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Aerial surveys and the potential biological removal technique indicate that the Torres Strait dugong fishery is unsustainable

Helene Marsh[1,*], Ivan R. Lawler[1], Donna Kwan[1], Steve Delean[1], Kenneth Pollock[2] and Matthew 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, USA

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Abstract

The globally significant dugong population of Torres Strait supports an important indigenous fishery for meat and oil. The fishery is protected by the *Torres Strait Treaty* between Australia and Papua New Guinea. A time series of aerial survey estimates from 1987–2001 confirms that there is considerable temporal variability in the size of the dugong population in the region and adds to a growing body of evidence from other aerial surveys and satellite tracking that dugongs undertake large-scale movements associated with temporal and spatial changes in the distribution of their seagrass food. The magnitude of these effects on both the size of the population and the catch cannot be disaggregated from the effects of population depletion from over-harvesting. The Potential Biological Removal method was used in conjunction with the aerial survey data to estimate sustainable anthropogenic mortality from all causes for a range of empirically-derived estimates of dugong life-history parameters. These estimates of a sustainable harvest are so far below the current harvest that it must be unsustainable. Governments should heed the Islanders' requests for assistance in implementing co-management of the fishery as a matter of urgency.

INTRODUCTION

Chapter 6 of Agenda 21 explicitly recognises the need for developing institutional arrangements that empower indigenous peoples, strengthen their participation in natural resource management and ensure that their use of resources is ecologically sustainable. The challenges in developing such arrangements are potentially greatest when natural resources include species that are listed as threatened, especially if they are of cultural and dietary value to indigenous peoples. Particularly in developed countries, the wider community often perceives indigenous hunting as a major threat to wildlife, particularly charismatic megafauna, even when there is little scientific basis for this perception (Bomford & Caughley, 1996; Freeman & Bogoslovskaya, 1998). Indigenous people perceive that they are competing with conservationists for wildlife and are concerned about their future access to prey species and the survival of important components of their culture. Conservationists and researchers are concerned about over-exploitation, potentially leading to local extinctions. Policy makers and day-to-day managers have statutory responsibilities to conserve threatened species. There is resultant tension among all these stakeholders and consequently managers must operate in a difficult and polarised environment.

The dugong, *Dugong dugon*, is a species of charismatic megafauna, which is of cultural value to coastal Aborigines and Torres Strait Islanders in northern Australia (Johannes & MacFarlane, 1991). Dugongs have been hunted in the region for thousands of years. Their meat is ranked highest among traditional foods. Hunting practices and prowess represent important aspects of Aboriginal and Islander traditions.

As the only surviving member of the family Dugongidae (Marsh *et al.*, 1999), the dugong is of high biodiversity value and is listed as vulnerable to extinction at a global scale by the IUCN (Hilton-Taylor, 2000). Anecdotal evidence suggests that dugong numbers have decreased throughout most of their range (Marsh, Penrose & Eros, 2003), but that significant populations persist in Australian waters. Australia has obligations to protect dugongs as a signatory to various international conventions including the Convention of Biological Diversity. It also has obligations under that Convention to protect traditional culture. In most coastal regions in tropical Australia, dugong hunting is a significant component of traditional culture.

Dugongs occur along much of the tropical and subtropical coast of Australia from Shark Bay in Western Australia to Moreton Bay in Queensland. The impacts on the dugong include habitat loss and degradation,

*All correspondence to: Helene Marsh. Tel: 61-747-815575; Fax: 61-747-816126; E-mail: helene.marsh@jcu.edu.au

pollution, incidental drowning in commercial gill nets and shark nets set for bather protection, boat strike, illegal poaching and indigenous hunting. The effects of these impacts are difficult to disaggregate and their relative importance varies in different areas (Marsh *et al*., 2002, 2003). Throughout most of the remote regions of northern Australia north of about 16°S, the major impacts are traditional hunting and accidental drowning in gill nets.

The globally significant dugong population in the remote region of Torres Stait between Cape York and Papua New Guinea (see Fig. 1) supports an important traditional fishery undertaken by Torres Strait Islanders for meat and oil. On the basis of wet-weight landings, the dugong fishery is the largest island-based fishery in the Torres Strait Protected Zone, which was established by the *Torres Strait Treaty* between Australia and Papua New Guinea to protect the Islanders' traditional way of life and livelihood. Dugong hunting is integral to this customary way of life or *Ailan Kastom* and is currently 'virtually unrestricted' (Waia, 2001), despite the declaration of a dugong sanctuary where hunting was technically banned in the western Torres Strait in the1980s (see Fig. 1).

The sustainability of this 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). Scientists have voiced their concern about the sustainability of this fishery since the mid-1980s (Hudson, 1986; Johannes & MacFarlane 1991; Marsh, 1996; Marsh, Harris & Lawler, 1997; Marsh *et al*., 2002) but it has been difficult to obtain the data required for a robust scientific assessment. The Australian and Queensland governments has been reluctant to intervene in the management of this fishery without firm evidence that the dugong is over-harvested, because such intervention would be controversial in the difficult political climate that characterises indigenous affairs in Australia.

Much of the information used to manage dugong populations in Australia has been provided by aerial surveys using a standardised technique developed by Marsh & Sinclair (1989). The Torres Strait region was surveyed in 1987, 1991, 1996 and 2001 to provide an assessment of the distribution and abundance of the dugong in Torres Strait and a time series for temporal comparisons. We present an assessment of the sustainability of the dugong harvest in Torres Strait based on the results of this series of surveys, plus information on the size of the indigenous harvest relative to an estimate of a sustainable harvest obtained using the Potential Biological Removal method (Wade, 1998). The results indicated that, although there is considerable temporal variability in the size of the dugong population in Torres Strait, it is likely that the present indigenous harvest is an order of magnitude too high to be sustainable. In a companion paper (Heinsohn *et al*., 2004) reach a similar conclusion using Population Viability Analysis.

METHODS

Survey methodology

All surveys used the aerial survey technique detailed in Marsh & Sinclair (1989) and essentially the same survey design (Fig. 1) and were performed in November and/or December in 1987, 1991,1996 and 2001. In 1996 and 2001 only, we used two aircraft flying concurrently with separate teams of observers over periods of less than a week, enabling the survey to be conducted under good conditions while minimising the likelihood of dugong movements between survey blocks within the survey period. The total survey area was 30 560 km^2. The overall sampling intensity was 5.85%, ranging from about 4% in Block 3 to 10% in Block 5 (Fig. 1).

Estimating the size of the dugong population

Estimates of dugong abundance were obtained using two methods:

1. Marsh & Sinclair (1989), which provides standardised relative estimates of dugong abundance (all surveys);
2. Pollock *et al.* (2004, unpublished results), which provides an absolute estimate of dugong abundance on which to base the estimate of the sustainability of the catch (2001 survey only).

Both methods corrected for the following survey biases: availability bias (animals not available to observers because of water turbidity) and perception bias (animals visible in the survey transect but missed by observers (*sensu* Marsh & Sinclair, 1989)). The method of Pollock *et al.* (2004, unpublished results) should be more accurate than that of Marsh & Sinclair (1989) because the corrections for availability bias are based on empirical data obtained from: (1) experiments to determine zones of detectability for dugongs over a range of depths, turbidities and sea states using fiberglass models of dugongs as 'sechi disks' and (2) dive profiles obtained from time depth recorders on 15 wild dugongs, enabling the probability of a dugong being available to be estimated for different depths, water turbidities and sea states.

Dugong abundance was estimated separately for each block in the survey area (Fig. 1) using the Ratio Method (Jolly, 1969; Caughley & Grigg, 1981). Input data were the corrected number of dugongs (in groups of <10 animals) for each side of the aircraft per transect. The standard error estimates incorporated the errors associated with all the correction factors described above. Any dugongs in groups of >10 were added to the estimates of population size and density as outlined in Norton-Griffiths (1978). All population estimates are given ± standard error.

Statistical analysis

Differences in dugong density between survey years in Torres Strait were examined using a split-plot analysis of

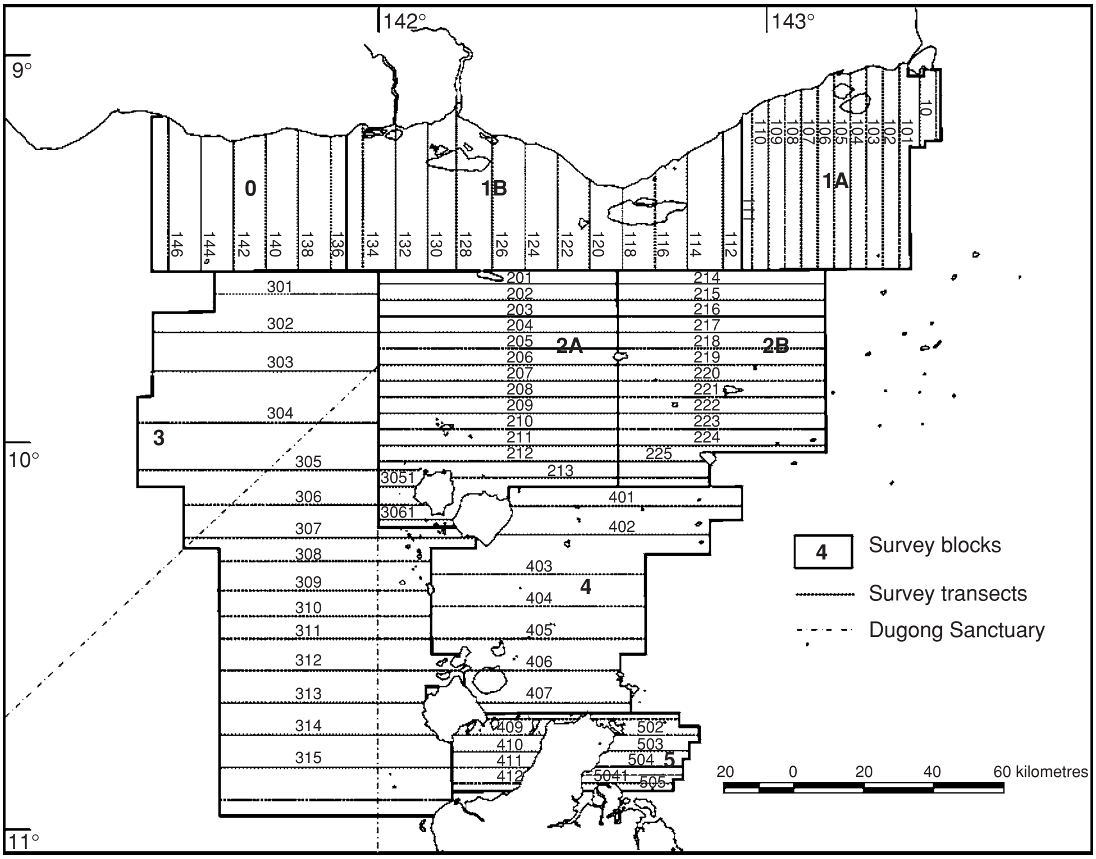

Fig. 1. Map of the survey region showing the positions of the survey blocks and transects and the Dugong Sanctuary established in the 1980s but never effectively enforced.

variance using the data generated by the method described by Marsh & Sinclair (1989). 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 using restricted maximum likelihood (REML). Variation in dugong density between blocks and between transects within blocks were random sources of variance, as was the variation due to the interaction between 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

The Potential Biological Removal (PBR) Method (Wade, 1998) was used to estimate a sustainable dugong catch in the Torres Strait region. 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:

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

The minimum population estimate of the stock, N_{min}, is defined as the 20th percentile of a log-normal distribution based on an absolute estimate of the number of animals, N, in that stock. We used the method of Pollock *et al.* (2004, unpublished results) to generate the absolute estimate N for the 2001 survey.

$\mathrm{R}_{\mathrm{max}}$ is the maximum rate of increase and $0.5\ \mathrm{R}_{\mathrm{max}}$ is a conservative surrogate for $\mathrm{R}_{\mathrm{MNPL}}$ because $0.5\ \mathrm{R}_{\mathrm{max}}$ will always be $< \mathrm{R}_{\mathrm{MNPL}}$ if MNPL is $\geq$ the carrying capacity (Wade, 1998). The estimates of $\mathrm{R}_{\mathrm{max}}$ for Torres Strait are based on empirical estimates of age of first reproduction and fecundity obtained by Boyd, Lockyer & Marsh (1999) and Kwan (2002) and a pattern of natural mortality based on that obtained from longitudinal studies of manatees

Table 1. 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 years	5 years[4]
Mabuiag, Torres Strait 1997–1998	6	5.08%	3.9%	1.15%
Townsville 1970-early 1980s	10	3.35%	2.45%	0.3%
Daru, Torres Strait 1976–1983	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 taken from Boyd *et al*. (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 Boyd *et al*., 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.
[4] Heinsohn *et al*. (2004) also use a mean calving interval of 6.3 years but show, using Population Viability Analysis, that this was unlikely in Torres Strait during the period spanned by the aerial surveys.

(Eberhardt & O'Shea, 1995; Langtimm *et al*., 1998). In view of the uncertainty associated with these estimates, we used a range of estimates for R_{max} of 0.01–0.05 (1–5%) as explained in Table 1.

The recovery factor (RF) of < 1 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 stocks of unknown status such as the dugong population of Torres Strait should be 0.5, the value used here. The suitability of this value rather than an alternative is considered in the discussion below.

Catch estimates

We obtained dugong catch estimates from various parts of Torres Strait from the literature as detailed in Table 2. The estimates include 'guesstimates', periodic sampling surveys and catch censuses. The values reflect differences in monitoring technique as well as spatial and temporal variation. The most accurate records are those of Kwan (2002) who lived at Mabuiag Island for 9 months in each of 1998 and 1999 and recorded carcasses as they were butchered at traditional sites.

RESULTS

Aerial survey estimates of dugong density and population size

Using the method of Marsh & Sinclair (1989), the estimated size of the dugong population in Torres Strait in 2001 was 14061 ± 2314, which is not significantly different from that in 1987 (13319 ± 2136) but significantly lower than the corresponding estimates derived for 1991 (24225 ± 3276) and 1996 (27881 ± 3095: Tables 3 and 4, Fig. 2). 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

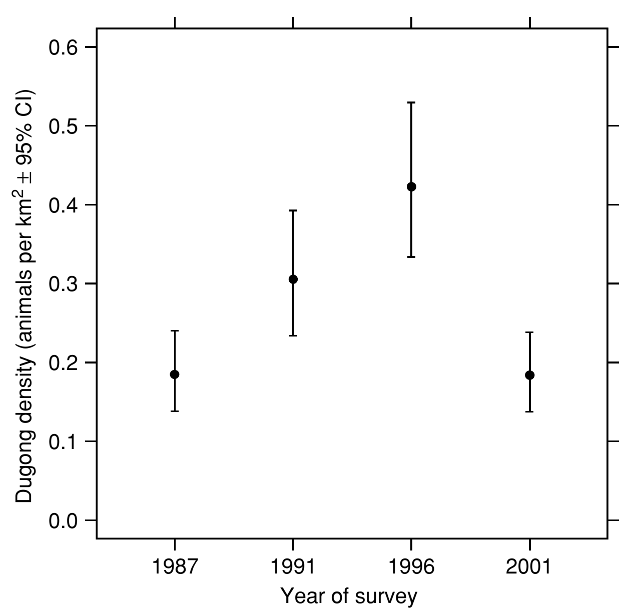

Fig. 2. Estimated mean dugong density (± 95% confidence interval) for each of the four surveys conducted in Torres Strait. The data for all surveys have been generated using the method described by Marsh & Sinclair (1989). CI, confidence interval.

Table 2. Estimates of the catch of dugongs in various Torres Strait communities between the 1970s and the 1990s

Area	Method of estimating catch	Date	Estimated dugong catch (annual unless otherwise indicated)	References
Mabuiag Is.	Sporadic census	1973	24	Bertram & Bertram (1973)
	Census	1977	103	Nietschmann (1985)
	Sporadic census	1983 1984	12	Johannes & MacFarlane (1991)
	Survey		274 (SE 175)	
	Census (9 mths)	1994	145	Kwan (2002)
	Census (9 mths)	1998	170	Kwan (2002)
	Survey	1999	183 (SE 77)	
Badu Is.	Survey	1994	107 (SE 80)	
	Survey	1999	200 (SE 66)	
	Survey	2000	166 (SE 65)	
Boigu Is.	Survey	1994	256 (SE 110)	
	Survey	1999	128 (SE 59)	
	Survey	2000	87 (SE 26)	
TSPZ[1]	Census	1976–77	750	Nietschmann (1985)
	Sporadic census	mid-1980s	110–130	Johannes & MacFarlane (1991)
	Census	1991–92	954	
	Survey	1991–92	1010 (SE 240)	
	Survey	1991–93	1226 (SE 204)	
	Survey	1994	860 (SE 241)	
	Survey	1996	241 (SE 92)[3]	
	Survey	1998	256 (SE 136)[3]	
	Survey	1999	692 (SE 150)	
	Survey	2000/01	619 (SE 134)	
Bamaga	Survey	1997	116	
Daru PNG	Census	1976–77[2]	74–120	Hudson (1986)
	Census	1978–83[2]	463	Hudson (1986)

All of the survey results were obtained by the CSIRO and the Australian Fisheries Management Authority. SE, standard error; TSPZ, Torres Strait Protected Zone; PNG, Papua New Guinea.

[1] Includes total catch for the Torres Strait Protected Zone (TSPZ) including Mabuiag, Badu and Boigu Islands.

[2] Catch statistics recorded during the period when dugong meat was legally sold in the Daru market.

[3] Rejected by Torres Strait Fisheries Scientific Committee because of low precision and potential downward bias.

Table 3. Estimates of dugong abundance (± standard error (SE)) in each of the survey blocks in Torres Strait (Figure 1) for surveys conducted in 1987, 1991, 1996 and 2001

	Year									
	1987		1991		1996		2001 Marsh & Sinclair method		2001 Pollock *et al.,* method	
Block	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
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	4720	14106	2314	11956	1189

of dugong density in 2001 and 1987. The between-blocks variance component (0.375) was large relative to the variance between transects within blocks (0.171) suggesting that some parts of the region (e.g. especially Block 2A, Fig. 1) 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 (Fig. 3). The largest variance component (0.756) corresponds to the between-transect within block variation between years (error) suggesting that dugongs make substantial small-scale movements within blocks over time.

Table 4. Results of the split-plot analysis of variance examining dugong density between surveys

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		

The estimated variances (Est. Var.) are calculated from the mixed-effects analysis. SS, sum of squares; MS, mean square.
[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, $p = 0.021$.

The population estimate for 2001 using the method of Pollock *et al*. (2004, unpublished results) was 11915 (± 1198) dugongs, about 15% less than the corresponding estimate using the older methodology.

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

The range of estimates for sustainable anthropogenic mortality (PBR) are summarised in Table 5 for the 1996 and 2001 estimates of dugong population size. The middle value for the estimated maximum rate of increase R_{max} ($= 0.03$) and an RF value of 0.5 suggest that the following total annual anthropogenic mortalities should be sustainable: about 190 dugongs for the1996 estimate; about 90 dugongs for the 2001 estimate using the method of Marsh & Sinclair (1989). The 2001 figure using the method of Pollock *et al*. (unpublished) is 82 dugongs.

DISCUSSION

Temporal changes in dugong population size in Torres Strait

The population estimates obtained from 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 3). Marsh *et al*. (1997) reviewed the possible reasons for

Table 5. 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 an RF value of 0.5

						Potential Biological Removal				
Date of survey	R.F.	N	SE	CV	N_{min}	$R_{max} = 0.01$	$R_{max} = 0.02$	$R_{max} = 0.03$	$R_{max} = 0.04$	$R_{max} = 0.05$
2001	0.5	14106	2314	16.4	12297	31	61	92	123	154
1996	0.5	27881	3095	11.1	25400	64	127	191	254	318

The values for the PBR based on the 2001 survey estimate are based on the population estimate derived using the method of Marsh & Sinclair (1989). The values derived using the method of Pollock *et al*. (unpublished) are slightly lower (27–137).

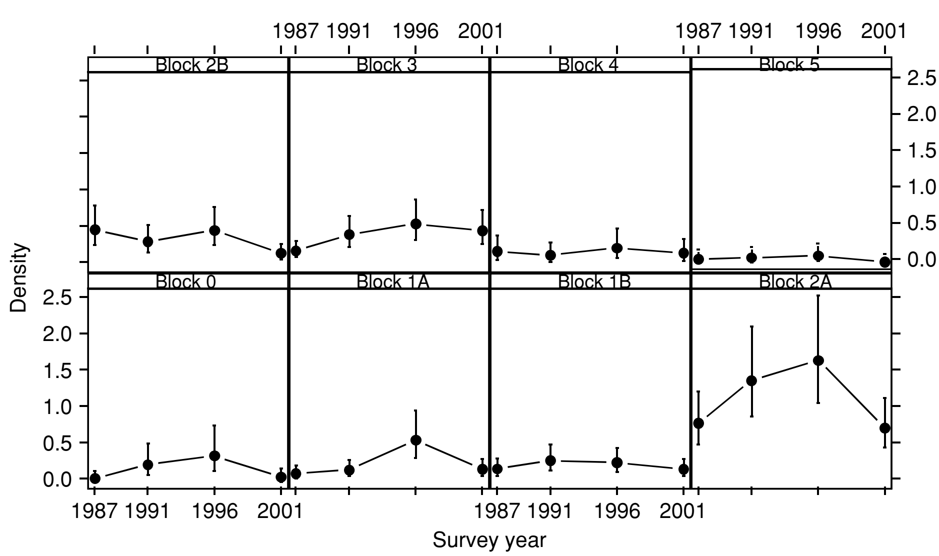

Fig. 3. Estimated mean dugong density (± 95% confidence interval) in each block in each survey year. The data for all surveys have been generated using the method described by Marsh & Sinclair (1989).

the significant difference between the dugong population estimates obtained in 1987 and 1991 and concluded that it: (1) could not be explained by natural increase in the absence of immigration into the survey area and (2) was unlikely to be the result of uncorrected fluctuations in the availability bias between surveys, but (3) the possibility of double counting as result of dugongs moving between survey blocks during the survey could not be dismissed. However, these last two explanations can now be ruled out. The empirical measurements of availability bias by Pollock *et al.* (2004, unpublished results) indicate that the method used to correct for availability bias in the earlier surveys was robust and the use of two aircraft enabled the 1996 and 2001 surveys to be completed in a few days. Marsh & Lawler (2001, 2002) and Gales *et al.* (2004) also explored possible reasons for the temporal differences between population estimates obtained from repeat aerial surveys of the southern Great Barrier Reef and Hervey Bay, the northern Great Barrier Reef and Western Australia, respectively, and concluded that large-scale movements of dugongs were the most likely explanation, a conclusion which we support. This pattern is also consistent with traditional knowledge (Johannes & MacFarlane, 1991), anecdotal information and satellite tracking (Marsh & Rathbun, 1990; Marsh *et al.*, 2002, 2003), all of which suggest that dugongs undertake large-scale and/or long-distance movements. The satellite tracking studies indicated that a dugong could move hundreds of kilometres in a few days but that such movements are individualistic and not coordinated among dugongs.

Reasons for temporal changes in the size of the dugong population of Torres Strait: the role of seagrass dieback

Large-scale dugong movements appear to be a 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 & Peterken, 1996). Such losses have been recorded in Torres Strait and in other regions of northern Australia. Islanders observed a major dieback of seagrasses in waters extending from Badu Island south to Thursday Island in the early 1970s. The cause of the dieback was never confirmed (see Johannes & McFarlane, 1991 for a more complete account of this controversy). In 1991–1992, several hundred square kilometres of seagrass disappeared from northern Torres Strait, probably because of high turbidities resulting from flooding of river(s) in Papua New Guinea coincident with an El Niño Southern Oscillation (ENSO) event (Poiner & Peterkin, 1996). Local fishers again reported seagrass dieback in the Orman Reef area (the most important dugong habitat in Torres Strait) in 1999–2000, prior to our last survey.

Extreme weather events cause extensive damage to tropical seagrass communities through severe wave action, shifting sand, adverse changes in salinity and light reduction (Heinsohn & Spain, 1974; Preen & Marsh, 1995; Preen, Lee Long & Coles, 1995). Recovery and recolonisation after such losses may take up to a decade or more (Poiner & Peterken, 1996). *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 being the primary factors affecting its survival (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 contributor to the causes of the large-scale loss of deep-water seagrasses in Torres Strait (Poiner & Peterken, 1996) and Hervey Bay in Queensland, Australia (Preen *et al.*, 1995).

Dugongs 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 that region declined from 2206 ± 420 in 1988 to between 521 and 571 with a standard error of 126 in 1993. Ninety-nine dugong carcasses were recovered in the Hervey Bay area, on the central and southern Queensland coast and along the New South Wales coast (Preen & 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.*, 1996). The seagrass had recovered by late 1998 (Coles, McKenzie & Campbell, 2003) and the dugong population estimated by aerial survey had increased to 1473 ± 242 by 1999 (Marsh & Lawler, 2001). 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 of dugongs to seagrass loss seems similar in Torres Strait. Islanders interviewed by Johannes & MacFarlane (1991) were unanimous that an unusually high proportion of dugongs 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 1976–1977. Spain & Heinsohn (1973) also report dugongs eating unusually high proportions of algae, *Thalassia* and *Cymodocea* 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) presented anecdotal evidence that none of the 35 female dugongs landed at Daru between November 1976 and July 1997 was pregnant. Kwan (2002) reported a corresponding gap in the age distribution of dugongs caught at Mabuiag in 1997–1998 confirming that recruitment failure was widespread in dugongs in Torres Strait at the time of the 1970s seagrass dieback. In addition, Marsh (1995*a*) reported a monotonic increase in the pregnancy rate of dugongs landed in Daru between 1978 and 1981, the period of reported seagrass recovery.

Given the anecdotal reports of seagrass dieback in the Orman Reef area (the most important dugong habitat in Torres Strait) in 1999–2000, it is salient that the dugong population in Block 2A was significantly lower during the 2000 survey than during the 1991 and 1996 surveys (Fig. 3). In addition, the percentage of calves in the region of the reported seagrass dieback around Orman Reef plus a region where we observed exceptionally turbid water during our survey (Blocks 0, 1A, 1B, 2A and 2b) was only 5.2%. This was 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. (Yates' corrected $\chi^2 = 13.19$, d.f. = 1, $p = 0.0003$).

Unfortunately the magnitude of the effects of emigration or immigration on the size of a dugong population cannot be disaggregated from the effects of population depletion from over-harvesting. Thus the recent trends detected by aerial surveys (Fig. 2) are not a reliable index of the status of the Torres Strait dugong population. Even if they were, relying on population trends to trigger management actions is likely to result in Type 2 error since trends are not likely to be detected until a population is seriously depleted (Taylor & Gerrodette, 1993; Marsh 1995*b*).

Preliminary estimates of a sustainable harvest

Evaluating whether or not the population can support the known level of harvesting should have a lower risk of Type 2 error (Wade, 1998) despite the challenge of estimating absolute abundance. Pollock *et al.* (2004, unpublished results) compared estimates of dugong abundance obtained using their new technique with estimates obtained using the technique of Marsh & Sinclair (1989) for two aerial surveys: the 2001 survey of Torres Strait reported here and a survey of the northern Great Barrier Reef region in 2000. In both cases the resultant population estimates were reasonably close (within −15% to +7% of each other) suggesting that the estimates obtained from the 1987, 1991 and 1996 surveys should also be close to absolute estimates of dugong abundance in the survey region at the times of those surveys.

Thus, based on the 1996 abundance estimate and assuming an RF value of 0.5, we estimate that the sustainable harvest is about 190 dugongs per annum for the entire region including the Papua New Guinea communities, the Protected Zone, the Inner Australian Islands and the Northern Cape York Peninsula Area based on the 1996 abundance estimate. The corresponding figure based on the 2001 population estimate is 80–90 dugongs, an estimate similar to that independently estimated by Heinsohn *et al.* (2004) using Population Viability Analysis. This estimate is substantially less than the harvest recorded between April and September 1998 and 1999 from a single major hunting community – Mabuiag Island (Kwan, 2002) and considerably less than the catch estimates for the various components of the whole region (Table 2).

Even though it is technically correct (Wade, 1998), the use of a RF value of 0.5 for a threatened species that is impacted on by occasional stochastic events is questionable. The use of a more conservative value such as 0.1 would mean that the harvest rate would be very low (38 dugongs per annum for the entire region based on the 1996 abundance estimate; 16–18 dugongs per annum based on the 2001 estimate) or that the fishery would have to be closed. In our opinion even though conservation and animal rights groups would support such an approach, setting such a low total allowable catch is likely to be a major obstacle to progressing co-management arrangements with indigenous groups throughout this remote region. Such action may also require the renegotiation of the Torres Strait Treaty between Australia and Papua New Guinea.

Some Australian Torres Strait Islander leaders have called for government assistance with implementing co-management arrangements for hunting for many years (e.g. Resolution from the workshop Towards Community-Based Management of Dugongs and Turtles in Torres Strait held by AFMA in 1998). Scientists (e.g. see Johannes & MacFarlane, 1991; Marsh, 1996; Marsh *et al.*, 1997) have made similar demands, but there has been little progress. 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.

CONCLUSION

The evidence presented here that dugongs are over-harvested in Torres Strait indicates that the present system of essentially unregulated dugong hunting is not sustainable. Heinsohn *et al.* (2004) came to a similar conclusion using Population Viability Analysis. Co-management arrangements for indigenous hunting in Torres Strait must be progressed as a matter of urgency, if Australia is to honour its international commitments to conserve dugongs and dugong hunting cultures. Dugong hunting is a very significant part of the Torres Strait Islanders' traditional culture. This culture cannot be conserved if the target species becomes locally extinct.

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