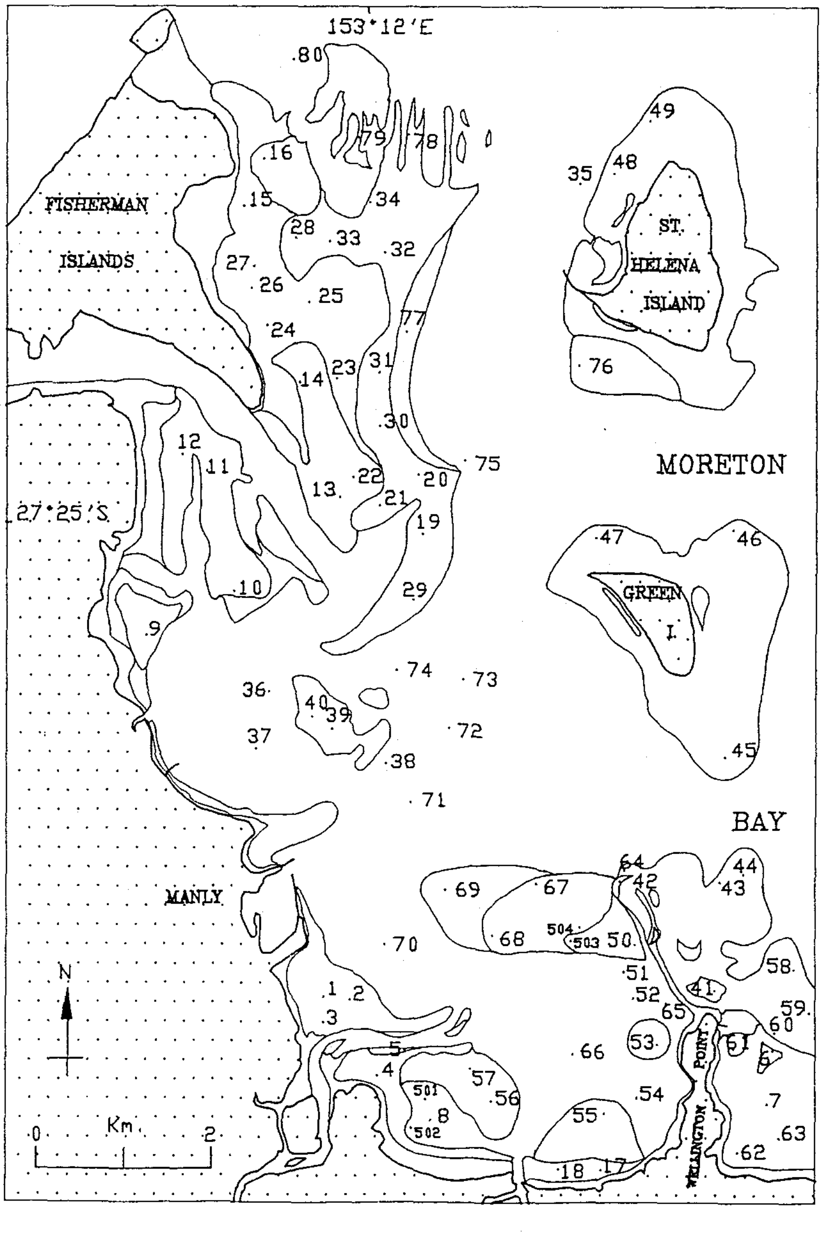
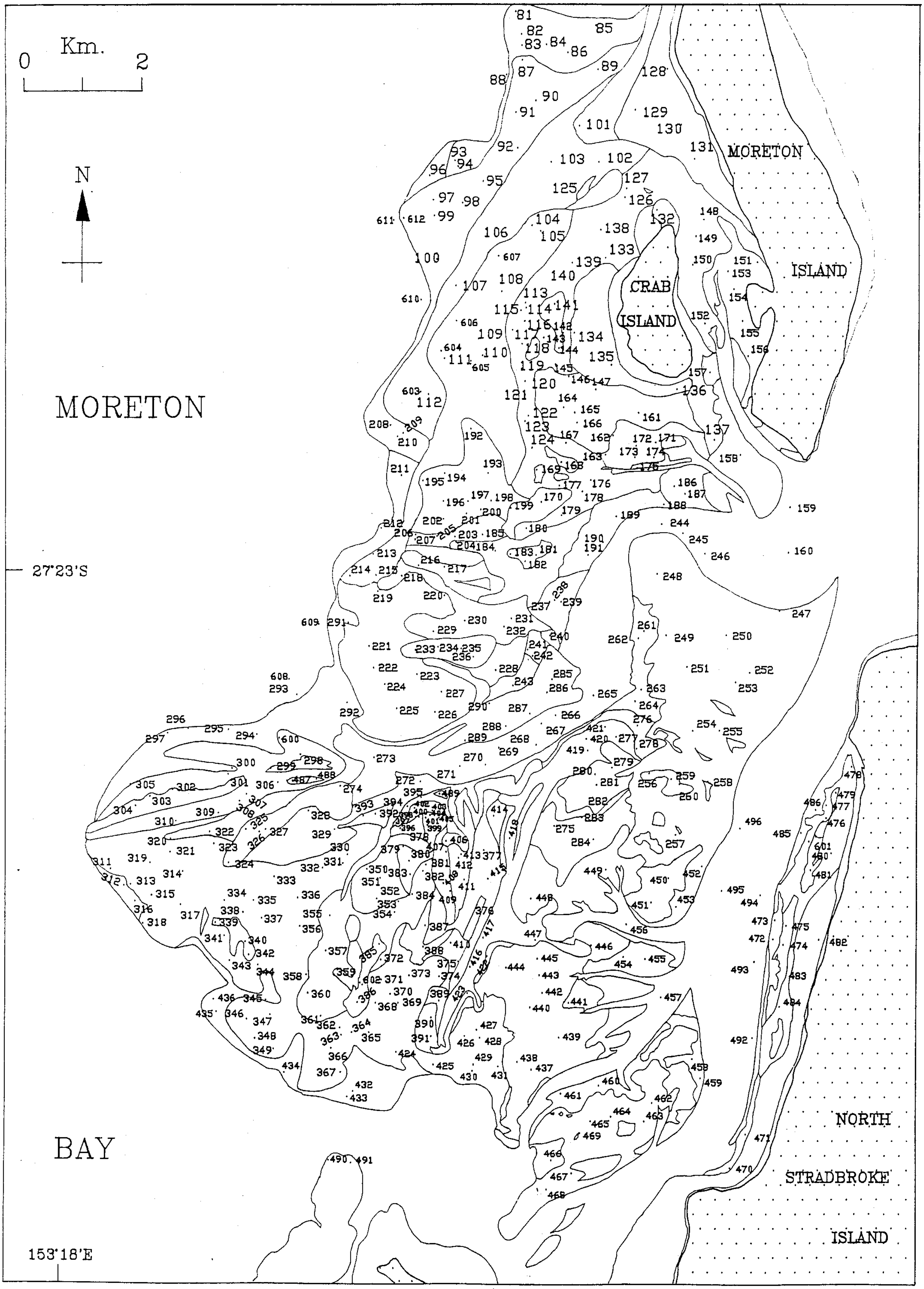
APPENDIX 1

Location of sites sampled for seagrass mapping and bathymetry in the (A) West and (B) East study areas in Moreton Bay.

A



B


0 Km. 2
N
MORETON
BAY
27°23'S
153°18'E
CRAB ISLAND
MORETON ISLAND
NORTH STRADBROKE ISLAND

APPENDIX 2

ALTERNATIVE METHOD OF ESTIMATING THE STANDING CROP (AND ASSOCIATED STANDARD ERROR) OF SEAGRASS IN COMMUNITIES IN THE STUDY AREAS

See section 3.2.5.2 for further information on this material.

1. The mean biomass of a community was estimated by averaging the biomass at all sites that sampled that community.
2. The total area of the community was the sum of the area of all tracts of seagrass of that community.
3. Community standing crop was estimated by:
   community biomass * community area
4. The variance of the community standing crop was estimated by:
   biomass variance * area^2
5. The standard error of the community standing crop was:
   √(standing crop variance/number of sites sampled)
6. The standing crop of a study area = sum of standing crop of each community
7. The standard error of the study area standing crop was estimated by:
   √(Σvariance of each community).

This approach avoids the problem of tracts of seagrass containing only one sample site, by using community as the minimum spatial unit. This assumes that there is no significant difference between the biomass of seagrass in each tract of each community, and therefore the different areas of each tract is inconsequential. This is unlikely to be the case.

The estimates of the standing crop, and associated standard error, of each community, calculated by this method are presented in the following table. Compared with Table 3.3, it is apparent that there is very little difference in the estimates of standing crop calculated by the two methods. The alternative method (above) results in smaller standard errors for most communities, but a larger standard error for the estimate of the standing crop of each study area.

Table A.2.1. Species composition, biomass, standing crop and area covered by the 15 community types in the study areas.

Community	Species/morph[1]	# sites	Area (km²)	Biomass[2] (g/m²)		Standing crop[2] (tonnes)	
				mean	SE		SE
East study area (428 sites)							
C	Cs	5	0.54	202.0	52.3	109.07	28.22
S	Si	4	0.63	250.5	61.3	157.78	38.63
ZB1	Si,Hub,Zcb	17	3.65	287.1	35.8	1047.88	130.49
ZB2	Hub,Zcb	53	15.28	260.0	18.8	3972.65	287.25
ZB3	Hub,Zcb,Ho	37	13.66	205.3	16.0	2804.26	219.09
ZB4	Zcb,Hs	7	2.10	45.7	31.3	95.91	65.77
ZB5	Zcb,Ho,Hs	14	2.63	66.9	10.1	175.81	26.45
H1	Ho,Hs	54	15.48	26.8	2.9	415.33	44.95
H2	Ho,Hs	44	11.50	8.6	1.3	98.64	14.61
H3	Hs	54	16.38	18.7	5.1	305.88	84.09
H4	Ho	11	4.86	2.6	0.7	12.63	3.54
H5	Ho,Hut	25	7.54	4.5	0.6	34.26	4.38
H6	Hs,Hd	14	3.24	2.5	0.6	8.10	1.84
ZT1	Ho,Hut,Zct	26	11.76	130.0	20.3	1528.56	238.54
ZT2	Zct	7	1.29	10.5	6.4	13.51	8.29
Total		372[3]	110.54			10780.28	2910.24
West study area (84 sites)							
ZB2	Hub,Zcb	12	6.69	173.6	38.0	1161.38	253.89
ZB3	Hub,Zcb,Ho	11	5.59	85.4	15.9	477.23	88.67
ZB5	Zcb,Ho,Hs	3	0.63	69.7	20.6	43.89	12.98
H1	Ho,Hs	11	4.54	44.0	13.4	199.72	60.96
H2	Ho,Hs	3	1.40	1.9	1.3	2.71	1.76
H3	Hs	4	1.70	0.3	0.2	0.51	0.36
H6	Hs,Hd	6	1.82	10.8	4.9	19.62	8.99
ZT1	Ho,Hut,Zct	2	0.44	81.9	14.3	36.01	6.27
Total		52[3]	23.80			1941.08	950.01

[1] Seagrass species/morphs: Cs: Cymodocea serrulata, Si: Syringodium isoetifolium; Zcb: Zostera capricorni broad; Zct: Z. capricorni thin; Hut: Halodule uninervis thin; Hub: H. uninervis broad; Ho: Halophila ovalis; Hs: H. spinulosa; Hd: H. decipiens.

[2] Biomass is the dry weight of the above and below ground components of the seagrass per unit area. Standing crop is the total dry weight of seagrass in the total area occupied by each community type.

[3] Some tracts of seagrass included sites that contained no seagrass, hence 372+52 > 417 (total number of sites that contained seagrass) see text.

APPENDIX 3

RELATIONSHIP BETWEEN WET WEIGHT AND DRY WEIGHT OF COMMON SEAGRASSES IN MORETON BAY

Regressions of wet weight (independent variable) against dry weight (dependent) of above- and below-ground components of the three most widespread seagrasses in Moreton Bay. Data were collected in July 1988.

Species	Component[1]	n	Regression model[2]	df	Adjusted R^2	F-ratio	p
H. spinulosa	above	148	DW = 0.013 + 0.090 * WW	146	0.9119	1523	0.0000
	below	141	DW = -0.001 + 0.098 * WW	139	0.9283	1815	0.0000
H. ovalis	above	124	DW = 0.010 + 0.089 * WW	122	0.9644	3329	0.0000
	below	120	DW = 0.031 + 0.062 * WW	118	0.8204	545	0.0000
Z. capricorni	above	53	DW = 0.046 + 0.075 * WW	51	0.9382	790	0.0000
	below	51	DW = -0.201 + 0.105 * WW	49	0.9681	1518	0.0000

[1] Above-ground or below-ground

[2] DW = dry weight, WW = wet weight

APPENDIX 4

ANALYSIS OF AERIAL SURVEY AND SATELLITE TRACKING DATA

by Glenn De'ath

4.1. Analysis of aerial survey data

4.1.1. Statistical analysis

A series of log-linear analyses was used to investigate the effects of habitat type, water depth, distance to deep water, season, year, water temperature, boats and their interactions on the numbers of dugongs observed in each of 181 1 km^2 grid-cells during 28 aerial surveys, plus an aditional 21 cells covered on 14 surveys (see section 5.2.1.5). All quantitative variables (depth, distance, temperature, boats and dugongs) were reduced to qualitative factors for the log-linear analyses, as coded below. Since temperatures were recorded only for winter, two different temperature regimes were denoted within winter to define 'warm water' and 'cold water' regions. Having established which factors affected dugong observations, logistic regression analyses were then used to investigate the pattern of effects and to quantify them more precisely. A total of 5152 cases (each corresponding to a survey cell) were used for the analysis.

The SPSS/PC+ (1990), GLIM 3.77 (1985), and SAS (1990) packages were used for various analyses.

4.1.1.1. Log-linear analysis

The log-linear analysis was conducted as follows:

First, a series of models was fitted to all the surveys using the following factors (detailed in section 5.2.1.5) and codings:

(i) Habitat (1-8)
(ii) Depth (≥ 0 m or <0 m relative to Port Datum)
(iii) Distance to deep water (≥ 1.5 km or <1.5 km)
(iv) Season (Winter ['warm': water temperature $>19°$ C or 'cold':

water temperature $\leq 19°$C], Spring, Summer,)

(v) Year (1988-9, 1989-90)

(vi) Boats (present or absent in grid cell)

(vii) Dugongs (0, 1, or >1 in grid cell)

Habitats were identified on the basis of their biotic or physical characteristics. The threshold for water depth (0 m) was based on the following: (1) seagrass is most abundant between depths of -1 and +1 m relative to Datum (section 3.4.1) and (2) the mean depth of feeding sites that were investigated was -0.1 m (section 6.2.2.1). The threshold for distance to deep water (1.5 km) was dictated partly by the resolution of the 1 km^2 grid size. Seasons were delineated by water temperature (section 2.2). In winter, grid cells were identified as warm (>19° C) or cold ($\leq$19° C) on the basis that 18-19° C is suspected to be the threshold temperature, below which dugongs cannot maintain homeostasis indefinately (section 5.4.2.2).

Hierarchal log-linear analyses using backward elimination were used to derive minimal models (Bishop et al., 1975). Because dugongs tend to form herds it is unlikely that the location of an individual dugong is independent of its neighbours. For log-linear analysis of such data over-dispersion (variance > mean) is likely (McCullagh and Nelder 1989), which violates the assumptions of using X^2 analysis of deviance. Accordingly, tests for the significance of model effects used approximate F-ratio tests based on changes in deviance and associated degrees of freedom.

The effects of various factors on dugong categories were subsequently broken down into two sub-analyses. The first of these involved the contrast between no dugongs observed in a cell and at least one dugong per cell, and the second looked at the difference between one and more than one observed dugong per cell. The rationale for this approach was that if the differences between the results of the analyses based on the categories of 1 and >1 dugongs per grid cell were negligible, the data could be simplified to presence/absence of dugongs. This would allow a simpler analysis (logistic regression) to be used that would be easier to interpret.

4.1.1.2. Logistic regression analysis

As was the case for the log-linear analyses, over-dispersion was anticipated and significance tests and confidence intervals were based on the mean deviance. A minimal model was obtained by backward elimination and a series of contrasts were used to investigate the seasonal effects on dugong presence within each habitat.

Estimated proportions of survey grids with dugongs for each season in each habitat type were estimated from the minimal model which included season, habitat, distance and temperature effects as follows.

The minimal logistic regression model can be written:

$$\begin{aligned} E[p_{ijkl}] &= f(lp_{ijkl}) \\ &= f(\mu + hs_{ij} + d_k + t_l) \end{aligned}$$

where $E[p_{ijkl}]$ denotes the expected proportion of dugongs in habitat i, season j, distance k, and temperature l. f denotes the logistic function and lp the linear predictor. μ denotes the overall mean, hs_{ij} the habitat by season effects, d_k the distance effects, and t_l the temperature effects.

The estimated proportions for each season within each habitat were estimated by:

$$\hat{p}_{ij\cdot\cdot} = f(\mu + hs_{ij} + d_k + t_l)$$

where . denotes the averaged effects. Approximate confidence intervals for the estimated proportions were obtained by transforming the corresponding estimated confidence interval of the linear predictor.

These estimated proportions can be interpreted as the proportion of dugongs that, on average, would be observed at the average of the two levels of both temperature and distance, and are analogous to population means or Least Squares Means (SAS 1990).

4.1.2. Results

4.1.2.1. Log-linear analysis

The final model generated by the backward elimination included second order interactions between habitat, seasons, and dugong abundance, and between habitat, distance and depth, and the first order interaction between distance and dugong abundance. The habitat, distance, depth interaction simply represents the different locations and depths of the habitats and is of no interest. The other two terms however indicate that the distribution of dugongs depends jointly on habitat and season, and also on distance.

The analysis based on the absence and presence of dugongs depended on other factors in the same manner as the analysis using the three levels of dugong abundance (0, 1, >1). The analysis contrasting one dugong and more than one dugong gave a minimal model dependent on the second order interaction between habitat, distance and depth, and the first order interaction between habitat and season (Table A.4.1). It also depended on the main effect of dugongs. Since the factor dugongs did not enter the final model in interactions with other factors, this suggests that the presence of either one or more than one dugong was not affected by other factors. Thus the distinction between these two categories was dropped and the data analysed simply as presence-absence data using logistic regression.

4.1.2.2. Logistic regression

Following the results of the log-linear analysis the data were converted to proportions of survey grids with dugongs for each category defined by the combinations of habitat, season, and distance. Temperature was included as a factor nested within the winter season.

A hierarchal analysis resulted in a model including an interaction between habitat and season, and the main effects of temperature and distance (Table A.4.2).

The parameter estimates of the model indicate that during winter, dugongs were

4.91 (95% ci = (1.88, 12.81)) times as likely to be seen in warmer regions (> 19° C) than in colder regions (≤ 19° C) than would be expected by chance. Dugongs were also 1.74 (95%ci = (1.24, 2.45)) times as likely to be seen in regions closer (≤ 1.5 km) to deep water than in other areas than would be expected by chance.

The estimated proportions of survey grids with dugongs for each season in each habitat, estimated from the minimal model, are listed in Tables A.4.3 and for habitat alone in Table A.4.4.

4.2. Analysis of satellite tracking data

4.2.1. Statistical Analysis

The data were analysed by log-linear analysis. The response variable was the number of dugongs, with habitats, seasons and dugong identity (nested in seasons) taken as qualitative explanatory variables. First order interactions between these factors were included in the model and the mean square deviance was used to test all effects for significance using approximate F-tests based on the mean deviance due to the presence of over-dispersion (McCullagh and Nelder, 1989). Since the total areas of the habitats varied, the logarithms of the areas of the habitats were used as offsets. This has the effect of adjusting each count for the habitat area under the assumption that the counts are proportional to the area of the habitats. A minimal model was selected by backwards elimination.

Contrasts between seasons within each habitat were based on the minimal model using an error term pooled from the deviance of the minimal model and the change in deviance due to dugongs within seasons.

Densities of locations from dugongs were estimated for each season within each habitat from the minimal log-linear model in a similar manner to the estimated proportions in the previous analysis of the aerial survey data. Confidence intervals were based on the error term used for contrasts between seasons within habitats.

4.2.2. Results

The final model includes the effects of habitats, seasons, dugongs ($F_{(10,69)} = 8.37$, $p < 0.001$) and the interaction between habitats and seasons ($F_{(14,69)} = 5.08$, $P < 0.001$). Although this interaction was highly significant, the main effects of habitat ignoring seasons were much greater than the interaction ($F_{(7,83)} = 34.13$, $p < 0.001$). The density of locations from areas with each combination of habitat and season presented in Table A.4.5, and the densities of locations in each habitat, averaged over seasons are in Table A.4.6.

Table A.4.1. Analysis of deviance for final hierarchal log-linear models assessing the effects of habitat (see section 5.2.1.5), season (winter, spring summer), distance to deep water (< or ≥1.5 km), depth (< or ≥0 m realtive to Datum) and abundance of dugongs.

Effect	df	Change in deviance	F-ratio	p
Dugong abundance (0, 1 or >1)				
Habitat.Distance.Depth	7	249.7	35.80	<0.001
Habitat.Season.Dugong	42	266.6	6.37	<0.001
Distance.Dugong	2	31.9	16.00	<0.001
Residual deviance	166	165.4		
Dugong abundance (0 vs 1, >1)				
Habitat.Distance.Depth	7	249.7	34.28	<0.001
Habitat.Season.Dugong	21	238.4	11.12	<0.001
Distance.Dugong	1	28.8	28.23	<0.001
Residual deviance	104	106.1		
Dugong abundance (1 vs >1)				
Habitat.Distance.Depth	7	39.1	5.93	<0.001
Habitat.Season	21	204.5	10.23	<0.001
Dugong	1	19.2	20.37	<0.001
Residual deviance	61	57.5		

Table A.4.2. Analysis of deviance for final hierarchal logistic regression models assessing the effects of habitat (1-8; see section 5.2.1.5), season (winter, spring, summer), distance (< or ≥1.5 km), and temperature (≤ or >19° C) on the presence of a dugong in a grid cell.

Effect	df	Change in deviance	F-ratio	p
Full model				
Habitat.Season	14	112.6	2.47	0.039
Distance	1	34.6	10.62	<0.001
Temperature	1	34.0	10.43	<0.001
Residual deviance	17	55.4		
Testing for effects of season and habitat after removing the interaction habitat and season				
Habitat	7	416.2	10.97	<0.001
Season	2	81.7	7.50	0.002
Residual deviance	31	168.0		

Table A.4.3. The estimated proportions (and the associated 95% confidence intervals) of relevant grids cells containing at least one dugong in each combination of habitat and season adjusted for the effect of the distance of the cell from deep water on dugong presence.

		Habitat[1]							
		1	2	3	4	5	6	7	8
Winter	Proportion[2]	0.412	0.286	0.228	0.162	0.248	0.347	0.039	0.360
	Upper 95%[3]	0.629	0.450	0.407	0.381	0.496	0.556	0.250	0.578
	Lower 95%[4]	0.225	0.164	0.113	0.057	0.099	0.184	0.005	0.187
Spring	Proportion	0.196	0.160	0.080	0.071	0.095	0.036	0.009	0.034
	Upper 95%	0.325	0.224	0.132	0.141	0.189	0.086	0.047	0.156
	Lower 95%	0.109	0.113	0.048	0.034	0.045	0.014	0.002	0.006
Summer	Proportion	0.211	0.144	0.039	0.010	0.058	0.026	0.062	0.126
	Upper 95%	0.338	0.202	0.075	0.052	0.132	0.070	0.112	0.396
	Lower 95%	0.122	0.102	0.020	0.002	0.024	0.009	0.033	0.030
$F_{(2,17)}$		1.09	1.35	5.06	5.05	1.89	10.51	3.49	8.37
p		0.357	0.286	0.019	0.019	0.180	0.001	0.053	0.003

[1] Habitats: 1: very low biomass communities dominated by H. ovalis; 2: other seagrass communities dominated by Halophila species; 3: communities dominated by Z. capricorni broad; 4: communities dominated by Z. capricorni thin; 5: sand; 6: Rous and Rainbow Channels; 7: deep water to west of banks: 8: deep water outside South Passage.

[2] The proportions for winter are higher than for the other seasons as the cells are all adjusted to the same temperature regime.

[3] Upper 95% confidence interval

[4] Lower 95% confidence interval

Table A.4.4. The estimated proportions (and associated 95% confidence intervals) of grids cells in each habitat that contained dugongs (averaged over seasons, and adjusted for the effect of the distance of the cell from deep water and the effect of water temperature on dugong presence).

	Habitat[1]							
	1	2	3	4	5	6	7	8
Proportion	0.263	0.202	0.105	0.051	0.114	0.115	0.029	0.167
Upper 95% ci	0.428	0.303	0.195	0.151	0.246	0.246	0.114	0.409
Lower 95% ci	0.146	0.129	0.055	0.016	0.048	0.049	0.007	0.055

[1] Habitats: 1: very low biomass communities dominated by H. ovalis; 2: other seagrass communities dominated by Halophila species; 3: communities dominated by Z. capricorni broad; 4: communities dominated by Z. capricorni thin; 5: sand; 6: Rous and Rainbow Channels; 7: deep water to west of banks: 8: deep water outside South Passage.

Table A.4.5. The estimated density of satellite tracking locations (km^{-2}; plus 95% confidence intervals) in areas characterised by each combination of habitat (1-8) and seasons (winter, spring summer).

		Habitat[1]							
		1	2	3	4	5	6	7	8
Winter	Density (locations/km^2)	0.038	0.651	0.594	0.113	0.409	0.100	0.113	0.160
	Upper 95% ci	1.059	0.937	0.932	0.663	0.773	0.301	0.278	0.416
	Lower 95% ci	0.001	0.045	0.379	0.019	0.217	0.033	0.048	0.061
Spring	Density (locations/km^2)	1.480	1.130	0.314	0.461	0.307	0.058	0.125	0.000
	Upper 95% ci	2.694	1.588	0.669	1.348	0.755	0.342	0.356	0.000
	Lower 95% ci	0.813	0.806	0.147	0.157	0.125	0.010	0.044	0.000
Summer	Density (locations/km^2)	1.165	0.889	0.198	0.162	0.076	0.044	0.150	0.000
	Upper 95% ci	25.54	1.383	0.596	1.310	0.613	0.461	0.452	0.000
	Lower 95% ci	0.534	0.571	0.066	0.020	0.010	0.004	0.050	0.000
$F_{(2,20)}$		3.83	1.84	1.93	0.85	1.39	0.21	0.06	2.52
p		0.039	0.185	0.171	0.444	0.271	0.809	0.943	0.105

[1] Habitats: 1: very low biomass communities dominated by H. ovalis; 2: other seagrass communities dominated by Halophila species; 3: communities dominated by Z. capricorni broad; 4: communities dominated by Z. capricorni thin; 5: sand; 6: Rous and Rainbow Channels; 7: deep water to west of banks: 8: deep water outside South Passage.

Table A.4.6. The estimated density of satellite tracking locations (km^{-2}; plus 95% confidence intervals) in each habitat (1-8) averaged over seasons (winter, spring summer).

	Habitat[1]							
	1	2	3	4	5	6	7	8
Density (locations/km^2)	0.261	0.829	0.378	0.189	0.254	0.070	0.124	0.002
Upper 95% ci	1.728	1.206	0.759	0.965	0.727	0.345	0.335	0.006
Lower 95% ci	0.039	0.570	0.189	0.037	0.088	0.014	0.046	0.000

[1] Habitats: 1: very low biomass communities dominated by H. ovalis; 2: other seagrass communities dominated by Halophila species; 3: communities dominated by Z. capricorni broad; 4: communities dominated by Z. capricorni thin; 5: sand; 6: Rous and Rainbow Channels; 7: deep water to west of banks: 8: deep water outside South Passage.

APPENDIX 5

THE DISTRIBUTION AND ABUNDANCE OF BOATS IN THE STUDY AREAS AND THE RESPONSE OF DUGONGS TO SPEED BOATS

5.1. Introduction

Boats were recorded during the 28 'standard' surveys of the East and West study areas in Moreton Bay. The details of those surveys, the categories of boats recognised and the methods of observation and recording are detailed in Chapter 5.

I have observed scores of interactions between boats and dugongs in Moreton Bay and I have drawn from my field notes to summarise the response of dugongs.

5.2. Distribution and abundance of boats

5.2.1. Abundance of boats

A total of 2,380 boats was sighted during the 28 'standard' aerial surveys. With some notable exceptions, the number sighted per survey was fairly consistent (mean = 85, SE = 8.7; Figure A.5.1).

The abundance of boats was underestimated by the 'standard' survey counts due to several biases. Firstly, boats were frequently missed when dugongs were abundant in an area, and when conditions were sub-optimal (less time to scan for boats). Secondly, boats were erratically recorded by the second observer (on three surveys no boats were recorded by that observer). Thirdly, most boating on Moreton Bay is recreational (80%, see below), and the abundance of boats is highest on weekends, yet the availability of my principal observer dictated that most surveys (25 of 28) were conducted on weekdays.

An indication of the number of boats that use the study areas on weekends, when the weather is fine is provided by survey 21 (17 September 1989). More than twice the number of boats were seen on this day than on most weekdays (Figure A.5.1). The other two weekend surveys (surveys 2 and 5) were associated with unfavourable weather. Most surveys with particularly low boat counts (surveys 2, 4, 18, 26, 28) were associated with unfavourable weather, either on the day or during the preceding days. Survey 27 was flown on the day after New Years Day, which accounts for the high boat count. This count is, however, a gross under-count as boats were recorded from the right-hand side of the aircraft only.

In southern Moreton Bay, weekend boat traffic is twice the level of week day traffic and the number of boats seen on public holidays was four and one half times the number seen during regular week days (Curgenven and Shanco, 1982). My limited data suggest that boat density on weekends and school holidays is about three times the level of week day density in central Moreton Bay, when the weather is fine (Figure A.5.1, surveys 21 and 27). As the East study area has little protection from bad weather, boat use is quite weather dependent. When conditions are rough, weekend counts can be well below the week day average (Figure A.5.1, surveys 2 and 5).

5.2.2. Boat types

The relative frequency of different types of boats is shown in Figure A.5.2. Punts were excluded as they are did not have motors (or sails) and were usually associated with professional fishing boats (where they are used as net boats) or oyster leases. When unaccompanied they create no disturbance.

The most common category of boat was speed boat/dinghy (51%), followed by sailing boats (20%), trawlers (14%), cruisers (9%), professional fishing boats (4%) and industrial craft such as barges, dredges and tugs (2%; Figure A.5.2). There was a significant difference in the abundance of the different boat types, but not in the abundance of boats between seasons. There was no interaction between boat type and season (Table A.5.1).

The relative abundance of boat types contrasts with the results of boat-ramp surveys in southern Moreton Bay and central and northern Moreton Bay. In both those surveys, virtually all craft were launched for recreational purposes, and most were power boats. In Southern Moreton Bay, only 5% of launched boats were sail boats (Curgenven and Shanco, 1982), while sail boats comprised 11% of the sample form central and northern Moreton Bay (Cameron McNamara, 1986, cited in Department of Environment and Conservation, 1989). The higher proportion of sailing boats recorded during the aerial surveys (20%) is accounted for by the presence of a regatta course in the West study area (Department of Environment and Conservation, 1989), which is heavily used by boats that are moored in a nearby marina.

5.2.3. Distribution of boats

The seasonal distribution of boats is presented in Figure A.5.3. Boats were most abundant in the inshore area. The West study area contained 46% of the boats sighted, but occupies only about 25% of the surveyed area. At the other extreme, boats were uncommon in the area outside South Passage, where a total of only eight boats were recorded in 14 surveys.

The distribution of boats seen during the summer of 1988-89 (Figure A.5.3) demonstrates that boats use all parts of the study areas. In the East study area, however, most boat traffic was concentrated near settlements near the south-western tip of Moreton Island, Amity and Dunwich (both on North Stradbroke Island), where they were frequently moored. Of the areas used by dugongs, boats were most common on the southern Amity Banks, the Rous and Rainbow Channels and Claire's Complex (Figure A.5.3).

5.3. Response of dugongs to speed boats

Dugongs respond to boats differently under different circumstances. They can detect a speed boat from at least 1 km, but their reaction is primarily determined by water depth and/or the distance to deep water. The shallower the water, or the further from deep water, the greater the disturbance to the dugongs. About 2 m appears to be the pivotal depth on the extensive, gently sloping banks in eastern Moreton Bay. At depths greater than about 2 m deep, dugongs are unlikely to react substantially to a passing boat. If they are in water less than about 2 m deep, dugongs are almost certain to respond to the boat.

The deeper the water, the less the dugongs react. Planing speed boats can pass through the centre of a herd of 50-100 dugongs (inevitably the driver and passengers are oblivious to the presence of the dugongs) apparently without causing any substantial disturbance. The dugongs simply dive several seconds before the boat arrives, and surface in its wake several seconds after it has passed. If subsequent boats pass through, or near the herd, the dugongs may move to deeper water and they may disperse. On one occasion I watched a herd of dugongs within 500 m of 7-10 stationary speed boats (being used as fishing platforms) for 80 minutes. The dugongs were in a channel 3.4 to 6 m deep and 1 km wide. During that period there were 19 boat movements, including three passes of planing boats through the core of the herd. Although the passes caused the dugongs to move, they did not leave the area.

If dugongs are in less than 2 m of water, they are likely to take evasive action to avoid an approaching or passing boat. The shallower the water, the more urgent the response. I have seen five dugongs in 1.7 m of water generate large bow waves as they sprinted away from a speed boat passing 1 km away. When in shallow water, the dugongs will normally move towards deeper water, even if that path takes them closer to the boat's trajectory.

Only once have I 'run into' a herd of dugongs in shallow water. In that instance the dugongs appeared to be taking refuge from some very rough weather in a shallow gutter (1.6 m) between shallower banks (1.0 m). The noise caused by the waves, or the varied sub-surface topography may have accounted for the dugongs delayed detection of my boat.

Dugongs will often react with a violent tail thrash when they detect a stationary boat, or when a nearby boat starts its engine. They appear to be particularly sensitive to the electric start of outboard engines. The tail thrash acts as an alarm call, usually causing the herd to move away from the boat, at least temporarily.

Table A.5.1. Result of analysis of variance testing the effect of boat type and season on the abundance of boats counted during standard aerial surveys of the East and West study areas in Moreton Bay.

Factor	df	MS	F	p
Type[1 2]	5	2546.4	9.59	0.0001
Season[1 3]	3	428.1	1.61	0.1901
Type*Season	15	69.9	0.26	0.9974
Error	125	265.6		
Total	148			

[1] Fixed factors

[2] Speed boat/dinghy, sail, trawler, cruiser, professional fishing, barge/tug/ferry

[3] Winter, spring, summer, autumn.

Figure A.5.1. The number of boats recorded during each 'standard' aerial survey of the East and West study areas. 1: a good-weather Sunday; 2: school holidays, boats recorded from one side of aircraft only.

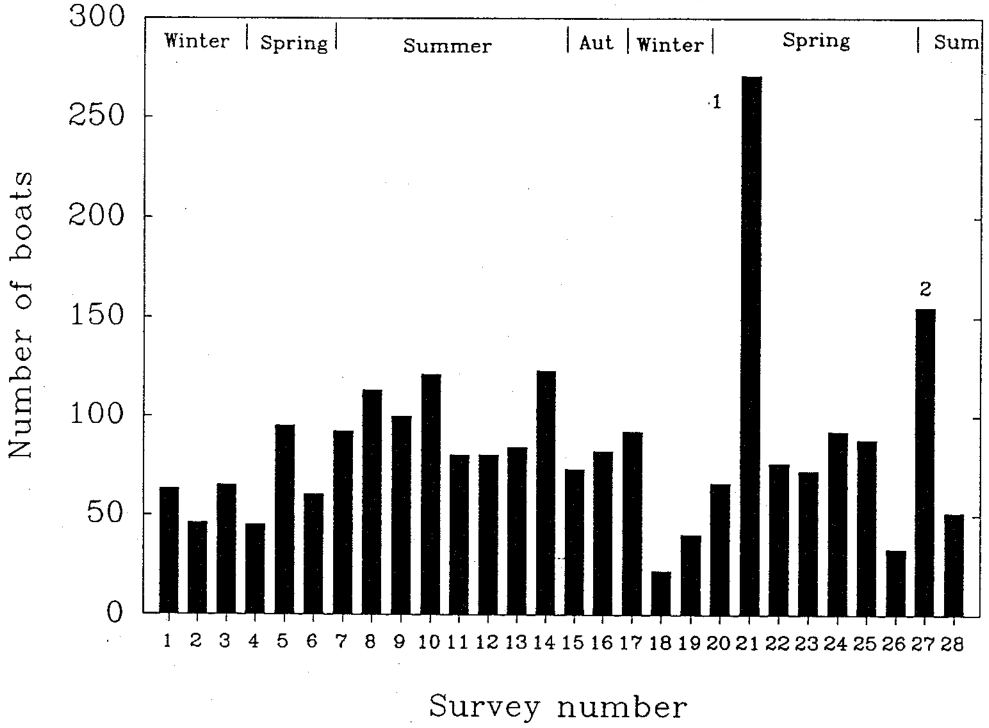


Figure A.5.2. Relative abundance of boat types recorded during 'standard' surveys of the East and West study areas.

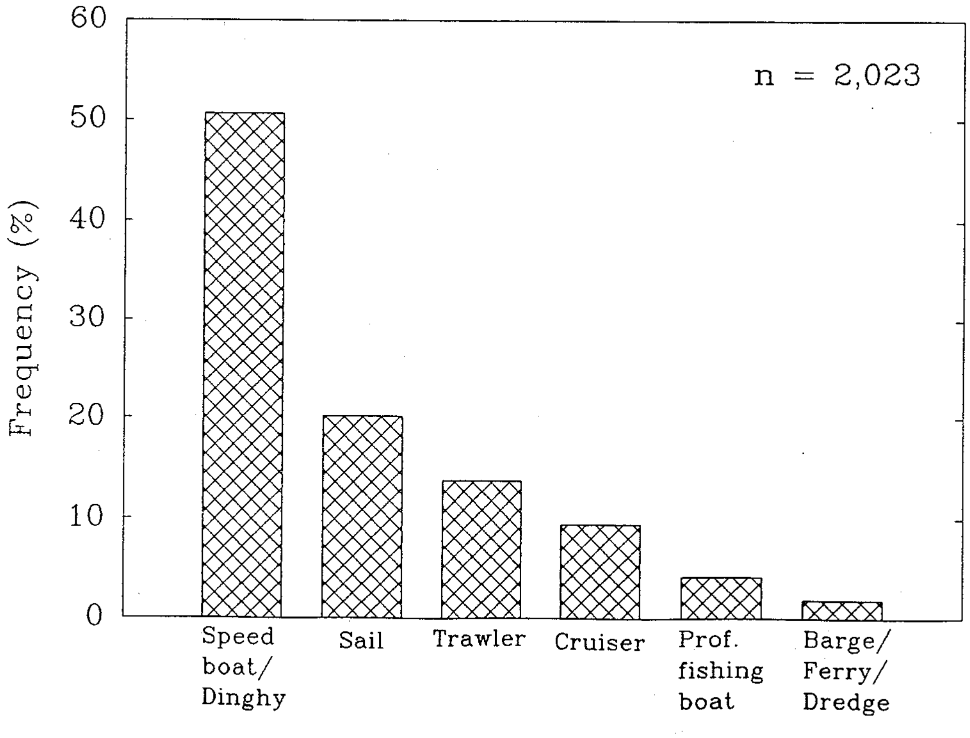
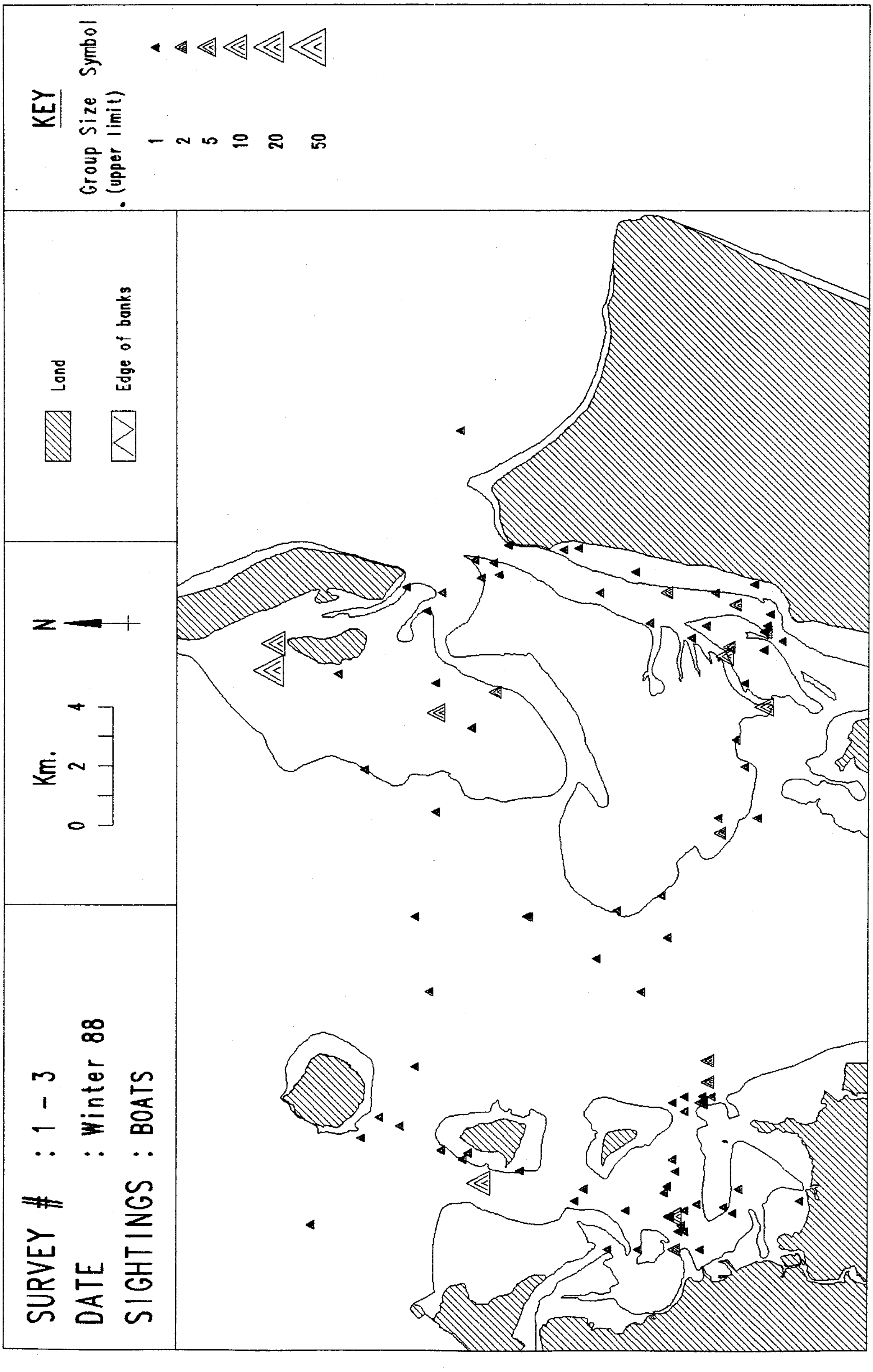
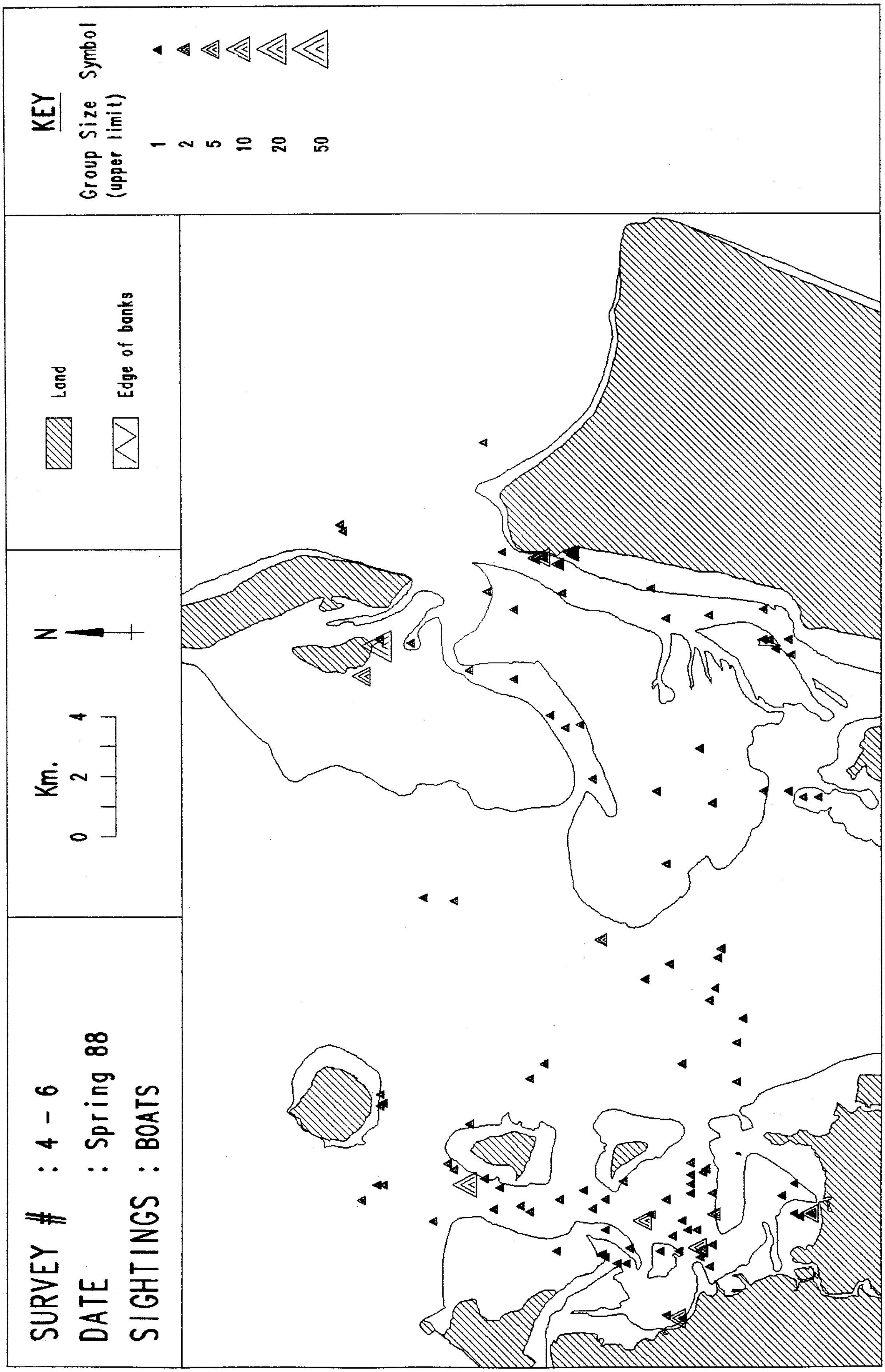
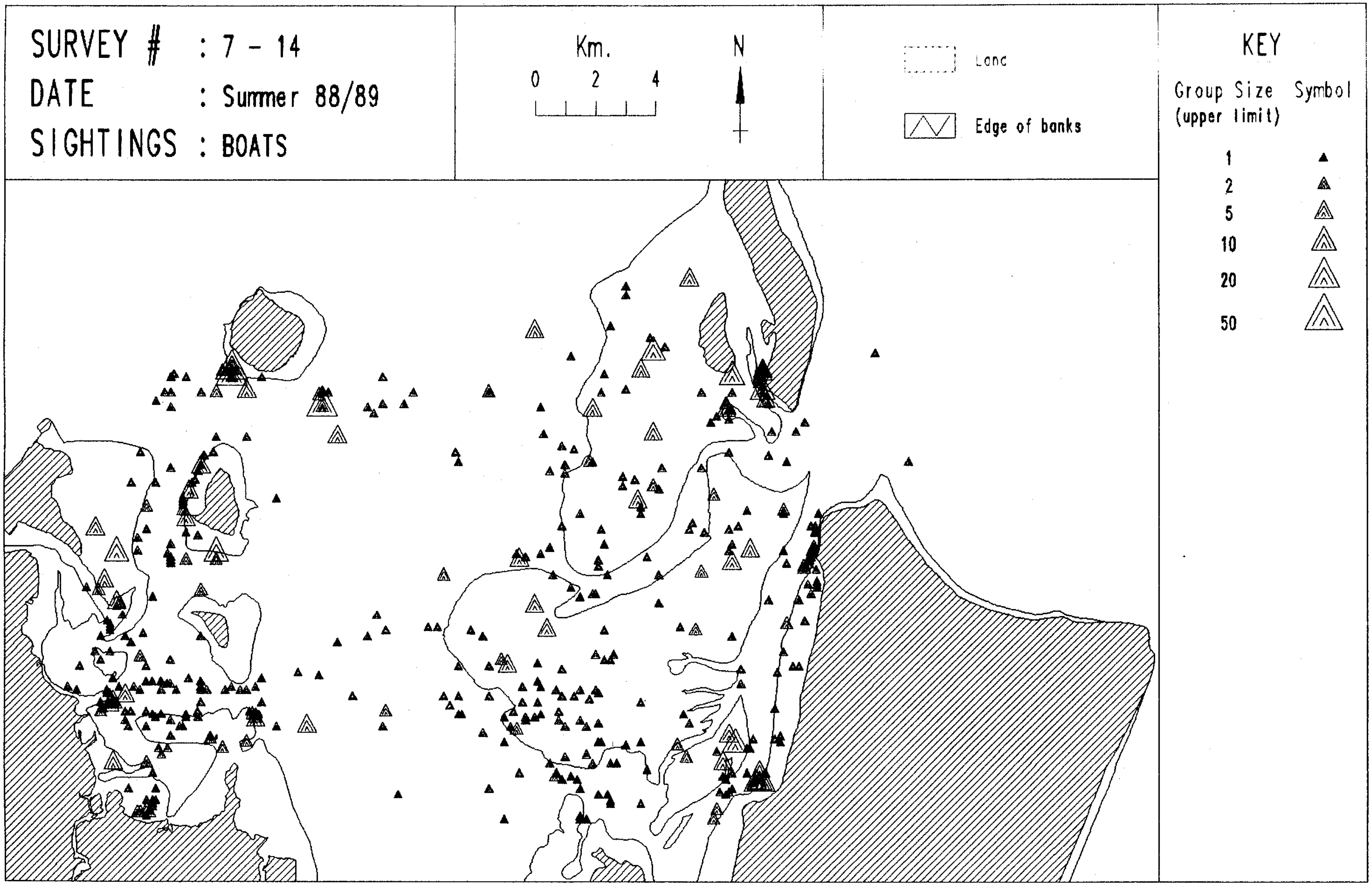
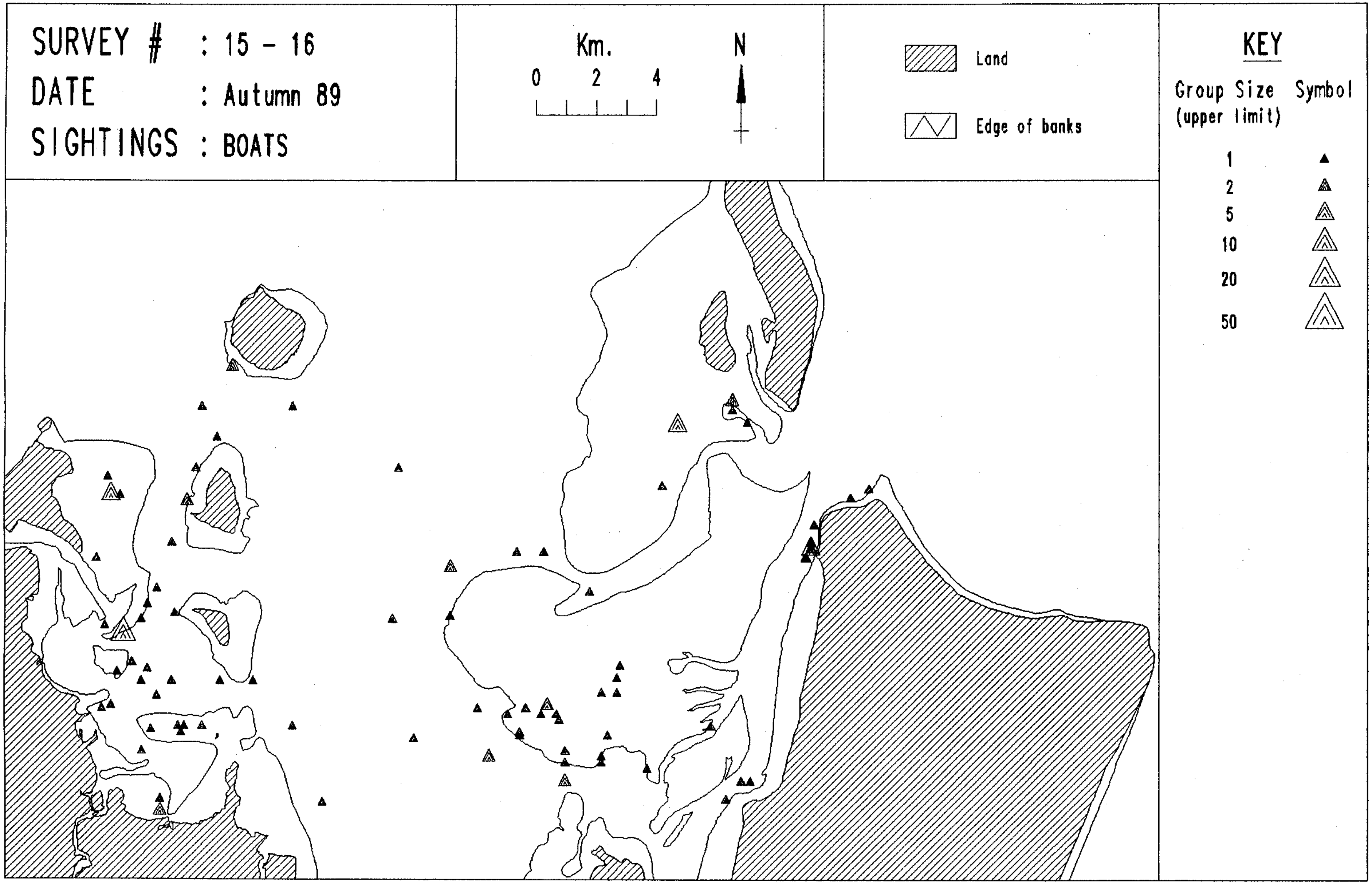


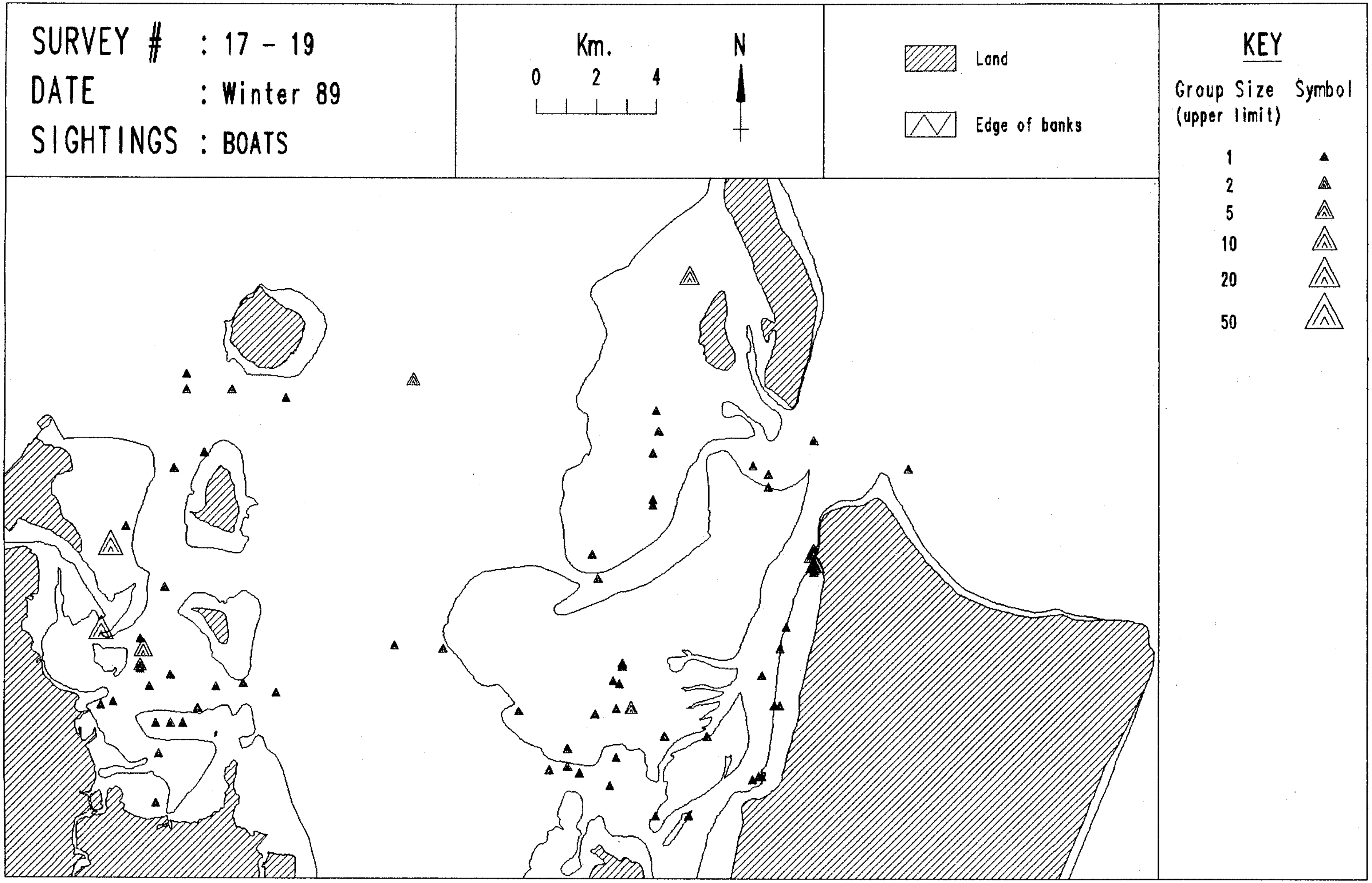
Figure A.5.3. The seasonal distribution of boats recorded on the standard aerial surveys of the East and West study areas.

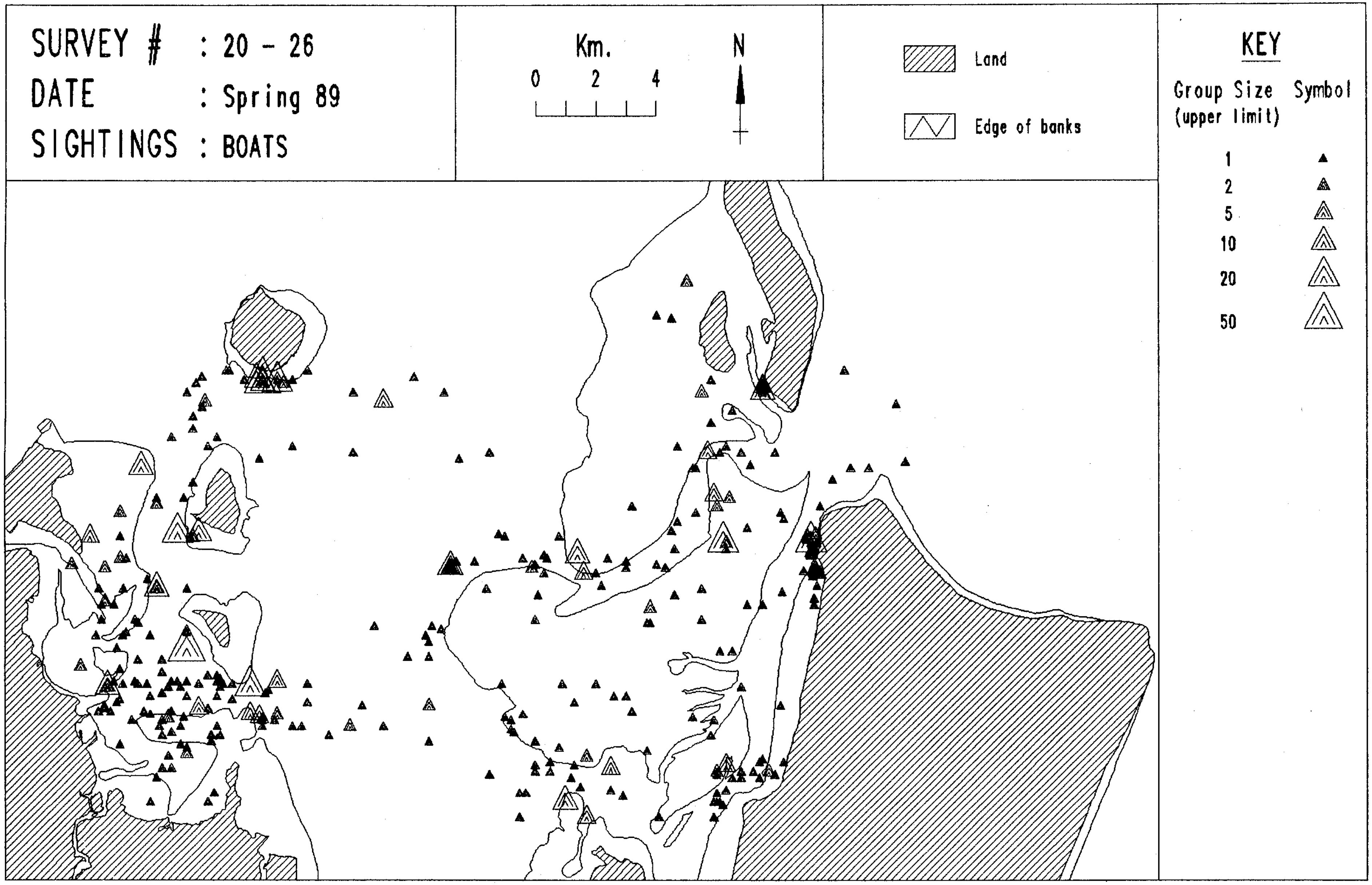

SURVEY # : 1 – 3
DATE : Winter 88
SIGHTINGS : BOATS
Km.
0
2
4
N
Land
Edge of banks
KEY
Group Size (upper limit)
Symbol
1
2
5
10
20
50

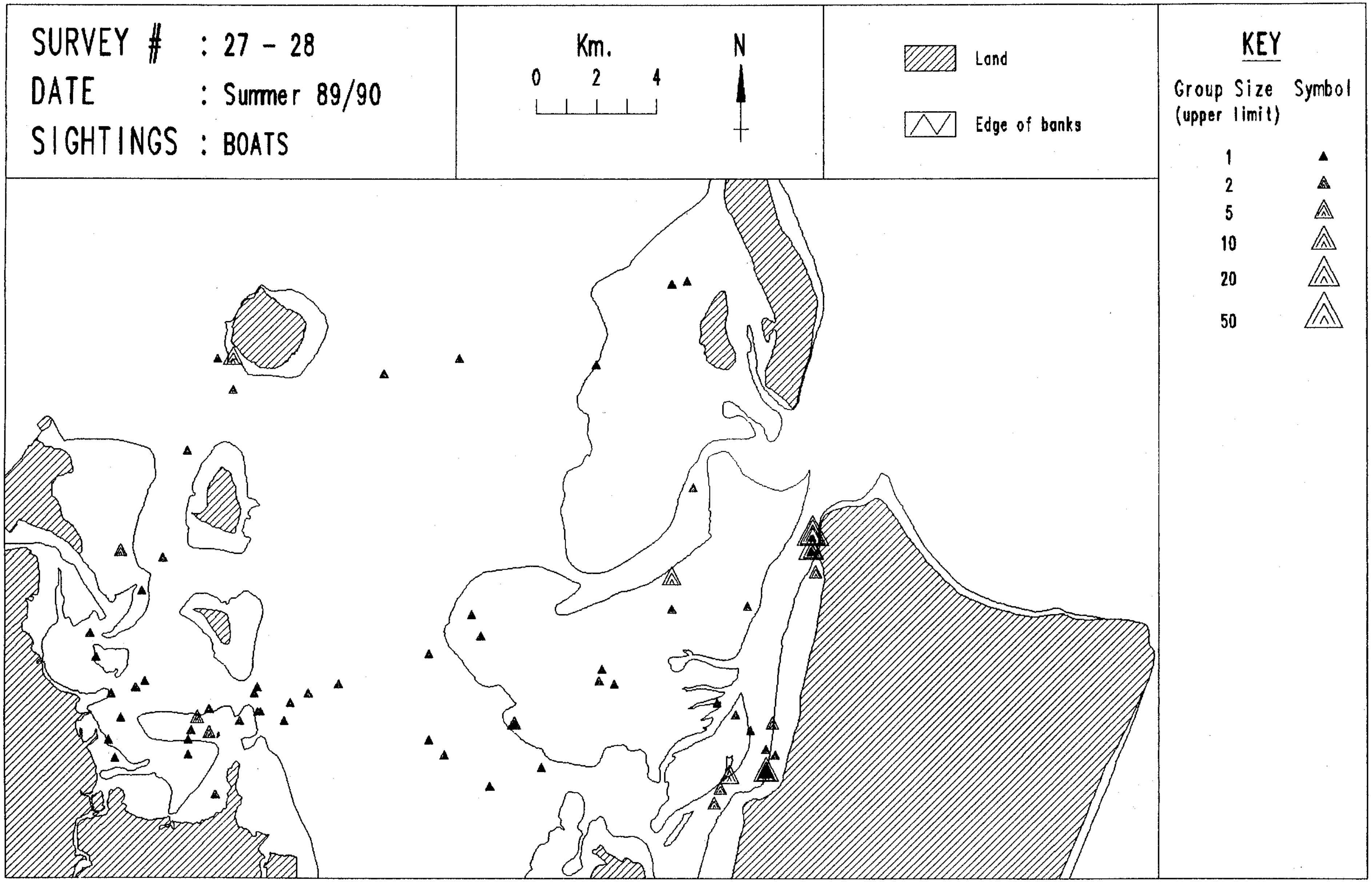

SURVEY # : 4 – 6
DATE : Spring 88
SIGHTINGS : BOATS
Km.
0
2
4
N
Land
Edge of banks
KEY
Group Size
(upper limit)
Symbol
1
2
5
10
20
50


SURVEY # : 7 - 14
DATE : Summer 88/89
SIGHTINGS : BOATS
Km.
0 2 4
N
Land
Edge of banks
KEY
Group Size (upper limit)
Symbol
1
2
5
10
20
50


SURVEY # : 15 - 16
DATE : Autumn 89
SIGHTINGS : BOATS
Km.
0
2
4
N
Land
Edge of banks
KEY
Group Size (upper limit)
Symbol
1
2
5
10
20
50


SURVEY # : 17 - 19
DATE : Winter 89
SIGHTINGS : BOATS
Km.
0
2
4
N
Land
Edge of banks
KEY
Group Size (upper limit)
Symbol
1
2
5
10
20
50


SURVEY # : 20 - 26
DATE : Spring 89
SIGHTINGS : BOATS
Km.
0
2
4
N
Land
Edge of banks
KEY
Group Size (upper limit)
Symbol
1
2
5
10
20
50



SURVEY # : 27 - 28
DATE : Summer 89/90
SIGHTINGS : BOATS

APPENDIX 6

FACTORS RELEVANT TO THE DETERMINATION OF THE HOME RANGE OF DUGONGS TRACKED IN MORETON BAY

6.1. Introduction

The concept of home range provides a useful, but necessarily imprecise, parameter of space utilisation. According to Burt's (1943) widely quoted definition, the home range is 'that area around the established home which is traversed by the animal in its normal activities of food gathering, mating and caring for young'. However, this definition is not appropriate for many types of animals which do not maintain 'established homes' (Leuthold, 1977). Jewell's (1966) definition: the area over which an animal normally travels in pursuit of its routine activities, is more appropriate for dugongs.

While intuitively useful, these definitions fail to provide criteria by which the spatial and temporal limits of home range can be determined (Cooper, 1978). Hence the appropriate way to represent an animal's home range is a persistent problem. There are numerous methods of estimating home range (for reviews and comparisons see Boulanger and White, 1990; White and Garrott, 1990; and Worton, 1987, 1989). All methods provide different estimates and no single procedure has gained primacy. Furthermore, different methods have been used in different studies, preventing direct comparisons between studies.

Home range is an index of space usage, not an absolute measurement of area (or volume), and animals use space unevenly within their home range. Therefore, emphasis on boundary estimation should not overshadow consideration of the internal anatomy of the home range. The presence of core areas within an animal's home range, where home sites, refuges and dependable food resources may occur was first recognised by Kaufmann (1962). A more sophisticated approach uses the concept of the utilisation distribution (Jennrich and Turner, 1969), which allows the interior of the home range to be mapped based on the probability of encountering an animal.

6.2. Selection of home range model

To determine the most appropriate home range model for the PTT derived data, home range estimates were initially computed by several methods. Kenward's (1990) Ranges IV package was used to calculate convex outer polygon, multi-nuclear polygons by clustering, harmonic mean and kernel based home ranges. Ranges were also estimated using D. J. Anderson's (1982) Fourier series. Home range estimates were calculated for each of the 13 dugongs tracked with PTTs for 50, 70, 90 and 95% of fixes (incrementing from the range centres). There was a significant difference between models (Table A.6.1). There was also a significant interaction between model type and number of fixes (Table A.6.1) due to the relatively large and relatively small increases in the estimates for harmonic mean and outer polygon, respectively, when sample size increased from 70 to 90% of fixes. Based on Least Significant Difference comparisons, there were three groups of models in which the means were not significantly different from one and other: (1) harmonic mean and kernel; (2) kernel and polygon; and (3) Anderson and cluster. The Anderson and kernel models had slightly lower coefficients of variation (sd/mean) of home range areas, averaged across the range of fix percentages tested (CV = 54% each) than the other models (harmonic mean: 65%; cluster 57%; polygon 70%).

Visual inspection of the plots of fixes and the resultant home range boundaries suggested that the kernel model most realistically represented the distribution of locations. The ranges from the Anderson Fourier series tended to fit the pattern of fixes very tightly, with little logical joining of 'core' areas. Probability contours produced by the harmonic mean ballooned out excessively (usually into unused habitat) in eight of the 13 ranges, due to the skewed or leptokurtic nature of those ranges (Spencer and Barrett, 1984). The cluster analyses produced unrealistically small home ranges with no logical linking of the numerous range cores. The convex outer polygon is sample size dependent and highly influenced by outlying points (Boulanger and White, 1990) and gives no information on the intensity of range usage.

Boulanger and White (1990) compared Anderson's Fourier series, harmonic mean, outer convex polygon and two 95% ellipse home range estimators using computer simulated data with a known home range area. While finding problems with each model, they concluded that the harmonic mean performed the best over the range of data they tested. Kenward (1990) considers the kernel estimator to be more robust mathematically than the harmonic mean function, and also less grid-dependent.

On the basis of the above considerations, the kernel estimator was chosen to examine the dugong home ranges. The kernel model (as presented in Ranges IV) uses the bivariate normal kernel estimator to derive the fix density at each intersection of a notional grid laid across the range. The range is described in terms of a probabilistic model based on the density of fixes. Hence, the 50% isopleth of the kernel range encloses the densest 50% of fixes (Kenward, 1990). The default smoothing factor of 1.0 was used for all range analyses.

6.3. Factors that affect the estimates of home range characteristics

6.3.1. Inclusion of non-guaranteed locations

The size of home ranges, calculated using (1) all fixes (location qualities 1, 2 and 3; see section 5.3.1.2) and (2) guaranteed locations only (qualities 2 and 3) were not significantly different based on 50% isopleths, but were significantly larger based on the 95% isopleths (paired t-Tests: df = 12, t = 1.6, p = 0.1351; df = 12, t = 2.79, p = 0.0163 respectively). Inclusion of the non-guaranteed locations (quality 1) did not, on average, significantly alter the dispersion or the skewness of the 95% isopleth ranges (Wilcoxon Signed Rank tests: p = 0.0574; p = 0.9396 respectively), although kurtosis was significantly changed (Wilcoxon Signed Rank test: p = 0.0214). The visual appearance of the home range plots was not substantially modified by the inclusion of non-guaranteed locations, each range maintaining its characteristic form. Hence, quality 1 locations were included in all home range calculations.

6.3.2. Assessment of probability isopleth for evaluating home range

To determine the appropriate isopleths for estimating home range boundaries and core areas, utilisation plots (home range area plotted against probability isopleth) were viewed for each dugong. Discontinuities in the curves indicate the probability values at which the largest number of fixes occupy the smallest areas. These values are the appropriate isopleths to define the home range boundaries and core areas. The 90 and 95% isopleths showed the most repeatable discontinuities in the utilisation plots. The plot of the coefficients of variation of home range size for each isopleth, when data from all dugongs were pooled, showed that the 95% isopleth had the lowest variation. Utilisation plots were also inspected for males/females, adults/sub-adults and winter/non-winter tracking periods. These plots supported the 95% isopleth as the most appropriate boundary for home range estimation.

There was no lower probability isopleth that showed a discontinuity in the utilisation plot: the dugongs' ranges do not have core areas. However, to allow comparisons of areas of intensive use, ranges were also calculated using the 50% isopleth. Selection of this value was arbitrary as it has no special biological significance.

6.3.3. Effect of sample size on home range estimates

The number of locations available for each dugong ranged from 31 to 166 (mean = 75.1, SE = 11.3; Table 5.5). To test the effect of the number of locations on the estimate of home range area, a series of data files composed of 30, 40, 60, 80 and 100 locations were generated by randomly deleting fixes from the files of four dugongs with over 100 locations. Home ranges were calculated based on a series of probability contours (50, 60, 75, 90 and 95%) for each file size for each of the four dugongs. The plotted values showed no consistent relationship between home range size and the number of locations used to derive the range area (Figure A.6.1). There was no significant difference in home range areas based on 30 locations and 100 locations for either the 50 or 95% isopleths, suggesting 30 locations were adequate to describe the home ranges during the periods of tracking (paired t-Tests: df = 3, t = -0.61, p = 0.5878; df = 3, t = 1.4, p = 0.2562 respectively). All the home ranges of the 13 tracked dugongs are based on more than 30 locations (Table 5.5).

6.3.4. Effect of tracking period on home range area

Dugongs were tracked for periods ranging from 20 up to 88 days (mean = 50.2, SE = 5.7; Table 5.5). The number of locations received was strongly correlated with the length of the tracking period (Spearman Rank Correlation: d.f. = 12, r = 0.7373, p = 0.00403). If range centers migrate over time, total home range area may increase with tracking period. If so, the validity of comparisons between ranges based on 30 days and 80 days of tracking may be questioned.

To test for the effect of tracking period on home range size, data from each dugong were sub-divided into files based (where possible) on the first 14, 28, 42, 56, 70, 84 and 98 days of tracking. Home ranges were derived for each of these sets of data and the increase in the home range areas was calculated as a percentage of the 14 day ranges. There was a significant increase in the size of the 50% range areas with increasing tracking period, but no increase in the 95% home range (correlations: d.f. = 40, r = 0.4014, p = 0.00929; d.f. = 40, r = -0.0150, p = 0.9258 respectively). These data suggest the 95% home ranges can be compared between dugongs, despite the different tracking periods.

Table A.6.1. Results of analysis of variance testing for differences in the size of home ranges estimated from the dugong tracking data from Moreton Bay calculated using different home range models and different proportions of the total number of fixes (isopleths) received for each dugong.

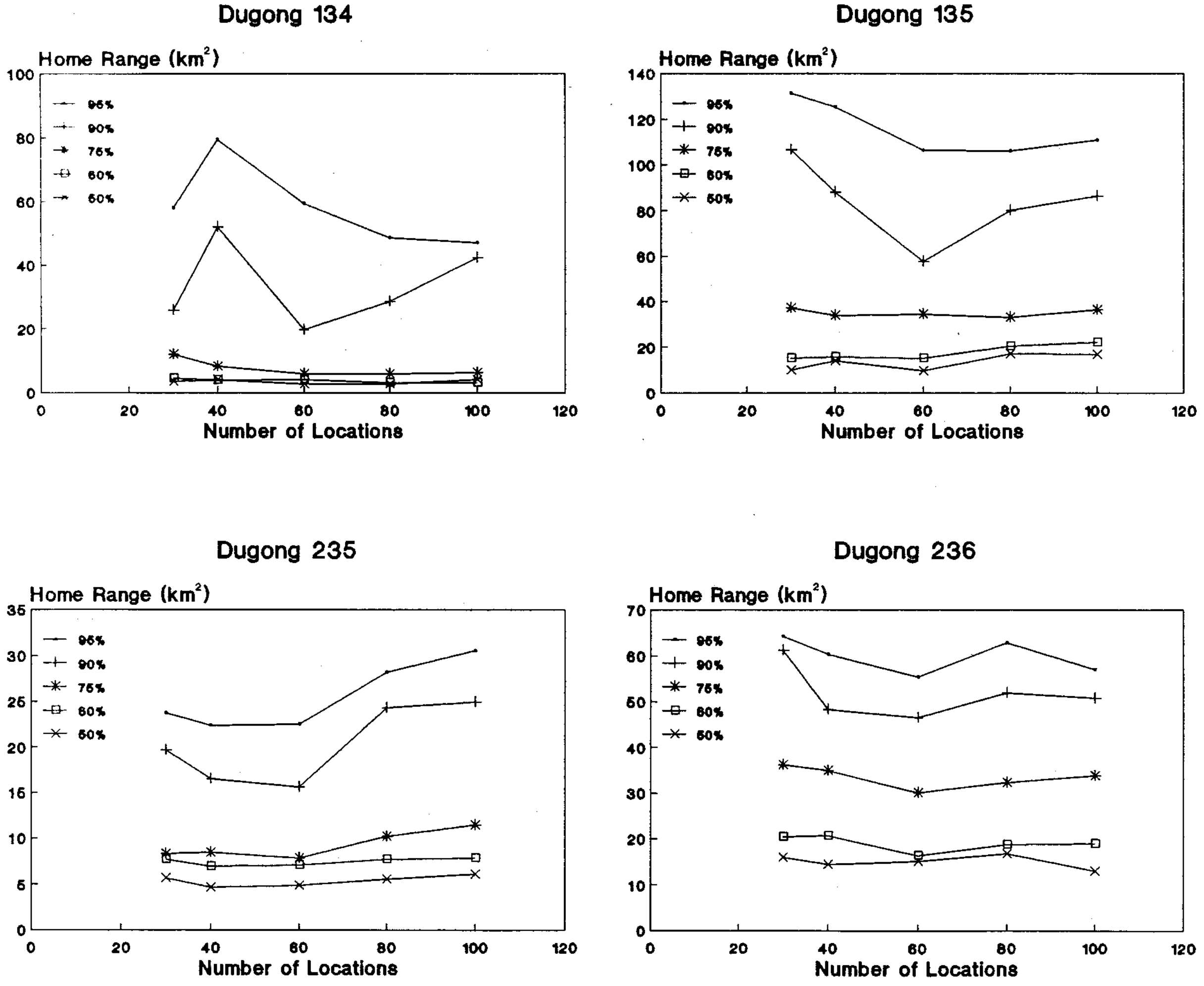
Factor	df	MS	F	p
Model[1] [2]	4	6222	14.49	0.0000
Isopleth[1] [3]	3	23052	53.69	0.0000
Model*Isopleth	12	1275	2.97	0.0007
Error	240	429		
Total	259			

[1] Fixed factors

[2] Convex outer polygon, multi-nuclear polygons by clustering, harmonic mean, kernel, Anderson's Fourier series

[3] 50%, 70%, 90% and 95% of fixes

Figure A.6.1. Effect of sample size (number of locations) on estimates of the home range area of four dugongs.



APPENDIX 7

ESTIMATION OF THE
DAILY CONSUMPTION OF SEAGRASS BY DUGONGS
AND
THE AREA OF SEAGRASS DISTURBED BY DUGONGS

7.1. Daily consumption of seagrass by dugongs

7.1.1. Estimates based on consumption by captive dugongs

Kataoka and Asano (1981) tabulate the amounts of seagrass eaten by captive dugongs. Estimates range from 8 to 40 kg wet weight per day. Some of these data, however, may not be reliable. Jones (1976 in Kataoka and Asano, 1981) states that two dugongs at Mandapam Camp in India consumed between them 30-35 kg/day. Yet Heinsohn et al. (1977 citing Jones, 1967) reports that these two dugongs each ate 50-55 kg/day. According to Jonklass (1961), together these dugongs were fed about 30 lb seagrass/day (13.6 kg/day). Similar confusion surrounds dugongs kept at Jaya Ancol in Jakarta. According to Tas'an et al. (1979 in Kataoka and Asano, 1981), two dugongs each consumed 30-40 kg seagrass daily. A subsequent pair of juvenile dugongs at Jaya Ancol were together fed 26-47.5 kg/day during a 13 day period (mean = 41.3 kg/day; Lanyon, 1991).

As the data quoted by Lanyon (1991) are reliable (I participated in recording them), 21 kg seagrass can be assumed to be the minimum daily requirements of juvenile dugongs. This is a minimum estimate, as these dugongs were maintained in a small enclosure (7 m diameter) and may have had lower energy requirements than wild animals. Furthermore, these dugongs showed minimal growth over the preceding 9 months, suggesting an inadequate diet. It should be noted that this inadequacy may be due to deficiencies in quality as well as quantity of their food. These dugongs, fed a staple diet of S. isoetifolium and C. serrulata leaves (Lanyon, 1991; pers. obs.), were unable to graze selectively to maximise their nutrient intake.

7.1.2. Estimate based on wild dugongs

A second estimate of daily consumption can be derived from the amount of seagrass removed from grazing Area 3 (see section 6.5.1).

The grazing and recovery of seagrass at Area 3 was monitored at three transects located in one (# 62; 16.3 ha) of three adjoining tracts of seagrass that comprised the 41 ha of Area 3 (areas derived from aerial photos). The biomass of seagrass in the three tracts was similar at the time the area was sampled for mapping (Chapter 3; tract 60: 2.7 g/m^2, SE = 0.39; tract 61: 3.4 g/m^2, SE = 1.53; tract 62: 2.7 g/m^2, SE =1.00).

Assuming the biomass data from tract 62 (above- and below-ground biomasses of 22.59 g/m^2 and 27.91 g/m^2 respectively, before the second grazing event; Table 6.17) was representative of all of Area 3, the standing crop of seagrass before this second grazing was 20,705 kg (50.5 g/m^2 * 41 ha). This is equivalent to 182,808 kg wet weight (dry weight to wet weight ratio of H. ovalis plus H. spinulosa: above-ground: mean = 9.31, SE = 0.177, n = 272; below-ground: mean = 8.44, SE = 0.150, n = 263)

Area 3 was ungrazed when it was observed during an aerial survey on 17-8-89, however, it had been thoroughly grazed by 2-9-89, when the aerial photos were taken for the seagrass mapping (section 3.2). Given that the dugongs removed 95.8% of the above-ground biomass and 71.3% of the below-ground biomass (Table 6.17), it follows that the dugongs removed 151,468 kg wet weight of seagrass in less than 17 days.

No dugongs were seen feeding at Area 3 during this period of grazing, although herds of 162 and 133 dugongs were located 500 m and 1 km from the area during an aerial survey on 4-9-89, and a herd of 302 dugongs was feeding in the area 1 km away during an aerial survey on 17-9-89. It is probable that these dugongs grazed Area 3 before moving to the new location 1 km away.

Assuming that the seagrass was removed over the maximum period available (17 days) and that, on average, 250 dugongs fed at the site daily, each dugong would need to consume 36 kg of seagrass/day.

7.1.3. Estimate based on percent body weight

Bengtson (1983) estimated that wild West Indian manatees consume the equivalent of 4-9% of their body weight/day. This estimate was refined by Etheridge et al. (1985), who estimated the daily consumption, as a percentage of body weight, to be 15.7% for calves, 9.6% for juveniles and 7.1% for adults. Best (1981) estimated that captive Amazonian manatees consume the equivalent of 8-9% of their body weight daily, rising to 10-13% for reproductive females.

The average of the daily consumption rates estimated for captive and wild dugongs was 28.5 kg. Assuming an average body weight of 350 kg (equivalent to a body length of 2.75 m, a 3 m adult is estimated to weigh 420 kg; Spain and Heinsohn, 1975), 28.5 kg is equivalent to 8.1% of body weight. This estimate concurs with the range of estimates for manatees, suggesting that a daily consumption of 28.5 kg seagrass may be an acceptable estimate. This is equivalent to 3.22 kg dry weight (wet weight to dry weight ratio for H. ovalis plus H. spinulosa plus Z. capricorni = 8.86, SE = 0.17, n = 642).

7.2. Area disturbed by dugongs

A total of 8,504 dugongs were seen on seagrass beds during the aerial surveys. The median total biomass (above- plus below-ground parts) of seagrass at these locations was 12.3 g/m^2 (the distribution was highly skewed, with a mean of 57.1 g/m^2). Biomass estimates have not been seasonally adjusted. As samples were collected in summer, when biomass is high (Figure 4.1), this creates a conservative bias to the estimated area disturbed.

Given that dugongs remove an average of 65.2% of the total biomass of seagrass along feeding trails (at sites not dominated by Z. capricorni; section 6.3.2.2), each dugong would have to disturb 401.5 m^2 of seagrass each day.

The eastern banks of Moreton Bay support an estimated population of 600 dugongs (section 5.2.2.1). The whole dugong population, therefore, would disturb 24.1 ha/day or a cumulative total of 67.9 km^2/year.

Based on the aerial survey sightings, the area of seagrass used by dugongs in the East study area was about 81 km^2 (this excludes the Oyster Bank, the Wanga Wallen Bank and the part of Dunwich Bank south-east of Dialba Passage, see Figure 2.2). The cumulative area disturbed annually by dugongs (67.9 km^2) represents 83.8% of the area used by the dugongs. This is equivalent to a turnover rate, the average time required to disturb the entire area (Sousa, 1984) of 1.2 years.

The dugongs did not, however, distribute their grazing evenly over the areas of seagrass used. Some areas were used almost continuously, while others were virtually never used. Hence, the return interval, the average time between disturbances (Sousa, 1984), was very variable (Table 8.1).

APPENDIX 8

PROPORTION OF SEAGRASS PRODUCTION CONSUMED BY DUGONGS ON THE TURTLE BANK

The proportion of seagrass production consumed by dugongs is found by dividing the annual consumption by dugongs by the annual production of seagrass.

All calculations pertain to the core area of the Turtle Bank and, due to the lack of data on below-ground productivity (section 4.4.4), consider only above-ground productivity.

8.1. Annual above-ground productivity of the Turtle Bank

Annual above-ground productivity is derived by:

above-ground standing crop * SGR

where:

above-ground standing crop = above-ground biomass * area and

SGR = the Specific Growth Rate (% standing crop/day).

The above-ground biomass of the Turtle Bank, at the time of seagrass mapping (Chapter 3) was 1.87 g/m^2 (SE = 0.37).

The seagrasses of the Turtle Bank were composed of H. ovalis (86.8% total biomass) and H. uninervis thin (13.2%). The SGR of H. ovalis is taken as 6.55% (mid-point of values in Table 4.11). I am not aware of any SGR measures of H. uninervis thin, although inter-tidal and subtidal measures of H. uninervis are 4.1% and 5.4% (Table 4.11). Given the biomass dominance of H. ovalis, and the lack of data for H. uninervis thin, production is calculated on the basis of H. ovalis productivity.

From aerial photographs (see section 3.2.1) the core area of the Turtle Bank covers 5.65 km^2.

Annual, above-ground production in the core area of the Turtle Bank, therefore, is calculated as:

1.87 g/m^2 * 5.65 km^2 * 0.0655 * 365 days = 252.59 tonnes

8.2. Annual consumption of seagrass by dugongs on the Turtle Bank

To calculate the annual consumption of **above-ground** seagrass components, I first had to estimate (1) the total (above- plus below-ground) annual consumption by dugongs on the Turtle Bank, (2) the proportion of total biomass on the Turtle Bank made up of above- and below-ground components and (3) how efficiently dugongs harvested above- and below-ground components.

8.2.1. Amount of seagrass consumed from Turtle Bank

A total of 8,504 dugongs seen on seagrass beds during the aerial surveys, and 19.9% of these were on the core area of the Turtle Bank (Table 8.1). If we assume that the dugongs do virtually all their grazing on the seagrass banks accessible around high tide (most dugongs move off the edge of the banks at low tide, often into areas without seagrass), it follows that approximately 19.9% of the total amount of seagrass consumed by dugongs is harvested from the Turtle Bank.

Assuming a population of 600 dugongs (section 5.4.1) and a daily consumption of 3.22 kg DW seagrass/dugong (Appendix 7), the estimated annual consumption of seagrass by dugongs in Moreton Bay is 705.18 tonnes DW.

Therefore, the estimated annual consumption (above- plus below-ground parts) on the Turtle Bank is 140.33 tonnes (19.9% * 705.18 t).

8.2.2. Distribution of seagrass biomass on the Turtle Bank

Based on the samples collected for mapping the seagrass (Chapter 3), the above-ground biomass of seagrasses of the Turtle Bank comprised 36.67% of the total biomass. (This compares with 37.2% (SE = 5.5), for H. ovalis at the five sites where feeding efficiency was measured, and 48% (SE = 0.5) for H. ovalis at the sites monitored for seasonal changes in seagrass abundance (Figure 4.5)).

8.2.3. Feeding efficiency

At five sites dominated or co-dominated by H. ovalis, dugongs removed 90.18% (SE = 3.06) of the above-ground biomass and 53.17% (SE = 13.10) of the below-ground biomass of H. ovalis from along feeding trails (Table 6.5).

I do not have an adequate number of samples to calculate the efficiency of dugongs feeding on H. uninervis thin. For simplicity, therefore, I assume a comparable efficiency for H. ovalis. Based on H. uninervis (mainly broad-leaved morph), this may be an overestimate (Table 6.5). This bias tends to cancel the bias introduced by assuming comparable productivity of the two species (see above).

8.3. Annual consumption of above-ground production by dugongs on the Turtle Bank

From the above figures it can be calculated that dugongs would remove a total of 66.75% of seagrass from along feeding trails on the Turtle Bank, and that 49.59% of their intake would have been above-ground components of the seagrass ([90.18%*36.67%]+[53.17%*63.33%] = 66.75% and [90.18%*36.67%]/66.75% = 49.59%).

Therefore, the annual consumption of above-ground biomass from the Turtle Bank is estimated to be 69.59 tonnes (49.59% * 140.33 tonnes). This is 27.6% of the total above-ground production (252.59 tonnes).