
The Sustainability of the Indigenous Dugong Fishery in Torres Strait, Australia/Papua New Guinea

H. MARSH,*‡ A. N. M. HARRIS,† AND I. R. LAWLER*

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

†CSIRO Division of Fisheries, P.O. Box 120 Cleveland, 4163, Australia

Abstract: *The sustainability of the indigenous dugong (Dugong dugon) fishery in Torres Strait is evaluated on the basis of aerial survey estimates of the size of the regional dugong population in 1987 and 1991 and a survey of catches of dugongs taken by local communities between 1991 and 1993. The estimate of the dugong population in the Torres Strait region in November-December 1991 was 24,225 (\pm SE 3,276) compared with the corresponding estimate of 13,319 (\pm SE 2,136) for November 1987. The difference between the two estimates cannot be explained by natural increase of the population or variations in the sighting conditions encountered during the two aerial surveys. We believe this difference is due to a major redistribution of dugongs within the survey region or migration into Torres Strait, probably from Irian Jaya (Indonesia). Dugongs are a major component of the traditional fishery in Torres Strait. The biomass of dugongs landed between June 1991 and May 1993 was higher than the weight of any other component of the traditional catch. The estimated annual dugong catch of 1226 (\pm SE 204) was higher than previous catch estimates. It is impossible to verify the sustainability of this harvest without an understanding of the movements of the dugong population, better absolute estimates of dugong population size, dugong catch statistics for Papua New Guinea and adjacent regions in Australia, and current estimates of life history parameters for dugongs in Torres Strait, all of which will be difficult to obtain. The mean estimate of the annual dugong catch in Torres Strait for 1991-1993, however, is approximately 5% of the mean estimate of the dugong population size in 1991. This is too close to the estimated maximum rate of increase of the dugong population to be sustainable if the estimate of dugong numbers is close to an absolute estimate or if there is substantial emigration of dugongs from the area. Co-management arrangements must be developed between the government agencies responsible for the dugong fishery and the Torres Strait Islanders in order to develop management strategies that will provide for the Islander's traditional hunting expectations and maintain dugong numbers.*

Es Sostenible la Caza Actual de Dugones en el Estrecho de Torres

Resumen: *La posibilidad de sostener la caza artesanal en el Estrecho de Torres es evaluado sobre la base de conteos aereos del número de la población de dugones (Dugong dugon) en esta región en 1987 y 1991, y una encuesta de los dugones cazados por la comunidad local entre 1991 y 1993. La población estimada de dugones en la región del Estrecho de Torres durante el periodo noviembre-diciembre 1991 fue de 24,225 (\pm SE 3,276) animales, comparada con la población correspondiente estimada en noviembre de 1987, la cual fue de 13,319 (\pm SE 2,136) animales. La diferencia entre los dos estimados no puede explicarse como un aumento natural de población o variaciones en visibilidad encontradas durante los dos conteos aereos. Creemos que esta diferencia se debe mas bien a un gran cambio en la distribución de dugones en el área estudiada o a una migración de animales al Estrecho de Torres, probablemente desde Irian Jaya. El dugón es todavía un componente importante de la caza artesanal en el Estrecho de Torres. El peso húmedo de los dugones cazados entre junio 1991 y mayo 1993 fue superior a cualquier otro componente de la pesca artesanal. El estimado caza anual de dugones de 1,226 (\pm SE 204) fue superior a cualquier estimado anterior. Es imposible verificar si la caza tradicional de dugones es sostenible sin antes conocer los movimientos de la población, mejores estimados absolutos de la población de dugones y la estadística de la caza para Papua*

‡Address correspondence to H. Marsh, Department of Tropical Environment Studies and Geography, James Cook University, Townsville, 4811, Australia, email belene.marsh@jcu.edu.au

Paper submitted June 19, 1995; revised manuscript accepted January 21, 1997.

Nueva Guinea y regiones ayacentes en Australia, y los parámetros de ciclo de vida de los dugones en el Estrecho de Torres, ninguno de los cuales es fácil de obtener. Sin embargo, el estimado medio de la caza anual de dugones en el Estrecho de Torres durante el período de 1991-93 es aproximadamente 5% del estimado medio de la población en 1991. Esta cifra está demasidada cerca a la tasa máxima de incremento estimada de la población de dugones para ser sostenible si es que los esimados poblacionales están en realidad cerca a un estimado absoluto, o si existe una migración apreciable de dugones fuera del area. Hay que desarrollar arreglos de colaboración entre las entidades del gobierno responsables para la caza de los dugones y los isleños del Estrecho de Torres con el fin de desarrollar estrategias administrativas que tomarán en cuenta las expectativas de caza tradicional de los isleños y al mismo tiempo mantener la población de dugones.

Introduction

The increasing interest of indigenous peoples to return to or remain on their traditional lands has raised concerns about the sustainability of their uses of wildlife resources in view of changes in hunting and foraging methods (Caughley et al. 1996). The wider community, particularly in developed countries, often perceives indigenous hunting as a major threat to wildlife even when there is little basis for this perception (Freeman 1989; Richard & Pike 1993; Bomford & Caughley 1996). There is tension between indigenous peoples on the one hand and wildlife managers, researchers, and conservationists on the other. The indigenous peoples perceive that they are competing with conservationists for wildlife and are concerned about their future access to the prey species. The wildlife managers, scientists, and conservationists are concerned about over-exploitation. These tensions

are potentially greatest when the prey species is listed as rare or endangered and is of considerable cultural value to the indigenous people who hunt it.

The dugong (*Dugong dugon*, order Sirenia), is a large, herbivorous marine mammal. It is listed as vulnerable to extinction by the World Conservation Union (IUCN 1990) and endangered under the U.S. *Marine Mammal Protection Act* 1972. Dugong meat is ranked highest among traditional foods by the peoples of Torres Strait, the strait which separates Cape York, the northern tip of Australia, from Papua New Guinea (Johannes & MacFarlane 1991). In 1985 Australia and Papua New Guinea entered into the Torres Strait Treaty to resolve the maritime boundaries in this region and to protect the way of life and livelihood of its traditional inhabitants. The treaty also establishes the Torres Strait Protected Zone (TSPZ, Fig. 1) within which each country exercises sovereign rights for marine life according to agreed jurisdic-

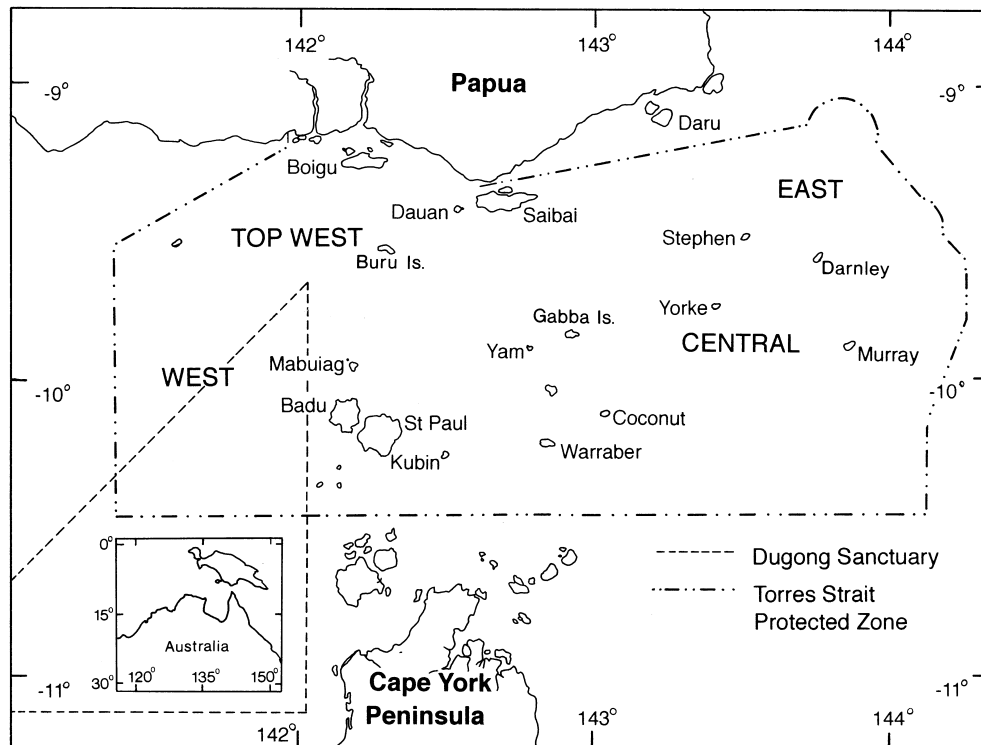


Figure 1. The 14 Islander communities in the Torres Strait Protected Zone (TSPZ) and their regional groupings: Top West—Boigu, Dauan, and Saibai Islands; West—Mabuiag, Badu, and Moa (Kubin and St Paul communities) Islands; Central—Yam, Coconut, Warraber, and Yorke Islands; East—Stephen, Darnley, and Murray Islands. The 2744 km² sanctuary established to protect dugongs in 1985 and other places mentioned in the text are also marked.

The survey design (Fig. 2) was determined by (1) the known distribution of suitable dugong habitat, (2) the endurance of the aircraft, and (3) the aircraft time available for the survey. The design was similar for both surveys except that we halved the sampling intensity along the Papuan coast west of 143°E in 1991 by flying every other transect sampled in block 1B in 1987 because of the low density of dugongs observed in this block in 1987. A global positioning system mounted in the Partavia 68B aircraft was used for navigation.

To estimate regional densities of dugongs, the area was divided into eight blocks (Fig. 2) on the basis of sampling intensity and placement of transects. Block areas (Fig. 2) were estimated from 1:1,000,000 digitized topographic coverage (AUSLIG) using the Arc Info GIS package. The areas of all islands were excluded from the block areas. The length of each transect was also estimated from the digitized maps using Arc Info. Observers reported the following information at the time of first sighting a group (subjectively distinct clumping) of dugongs: group size (total number of animals in the group including calves), number of calves (small individuals that appeared to be in attendance to a larger individual presumably their mother), and number of animals at the surface.

Correction factors (Table 2) were calculated to compensate for perception and availability biases as outlined in Marsh and Sinclair (1989). The corrections for perception bias were calculated on the basis of the proportion of sightings (groups of dugongs) seen by one (specified) member or both members of each of two tandem teams of observers (one on each side of the aircraft) using the Petersen mark-recapture model. The correction for availability bias was calculated by standardizing the proportion of individual dugongs sighted at the surface during the survey against the proportion on the surface

in a clear water area where all dugongs were potentially available (Marsh & Sinclair 1989). The availability correction factor is likely to be conservative because in Torres Strait many dugongs are sighted swimming in relatively deep water (≥ 10 m; H. Marsh and W. K. Saalfeld unpublished data) in contrast to the area where the correction factor was developed, where most dugongs occur in depths of < 3 m (Preen 1993).

Because transects were variable in length and therefore in area surveyed, the ratio method (Jolly 1969; Caughley & Grigg 1981) was used to estimate the density and population size and their associated standard errors for dugongs for each block for each survey. Any statistical bias resulting from this method is considered inconsequential because of the relatively high sampling intensity (Fig. 2; see Caughley & Grigg 1981). Input data were the estimated number of dugongs for each tandem team per transect calculated using the correction factors described above. The resultant standard errors were adjusted to incorporate the errors associated with the appropriate estimates of the perception and availability correction factors and the mean group size (Table 2) as outlined in Marsh and Sinclair (1989).

The significance of the differences between the surveys conducted in 1987 and 1991 in the densities of dugongs were tested using analysis of variance. "Block" and "time" were treated as fixed factors and "transect" as a random factor nested within block. The analysis was also run with the modal Beaufort sea state for each transect as the covariate to compensate for differences in weather conditions between surveys. Input data for all analyses were corrected densities per square kilometer based on mean group sizes and the estimates of the correction factors for perception and availability bias, each transect contributing one density per survey based on the combined corrected counts of both tandem

Table 2. Details of dugong group size estimates and correction factors used in the population estimates for the dugong surveys in 1987 and 1991.

Year blocks and transect numbers	Group size mean (CV) ^a	Perception correction factor estimate (CV) ^a		Availability correction factor estimate (CV) ^a
		Port	Starboard	
1987				
5:9-13	1.3863 (0.0470)	1.3538 ^b (0.0087)	1.3913 ^b (0.0188)	2.7203 (0.1196)
2:1-8; 3:13-16	1.3863 (0.0470)	1.0425 ^c (0.0087)	1.3913 ^b (0.0188)	2.7203 (0.1196)
0; 1; 2:9-28; 3:1-12; 4; 5:1-8, 14-16; 6	1.3863 (0.0470)	1.0425 ^c (0.0087)	1.0896 ^c (0.0188)	2.7203 (0.1196)
1991				
0 ^d ; 1B ^d :1.14-1.34	1.3516 (0.0429)	1.0634 ^c (0.0158)	1.0814 ^c (0.0182)	3.2506 (0.1115)
1A ^d ; 1B:1.12	1.3516 (0.0429)	1.3514 ^b (0.0158)	1.3256 ^b (0.0182)	3.2506 (0.1115)
2A:2.1-2.7	1.3516 (0.0429)	1.1000 ^b (0.0188)	1.3256 ^b (0.0182)	3.2506 (0.1115)
2A:2.8-2.13,3.5,3.5A,3.6,3.6A;2B; 3; 4; 5	1.3516 (0.0429)	1.1000 ^c (0.0188)	1.1100 ^c (0.0308)	3.2506 (0.1115)

^aCV, coefficient of variation.

^bOne observer on that side of aircraft.

^cTwo observers on that side of aircraft.

^dBlocks 0, 1A, and 1B were flown with different observer teams from the remaining blocks in 1991, hence the different perception correction factors.

teams. The densities were transformed ($\log_{10} \times + 1$) for analysis to equalize the error variances.

To examine the spatial density of the dugong population, a map of dugong density in 5 minutes latitude \times 5 minutes longitude grid cells was produced using the Arc Info GIS package. The grid coverage was combined with the coastline coverage. The corrected number of dugongs as well as the transect length was calculated separately for each grid cell from the raw data. Density (number of dugongs per square kilometer) within each grid cell was then calculated as

$$\text{density} = \frac{\text{corrected no. dugongs}}{(\text{transect length} * 0.4)}$$

where 0.4 is the transect width in kilometers.

Catch Statistics

Information on the dugong catch between June 1991 and May 1993 was estimated from information on the size and number of dugongs landed at the 14 communities in the TSPZ (Fig. 1). These data were collected by biologists and trained Islanders on 186 days between May 1991 and June 1992 (subsequently referred to as the 1991/1992 year) and 85 days between June 1992 and May 1993 (referred to as the 1992/1993 year). The survey days were distributed between the 14 communities in approximate proportion to their human population in 1991/1992, but in 1992/1993 concentrated on the communities of Boigu, Mabuiag, Badu, Yorke, and Murray Islands (Fig. 1) because these communities accounted for most of the catch in 1991/1992. Dugong length or fluke width was converted to body weight using length-weight relationships from Spain and Heinsohn (1975). Information on hunting effort was obtained by interviewing hunters.

Results

Comparison of Results of the Aerial Surveys

The frequency distribution of dugong group sizes observed on the November-December 1991 survey did not differ significantly from that observed in November 1987 (G with William's Correction = 5.813, $p = 0.12$, 3 df). The largest group (subjectively distinct clumping) seen in November-December 1991 was eight dugongs, compared with five dugongs in November 1987. These results are comparable with the November 1983 survey (flown at a survey altitude of 274 m ASL) where the largest group seen was six dugongs (Marsh 1986). In all three surveys, more than 75% of the dugongs sighted were alone or in a group of two animals.

The proportion of calves seen was reasonably similar in the three surveys: 14.3% in November 1983; 13.6% in

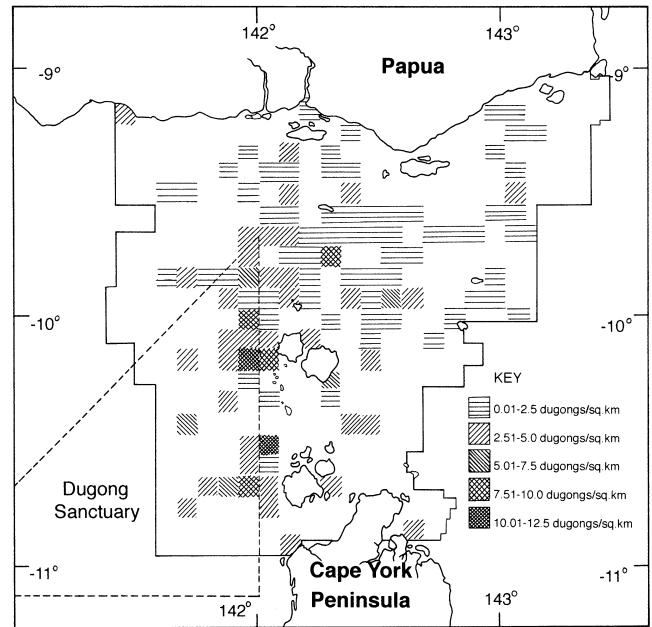


Figure 3. Density distribution map (5 minutes latitude \times 5 minutes longitude grid) for dugongs in Torres Strait based on the 1991 survey.

November 1987; 11.8% in November-December 1991. Calving is diffusely seasonal in Torres Strait (Marsh 1995a), and the calves can stay with their mothers for at least 18 months (Marsh et al. 1984). On all three surveys, more than 70% of the cow-calf pairs identified were unaccompanied by any other dugongs.

The distributions of dugongs in 1987 and 1991 were similar to that in 1984 (Marsh 1986) with dugong den-

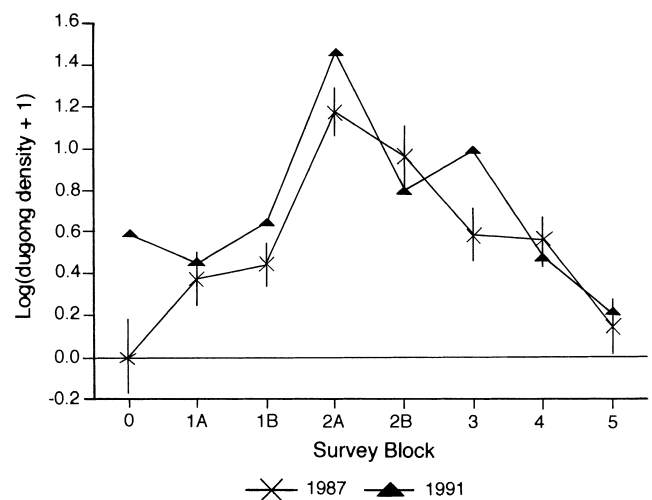


Figure 4. Comparison of the mean density of dugongs ($\log_{10} \times + 1$) in each survey block in Torres Strait (see Fig. 2) in 1987 and 1991. The error bars represent standard errors of the 1987 estimates.

Table 3. Estimated numbers (SE) of dugongs per block in 1987 and 1991.

Block	1991 survey (with 1987 availability correction factor)		1991 survey (with 1991 availability correction factor)	
	1987 survey ^a			
0	0	572 (6)	695 (238)	
1 ^b	1131 (278)	4496*	5374*	
1A		1396 (837)	1669 (999)	
1B		3100 (1283)	3705 (1529)	
2A	6424 (1679)	7626 (1523)	9113 (1798)	
2B	2019 (573)	1227 (336)	1467 (399)	
3	2822 (1102)	5640 (1648)	6740 (1958)	
4	848 (347)	434 (166)	518 (197)	
5	76 (55)	268 (232)	320 (277)	
Total	13,319 (2136)	20,274 (2760)	24,225 (3276)	

^aPreliminary results of the 1987 aerial survey are reported in Marsh and Saalfeld (1992).

^bAll of Block 1 was flown at a sampling intensity of about 8% in 1987. In 1991 the western part of the Block (1B) was flown at about half the intensity of the eastern section (1A). The results have been presented separately with the summed total for Block 1 in 1991 marked with an asterisk.

sity (Fig. 3) generally highest in the seagrass beds around Badu Island and extending north around Buru Island and east to Gabba Island and west of Prince of Wales Island. The next highest density was observed along the Papuan coast and immediately south of Boigu Island. Significantly more dugongs were sighted in block 0 and in block 3 in 1991 than in 1987 (Fig. 4). Block 3 includes part of the dugong sanctuary which was established in 1985 (Figs. 1 & 3) and in which dugong hunting is nominally banned.

The population estimates for November–December 1991 were $24,225 \pm \text{SE } 3,276$ dugongs for the whole re-

gion (at an overall density of $0.79 \pm \text{SE } 0.11$ dugongs per km^2), compared with the estimate for the same region in November 1987 of $13,319 \pm \text{SE } 2,136$ dugongs (at an overall density of $0.44 \pm \text{SE } 0.07$ dugongs per km^2 ; Table 3). Overall, the density estimates were significantly higher in 1991 than in 1987 (Table 4). The addition of Beaufort sea state as a covariate in the analyses made no substantive difference to the results (Table 4) indicating that the difference between the two surveys was unlikely to be due to sighting conditions.

The proportion of dugongs recorded as being on the surface in 1991 was higher than in 1987; however, the

Table 4. Summary of analysis of variance comparing observed dugong density^a in Torres Strait in 1987 and 1991 using 1991 availability correction factor and 1987 availability correction factor for 1991 sightings.

Sources of variation	df		F		Significance of F	
	No covariates	Covariate Beaufort sea state	No covariates	Covariate Beaufort sea state	No covariates	Covariate Beaufort sea state
1991 availability correction factor						
Blocks ^b	7	7	8.79	8.90	0.0001	0.0001
Time ^c	1	1	6.85	7.03	0.0105	0.0096
Transect nested in block ^c	86	86	2.14	2.09	0.0003	0.0004
Block by time ^c	7	7	1.63	1.66	0.1377	0.1288
Residual	86	85				
Regression ^c		1		0.54		0.4638
1987 availability correction factor for 1991 sightings						
Blocks ^b	7	7	8.80	8.92	0.0001	0.0001
Time ^c	1	1	3.90	4.35	0.0516	0.0401
Transect nested in block ^c	86	86	2.18	2.13	0.0002	0.0001
Block by time ^c	7	7	1.65	1.68	0.1321	0.1260
Residual	86	85				
Regression ^a		1		0.54		0.4638

^aData were transformed by $\log_{10}(x + 1)$.

^bTested against transect nested in block.

^cTested against transect nested in block by time.

Table 5. The estimated mean daily dugong catch, fishing effort, and per capita consumption for the 14 communities surveyed in the Torres Strait Protected Zone (TSPZ) between June 1991 and May 1993.

<i>Community</i>	<i>Number of days surveyed</i>	<i>Mean number of fishing trips per day (SE)</i>	<i>Mean daily catch in kg (SE)</i>	<i>Per capita consumption per day in grams (SE)*</i>
Top West Islands				
Boigu	26	1.1 (0.3)	212.9 (57.0)	387.9 (103.8)
Dauan	10	0.3 (0.2)	41.0 (31.6)	140.8 (108.5)
Saibai	21	0.1	8.6 (0.5)	16.0 (0.9)
Western Islands				
Mabuiag	24	1.2 (0.3)	127.7 (41.4)	315.7 (102.4)
Badu	29	0.8 (0.3)	168.4 (39.8)	155.6 (36.8)
Kubin	15	0.1	51.0 (39.8)	65.2 (50.9)
St Paul	12	0	0	0
Central Islands				
Yam	20	0.1	28.6 (20.3)	55.2 (39.2)
Warraber	13	0	0	0
Coconut	13	0	0	0
Yorke	37	0	5.0	9.0
Eastern Islands				
Stephens	4	0	0	0
Darnley	11	0	0	0
Murray	36	0	0	0

*Assuming that the meat yield from a dugong is 45% by weight (Nietschmann, unpublished 1982) and that all meat is consumed on the island from which it was caught. Per capita consumption is based on data from populations in the collection districts for the 1991 census. In some cases the population was for a group of sparsely populated islands and consequently some of the values listed may be underestimates.

change in observed numbers cannot be attributed solely to the resultant change in the availability correction factor (Table 2). Reanalysis of the 1991 data using the 1987 availability correction factor (Table 4) still resulted in a significant difference between surveys; the probability of rejecting the null hypothesis changed from 0.01 to 0.05.

Catch Statistics

On an average day between June 1991 and May 1993, four hunting parties, each of about three men in an aluminum dinghy, caught $3.36 \pm \text{SE } 0.56$ dugongs weighing a total of $645 \pm \text{SE } 102$ kg. This equates to an estimated annual harvest of $1226 \pm \text{SE } 204$ dugongs for the TSPZ.

As a source of food, dugong hunting was the most important traditional fishing activity in the Top West Island Group and the Western Islands (unpublished data), but much less important in the Central Islands (Table 5). No dugongs were recorded as caught by residents of the Eastern Islands (Table 5). The level of dugong hunting also differed among islands within a region. The two most easterly communities in the Top Western and Western Island Groups, Saibai and St. Paul respectively, caught fewer dugongs and had fewer dugong hunters within their communities than the other communities in their region. Yam, the western most island of the Central Group, recorded the highest level of dugong hunting for its region (Table 5).

The data allowed an interannual comparison of the dugong catch of Boigu, Badu, Mabuiag, Yorke, and Murray Islands for the periods between September and May

1991/1992 and 1992/1993. There was a marked change in the numbers of dugongs from 3.8 (SE 0.85) animals per day in 1991/1992 to 2.35 (SE 0.60) animals per day in 1992/1993. The daily weight of dugongs landed on these islands in 1991/1992 was 679 (SE 149) kg compared to 496 (SE 141) kg in 1992/1993. Boigu, Mabuiag, and Badu accounted for a large percentage (86%) of the dugongs caught in 1991/1992 so that their catches in 1992/1993 probably reflect a general decrease throughout the TSPZ in 1992/1993.

Using B. Nietschmann's (unpublished 1982) estimates of the meat yield from a dugong butchered by Torres Strait Islanders and assuming the meat was eaten in the community from which the hunters originated, the survey results showed that the per capita consumption of the 3031 inhabitants of the TSPZ (1991 population census) was 96 g of dugong meat per day. The per capita consumption at some communities was much higher than this (e.g., an average of 388 g per day at Boigu and 316 g per day at Mabuiag) (Table 5).

Discussion

Estimates of the Dugong Population

The difference between the 1987 ($13,319 \pm \text{SE } 2,136$) and 1991 ($24,225 \pm \text{SE } 3,276$) estimates of the dugong population represents a population increase of 82% if the 1991 availability correction factor is used for the 1991 data. If the 1987 availability correction factor is used for both surveys, the increase is 52% (Table 3). Nei-

Table 6. Comparison of the dugong population estimates obtained from repeat surveys of the same area.^a

<i>Location</i>	<i>Survey date</i>	<i>Population estimate (SE)</i>	<i>Reference</i>
Shark Bay, WA	July 1989	10,146 (1478)	Marsh et al. (1994)
	July 1994	10,126 (1665)	Preen et al. (1997)
Western Gulf of Carpentaria, NT	August 1984	16,816 (2946)	Bayliss & Freeland (1989)
	February 1985	16,846 (3257)	Bayliss & Freeland (1989)
Cape Bedford—Cape Melville, QLD	November 1984	2899 (454)	Marsh & Saalfeld (1989)
	November 1985	2542 (634)	Marsh & Saalfeld (1989)
Campbell Point—Hunter Point, QLD	April 1985	2172 (552)	Marsh & Saalfeld (1989)
	November 1985	1938 (491)	Marsh & Saalfeld (1989)
Cape Bedford—Hunter Point, QLD	November 1985	8100 (1073)	Marsh & Saalfeld (1989)
	November 1990	10,472 (1579)	Marsh & Corkeron (1997)
	November 1995	8190 (1172)	Marsh & Corkeron (1997)
Southern Great Barrier Reef, QLD ^b	Oct.–Nov. 1986/87	3497 (459)	Marsh & Corkeron (1997)
	Nov.–Dec. 1992	1857 (292)	Marsh & Corkeron (1997)
	Nov.–Dec. 1994	1750 (257)	Marsh & Corkeron (1997)

^aIn contrast to the survey of Torres Strait, these surveys covered all the potential dugong habitat in the survey area.

^bThese surveys are believed to have detected a significant decline between 1986/1987 and 1992.

ther difference can be explained by natural increase in the absence of immigration. Marsh (1986) calculated that even with the most optimistic combination of dugong life history parameters (calving interval of 3 years and a pre-reproductive period of 10 years) an *unbarvested* dugong population was unlikely to increase at more than about 5% per year (i.e., 21.5% over the 4-year interval between surveys). In the absence of immigration, the rate of increase of dugong numbers in Torres Strait would be considerably less than this because of the substantial harvest by indigenous peoples.

Repeated aerial surveys of dugong populations in most other areas have been remarkably consistent (Table 6), suggesting that the differences between surveys observed in Torres Strait are due to changes in population size rather than an artefact of the survey technique. The 1991 survey took nearly a month because of interruptions caused by bad weather and aircraft malfunction. Dugongs may have been counted twice if they moved during this period. This could have a significant effect on the population estimate if there was a major redistribution of dugongs within the survey area in response to rough seas. In addition, although our analysis suggests that the difference between surveys is unlikely to be due to the change in the availability correction factor per se (Tables 2 and 4), the possibility that it was due to a change in the availability bias cannot be ruled out. This correction factor is designed to compensate for the difference in water turbidity between surveys of the same region but assumes that the distribution of water depths in which dugongs are sighted is the same for each survey. If this were not the case, then this correction factor would fail to standardize the availability bias across surveys. Unfortunately, the bathymetry of much of Torres Strait is poorly known and we are unable to compare the depths at which dugongs were sighted in 1987 and 1991. Our analysis also suggests that the difference be-

tween surveys is unlikely to be due to sighting conditions, which were slightly worse in 1991 than in 1987 (Table 1).

We consider that the most likely explanation for the observed difference between surveys is that dugongs migrated into the area between the surveys, probably from the coastal waters of Irian Jaya, the western half of the island of New Guinea which is part of Indonesia. Torres Strait supports one of the largest seagrass areas in Australia. A total of 17,500 km² of seagrass supporting habitat has been identified and mapped in the Australian waters of the Strait (Poiner & Peterkin 1995). Open ocean seagrass communities occur subtidally to around 40 m depth in the extensive waters of northwestern Torres Strait. It is likely that our survey area which was constrained by the endurance of the aircraft, fuel availability, and the proximity of the Irian Jayan border did not cover all the seagrass-supporting habitat in the region. Nothing is known of the distribution of seagrasses or dugongs along the Irian Jayan coast. The hypothesis that dugongs migrated into our survey area from the west between 1987 and 1991 is consistent with the significant increases in dugong density occurring in western Torres Strait (blocks 0 and 3) (Fig. 4).

The stimulus for such a migration is unknown. The most plausible explanation would be a large-scale loss of seagrasses along the Irian Jayan coast possibly as a result of intense flooding. Seagrasses are susceptible to dieback events in northern Australia (Poiner & Peterkin 1995; Preen & Marsh 1995). There is anecdotal evidence of a massive dieback of seagrasses in Torres Strait in the mid 1970s (Johannes & MacFarlane 1991), and several hundred square kilometers of seagrass disappeared from northwestern Torres Strait in 1991–1992, possibly because of high turbidities from flooding of the Mai River in Papua New Guinea (Poiner & Peterkin 1995). After a major flood followed by a cyclone in 1992, more than

1000 km² of seagrass were lost from the southern half of Hervey Bay in southeast Queensland, a region which in 1988 was estimated to support 2206 ± SE 420 dugongs (Preen & Marsh 1995). A repeat of the 1988 survey in November 1992 indicated that there were only 71 ± SE 40 dugongs in the affected area. Although some animals died (99 carcasses were recovered), most of the dugongs traveled south to Great Sandy Strait. Others apparently migrated further south to Moreton Bay and along the New South Wales coast (Preen & Marsh 1995).

We consider that, unless dugongs were double counted as a result of mass movements of dugongs when the survey was interrupted due to bad weather, even the 1991 estimate of dugong numbers in Torres Strait (Table 3) is more likely to be an underestimate than an overestimate of the population size at that time. The correction for availability bias assumes that the proportion of dugongs at the surface is the same for all habitats and at all times (Marsh & Sinclair 1989). This assumption is unlikely to be valid in Torres Strait, where significant numbers of animals were seen in relatively deep water (Marsh & Saalfeld unpublished data). Observations suggest a trend for dugongs to remain submerged longer in deeper water (Anderson 1994) which would make the correction for availability bias relatively more conservative than it is in shallow water areas. A more accurate correction for availability bias in Torres Strait will require further investigation of dugong diving and migratory behavior in this area.

Magnitude of the Dugong Catch

Dugongs are an important component of the traditional fishery in Torres Strait. The wet weight of dugongs landed between June 1991 and May 1993 was higher than the weight of any other component of the traditional fisheries catch in the TSPZ including turtles, lobster, and finfish (unpublished data). In addition to the estimated annual catch in the TSPZ of 1226 ± SE 204 dugongs, an estimated 70 to 80 animals per year were taken by Australian residents of the region south of the TSPZ (H. Nona personal communication 1992) plus an unknown number by Papua New Guinean residents outside the TSPZ. Karre (1995) reports that 17 dugongs were sold in the market at the Papuan island of Daru (Fig. 1) between 1992 and 1994 despite strong warnings from wildlife authorities about the illegality of this activity. This estimate did not include dugongs caught by local fishers for home consumption.

Average daily catches of dugongs in the five communities for which data are available for the entire study period (three of which together land about 80% of the TSPZ catch) declined markedly over 2 years suggesting large variations in the dugong harvest between years, coincident with the loss of seagrass in northwestern Torres Strait in 1991 (Poiner & Peterkin 1995). There are also

longer term variations in the dugong harvest not easily explained by a gradual increase in hunting efficiency arising from the use of motorized boats. Nietschmann (1984) roughly estimated that an average annual catch of 750 dugongs was taken in Torres Strait between 1976 and 1978. He reported that many dugongs were unusually close to the main hunting islands, allegedly as a result of extensive dieback in deepwater seagrasses. Johannes and MacFarlane (1991) found that only one-fifth as many dugongs were caught in the Western Islands between 1983–1984 as were caught in 1976–1978 and were then concerned that the numbers would decline further. The estimate of the annual catch of dugongs taken between June 1991 and May 1993 was higher than estimates of the annual catch in the mid 1980s and the mid 1970s (Table 7). Catch estimates made roughly a decade apart thus show no clear trends, possibly because of variations in the size and distribution of the dugong population in the Australian waters of Torres Strait. Such variations are also suggested by the results of the 1987 and 1991 aerial surveys.

The estimates of per capita consumption of dugong meat between 1991 and 1993, especially at Boigu (387.9 g per day) and Mabuiag (315.9 g per day) are extremely high given the large quantities of other seafood landed in these communities (unpublished data) and the availability of meat from community stores. These consump-

Table 7. Mean daily catch rates in numbers of dugongs for communities in the Torres Strait Protected Zone (TSPZ).

Community	Johannes & MacFarlane ^b		
	Nietschmann ^a 9/1976-3/1979	1983-1986	CSIRO ^c 6/91-5/93
Top West Islands			
Boigu		0.118	1.109
Dauan		0.008	0.214
Saibai		0.137	0.045
Western Islands			
Mabuiag	0.337	0.033	0.665
Badu	0.258	0.055	0.877
Kubin	0.137	0.033	0.266 ^d
St Paul		0.027	
Central Islands			
Yam		0.011	0.149
Warraber			0
Coconut		0.005	0
Yorke		0.014	0.026
Eastern Islands			
Stephens		<0.003	0
Darnley		<0.003	0
Murray		<0.003	0

^aData from Nietschmann (1984) have been calculated by dividing the totals in his Table 4 by the total number of days monitored.

^bData from Johannes and MacFarlane (1991) are taken from their Table 1 of yearly catches divided by 365 days.

^cData for this study have been converted from daily catch in kilograms by multiplying by 3.36/645 (mean no. dugongs/mean kilogram dugongs caught per day).

^dIncludes St. Paul community.

tion estimates suggest some or all of the following: (1) the estimates of the dugong catch are too high; (2) excess meat is exported to other communities; or (3) much of the meat is wasted. These issues need to be addressed if the dugong fishery is to be managed sustainably.

Sustainability of the Dugong Fishery

Population simulations (Marsh 1986, 1995a) based on dugong life history data from various regions including Torres Strait indicate that the maximum rate of increase of a dugong population (r_m) will be approximately 5% per annum. The maximum sustainable loss from all anthropogenic impacts will thus be expected to be of the order of $0.5r_m$ or 2.5% of females (Caughley & Sinclair 1994) from a population size of $K/2$, K being the average size of the unharvested population (which is unknown). Without up-to-date information on the life history parameters of dugongs in Torres Strait, an accurate estimate of the absolute abundance of dugongs in the area and accurate data on dugong catch levels throughout the entire region (including the Australian areas south of the TSPZ, the Papuan coast, and Irian Jaya), we cannot be sure whether the dugong fishery is sustainable at current harvest levels. As illustrated in Table 8, however, the fishery is unlikely to be sustainable unless the dugong population size was underestimated by a factor of at least two in 1991.

Future Action

A more robust assessment of the sustainability of the dugong catch in Torres Strait will require longer, more comprehensive, and more accurate time series data for both the dugong population and the dugong catch, plus more reliable data on life history parameters, especially adult survivorship. This will take many years given the interannual fluctuations in both the population estimates and the catch (Tables 3 and 7), the logistical and jurisdictional problems associated with surveying the entire area of seagrass supporting habitat in the region, and the difficulties of detecting trends in populations of long-lived species such as dugongs (Taylor & Gerrodette 1993; Marsh 1995b) and of quantifying the bias in the

population estimates (Marsh 1995b). Meanwhile, the available data reinforce the previous concerns (Hudson 1986; Marsh 1986; Johannes & MacFarlane 1991) that the Torres Strait dugong fishery is not sustainable.

Theoretically, hunting per se should be unlikely to drive a species to extinction because hunting pressure declines with the density of the prey species because it takes longer to find animals when density is low. However, this inbuilt safeguard does not necessarily apply when hunting is targeted toward more than one species (Bomford & Caughley 1996). In Torres Strait dugongs and green turtles are hunted together. Thus unregulated dugong hunting would be expected to cease only when the combined density of dugongs and green turtles is so low that hunting is not worthwhile. Because our aerial surveys indicate that turtles are much more abundant than dugongs in this region (unpublished data), we believe there is a real danger of dugong populations being seriously affected by hunting in Torres Strait unless it is regulated.

The support and cooperation of Torres Strait Islanders is crucial to the success of any initiative to regulate hunting. Given the remoteness of the area, it will be impossible to enforce management restrictions without the cooperation and involvement of local peoples. Although the present dugong sanctuary (Figs. 1 & 3) was designated in 1985 after extensive community consultation, it is a "paper park," the existence of which is probably irrelevant to most hunters. The dugong fishery will not be effectively managed until the Islanders and the government management agencies develop mutually acceptable management objectives for the dugong fishery. The Islanders continue to perceive that they are competing with the management agencies for dugongs, and they will not consider it in their best interests to harvest sustainably, particularly if they believe there is a risk that they will be prevented from hunting dugongs, an activity which they regard as central to their indigenous identity.

We suggest that the Torres Strait Regional Authority, the body established to represent indigenous peoples in the Australian regions of Torres Strait, should be empowered to manage dugong resources under Australian jurisdiction in a formal cooperative management arrangement with the Australian Fisheries Management

Table 8. Estimates of the annual catch of dugongs in the TSPZ in Torres Strait between June 1991 and May 1993 (mean \pm 2 SE) as percentages of the population estimates (mean \pm 2 SE) for dugongs in Torres Strait obtained as a result of the aerial surveys conducted in 1987 and 1991.*

Annual catch 1991-93	Population estimate 1987 survey			Population estimate 1991 survey		
	Mean - 2 SE	Mean	Mean + 2 SE	Mean - 2 SE	Mean	Mean + 2 SE
Mean - 2 SE	9.0	6.1	4.7	4.6	3.4	2.7
Mean	13.6	9.2	7.0	6.9	5.1	4.0
Mean + 2 SE	18.1	12.3	9.3	9.2	6.7	5.3

*The sustainable harvest is likely to be of the order of 2.5% of females.

Authority, the government agency that currently manages the fishery. Parallel arrangements should be developed for the fishery in Papua New Guinean waters. There are several models for co-operative management of indigenous hunting of marine mammals in Alaska that could be used as a basis for negotiations (e.g., Freeman 1989; Richard & Pike 1993; Marine Mammal Commission 1995).

A cooperative management arrangement would enable Torres Strait Islanders to play a key role in the design of appropriate educational, research and management strategies to ensure that dugong hunting in the region is sustainable. These strategies could be implemented at the community level through dugong management plans and local government by-laws. With the support of local leaders, some progress is being made along these lines at Boigu, one of the major dugong hunting communities. An important feature of this program is the exchange of information between fishers and researchers. As Johannes and MacFarlane (1991) have pointed out, dugong conservation in Torres Strait is primarily an education issue, not a problem that can be solved solely by legislation and enforcement (or scientific research).

Acknowledgments

This research was funded by the Australian Fisheries Management Authority. Thanks are due to the following people and organizations: Queensland Departments of Environment and Heritage and Primary Industries for providing some of the aerial survey observers; the aerial survey observers, A. Budiwan, M. Brown, D. Couchman, J. Lanyon, J. Mellors, K. Smith, K. Vidler; the pilot, B. Griffin; G. Dews for assistance in the organization and execution of the traditional fishing survey; the fisheries observers, F. Bowie, T. Courie, K. Hirakawa, W. Mene, F. Mills (AFMA), and K. Waireg (late); R. Coles and M. Bishop (AFMA), I. Poiner (CSIRO), and J. Vanderkamp (JCU); G. De'ath and J. Kerr for statistical advice; L. Smith and L. Line for assistance with the figures; the fishers from whom the catch information was gathered; and the people of Torres Strait for their hospitality. The manuscript benefited from the comments of M. Bishop, C. Deutsch, G. Dews, L. Lefebvre, R. Pitcher, and three anonymous reviewers.

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