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Dugong distribution and abundance in Torres Strait

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Helene Marsh[1], Ivan Lawler[1], Donna Kwan[1], Steve Delean[1], Kenneth Pollock[2] and Mathew Alldredge[2]

[1]School of Tropical Environment Studies and Geography, James Cook University, Douglas, Townsville, 4811 and CRC Torres Strait P.O.Box 772 Townsville 4801, Australia
[2]Statistics, Biomathematics, and Zoology, North Carolina State University, Raleigh, NC 27695-8203, U.S.A.

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Australian Fisheries Management Authority Torres Strait Research Program Final Report

Table of Contents

Non-technical Summary

- The Torres Strait region was surveyed for dugongs in November 2001 using the same aerial survey technique as had been used for similar surveys in 1987, 1991 and 1996. The aim of these surveys is to provide assessments of the distribution and abundance of the dugong in Torres Strait.
- The 2001 survey was conducted in November 2001. The survey was preceded by community visits by some members of the survey team to Horn Island, Kubin, Mabuiag, Saibai, and Boigu. The purpose of these visits was to explain the details of the survey technique to the Islanders and to demonstrate the set up of the aircraft.
- The aerial surveys confirm that the size of the Torres Strait dugong population is very variable. The population estimate resulting from the 2001 survey was similar to that recorded in 1987 but only about half the size estimated from the 1991 and 1996 surveys.
- The results of the 2001 survey add to a growing body of evidence from other aerial surveys in Queensland and Western Australia and satellite tracking, that dugongs undertake large-scale movements, which seem to be primarily associated with changes in their seagrass food. These results indicate that dugongs should be managed across jurisdictions in northern Australia and that population trends are an unreliable index of the status of dugong stocks.
- The population estimate obtained from the aerial survey was used to estimate an annual sustainable harvest for dugongs in the Torres Strait region as a whole. The results suggest that the following total harvest should be sustainable and allow the population to recover:
  - Based on the 1996 population estimate: about 190 dugongs
  - Based on the 2001 population estimate: about 80-90 dugongs

  In our opinion, the 2001estimate would be a more prudent total allowable catch.

- All these estimates are so far below the current estimates of the annual dugong harvest in the Torres Strait region (which do not include data from the Northern Peninsula Area, the Inner Islands or Papua New Guinea), that we consider that it is almost certain that the present level of dugong harvest is unsustainable and that the annual catch needs to be reduced as a matter of urgency if the traditional way of life of Islanders of Torres Strait is to be maintained.

Acknowledgments

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We thank the following people for their invaluable assistance with the survey and/or the subsequent report:

- Our observers: Chieko Azuma, Vimoksalehi Lukoschek, Josh Smith, Helen Penrose, Suwan Pitaksintorn, Leela Rajamani, Amanda Hodgson,
- Our pilots from Aero-tropics,
- Douglas Jacobs, TSRA Fisheries Coordinator,
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- Chairmen and members of communities of Horn Island, Mabuiag, Boigu, Kubin and Saibai,
- Adella Edwards for assistance with figures,
- Pam Quayle for editorial assistance
- Two anonymous reviewers for the journal *Animal Conservation* in which an article derived from this work will be published in 2004 entitled: Marsh, H., I. Lawler, D. Kwan, S. Delean, K. Pollock and M. Alldredge. 2004. Aerial surveys and the potential biological removal technique indicate that the Torres Strait dugong fishery is unsustainable. *Animal Conservation.*

Background

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 (Hilton-Taylor 2000), along with the other three species in the order Sirenia, the manatees (family Trichechidae). Anecdotal evidence suggests that dugong numbers have decreased throughout most of their range (Marsh *et al*. 2002). Significant populations persist in Australian waters, which are now believed to support most of the world's dugongs. Consequently, Australia has an international obligation to ensure that dugong stocks are conserved in Australian waters (Bertram 1981).

Dugongs occur along much of the tropical and sub-tropical coast of Australia from Shark Bay in Western Australia to Moreton Bay in Queensland. Torres Strait is the most important area within this region supporting the largest population of dugongs in Australian waters and probably the world (Marsh *et al.* 1997a, 2002).

The globally significant dugong population in Torres Stait supports an important traditional fishery undertaken by Torres Strait Islanders for meat and oil. The fishery is cited under *Article 22* of the *Torres Strait Treaty* between Australia and Papua New Guinea. The Torres Strait Islanders hunt dugongs as part of their traditional way of life and livelihood, which is protected by the Treaty. On the basis of wet-weight landings, the fishery is the largest island-based fishery in the Torres Strait Protected Zone (Harris *et al.* 1994). The traditional fishing activities of Torres Strait Islanders are ‘virtually unrestricted’ (Waia 2001). Under the Treaty, Torres Strait Islanders include persons who i) ‘are Torres Strait Islanders who live in the Protected Zone or the adjacent coastal area of Australia, ii) are citizens of Australia, and iii) maintain traditional customary associations with areas or features in or in the vicinity of the Protected Zone in relation to their subsistence or livelihood or social, cultural or religious activities.'

The sustainability of the Torres Strait dugong fishery is a major imperative for the Torres Strait peoples who greatly value dugongs for their nutritional, cultural, social, economic and ideological significance. The issue is also a priority for managers in relevant government environment agencies, particularly the Australian Fisheries Management Authority (AFMA) and some scientists (Hudson 1986; Johannes and MacFarlane 1991; Marsh 1996; Marsh *et al.* 1997a; Marsh *et al*. 2002). AFMA has supported research on dugongs in Torres Strait since the 1980s.

Much of the information used to manage dugong populations in Australia has been provided by aerial surveys using standardised techniques developed by Marsh and Sinclair (1989 a, b). The Torres Strait region was surveyed using this technique in 1987, 1991 and 1996. The objective of these surveys was to provide an assessment of the distribution and abundance of the dugong in Torres Strait and a time series for temporal comparisons.

Need

Management of the Torres Strait dugong fishery requires knowledge of the dugong population size and an estimated sustainable harvest rate. In this report, we present the results of the fourth aerial survey in the time series, which was conducted in November 2001, five years after the last survey.

The results of the aerial survey have been used as the basis for estimating the sustainable harvest for dugongs in Torres Strait.

Objectives

To evaluate the status of the dugong in Torres Strait and the likely sustainability of the Torres Straight Fishery by:

- Conducting an aerial survey in November 2001 to quantify the distribution and relative abundance of the dugong to enable statistical comparisons with data obtained using similar techniques in November 1987, 1991 and 1996.
- Using data from the aerial survey to estimate the absolute abundance of the dugong in Torres Strait using new techniques developed with funding from AFMA, ARC SPIRT and the Pew Foundation (Pollock *et al.* 2004).
- Comparing AFMA estimates of the current harvest of the dugong in the traditional fishery in Torres Strait with the sustainable yield estimated using the Potential Biological Removal Method in association with data on dugong life history obtained from the AFMA project conducted by Dr Donna Kwan (Kwan 2002).
- Communicating this information to the Torres Strait Islander community to assist in the development of community-based management of the fishery

Methods

Community Education

The traditional inhabitants of Torres Strait are keenly interested in the status of the dugong stock in their region and wish to know about research methodology and to exchange information with researchers.

If the results of our research are to influence the management of dugongs in Torres Strait, it is important that the Islanders trust the results. To this end, we worked with Douglas Jacobs, who was then the Fisheries Coordinator for the Torres Strait Regional Authority, to organise the following extension activities during our field time in Torres Strait in November 2001:

- An article about our survey and extension efforts was published in 'Torres News', the local newspaper, on 2 November.
- Local radio station staff interviewed Douglas Jacobs, Donna Kwan and Helene Marsh on 5 November.
- Meetings with local stakeholders were held at the major dugong hunting communities, including Horn Island (6 November), Kubin (7 November), Saibai (8 November), Boigu (8 November), Mabuiag (8 November). Eight to 15 people, many of whom are hunters, attended each meeting. Although we were unable to visit Badu Island as the airstrip was closed, Badu Islanders were invited to attend the meeting at Kubin.
- Each meeting comprised the following components:
  - We showed a research video of dugong behaviour, filmed in clear water in Moreton Bay. This was of considerable interest to the local peoples and improved our credibility as dugong researchers.
  - We explained all aspects of our aerial survey technique, including the observer protocols, the computer recording and editing of data. The local stakeholders were provided with the opportunity to inspect our survey aircraft and equipment. We allowed time for open discussion and information exchange. Some stakeholders were generous in sharing their traditional ecological knowledge of dugongs.

On 12 November, Donna Kwan and Helene Marsh recorded a second interview on local radio. This provided us with the opportunity to inform the local people about the preliminary results of the survey. On 12 November, Donna Kwan and Helene Marsh briefed Tony Kingston and Jim Prescott of Australian Fisheries Management Authority on the results of the survey. A similar briefing was held with Douglas Jacobs on 13 November.

An article reporting on the preliminary results of the aerial survey was published in 'Torres News' on 29 March.

Capacity Building

Our original proposal did not provide adequate time or funds to recruit and train Islander observers in the protocols of the survey and the preliminary data processing that must occur during the fieldwork. In future, we recommend that funding proposals for dugong aerial surveys: (1) assume the use of two aircraft, and (2) explicitly request money to advertise for several Islander observers with a suitable background, and to train them prior to the survey.

Survey methodology

As in 1987, 1991 and 1996 we used the strip transect aerial survey technique detailed in Marsh and Sinclair (1989a, b). This involved flying two twin-engine Partenavia B aircraft each fitted with a GPS at a speed of 100 knots at a height of 137m above sea level. Transects were generally flown in an east-west direction as this reduces the interference of glare with the observations. The transects adjacent to the PNG coast were flown in a north-south direction across the depth gradient to minimise the ecological differences between the transects. The transect positions and lengths were based on those flown in the previous surveys of the region (Marsh and Saalfeld 1991; Marsh *et al.* 1997a; Marsh *et al*. 1997b) (see Figure 1 for details of transect and block positions). Table 1 lists the areas of the survey blocks and the sampling intensity for each block.

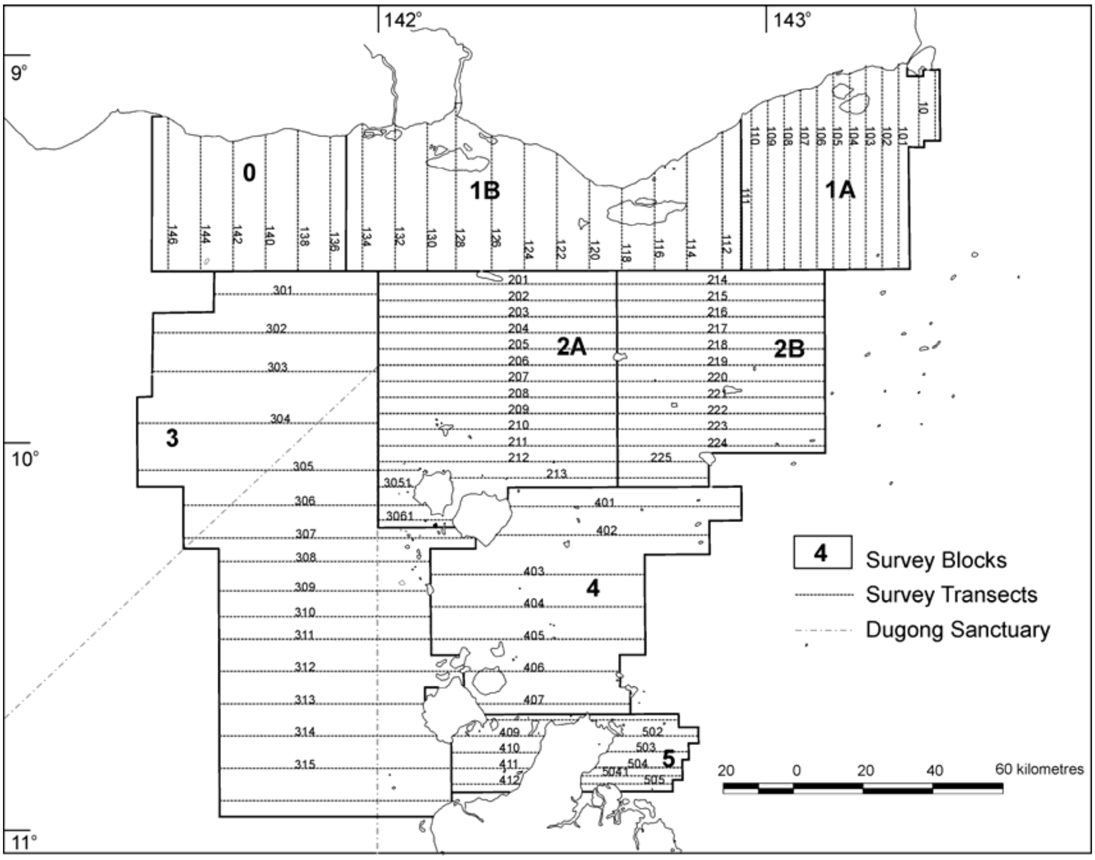


Figure 1. Map of the survey region showing the positions of the survey blocks and transects. The areas of the survey blocks and sampling intensities are presented in Table 1.

Table 1. Areas of survey blocks and sampling intensities.

Block number	Block area in km^2	Percentage of block surveyed
0	2172	4.4
1A	2657	8.50
1B	3784	4.34
2A	4339	8.40
2B	3290	8.43
3	9651	4.14
4	3636	4.25
5	1031	10.17
Total	30560	5.85

Transects 200m wide on the water surface were demarcated using fibreglass rods attached to artificial wing struts on each side of the aircraft. Tandem teams, each of two observers on each side of each aircraft, recorded their sightings independently onto separate tracks of an audiotape. These independent sightings were then used to develop survey specific correction factors (see below). The transect on each side of the aircraft was divided into four horizontal strips using markers on the wing struts. Each sighting was designated as being made in one of these substrips to enable us to decide if simultaneous sightings by members of the same group of tandem observers were of the same group of animals.

We surveyed the entire area covered in previous surveys. As the window of opportunity when the weather is suitable for aerial survey is small in Torres Strait, we used two aircraft flying concurrently with separate teams of observers. The survey was conducted between November 9th and 12th, 2001.

Block 2A was surveyed on both the 9th and 12th of November because the weather conditions on the 9th were marginal. The data for Block 2A from November 12th only are reported here except for the correction for availability bias which was based on the entire data set.

Correction factors

Estimates of dugong abundance were obtained using two methods:

1. The method developed by Marsh and Sinclair (1989a) to develop standardised relative estimates of dugong abundance and used in the 1987, 1991 and 1996 surveys of Torres Strait.
2. The new method developed by Pollock *et al.* (2004) to develop an absolute estimate of dugong abundance.

Both methods corrected dugong sightings for perception bias and availability bias. Availability bias corrects for animals that are not available to observers because of water turbidity. Perception bias occurs when animals are visible in the survey transect but missed by observers.

Method of Marsh and Sinclair (1989a)

The correction factor used to account for the perception bias was calculated using a modified Mark-Recapture model that is based on the proportions of animals seen by one or other, or both, observers (Marsh and Sinclair 1989a). Perception correction factors were calculated for each team of observers in each aircraft.

Availability bias was corrected for by standardising the proportion of animals classified as 'at the surface' against the corresponding proportion in an earlier survey conducted over an area where water conditions enabled all animals in the survey area to be potentially available to the observers (Marsh and Sinclair 1989a). This approach makes the untested assumption that a constant proportion of animals are at the surface under all survey conditions. Availability correction factors were estimated separately for the two aircraft as detailed in Table 2. Appendix Table 1 lists the raw data used to calculate the correction factors.

Table 2. Details of group size estimates and correction factors used in the population estimates for dugongs in the 2001 survey of Torres Strait using the method of Marsh and Sinclair (1989a). Correction factors for Perception Bias were calculated for each tandem team in each survey aircraft. Corrections for availability bias were calculated for each survey aircraft.

Blocks: Transects[1]	Group size (C.V)[2]	Perception correction factor estimate (C.V)[2]		Availability correction factor estimate (C.V)
		Port	Starboard	
1, 1A, 2B, 4, 5: all transects *1B: 132, 134* 3: 311-316	1.39 (0.597)	1.04 (0.015)	1.13 (0.080)	2.75 (0.139)
2A: all transects 1B: 112-130 3: 301-310	1.23 (0.467)	1.09 (0.020)	1.19 (0.039)	2.19 (0.137)

[1]See Figure 1 for positions of blocks and transects
[2]Coefficient of variation

Method of Pollock *et al*. (2004)

As recognized by Marsh and Sinclair (1989a), modeling availability bias requires information additional to that obtained in the survey. Pollock *et al*. (2004) carried out experiments to determine zones of detectability for dugongs over a range of depths, turbidities and sea states using dugong models and deployed timed depth recorders on 15 wild dugongs to obtain dive profiles. This enabled them to calculate the probability of a dugong being available in different strata based on depth, turbidity, and sea state. Extending Marsh and Sinclair (1989a), perception bias was modeled using the results from the tandem team of two observers on either side of the aircraft. This permitted the fitting of generalized Lincoln-Petersen models with Program MARK. The simplest model that explains the data adequately was selected using the AIC technique. The generalized Horvitz-Thompson estimator based on the overall detection probability of each individual group was then used to generate the population estimates. Simulation was used to calculate the standard errors.

Population estimation

Dugong abundance was estimated separately for each block in the survey area (Figure 1). As transects vary in length, and hence area, the Ratio Method was used to estimate dugong density, population size and associated standard errors (Jolly 1969; Caughley and Grigg 1981). Any statistical bias resulting from this method is considered inconsequential because of the relatively high sampling intensity (Table 1; see also Caughley and Grigg 1981). Input data were the estimated number of dugongs (in groups of <10 animals) for each tandem team per transect calculated from the raw data using: (1) the corrections for perception and availability biases and the estimates of mean group size using the method of Marsh and Sinclair (1989a; Table 2); and (2) the new method developed by Pollock *et al.* (2004). The estimated standard errors incorporate the errors associated with the correction factors described above. The numbers of dugong in groups of >10 were to be added to the estimates of population size and density as outlined in Norton-Griffiths (1978). However, no groups of >10 dugongs were seen in Torres Strait in 2001.

Statistical analysis

As for the analysis of the 1996 survey (Marsh *et al.* 1997a), differences in dugong density among survey years in Torres Strait were examined using a split-plot analysis of variance. To facilitate comparisons with previous surveys, the data used in this analysis were those generated using the method of Marsh and Sinclair (1989a). Mixed-effects models were employed to estimate the random components of variance for this analysis and to provide appropriate tests for differences between years. The parameters of these models were estimated by restricted maximum likelihood (REML). Variation in dugong density among blocks and among transects within blocks were random sources of variance, as was the variation due to the interaction among blocks across years. The (fixed) year effect was tested against the (random) block*year interaction using dugong density in each transect within blocks as the response. The data were log transformed (i.e., ln (y + 0.1)) to ensure a constant mean-variance relationship. The test for the year effect assumed sphericity (i.e., constant correlation between blocks across years) and conservative tests were performed in case this assumption was violated. Beaufort Sea State was included as a single degree of freedom covariate in the analysis. The term estimating the linear association of Beaufort Sea State with density was conditional on the other terms in the model.

Estimating the size of a sustainable dugong catch

We used the Potential Biological Removal (PBR) Method (Wade 1998) to estimate the size of a sustainable dugong catch in the Torres Strait region shown in Figure 1. The PBR is defined as the maximum number of animals, not including natural mortalities that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population, which is defined as a population level between carrying capacity and the population size at maximum net productivity. Thus the specific goal of the PBR is to allow each stock to reach or maintain a level at or above the maximum net productivity level (MNPL) (Wade 1998). The PBR is calculated using the following formula:

$$PBR = N_{min} \times 0.5\, R_{max} \times RF \text{ (Wade 1998)}$$

Thus, the PBR is the product of the following factors:

1. The minimum population estimate of the stock N_{min} (defined as the 20th percentile of a log-normal distribution based on an absolute estimate of the number of animals in that stock).

   $$N_{min} = \hat{N} / \exp\{z[\ln(1+CV(N)^2]^{0.5}\}$$

   where z is a standard normal variate and thus equals 0.842 for the 20^{th} percentile and CV(N) is the coefficient of variation of the population estimate $\hat{N}$. We used the method of Pollock *et al.* (2004) to generate the absolute estimate $\hat{N}$.

2. Half the maximum rate of increase R_{max}.. This is a conservative surrogate for R_{MNPL} because 1/2 R_{max} will always be < R_{MNPL} if MNPL is $\geq$ carrying capacity (Wade 1998).

3. A recovery factor (RF) of between 0.1 and 1. The use of a RF of less than one allocates a proportion of expected net production towards population growth and compensates for uncertainties that might prevent population recovery, such as biases in the estimation of N_{min}, and R_{max} or errors in the determination of stock structure. Population simulations (Wade 1998) suggest that the default value for endangered species should be 0.1 and that the default for depleted or threatened stocks, or stocks of unknown status should be 0.5. We used the values of 0.1 and 0.5 as explained below.

Results

Survey conditions

The survey was conducted under good conditions that were generally within the range of those encountered on other surveys in the temporal series of dugong surveys in Torres Strait (Table 3). The details of Beaufort sea state and glare for each transect are given in Appendix Table 2.

Table 3. Weather conditions encountered during the survey.

Variable	1987	1991	1996	2001
Wind speed ($km.h^{-1}$)[1]	< 15	< 15	< 10	<15
Cloud cover (oktas) [1]	1 to 8	0 to 5	0 to 7	0 to 7
Minimum cloud height (m) [1]	270 to 4000	460 to 750	1000 to 5000	2000-5000
Beaufort sea state[2]	1.3 (0-4)	1.9 (0-4)	1.1 (0-3)	1.4 (0-3)
Glare[2, 3, 4] North/West	1.4 (0-3)	1.7 (0-3)		0.9 (0-3)
Glare[2, 3, 4] South/East	0.75 (0-3)	2.3 (0-3)		1.3 (0-3)
Visibility (km) [1]	N/A	>20	>10	>20

[1]Range
[2]Means of modes for each transect
[3] 0-none, 1<25% of field of view affected, 2<25-50%, 3>50%
[4]Taken from the side of the aircraft with the higher glare

Group size and composition

Two hundred and ninety-three dugongs were seen during the survey. Most were solitary individuals (178) or in pairs (74). The largest group size comprised five individuals. Twenty-nine calves (9.9%) were seen during the survey. Twenty-six of these were cow-calf pairs (other calves were in two groups of three animals and one group of five animals see Figure 2). The proportion of calves differed significantly by survey block (Yates' Corrected Chi-square =13.19, d.f. =1, p=0.0003) as follows: 5.2% in Blocks 0,1a, 1b, 2a and 2b, 19.2 % Blocks 3 and 4. No dugongs were sighted in Block 5.

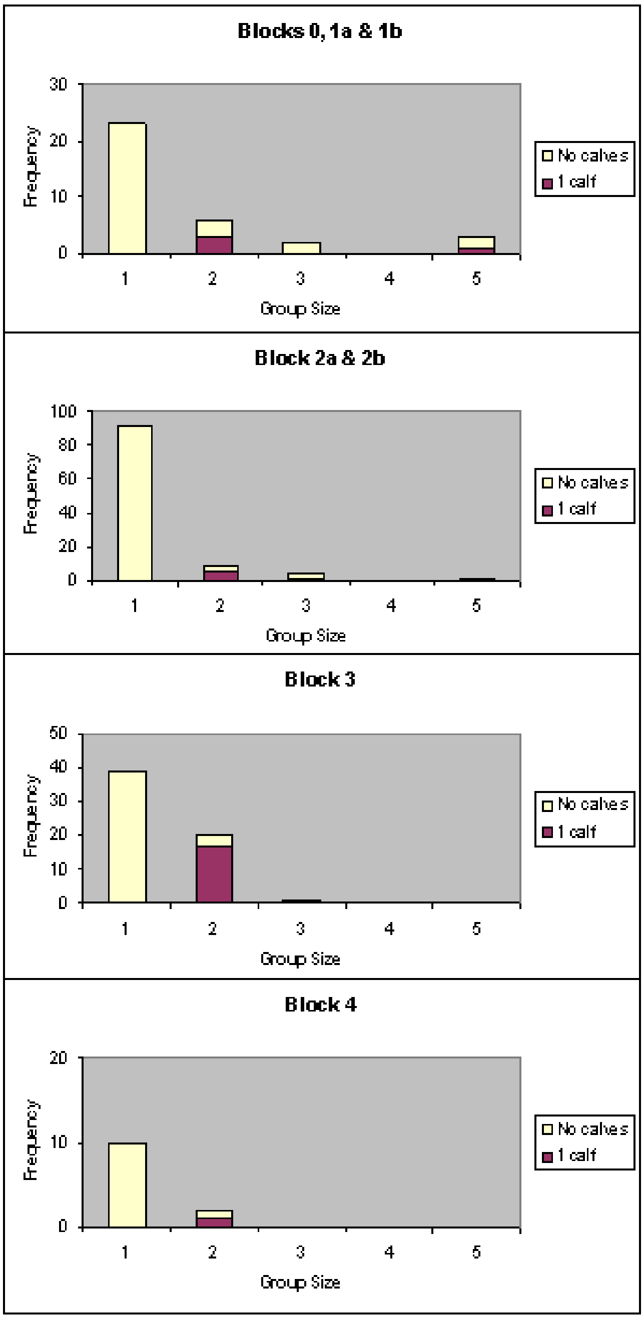


Figure 2. Histograms showing the frequencies of groups of dugongs of various sizes and with varying number of calves sighted in November 2001. Note the variation in the scales on the y-axis of the various histograms. See Figure 1 for details of survey blocks.

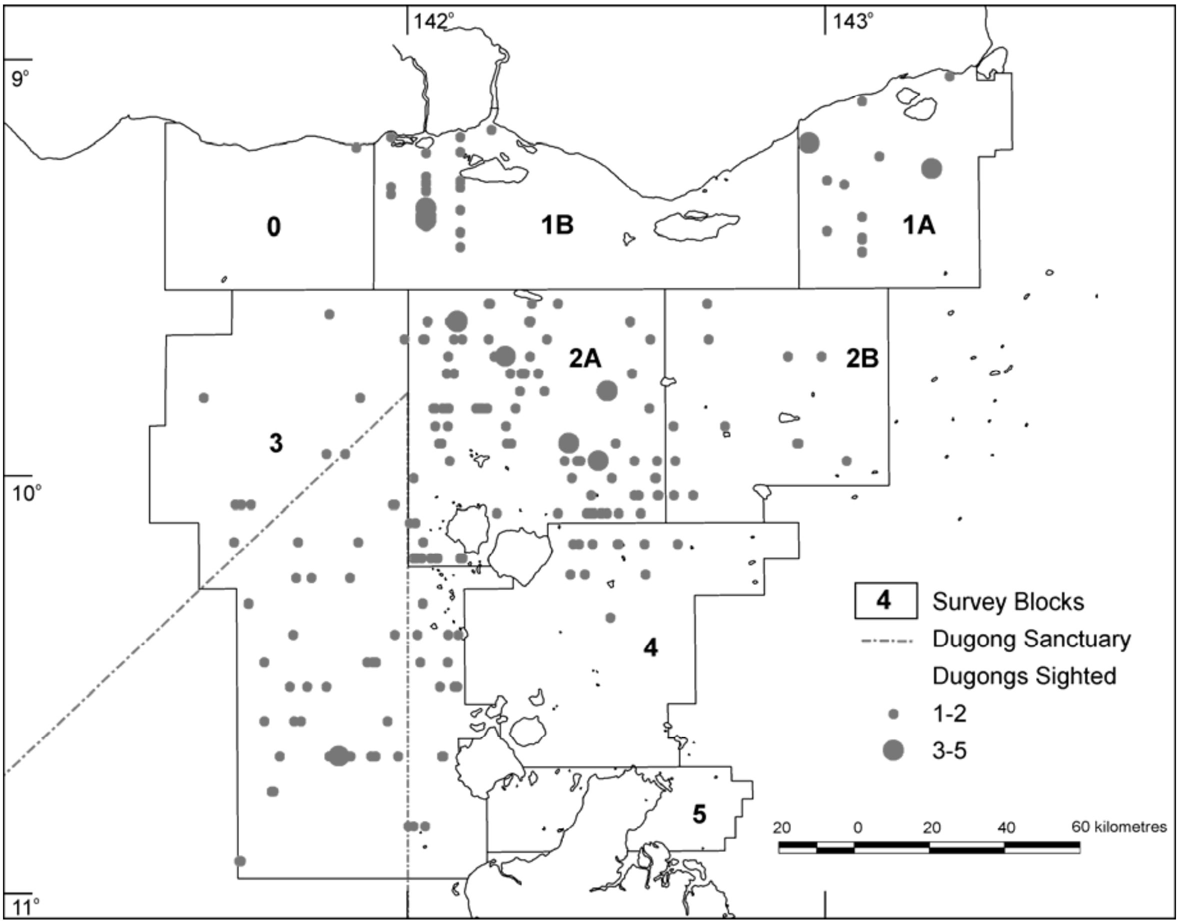


Figure 3. Sightings of dugongs during the November 2002 aerial survey in relation to the survey blocks and the Dugong Sanctuary.

Dugong abundance and distribution

The positions of the sightings of dugongs during the November 2002 aerial survey are illustrated in Figure 3. The estimated size of the dugong population in the survey area using the method of Marsh and Sinclair (1989a) was 14106 dugongs (± s.e. 2314). The corresponding estimate using the method of Pollock *et al*. (2004) was 11956 dugongs (± s.e. 1189) (Table 4).

The results of the split plot analysis of variance provide evidence for significant differences among years in dugong density in Torres Strait (Table 5, Figure 4). Contrasts suggested significant increases between 1987 and 1991 (contrast estimate 0.305, $p = 0.024$), and between 1991 and 1996 (contrast estimate 0.339, $p = 0.012$), and a significant decline between 1996 and 2001 (contrast estimate -0.667, $p < 0.001$). There was no difference between the estimates of dugong density in 2001 and 1987. The among-blocks variance component (0.375) was large relative to the variance among transects within blocks (0.171) suggesting that some parts of the region (e.g., especially Block 2A) are consistently much more important to dugongs than others. The year*block variance component (0.02) was very small suggesting that these spatial differences are temporally robust (Figure 5). The largest variance component (0.756) corresponds to the among transect within block variation among years (error) suggesting that dugongs make substantial small-scale movements within blocks over time.

Table 4. Estimates of dugong abundance (+ s.e.) in each of the survey blocks in the Torres Strait survey in 2001 in comparison with the corresponding data for 1987, 1991, 1996 and 2001.

Block	Year									
	1987		1991		1996		2001 Marsh and Sinclair Method		2001 Pollock et al. Method	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
0	0		696	238	1152	381	0	0	0	0
1A	1131	278	1669	999	2427	663	685	317	635	94
1B			3705	1529	1681	615	2678	1695	1757	475
2A	6424	1679	9113	1798	10869	1600	3504	403	3429	453
2B	2019	573	1467	399	1905	370	583	166	440	83
3	2822	1102	6740	1958	8623	2411	5473	1327	4927	972
4	848	347	518	197	984	313	1183	655	778	150
5	76	55	320	277	240	70	0	0	0	0
Total	13319	2136	24225	3276	27881	3095	14106	2314	11956	1189

Table 5. Results of the split-plot analysis of variance examining dugong density among surveys. The estimated variances (Est. Var.) are calculated from the mixed -effects analysis.

Term	SS	d.f.	MS	Est. Var.	F	p
Block[3]	154.4	7	22.05	0.375		
Transect (Block)[3]	124.3	86	1.45	0.171		
Year[1, 2, 4]	25.8	3	8.61		8.89	0.0005
Year*Block[3]	20.4	21	0.97	0.020	1.28	0.187
Beaufort[2]	2.3	1	2.34		3.10	0.080
Error	194.3	257	0.76	0.756		

[1]Tested against year by block interaction
[2] Fixed factor covariate
[3] Random factor
[4]Conservative lower bound test for year effects which does not assume sphericity: $F = 8.89$, d.f. = 1 & 7, $p = 0.021$.

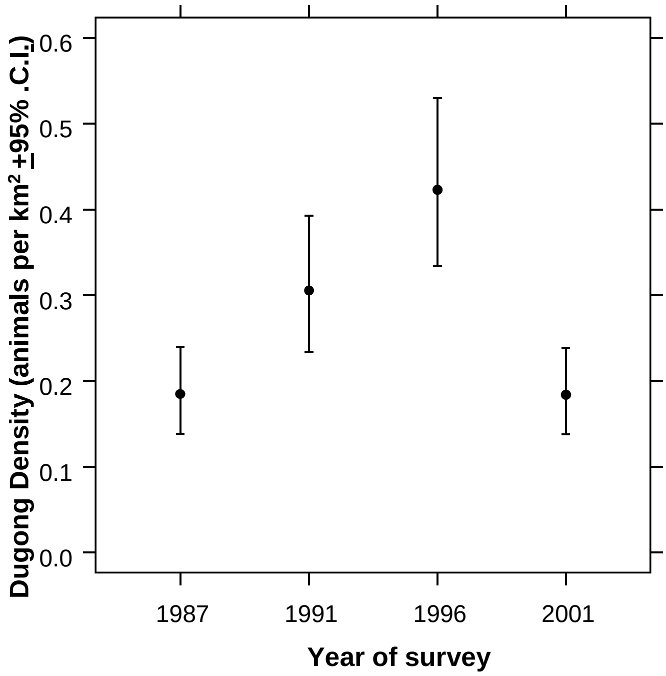


Figure 4. Estimated mean dugong density (±95% confidence interval) for each of the four surveys conducted in Torres Strait. The data for all surveys have been generated using the method of Marsh and Sinclair (1989a).

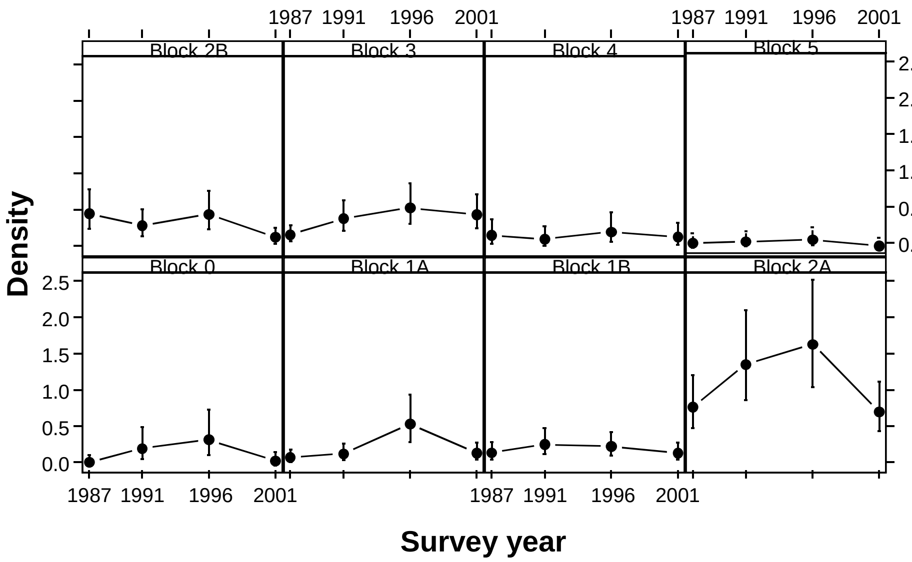


Figure 5. Estimated mean dugong density (±95% confidence interval) in each block in each survey year. The data for all surveys have been generated using the method of Marsh and Sinclair (1989a).

Estimating a sustainable level of human-induced mortality for dugongs in the Torres Strait survey region

Minimum population estimate N_{min}

The population estimates obtained from the aerial surveys using the method of Marsh and Sinclair (1989a) are standardised indices designed to monitor population trends. The methodology of Pollock *et al.* (2004) aims to estimate the absolute abundance of dugongs as required by the Potential Biological Removal method (Wade 1998). We then used this estimate of absolute abundance to estimate N_{min} as outlined above.

Maximum rate of increase maximum rate of increase R_{max}.

The application of population models to dugongs has been hampered by uncertainty about the estimates of the population parameters as discussed by Marsh (1995,1999). Age determination has been validated only by the marginal increment method (Marsh 1980). This is unlikely to be a significant error as the mammalian literature indicates that the rate of deposition of growth layer groups is remarkably similar across taxa. The rate for dugongs is also in accord with that for Florida manatees, a rate that has been verified using tetracycline marking (Marmontel 1995).

The estimates of R_{max} for Torres Strait are based on the data of Marsh (1999) and Kwan (2002). Dugong life history parameters are spatially and temporally variable as discussed by Marsh (1999) and Kwan (2002). However, these data should be used with caution. Estimates of the calving intervals of these populations may be biased by hunters targeting pregnant females (Johannes and MacFarlane 1991; Roberts *et al*. 1996; Kwan 2002). In addition, the sample sizes are not large enough to calculate the age at which 50% of females mature, rather they are suitable only to define the range of ages at which maturity has been observed to occur. The minimum ages of first reproduction observed are 6 years (Mabuaig in 1997: Kwan (2002); 10 years (Townsville) and 13 years (Daru): Marsh 1995).

There are no estimates of natural mortality. The early models assumed a pattern of natural mortality based on that of the dugong's nearest living terrestrial relative, the African elephant. More recent modelling (Marsh 1999; Table 6) uses a pattern of natural mortality based on that obtained from longitudinal studies of manatees (Eberhardt and O'Shea 1995; Langtimm *et al.*1998) which is likely to be more realistic for dugongs than the pattern based on that for elephants. In view of these uncertainties, we have used a range of estimates of R_{max} from 0.01 to 0.05 (1-5%). The basis for these estimates is summarised in Table 6.

Table 6. Leslie Matrix estimates of the maximum rate of population increase R_{max} for dugong populations for combinations of life history parameters (age of first calving and mean calving intervals spanning the known range of these parameters in various wild populations).

	Age at first reproduction (years)[1]	R_{max} [2.3] for each of the following mean calving intervals		
		2.5 years[1]	3.0 years[1]	5.0 years[1]
Mabuiag, Torres Strait 1997-98	6	5.08%	3.9%	1.15%
Townsville 1970-early 1980s	10	3.35%	2.45%	0.3%
Daru, Torres Strait 1976-83	13	2.46%	1.65%	-0.22%
Mornington Island 1970-early 1980s	15	1.92%	1.2%	-0.53%

[1] These data are based on recorded age of first reproduction (calf birth) rather than mean age of first reproduction and are from Marsh (1999) and Kwan (2002)
[2] The population models use survivorship schedules based on empirical data for the Florida manatee as follows: dependent calves - 0.822 p.a., independent young - 0.965 p.a., reproductive adult - 0.965 p.a. (see Marsh 1999 for details)
[3] The age distribution has been truncated at 45 years. Extending it to the maximum age recorded for dugongs of 70 years makes only a trivial difference.

The Recovery Factor (RF)

We used values of 0.1 and 0.5 for the Recovery Factor (RF) in the calculations of a sustainable catch for the dugong in Torres Strait. The dugong is listed as a threatened species in Queensland and the default value is 0.5 for such stocks as it potentially allows the stock to recover to the optimum sustainable population level and for uncertainty in the parameter estimates (Wade 1998). The alternative Recovery Factor of 0.1 is much more conservative and has been developed because: (1) there is some evidence that the hunters tend to target females (Johannes and MacFarlane 1991, Skewes *et al.* 2002), and (2) PVA modelling also suggests that the population to be seriously over-harvested (Heinsohn *et al.* 2004).

The above ranges and uncertainties produce the scenarios for the sustainable anthropogenic mortality (Potential Biological Removal) in Table 7. The middle value for the estimated maximum rate of increase R_{max} (=0.03) and a Recovery Factor of 0.5 (which we consider is more appropriate in this instance) suggest that the following total annual anthropogenic mortalities should be sustainable:

- Based on the 1996 population estimate: about 190 dugongs
- Based on the 2001 population estimate according to the method of Marsh and Sinclair (1989a) about 90 dugongs
- Based on the 2001 population estimate according to the method of Pollock *et al.* (2004) about 80 dugongs

Table 7. Estimates of the total sustainable anthropogenic mortality (Potential Biological Removal *sensu* Wade 1998) for the 1996 and 2001 aerial survey estimates of the size of the dugong population in Torres Strait for a range of estimates of R_{max} and assuming values for the Recovery Factor of 0.5 and 0.1. The values for the PBR based on the 2001 survey estimate have been calculated based on: (1) the population estimates derived using the method of Marsh and Sinclair (1989a), and (2) the method developed by Pollock *et al.* (2004).

Date of survey and methodology	R.F.	N	SE	CV	N_{min}	Potential Biological Removal				
						R_{max} =0.01	R_{max} =0.02	R_{max} =0.03	R_{max} =0.04	R_{max} =0.05
2001 (Marsh and Sinclair 1989)	0.5	14106	2314	16.4	12297	31	61	92	123	154
	0.1					6	12	18	25	31
2001 (Pollock *et al.* 2004)	0.5	11956	1189	10.0	10998	27	55	82	110	137
	0.1					5	11	16	22	27
1996(Marsh and Sinclair 1989a)	0.5	27881	3095	11.1	25400	64	127	191	254	318
	0.1					13	25	38	51	64

Discussion

Temporal changes in dugong population size in Torres Strait

Irrespective of the method used to derive them, the population estimates obtained by the survey conducted in November 2001 confirm that there is considerable temporal variability in the estimated size of the dugong population in Torres Strait (Table 4). The minimum population estimates for dugongs in the survey area in 2001 using the method of Marsh and Sinclair (1989a) was 14061 ± s.e. 2314, which is not significantly different from that in 1987 (13 319 ± s.e. 2 136) but significantly lower than the estimates derived for 1991 (24225 ±3 276) and 1996 (27 881 ± s.e. 3 095) using the same technique (Table 5). The population estimate for 2001 using the method of Pollock *et al.* (2004) was 11956 dugongs (± s.e. 1189), about 15% lower than the corresponding estimate using the older methodology.

Marsh *et al* (1997a) reviewed the possible reasons for the significant difference between the dugong population estimates obtained for Torres Strait in 1987 and 1991 using the method of Marsh and Sinclair (1989a) (see above) and concluded that: (1) this difference could not be explained by natural increase in the absence of immigration into the survey area, and (2) it was unlikely to be the result of fluctuations in the availability bias between surveys. Marsh and Lawler (2001) and Gales *et al*. (2004) used similar logic to explore the possible reasons for the temporal differences between population estimates obtained from repeat aerial surveys of the southern Great Barrier Reef and Western Australia respectively, and also concluded that movement of dugongs was the most likely explanation.

Results of temporal series of aerial surveys of Torres Strait, the northern Great Barrier Reef, the southern Great Barrier Reef, Hervey Bay, Moreton Bay and Western Australia all suggest that dugongs move both within survey regions and into and out of survey regions even when these regions are very large (e.g.> 30000 km^2) as in Torres Strait (Table 8).

This pattern is also consistent with traditional knowledge, anecdotal information and satellite tracking, all of which suggest that dugongs undertake large-scale movements. Johannes and MacFarlane (1991) report that many Islanders attributed the change in the availability of dugongs in Torres Strait to the animals moving elsewhere, rather than to over-harvesting. Unfortunately as discussed below, these two potential influences on dugong abundance are confounded and impossible to disaggregate with the present state of knowledge.

There is also anecdotal evidence for large-scale movements of dugongs in the region in 2001/2002. When we visited the Western Island communities (see Methods above), Islanders reported unusually large numbers of dugongs seen close to communities such as St Paul's, Horn and Thursday Islands in 2001. We also received consistent reports of unusually large numbers of dugongs off the Northern Peninsula Area communities on the northern coast of Cape York (Leanne Sommers GBRMPA *pers comm*. 2002) and off Weipa in the Gulf of Carpentaria in the early months of 2002 (Michael Rasheed QDPI *pers comm*. 2002), and of fishers catching dugongs in their nets in the Karumba region in the Gulf of Carpentaria in areas where they had not seen them for years (Bill Kehoe *pers comm*. 2002). These sightings of dugongs in unusual locations have been accompanied by considerable anthropogenic mortality. In addition to the unusual fishing-related mortality reported above, we received anecdotal reports of an estimated 30-60 dugongs killed off Weipa, particularly by residents of the Naparum community in the early months of 2002 (David Donald and Ian Little *pers comm*. 2002). Dugongs were apparently attracted to the area because of the emergence of a previously undetected meadow of the seagrass *Halophila.* This meadow was not detected by the seagrass monitoring of the area conducted by QDPI staff in April and September 2000 and April and September 2001 and can be assumed not to have been present at the above times (M. Rasheed QDPI *pers comm*. 2002).

Satellite telemetry studies in Queensland (Marsh and Rathbun 1990; Preen 2001; see Marsh *et al.* 2002) and Western Australia (Holly *et al*. 2001; see Marsh *et al.* 2002) demonstrate that some individual dugongs undertake movements at the spatial scale suggested by the aerial surveys. An adult female moved 600km between two sites in the Gulf of Carpentaria over about five days (Preen 1995). Another male travelled a straight-line distance of 140km, three times in six weeks between two localities in the Central Section of the GBR (Marsh and Rathbun 1990). Of the ten dugongs fitted with satellite transmitters in Shoalwater Bay in the Southern Section of the GBR by Preen (1999), four made substantial trips out of that bay. Two made return trips: one 100m north, the other 220km north. Two other animals journeyed 400km south to Hervey Bay where their transmitters came off. Thirteen dugongs were tracked between the Townsville and Hinchinbrook Island region in Queensland. Twelve trips were made of more than 30km beyond the area regularly used by these animals, six trips of more than 100 km and one trip of more than 600km (Preen 2001). Most of these movements were return trips. For example, the animal that moved more than 600km north returned to her capture point after five months and almost immediately moved another 165km south along the coast. The movements of this dugong thus spanned about 800km of coast.

Table 8. Evidence for significant changes in dugong abundance between and within survey areas suggested by standardised aerial surveys in Australia. All estimates have been derived using the method of Marsh and Sinclair (1989a).

Region	Evidence of significant change in dugong abundance suggested by standardised aerial surveys: Date	Population estimate + s.e.[1]	Likely reason for change
Torres Strait Qld (Marsh et al 1997a, 1997b, this report)	1987 1991 1996 2001	13319 + 2136 a 24225 +3276 b 27881 + 3216c 14106 + 2314a	Unknown. Anecdotal reports of seagrass dieback in 1991-92 in northern Torres Strait and in 1999 and 2001 in the Orman Reef area
Northern GBR Qld Marsh and Lawler (2002)	1985 1990 1995 2000	7925+ 1068 10176+1575 7843+ 1155 9081+ 917	Major change was between survey blocks in 2002 relative to the other surveys. The reason for this change is unknown
Southern GBR Qld (Marsh *et al.* 1996a, Marsh and Lawler 2001)	1986/87 1992 1994 1999	3479 + 459 a 1857 + 292 b 1682 + 236 b 3993 + 641 a	Unknown
Hervey Bay Qld[3] (blocks 1-4) (Preen and Marsh 1995; Marsh *et al.* 1996a, Marsh and Lawler 2001, Lawler 2002)	1988 1992 1993 1994 1999 2001 Nov.[2]	2206+ 420 1109+383 521-571+126 775+150 1473+242 a 1708 ±392 a	1000 km^2 seagrass lost in 1992 after episodic disturbance; some seagrass loss in 1999
Moreton Bay Qld[3,4] (Marsh *et al.* 1990, Lanyon 2003, Lawler 2002)	1988 1995 2000 Dec 2001 Apr 2001 Nov	458 ±78 366+159 – 896 + 201[5] 344+88a 366+41a 493+45a	Outbreak of toxic blue-green alga *Lyngbea* on seagrass beds in March 2002
Shark Bay, W.A. (Marsh *et al.* 1994; Preen *et al.* 1997, Gales *et al.*2004)	1989 1994 1999	10146 + 1665a 10529 + 1464a 13929 + 1793	Seagrass loss in Exmouth Gulf after episodic disturbance in 1999
Exmouth Gulf/Ningaloo , W.A. (Preen *et al.* 1997, Gales *et al.*2004; Prince *et al.* 2001)	1989 1994 1999 2000	1062 + 321a 1006 + 494a 337 too small to estimate	Seagrass loss in Exmouth Gulf after episodic disturbance in 1999 Time x Block Interaction significant for 1989-94 comparison; 1999 –2000 comparisons n.a.

[1] Populations estimates that have same letters after them within a temporal series have been shown statistically not to be significantly different from each other

[2] Hervey Bay was also incompletely surveyed (block 5 omitted) by Lawler in April 2001. The resultant population estimate was 919 ± 146

[3] Population estimates confounded by slightly different survey techniques. Surveys by Heinsohn and Marsh (1980) and Preen (1993) have not been included as no correction factors were used.

[4] Moreton Bay was also incompletely surveyed in 1999 Due to poor weather, (Marsh and Lawler 2001). The resultant population estimate was 171 ± 76

[5] Series of bi-monthly surveys conducted by Lanyon (2003)

Reasons for Temporal Changes in the Size of the Dugong Population of Torres Strait: the Role of Seagrass Dieback

Although the reasons for the significant variation in most of the dugong populations estimates between surveys listed in Table 8 have not been confirmed, the most plausible reason is large-scale movements of dugongs in response to seagrass dieback. Episodic losses of hundreds of square kilometres of seagrass are associated with extreme weather events such as some cyclones, hurricanes and floods (Poiner and Peterken 1996). Such losses have been recorded in Torres Strait and in other regions of northern Australia. For example, in the Gulf of Carpentaria in 1985, cyclone Sandy caused the loss of 151km^2 of seagrass, representing ~20% of the Gulf's entire seagrass area. More than 1000km^2 of seagrass were lost in Hervey Bay, Queensland in 1992–93, probably because of high turbidities resulting from flooding of local rivers, and runoff turbulence from a cyclone three weeks later (Preen *et al.* 1995, Preen and Marsh 1995). Seagrass was also lost from the Hervey Bay region after floods in February 1999 (McKenzie et *al*. 2000). However, the impact on the dugongs was less than in previous floods, presumably because the magnitude of the loss was less and it was less critical dugong habitat.

Islanders observed a major dieback of seagrasses in waters extending from Badu Island south to Thursday Island in the early 1970s. The former seagrass habitats were covered by sand (Johannes and MacFarlane 1991). The cause of the dieback was never established. Some Islanders blamed the *Oceanic Grandeur* oil spill in 1970, but the limited scientific evidence does not support this hypothesis (see Johannes and McFarlane 1991 for a more complete account of this controversy). Thus it is not known whether the sand deposits were a cause or a consequence of the seagrass dieback. In 1991–92 several hundred square kilometres of seagrass disappeared from Torres Strait north of Turnagain Island (Figure 3), probably because of high turbidities resulting from flooding of river(s) in Papua New Guinea coincident with an ENSO event (Poiner and Peterkin, 1996). We received anecdotal reports from fishers who reported seagrass dieback in the Orman Reef area (the most important dugong habitat in Torres Strait) in 1999-2000, coincident with reduced recruitment in the lobster fishery (Pitcher *et al.* 2002). During our 2001 survey, we noted turbid water not only along the Papua New Guinea coastline (which is normal) but extending south to about the latitude of Turnagain (Buru) Island (a phenomenon which was not recorded during the previous aerial surveys in 1987, 1991 and 1996). If this turbid water was present over an extended period, we predict that it may have caused additional seagrass dieback in the region north of Turnagain Is due to light reduction as discussed below.

Extreme weather events can cause extensive damage to seagrass communities through severe wave action, shifting sand, adverse changes in salinity and light reduction (Heinsohn and Spain 1974; Kenyon and Poiner 1987; Preen and Marsh 1995; Preen *et al.* 1995). Recovery and recolonisation after large-scale losses of tropical seagrasses may take up to a decade or more (Poiner and Peterken 1996). For example, the recovery from the dieback in Torres Strait in the early 1970s was not reported until the early 1980s (Johannes and MacFarlane 1991). *Halophila ovalis*, one of the preferred food species of dugongs, appears to be particularly sensitive to light reduction, with the duration and frequency of light-deprivation events apparently being the primary factors affecting the survival of this seagrass in environments that experience transient light deprivation (Longstaff *et al.*1999). During light-deprivation experiments, the biomass of *H. ovalis* declined rapidly and recovered slowly, with a complete die-off occurring after 30 days of deprivation (Longstaff *et al.* 1999). Members of the genus *Halophila* occur at greater depths than other species of tropical seagrasses and this sensitivity to light reduction is a plausible explanation of the large-scale loss of deep-water seagrasses in Torres Strait (Poiner and Peterken 1996) and Hervey Bay in Queensland, Australia (Preen *et al*. 1995).

Dugongs apparently respond in one of two ways to large-scale seagrass loss. Some animals remain in the area losing body condition and delaying breeding; others move hundreds of kilometres with varying probabilities of survival. For example, after the loss of seagrass in Hervey Bay in 1992, the estimated size of the dugong population in the Hervey Bay region declined from 2206± s.e.420 in 1988 to 521-571±s.e.126 in 1993. A total of 99 dugong carcasses were recovered in the Hervey Bay area, on the central and southern Queensland coast and along the New South Wales coast (Preen and Marsh 1995). Most animals appeared to have died of starvation. The percentage of the population remaining in Hervey Bay that was identified as calves on the basis of aerial surveys plummeted from 22.5% in 1998 to 2.2% in 1993 and 1.55% in 1994 (Marsh *et al.* 1996a). The seagrass in the area had recovered by late 1998 (R. Coles *pers comm.* 1999) and the dugong population estimated by aerial survey had increased to 1473± s.e.242 by 1999. As such an increase is biologically impossible in the absence of migration, we assume that dugongs migrated to the region as the seagrass recovered.

The response to seagrass loss seems similar in Torres Strait. The Islanders interviewed by Johannes and MacFarlane (1991) were unanimous that an unusually high proportion of dugongs (and green turtles) caught in Torres Strait during the 1970s were lethargic, thin and poor-tasting *wati dangal*. Niestchmann (1985) reported an unusually high proportion of algae, and the seagrasses *Thalassia* and *Enhalus* in the stomach contents of dugongs caught in 1976-77. Spain and Heinsohn (1973) also report dugongs eating unusually high proportions of algae, *Thalassia* and *Cymodcea* when seagrass was in short supply after a cyclone near Townsville in 1971. Dugongs do not appear to be well adapted to using algae as a food source and apparently prefer seagrass species such as *Halophila* and *Halodule* rather than *Thalassia*, *Cymodocea* and *Enhalus* (Marsh *et al.* 1982).

Hudson (1986) presents anecdotal evidence that none of the 35 female dugongs landed at Daru between November 1976 and July 1997 was pregnant. Kwan (2002) reports a gap in the age distribution of dugongs caught at Mabuiag in 1997-98 corresponding to animals, which should have been born in the late 1970s. These results suggest that recruitment failure was widespread in dugongs in Torres Strait at the time of seagrass dieback. Conversely, Marsh (1995) reports a monotonic increase in the pregnancy rate of dugongs landed in Daru between 1978 and 1981, the period of reported seagrass recovery.

The aerial survey conducted in November 1991 indicated that, in spite of the loss of 1000 km^2 seagrass habitat in northern Torres Strait (which is not major dugong habitat see Figure 3) during the wet season in 1990-91 (Long *et al*. 1997), the dugong population of the entire Torres Strait survey region (Figure 1) was significantly higher than in 1987, a result attributed to large-scale immigration of dugongs into the survey region (Marsh *et al.* 1997a). Given the anecdotal reports of seagrass dieback in the Orman Reef area (the most important dugong habitat in Torres Strait) in 1999-2000 (Pitcher *et al*. 2002), it is salient that, not only was the dugong population in Block 2A significantly lower than during the 1991 and 1996 surveys (Figure 5), but the percentage calves in the region of the reported seagrass dieback around Orman Reef plus the region where we observed the turbid water (Blocks 0, 1A, 1B, 2A and 2b) was only 5.2%, significantly lower than the 19.2% reported from the region to the west (Block 3) and south (Block 4) where no seagrass dieback was reported.

To date, the approach to seagrass protection has largely been through marine parks and fishing industry closures to prevent structural damage to seagrass beds through trawling. There have been few attempts to protect seagrass beds from adverse impacts on ecosystem processes associated with land use, even though such impacts have been recorded as of concern in most of the countries in the dugong's range for which information is available (Marsh *et al.* 2002). Localities that provide shelter and water conditions ideal for seagrasses are often at the down-stream end of catchments severely affected by land use practices (Lee Long and Coles 1997). It will be important to investigate whether clearing in the catchments draining into the Papua New Guinea waters of Torres Strait is affecting water quality in the region. Considerable research has been conducted on the likely impacts of heavy metals from the Ok Tedi mine via the Fly River system on the biota of Torres Strait (e.g., Dight and Gladstone 1993, Gladstone 1996, Haynes and Kwan 2001). We suggest that comparable research effort should be directed at the impacts of the runoff from the other rivers entering Torres Strait from the Western Province of PNG on the Torres Strait seagrass ecosystem.

Local Movements

The results of the split-plot analysis of variance (Table 5; see relatively large among transect within block variation) suggest that dugongs make substantial small-scale movements within survey blocks over time. This result is supported by traditional knowledge from Torres Strait and western science information. Neitschmann and Neitschmann (1981) and Johannes and MacFarlane (1991) document the considerable body of traditional knowledge of Torres Strait peoples with respect to local dugong movements including information on how movements are affected by season, tide, weather conditions and hunting activity. Results of the satellite tracking of dugongs on the east coast confirm that most movements of dugongs are local (Marsh and Rathbun 1990, Preen 1993; Marsh *et al*. 2002). Marsh *et al.* (1996b) conducted aerial surveys of Block 2A in Torres Strait on two successive days in 1993 and four successive days in 1994. The results showed that there were low rates of movement between sampling days within years but a significant difference between years.

Areas in Torres Strait that are Consistently Important to Dugongs

The among-blocks variance component was relatively large in the split-plot ANOVA (Table 5) suggesting that some parts of the region (e.g., especially Block 2A) are consistently much more important to dugongs than others. Figure 5 shows that this pattern is evident for all the surveys in the period 1987-2001, despite the large-scale movements of dugongs suggested by Table 8. The situation is similar in the other major dugong areas along the eastern coast of Australia and in the Queensland waters in the Gulf of Carpentaria and is the rationale behind the zonal protection of dugongs in the Great Barrier Reef Region, Hervey Bay and Moreton Bay (Marsh *et al*. 1998; Marsh 2000; Marsh and Lawler 2001, 2002; Lawler 2002). If zonal protection such as spatial closure(s) to hunting is to continue as a part of the strategy to conserve dugongs in Torres Strait, it would be advisable to discuss with the Islanders the possibility of formally closing some of the deepwater areas in Block 2A to hunting and possibly to other extractive marine activities. Although the present dugong sanctuary has the potential to offer some protection, it is clearly not in the highest density habitat for dugongs in Torres Strait (Figure 3).

Preliminary Estimates of a Sustainable Harvest

Unfortunately the magnitude of the effects of emigration or immigration on the size of a dugong population cannot easily be disaggregated from the effects of population depletion from over-harvesting. Thus the trends detected by aerial surveys are not a reliable index of the status of the Torres Strait dugong population. Even it they were, relying on population trends to trigger management actions is likely to be an insensitive approach as trends are not likely to be detected until a population is seriously depleted (Taylor and Gerrodette 1993, see also Wade 1998).

Table 9. The annual catch of dugongs landed in various Torres Strait communities obtained by various methods (From Kwan 2002 adapted from Marsh 1998).

Area	Method of estimating catch	Date	Estimated annual dugong catch	References
Mabuiag Is.	Limited continuous	1973	24	Bertram and Bertram 1973
	Continuous	1977	103	Nietschmann 1985
	Limited continuous	1983-84	12	Johannes and MacFarlane 1991
	Survey	1994	274 (s.e. 175) 145	Harris *et al.* 1994
	Continuous (9 mths)	1998	170	Kwan 2002
	Continuous (9 mths)	1999	183 (s.e. 77)	Kwan 2002
	Survey	1999	238 (s.e. 67)	Skewes *et al.* 2002[1]
	Survey	2000		Skewes *et al.* 2002[1]
Badu Is.	Survey	1994	107(s.e. 80)	Harris *et al*. 1997
	Survey	1999	200 (s.e. 66)	Skewes *et al*. 2002[1]
	Survey	2000	166 (s.e. 65)	Skewes *et al*. 2002[1]
Boigu Is.	Survey	494	256(s.e. 110)	Harris *et al.* 1997
	Survey	1999	128 (s.e. 59)	Skewes *et al*. 2002[1]
	Survey	2000	87 (26 s.e.)	Skewes *et al*. 2002[1]
TSPZ[2]	Continuous (no confidence limits)	1976-78	750	Nietschmann 1985
	Limited continuous (no confidence limits)	1983-86	110-130	Johannes and MacFarlane 1991
	Continuous	1991-92	954	Harris and Nona 1997
	Survey	1991-92	1010 (s.e. 240)	Harris *et al.* 1994
	Survey	1991-93	1226 (s.e. 204)[3]	Harris *et al.* 1994
	Survey	1994	860 (s.e. 241) 241	Harris *et al.* 1997
	Survey	1996	(s.e. 92)	Skewes *et al.* 2002 [1,4]
	Survey	1998	256 (s.e. 136)	Skewes *et al.* 2002[5]
	Survey	1999	692 (s.e. 150)	Skewes *et al.* 2002
	Survey	2000/01	619 (s.e. 134)	Skewes *et al.* 2002
Bamaga	Survey	1997	116	M. Bishop pers. comm. 1997
Injinoo	Survey	Jan 1999-August 2000	14 in 3 days	M. Phelan unpublished data
Daru, PNG	Continuous	1976-77[5]	74-120	Hudson 1986
	Continuous	1978-83[5]	463	Hudson 1986

[1] Catch estimates for 1996 and 1998 rejected by TSFSAC because of low precision and potential bias
[2] Includes total catch for the TSPZ including Mabuiag, Badu and Boigu Islands. Nietschmann recorded a catch of 243 animals from the 3 mid western islands alone.
[3] Considered to be biased upwards
[4] Considered to be biased downwards
[5] Catch statistics recorded during period when dugong meat was legally sold in the Daru market

Evaluating whether or not the population can support the known level of harvesting is likely to be a less risky approach (Wade 1998). Acknowledging the inadequacies in both data sets, comparison of the results of the Potential Biological Removal modelling (Table 7) with the information on the dugong catch Torres Strait (Table 9) suggests that the current level of dugong harvest is unsustainable, especially given that: (1) the catch mostly estimates do not include data from the Northern Peninsula Area, the Inner Islands and Papua New Guinea (or West Papua); and (2) the aerial survey evidence that many dugongs migrated out of the area between November 1996 and November 2002. Based on the 1996 population estimate of 27881 ± s.e. 3216, Marsh (1998) suggested that a total harvest of 500 dugongs per year should be sustainable using the conservative Potential Biological Removal Method. This figure was based on the assumption that the relative estimate of dugong abundance obtained from aerial survey was very conservative. The revised estimate of absolute abundance obtained by the method of Pollock *et al.* (2004) indicate that this is not the case and that the estimates obtained from the 1987, 1991 and 1996 surveys are likely to be close to or lower than the absolute estimates of dugong abundance in the survey region at the times of those surveys. Thus we estimate that the sustainable harvest is about 190 for the entire region including the harvest from Daru and the other Papua New Guinea communities along the coast, the Protected Zone, the Inner Islands and the Northern Peninsula Area based on the 1996 abundance estimate and assuming a Recovery Factor of 0.5. The corresponding figure based on the 2001 population estimates is about 80-90 dugongs, which is substantially less than the harvest between April and September 1998 and 1999 from a single major hunting community - Mabuiag Island (Kwan 2002).

If the hunters tend to target females (Johannes and MacFarlane 1991, Skewes *et al.* 2002), these values are over-estimates and the more conservative Recovery Factor of 0.1 should be used. This approach suggest that the fishery should be closed, a move that we consider would be impossible to implement without considerable Islander support. The significant temporal change in the ratio of females to males in the catch from 2.0:1in 1990-1992 (Harris *et al.* 1997) to 1.3 to 1 in1996-2001 (Skewes *et al*. 2002) is a further cause for concern.

Skewes *et al.* (2002) point out that the AFMA/CSIRO dugong catch estimates for the Torres Strait Protected Zone in 1999 and 2000/01 (which are thought to be more reliable than those for 1996 and 1998) are significantly less than those obtained in 1991-93 using the same methodology. The significance of this result is uncertain because of the absence of reliable information on hunting effort and the changing availability of dugongs in the hunting grounds (Table 4). However, it adds to the concern about the status of the Torres Strait dugong stock as does Heinsohn *et al*'s. 2004 conclusion that the dugong was seriously over-harvested in Torres Strait using the technique of PVA modelling.

Of course, the estimated sustainable harvest would also be higher, if it were decided to manage the Torres Strait dugong population as a fishery for sustainable yield rather than as a depleted population of a threatened species. Menham *et al*. (2002) discuss the implications of managing the Torres Strait dugong population as a fishery and conclude that the dugong population of Torres Strait is currently over-harvested irrespective of the underlying management approach. They express reservations about the use of traditional fisheries models that are based on assumptions related to sustainable yields in fish and invertebrates for a marine mammal such as the dugong. We share this concern. The basis on which the dugong fishery is to be managed needs to be discussed at the stock assessment workshop proposed by AFMA. As the Torres Strait dugong stock also ranges into the Great Barrier Reef World Heritage Area (where managers are required to manage the dugong in a manner which retains that region's World Heritage values), this is also an important matter for cross-jurisdictional discussion, especially as Heinsohn *et al*. (2004) also conclude that the dugong is over-harvested in the Northern Great Barrier Reef.

Management Outcomes

Development of community-based management

The evidence presented in this report and by Heinsohn (2004) that dugongs are being seriously over-harvested in Torres Strait indicates that the present system of unrestricted dugong hunting is not sustainable. For many years, there have been calls for community-based management by Torres Strait Islander peoples hunting in Australian waters (e.g., resolution from the workshop Towards Community-Based Management of Dugongs and Turtles in Torres Strait held by AFMA in June 1998) and scientists (e.g., see Johannes and MacFarlane 1991, Marsh 1996, Marsh *et a*l 1997a and b, Marsh 1998, Kwan 2002; Menham *et al*. 2002), but there has been little progress to date. In contrast there was considerable progress with community-based management in the Western Province of Papua New Guinea (especially

Daru) in the early 1980s (Hudson 1986), but that initiative lapsed after its champion (Hudson) left Papua New Guinea.

As noted above, AFMA co-coordinated a workshop in 1998 attended by Islander leaders, management agency staff and scientists on Thursday Island entitled ‘Towards Community-Based Management of Dugongs and Turtles in Torres Strait’. The attendees developed the following Mission Statement to guide the future of hunting management for dugongs and turtles in Torres Strait.

> *Effective community based management of dugongs and turtles conducted in a way which maintains Ailan Kastom and ensures the long-term survival of these species as an essential component of Torres Strait culture, identity and sea life*

The workshop recognised that the achievement of this vision was conditional on the funding being available to implement a regional strategy and associated community management plans for dugongs (and green turtles). The meeting resolved that these arrangements would be developed and implemented by the Islander Co-ordinating Council in cooperation with the Torres Strait Islander communities and relevant agencies. The meeting also recognised the need to develop a strategy for the training, employment and resourcing of community rangers in a way that focused on the needs of Torres Strait and the need to secure funding to enable this to be implemented as soon as possible.

Progress on implementing the outcomes of this workshop has been slow as has been recognised by AFMA. In August 2002, AFMA and TSRA held another workshop entitled ‘Towards Community-Based Management Brainstorming Workshop’. This workshop was followed by community visits to canvas various options with a view to convening a further workshop to present draft management plans and discuss outcomes. In 2003, the Australian Minister of Environment instructed that this matter be addressed with high priority and management agency staff are working with traditional owners to develop a mutually -acceptable, framework for sustainable dugong hunting. In addition, considerable funding has recently been identified for community-based management and catch monitoring initiatives.

We consider that it is advisable that community-based management of hunting be given legal status rather than be dependent on administrative arrangements that be changed easily. Within the Great Barrier Reef Region Traditional Use Marine Resource Management Agreements (TUMRAs) are being developed with Indigenous communities under the *Great Barrier Reef Marine Park Act 1975,* the *Great Barrier Reef Marine Park Regulations 1983*. These agreements will describe how individual groups would like to manage the traditional use of marine resources in their sea country areas and will be consistent with the *Native Title Act 1993*. The development of parallel initiatives consistent with the statutory environment in Torres Strait needs to be progressed as a matter of urgency. We suggest that the legislative options for regulating community-based management of hunting in Torres Strait be formally investigated and if necessary Torres Strait fisheries legislation be revised as requested by Waia (2001).

Experience in the Great Barrier Reef region has shown that the development of community-based management plans for dugong and turtle hunting is achievable as exemplified by *Guugu Yimmithirr Bama Wii* (HVAC 1999*)*, the turtle and dugong hunting management plan developed by Hope Vale community which won the Prime Ministers’ Community Environment Award in 2000. Despite this accolade, this plan has not been implemented partially because the community has not been able to access the resources required to acquire the necessary infrastructure and capacity (see Marsh 2003 for details).

Young, Ross and their co-workers (see Davies *et al.* 1999 for details) have pointed out that management of country, including wildlife, provides a logical basis for building community capacity. A formal link between community development and ‘caring for country’ would have the potential to help the Torres Strait communities address some if their social and economic problems and may open up additional sources of funding. Grounding community development in ‘caring for country’ is an excellent long-term investment because community development would then strengthen ties to traditional land (Davies *et al*. 1999). The need to break the cycle of welfare dependency for remote indigenous communities in northern

Australia has been recognised by indigenous leaders, especially Noel Pearson, and by the Queensland and Commonwealth governments. The development of hunting management in Torres Strait should be considered as part of broader ‘caring for country’ initiatives such as MASTERS (Mulrennan and Hanssen 1994) in the context of community development.

We suggest that in view of the results of the evidence presented here and in Heinsohn (2004) that dugongs are over-harvested in Torres Strait, discussions regarding the development and implementation of community-based management of hunting in Torres Strait be progressed as a matter of urgency with a view to developing concrete initiatives for management planning and *implementation*. Experience in the Great Barrier Reef Region (Marsh 2003) indicates the implementation of community-based management is much more challenging than the development of hunting management plans *per se*.

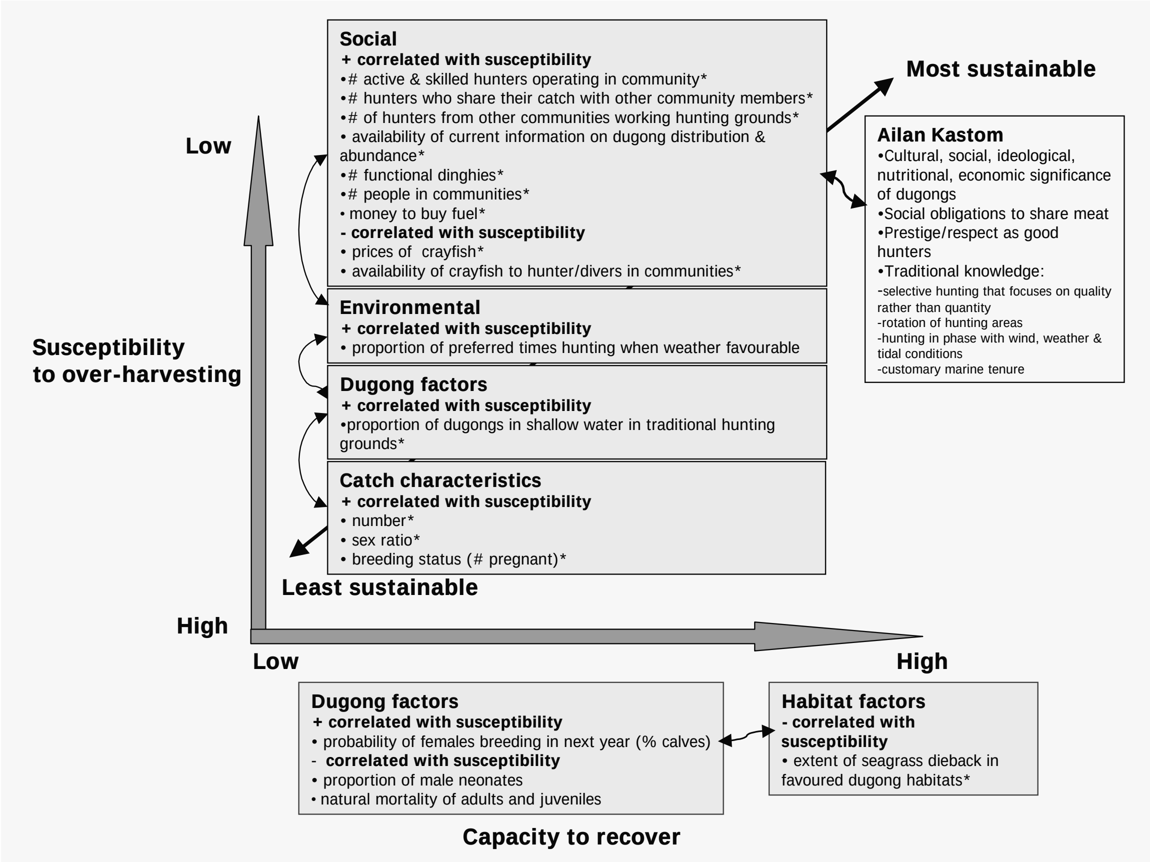
In 1985, an 800-km^2 dugong sanctuary was established in Western Torres Strait after extensive consultation between managers and Torres Strait Islander peoples. To date, this sanctuary has been a ‘paper park’ without effective management. For example, we understand that many Islanders are unaware of its existence. If this sanctuary is to be effective, a plan for its management must be developed and implemented. Another option that might be discussed as part of a regional strategy to protect dugongs in Torres Strait is the development of a dugong sanctuary – a ‘no-take’ Marine Protected Area in part of the most important dugong habitat in Torres Strait, the deepwater area to the between Orman Reef and Gabba Island. Closing this area to hunting and fishing activities would be of considerable conservation benefit. The reasons for suggesting that the area be closed to fishing are twofold: (1) dugongs are caught incidentally on fishing trips, and (2) some Islanders are concerned that boating activity frightens dugongs away (Johannes and MacFarlane 1991). This option could be canvassed in the Northern Regional Marine Planning Process currently being conducted by the National Oceans Office.

Monitoring catch and other factors

The likelihood of dugongs undertaking large-scale movements between aerial surveys suggested by Table 8 means that the effects of dugong movements and any reduction of the population resulting from over-harvesting are confounded and impossible to disaggregate by monitoring the population via aerial surveys, except over very long time-frames. As discussed above, the use of the Potential Biological Removal technique to estimate a sustainable harvest is a more promising approach but requires considerable data on absolute population size and maximum rate of population increase both of which exhibit considerable temporal variation in Torres Strait (Table 4, Figure 4; Marsh 1999, Kwan 2002). Accordingly, we suggest the following community initiatives to provide additional indicators of whether dugong hunting is sustainable in Torres Strait at any point in time.

Stobutzki *et al.* (2001) defined a sustainable fishery as one in which the ability for renewal of the species caught does not exceed the impact of the fishery. They developed a ‘broadbrush’ method of examining the likely impact of prawn trawling on the sustainability of bycatch species by identifying those species least likely to be sustainable in the bycatch, on the assumption that these species would need further research and management actions to protect them. The process focused on two major factors that determined sustainability: (1) each species’ susceptibility to capture and mortality, and (2) the inherent capacity of each species to recover after a population is depleted. Each component contributing to the score on in each axis was derived from relevant criteria and aspects of the biology and ecology of the species involved.

Kwan (2002) modified this process to conceptualise temporal changes in the sustainability of the dugong fishery (as a single species fishery) in Torres Strait (Kwan 2002). Her model was used to illustrate the complex interactions of different factors that determine the temporal variability in the susceptibility of the dugong fishery to over-harvesting and the capacity of the population to recover in the event of depletion over-harvesting (Figure 6).



* Components that are readily identified by anecdotal or monitoring data that can be obtained by communities with assistance from AFMA.

Figure 6. A conceptual model outlining the main factors influencing the sustainability of the dugong fishery in Torres Strait (adapted from Stobutzki *et al*. 2001; see Kwan 2002). Kwan (2002) defined the components of this model, which are not ranked. The correlation of the individual components with an increased or decreased risk of unsustainable harvests is indicated. Reproduced from Kwan (2002).

According to the model, the sustainability of the dugong fishery is dependent upon factors that determine:

(1) The susceptibility of the fishery to over-harvesting such as:

- the imperative of meeting the basic social and cultural needs of Torres Strait Islanders (see Folke *et al.* 2000) within *Ailan Kastom*;

- the economic imperative of meeting the basic material needs of Torres Strait Islanders (i.e., the importance of the dugong fishery to the diet of some Islanders and the socio-economic implications of interactions with other fisheries, especially the lobster fishery) (see Folke *et al.* 2000).

- the environmental, temporal and spatial factors that determine hunting pressure as identified by Kwan (2002)

(2) The capacity of the population to recover after depletion:

- i.e., the major factors that affect the life history and population dynamics of dugongs that affect the population to recover in the event of depletion harvesting (see Kwan 2002 for details).

As outlined in Figure 6, knowledge of the major factors affecting hunting effort and catch rates should improve management by enabling actions to be more directly focused on aspects which increase the susceptibility of the traditional fishery in Torres Strait to over-harvesting.

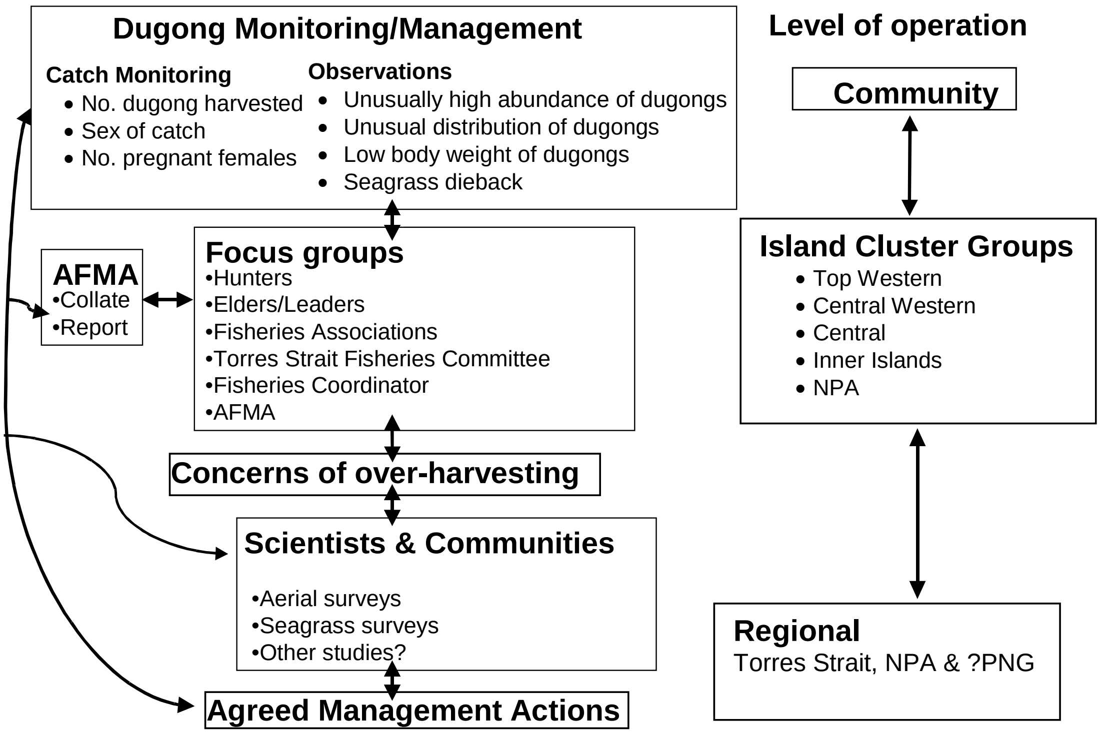
In remote areas such as Torres Strait where long-term data are incomplete or unavailable, anecdotal information from fishers (e.g., about dugong movements, see above) provides the only source of information on historical changes in local marine stocks and marine environmental conditions (see Johannes *et al*. 2000). There is potential to use such anecdotal information to enable Islander communities to be actively involved in monitoring the status of their dugong fishery as part of community-based management. Figure 7 indicates that there are various components in the model that can provide important anecdotal information that should be easily obtained by and from community members. For example, information on the number of dugongs in hunting areas, whether hunters have money to buy fuel or if there is any dieback in the hunting areas is usually anecdotal information that is widely known within the community. This information could contribute to assessments of the risks of over-harvesting in the dugong fishery (Figure 7).

Given the current interest in developing and implementing community catch monitoring programs in Torres Strait, we suggest that it should be feasible for communities to be provided with the capacity to record information such as:

- the number of active hunters landing dugongs in a community
- the home communities of these hunters,
- the number of functional dinghies in a community
- catch information including the number of dugongs caught, their catch sex ratio and the number of pregnant females.

Given the negative correlation between dugong and lobster catches (Johannes and MacFarlane 1991, Kwan 2002), information on the lobster catches landed in communities, which is routinely collected by AFMA, could be used supplement the information discussed above in community-based assessments of the likely status of the dugong fishery.

Regular focus groups co-coordinated by the Community Fisheries Associations (facilitated by the TSRA Fisheries Co-coordinator and relevant Fisheries Task Force members) and supported by AFMA could meet to discuss, clarify, collate and/or review these findings (Figure 7). In the event of any apparent risk of over-harvesting, scientists could be consulted to undertake additional research as required. The focus groups and the communities in collaboration with AFMA could then consider if any management actions are necessary (Figure 7).



Island Cluster Groups - Top Western: Boigu, Saibai and Dauan Is.; Central Western: Mabuaig, Badu and Moa Is.; Central: Yam; Inner Islands: Thursday, Horn, Prince of Wales and Hammond Is.; NPA: Siesia, Bamaga, New Mapoon, Injinoo and Umagico.

Figure 7. A process by which information (shown in Figure 6) could be obtained and used by communities, their fisheries representatives and AFMA to assess the status of the dugong fishery when risks of over-harvesting are evident.

Given the importance of the dugong fishery to the peoples of Torres Strait, we consider that discussions should be continued to develop a program to monitor the dugong catch and the other factors influencing the harvest of dugongs identified by Kwan (2002). In our opinion catch monitoring should be the highest priority component of a comprehensive program of community-based management of the dugong fishery in the Torres Strait region (including the Western Province of Papua New Guinea and the Northern Peninsula Area). The catch monitoring workshop held in May 2003 (AFMA 2003) was a promising start to this process and the project on catch monitoring currently being conducted by CRC Torres Strait Ltd should provide a robust information base for monitoring the catch of dugongs and turtles, particularly in the inner Island communities.

Cross-jurisdictional Initiatives

As documented above and in Marsh *et al.* (2002), there is now considerable evidence from both aerial surveys and satellite tracking, that dugongs move across jurisdictions both internationally and within Australian waters. Although the *Torres Strait Treaty* recognises that dugong management in Torres Strait is an issue for both the Australian and Papua New Guinean Governments, there has been much less formal acknowledgment of the need for cross-jurisdictional management within Australian waters.

Unfortunately, the large-scale aerial surveys conducted every five years or so since the 1980s in both the Great Barrier Reef region and Torres Strait have been staggered across years (see Table 8) for funding and logistical reasons. The corresponding surveys in the Gulf of Carpentaria have been conducted on an opportunity basis. Except in Western Australia (Table 8), the surveys provide limited evidence of actual dugong movements between survey regions. Nonetheless, the anecdotal evidence presented above suggests that dugongs moved from Torres Strait to the Northern Peninsula Area and the Gulf of Carpentaria in 2001/2002 with an associated increase in anthropogenic mortality. There is also evidence from aerial surveys, that dugongs were present (Heinsohn 1976, Ligon 1976, Heinsohn and Marsh 1978) and hunted (Anderson and Heinsohn 1978) off the west coast of Cape York in the 1970s, in areas where they were not hunted traditionally (Chase 1981) and where there is usually a relatively small area of seagrass (in 1986 the total area of seagrass between Albany Island (Cape York) and Tarrant Point (southern Gulf of Carpentaria) was 184.4 km^2 in 1986, less than the 225 km^2 in the Wellesley Island area alone in 1984 (Coles *et al.* 2002). Dugongs have not been seen in this area on the limited aerial surveys that have been conducted subsequently (Marsh *et al.* 1998). Taken together, this information in consistent with dugongs moving into the Gulf of Carpentaria from Torres Strait coincident with the Torres Strait seagrass dieback in the 1970s as well as in 2001/2.

In view of this evidence for large-scale movements and the lack of evidence of clearly defined stock boundaries for dugongs in the coastal waters of northern Australia, dugong research and management clearly need to be coordinated within Australian waters as well as between Australia and Papua New Guinea. We suggest that this report and associated plain-English summary widely circulated among relevant indigenous leaders via the Torres Strait Regional Authority and other major indigenous representative bodies in northern Australia, plus managers and scientists in Papua New Guinea and the Commonwealth, Queensland and Northern Territory Governments.

The challenge of ensuring that traditional hunting of dugongs is sustainable in the waters of tropical Australia including Torres Strait has many parallels with Inuit whaling. Freeman *et al*. (1998) review the various whaling management regimes that have developed in the Arctic including the Alaska Eskimo Whaling Commission, the Alaska Beluga Whale Committee, the Beaufort Sea Beluga Management Plan, the Southeast Baffin Beluga Management Plan, and the Canada-Greenland Joint Commission on Narwhal and Beluga. All of these initiatives have taken many years to mature (Freeman *et al*. 1998). None is entirely appropriate for the management of dugongs and green turtles in tropical Australia/ Torres Strait but they all contain elements that we suggest should be included in the terms of reference of any discussions. These elements include:

- Protection and enhancement of indigenous culture, traditions and activities associated with the sustainable traditional hunting of the target species.
- Preservation and enhancement of the marine resources used by the target species and the protection of habitat.
- Research and educational activities that incorporate both western science and traditional knowledge.

Conclusion

This project met its objective to evaluate the status of the dugong in Torres Strait and the likely sustainability of the Torres Straight Fishery by: (1) conducting an aerial survey to quantify the distribution and relative abundance of the dugong , (2) using data from the aerial survey to estimate the absolute abundance of dugong in Torres Strait, (3) comparing AFMA estimates of the current harvest of the dugong in the traditional fishery in Torres Strait with the sustainable yield estimated using the Potential Biological Removal Method and (4) communicating this information to the Torres Strait Islander community to assist in the development of community-based management of the dugong fishery.

This report supports earlier concerns that dugongs are over-harvested in Torres Strait and provides the strongest evidence to date that this over-harvest is significant. The current harvest of the whole Torres Strait region is probably at least an order of magnitude too high if the dugong is to be managed as threatened species as required by Queensland legislation. Current discussions regarding the development and implementation of community-based management of hunting in Torres Strait must be progressed as a matter of urgency with a view to developing concrete initiatives for management planning and implementation.

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Appendices

Appendix Table 1. Raw data used for calculation of correction factors for dugongs for the survey using the method of Marsh and Sinclair (1989a).

a. *Correction for perception bias*

Blocks: Transects	No. of groups of dugongs					
	Port			**Starboard**		
	Mid	**Rear**	**Tandem**	**Mid**	**Rear**	**Tandem**
0, 1A, 2B, 4, 5: all transects **1B: 132, 134** **3: 311-316**	16	3	27	35	2	11
2A: all transects **1B: 112-130** **3: 301-310**	21	15	43	38	17	37

b. *Correction for availability bias (*All sightings used including repeat survey of Block 2A)

	No. of dugongs in groups less than 10		
	Surface	Under	Total
0, 1A, 2B, 4, 5: all transects **1B: 132, 134** **3: 311-316**	60	71	131
2A: all transects **1B: 112-130** **3: 301-310**	77	134	211

Appendix Table 2. Beaufort sea state and glare for each transect. See Figure 1 for transect locations.

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

Transect No.	Beaufort sea state			Glare					
	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
1	1	1	1	2	2	2	0	0	0
10	1	1	1	0	1	0.5	0	0	0
101	1	1	1	0	1	0.5	0	0	0
102	1	1	1	0	0	0	0	0	0
103	1	1	1	0	0	0	0	0	0
104	1	1	1	0	0	0	0	0	0
105	0	0	0	0	0	0	1	1	1
106	0	1	0	0	1	0.5	1	2	1.5
107	0	0	0	0	0	0	0	0	0
108	1	1	1	0	0	0	2	2	2
109	0	0	0	0	0	0	2	2	2
110	0	1	0	0	0	0	2	2	2
112	1	1	1	0	0	0	0	0	0
114	1	1.5	1	1	3	2	0	0	0
116	1	1	1	0	0	0	3	3	3
118	0	1	1	0	0	0	3	3	3
120	1	1	1	0	0	0	3	3	3
122	0	1	0.5	0	1	0	2	3	2
124	1	1	1	0	0	0	2	3	2
126	0	1	0	0	1	0	2	2	2
128	0	0.5	0.5	0	1	0	2	3	3
130	0	1	0	1	1	1	2	2	2
132				0	0	0	0	0	0
134	1	1	1	1	1	1	0	0	0
136	1	1	1	1	2	1.5	0	0	0
138	1	1	1	0	0	0	0	0	0
140	0	0	0	1	1	1	0	0	0
142	1	1	1	0	0	0	0	0	0
144	0	0	0	2	2	2	0	0	0
146	1	1	1	0	0	0	0	0	0
201	0	2	1	2	2	2	2	2	2
202	0.5	1	1	2	2	2	1	3	1
203	0	1	1	1	2	1	2	2	2
204	0	3	1	2	2	2	3	3	3
205	0.5	1	1	1	2	2	2	3	2
206	0.5	1	1	2	2	2	3	3	3
207	1	3	1	2	3	2	3	3	3
208	1		1	2	3	2	2	2	2
209	0	0	1	1	1	1	2	2	2
210	1	3	3	0	3	3	0	2	2
211	1	3	1	2	2	2	3	3	3
212	0.5	3	2	3	3	3	3	3	3
213	1	3	2	2	2	2	2	2	2
214	1	3	1	2	3	2.33	1	2	1.66
215	1	3	3	1	1	1	1	1	1

Transect No.	Beaufort sea state			Glare					
	Min	Max	Mode	Min	Max	Mode	Min	Max	Mode
216	3	3	3	2	3	2.33	2	2	2
217	3	3	3	1	1	1	1	2	1.5
218	2	3	3	1	1	1	1	1	1
219	3	3	3	1	1	1	1	1	1
220	3	3	3	1	1	1	1	1	1
221	3	3	3	1	1	1	1	1	1
222	3	3	3	1	1	1	1	2	1.5
223	3	3	3	1	1	1	1	2	1.5
225	3	3	3	1	1	1	1	1	1
301	1	1	1	0	0	0	0	0	0
302	0		0	0	0	0	3	3	3
303	0	1	0	2	2	2	2	2	2
304	0	1	1	1	1		2	2	2
305	1	1	1	2	3	3	2	3	2
306	0	1.5	1	1	2	1	1	3	1
307	1	3	2	0	2	0	2	3	2
308	2	2	2	1	2	1	2	3	2
309	2	2.5	2	2	2	2	2	2	2
310	2	2	2	2	3	2	1	3	1
311	1	2	1	1	2	1.5	0	1	0.5
312	2	2	2	0	0	0	0	0	0
313	1	2	1	0	0	0	1	1	1
314	2	2	2	0	0	0	0	0	0
315	2	2	2	0	0	0	1	1	1
316	1	2	1	0	0	0	0	0	0
401	2	2	2	1	1	1	1	1	1
402	3	3	3	0	0	0	1	1	1
403	2	2	2	1	1	1	1	1	1
404	2	2	2	0	0	0	2	2	2
405	1	2	2	1	1	1	1	1	1
406	1	1	1	0	0	0	1	1	1
407	1	2	1	1	1	1	1	1	1
408	1	0	3	2	2	2	0	3	0
409	1	3	1	1	2	1	0	3	3
410	1	3	3	2	2	2	3	3	3
411	2	2	2	2	2	2	3	3	3
412	1	3	2	2	2	2	2	3	2
501	3	3	3	1	1	1	0	0	0
502	3	3	3	1	1	1	1	1	1
503	2	2	2	1	1	1	1	1	1
504	2	2	2	0	0	0	0	0	0
505	2	3	2	1	1	1	1	1	1
3051	0	0	0	1	1	1	1	1	1
3061	0	1	0	1	1	1	1	2	1
5041	2	2	2	1	1	1	1	1	1

Appendix Table 3. Raw data for sightings of dugong groups for each transect in each block used for population estimates.

Block, Transect Number	Transect length (over sea only) (km)	Transect area (km^2)	# groups port	# groups starboard
0				
136	38.4	15.36	1	0
138	40.3	16.12	0	0
140	38.7	15.48	0	0
142	36.9	14.76	0	0
144	38.6	15.44	0	0
146	43.9	17.56	0	0
1A				
1	20.3	8.12	0	0
10	20.2	8.08	0	0
101	58.2	23.28	0	0
102	57.6	23.04	1	0
103	53.9	21.56	1	0
104	50.9	20.36	0	0
105	55	22	0	0
106	52.4	20.96	1	0
107	51.5	20.6	2	5
108	49.9	19.96	0	1
109	48.6	19.44	1	1
110	45.9	18.36	1	0
1B				
112	39.6	15.84	0	0
114	33.7	13.48	0	0
116	21.6	8.64	0	0
118	17.6	7.04	0	0
120	25.7	10.28	0	0
122	33.5	13.4	0	0
124	36.5	14.6	0	0
126	37.2	14.88	0	0
128	42.1	16.84	0	1
130	41.4	16.56	2	6
132	39.2	15.68	6	12
134	42	16.8	3	0
2A				
201	67.2	26.88	3	1
202	67.2	26.88	4	6
203	67.3	26.92	6	2
204	67.3	26.92	1	3
205	67.4	26.96	3	4
206	67.4	26.96	3	2
207	67.4	26.96	3	8
208	67.5	27	3	0
209	67.5	27	5	1
210	65.2	26.08	3	4
211	67.6	27.04	2	3
212	67.1	26.84	3	2

Block, Transect Number	Transect length (over sea only) (km)	Transect area (km^2)	# groups port	# groups starboard
213	47.1	18.84	3	7
3051	10.7	4.28	2	0
3052	20.8	8.32	4	4
305	11.8	4.72	0	0
306	13.7	5.48	1	0
2B				
213	25.7	10.28	1	0
214	58.5	23.4	0	0
215	58.5	23.4	1	0
216	58.5	23.4	2	0
217	58.5	23.4	0	0
218	58.5	23.4	0	0
219	58.5	23.4	0	0
220	58.1	23.24	1	1
221	58.5	23.4	1	1
222	58.5	23.4	1	1
223	58.5	23.4	1	1
224	58.5	23.4	0	0
225	24.4	9.76	0	0
3				
301	45.7	18.28	0	1
302	63.1	25.24	0	0
303	63.1	25.24	0	2
304	67.7	27.08	1	1
305	67.7	27.08	2	3
306	54.9	21.96	1	3
307	82.2	32.88	1	1
308	59.6	23.84	0	2
309	58.8	23.52	4	1
310	59.7	23.88	4	2
311	59.7	23.88	3	3
312	67.9	27.16	2	2
313	57.4	22.96	6	8
314	61.2	24.48	1	1
315	65.2	26.08	2	1
316	65.3	26.12	2	2
4				
401	65.3	26.12	2	5
402	60.1	24.04	2	2
403	60.3	24.12	1	0
404	60.3	24.12	0	0
405	60.3	24.12	0	0
406	36.9	14.76	0	0
407	42.9	17.16	0	0
5				
501	24.2	9.68	0	0
502	22.2	8.88	0	0
503	22.5	9	0	0
504	24.5	9.8	0	0
5041	28.4	11.36	0	0

Block, Transect Number	Transect length (over sea only) (km)	Transect area (km^2)	# groups port	# groups starboard
505	24.3	9.72	0	0
408	24.4	9.76	0	0
409	25.8	10.32	0	0
410	24.6	9.84	0	0
411	22	8.8	0	0
412	19.2	7.68	0	0