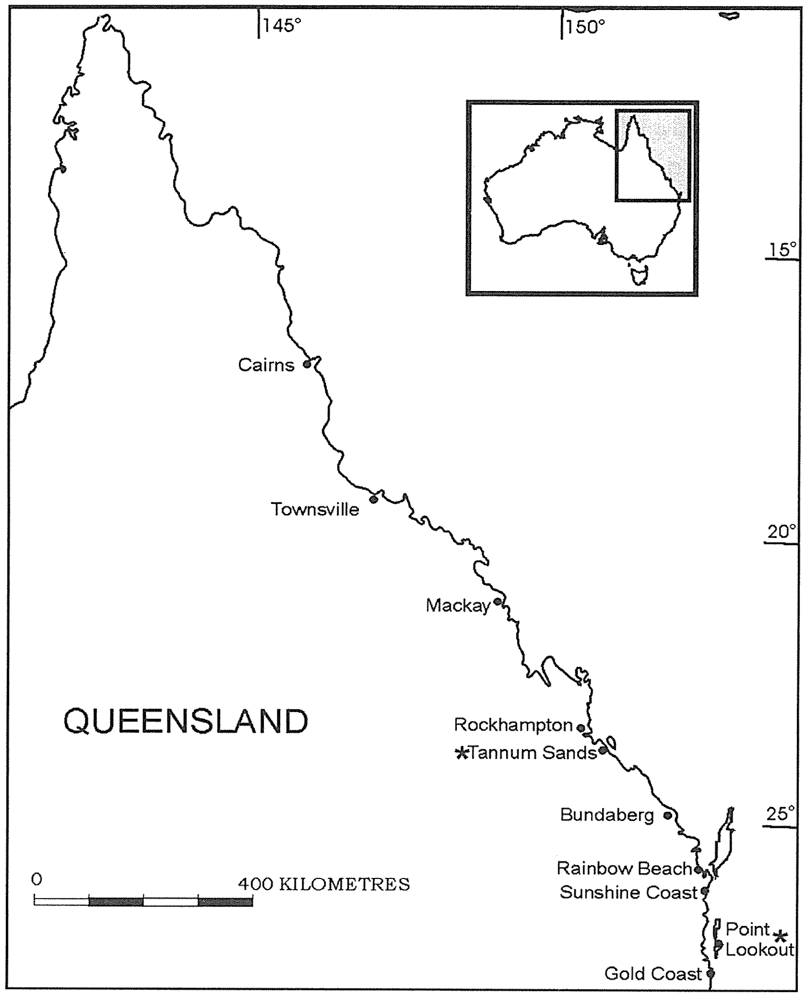

Figure 1. Map showing the deployment of shark control nets along the eastern coast of Queensland. The two contract areas marked with an asterisk were excluded from all analyses. No shark nets were deployed at Tannum Sands. Those at Point Lookout were deployed at only one beach and for seven years only (1974–1980).

We reanalysed the dugong by-catch data with two objectives: (1) to investigate factors affecting dugong mortality in nets, and (2) to consider the change in catch per unit effort of dugongs in shark nets as an additional index of change in the status of the dugong population in the region between 1962 and 1999. Our analysis suggests that dugong catch rates declined to 3.1% [95% CI = (1.4, 6.1)] of the initial catch rates over the 38-year sampling period, reinforcing concern about the status of the dugong along the urban coast of Queensland.

METHODS

Preparation of the Data for Statistical Modelling

Three sources of data were relevant to the study: (1) duplicates of the log books maintained by individual shark contractors, (2) the ledgers maintained by officers of the Queensland Department of Primary Industries (QDPI ledgers), and (3) the electronic database maintained by the Queensland Department of Primary Industries (QDPI database). The contractors employed by the Queensland Shark Control Program are required to enter catch data into individual logbooks. These data were subsequently transferred to the QDPI ledgers. Electronic records that had been entered in to the QDPI database were checked using archived duplicates of contractor's logbooks. If anomalies were detected, these were checked with the individual contractor, if possible. For our study, the following data were included for each month at each beach where shark nets were deployed: year; month; number of nets (0–3); number of days fished (effort/month); number of days not fished; number of months of net fishing since the nets were last removed; total number of months net operated in area/beach; total number of dugongs caught. A total of 446 records were excluded from the analyses, reflecting inconsistencies between the sources of data consulted. Two contract areas were excluded from all our analyses: (1) Tannum Sands where nets were never deployed, and (2) Point Lookout where nets were deployed only at a single beach for only seven years. Thus our analysis is conservative, especially with respect to dugong mortality in the early years of the Queensland Shark Control Program, e.g. *Review of the operation and maintenance of shark meshing equipment in Queensland waters* (1992) reports a total of 837 dugongs caught between 1962 and 1992 whereas our analysis is based on a catch of 579 dugongs.

The full data set we studied comprised 14 636 monthly records over 38 years (1962–1999) at 47 beaches within eight of the 10 contract areas including five of the six areas in the Great Barrier Reef World Heritage Area. The monthly catch at the eight contract areas studied ranged from 0–5 dugongs with almost 97% zeros.

Number of dugongs caught	0	1	2	3	4	5
Number of cases	14 169	380	69	12	5	1
Percentage of cases	96.81	2.69	0.47	0.08	0.03	0.01

Statistical Analysis

Data were analysed using generalized linear models (GLMs). The effects of the number of nets, the number of days fished and the month of the year were assessed using analysis of deviance tests, based on a model including these effects together with a smooth term in year (natural spline with 4 d.f.), beach and the year by beach interaction. Thus, all effects were adjusted for all other terms in the model. Shark nets were removed from most beaches for repair in most years, typically for 1–2 months. Catch rates of dugongs were compared for pre- and post-removal periods of one and three months using GLMs, and adjusting for beach and year as in the case of nets, days fished and month effects.

As detailed below, the effects of the number of nets, the number of days fished, months, and nets removal were statistically non-significant, and thus, to simplify further analyses, dugong catches were summed to give annual totals for each beach when at least one net was deployed. For years with less than 12 months of effort, totals were rescaled according to the number of months for which nets were used.

The 47 beaches considered here were selected by the Queensland Shark Control Program based on the extent and pattern of human use. Hence, for catch rates of dugongs, it is reasonable to treat these beaches as representative of the relevant contract areas. On this basis, we used variation of temporal profiles at the different beaches as the source of variation against which to compare differences between contract areas, and to obtain estimates of precision of the area and overall profiles. The catch data were difficult to model because of: (1) the large percentage of months with zero catches, (2) the repeated measures on individual beaches, and (3) the unbalanced data resulting from the nets not being deployed at each beach at all possible sampling times. To simplify the problem, we took the following steps to create a reduced data set which was more balanced and therefore more robust to statistical analysis than the full data set:

1. Data from beaches with total dugong captures of < 2 were removed since they provided minimal trend information.
2. Date from beaches with less than eight years of observations were removed since, compared to the overall period of 38 years, they provided little trend information, and they also greatly increased the imbalance of the data.
3. One contract area (Rainbow Beach) where nets were deployed at only one beach was also removed since the precision of the area profile could not be estimated because of the lack of replication.
4. Data were aggregated across months to give a single total for each combination of year and beach, and adjusted according to the number of months of observations; the non-significant effect of months justified this aggregation.

This reduced data set included six of the eight contract areas (four in the Great Barrier Reef World Heritage Area), and 31 of the 47 beaches in the full data set. The number of cases was reduced from 14 636 to 942 (largely because of aggregating the data from monthly to annual totals), and the total dugongs caught from 579 to 523. The sampling times of all beaches and the reduced data set are shown in figure 2.

Given the difficulties described above, we used resampling methods to estimate profiles for each contract area and overall. Since the data were counts, we used GLMs with a log link and Poisson error (log-linear models) for modelling the profiles from the resampled data. Confidence intervals for contract area and overall profiles were not based on GLM theory, because we consider the beaches as random effects, and instead we used the distributions of estimated profiles under resampling.

To estimate the mean profiles for each contract area and overall, we proceeded as follows:

1. GLMs with Poisson error and log link function (a log-linear model) and year as a numeric variable were used to model the profiles of each beach across years. Linear, quadratic and smooth profiles in year (natural spline with 4 d.f.) were compared, and the quadratic model was chosen based on deviance tests and residual plots. Temporal correlation along each beach profile was assessed by including an autoregressive term in year in the GLMs. In all cases these were non-significant.
2. We then estimated the profile and pointwise confidence intervals for each area. To do this, we took 500 bootstrap samples with replacement, using beach as the sampling unit. Thus each beach was either all-in or all-out of each sample, and if in, it could occur multiple times in a bootstrap sample. For each sample, we fitted the quadratic model (see 1 above), and predicted the mean profile for years 1962 to 1999. From the 500 sets of predictions, the 50%ile, 2.5%ile and 97.5%ile were calculated to estimate the mean profile for the contract area and its 95% confidence intervals at each year.
3. To estimate the overall profile, we used beach as the sampling unit for the reduced data as in 2, but also stratified by contract area, so that each bootstrap sample included the same number of beaches occurring in each contract area.

4. We then estimated the rate of capture of dugongs for each year by fitting a cross-validated smoothing spline through the estimated overall profile and calculating the gradient at each year.
5. The overall mean profile, and the rate of capture of dugongs at each year, were also estimated from the full data set (47 beaches) as in 3 above.

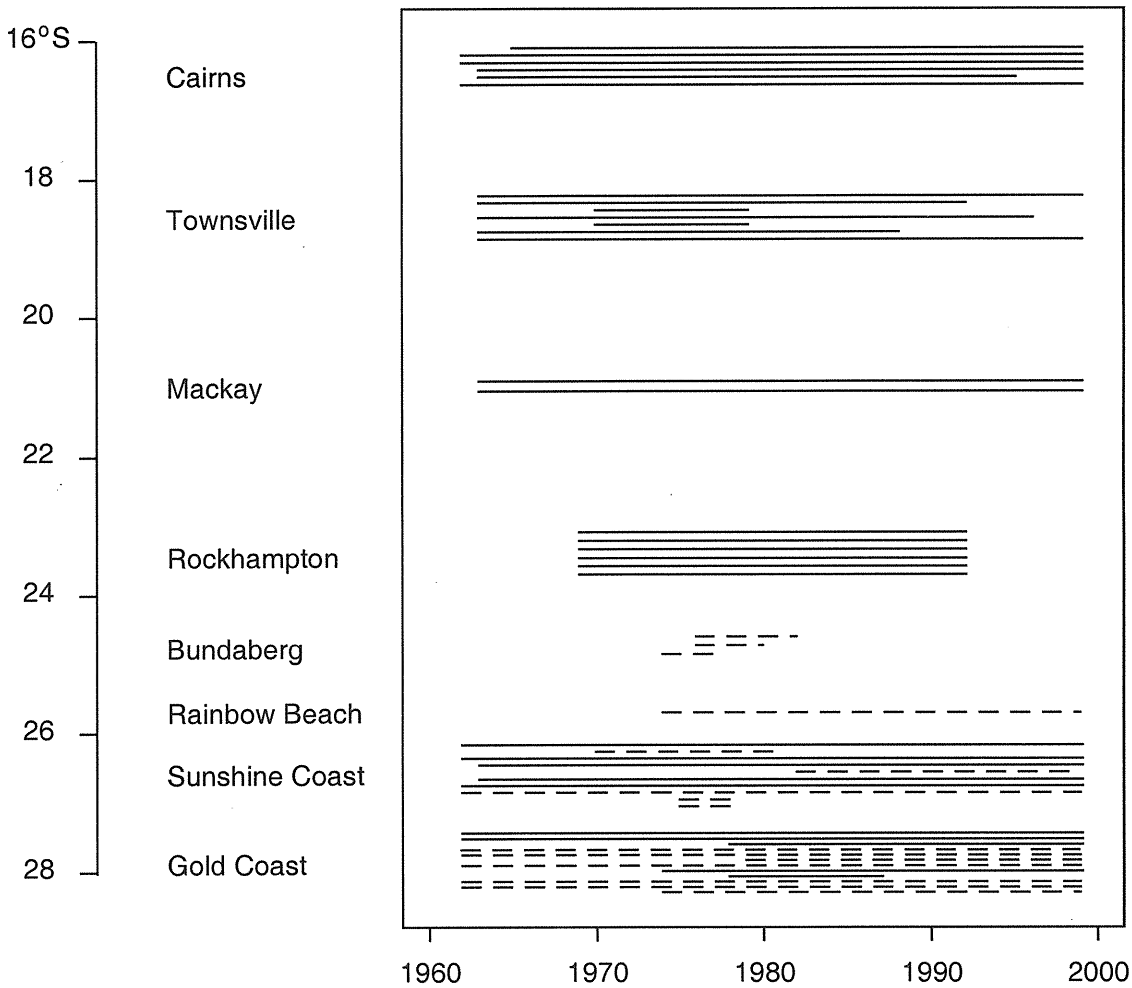

Figure 2. Sampling times for the 47 beaches within the eight contract areas used in the analyses. Beaches with less than eight years of sampling, or having less than two dugongs caught, and Rainbow Beach (a single beach in an area) were excluded from the full data set for some analyses and are indicated by dashed lines. The reduced data set was based on the beaches represented by solid lines.

RESULTS

Temporal Changes in the Shark Control Program

The number of shark nets in each location changed over time in figures 3(a), (b) and (c). There was a general increase in the number of nets and the number of locations between 1962 and 1980, followed by a decline especially after the review in 1992.

(a)

(b)

(c)

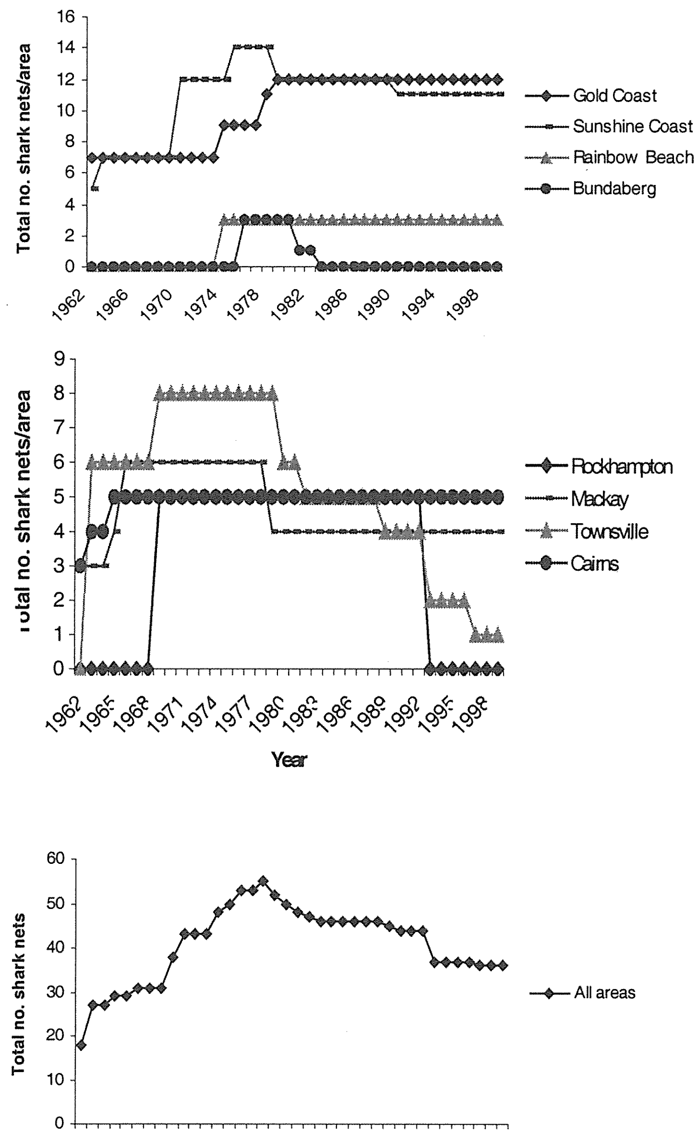

Figure 3. Temporal changes in the number of nets deployed by the Queensland Shark Control Program, a) southern Queensland contract areas, (b) northern Queensland contract areas, (c) all contract areas. Shark net usage steadily increased from 1962, peaked between 1975 and 1980, and has slowly declined to the present total of 36 nets.

Factors with the Potential to Affect the Capture Rate of Dugongs

The number of nets at a netted beach did not affect the number of dugongs caught ($\chi^2 = 0.10$, d.f. = 1, p = 0.752). This surprising result is explained by the number of nets being confounded with beach and, to a lesser degree, year. Beach and year explain 89% of the variation in the number of nets. Hence, when we adjusted for beach and year, the power to detect the effect of the number of nets on dugong mortality is low.

The effect of the number of days fished at a beach in a given year was also non-significant ($\chi^2 = 2.74$, d.f. = 1, p = 0.097). Over all beaches, every day of any given month was fished for 94% of months. When testing for the effect of the number of days fished, including months in the model adjusted for differences in month length (i.e. 28–31 days). We investigated whether this effect was masking the effect of number of days fished by dropping all fully-fished months from the analysis and repeating it. The effect was again non-significant ($\chi^2 = 0.022$, d.f. = 1, p = 0.882).

The effect of months was non-significant, although this effect was marginal ($\chi^2 = 19.15$, d.f. = 11, p = 0.058). The largest difference between any two months was between June and July with a 65% increase in the latter (figure 4). Catch rates were lower in the first half of the year than the second ($\chi^2 = 7.05$, d.f. = 1, p = 0.008).

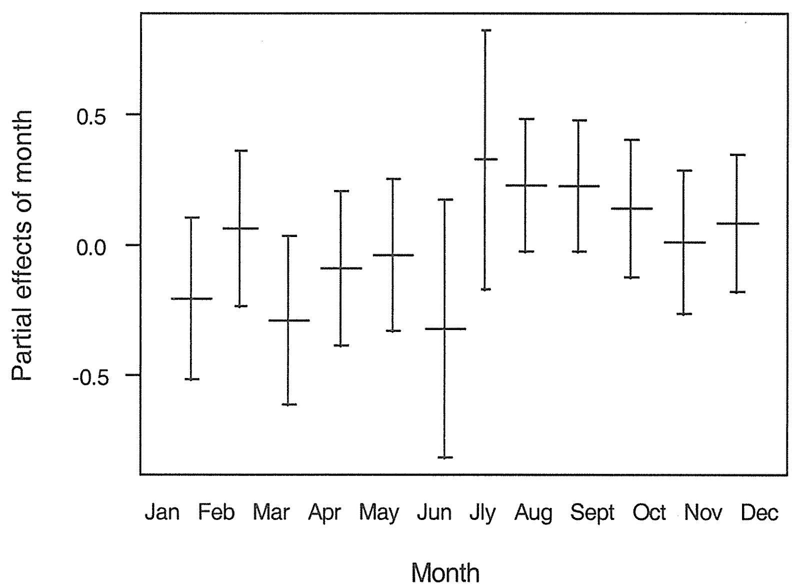

Figure 4. Partial effects plots for month adjusted for year, beach, number of nets and number of days fished on the number of dugongs caught in the Shark Control Program. The largest difference occurred between June and July (a 65% increase). Catches were significantly higher in the second half of the year than in the first half.

There was no detectable effect of previous net removal on the number of dugongs caught in the nets. We compared dugong catches for one month pre and post net removal ($\chi^2 = 1.02$, d.f. = 1, p = 0.353), and for the corresponding three month periods ($\chi^2 = 1.32$, d.f. = 1, p = 0.250). Net removals tended to be systematic at a given beach, but varied between beaches. Adjusting for the effects of beach and month weakened the power of the tests.

The Profiles for Contract Areas

The variation of profiles for beaches within contract areas was small compared to variation between areas (figure 5). Area profiles accounted for 34.9% (d.f. = 17) of the model deviance, whereas beaches within profiles accounted for 21% (d.f. = 75). This gives an approximate F-test [F = 7.33, d.f. = (17, 75), p < 0.001] to compare the effects of area profiles to the profiles of beaches within areas. Thus, if we accept that the beaches are representative of their areas, then there are significant differences between area profiles (figure 5). This is confirmed by inspection of the bootstrap confidence intervals for the area profiles (figure 6).

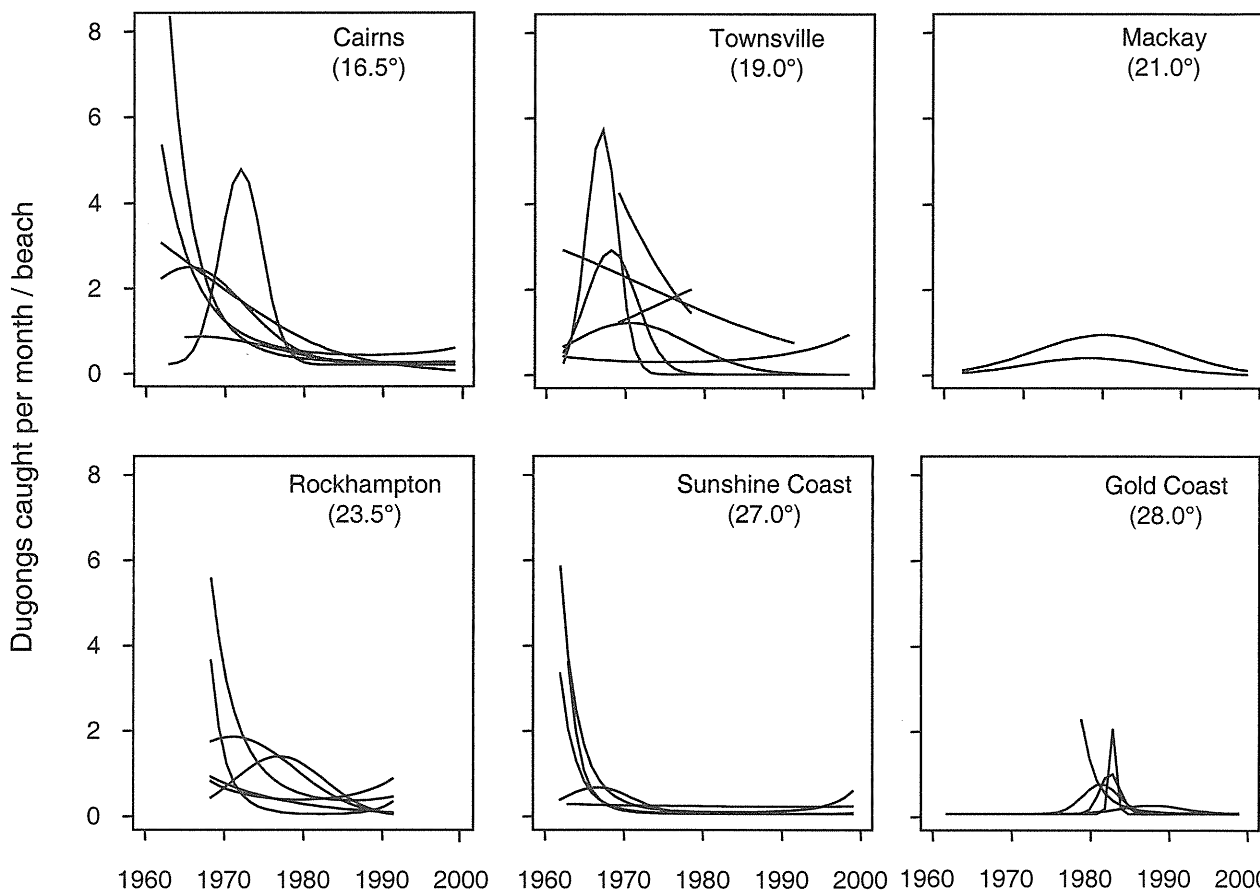

Figure 5. Profiles of the annual estimated mean numbers of dugongs caught at each beach for each of six contract areas for the period 1962–1999 based on the reduced data set. These profiles were estimated by log-linear models with linear and quadratic terms in year. The variation between beaches within areas is relatively small compared to the between-area variation. This result suggests that beaches are representative of their areas, and that there are significant differences between area profiles of the number of dugongs caught.

The Overall Profile

The overall profile for the reduced data set (figure 7) shows a strong decline. Over the period 1962–1999, the capture rate declined at an average of 8.7% per year 95% CI = 7.1, 0.6)]. This corresponds to an overall decline from 100% to 3.1% (7.1, 10.6) or a halving in the catch rate every 8.0 years (6.5, 9.8). The rate of decline increased over time, starting at about 5% in 1962, and increasing to 14% in 1999 (figure 8).

For the full data set, the overall capture rate declined at 8.2% per year (6.8, 9.7), only marginally lower than for the reduced data set. The rate of decline also increased over time, starting at about 6% in 1962, and increasing to 14% in 1999 (figure 8). Because of the changes introduced into the Shark Control Program as a result of the review in 1992 (*Review of the operation and maintenance of shark meshing equipment in Queensland waters*, 1992), we compared the profile for the full data set for 1962–1999 with the corresponding data set for the period 1962–1991. There was no significant difference in the two profiles. If the significant quadratic term is ignored and only a linear term fitted, then we get estimates of 8.7% per year for the full data set and 8.5% per year for the pre-1992 data. The difference is not significant. Thus there is no statistical evidence for a different pattern of decline for the periods pre and post 1992.

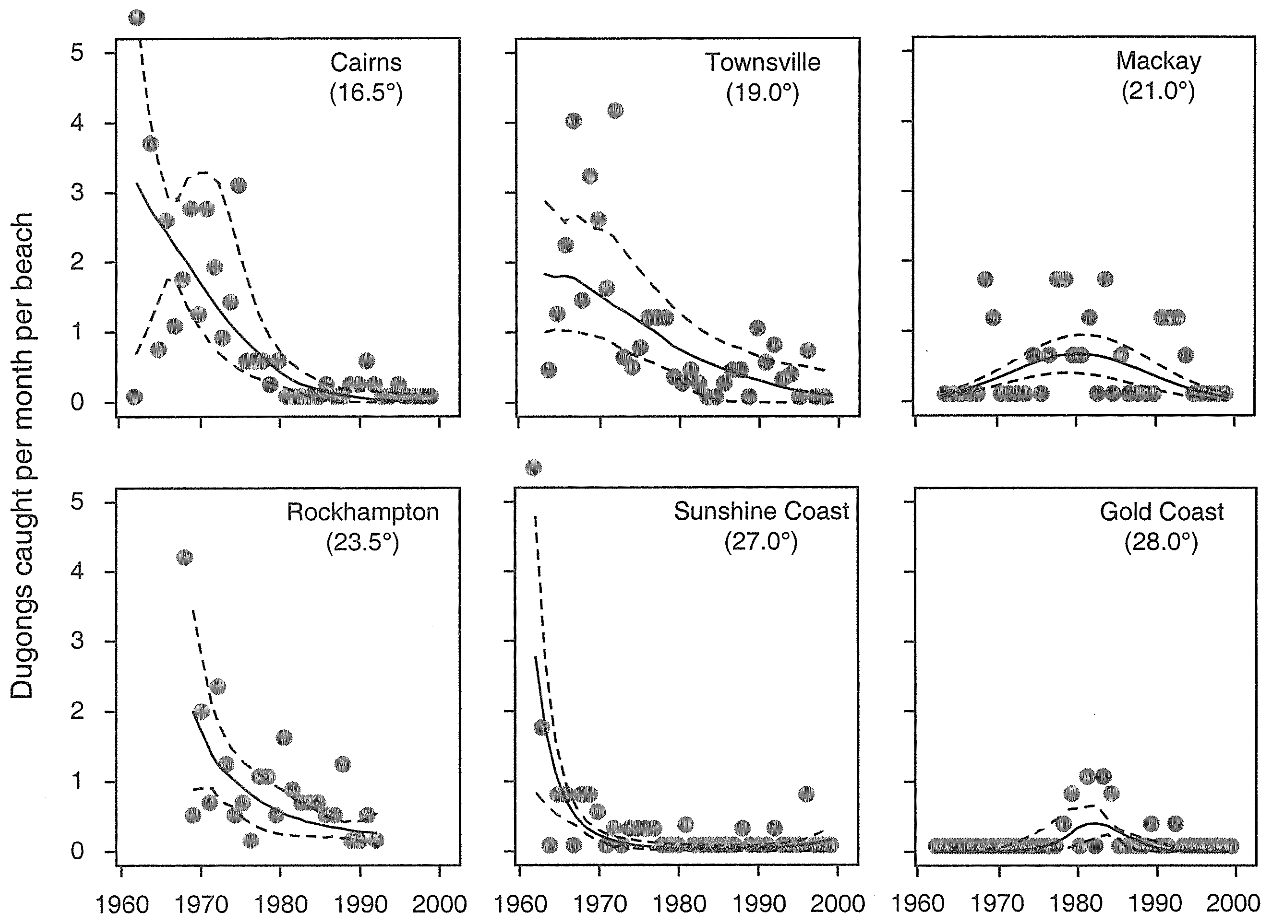

Figure 6. Profiles of the annual estimated mean numbers of dugongs caught per beach in each of six contract areas for the period 1962–1999 for the reduced data set. The profiles were estimated by bootstrapped fits of log-linear models with linear and quadratic terms in year. The bootstrap samples were generated by stratifying on beach within area, thus, for any sample, a beach was either completely included or excluded. Four of the six areas show strong declines, whereas the remaining two have low modal catches centred around 1980–1982. In all areas, catches in the period 1990–1999 have been very low. The confidence intervals have 95% pointwise coverage. Out of range points for Cairns and the Sunshine Coast had values of 6.5 and 6 dugongs caught per month/beach respectively.

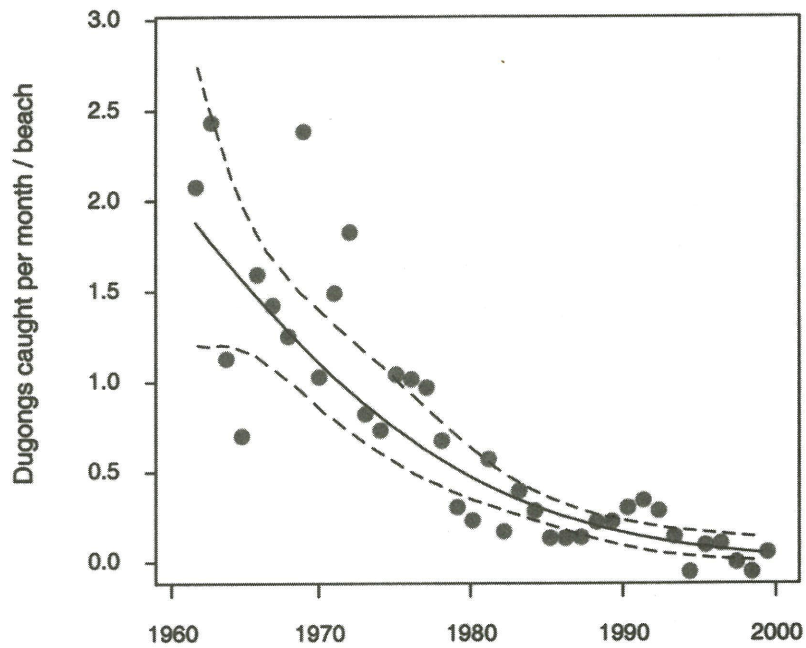

Figure 7. Profile of the annual estimated mean numbers of dugongs caught for the period 1962–1999 for the reduced data set showing a strong overall decline in the number of dugongs caught per month per beach. The profile was estimated by bootstrapped fits of log-linear models with linear and quadratic terms in year for each beach. The bootstrap samples were generated by stratifying on beach within area, thus, for any sample, a beach was either completely included or excluded. The confidence bands have 95% pointwise coverage.

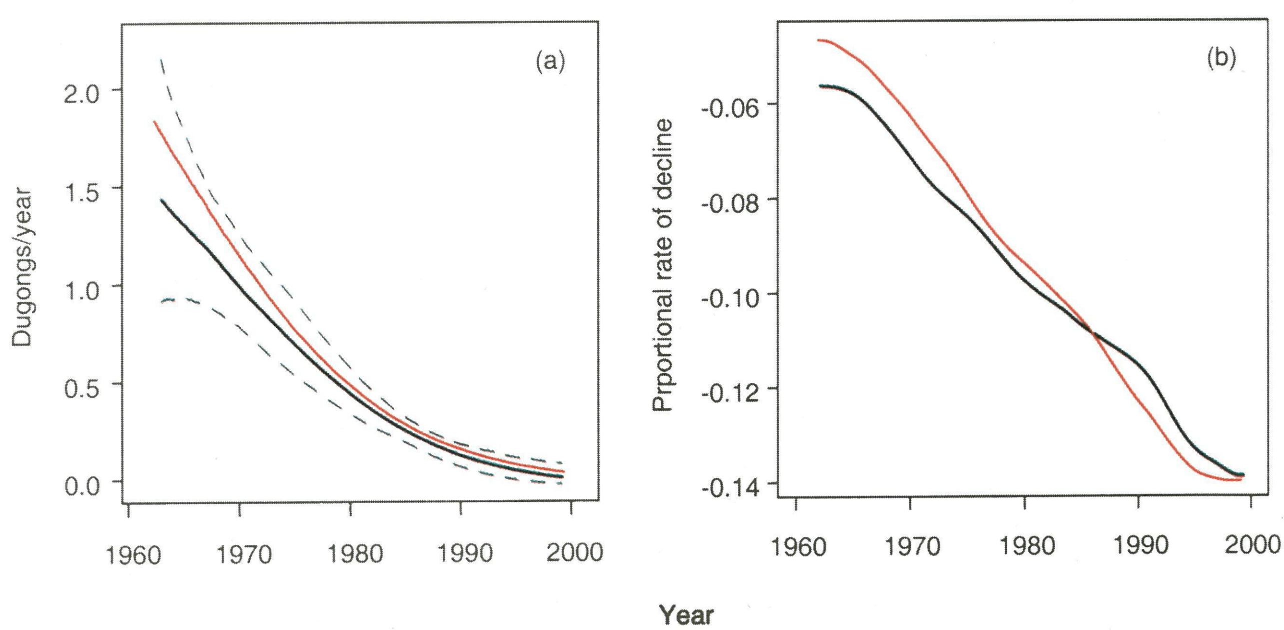

Figure 8. Profiles of the annual estimated mean numbers of dugongs (a) caught for the period 1962–1999 for the full data set (blue solid line) with 95% confidence bands (dashed), and the reduced data set (red solid line). Both data sets show strong overall declines. The profiles were estimated by bootstrapped fits of log-linear models with linear and quadratic terms in year for each beach. Proportional rates of decline for the period 1962–1999 (b) for all data (blue solid line) and the reduced data set (red solid line).

DISCUSSION

The numbers of dugongs caught in shark nets set off the urban coast of Queensland at shark contract areas between the latitudes of 16.5° and 27.5°S declined strongly from the inception of the Queensland Shark Control Program in 1962. The estimated rate of decline for a reduced (balanced) data set averaged 8.7% per year [95% CI = (7.1, 10.6)]. This represents a decline to 3.1% (1.4, 6.1), of initial catch rates over the 38-year sampling period (1962–1999). For the full data set, the overall capture rate declined at 8.2% per year (6.8, 9.7), a rate only marginally lower than for the reduced data set. The rate of decline also increased over time, starting at about 6% in 1962, and increasing to 14% in 1999 (figure 8). There is no statistical evidence that the changes to the Program introduced after the 1992 review (*Review of the operation and maintenance of shark meshing equipment in Queensland waters*, 1992) changed the pattern of declining catches. However, given the low number of dugongs caught post 1992, the power to detect such a change is weak. As explained above, our overall analysis is conservative, especially with respect to dugong mortality in the early years of the Queensland Shark Control Program. Thus it is likely that the actual decline in the number of dugongs caught is greater than that reported here.

The catch rates varied strongly between contract areas, and to a lesser degree between beaches within contract areas (figures 5 and 6). Four of the six contract areas (Cairns, Townsville, Rockhampton (all in the Great Barrier Reef World Heritage Area), and the Sunshine Coast (figure 1) showed large declines over the sampling period. Two areas (Mackay and the Gold Coast, figure 1) showed a modal distribution of catches, with higher catches centred around 1980–1982. There was weak monthly variation in catch rates (figure 4). Dugong catches tended to be higher in the second half of the year than in the first half. A similar seasonal pattern is also reflected in the Queensland Parks and Wildlife Service stranding database for 1996 and 1999 (Limpus et al. 1999). This seasonal effect may reflect changes in dugong activity in the second half of the year in response to a seasonal reduction in above-ground seagrass biomass (Aragones & Marsh 2000) and/or dugong breeding activity (Marsh et al. 1984; Boyd et al. 1999). Catch rates did not appear to be influenced by the number of nets deployed at a netted beach and the number of fishing days per month, although the power to detect these effects was weak because of the confounding effects of beach and year. The catch rates did not change following the annual removal of the nets for periods of 1–2 months.

Explanations for the Decline in Dugong Catches in Shark Nets

This estimated decline in dugong catch could be taken as an estimate of a decline from all causes in dugong numbers averaged over the areas where nets were deployed if there are no confounding factors unrelated to any real change in population numbers. Before reaching the conclusion that dugong numbers have seriously declined, it is important to examine the following underlying assumptions, which are related to possible confounding factors:

1. Practices of shark netting have not changed over the sampling period.
2. Dugongs have not changed their behaviour in the areas fished by the shark nets.
3. Catch rates are dependent on dugong population density.

Changes in the Practice of Shark Meshing?

The Queensland Shark Control Program uses cord nets. These nets are 62 m long, 6.4 m deep and have a mesh size of 50 cm (*Review of the operation and maintenance of shark meshing equipment in Queensland waters*, 1992). In 1992, the Queensland Shark Control Program introduced measures to reduce the capture of non-target species as detailed by Gribble et al. (1998). These measures included: the replacement of shark nets at Rockhampton and at one beach near Townsville with drumlines; education and training initiatives to increase the chances of non-target species being released alive; and the staged introduction of acoustic alarms on nets at beaches in the Gold Coast (1992–1993); Sunshine Coast (1994 whales/1998 dolphins) and Cairns contract areas (1994–1995). These alarms were introduced to reduce the possibility of accidental entanglement of cetaceans. Their effect on dugongs is unknown. We conclude that these changes in the practice of shark meshing are unlikely to have a major impact on the long-term declines in dugong catch depicted in figures 5–8, as the major declines occurred before the 1990s. This conclusion is supported by the lack of a significant difference between the pre- and post-1992 capture rates of dugongs in the Shark Control Program as explained above (but note the lack of power in the test).

Changes in the Behaviour of Dugongs in the Areas Fished by the Nets?

A possible explanation for the decline in the by-catch of dugongs in the Queensland Shark Control Program is that dugongs learn to avoid the nets, which have been left in place for long periods. We have no data to support this assumption and limited data to reject it. As outlined below, most captures have been of single dugongs and the only long-term social unit identified for dugongs is the cow-calf pair, suggesting a limited opportunity for dugongs to learn about the nets from the experience of others. The confirmed proportion of animals released alive from the nets is low (2%, *Review of the operation and maintenance of shark meshing equipment in Queensland waters*, 1992). However, this percentage probably underestimates the actual percentage released alive as the status of most dugongs in the nets was not recorded. Dugongs of all ages and both sexes are caught, and when the distributions of sizes, sexes and estimated ages are considered there are no major gaps (Marsh 1980). If dugongs learned to avoid nets we might expect a preponderance of young animals in the nets and a rise in dugong catch rates when the nets were reintroduced each year after their annual removal. However, the removal time may have been too short for dugongs to unlearn any avoidance behaviour. We conclude that, at our current state of knowledge, the decline in dugong catches cannot be explained by dugongs learning to avoid the nets.

A more plausible explanation for the decline in dugong by-catch is that dugongs have been alienated from the beaches where shark nets have been located by increased human use. Although boat traffic is banned from the immediate vicinity of nets, the presence of a net is an inducement to bathers. There is no evidence to reject or support this displacement hypothesis.

Catch Rates do not Reflect Dugong Population Density?

Heinsohn (1972) analysed the pattern of dugong mortality in Townsville shark nets from their introduction in 1964 through July 1971. His data were obtained directly from the local contractor and are more detailed than the official QDPI data analysed in this study. In addition, Heinsohn's data include catches that were not included here because of discrepancies among the QDPI database and the QDPI logbooks. Heinsohn (1972) reports that 22% of 119 nettings comprised multiple captures of up to five dugongs (a netting was defined as an instance in which one or more dugongs were found in a single shark net at the time it was checked every second day). Eleven of the 18 pairs of dugongs caught were netted in the first year. All the aggregations of more than two dugongs were caught in the first year of netting. Heinsohn & Spain (1974) compared the shark netting statistics for 1972, the year after cyclone Althea caused extensive damage to seagrass beds in the Townsville region. The annual catches of dugongs increased from an average of 12.7 before the cyclone to 41 in 1972. Heinsohn & Spain (1974) attributed this change to increased dugong movements in search of food following extensive cyclone damage to the seagrass beds. In 1972, 18% of nettings were multiple captures of up to three dugongs (three occasions). After 1972, at least 98.5% of dugong nettings in Townsville have been of single individuals. Over all contract areas, at least 97.3 % of dugong nettings have been of single individuals, suggesting no substantive change in the relationship between the pattern of dugong catches and population density since at least the early 1970s.

Is the Decline Plausible?

If dugong catches in shark nets are a reliable index of dugong numbers, and if the depletions occurred at regional rather than at local scales, the dugong population in the Great Barrier Reef region would have been of the order of 50 000 animals in the early 1960s based on the 1986–1987 population estimate for the region (Marsh & Saalfeld 1990). Is this plausible? Unfortunately, it is impossible to estimate the dugong carrying capacity of the region in the 1960s for two reasons: (1) we do not know the carrying capacity of any seagrass meadow, and (2) we do not know the area of seagrass along the Queensland coast in the 1960s. Thus we cannot use an estimate of carrying capacity to check the plausibility of the decline suggested by the shark netting data. Preen (1992) estimated a dugong density of 7.4 km^2 of seagrass in Moreton Bay in the early 1990s. Whether dugongs were at carrying capacity at this density and whether this result is applicable to other seagrass communities is unknown.

Additional Evidence for a Decline in Dugong Numbers Along the Urban Coast of Queensland

Analysis of dugong catches in shark nets (figures 5 and 6) indicate strong declines between the early 1960s and 1999 in four of the six areas (Cairns, Townsville, Rockhampton (all in Great Barrier Reef World Heritage Area), and the Sunshine Coast, figure 1). The data suggest that the number of dugongs remaining in the contract areas should be higher in Townsville and Rockhampton than in Cairns and variable in Mackay. These patterns are reasonably consistent with the results of dedicated aerial surveys for dugongs conducted in 1986–1987, 1992 and 1994 (Marsh & Saalfeld 1990; Marsh et al. 1994, 1996). The difference between the aerial survey population estimates for dugongs in the Great Barrier Reef World Heritage Area in 1986–1987 (3479 $\pm$ s.e. 459) and 1994 (1682 $\pm$s.e. 236) (Marsh et al. 1996) accords with the decline predicted from these data (8.7% p.a decline for seven years = 47%). The large decline in the Cairns area (figures 5 and 6) is supported by both: (1) the aerial survey results (too few dugongs were sighted in 1987 and 1992 to estimate the dugong population in the area), and (2) the anecdotal information of Bertram & Bertram (1973) who reported that 200 dugongs per year were being taken by Aboriginal people from nearby Yarrabah in 1965. Aboriginal elders also consider that dugong numbers in the southern Great Barrier Reef World Heritage Area have been declining for at least 20 years (Ross Williams pers comm. 1996).

Marsh and Lawler (2001) conducted another standardised aerial survey in the time series in 1999, five years after the last survey, to assess again the status of the dugong in the southern Great Barrier Reef region. This is the first estimate of dugong abundance in the region since the establishment of the Dugong Protection Areas (Marsh 2000) and the ban on Indigenous hunting of dugongs south of Cooktown. The results of the 1999 survey indicate that dugong numbers in both the southern Great Barrier Reef and Hervey Bay regions in October–December 1999 were significantly higher than the corresponding estimate in 1994, and not significantly different from that obtained in 1986–1987. Most of the increase was in the northern part of the survey region (the Central Section of the Great Barrier Reef Marine Park). It is not possible for the differences between the 1994 and 1999 surveys to be 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 1995; 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 sources of anthropogenic mortality, Indigenous hunting and commercial net fishing, were not introduced until 1997. Marsh and Lawler (2001) considered that the most plausible explanation for the increase observed is movement of substantial numbers of dugongs into the survey area, probably from the northern Great Barrier Reef region. While there is no direct evidence for this occurring, there is increasing evidence that seagrass abundance fluctuates over spatial scales on hundreds of kilometres in response to extreme weather events (Preen et al. 1995; Poiner & Peterken 1996). Satellite tracking of dugongs has also proven that dugongs commonly move over large distances (Marsh & Rathbun 1990; Marsh et al. 1999; Preen 2000).

Two of the shark-meshing contract areas (Mackay and the Gold Coast, figure 1) showed a modal distribution of catches, with higher catches centred around 1980–1982. This pattern also accords with the hypothesis of changes in seagrass distribution in response to extreme weather events. A plausible but unproven explanation for the observed increase in dugong catches in these contract areas in the 1980s is that dugongs moved into the Mackay and Gold Coast contract areas in response to seagrass loss elsewhere (see Marsh et al. 1999).

Nonetheless, none of these results is inconsistent with the hypothesis that there has been a long-term decline in dugong numbers on the urban coast of Queensland. These results are consistent with the hypothesis that the overall pattern decline has been complicated by large-scale movements of dugongs, possibly in response to changes in seagrass distribution.

Implications for Management of the Dugong in Queensland

The results of this analysis of the dugong catch in shark nets set for bather protection along the Queensland coast reinforce the assertion that the dugong numbers recorded in the dedicated aerial surveys reflect population numbers far below those in the early 1960s (Marsh et al. 1996). We cannot quantify the spatial scale over which this decline has occurred, i.e. whether it represents local or regional scale depletions. However, our current understanding of dugong movements (Marsh et al. 1999; Preen 2000) suggest that the depletion is likely to have occurred over a regional scale. More than 50% of dugongs tracked using satellite transmitters in the Great Barrier Reef World Heritage Area have moved more than 80 km in a few months (unpublished data) with maximum movement up to 800 km in a few days (Marsh et al. 1999; Preen 2000). In addition, we cannot quantify the relative importance of the various causes of this long-term decline in dugong numbers. They probably differ in different areas (Marsh et al. 1996). However, shark meshing *per se* was estimated to cause an average mortality of about 0.5% of the estimated 1986–1987 population in the southern Great Barrier Reef (Gribble et al. 1998). This is about 6% of the overall decline in shark net captures for the whole region (8.7% per year).

The relationship between dugong numbers in the early 1960s and those at the time of European settlement along the east Queensland coast during the 19th century is unknown. However, we consider it unlikely that dugong numbers were higher in 1960 than at the time of European settlement, given that a cottage commercial industry for dugong oil was widespread along the Queensland coast from the latter half of the 18th century until dugongs were protected in 1967 (Nishiwaki & Marsh 1985). This conclusion is supported by anecdotal information, e.g. Bertram & Bertram (1973). Thus the most salient questions to be determined by management agencies and stakeholders is the target level of recovery for dugong populations in this region and the time frame to achieve this target. As discussed above, population models suggest that dugong populations are unlikely to increase at more than 5% p.a. (Marsh 1995; Boyd et al. 1999). On this basis the dugong populations on the urban coast of Queensland would take at least 70+ years to recover to 1960 levels in the absence of immigration from more remote areas further north. As explained above, our current understanding of dugong movements suggests that such immigration is likely (Marsh et al. 1999) a result supported by the 1999 aerial survey Marsh and Lawler (2001).

If recovery to an agreed target is to be achieved, all sources of impact will need to be addressed. At present, management focuses on reducing dugong mortality by banning Indigenous hunting south of Cooktown (15°S) (Marsh 2000) and reducing the probability of dugongs drowning in nets (including both shark nets set for bather protection (Gribble et al. 1998) and commercial gill and mesh nets (Marsh 2000). Dugong habitat protection has concentrated on banning trawling from the inshore seagrass beds. The Great Barrier Reef Marine Park Authority zoning plans and the Queensland Fisheries Management Authority coastal strip closures, restrict trawling activity to 55% of the seagrass beds within the entire Great Barrier Reef Marine Park (Wachenfeld et al. 1998). This percentage should be increased as a result of the Representative Area Program currently being conducted by the Great Barrier Reef Marine Park Authority (Jon Day pers comm. 2000).

So far little has been done to protect dugong habitat from land-based inputs of nutrients, sediments and herbicides. *Halophila*, a genus that is a preferred food 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. Members of the genus *Halophila* occur at greater depths than other species of tropical seagrasses. This sensitivity to light reduction is a plausible explanation of the large-scale loss of deep-water seagrasses in Torres Strait (10°S) and Hervey Bay (25°S) after floods (Preen et al. 1995; Poiner & Peterken 1996; McKenzie et al. 2000).

The impact of extreme weather events on the dugong's seagrass habitat seems to be influenced by land-use. For example, anecdotal evidence suggests that the loss of seagrass from Hervey Bay following the 1992 floods was unprecedented in the past 100 years, even though the magnitude of the flood was not (Preen et al. 1995). Preen et al. concluded that the impacts of natural disturbance on seagrass beds can be exacerbated by poor catchment management. Catchment activities including vegetation clearing, grazing, agriculture, aquaculture and urban and industrial development may result in increased sediments and nutrients entering coastal waters. In the central Great Barrier Reef World Heritage Area for example, 39% of all nitrogen and 52% of phosphorous originate from river inputs (Cosser 1997). The increase in sediment and nutrient load from these activities may affect the ability of seagrass beds to recover from damage caused by natural events (Wachenfeld et al. 1998). The amount of sediments, nitrogen and phosphorous entering Queensland's oceans each year has increased three to fivefold since European settlement (~1850), with most originating from large areas of agricultural land in central and northern Queensland (Moss et al. 1993). Probably the greatest threat to seagrass habitat is land run-off and its effect on water quality (Wachenfeld et al. 1998). Herbicide runoff from agricultural lands also presents a potential risk to seagrass functioning adjacent to sugarcane production areas (Haynes et al. 2000a, b). Unfortunately data are not available to indicate the extent of change in seagrass habitats off the east coast of Queensland, over the 38 year time-frame reported here for dugongs. However, it is likely that the changes in water quality have reduced the depth range of at least some species of subtidal seagrasses in the region (Abal & Dennison 1996).

The development of management strategies to achieve an agreed target for dugong recovery will need to be more comprehensive than at present, and to pay particular attention to catchment management to reduce the influx of nutrients, sediments and herbicides into coastal waters from the land. These strategies will also need to be developed in the context of: (1) the likelihood of a change in the frequency of extreme weather events as a result of climate change, as well as (2) the aspirations and rights of the Indigenous communities in the region. The need to take a more comprehensive approach to dugong management than provided by Dugong Protection Areas is in accord with the generic recommendations regarding marine reserves of Allison et al. (1998). They ask several questions pertinent to dugong management in Queensland including:

1. Will reserve populations be able to persist despite greater fishing pressure outside the reserve (in this case the Dugong Protection Areas)?
2. Will reserve populations be able to persist despite episodic climatic events and directional climate change?
3. Will reserve populations be able to persist despite increases in threats from pollution, species introductions, and disease spread?

Implications for Determining the Status of Other Long-lived Species

Quantitative monitoring of dugong numbers was initiated in the southern Great Barrier Reef World Heritage Area (Marsh & Saalfeld 1990) and Hervey Bay (Preen & Marsh 1995) in the mid- to late 1980s, providing a relatively small temporal window in to the status of the dugong along the urban coast of Queensland (Marsh et al. 1994, 1996; Marsh & Lawler 2001). Catch data from the dugong by-catch of the Queensland Shark Control Program provides a longer-term perspective and confirms anecdotal evidence that the populations of the region were in far from pristine condition at the commencement of formal monitoring. This example emphasises the need for population assessments to be based on a synthesis of all available information, rather than relying solely on formal monitoring programs.

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Dugong Distribution and Abundance in the Southern Great Barrier Reef Marine Park and Hervey Bay: Results of an Aerial Survey in October–December 1999

Helene Marsh and Ivan Lawler

SUMMARY

- Australia has international responsibilities for dugong conservation, particularly in the Great Barrier Reef (GBR) region, where the dugong feeding grounds are listed as one of the World Heritage values of the region. Dugongs are of significant biodiversity value as the only extant species in the Family Dugongidae and one of only four species in the Order Sirenia, all of which are listed as vulnerable to extinction by the IUCN.

- A series of standardised aerial surveys between 1986–1987 and 1994 suggested a decline in dugong numbers over more than a thousand kilometres of coastline in the Great Barrier Reef World Heritage Area. Anecdotal evidence and analysis of by-catch data from the Queensland Shark Protection Program suggested that this decline had been going on for decades.

- The reasons for this decrease are complex and could include habitat loss and change, incidental drowning in both commercial and illegal gill nets and in shark nets set for bather protection, and Indigenous hunting. The data were not available to quantify the relative importance of these impacts or to determine how much of the change in dugong abundance resulted from a reduction in the size of the dugong population rather than emigration from the survey area.

- This decline threatened the World Heritage values of the Great Barrier Reef region. The Australian and Queensland governments agreed to several measures aimed at arresting the decline in 1997, including a resolution not to issue permits for the Indigenous hunting of dugongs in the region south of Cooktown. The most controversial measure was to establish a two-tiered system of Dugong Protection Areas (DPAs) in which gill and mesh netting are greatly restricted or banned, or subject to lesser modifications designed to reduce dugong mortality. Another DPA in which gill and mesh netting practices were modified was established in Hervey Bay, immediately south of the region.

- Another standardised aerial survey in the time series was conducted in 1999, five years after the last survey, to again assess the status of the dugong in the southern GBR, the region south of Cooktown. This is the first estimate of dugong abundance in the region since the establishment of the DPAs and the ban on Indigenous hunting of dugongs south of Cooktown. The survey period was characterised by unseasonally poor weather, and opportunities to survey under suitable conditions were limited. For this reason, the survey coverage was incomplete, with the focus directed towards high quality habitats at the expense of regions where few or no dugongs have been recorded in previous surveys. This resulted in the omission of the region between Cape Bedford and Innisfail, part of the coastline south of Mackay, including Broad Sound, the coast between Hervey Bay and Moreton Bay, and three of six blocks in Moreton Bay.

- The results of the 1999 survey indicate that dugong numbers in both the southern GBR and Hervey Bay regions in October–December 1999 were significantly higher than the corresponding estimate in 1994, but not significantly different from that obtained in 1986–1987. Most of the increase was in the northern part of the survey region (the Central Section of the GBR).

- Moreton Bay near Brisbane was also surveyed using the same techniques but the survey was not completed because of poor weather conditions. Our estimate of 171 $\pm$ 76 s.e. dugongs is almost certainly a substantial underestimate of the dugong population of

Moreton Bay as the blocks known to support the most significant dugong densities were not surveyed.

- We consider that the observed increase in dugong numbers in the southern GBR and Hervey Bay is unlikely to be explainable solely by changes in sighting conditions. Weather conditions were very good in two significant areas (Hinchinbrook and Hervey Bay/Great Sandy Straits) and population increases were recorded in both. However, conditions were marginal throughout much of the remainder of the survey area, where increases were also observed. Inclusion of Beaufort Sea State (a surrogate for survey conditions) in statistical analyses did not reduce the significance of the overall increase.

- It is also not possible for the differences between the 1994 and 1999 population estimates to be solely 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. 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 sources of anthropogenic mortality, Indigenous hunting and commercial net fishing, were not introduced until 1997.

- We consider that the most plausible explanation for the increase observed is movement of substantial numbers of dugongs into the survey area, probably from the northern GBR (the region north of Cooktown). In addition, northerly movement of dugongs from Moreton Bay cannot be ruled out because the survey of Moreton Bay was incomplete. While there is no direct evidence for such movements, there is increasing evidence that seagrass abundance fluctuates over spatial scales of hundreds of kilometres in response to extreme weather events. Satellite tracking of dugongs has also proven that dugongs commonly move over large distances. One animal has been tracked moving from the northern GBR to the Central Section of the GBR.

- 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 (Bertram 1981). 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.

MANAGEMENT OPTIONS

- The data from this survey support the location of the Dugong Protection Areas as areas that provide increased protection to a significant proportion of the dugongs in the region. As in previous years, in the southern GBR over 50% of all dugongs were in Zone A DPAs (10% of the 1999 survey area in this region). In addition, a further 22% were in Zone B DPAs (9.3% of the survey area in the southern GBR). In Hervey Bay/Great Sandy Straits 72.5% of dugongs were in the Zone A DPA (18.3% of the survey area in this region). Over the entire region and based on mean population estimates, 58% of the estimated dugong population was in the Zone A DPAs and 16% in Zone B DPAs. The Whitsunday Area is the only 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. We suggest that consideration be given to increased dugong protection in this area.

- 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 in developing strategies for dugong conservation. The efficacy of the DPA Bs in reducing dugong mortality in commercial gill nets is uncertain. Hence, 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 localised loss of seagrass in the Hervey Bay region.

OPTIONS FOR FUTURE AERIAL SURVEYS

- The results of this survey and others suggest that the capacity for aerial surveys to detect trends in dugong numbers over large spatial scales is confounded by the dugong's 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, timing 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 (Australian Fisheries Management Authority, Conservation and Land Management Western Australia, Parks and Wildlife Commission Northern Territory, Great Barrier Reef Marine Park Authority and Queensland Parks and Wildlife Service). 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.

INTRODUCTION

The waters of northern Australia are internationally recognised as the stronghold of the dugong (*Dugong dugon*). As the only surviving member of the family Dugongidae (Marsh et al. 1999), the dugong is a species of high biodiversity value. The dugong is listed as vulnerable to extinction by the IUCN (1996), along with the other three species in the order Sirenia, the manatees (family Trichechidae). Anecdotal evidence suggests that dugong numbers have decreased dramatically throughout most of their range (Marsh et al. 1999), but significant populations persist in Australian waters, which are now believed to support most of the world's dugongs. In Australian waters dugongs occur along much of the coast from Shark Bay in Western Australia to Moreton Bay in Queensland. Consequently, Australia has an international obligation to ensure their conservation (Bertram 1981).

Aerial surveys using standard techniques developed by Marsh and Sinclair (1989a, b) have provided much of the information used to manage dugong populations in Australia. The Great Barrier Reef region south of Cape Bedford was first surveyed using these techniques in 1986–1987, with a resulting population estimate of 3479 (± 459 s.e.) dugongs (Marsh & Saalfeld 1990). At that time, it was recommended that the survey be repeated every five years to monitor trends in dugong distribution and abundance. The follow-up survey in 1992 recorded a reduction in dugong numbers to 1857 (± 292 s.e.). A repeat of the survey in 1994 confirmed this decline, and further, that it was not an artifact of the poor weather conditions encountered in the 1992 survey, which were less ideal than in 1986–1987 (Marsh et al. 1995).

Hervey Bay supports a substantial dugong population immediately south of the boundaries of the Great Barrier Reef Marine Park (GBRMP) (Preen & Marsh 1995; Marsh et al. 1995), and thus may act as a source or sink for dugongs moving into or out of the southern GBRMP. Hervey Bay was added to the survey region in 1994 to investigate whether the observed decline in the southern Great Barrier Reef region was a result of animals moving into Hervey Bay. In 1988, Hervey Bay and the adjacent Great Sandy Straits supported an estimated 2206 (± 420 s.e.) dugongs, but this decreased to 600 (± 126 s.e.) in 1993 following widespread destruction of seagrass beds after a cyclone and repeated flooding in early 1992 (Preen & Marsh 1995). The estimated dugong population for the region in 1994 was 807 (± 151 s.e.) (Marsh et al. 1995). However, the temporal changes in dugong numbers in the Hervey Bay region could not account for the magnitude of the population decline in the southern GBR region.

These aerial surveys suggested a decline in dugong numbers over more than a thousand kilometres of coastline in the Great Barrier Reef World Heritage Area. Anecdotal evidence indicated that such a decline had been going on for decades (Marsh et al. 1995) as did an analysis of the temporal changes in the number of dugongs caught in shark nets set for bather protection (Marsh et al. 2001). The reasons for this decrease are complex and may include habitat loss and change, incidental drowning in both commercial and illegal gill nets and in shark nets set for bather protection, and traditional hunting (Marsh et al. 1995). The data are not available to quantify the relative importance of these impacts, or to determine how much of the change in dugong abundance resulted from a reduction in the size of the dugong population as opposed to emigration from the survey area (absence bias *sensu*, Lefebvre et al. 1995). There are no reliable data on temporal changes in Indigenous catch, or by-catch apart from the by-catch in shark nets (Marsh et al. 2001).

This decline has threatened the World Heritage values of the Great Barrier Reef region. An explicit justification for the regions' inclusion onto the World Heritage List was the fact that it 'provides major feeding grounds for large populations of the endangered species, *Dugong dugon*' (Great Barrier Reef Marine Park Authority 1981). In 1997 the Australian and Queensland governments agreed to several measures aimed at arresting the decline, including a resolution not to issue permits for the Indigenous hunting of dugongs in the region south of Cooktown. The most controversial measure was to establish a two-tiered system of Dugong Protection Areas (DPAs). Gill and mesh netting are greatly restricted or banned in seven Zone A DPAs totalling 2407 km^2, and subject to lesser modifications in eight Zone B DPAs totalling 2243 km^2 (Fisheries Regulation [No. 11] 1997 [Queensland]). An additional Zone A DPA of 1703 km^2 in which gill and mesh netting practices were modified was established in Hervey Bay, immediately south of the region (Marsh 2000).

In this report we present the results of aerial surveys conducted in 1999, five years after the last survey, to again assess the status of the dugong in the southern Great Barrier Reef region. This is the first estimate of dugong abundance in the region since the establishment of the DPAs, and the resolution not to issue permits for Indigenous hunting of dugongs south of Cooktown. The results indicate that dugong numbers in both the southern GBR and Hervey Bay regions in October–December 1999 were significantly higher than the corresponding estimates in 1994, but not significantly different from that obtained for the southern GBR in 1986–1987. Most of the increase was in the northern part of the survey region (the Central Section of the GBR).

METHODS

The initial plan for the surveys included all the inshore waters of the southern Great Barrier Reef region (referred to as the southern GBR) and extended south to include both Hervey and Moreton Bays, and the intervening coastline.

Unfortunately, the survey period was characterised by unseasonally poor weather, and suitable survey conditions were limited. For this reason, the survey coverage was incomplete, and focussed on known high quality dugong habitats at the expense of regions where few or no dugongs had been recorded previously. This resulted in the omission of the region between Cape Bedford and Innisfail, part of the coastline south of Mackay, including Broad Sound, much of the coast between Hervey Bay and Moreton Bay, and three of the six blocks in Moreton Bay. More specific details of the survey design and subsequent alterations are provided below.

Survey Methodology

The surveys were conducted in October–December 1999. The aerial survey method used was the strip transect technique detailed in Marsh and Sinclair (1989a, b). The reasons for adopting this survey methodology rather than the line-transect methodology (Buckland et al. 1993) were as follows: (1) we wished to use the same survey methods as the previous surveys in the time series to avoid confounding survey methodology with temporal change in dugong numbers; (2) a review of dugong survey methodology in 1997 by Professor Ken Pollock recommended that we retain the strip transect methodology.

Transects were flown in an east-west direction as this reduces the interference of glare with the observations. The exception to this was in the Hinchinbrook Channel where mountains make east-west flight dangerous. The transect positions and lengths were modelled on previous surveys of the region (see figure 1(a-g) for details of transect and block positions).

The survey altitude was 137 m and transects of 200 m width on the water surface were demarcated using fibreglass rods attached to artificial wing struts on each side of the aircraft. Tandem teams of observers on each side of the aircraft recorded their sightings independently onto separate tracks of an audio tape using a two-track tape recorder. These independent sightings were then used to develop survey-specific correction factors (see below). Each sighting was designated to the first (top), second, third or fourth (bottom) quarter of the transect to enable us to decide if simultaneous sightings by the tandem observers were of the same group of animals. Other large marine vertebrates (especially sea turtles and cetaceans) were also recorded during the survey.

Our intention was to survey the entire coastline from Cape Bedford in the north to Moreton Bay at the southern limit of the dugong's range, basing the survey design on those of previous surveys (Marsh et al. 1994a, 1995; Lanyon & Morrice 1997). The suitability of weather for aerial surveying leaves only a small window of opportunity, therefore we intended to use two aircraft flying concurrently with separate teams of observers. One team was to survey the region north of Shoalwater Bay, while the other surveyed the region south of Shoalwater Bay. Shoalwater Bay was surveyed separately two weeks prior to the main body of the survey (30 October - 1 November), as military activity prevented access at the desired time.

The region south of Shoalwater Bay including Hervey Bay and the Great Sandy Straits was surveyed under generally good conditions, and in general accordance with previous surveys from 13–20 November 1999. Poor weather occasionally caused delays in this region. In particular, the survey block covering the region between Hervey Bay and Moreton Bay was truncated to allow our transfer to Brisbane in the hope of encountering sufficient good weather to complete the coverage of Moreton Bay. Part of Moreton Bay was surveyed in marginal conditions before the weather degenerated to levels unsatisfactory for aerial surveys. After waiting several days, the weather did not improve and the remainder of the Moreton Bay leg was cancelled due to the increasing costs of keeping an aircraft and six crew in Brisbane, with no prospects of completing the surveying. Consequently, blocks M2, M4 and M5 (table 1, figure 1g) were omitted.

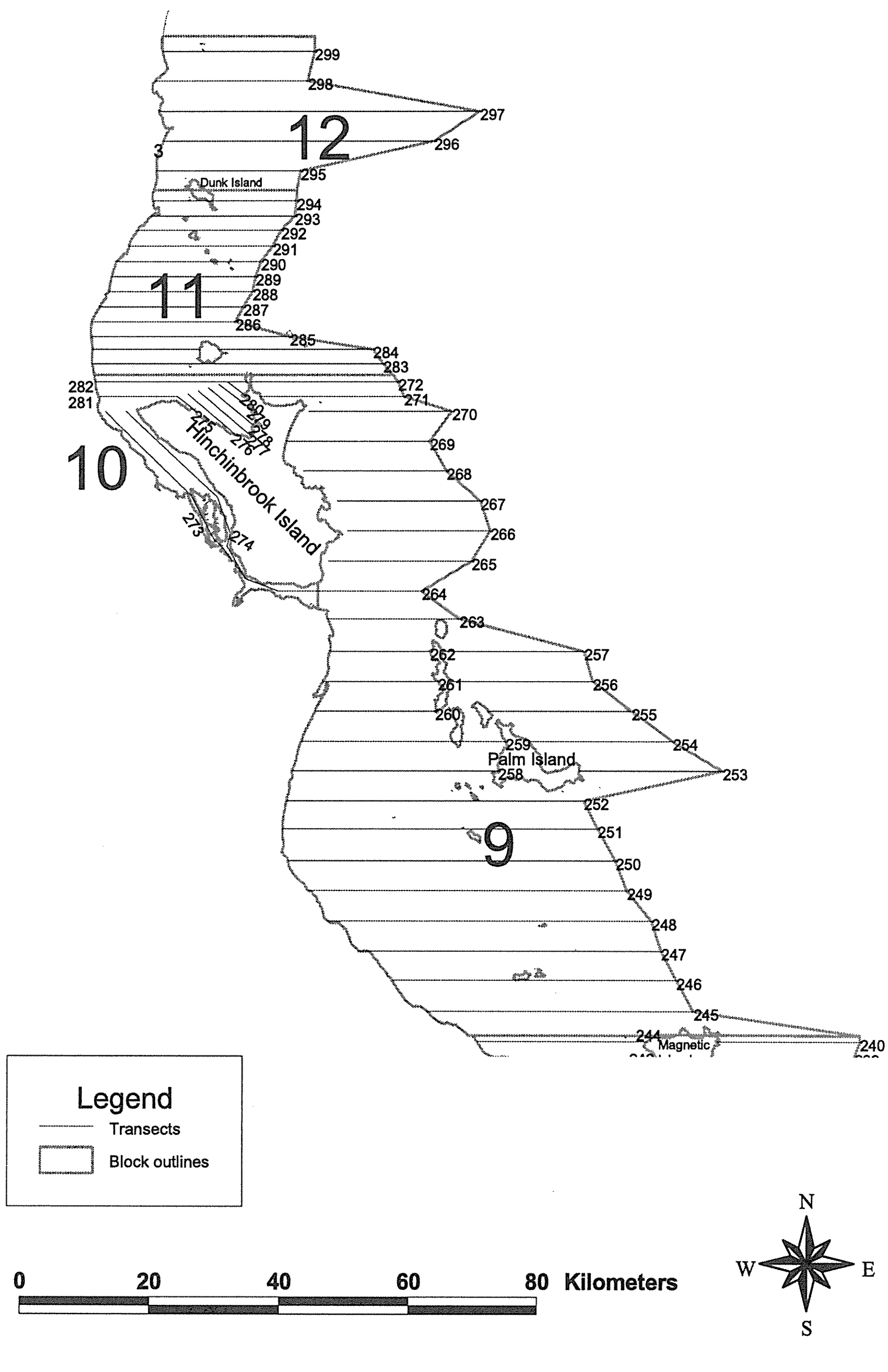

Figure 1a. Positions of blocks C9 to C12, and transects contained within, in the Central Section of the Great Barrier Reef region, from Innisfail to Magnetic Island

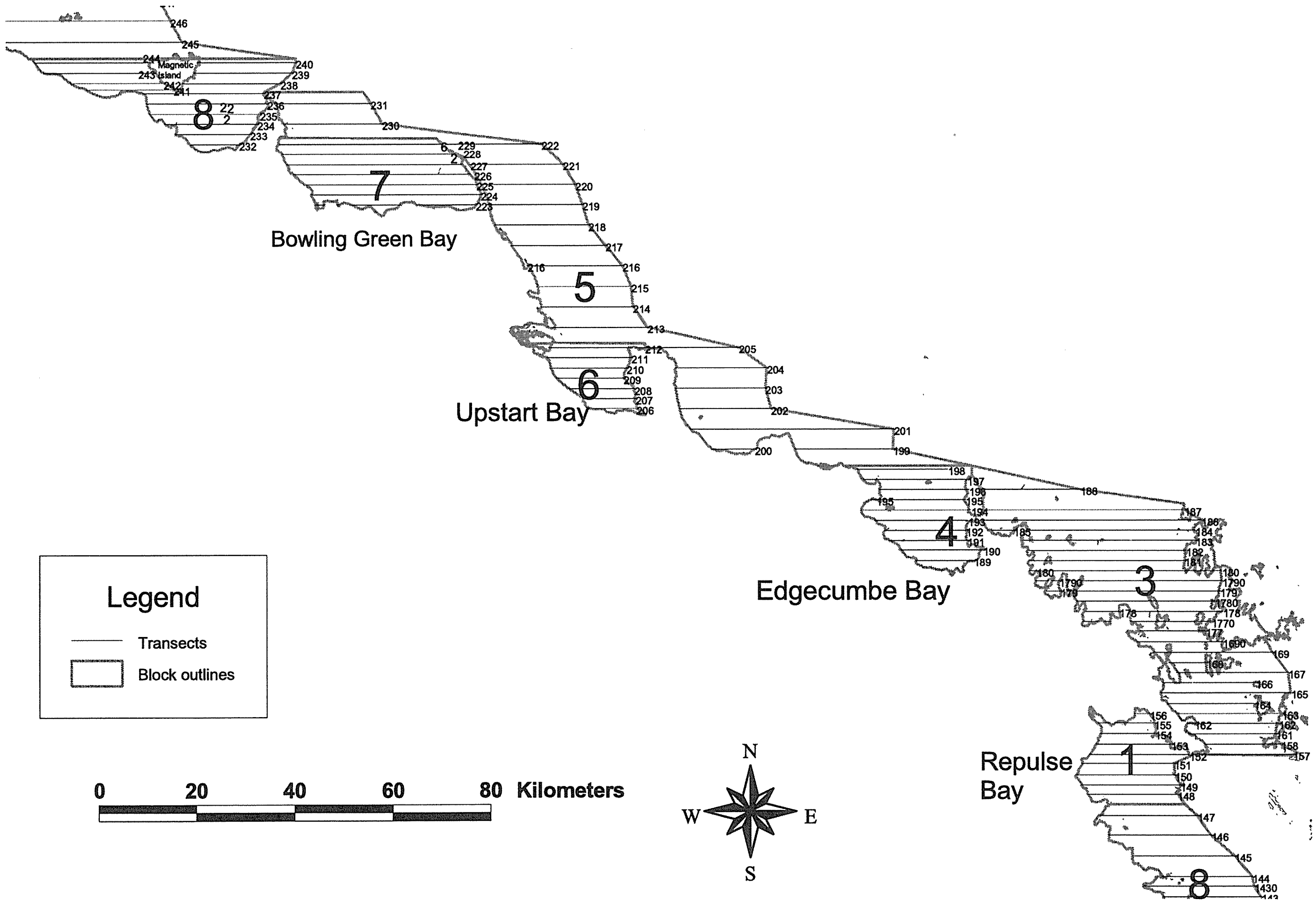

Figure 1b. Positions of blocks C1to C8, and transects contained within, in the Central Section of the Great Barrier Reef region, from Cleveland Bay to Repulse Bay

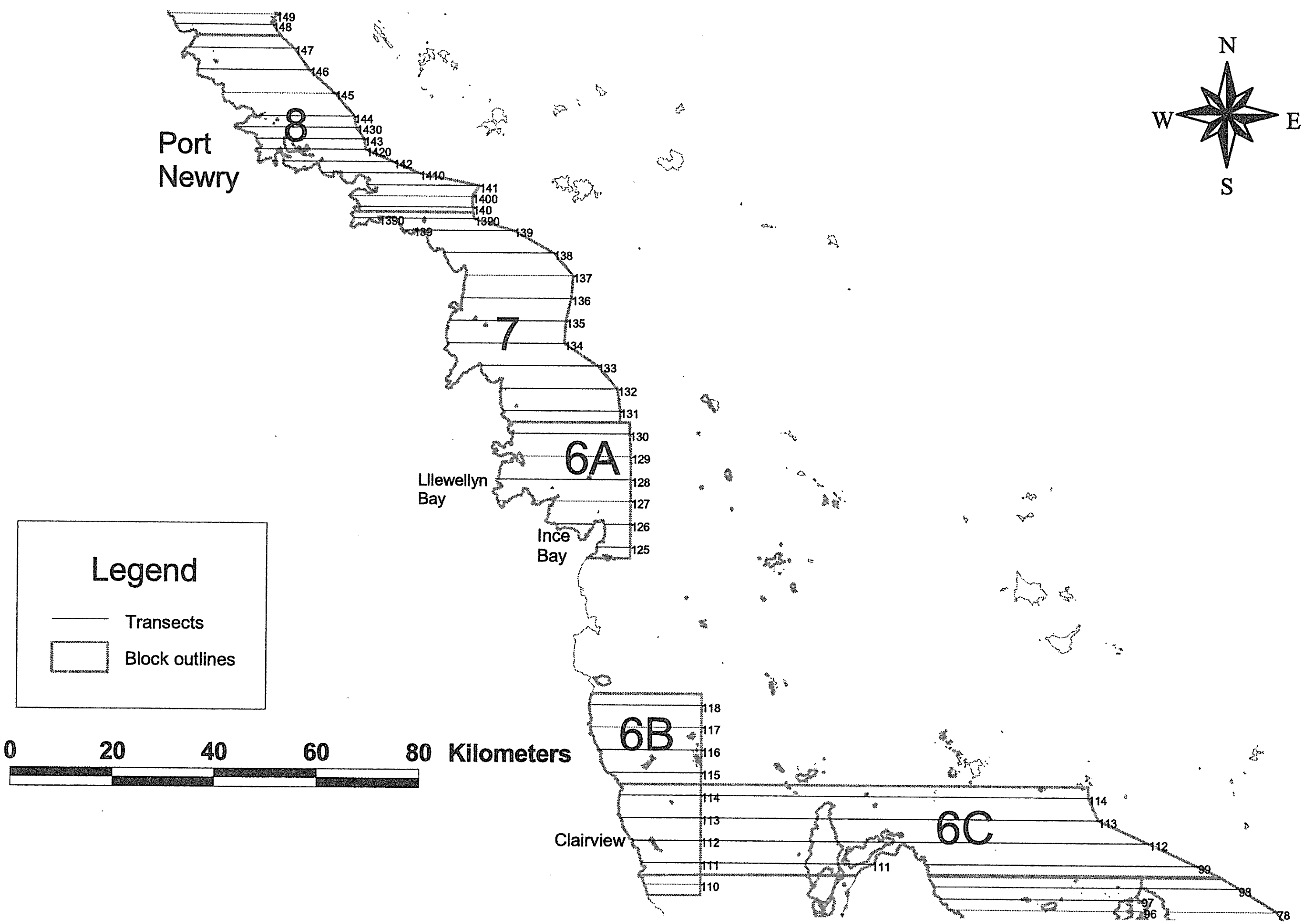

Figure 1c. Positions of blocks S6 to S8, and transects contained within, in the Southern Section of the Great Barrier Reef region, from the Newry Region to Clairview

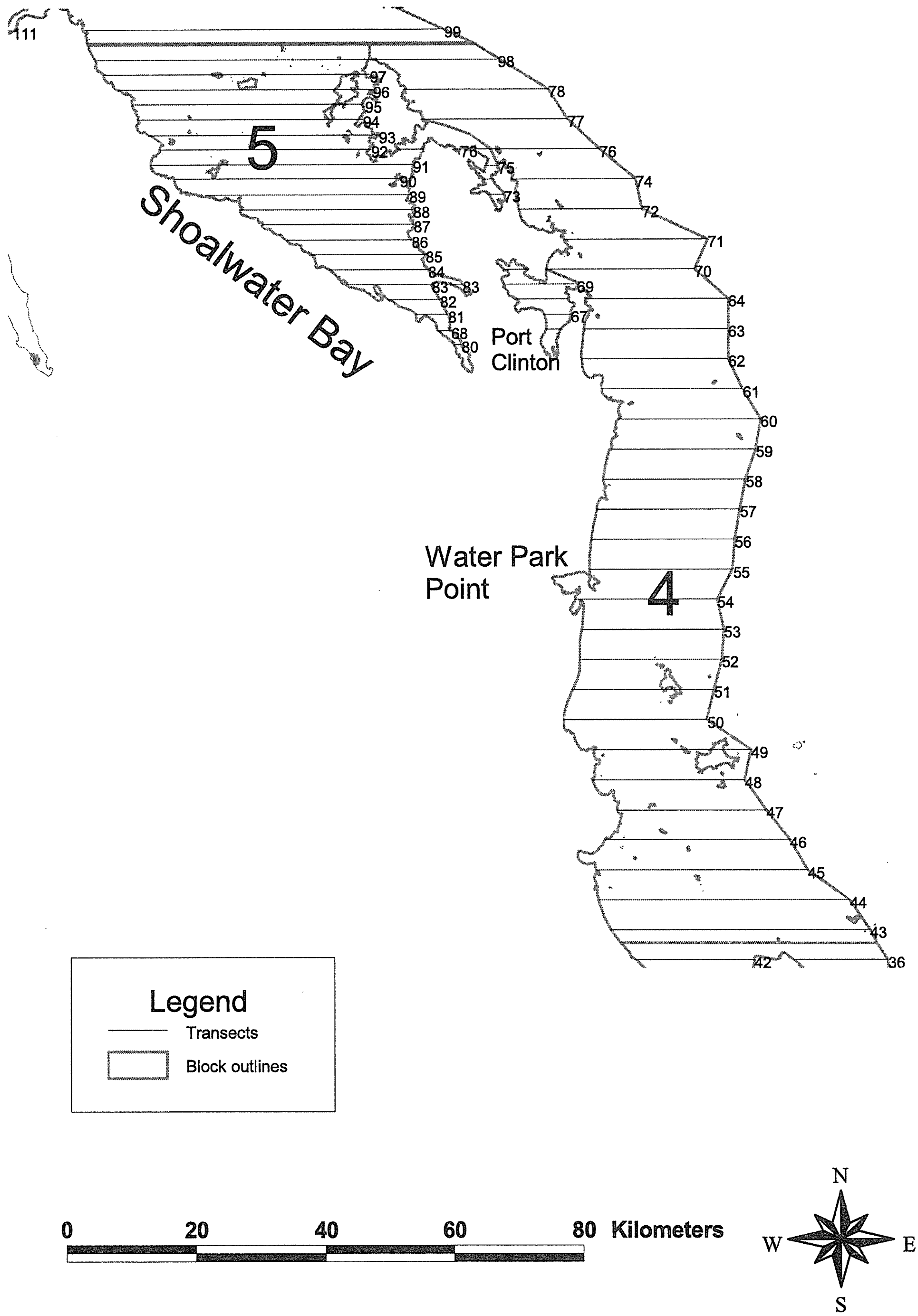

Figure 1d. Positions of blocks S4 and S5, and transects contained within, in the Southern Section of the Great Barrier Reef region, from Shoalwater Bay to the northern end of Curtis Island

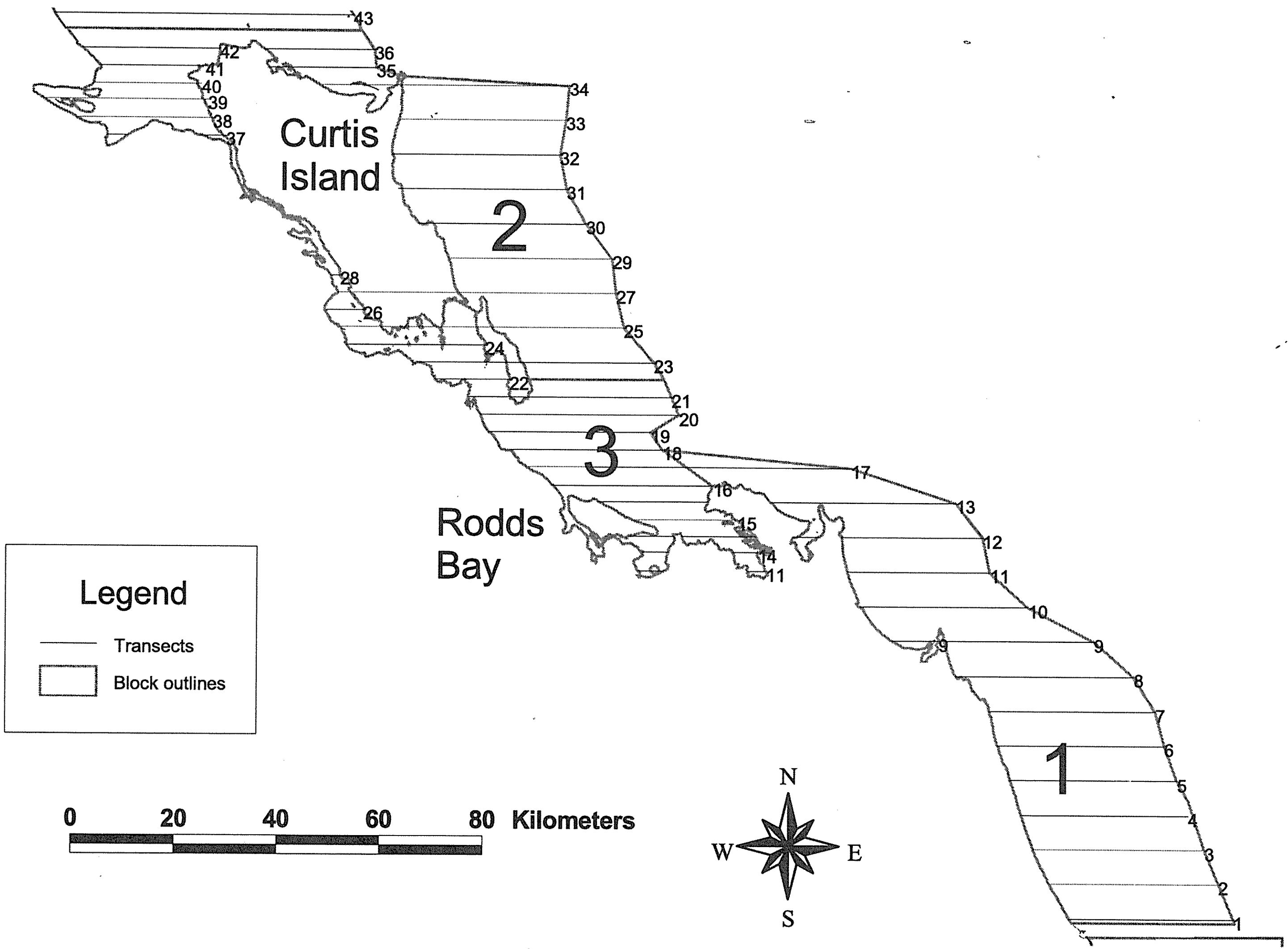

Figure 1e. Positions of blocks S1 to S3, and transects contained within, in the Southern Section of the Great Barrier Reef region, from Curtis Island to Baffle Creek

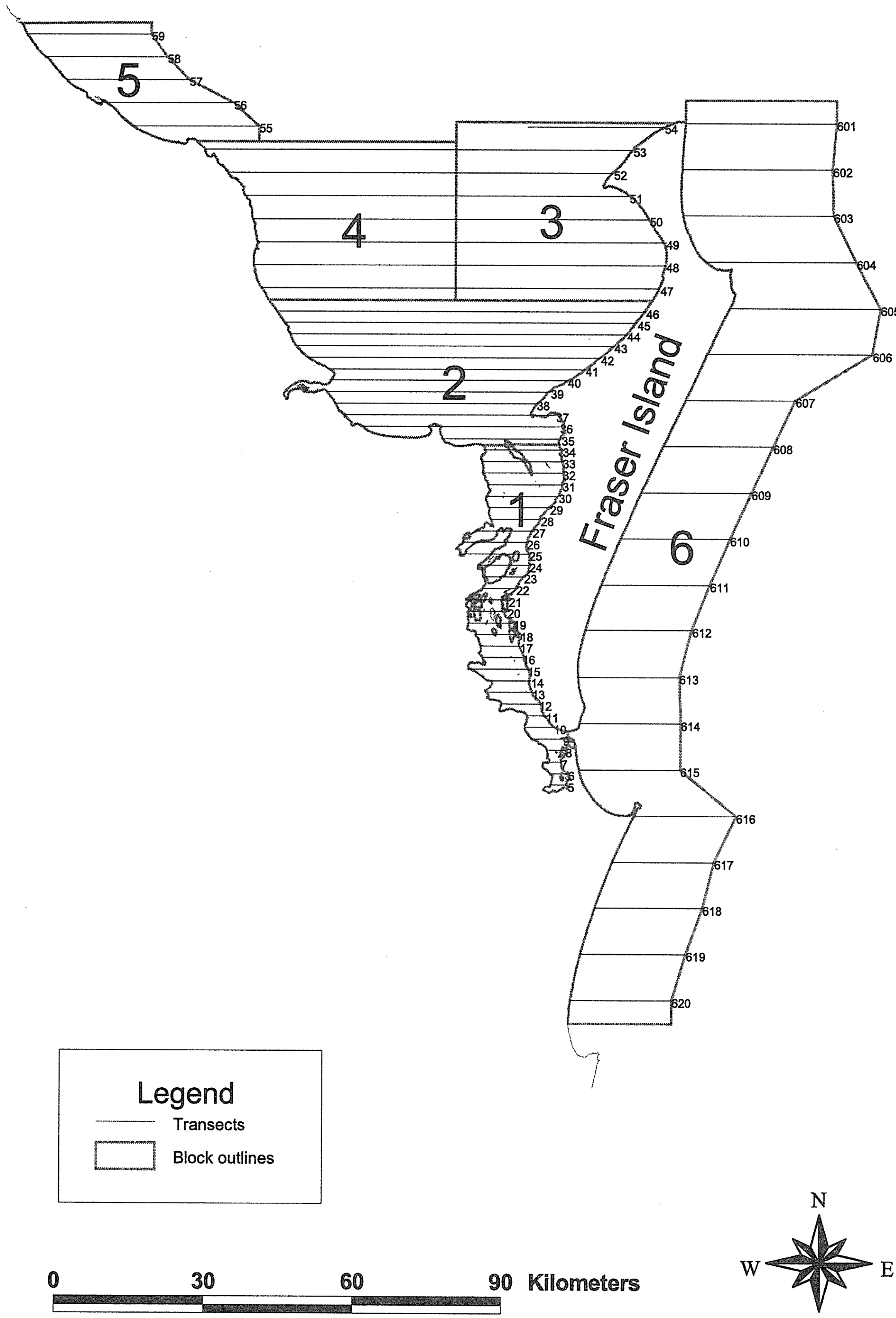

Figure 1f. Positions of blocks H1 to H5, and transects contained within, in the Hervey Bay/Great Sandy Straits region

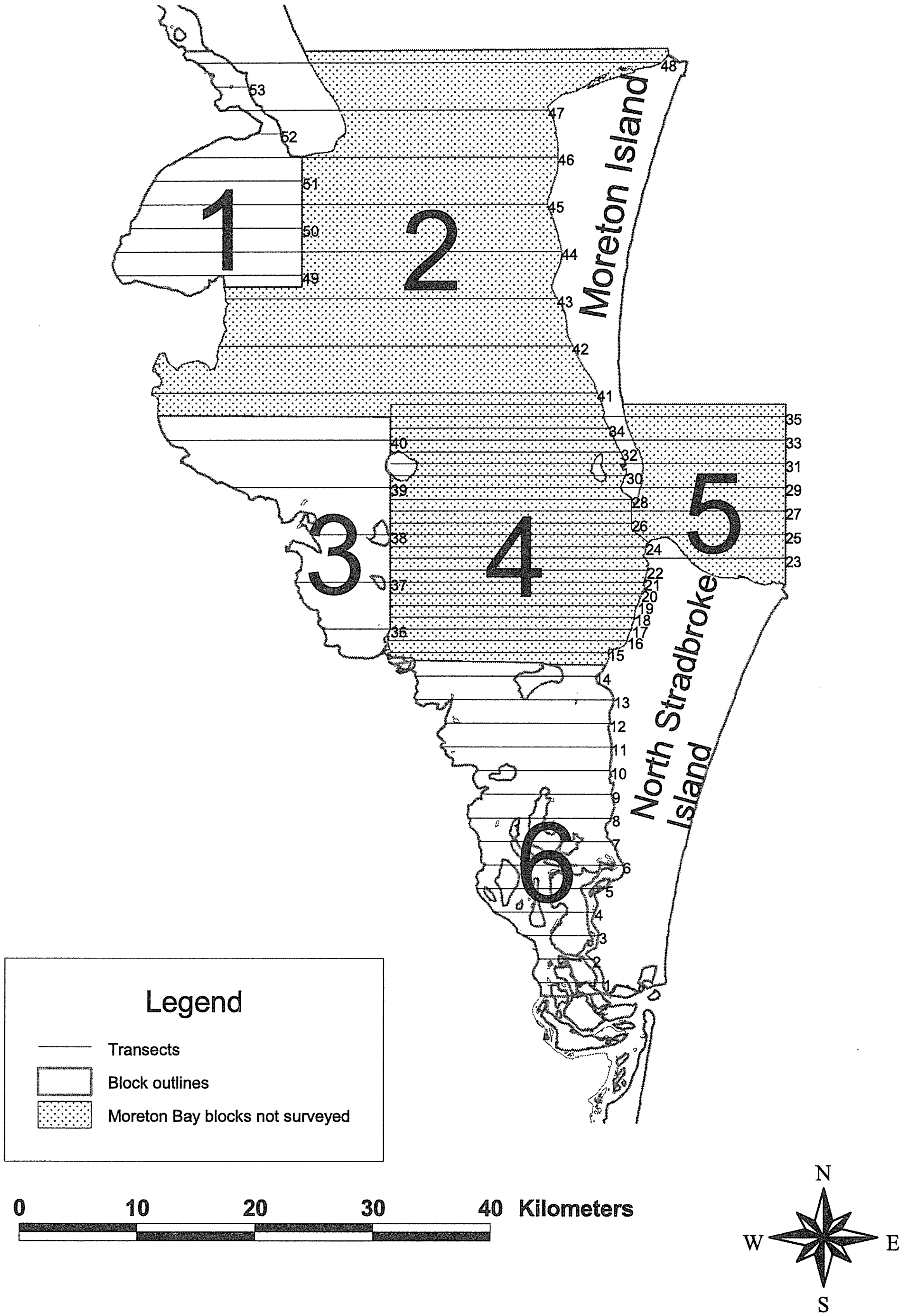

Figure 1g. Positions of blocks M1-M6, and transects contained within, in Moreton Bay

Table 1. Modification of the survey design[1] from previous surveys, mainly as a result of poor weather conditions encountered during the surveys.

Region	Block	Modification detail
Central GBR	Block C12 – abbreviated	only transcts 295–299 flown transects 298, 299 truncated to 12 nautical miles
	Block C2 omitted (outside Whitsundays)	
	Block C3 – transects added	four extra transects added interspaced between transects 169 and 180
Southern	Block S6 – abbreviated, split into two blocks	transects 100–109,119–124 omitted transects 125–130 truncated at 143°32' – new block S6A transects 110–118 truncated at 149°40' – new block S6B - A portion of this block (block S6C) was also surveyed during the Shoalwater Bay leg. It overlaps with block S6B
	Block S7	transects 135 truncated to 131 truncated to 12 nautical miles
	Block S8	Extra transects included between transects 139 and 143
Hervey Bay	Block H6	New block on east coast of Fraser Is and extending south to mainland[2]
Moreton Bay	Blocks M2, M4 and M5 omitted	

[1]See figure 1(a-g) for positions of blocks and transects
[2]Added as per contract with QPWS

Poor weather also meant that the northern team was only able to survey the region from Innisfail south to Cape Upstart, from 14–17 November 1999. The transects from Innisfail to Cape Bedford were omitted from the survey. The region between Cape Upstart and Shoalwater Bay (referred to as the Whitsunday leg) was surveyed between 10 and 12 December 1999. Again, poor weather was a limiting factor, and parts of this section also had to be omitted to enable the region to be adequately sampled within logistical limitations. Small sections of the coast where dugongs have not previously been seen were omitted, as was the block on the eastern side of the Whitsunday Islands. Transects were shortened in some blocks so that effort could be focussed on areas of potentially good dugong habitat. Details of changes to the previous survey designs are provided in table 1. Weather conditions encountered during this and previous surveys of the region are summarised in table 2. The areas of the survey blocks and the intensity of the survey coverage are shown in table 3.

Correction Factors

Estimates of dugong abundance were obtained by correcting sightings for perception bias and availability bias *sensu* Marsh and Sinclair (1989a). Perception bias occurs when animals are visible in the survey transect but missed by observers. A correction factor used to account for this bias is calculated using a modified Mark-Recapture model that is based on the proportion of animals seen by one or other, or both, observers (Marsh and Sinclair 1989a). Perception correction factors were calculated for each tandem team of observers. Unfortunately, the composition of some teams varied between survey legs because of the logistical difficulties described above and separate perception correction factors were calculated for each pair of observers.

Availability bias is corrected for by standardising the proportion of animals classified as 'at the surface' against the corresponding proportion in an earlier survey over very clear shallow water over white sand which enabled all animals in the survey area to be seen (Marsh & Sinclair 1989a). This approach makes the untested assumption that a constant proportion of animals is at the surface across all survey conditions. Availability correction factors were also estimated separately for different legs of the survey.

Population Estimation

Dugong abundance was estimated separately for each block in the survey area. As transects varied in length, and hence area, the Ratio Method was used to estimate density, population and associated errors (Jolly 1969; Caughley & Grigg 1981). The estimated standard errors incorporate the errors associated with the correction factors described above (Marsh & Sinclair 1989a).

Statistical Analysis

Differences in dugong density between this and previous surveys of the same region were tested using linear mixed effects models estimated by restricted maximum likelihood (REML). The (fixed) year effect was tested against the random year*block variation using density averaged across all transects within blocks (in this model the mean square error is equivalent to the year*block variation). The initial models also included Beaufort Sea State as a fixed factor, but its effect was found to be weak and was omitted from the final models.

Two analyses were conducted. The first compared the densities of dugongs in the blocks in the Great Barrier Reef Marine Park only for four surveys in 1987, 1992, 1994 and 1999. The second analysis also included Hervey Bay, but used data from 1994 and 1999 when the two areas were surveyed together for the first time. Data were ln (x+0.01) transformed to stabilise variances.

Table 2. Weather conditions encountered during the survey in comparison to previous surveys of the same areas

	SGBR Northern Sector[1]	SGBR Whitsunday Sector[2]	SGBR Shoalwater Bay Sector[3]	SGBR Southern Sector[4]	Southern GBR All sectors			Hervey Bay				Moreton Bay
Year of survey	1999	1999	1999	1999	1994	1992	1986–87	1999	1994	1993	1988	1999
Wind speed (km.h^{-1})	< 10	< 10	< 10	< 10	< 15	< 37	< 37	< 10	< 10	< 20	< 28	< 10
Cloud cover (oktas)	0–3	0–6	0–6	0–6	0–5	0–5	0–4	0	1–3	1–4	1–6	0–3
Minimum cloud height	3000	2500	2000	1500	2000-5000	2500	300	-	2000-5000	460-1800	610-2400	3500
Beaufort sea state (range)	1.45 (0–4)	1.55 (0–3)	1.87(0–4)	1.95 (0–3)	1.87 (0–4)	1.0 (0–4)	1.0 (0–3)	1.67 (0–4)	1.94 (1–3)	1.2 (0–3)	2.1 (0–4)	0.87 (0–3)
Glare[5]												
North	0.67	1.10	0.53	1.76	1.44			1.92	0.92			1.42
South	0.70	1.32	1.08	1.85	1.29			1.86	1.08			1.23
Overall	0.69	1.21	0.80	1.80	1.36	2	2	1.89		1.4	0.9 (0-3)	1.32
Visibility (km)	> 20	> 20	> 20	> 10	> 15	N/A	> 20	> 30	> 20	N/A		> 20

[1]Innisfail to Upstart Bay - Blocks C6–C12, C5 transects 213–231 (figure 1a, b)
[2]Cape Upstart to Clairview - Blocks S6A, B - S8, C1–C4, C5 transects 199–205 (figure 1b, c)
[3]Shoalwater Bay to approximately Great Keppel Island - Blocks S4, S5, S6C (figure 1c, d)
[4]Curtis Island to southern limit of GBRMP (approximately Baffle Creek) - Blocks S1–3 (figure 1e)
[5]Values for Beaufort sea state and glare are the mean of the modes for each transect.
[6]The scale for glare is: 0 - no glare, 1 - up to 25% of field of view affected by glare, 2 - 25–50% affected, 3 - > 50%

Table 3. Areas of survey blocks and sampling intensities

Block	Area (km²)	Sampling intensity (%)
	1999 (1994 if different)[1]	1999 (1994 if different)[1]
Southern section of SGBR		
S1	1390	9.57
S2	836	9.79
S3	1021	16.34
S4	3242	9.45 (11.4)
S5	1347	15.8
S6	Not done (6498)	Not done (8.4)
S6A	508	8.96
S6B	661	8.68
S6C	1633	8.55
S7	957 (1567)	9.37
S8	796	14.59 (9.36)
Central section of SGBR		
C1	371	16.4
C2		Not surveyed
C3	1733	17.05 (13.2)
C4	466	17.02
C5	2087	7.98
C6	244	18.03
C7	579	18.59
C8	620	18.83
C9	3829	8.66
C10	288	20.04
C11	756	16.95
C12A	713	8.59
Hervey Bay		
H1	517	18.87
H2	1414	15.17
H3	1232	8.07
H4	1246	8.20
H5	546	8.36
H6[2]	4090	4.3
Moreton Bay[2]		
M1	166	19.86
M3	188	10.05
M6	226	24.30

[1]In some blocks transects were added or modified leading to differences in the estimates of the area of the block and sampling intensity. See table 1 and figure 1a-g for details of these changes.
[2]Not surveyed in 1994.

RESULTS

Group Size and Composition

Southern Great Barrier Reef

A total of 198 dugongs were seen in the southern GBR in 123 groups (figure 3c-e). Of these, 35 (17.7%) were calves. Most of the dugongs (157) were seen in the Central Section of the GBR region (figure 3a, b) and 31 (19.7%) of these were calves. In contrast, the 41 dugongs seen in the Southern Section of the GBR (from south of Repulse Bay to Baffle Creek) (figure 3 c-e) comprised only four (9.8%) calves. There were 81 solitary animals, 28 pairs (17 cow-calf), six groups of three dugongs, three groups each of four and five animals and one group each of six and 10. The proportion of calves for the Southern Section is similar to the figures recorded in the 1994 survey (Central Section 10.3%, Southern Section 11.4%, overall for SGBR 10.8%). However, the proportion of calves sighted in the Central Section in 1999 was significantly higher than in the Southern Section (X^2=30.2, 1 df, p<0.001).

Two groups of dugongs were seen off transect in blocks 6A and 6B (figure 3c), but were not included in the population estimates. These groups were of approximately 15 and 25 animals respectively, though it was not possible to obtain total counts because of the turbid water.

Hervey Bay

One hundred and sixty-one dugongs were seen in Hervey Bay (figure 3f) of which 50 were solitary animals, 14 pairs (nine cow-calf), three groups each of three and four animals and one group each of eight, 10 and 44 animals. Seventeen calves were sighted at a percentage of 14.5% (excluding the group of 44 as it was not possible to determine a calf count for the herd). This is a substantially higher proportion of calves than were observed in 1994 (1.54%).

Moreton Bay

Twelve dugongs were seen (figure 3g), none of which was a calf. This was an inadequate sample of the population in Moreton Bay. Poor weather prohibited our surveying the most significant dugong habitats in the Bay, the sandbanks to the west of Stradbroke and Moreton Islands, blocks 4 and 5 (figure 1g) (Lanyon & Morrice 1997).

Dugong Abundance

Appendix table 2 contains the raw sighting data used in the population estimates. Appendix table 3 lists the data used to calculate the correction factors. The parameters used to estimate population size, mean group sizes and correction factors, are provided in table 4.

Southern Great Barrier Reef

The estimated size of the dugong population for this region in 1999 was 3993 dugongs (± 641 s.e.) (table 5). This is a significant increase in population since the previous survey in 1994 (when the population was estimated at 1682 ± 236 s.e.) but is not significantly different from the combined population estimates from the 1986–1987 surveys (table 6).

Comparison of the changes in population within blocks across the period covered by the surveys (figure 2a-c) shows that most of the increase has occurred in the Central Section of the GBR region, particularly the Hinchinbrook/Halifax bay region and Edgecumbe Bay/Whitsundays (figure 2a).

Based on the means of the population estimates, the only block in the Southern Section of the GBR to contribute more than 5% of the increase was Shoalwater Bay (9.5% of the total). Four of the remaining blocks in Southern Section had no dugongs seen on transect (though groups were seen off transect in blocks 6A and 6B), while the remainder showed little change (figure 2b).

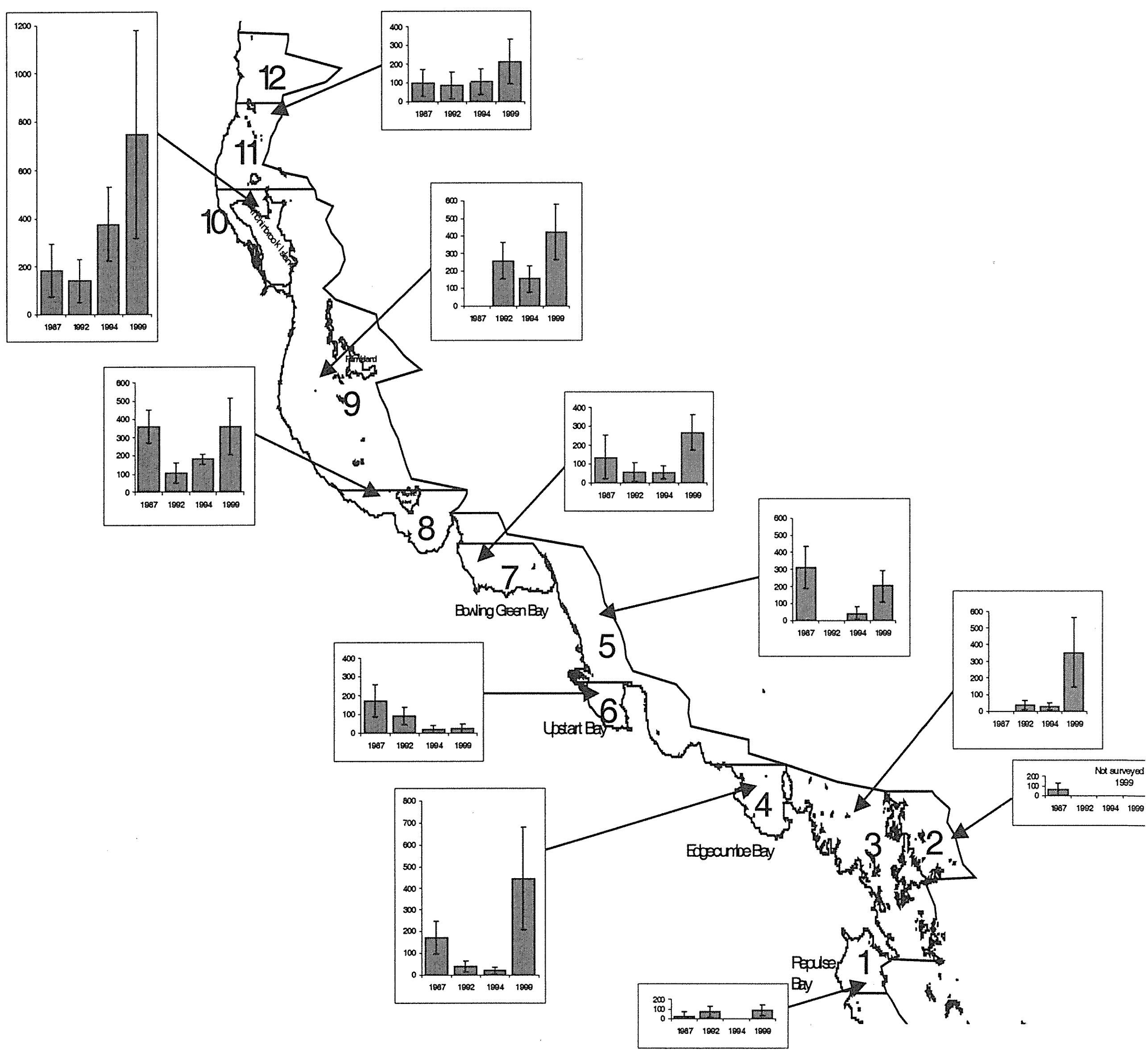

Figure 2a. Estimated dugong abundance for the Central Section of the Great Barrier Reef region for four consecutive surveys in 1986–1987, 1992, 1994 and 1999. Y axes show the estimated dugong population for the block ± s.e.

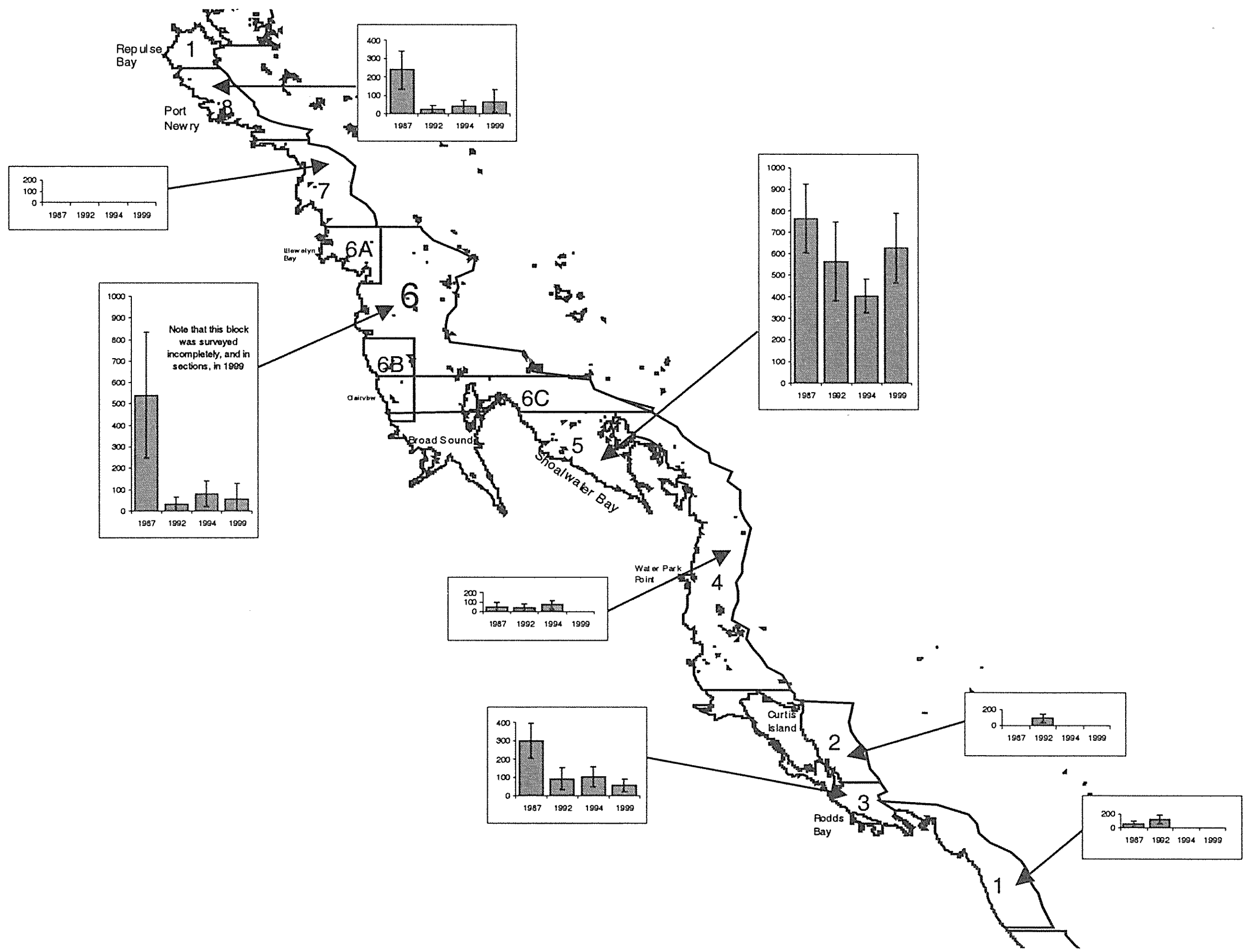

Figure 2b. Estimated dugong abundance for the Southern Section of the Great Barrier Reef region for four consecutive surveys in 1986–1987, 1992, 1994 and 1999. Y axes show the estimated dugong population for the block ± s.e.

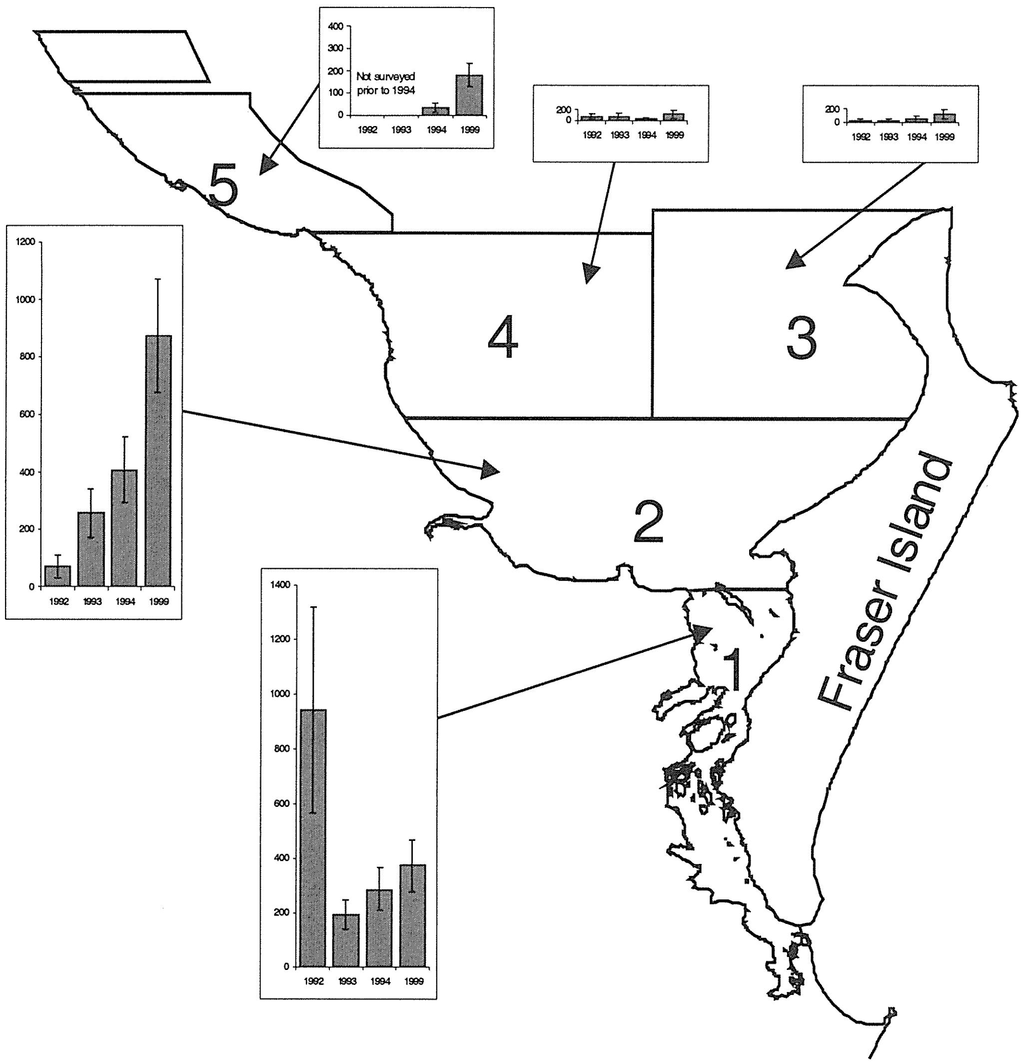

Figure 2c. Estimated dugong abundance for the Hervey Bay/Great Sandy Straits region for four consecutive surveys in 1992, 1993, 1994 and 1999. Y axes show the estimated dugong population for the block ± s.e. Note that block 6 (the eastern coast of Fraser Island) is not included in this figure as it was not surveyed prior to 1999 and there were no dugongs seen in 1999.

Table 4. Details of groups size estimates and correction factors used in the population estimates for dugongs in the 1999 survey of the southern Great Barrier Reef region and Hervey Bay.

Blocks: Transects	Group size (C.V)	Number of observers		Perception correction factor estimate (C.V)		Availability correction factor estimate (C.V)
		Port	Starboard	Port	Starboard	
Central section[1,5]						
1, 3, 4, 5:199–205	2.625 (0.588)	2	2	1.429 (0.277)	1.111 (0.088)	3.429 (0.168)
5:213–222, 230–231	1.385 (0.585)	2	2	1.013 (0.005)	1.032 (0.011)	3.300 (0.136)
6, 7, 8:232–235, 241, **9**:254–256, 259–272, **10, 11, 12**	1.382 (0.591)	2	2	1.013 (0.005)	1.032 (0.011)	3.216 (0.139)
8:236–240, 242–244, **9**:245–253, 258	1.382 (0.591)	1	1	1.074 (0.005)	1.308 (0.011)	3.216 (0.139)
Southern Section[2,5]						
1, 2 ,3	1.430 (0.708)	2	2	1.076 (0.03)	1.159 (0.060)	1.930 (0.169)
4, 5, 6C	1.676 (0.635)	2	2	1.222 (0.185)	1.095 (0.044)	2.352 (0.202)
6A, 6B, 7, 8	2.625 (0.588)	2	2	1.429 (0.277)	1.111 (0.088)	3.429 (0.168)
Hervey Bay[3,5]						
1, 2:43–46, **3-5**	1.430 (0.708)	2	2	1.076 (0.033)	1.159 (0.061)	1.930 (0.170)
2:35–42	1.430 (0.708)	1	1	1.188 (0.033)	1.636 (0.061)	1.930 (0.170)
Moreton Bay[4,5]						
1,3, 6	1.430 (0.708)	2	2	1.076 (0.033)	1.159 (0.061)	1.930 (0.170)

[1]Blocks labelled C in tables 1, 3 and 5
[2]Blocks labelled S in tables 1, 3 and 5
[3]Blocks labelled H in tables 1, 3 and 5
[4]Blocks labelled M in tables 1, 3 and 5
[5]See figures 1(a-g) for positions of blocks and transects

Table 5. Estimates of dugong numbers for each survey block in the region between Innisfail and Moreton Bay

Block	Population (s.e.)	**1986–1987** Population (s.e.)	**1992** Population (s.e.)	**1994** Population (s.e.)	**1999** Population (s.e.)
Population Southern Section					
S1		48 (46)	122 (71)	0	0
S2		0	94 (50)	0	0
S3		301 (95)	91 (60)	104 (56)	55 (37)
S4		51 (48)	42 (40)	67 (44)	0
S5		765 (161)	566 (185)	406 (78)	628 (162)
S6		542 (293)	34 (33)	82 (60)	
S6A					0
S6B					0
S6C					56 (72)
S7		0	0	0	0
S8		240 (104)	24 (22)	38 (37)	69 (63)
Central Section					
C1		31 (35)	70 (59)	0	90 (57)
C2		65 (69)	0	0	N/A
C3		0	35 (27)	27 (21)	353 (211)
C4		173 (77)	40 (24)	20 (17)	445 (236)
C5		312 (122)	0	44 (38)	203 (90)
C6		171 (87)	91 (46)	19 (19)	25 (26)
C7		136 (120)	58 (50)	54 (38)	270 (96)
C8		360 (92)	106 (56)	183 (29)	361 (157)
C9		0	257 (105)	157 (77)	424 (159)
C10		184 (110)	141 (89)	377 (154)	748 (432)
C11		100 (71)	86 (72)	107 (71)	213 (118)
C12A					52 (55)
Total		3479 (459)	1857 (292)	1682 (236)	3993 (641)
Hervey Bay	**1988**	**1992**	**1993**	**1994**	**1999**
H1	269 (147)	943 (377)	168-218 (52)	287 (79)	373 (96)
H2	1753 (388)	71 (40)	257 (85)	408 (115)	875 (196)
H3	151 (55)	21 (22)	22 (21)	49 (50)	113 (71)
H4	33 (32)	74 (50)	74 (74)	31 (22)	112 (76)
H5				32 (21)	180 (53)
H6					0
Total	2206 (420)	1109 (383)	579-629 (126)	807 (151)	1654 (248)
Moreton Bay				**1995**[1]	
M1				3.5 (2.3)	15 (14)
M2				3.6 (3.3)	
M3				3.7 (3.9)	30 (32)
M4				758.9 (407.6)	
M5				0	
M6				3.1 (3)	126 (67)
Total				772.8 (377)	171 (76)

[1]Data from estimate made in December 1995 by Lanyon & Morrice (1997)

Hervey Bay

The estimated numbers of dugongs in Hervey Bay in 1999 were significantly greater than in 1994 (tables 5 and 6, figure 2c). The total estimated dugong population for Hervey Bay in 1999 was 1654 (± 248 s.e.). The majority of this increase occurred in block 2. The next largest portion of the increase was in block 5 (the area of coast between Hervey Bay itself and the southern boundary of the GBRMP). The numbers of dugongs in the Great Sandy Straits (block 1) also increased slightly but there were still fewer dugongs in this region than in the first survey in 1992.

We also included transects along the east coast of Fraser Island and extending south along the mainland in 1999 (figure 1f, block 6). No dugongs were sighted in this region. This part of the survey was conducted in sub-optimal weather conditions.

Table 6. Summary of Restricted Maximum Likelihood (REML) analyses comparing dugong densities across consecutive surveys.

a. Comparison of dugong densities in the southern Great Barrier Reef region across surveys in 1986–1987, 1992, 1994 and 1999.

Term	df	SS	MS	F	p
Year	3	20.8812	6.960388	8.56950	0.0001
Block	16	112.9737	7.060854		
Year*Block	48	38.9870	0.812229		

b. Comparison of dugong densities in the southern Great Barrier Reef and Hervey Bay/Great Sandy Straits regions across surveys in 1994 and 1999.

Term	df	SS	MS	F	p
Year	1	15.05275	15.05275	31.09586	<0.0001
Block	21	79.851	3.8024		
Year*Block	21	10.16559	0.48408		

The model is parameterised as treatment contrasts, such that each year is compared to the first year. The error term is the year*block interaction.

Moreton Bay

As the survey was incomplete (figure 1g), it was not possible to estimate the total numbers of dugongs in Moreton Bay (table 5). Our total estimate was 171 ($\pm$ 76 s.e.), while Lanyon and Morrice (1997) estimated dugong numbers for the bay in December of 1995 at 773 ($\pm$ 377 s.e.), of which 759 ($\pm$ 408s.e.) were in block 4 which was not surveyed in 1999 due to poor weather.

Dugong Protection Areas (DPAs)

Within the Great Barrier Reef Marine Park, a mean estimate of 2073 dugongs (52% of the overall mean estimate) occurred in DPA A areas with a further 882 (22% of the overall mean) in areas zoned DPA B (table 7, figures 3a–e). All of the dugongs seen in the Southern Section of the GBR were inside DPAs. The most important DPAs in the GBR region are those in Shoalwater Bay and Hinchinbrook, which collectively accounted for over 40% of the dugongs in the region in 1999, and almost 80% of dugongs in Zone A DPAs.

In the Hervey Bay region, an estimated 72.5% of dugongs were within the DPA in November 1999. If only the Bay itself is considered (i.e. block 5 omitted) this figure increases to 83.4%.

Other Protection of Dugongs

In the Central Section of the GBR region approximately 62 dugongs (1.9% of the section estimate) were estimated to be in areas with current protection levels of General Use B or higher. The remaining 31% were in General Use A zones or outside of the GBR boundaries (figures 3a–e).

Within Hervey Bay, an estimated 288 dugongs (17.4%) were outside of the DPA, but within the boundaries of the Hervey Bay Marine Park (figure 3f).

Such estimates are not valid for Moreton Bay due to the inadequate sampling. The few dugongs seen were generally in habitat zones, apart from one sighting in the conservation zone near the southern end of North Stradbroke Island. This excludes consideration of the most significant dugong habitat, which is principally contained in the conservation zones surrounding the sand banks on either side of the South Passage.

Table 7. Percentages of dugongs in southern GBR region and Hervey Bay region found in Dugong Protection Areas (DPAS) in 1999 based on mean population estimates.

Region	DPA A	% of dugongs in GBR section	% of dugongs in total SGBR	DPA B	% of dugongs in GBR section	% of dugongs in total SGBR
Central	Hinchinbrook	31.1	24.8	Lucinda	1.7	1.4
	Cleveland Bay	11.0	8.7	Bowling Green Bay	8.5	6.8
	Upstart Bay	0.8	0.6	Edgecumbe Bay	14.0	11.1
				Repulse Bay	0	0
	Total	42.9	34.2	**Total**	24.2	19.3
Southern	Newry Region	8.5	1.7	Sand Bay	0	0
	Ince Bay	0	0	Llewellyn Bay	0	0
	Shoalwater Bay	77.6	15.7	Clairview Region	7.0	1.41.4
				Rodds Bay	6.9	2.8
	Total	86.1	17.4	**Total**	13.9	
	Overall SGBR total		51.6			21.7
Hervey Bay			72.5			
Grand Total (SGBR + Hervey Bay			58.3			15.8

Table 8. The estimated proportion of dugongs occurring in DPAs in the southern GBR on the basis of the large-scale surveys conducted in 1992, 1994 and 1999 based on mean population estimates. The data for 1986–1987 have not been included as the survey was conducted over two years.

	Estimated proportion of dugongs in DPA As	Estimated proportion of dugongs in Shoalwater and Hinchinbrook DPA As	Estimated proportion of dugongs in DPA Bs
1992 survey[1]	50	38	10
1994 survey[1]	61	47	11
1999 survey	52	41	22

[1] [Marsh 2000]

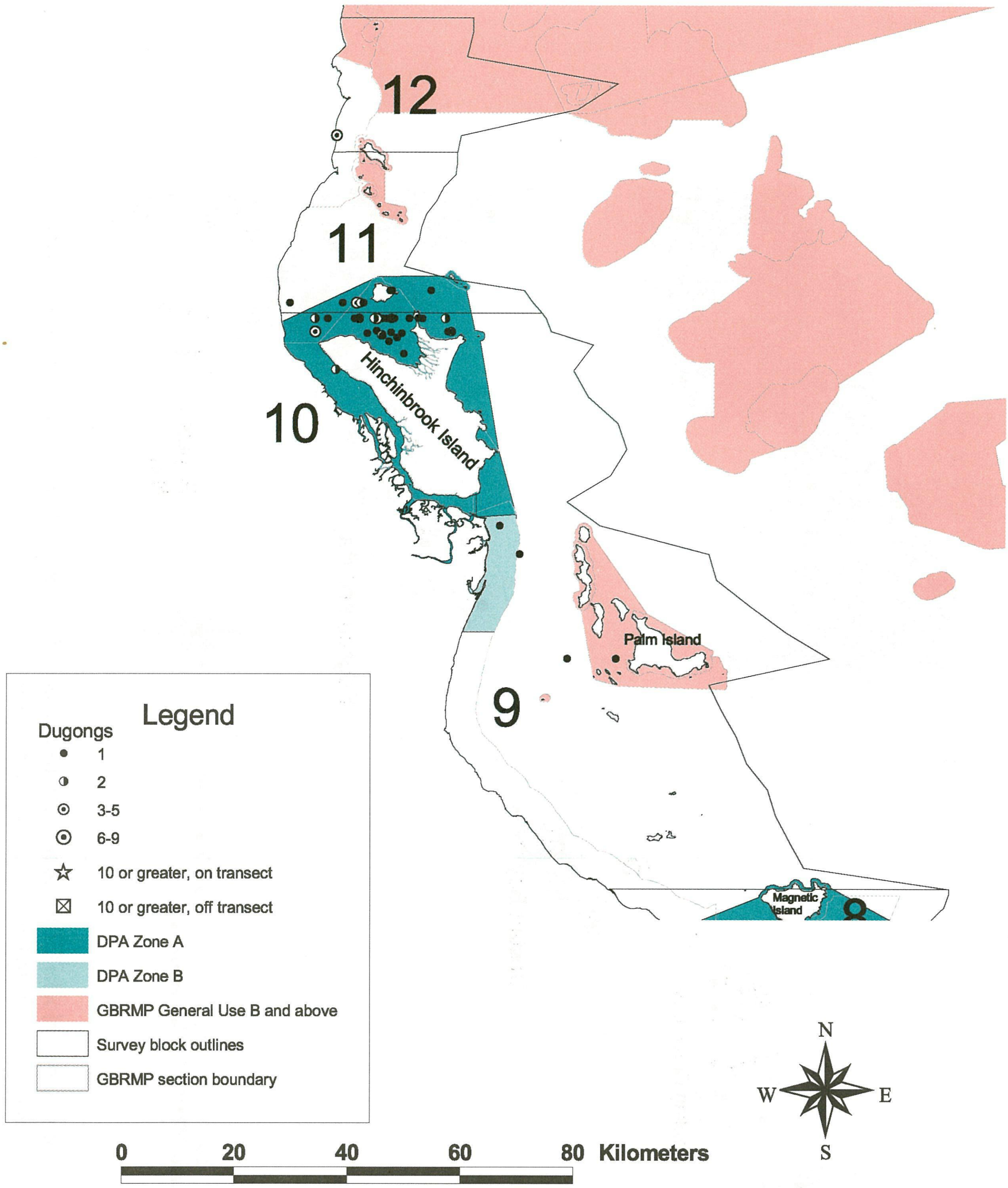

Figure 3a. Positions of dugong sightings in blocks C9 to C12 relative to Dugong Protection Areas and region zoning in the Central Section of the Great Barrier Reef region, from Innisfail to Magnetic Island

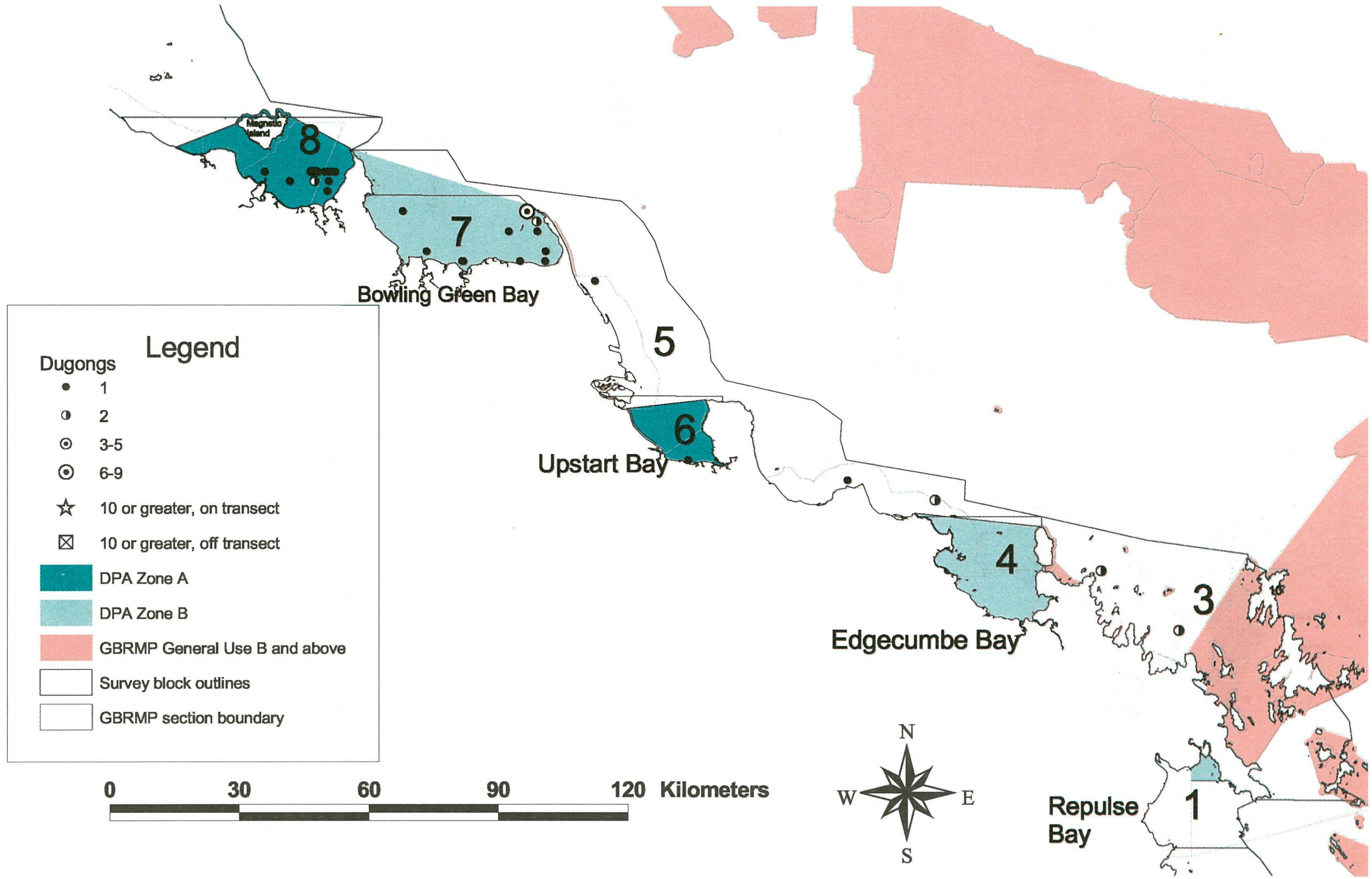

Figure 3b. Positions of dugong sightings in blocks C1 to C8 relative to Dugong Protection Areas and region zoning in the Central Section of the Great Barrier Reef region, from Cleveland Bay to Repulse Bay

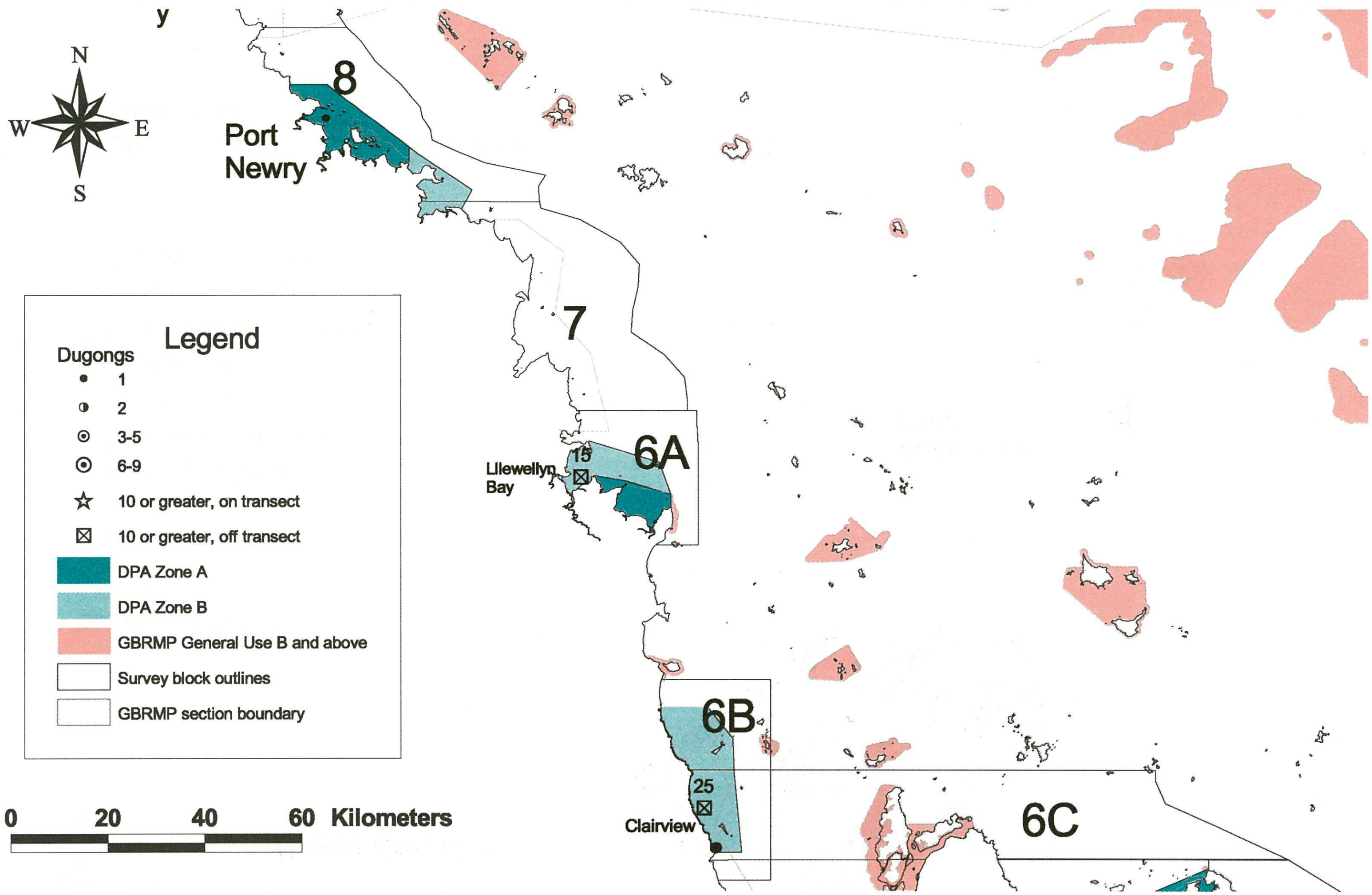

Figure 3c. Positions of dugong sightings in blocks S6 to S8 relative to Dugong Protection Areas and region zoning in the Southern Section of the Great Barrier Reef region, from the Newry Region to Clairview

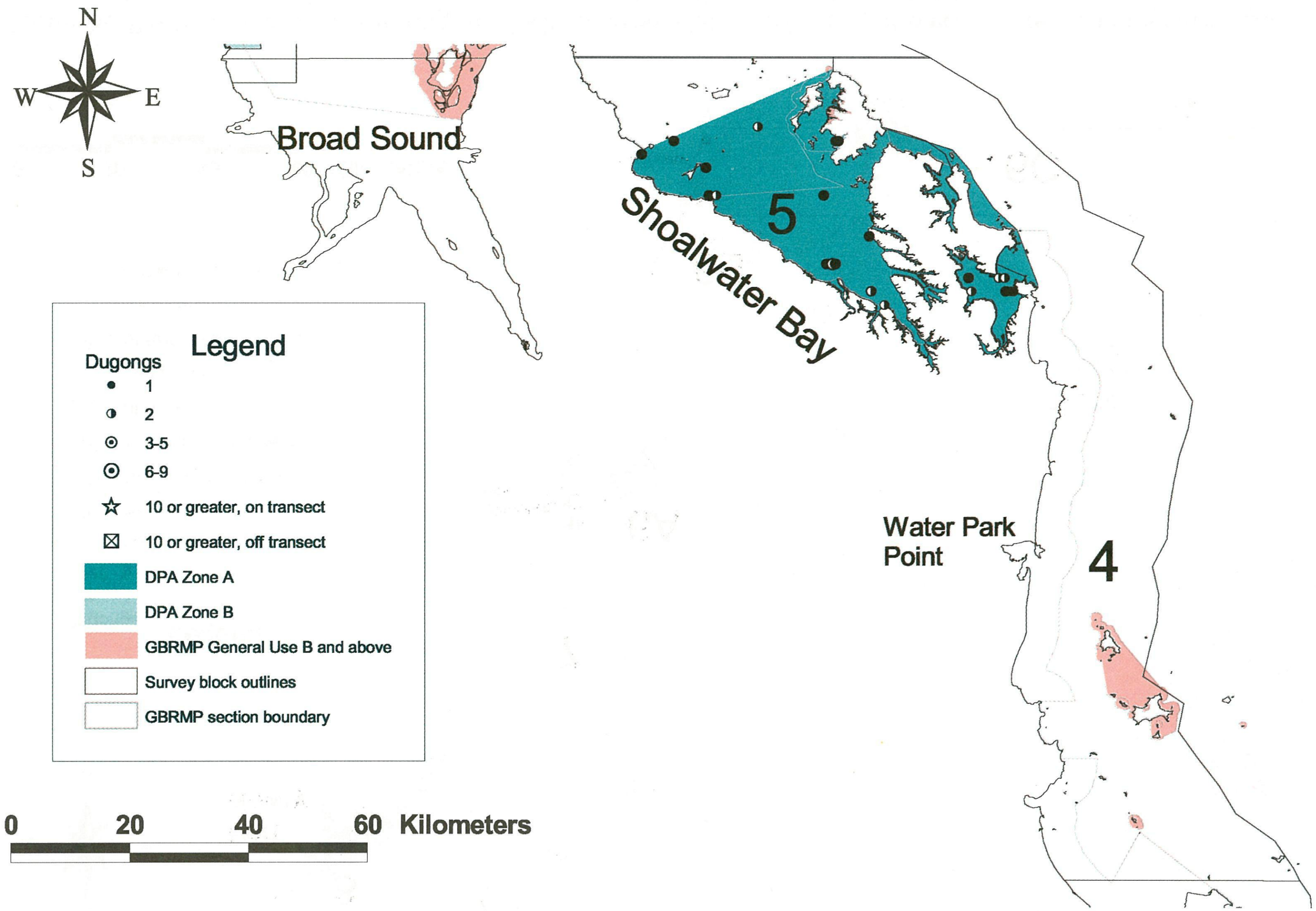

Figure 3d. Positions of dugong sightings in blocks S4 and S5 relative to Dugong Protection Areas and region zoning in the Southern Section of the Great Barrier Reef region, from Shoalwater Bay to the northern end of Curtis Island

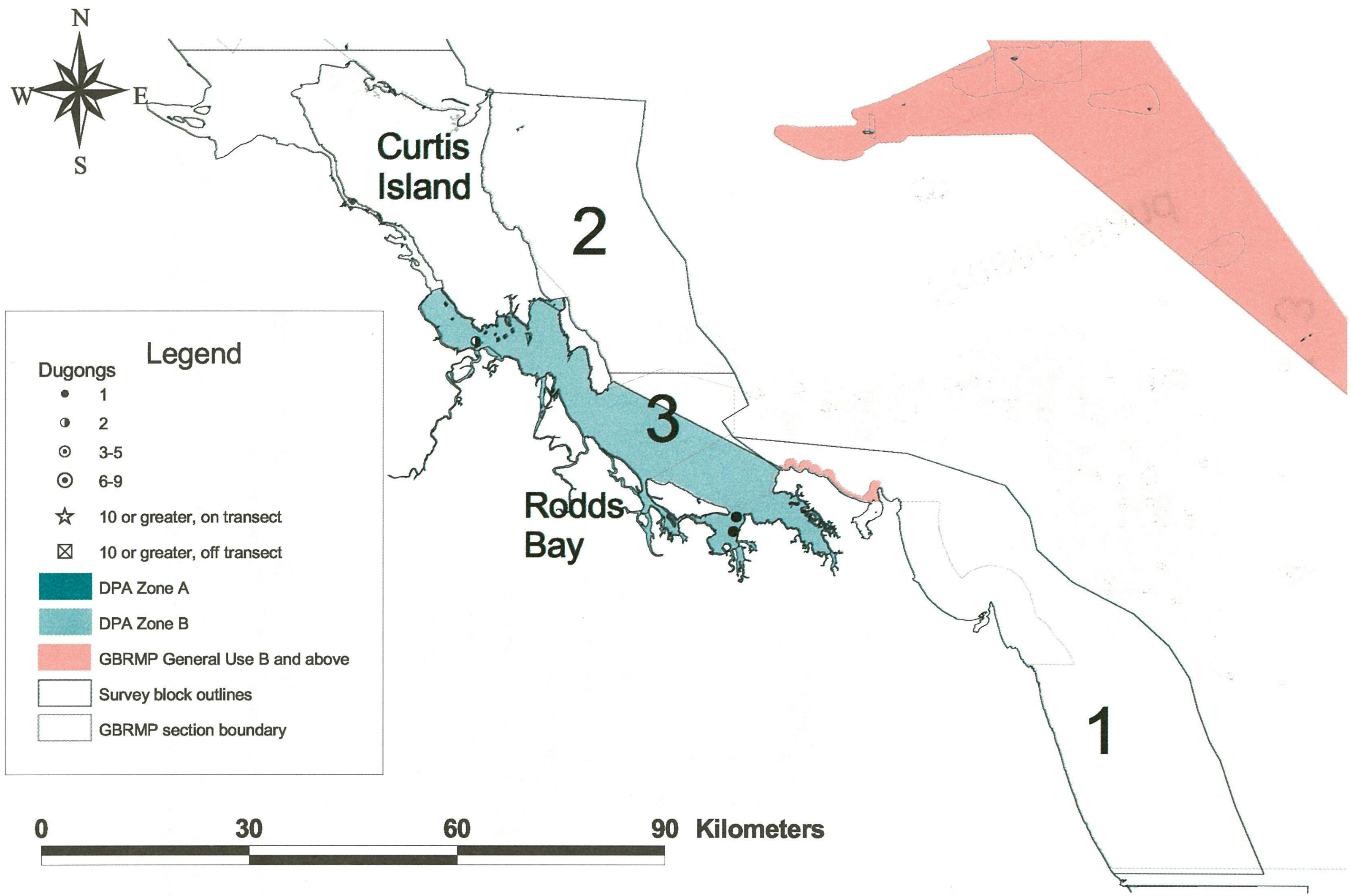

Figure 3e. Positions of dugong sightings in blocks S1 to S3 relative to Dugong Protection Areas and region zoning in the Southern Section of the Great Barrier Reef region, from Curtis Island to Baffle Creek

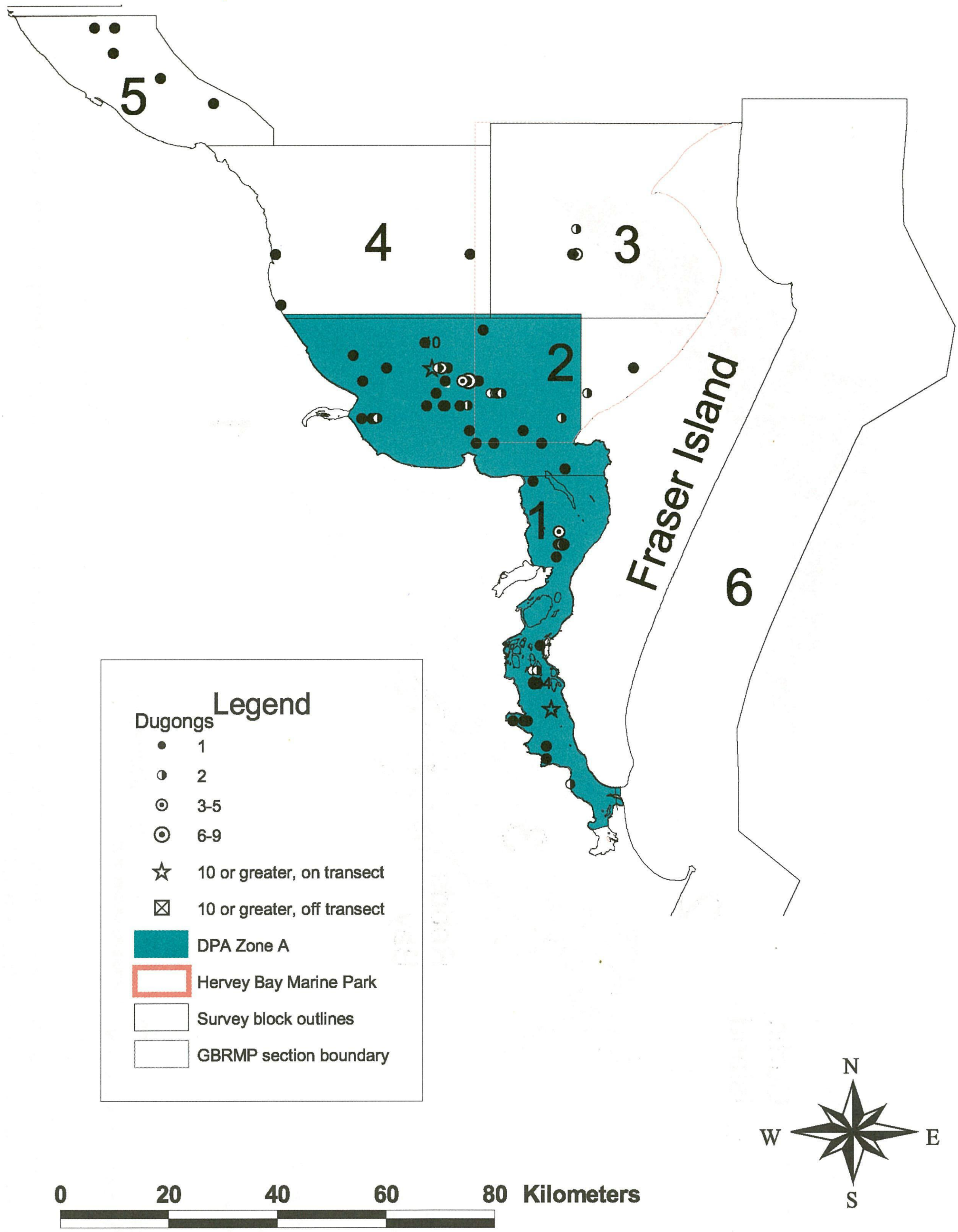

Figure 3f. Positions of dugong sightings in blocks H1 to H5 relative to Dugong Protection Areas and Marine Park zoning in the Hervey Bay/Great Sandy Straits region.

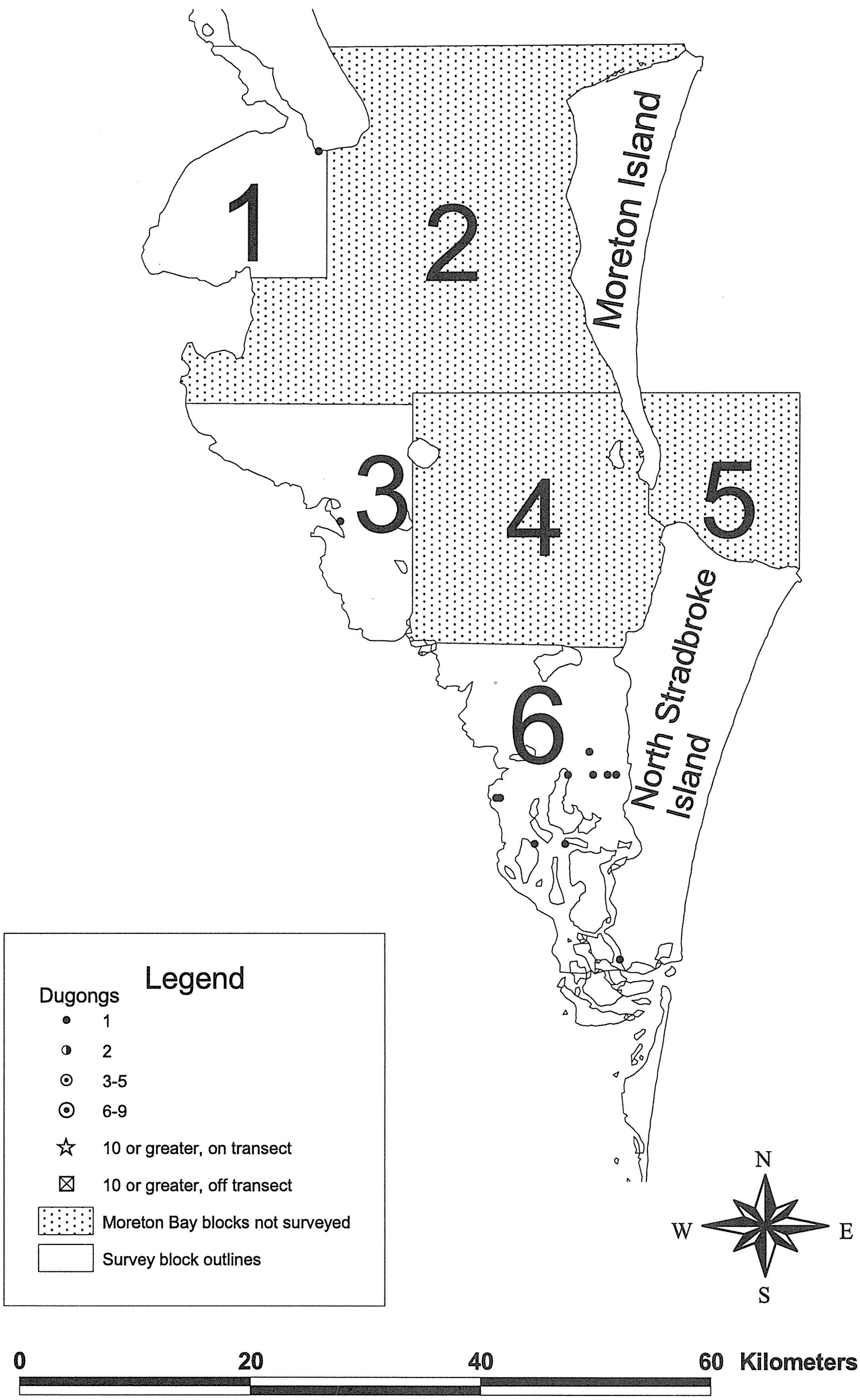

Figure 3g. Positions of dugong sightings in blocks M1–M6 in Moreton Bay

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 ($\pm$ 641 s.e), which is significantly higher than the corresponding estimate in 1994 (1682 $\pm$ 236 s.e) but not significantly different from that obtained in 1986–1987 of 3479 ($\pm$ 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 ($\pm$ 248 s.e), also significantly higher than the corresponding estimate in 1994 (807 $\pm$ 151 s.e). It was however, lower than the 1988 estimate of 2206 ($\pm$ 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 $\pm$ 0.170s.e.) than in 1994 (0.8903 $\pm$ 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 ($\pm$ 154s.e.) to 748 ($\pm$ 432s.e.) from 1994 to 1999. The availability correction factor was significantly larger in 1999 (3.216 $\pm$ 0.139) than in 1994 (2.4706 $\pm$ 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 <u>not</u> 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.

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APPENDIX

Appendix Table 1. Beaufort sea state and glare for each transect. See figure 1a-g for transect locations.

Glare scale: 0 - no glare
1 - 0#25%
2 - 25#50%
3 - >50%

	Beaufort			**Glare**					
					North			**South**	
	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
Southern GBR									
1	2	2	2	1	1	1	2	2	2
2	2	2	2	2	2	2	2	2	2
3	1	2	1	1	1	1	2	2	2
4	2	2	2	2	2	2	2	2	2
5				1	1	1	2	2	2
6	2	2	2	2	2	2	2	2	2
7	2	2	2	2	2	2	1	1	1
8	2	2	2	2	2	2	2	2	2
9	2	2	2	1	1	1	2	2	2
10	2	2	2	2	2	2	2	2	2
11	2	2	2	2	2	2	2	2	2
12	1	2	1	1	3	2	1	1	1
13	1	2	1	1	2	1	1	2	1
14	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1
16	2	2	2	2	2	2	1	1	1
17	2	2	2	2	3	2	2	2	2
18	3	3	3	3	3	3	1	1	1
19	3	3	3	3	3	3	2	2	2
20	3	3	3	3	3	3	1	1	1
21	3	3	3	3	3	3	3	3	3
22	2	2	2	2	2	2	1	2	1
23	3	3	3	3	3	3	1	1	1
24				2	2	2	1	1	1
25	1	3	1	1	3	2	1	3	1
26	1	1	1	1	1	1	1	1	1
27	1	3	1	1	3	1	1	1	1
28	1	1	1	1	1	1	1	1	1
29	3	3	3	3	3	3	3	3	3
30	3	3	3	3	3	3	3	3	3
31	3	3	3	2	2	2	3	3	3
32	3	3	3	3	3	3	3	3	3
33	3	3	3	2	2	2	3	3	3
34	2	3	2	2	2	2	2	3	2
35	3	3	3	1	1	1	2	2	2
36	3	3	3	3	3	3	2	3	2
37	1	1	1	2	2	2	2	2	2
38	1	1	1	2	2	2	2	2	2
39	1	2	1	1	1	1	1	1	1
40	1	1	1	1	1	1	2	2	2
41	1	1	1	1	3	1	1	2	1
42	2	2	2	0	1	0	1	1	1
43	2	3	2	1	1	1	2	2	2
44	2	3	2	2	3	2	2	3	3

	Beaufort			Glare					
					North			South	
	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
45	2	3	2	2	3	2	1	2	1
46	2	2	2	3	3	3	3	3	3
Shoalwater									
47	2.5	3	2.5	2	2	2	1	1	1
48	1	3	2	2	2	2	1	1	1
49	2	2.5	2	2	2	2	1	1	1
50	2	3	2	1	1	1	1	1	1
51	2	3	2	2	2	2	1	1	1
52	2.5	3	2.5	2	2	2	1	1	1
53	2	3	3	2	2	2	1	1	1
54	2.5	2.5	2.5	1	2	1	1	1	1
55	2	3	3	2	2	2	1	1	1
56	2.5	2.5	2.5	2	2	2	1	1	1
57	2.5	3	2.5	2	2	2	1	1	1
58	2	2.5	2.5	2	2	2	1	1	1
59	1	1	1	0	0	0	1	1	1
60	0.5	1	1	1	1	1	0	0	0
61	1	1	1	1	1	1	1	1	1
62	1	1	1	1	1	1	0	0	0
63				1	1	1	1	1	1
64	0	0	0	1	1	1	0	0	0
68	1	1	1	1	1	1	0	0	0
69	1	2	1						
70	2	3	2	1	1	1	0	1	0
71	2	2	2	1	1	1	0	0	0
72	1	2	2	1	1	1	0	1	0
73	1	1	1	0	0	0	0	0	0
74	1	2	2	1	1	1	0	0	0
75	1	1	1	1	1	1	0	0	0
76	1	2	1	1	1	1	1	1	1
77	2	2.5	2	0	1	0	1	1	1
78	2	2	2	1	1	1	1	1	1
80	1	1	1	0	0	0	0	0	0
81	1	1	1	1	1	1	0	0	0
82	2	3	3	1	1	1	0	0	0
83	1	3	1	1	1	1	0	1	0
84	2	3	3	1	1	1	0	0	0
85	2	2	2	1	1	1	0	0	0
86	2	4	2						
87	2	3	2	1	1	1	1	1	1
88	2	3	3	1	1	1	0	0	0
89	2	3	3	1	1	1	0	0	0
90	1	3	1	0	0	0	1	1	1
91	1	3	1	1	1	1	0	0	0
92	1	3	3	1	1	1	1	1	1
93	1	3	3	0	0	0	0	0	0
94	2	3	3	1	1	1	1	1	1
95	2	2	2	0	1	0	1	1	1
96	1	2	1	0	0	0	0	0	0
97	1	2	2	1	1	1	1	1	1
98	0	1	1	1	1	1	0	0	0
99	0.5	1	1	2	2	2	1	1	1
111	1	3	1						

	Beaufort			Glare					
					North			South	
	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
112a	0	1	0	1	1	1	0	0	0
112b	1	3	3	1	1	1	1	1	1
113a	2	3	3	1	2	1	0	1	0
113b	1	3	3	2	2	2	1	1	1
Whitsunday									
110	1	1	1	1	1	1	0	0	0
111	1	1	1	0	0	0	3	3	3
112	1	1	1	0	1	0	0	1	0
113	1	1	1	1	1	1	2	2	2
114	1	1	1	1	1	1	1	1	1
115	1	1	1	1	1	1	1	1	1
116	1	1	1	1	1	1	1	1	1
117	1	1	1	1	1	1	2	2	2
118	1	1	1	1	2	1	1	2	1
125	1	1	1	2	2	2	2	2	2
126	1	1	1	2	3	2	1	1	1
127	1	1	1	2	3	2	3	3	3
128	1	1	1	1	3	1	2	2	2
129	1	1	1	2	3	2	3	3	3
130	1	1	1	2	2	2	2	2	2
131	1	1	1	2	3	2	3	3	3
132	1	1	1	2	2	2	1	3	1
133	1	1	1	2	2	2	1	2	1
134	1	1	1	1	2	1	1	2	1
135	3	3	3	1	1	1	2	2	2
136	3	3	3	2	3	2	1	1	1
137	3	3	3	1	1	1	2	2	2
138	3	3	3	3	3	3	2	2	2
139	3	3	3	2	2	2	2	2	2
140	3	3	3	2	2	2	2	2	2
141	3	3	3	2	2	2	3	3	3
142	3	3	3	1	1	1	2	2	2
143	2	3	2	1	2	1	3	3	3
144	2	2	2	1	1	1	3	3	3
145	2	3	2	3	3	3	1	1	1
146	2	2	2	1	1	1	3	3	3
147	1	1	1	2	2	2	1	1	1
148	1	1	1	0	1	0	0	3	0
149	1	1	1	1	1	1	1	1	1
150	0	1	0	0	1	0	0	2	2
151	0	1	0	0	0	0	0	0	0
152	0	2	0	1	1	1	1	2	1
153	0	1	1	2	2	2	1	1	1
154	1	1	1	1	1	1	2	2	2
155	1	1	1	1	2	1	1	1	1
156	1	1	1	1	1	1	2	2	2
157	1	3	1	0	0	0	1	1	1
158	1	2	1	0	0	0	2	2	2
161	1	2	1	1	1	1	1	1	1
162	1	2	1	0	0	0	2	2	2
163	2	2	2	2	2	2	1	1	1
164	1	1	1	0	0	0	1	1	1
165	1	2	1	0	0	0	2	2	2

	Beaufort			Glare					
				North			South		
	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
166	2	3	2	1	1	1	2	2	2
167	1	1	1	1	1	1	1	1	1
168	2	2	2	1	1	1	2	2	2
169	1	2	1	1	1	1	1	1	1
177	1	2	1	0	0	0	1	1	1
178	2	3	2	1	1	1	1	1	1
179	2	2	2	1	1	1	2	2	2
180	1	2	1	1	1	1	1	1	1
181	1	1	1	2	2	2	1	1	1
182	2	2	2	1	1	1	2	2	2
183	1	1	1	0	1	0	0	1	0
184	1	1	1	1	1	1	2	2	2
185	2	2	2	1	1	1	1	1	1
186	1	1	1	2	2	2	1	1	1
187	1	1	1	1	1	1	1	3	1
188	1	2	1	1	1	1	0	0	0
189	2	2	2	1	1	1	2	2	2
190	2	2	2	2	2	2	1	1	1
191	3	3	3	1	1	1	2	2	2
192	1	3	1	2	2	2	1	1	1
193	2	3	2	1	1	1	1	1	1
194				0	0	0	0	0	0
195	1	1	1	0	1	0	0	1	0
196	1	1	1	0	0	0	0	0	0
197	2	2	2	0	0	0	0	1	0
198	2	2	2	0	0	0	0	0	0
199	2	2	2	1	1	1	2	2	2
200	2	2	2	0	0	0	1	1	1
201	2	2	2	0	0	0	0	0	0
202	2	2	2	0	0	0	0	0	0
203	2	2	2	0	0	0	1	1	1
204	2	2	2	0	0	0	1	1	1
205	2	2	2	0	0	0	0	0	0
1390	3	3	3	3	3	3	2	2	2
1400	3	3	3	3	3	3	2	2	2
1410	3	3	3	3	3	3	1	1	1
1420	3	3	3	3	3	3	2	2	2
1430	2	2	2	3	3	3	1	1	1
1690	1	2	1	0	0	0	1	1	1
1770				1	1	1	0	0	0
1780				1	1	1	1	1	1
1790	2	2	2	1	2	1	1	2	1
Northern									
206	1	1	1	1	1	1	1	1	1
207	1	2	1	1	1	1	0.5	0.5	0.5
208	2	3	2	1	1	1	1	1	1
209	3	3	3	2	2	2	1	1	1
210	2	3	2	1	1	1	1	1	1
211	1	3	1	1.5	1.5	1.5	2	2	2
212	2	3	2	1	1	1	1	2	1
213	2.5	3	2.5	1	1	1	1	1	1
214	2.5	3	2.5	2	2	2	1	1	1
215	2	3	3	1	1	1	1	1	1

	Beaufort			Glare					
					North			South	
	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
216	2.5	3	2.5	1	1	1	1	1	1
217	2	3	3	1	1	1	1	1	1
218	2.5	2.5	2.5	1	1	1	1	1	1
219	2.5	2.5	2.5	1	1	1	0	0	0
220	2.5	2.5	2.5	1	1	1	1.5	1.5	1.5
221	2	2.5	2	1	1	1	1	1	1
222	2	2	2	1	1	1	2	2	2
223	1	1	1	0	0	0	0	0	0
224	0	2	1	1	1	1	1	1	1
225	1	1	1	0	0	0	0	0	0
226	1	1	1	0	0	0	0	0	0
227	0.5	2	1	0	0	0	0	0	0
228	1	1	1	0	0	0	0	0	0
229	2	2	2	0	0	0	0	0	0
230	2	2	2	0	0	0	0.5	0.5	0.5
231	1.5	2	2	0	0	0	0	0	0
232	2	2	2	0	0	0	0	0	0
233	0	1	0	1	1	1	0	0	0
234	0	1	1	0	0	0	0	0	0
235	1	2	1	0	1	0	0	0.5	0
236	2	3	2	1	1	1	1	1	1
237	0.5	2	2	1	1	1	1	1	1
238	2	3	2	1	1	1	1	1	1
239	2	2	2	1	1	1	1	1	1
240	2	2	2	0.5	0.5	0.5	1	1	1
241	1	3	2	0.5	0.5	0.5	1	1	1
242	1	2	1	0	1	1	0.5	0.5	0.5
243	1	3	1	1	1	1	1	1	1
244	1	2	2	1	1	1	1	1	1
245	1	2	2	0	0	0	0.5	0.5	0.5
246	0	2	2	1	1	1	1	1	1
247	2	2	2	0	0	0	0	0	0
248	2	3	2	1	1	1	0.5	0.5	0.5
249	2	2.5	2	0	0	0	0	0	0
250	2	2.5	2	0	0	0	1	1	1
251	2	3	2	0	1	0	0	1	0
252	2	3	3	1	1	1	0.5	0.5	0.5
253	3	3	3	0	0	0	0	0	0
254	1.5	3	1.5	2	2	2	1	1	1
255	2	4	2.5	1	1	1	2	2	2
256	2	2.5	2	1	1	1	1	1	1
257	1	3	3	2	2	2	2	2	2
258	1	2.5	2.5	0	0	0	0	0	0
259	0	1	1	1	1	1	0	0	0
260	0	1.5	1	1	1	1	0	1	0
261	0	2	0	1	1	1	0	0	0
262	0.5	1.5	0.5	1	1	1	1	1	1
263	0	3	2	0	2	1	0	2	1
264	2	3	2.5	1	1	1	0	0	0
265	1	3	1	0	0	0	1	1	1
266	0.5	2	2	1	2	1	1	1	1
267	0.5	2	0.5	1	2	1	1	2	1
268	1	3	1	1	1	1	1	1	1
269	1	2	1	1	1	1	1	1	1

	Beaufort			Glare					
				North			South		
	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
270	0	1	0	0	0	0	0	0	0
271	0.5	2	1	1	1	1	1	1	1
272	0	1	1	0	0	0	0	0	0
273	1	3	1	1	2	1	1	2	1
274	0.5	2	1	1	1	1	1	1	1
275	0	1	0.5	1	1	1	1	1	1
276	0	1	0						
277	0	0.5	0	1	1	1	1	1	1
278	0	0.5	0	0	1	0	0	1	0
279	0	1	0	2	2	2	2	2	2
280	0.5	0.5	0.5	1	1	1	1	1	1
281	0.5	2	0.5	1	1	1	1	1	1
282	0	0	0	0	0	0	0	0	0
283	0	1	0	0	0	0	0	0	0
284	0	2	0	1	1	1	0	0	0
285	0	1	1	0	0	0	0	0	0
286	0	1	0	0	0	0	0	0	0
287	0	1	0	0	0	0	0	0	0
288	0	1.5	0	0	0	0	0	0	0
289	0	1.5	0	0	0	0	0	0	0
290	0	1.5	1	0	0	0	0	0	0
291	0.5	1.5	1.5	0	0	0	1	1	1
292	0.5	2	1.5	0	0	0	1	1	1
293	0	2	1.5	1	1	1	1	1	1
294	0.5	2	1	0	0	0	1	1	1
295	2	3	2	2	2	2	1	1	1
296	1	4	1	1	2	1	1	2	1
297	0	4	3	1	1	1	1	1	1
298	1	3	1	1	1	1	1	1	1
299	2	4	3	1	2	1	1	1.5	1
Hervey Bay									
5				1	2	1	1	1	1
6				1	1	1	1	1	1
7	1	1	1	2	2	2	1	1	1
8	1	1	1	1	1	1	1	1	1
9	1	1	1	2	2	2	1	1	1
10	1	1	1	2	2	2	1	1	1
11				1	1	1	1	1	1
12	1	1	1	1	2	1	1	1	1
13	1	1	1	1	1	1	1	1	1
14				2	2	2	1	1	1
15				1	2	1	1	1	1
16	1	1	1	1	1	1	1	1	1
17				1	2	2	1	2	1
18				2	2	2	1	1	1
19				2	2	2	1	1	1
20				1	2	1	1	1	1
21				1	2	1	1	1	1
22	1	1	1	1	2	1	1	1	1
23				1	1	1	1	1	1
24				1	1	1	1	1	1
25				1	1	1	1	1	1
26	1	1	1	1	2	1	1	2	1

	Beaufort			Glare					
					North			South	
	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
27				1	1	1	1	1	1
28	0	0	0	0	0	0	1	1	1
29									
30	0	0	0	1	1	1	1	1	1
31	0	0	0	1	1	1	1	1	1
32				1	1	1	1	1	1
33				1	1	1	1	1	1
34	0	0	0	1	1	1	1	1	1
35	0	0	0	2	2	2	2	2	2
36	1	1	1	0	1	1	0	1	0
37	1	1	1	0	3	0	1	2	1
38	1	1	1	1	1	1	0	1	1
39				0	1	0	1	1	1
40				1	1	1	1	1	1
41	1	1	1	1	2	1	1	1	1
42	1	1	1	1	1	1	1	1	1
43	0	1	0	0	1	1	1	1	1
44	1	1	1	1	1	1	1	1	1
45	1	1	1	1	1	1	1	1	1
46	1	1	1	1	2	2	1	1	1
47				1	1	1	1	1	1
48	1	1	1	2	2	2	1	1	1
49				1	2	1	2	2	2
50	1	3	1	1	2	1	1	1	1
51	1	3	2	2	2	2	1	2	2
52	1	2	1	1	2	1	1	1	1
53	1	2	1	1	1	1	2	2	2
54	1	1	1	1	1	1	1	2	1
55				1	2	1	1	1	1
56				1	1	1	2	2	2
57	2	2	2	1	2	1	1	2	1
58	2	2	2	1	1	1	2	2	2
59	2	2	2	2	2	2	2	2	2
601	3	4	3	3	3	3	3	3	3
602	3	3	3	3	3	3	3	3	3
603	3	3	3	3	3	3	3	3	3
604	3	3	3	3	3	3	3	3	3
605	3	3	3	3	3	3	3	3	3
606	3	3	3	3	3	3	3	3	3
607	3	3	3	3	3	3	3	3	3
608	3	3	3	3	3	3	3	3	3
609	3	3	3	3	3	3	3	3	3
610	3	3	3	3	3	3	3	3	3
611	3	3	3	3	3	3	3	3	3
612	3	3	3	3	3	3	3	3	3
613	3	3	3	3	3	3	3	3	3
614	3	3	3	3	3	3	3	3	3
615	3	3	3	3	3	3	3	3	3
616	3	3	3	3	3	3	3	3	3
617	3	3	3	3	3	3	3	3	3
618	2	2	2	3	3	3	3	3	3
619	2	2	2	3	3	3	3	3	3
620	2	2	2	3	3	3	3	3	3

	Beaufort			Glare					
					North			South	
	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
Moreton Bay									
1	0	0	0	1	1	1	1	1	1
2	0	0	0	0	0	0	1	1	1
3	0	0	0	1	1	1	1	1	1
4	0	0	0	0	0	0	1	1	1
5	0	0	0	1	1	1	1	1	1
6	0	0	0	0	0	0	1	1	1
7	0	0	0	1	1	1	1	1	1
8	0	0	0	1	1	1	1	1	1
9	0	0	0	1	1	1	1	1	1
10	0	0	0	1	1	1	2	2	2
11	0	1	0	1	1	1	0	2	0
12	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	2	1
36	0	0	0	0	0	0	1	1	1
37	1	1	1	1	1	1	1	1	1
38	1	1	1	1	1	1	1	1	1
39	1	1	1	1	1	1	1	1	1
40	1	2	1	1	2	2	1	2	2
41	2	2	2	1	2	1	1	1	1
42	1	2	2	1	2	1	1	2	1
43	1	3	1	1	2	1	1	2	1
44	2	2	2	1	3	1	1	3	3
45	1	1	1	2	3	2	1	3	1
46	2	2	2	2	3	2	1	3	3
47	2	2	2	3	3	3	3	3	3
48	1	3	1	2	3	3	3	3	3
49	2	2	2	2	3	2	3	3	3
50	2	2	2	2	3	2	2	2	2
51	2	2	2	2	3	2	1	3	1
52	1	1	1	2	2	2	2	2	2
53	1	1	1	1	1	1	1	1	1

Appendix Table 2. Raw data for sightings of dugong groups for each transect in each block used for population estimates.

Block, Transect Number	Adjusted transect height	Transect length (sea only)	Transect area (km^2)	# groups port	# groups starboard
Southern Section GBR					
S1					
1	450	22.2	8.9	0	0
2	450	22.9	9.2	0	0
3	450	22.9	9.2	0	0
4	450	22.3	8.9	0	0
5	450	22.2	8.9	0	0
6	450	22.3	8.9	0	0
7	450	22.1	8.8	0	0
8	450	23.7	9.5	0	0
9	450	27.0	10.8	0	0
10	450	22.5	9.0	0	0
11	450	22.2	8.9	0	0
12	450	24.7	9.9	0	0
13	450	29.5	11.8	0	0
17	450	26.1	10.4	0	0
S2					
23	450	22.2	8.9	0	0
25	450	22.2	8.9	0	0
27	450	21.3	8.5	0	0
29	450	22.0	8.8	0	0
30	450	22.5	9.0	0	0
31	450	22.5	9.0	0	0
32	450	22.5	9.0	0	0
33	450	22.5	9.0	0	0
34	450	27.0	10.8	0	0
S3					
11	450	10.2	4.1	0	0
12	450	18.5	7.4	1	0
13	450	14.8	5.9	0	0
14	450	17.0	6.8	1	0
15	450	13.7	5.5	0	0
16	450	21.5	8.6	0	0
17	450	22.2	8.9	0	0
18	450	20.4	8.2	0	0
19	450	21.7	8.7	0	0
20	450	26.7	10.7	0	0
21	450	27.2	10.9	0	0
22	450	9.9	4.0	0	0
23	450	9.3	3.7	0	0
24	450	18.5	7.4	1	0
25	450	16.7	6.7	0	0
26	450	5.0	2.0	0	0
27	450	1.9	0.8	0	0
28	450	1.3	0.5	0	0
34	450	8.0	3.2	0	0
35	450	14.4	5.8	0	0
36	450	14.8	5.9	0	0
37	450	15.9	6.4	0	0

Block, Transect Number	Adjusted transect height	Transect length (sea only)	Transect area (km^2)	# groups port	# groups starboard
38	450	18.3	7.3	0	0
39	450	22.1	8.8	0	0
40	450	14.5	5.8	0	0
41	450	14.1	5.6	0	0
42	450	18.5	7.4	0	0
S4					
43	450	40.3	16.1	0	0
44	450	39.0	15.6	0	0
45	450	32.9	13.2	0	0
46	450	28.6	11.4	0	0
47	450	23.1	9.2	0	0
48	450	23.7	9.5	0	0
49	450	24.4	9.8	0	0
50	450	22.2	8.9	0	0
51	450	21.9	8.8	0	0
52	450	22.0	8.8	0	0
53	450	22.0	8.8	0	0
54	450	22.0	8.8	0	0
55	450	22.2	8.9	0	0
56	450	22.2	8.9	0	0
57	450	22.2	8.9	0	0
58	450	22.2	8.9	0	0
59	450	22.5	9.0	0	0
60	450	22.1	8.8	0	0
61	450	21.8	8.7	0	0
62	450	27.5	11.0	0	0
620	450	37.3	14.9	0	0
64	450	22.0	8.8	0	0
70	450	29.5	11.8	0	0
71	450	22.2	8.9	0	0
72	450	22.5	9.0	0	0
73	450	2.3	0.9	0	0
74	450	1.9	0.8	0	0
75	450	23.6	9.4	0	0
76	450	31.5	12.6	0	0
77	450	22.6	9.0	0	0
78	450	22.5	9.0	0	0
98	450	23.3	9.3	0	0
S5					
68	450	2.1	0.8	0	0
79	450	3.6	1.4	0	0
80	450	1.1	0.4	0	0
81	450	5.0	2.0	1	0
82	450	8.2	3.3	2	0
83	450	18.1	7.2	0	0
84	450	15.3	6.1	1	2
85	450	17.7	7.1	0	0
86	450	19.3	7.7	0	1
87	450	23.8	9.5	0	0
88	450	26.7	10.7	0	0
89	450	31.6	12.6	0	3
90	450	35.0	14.0	0	0
91	450	40.6	16.2	1	0

Block, Transect Number	Adjusted transect height	Transect length (sea only)	Transect area (km^2)	# groups port	# groups starboard
92	450	32.8	13.1	1	0
93	450	35.7	14.3	0	3
94	450	34.9	14.0	0	1
95	450	36.1	14.4	0	0
96	450	39.5	15.8	0	0
97	450	41.2	16.5	0	0
98	450	39.0	15.6	0	0
64	450	8.1	3.2	4	0
67	450	4.4	1.8	0	0
69	450	10.9	4.4	1	2
S6A					
125	450	6.3	2.5	0	0
126	450	13.9	5.6	0	0
127	450	25.2	10.1	0	0
128	450	25.3	10.1	0	0
129	450	20.8	8.3	0	0
130	450	22.2	8.9	0	0
S6B					
110	450	10.6	4.2	0	0
111	450	11.2	4.5	0	0
112	450	12.8	5.1	0	0
113	450	15.0	6.0	0	0
114	450	15.1	6.1	0	0
115	450	17.1	6.8	0	0
116	450	19.5	7.8	0	0
117	450	20.9	8.4	0	0
118	450	21.2	8.5	0	0
S6C					
99	450	56.0	22.4	0	0
110	450	42.3	16.9	0	0
111	450	47.3	18.9	1	0
112	450	105.8	42.3	0	0
113	450	97.8	39.1	0	0
S7					
131	450	22.4	8.9	0	0
132	450	22.4	8.9	0	0
133	450	22.3	8.9	0	0
134	450	22.4	8.9	0	0
135	450	22.4	8.9	0	0
136	450	22.5	9.0	0	0
137	450	22.1	8.8	0	0
138	450	22.6	9.0	0	0
139	450	22.9	9.2	0	0
S8					
147	450	22.0	8.8	0	0
146	450	23.0	9.2	0	0
145	455	22.9	9.3	0	0
144	450	20.2	8.1	0	0
143	450	22.1	8.8	0	0
142	450	27.7	11.1	0	0
141	450	23.0	9.2	0	0
140	450	23.3	9.3	0	0
1390	450	20.4	8.1	0	0

Block, Transect Number	Adjusted transect height	Transect length (sea only)	Transect area (km^2)	# groups port	# groups starboard
1400	450	23.5	9.4	0	0
1410	450	17.7	7.1	0	0
1420	450	21.1	8.4	0	0
1430	450	23.3	9.3	0	1
Central Section GBR					
C1					
148	450	39.6	15.8	0	0
149	450	38.6	15.4	1	0
150	450	3.5	1.4	0	0
151	450	9.7	3.9	0	0
152	450	10.6	4.2	0	0
153	450	9.1	3.6	0	0
154	450	6.2	2.5	0	0
155	450	3.2	1.3	0	0
156	450	12.1	4.8	0	0
C2 - Not surveyed					
C3					
157	450	22.7	9.1	0	0
158	450	17.3	6.9	0	0
161	450	19.4	7.8	0	0
162	450	20.6	8.2	0	0
163	450	23.4	9.4	0	0
164	450	19.5	7.8	0	0
165	450	29.2	11.7	0	0
166	450	20.9	8.4	0	0
167	450	25.1	10.0	0	0
168	450	8.5	3.4	0	0
169	450	26.7	10.7	0	0
177	450	14.7	5.9	0	0
178	450	30.9	12.4	0	0
179	450	39.9	16.0	0	0
180	450	43.2	17.3	0	0
181	450	34.9	14.0	0	0
182	450	35.5	14.2	0	0
183	450	38.8	15.5	0	0
184	450	5.1	2.0	0	0
185	450	38.4	15.4	0	0
186	450	49.9	20.0	0	1
187	450	46.1	18.4	3	0
188	450	22.7	9.1	0	0
1690	450	18.0	7.2	0	0
1770	450	21.5	8.6	0	0
1780	450	29.2	11.7	0	0
1790	450	37.0	14.8	0	1
C4					
189	450	13.0	5.2	0	0
190	450	18.5	7.4	0	0
191	450	17.5	7.0	0	0
192	450	18.4	7.4	0	0
193	450	21.0	8.4	1	3
194	450	24.7	9.9	1	1
195	450	21.4	8.6	0	0

Block, Transect Number	Adjusted transect height	Transect length (sea only)	Transect area (km^2)	# groups port	# groups starboard
196	450	20.1	8.0	0	0
197	450	23.4	9.4	0	0
198	450	20.3	8.1	0	1
C5					
199	450	22.1	8.8	0	1
200	450	9.6	3.8	0	0
201	450	46.0	18.4	1	0
202	450	20.8	8.3	0	0
203	450	20.4	8.2	0	0
204	450	20.6	8.2	0	0
205	450	21.3	8.5	0	0
213	450	21.6	8.6	0	0
214	450	20.7	8.3	0	0
215	450	21.0	8.4	0	0
216	450	21.6	8.6	0	0
217	450	21.3	8.5	0	0
218	450	21.1	8.4	1	0
219	450	21.1	8.4	0	0
220	450	21.2	8.5	0	0
221	450	21.1	8.4	0	0
222	450	21.6	8.6	0	0
230	450	22.1	8.8	0	0
231	450	21.3	8.5	0	0
C6					
206	450	10.4	4.2	1	0
207	450	11.9	4.8	0	0
208	450	14.7	5.9	0	0
209	450	15.1	6.0	0	0
210	450	17.1	6.8	0	0
211	450	19.0	7.6	0	0
212	450	21.8	8.7	0	0
C7					
223	450	36.3	14.5	1	3
224	452.5	38.3	15.4	1	1
225	450	38.6	15.4	0	0
226	450	40.0	16.0	0	2
227	450	39.7	15.9	0	1
228	450	39.2	15.7	1	1
229	450	36.7	14.7	0	0
C8					
232	450	11.2	4.5	0	0
233	450	17.1	6.8	1	0
234	450	21.0	8.4	1	2
235	442.5	25.1	9.9	7	4
236	456.67	27.5	11.2	0	0
237	450	27.6	11.0	0	0
238	454	23.8	9.6	0	0
239	450	22.2	8.9	0	0
240	460	22.2	9.1	0	0
241	453.33	20.0	8.1	0	0
242	450	21.2	8.5	0	0
243	453.3	25.5	10.3	0	0
244	450	26.4	10.6	0	0

Block, Transect Number	Adjusted transect height	Transect length (sea only)	Transect area (km^2)	# groups port	# groups starboard
C9					
245	450	41.2	16.5	0	0
246	450	44.2	17.7	0	0
247	453.3	47.0	18.9	0	0
248	450	50.3	20.1	0	0
249	450	49.4	19.8	0	0
250	453.3	50.8	20.5	0	0
251	450	49.0	19.6	0	0
252	457.5	46.2	18.8	0	0
253	450	22.2	8.9	0	0
254	450	22.2	8.9	0	0
255	450	22.2	8.9	0	0
256	450	22.2	8.9	0	0
257	450	22.2	8.9	0	0
258	464	32.0	13.2	2	0
259	450	31.7	12.7	0	0
260	450	18.7	7.5	0	0
261	450	17.8	7.1	0	0
262	453.3	15.5	6.2	1	0
263	450	20.4	8.2	1	0
264	445	22.2	8.8	0	0
265	453.3	22.2	8.9	0	0
266	450	22.2	8.9	0	0
267	450	22.2	8.9	0	0
268	453.3	22.2	8.9	0	0
269	450	22.2	8.9	0	0
270	450	22.2	8.9	0	0
271	450	22.2	8.9	1	1
272	455	22.8	9.2	1	1
C10					
273	445	39.6	15.7	0	0
274	450	38.6	15.4	0	2
275	450	3.5	1.4	2	0
276	450	9.7	3.9	0	1
277	450	10.6	4.2	2	3
278	450	9.1	3.6	1	1
279	450	6.2	2.5	1	0
280	450	3.2	1.3	0	0
281	450	12.1	4.8	1	0
282	450	12.1	4.8	10	9
C11					
283	450	45.1	18.0	5	0
284	450	43.7	17.5	1	2
285	450	30.8	12.3	0	0
286	450	22.2	8.9	0	0
287	450	22.2	8.9	0	0
288	450	22.2	8.9	0	0
289	450	22.2	8.9	0	0
290	460	22.2	9.1	0	0
291	450	22.2	8.9	0	0
292	450	22.2	8.9	0	0
293	460	22.2	9.1	0	0
294	450	22.2	8.9	0	0

Block, Transect Number	Adjusted transect height	Transect length (sea only)	Transect area (km^2)	# groups port	# groups starboard
C12A					
295	450	21.2	8.5	1	0
296	450	39.9	15.9	0	0
297	450	47.3	18.9	0	0
298	450	22.4	9.0	0	0
299	450	22.4	9.0	0	0
Hervey Bay					
HB1					
5	442.442	3.2	1.3	0	0
6	441.7634	3.2	1.3	0	0
7	440.8951	2.9	1.1	0	0
8	440.3237	3.4	1.3	0	0
9	439.0313	5.5	2.1	0	0
10	437.9219	5.1	2.0	0	1
11	436.7768	3.4	1.3	0	0
12	435.9375	6.9	2.7	0	1
13	434.6049	8.5	3.3	0	1
14	433.4933	7.6	2.9	0	0
15	432.1652	10.5	4.0	1	2
16	430.8504	7.3	2.8	0	0
17	429.5625	7.1	2.7	0	0
18	428.529	8.2	3.1	3	1
19	427.2277	8.2	3.1	1	1
20	426.1228	6.3	2.4	0	0
21	425.2299	7.7	2.9	0	1
22	424.0737	6.2	2.3	0	0
23	422.8817	7.6	2.8	0	0
24	421.6964	9.5	3.5	0	0
25	420.0022	12.7	4.7	0	0
26	418.4107	11.7	4.4	0	0
27	445.173	10.2	4.0	0	0
28	443.3467	9.0	3.6	1	0
29	441.7729	11.0	4.3	1	3
30	439.787	13.2	5.2	0	1
31	437.7908	13.5	5.2	0	0
32	435.7121	14.7	5.7	0	0
33	433.5742	14.8	5.7	0	0
34	431.5419	14.5	5.6	1	0
HB2					
35	445.5722	21.7	8.6	0	1
36	442.2983	36.1	14.2	0	0
37	438.2734	39.0	15.2	2	1
38	434.4974	37.0	14.3	2	0
39	430.6033	41.0	15.7	5	0
40	426.3675	43.3	16.4	5	0
41	421.6844	46.8	17.6	6	0
42	416.4782	53.7	19.9	6	2
43	424.4199	58.1	21.9	3	3
44	417.7692	61.8	23.0	0	1
45	410.8017	64.7	23.6	1	0
46	403.422	67.5	24.2	0	1
HB3					
47	395.9471	37.5	13.2	0	0

Block, Transect Number	Adjusted transect height	Transect length (sea only)	Transect area (km^2)	# groups port	# groups starboard
48	386.1102	38.5	13.2	0	0
49	378.2875	38.5	12.9	2	0
50	446.5974	35.4	14.1	0	1
51	443.1839	31.8	12.5	0	0
52	439.612	28.9	11.3	0	0
53	431.7268	32.5	12.5	0	0
54	435.3313	25.1	9.7	0	0
HB4					
47	395.9471	35.7	12.6	1	0
48	386.1102	37.3	12.8	0	0
49	378.2875	36.7	12.3	1	1
50	446.5974	37.4	14.9	0	0
51	443.1839	38.9	15.3	0	0
52	439.612	42.2	16.5	0	0
53	431.7268	46.3	17.8	0	0
HB5					
55	428.7703	23.0	8.8	0	0
56	446.4535	25.4	10.1	1	0
57	445.2882	22.6	8.9	1	0
58	444.186	22.4	8.9	0	1
59	443.1362	22.9	9.0	2	0
HB6					
601	450	27.8	11.1	0	0
602	450	27.7	11.1	0	0
603	450	27.7	11.1	0	0
604	450	27.7	11.1	0	0
605	450	27.7	11.1	0	0
606	450	30.3	12.1	0	0
607	450	20.1	8.0	0	0
608	450	20.3	8.1	0	0
609	450	20.2	8.1	0	0
610	450	19.9	8.0	0	0
611	450	19.7	7.9	0	0
612	450	19.6	7.8	0	0
613	450	18.5	7.4	0	0
614	450	18.5	7.4	0	0
615	450	18.5	7.4	0	0
616	450	18.6	7.4	0	0
617	450	18.5	7.4	0	0
618	450	19.6	7.8	0	0
619	450	19.2	7.7	0	0
620	450	18.4	7.4	0	0
Moreton Bay					
MB1					
44	450	14.1	5.6	0	0
45	450	12.2	4.9	0	0
46	450	9.1	3.6	1	0
47	450	1.5	0.6	0	0
48	450	2.5	1.0	0	0
49	450	14.1	5.6	0	0
50	450	13.1	5.2	0	0
51	450	11.3	4.5	0	0
52	450	2.0	0.8	0	0

Block, Transect Number	Adjusted transect height	Transect length (sea only)	Transect area (km^2)	# groups port	# groups starboard
53	450	2.6	1.0	0	0
MB3					
36	450	5.1	2.1	0	0
37	450	7.2	2.9	0	0
38	450	6.0	2.4	1	0
39	450	12.0	4.8	0	0
40	450	16.9	6.8	0	0
MB6					
1	450	4.9	2.0	1	0
2	450	4.1	1.6	0	0
3	450	5.7	2.3	0	0
4	450	7.7	3.1	0	0
5	450	9.8	3.9	0	0
6	450	10.5	4.2	1	1
7	450	10.0	4.0	0	0
8	450	10.8	4.3	1	1
9	450	9.9	3.9	2	2
10	450	10.1	4.0	1	0
11	450	12.9	5.1	0	0
12	450	12.5	5.0	0	0
13	450	15.0	6.0	0	0
14	450	13.6	5.5	0	0

Appendix Table 3. Raw data used for calculation of correction factors for dugongs for the survey.

a. Correction for perception bias

Blocks:lines	No. of groups of dugongs					
		Port			Starboard	
	Mid	Rear	Tandem	Mid	Rear	Tandem
Northern leg **Central Section 5**:213–222, 230–231, **6, 7, 8**:232–235, 241, **9**:254–256, 259–272, **10, 11, 12**	6	2	27	4	8	26
Whitsunday leg **Central section 1, 3, 4, 5**:199–205, **Southern section 6A, 6B, 7, 8**	3	2	2	4	1	4
Shoalwater leg **Southern section 4, 5, 6C**	8	1	3	3	6	10
Southern SGBR (**Southern section 1, 2, 3**), **Hervey Bay** (all blocks and lines), **Moreton Bay** (all blocks and lines)	13	3	16	6	7	11

b. Correction for availability bias
All sightings used

	No. of dugongs in groups less than 10		
	Surface	Under	Total
Northern leg **Central section 6–12**	52	45	97
Whitsunday leg **Central section 1, 3, 4, 5**:199–205 **Southern section 6A, 6B, 7, 8**	24	18	42
Northern/Whitsunday overlap **Central section 5**: 213–222, 230–231	55	45	100
Shoalwater leg **Southern section 4, 5, 6C**	20	31	51
Southern SGBR (**Southern section 1, 2, 3**), **Hervey Bay** (all blocks and lines), **Moreton Bay** (all blocks and lines)	37	78	115

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