PRELIMINARY ASSESSMENT FOR THE SPINY LOBSTER FISHERY OF THE SOUTH COAST (SRI LANKA)

by

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Appendices:

INTRODUCTION

General

This study was done as a component of two jointly coordinated projects. The first is titled 'Capacity enhancement of the National Aquatic Resources Research and Development Agency (NARA) for marine resource surveys and stock assessments in selected fisheries/resources in the coastal waters of Sri Lanka'. It is funded by the Canadian International Development Agency (CIDA). The second is titled 'Support to conduct of resource surveys and stock assessments and the promotion of participatory fisheries management for selected fisheries/resources in the Tsunami affected districts' and is funded by the International Fund for Agricultural Development (IFAD). Local implementation is by the Ministry of Fisheries and Aquatic Resources (MFAR) and NARA.

The objective was to assess the present performance of the south coast fishery. The reefs mostly intensely fished are within 5 km from the coastline. During the past decade some fishing has occurred on the reefs 15 to 20 km offshore. Gill nets are by far the most common gear. They are set during afternoon and evening, and recovered the next morning. Trammel nets were the preferred gear in the past. There are also SCUBA divers collecting lobster, mostly from the offshore reefs. Fishing occurs in all months, but is mainly from August to March. Highest prices received by the fishermen are for lobster able to be exported alive. Almost all the catch from the south coast is intended for export as live product.

The first part of the assessment is in respect to the well-being of the lobster stock. There were two sources of data. The most useful was from sampling catches at landing sites and purchasing centres during 2007. This provided information on the species, sexes and sizes of lobster being caught. It also included catches per unit effort (CPUEs) for each category of boat type. Data from the fishery-independent diving surveys conducted in ??? were less useful. The second part concerns the financial viability of the fishery and the sharing of benefits. The available data for this were product prices, the operational costs associated with fishing, fixed costs, and the basis for sharing revenues between owners, skippers and crew. This information was collected recently by questioning owners and skippers.

LOBSTER LENGTH FREQUENCIES

Introduction

The most recent data available were for the twelve months of 2007. In each month enumerators from NARA visited landing sites and purchasing centres and gained access to catches. All the lobsters in the sampled catches were measured. The measurements taken were carapace length and total length. Carapace length was from the postorbital margin to the mid-dorsal termination of the carapace. Total length was from the post orbital margin to the tip of the telson. The carapace lengths were plotted as histograms, separately for each species and sex in recognition of possible differences in growth characteristics. The annual length frequency plots are shown in Figure 1.

Species Composition

The data provides a useful indication of the relative abundance of the various lobster species. By far the most abundant in the sampled landings was *Panulirus homarus*. It represented 86 % of the total. Of the remaining species *P. versicolor* was 6 %, *P. ornatus* and *P. penicillatus* were each 3 %, and *P. longipes* was 2 %.

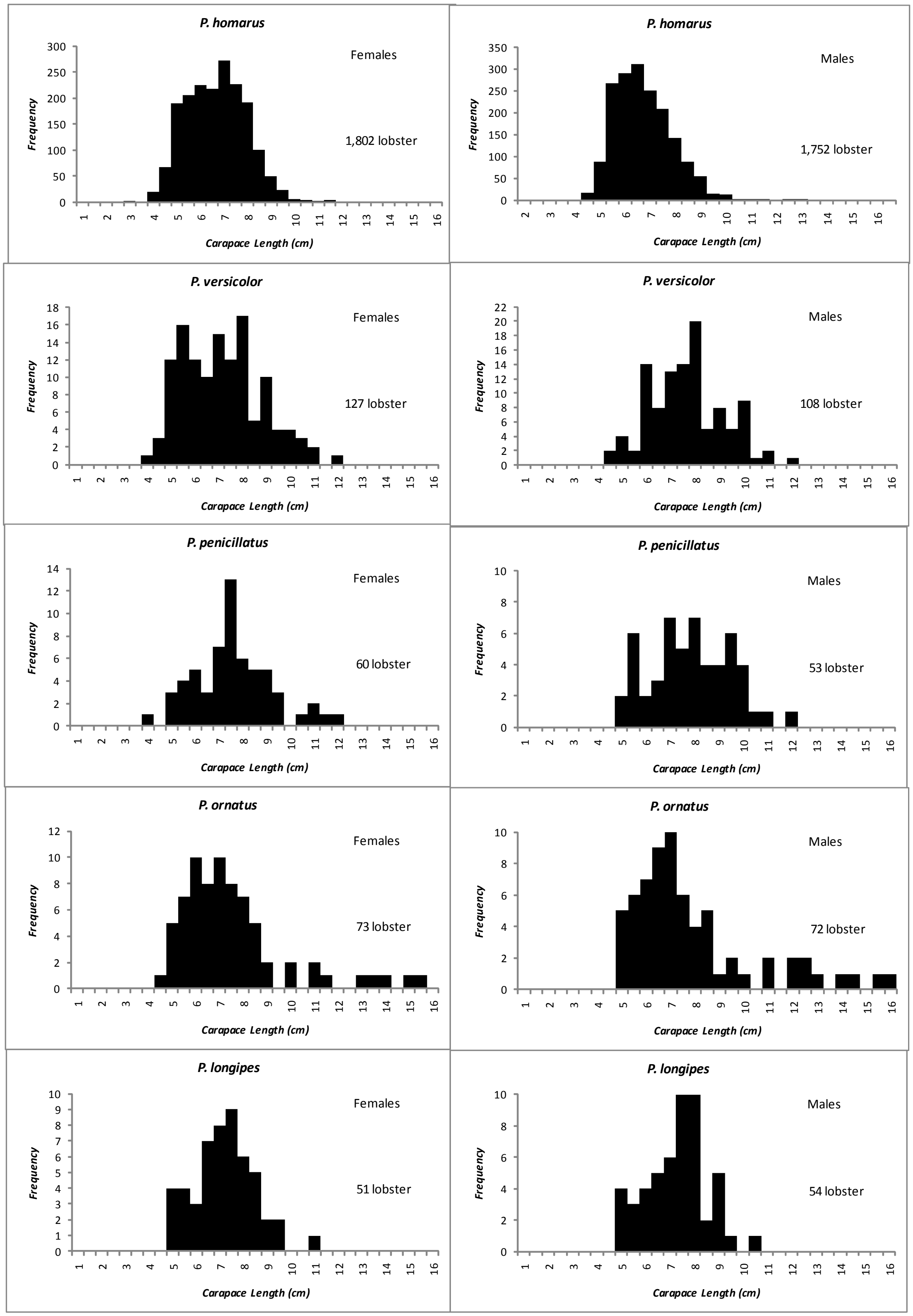
Annual Length frequencies

Nearly all the lobsters measured were in the carapace length range from 5 to 10 cm. This was generally so for all species. Substantial quantities were below the applicable legal minimum lengths. The minimum sizes are presently 6 cm carapace length for all the species other than *P. ornatus*, which has a minimum size of 10 cm carapace length. Prior to 2000, the sizes were respectively 5 cm and 6 cm. In the sampled landings 36 % of *P. homarus*, 17 % of *P. versicolor*, and 14 % of both *P. penicillatus* and *P. longipes* were below the present minimum size. Only 15 % of the *P. ornatus* in the sampled catches were of legal size.

Discussion

The length frequencies appear indicative of high levels of exploitation. This is in the sense that large lobsters were generally absent from the sampled catches. The exception was *P. ornatus* for which the larger sizes were present. This species exists in the deeper offshore waters, which are likely to have received less fishing pressure than the coastal reefs. The finding that substantial quantities of undersize lobster are taken was disappointing. This may be indicative of high levels of exploitation, with fishermen seeking to maintain catch rates by taking small lobster as they recruit into the fishery.

Figure 1: Annual length frequencies.



MORPHOMETRIC RELATIONSHIPS

Introduction

During the sampling of catches in 2007, both carapace lengths and total lengths were taken, as well as whole weights for a lesser number of lobsters. These data were used to determine the constants enabling conversion between carapace length and total length, and between whole weight and each of carapace and total length. The length versus length relationships were assumed to be proportional, while a power curve relationship was assumed for weight versus length. The curve fitting procedures in EXCEL were used. The plots and associated equations for each species and sex are shown in Figures 2 to 5. The constants in the relationships for each combination are given in Table 1.

Length to Weight Conversions

Although not formally tested, it is doubtful that the constants for converting lengths to weights are significantly different between either species or sex. The relationships are themselves significant as reflected by the R^2 values shown with the plots. As expected they are well represented by the power curve equation.

Length to Length Conversions

In all species the proportionality constants for males were lower when total length was regressed against carapace length and higher when carapace length was regressed against total length. This is indicative of the females having a greater total length for a given carapace length, and vice versa. In reality the differences between the sexes is small for the size ranges represented by the data.

Table 1: Morphometric constants.

Species	Sex	Total Weight vs Carapace Length		Total Weight vs Total Length		Total Length vs Carapace Length	Carapace Length vs Total Length
		a x 10^{-3}	b	a x 10^{-5}	b	b	b
P. homarus	Females	2.2	2.54	10	2.67	2.771	0.359
	Males	1.5	2.71	10	2.63	2.694	0.369
P. versicolor	Females	1.2	2.86	9	2.74	2.764	0.360
	Males	2.4	2.44	10	2.68	2.656	0.375
P. penicillatus	Females	1.5	2.70	10	2.62	2.692	0.370
	Males	1.9	2.61	2	3.32	2.597	0.383
P. ornatus	Females	0.8	3.04	6	2.86	2.736	0.364
	Males	2.8	2.38	10	2.69	2.576	0.377
P. longipes	Females	2.8	2.32	4	2.98	2.748	0.362
	Males	0.9	2.92	3	3.05	2.702	0.369

Note: The respective relationships are $TW = a.CL^b$, $TW = a.TL^b$, TL = b.CL, and CL = b.TL, with the weights measured in kilograms and the lengths in centimetres.

Discussion

The importance of the relationships presented here is in enabling the conversion between the different measurements of length, and from lengths to weights. They were utilised for this purpose in the analyses reported in a later section.

Figure 2: Morphometrics (whole weight vs carapace length).

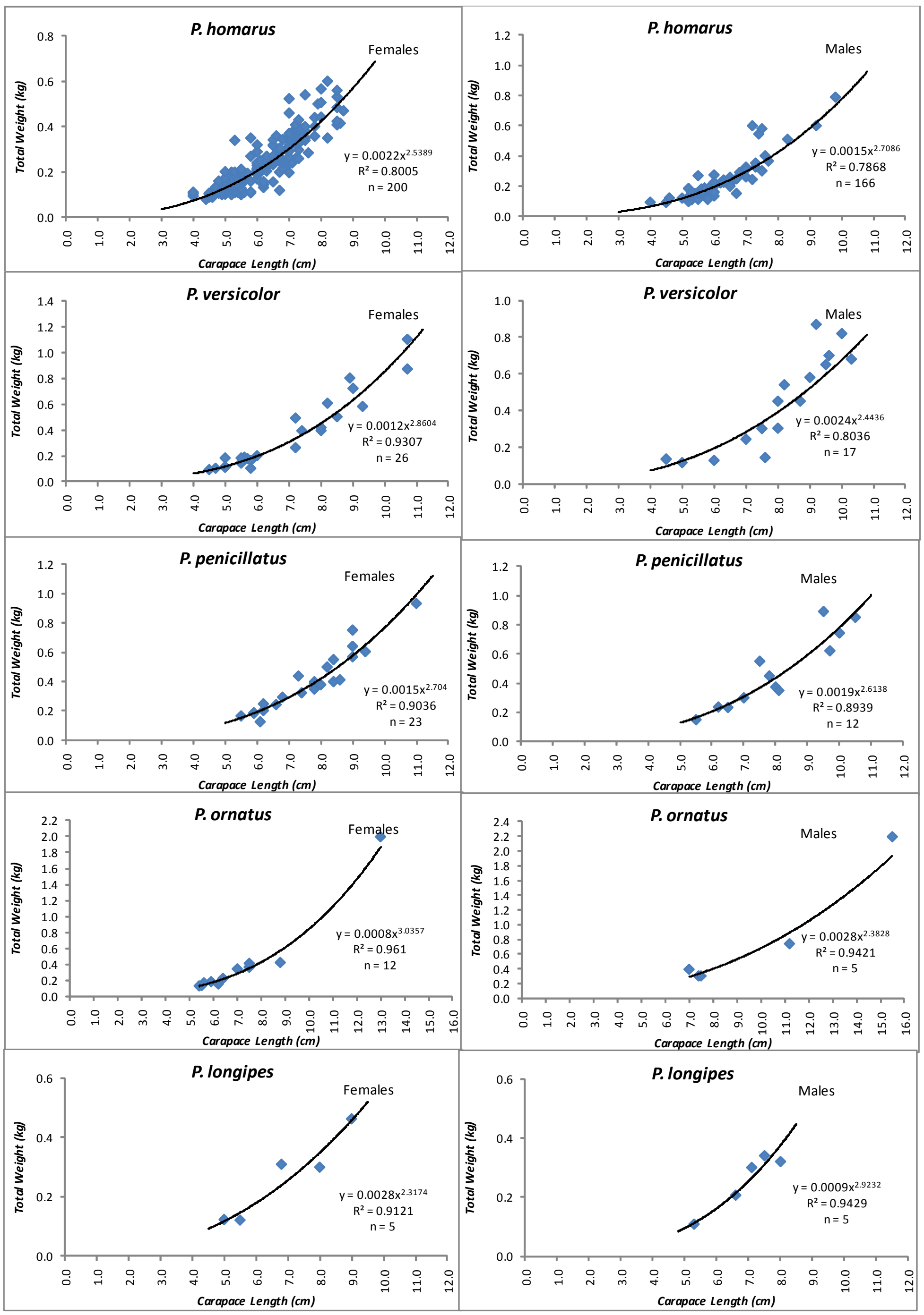


Figure 3: Morphometrics (whole weight vs total length).

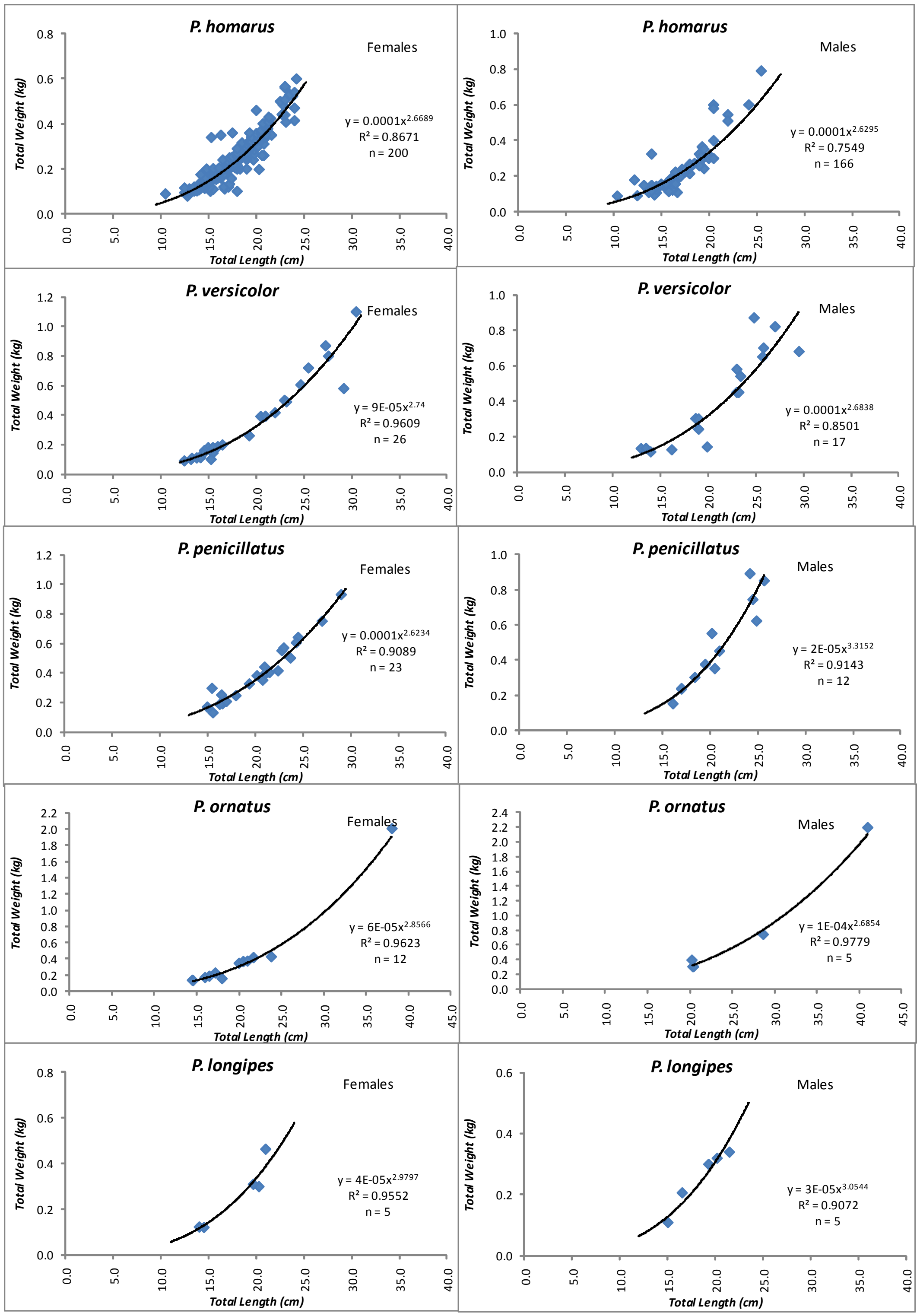


Figure 4: Morphometrics (carapace length vs total length).

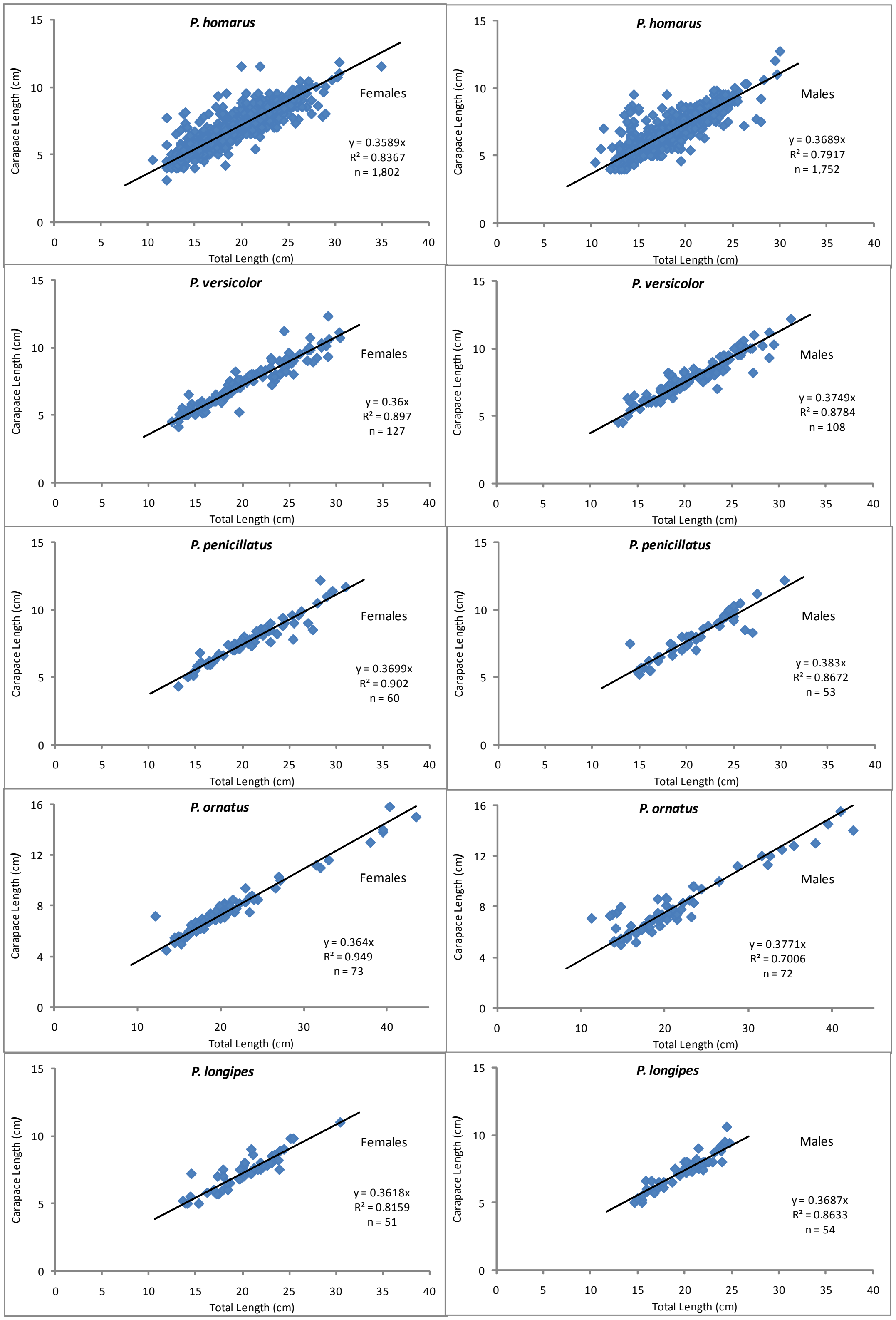
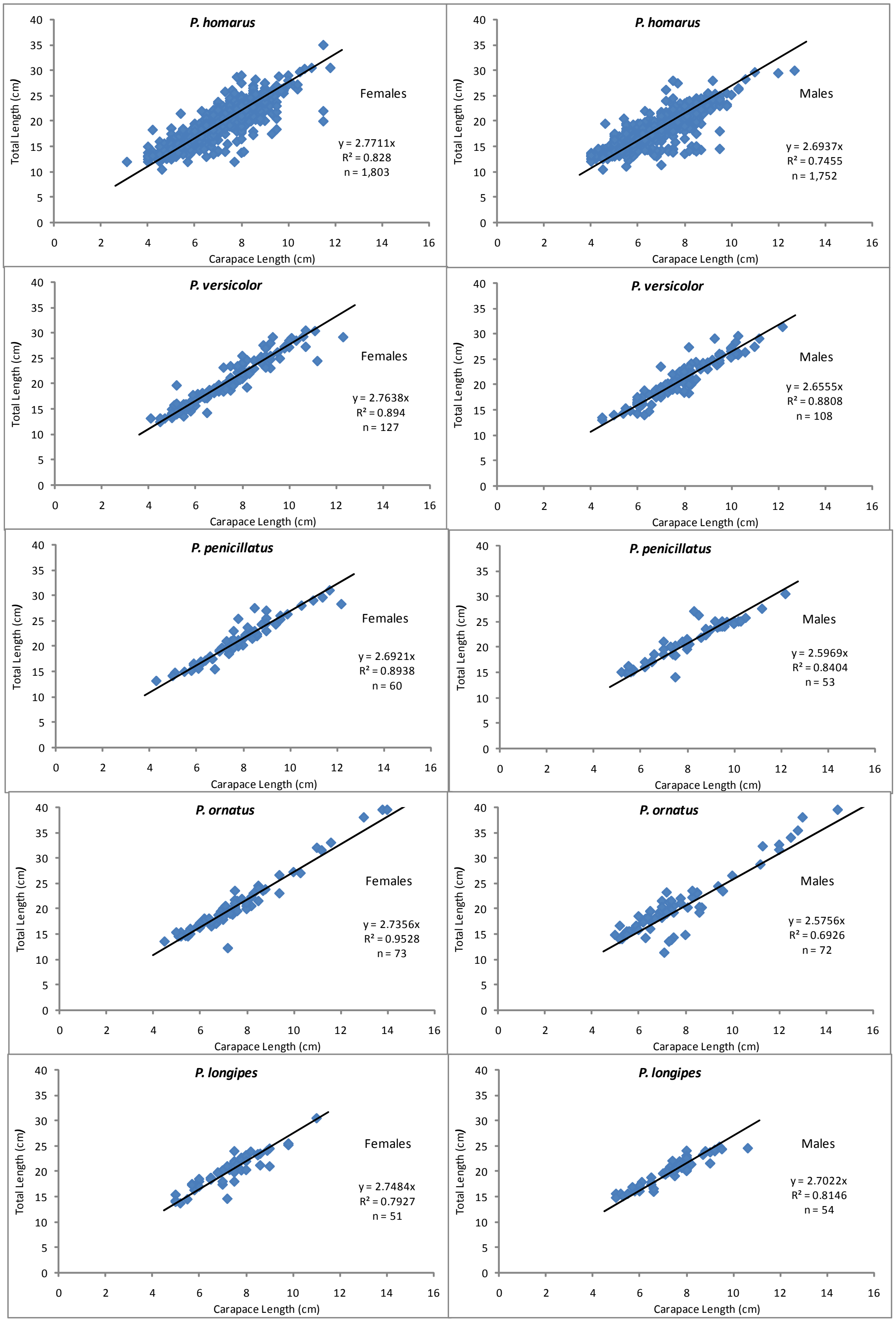


Figure 5: Morphometrics (total length vs carapace length).



LENGTH AT AGE

Introduction

The data used for determining length at age were the monthly length frequencies from the sampling of catches in 2007. The analysis was undertaken for *P. homarus* only, as there were insufficient data for the other species. The sexes were treated separately in recognition of possible differences in growth characteristics. In accord with general practice, it was assumed that growth in length conformed to the von Bertalanffy equation. The ELEFAN 1 and 'Length at Age' sub-routines in the FISAT II computer software package were used to determine the constants (L_α and K) in this equation. The associated identification of modal groups was from using the procedure of Bhattacharya.

The resulting estimates for the von Bertalanffy constants and other indicators of growth performance are shown in Table 2. The relevant equations are given below the table. The associated plots of length at age are shown in Figure 6. The monthly length frequencies are given in Figure 7.

Length at Age Constants

The von Bertalanffy constants determined here are in good agreement with published values in Jayakody (1993) and Sanders and Bouhlel (1984). As anticipated, males were found to have higher values for each of Lα and K, although the differences are probably not statistically significant. A more comprehensive data set would be required to establish a statistical difference.

Table 2: Growth performance.

Species	Sex	CLα (cm)	TLα (cm)	K (/yr)	K (/mth)	CLα.K/2 (cm/mth)	ϕ'
P. homarus	Females	13.0	36.0	0.48	0.040	0.26	1.91
	Males	13.4	36.1	0.51	0.043	0.28	1.96

Note: Lα and K are constants in the von Bertalanffy equation : $Lt = L\alpha .(1 - \exp(- K.(t - to)))$.
CLα.K/2 provides a measure of growth rate at half CLα.
$\phi' = \log10 K + 2 . \log10 CL\alpha$ is from Pauly and Munro (1984).

Discussion

It appears that *P. homarus* recruit to the fishery at 1 year of age. This is at lengths of around 5-5.5 cm. The recruits contribute to the catches for another year by which time those surviving will have reached lengths of about 8-8.5 cm. On this basis, and accepting that spawning occurs at six-monthly intervals, means that catches are almost entirely comprised of 3 cohorts. Larger lobsters make only negligible contributions to the landings. These findings are suggestive of high levels of exploitation.

They are also indicative of the bulk of egg production being dependent on these three cohorts. Females can be found bearing eggs at carapace lengths below 5 cm; Jayakody (1989). Fecundity at this size is given as about 100,000 eggs, and about 400,000 eggs at carapace lengths of 9 cm; Jayakody (1991). He found egg-bearing females present in all months, and spawning peaks around April and October. A visual examination of the monthly length frequencies for 2007 suggests these are also the months of peak recruitment.

Figure 6: Length at age.

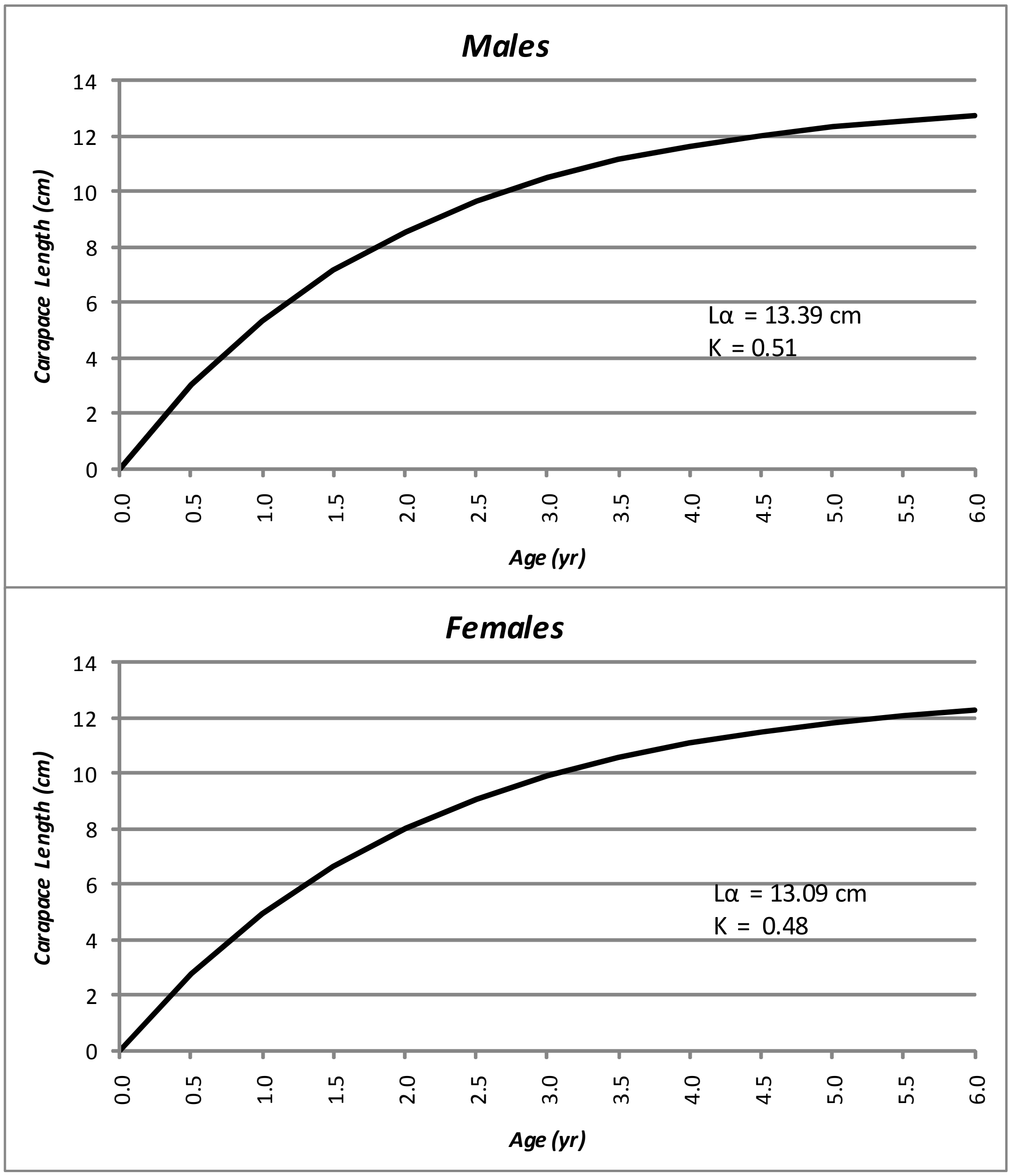
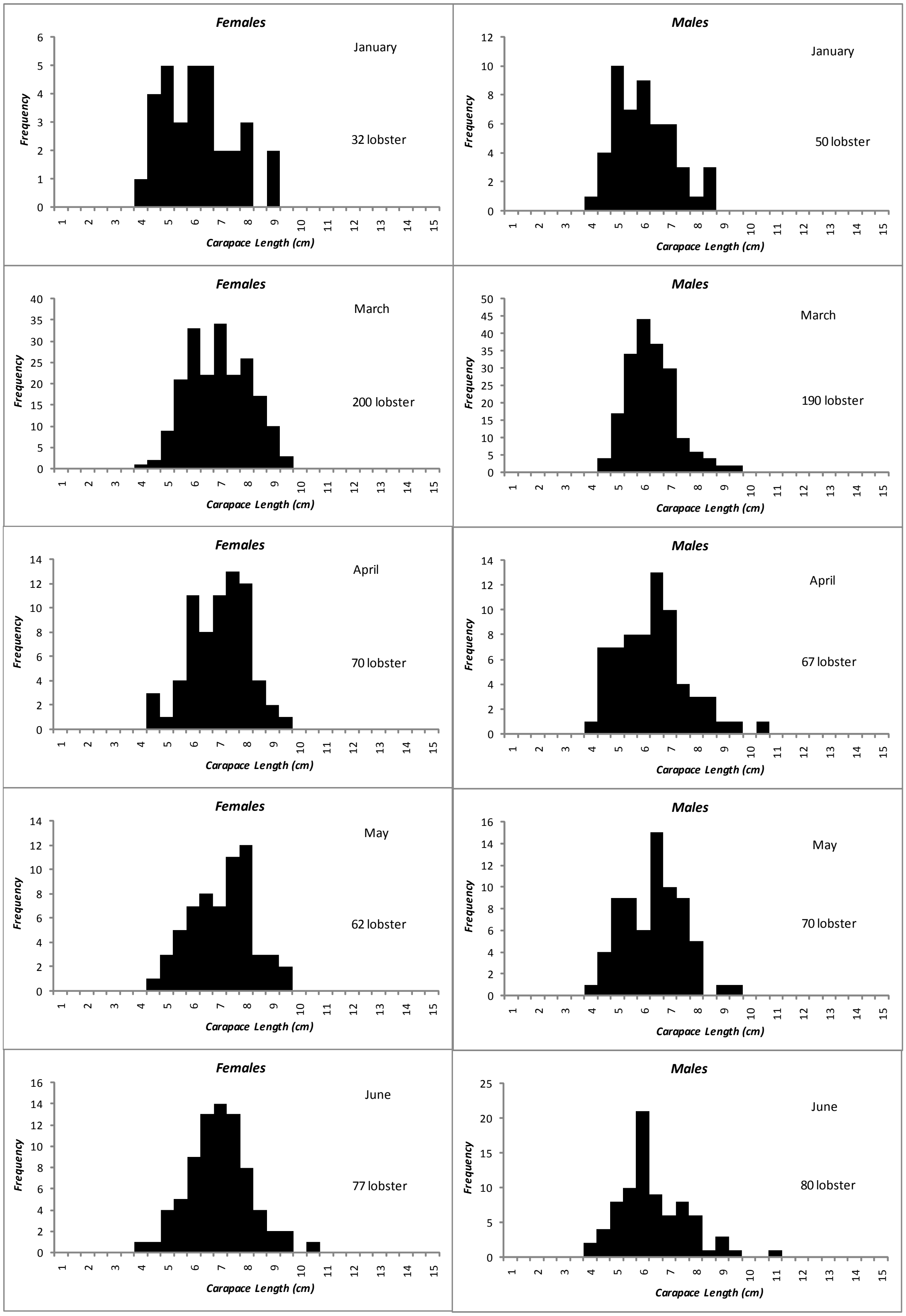
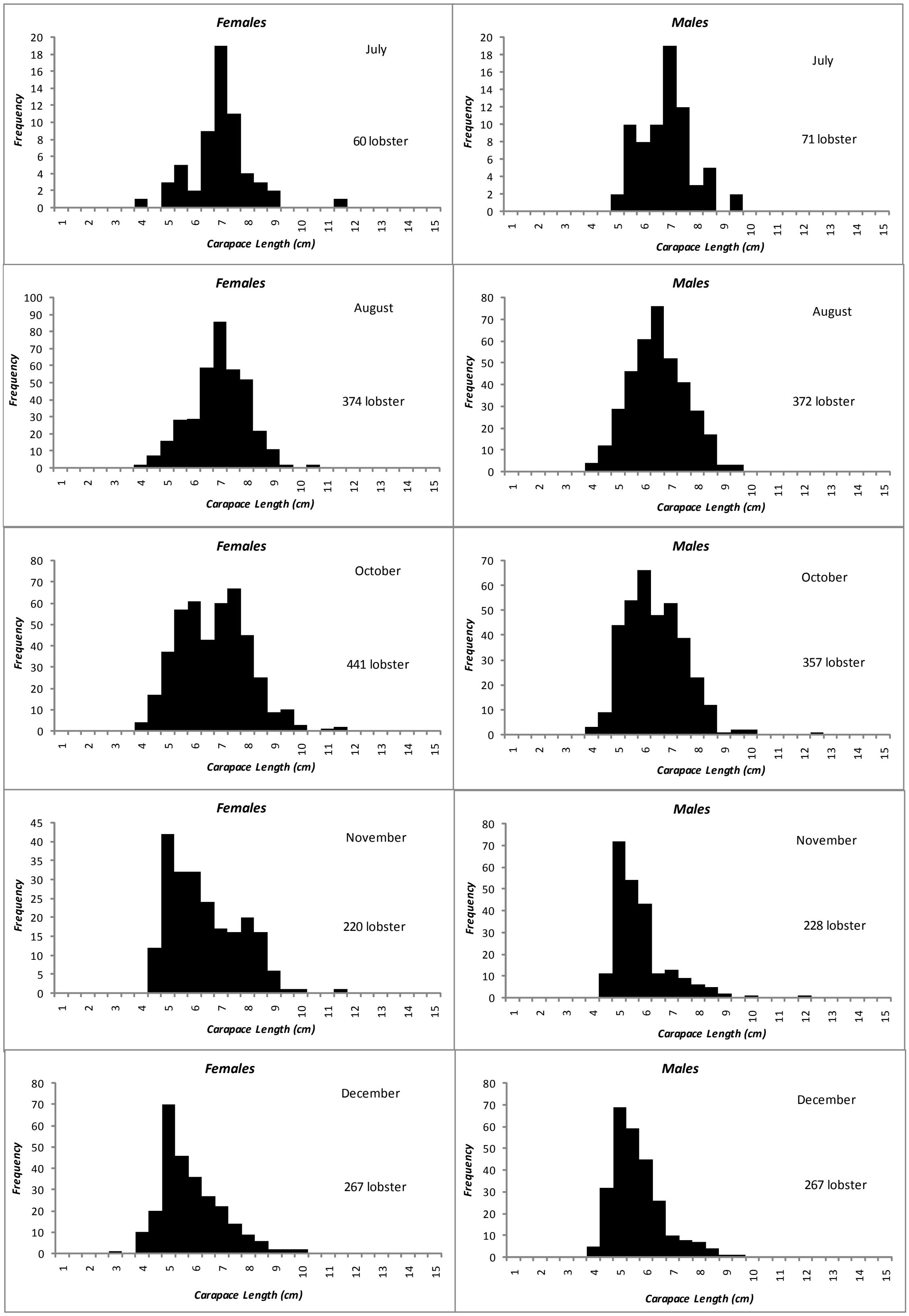


Figure 7: Monthly length frequencies.




Females
July
60 lobster
Males
July
71 lobster
Females
August
374 lobster
Males
August
372 lobster
Females
October
441 lobster
Males
October
357 lobster
Females
November
220 lobster
Males
November
228 lobster
Females
December
267 lobster
Males
December
267 lobster
Frequency
Carapace Length (cm)

NATURAL MORTALITY

Introduction

The method used here to estimate the natural mortality applying to adult lobster, utilises the relationship between natural mortality and the von Bertalanffy growth constants from the previous section. Another method, which requires information about fecundity and mean parental age, was used to estimate the constants in the relationship between natural mortality and age. This was done in recognition that natural mortality is highest during early life, when lobsters are small and fragile. The outputs from both methods are given in Table 3. The associated worksheet for estimating natural mortality at age is shown in Table 4.

Natural Mortality Constants

The magnitude of the natural mortalities for adults is indicated by the M values. They are quite high. This can be appreciated from applying the values with the equation $N_2 = N_1.e^{-Mt}$; where N_1 and N_2 are the numbers of individuals at the beginning and end of time interval t, and death is due solely to natural causes. With M=1 there would be 37 % remaining after 1 year, 13 % remaining after 2 years, and less than 1 % remaining after 5 years. It would seem that the longevity of *P. homarus* is about 5 years. The utility of the constants A and B was in enabling the estimation of the natural mortalities applying to lobster of different ages, as required in a later section.

Table 3: Natural mortalities

Species	Sex	M (/yr)	M/K	A	B
P. homarus	Females	1.05	2.19	0.5343	0.977
	Males	1.09	2.14		

Note: Adult M values were determined from L_α, K, and water temperature T = 28 °C, with L_α as total length in cm, using the Pauly equation $LN(M) = -0.0152-0.279.LN(L_\alpha)+0.6543.LN(K)+0.463.LN(T)$.
The relationship between natural mortality at age: $M_t = A+B/t$ is from Caddy (1991). A modification of the method in Caddy (1996) was used to estimate A and B.

Discussion

As indicated the estimates of adult M are high. They are in agreement with values in the literature: see Sanders and Boulel (1984)and Jayakody (1993). The values for A and B are for female lobster. It was assumed (for the purpose of the later modelling exercise) that the males have the same values. This would seem reasonable in view of the length at age constants being very similar.

Table 4: Natural mortality at age worksheet.

Carapace Length (cm)	Age (yr)	Mean Age (yr)	Natural Mortality Coef. (/yr)	Population Number	Description
L1',L2'	t1, t2	t'	Mt'	N1,N2	**Objective:** Estimate A and B in the relationship
0.0	0.000	0.010	102.64	550,000.0	Mt' = A + B/t' where Mt' is the natural mortality
0.5	0.082	0.119	8.73	125.6	coefficient at mean age t' = (t2-t1)/LN(t2/t1) and
1.0	0.167	0.208	5.23	59.8	A and B are constants (see Caddy, 1991).
1.5	0.255	0.299	3.80	37.6	**Method:** Input values for the von Bertalanffy
2.0	0.348	0.394	3.01	26.4	growth constants L_α and K were used to estimate
2.5	0.445	0.494	2.51	19.7	t1, t2 and t'. Next estimates of Mt' were obtained
3.0	0.547	0.598	2.17	15.3	based on assumed values for A and B. The latter
3.5	0.653	0.708	1.91	12.1	were improved by 'iteration' with the best choice
4.0	0.766	0.824	1.72	9.8	being when the mean lifetime fecundity (MLF)
4.5	0.885	0.947	1.57	8.0	of an individual female is reduced to two offspring
5.0	1.011	1.077	1.44	6.5	at the mean parental age(MPA), with the adult
5.5	1.146	1.216	1.34	5.4	mortality at this age being as determined from the
6.0	1.290	1.365	1.25	4.4	Pauly equation.
6.5	1.444	1.526	1.17	3.7	**Inputs:** L_α = 13.0 cm, K = 0.48, MLF = 550,000 egg
7.0	1.611	1.700	1.11	3.0	MPA = 2 yr, and adult M = 1.0.
7.5	1.792	1.889	1.05	2.5	**Outputs:** A = 0.5343, B = 0.9771.
8.0	1.990	2.098	1.00	2.0	
8.5	2.210	2.330	0.95	1.6	
9.0	2.455	2.592	0.91	1.3	
9.5	2.733	2.891	0.87	1.0	
10.0	3.054	3.240	0.84	0.7	
10.5	3.434	3.661	0.80	0.5	**Note:** MPA is the age attained by an average parent,
11.0	3.899	4.191	0.77	0.4	and MLF is the eggs released during the lifetime of
11.5	4.497	4.907	0.73	0.2	an average parent. The SOLVER routine in EXCEL
12.0	5.341	8.342	0.65	0.1	was used for the iterations.

CATCH WEIGHTS AND CPUEs

Introduction

There are no recent data allowing estimation of the annual catch weight. The most recent values are given in Jayakody (1999), referring to his own and unpublished work by Edirisinghe and Gallage. The value given for 1985 is 303 tonnes. The values for subsequent years show a steady decline to 116, 121, and 110 tonnes for 1996, 1997 and 1998 respectively. The fishing efforts in those years are given as 104,000, 116,000, and 126,600 boat days respectively. The official statistics collated by the Fisheries Statistics Unit in the Department of Fisheries and Aquatic Resources (DFAR) are not believed by the scientists at NARA and are not used here. The export statistics produced by the Customs Department are presumed to be accurate, but do not distinguish between lobster from the south coast and elsewhere.

In order to proceed with the analyses reported in a later section, three alternative values for the catch weights in recent years were assumed. These are 90, 110, and 130 tonnes. The choices were guided by comment from relevant industry and government officials. Monthly CPUEs for each of the three boat types were available from the sampling at landing sites undertaken in 2007. The values are given in Table 5. The bracketed figures are the number of observations contributing to the means. The CPUEs were applied with the assumed catch weights to get values for the annual fishing efforts.

Catches per Unit Effort

The mean CPUEs over all months were 2.46, 1.20, and 0.92 kg/boat day for the motorised fibreglass craft (FRP), motorised traditional craft (MTC), and non-motorised traditional craft (NMTC) respectively. The ratios of these CPUEs are reflective of the relative fishing power or each boat type. Relative to the NMTC, the FRP and MTC had fishing powers of 2.7 and 1.3 respectively. The differences reflect the number of nets able to be carried. According to recent interviews, the numbers of nets currently used during a fishing day are 20-25 for FRPs, about 15 for MTC, and about 10 for NMTC.

The monthly CPUEs are highest in October and November, at least for the FRP and NMTC boat types. These are the months corresponding to the peak recruitment of young lobster into the fishery.

Previous publications have chosen the NMTC as the ‘standard’ boat type, and defined a boat day with this type as the ‘standard’ fishing effort. As such the ‘standard’ fishing effort in respect to the three assumed annual catch weights are 97,000 st. boat days (when C_w = 90 tonnes), 120,000 st. boat days (when C_w = 110 tonnes), and 141,000 st. boat days (when C_w = 130 tonnes).

Discussion

The absence of credible catch and fishing effort statistics is a serious impediment to the future management of this fishery. The observation that the official statistics produced by the Fisheries Statistics Unit in DFAR are not believed is damming. This is not a new situation. The records of catches forwarded to the Fisheries Statistics Unit are from the fisheries inspectors at the district offices. The ability of the fisheries inspectors to function fully effectively is constrained by a lack of vehicles, and dependence on public transport. Many inspectors have received training in fisheries statistics, however more may be required.

Table 5: Monthly catches per unit effort.

Boat Type	Jan '08	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sums/Means
						Observed CPUEs (kg/boat day)							
FRP	1.06 (4)		1.76 (11)	1.99 (22)	1.62 (16)	1.51 (14)	2.50 (22)	2.47 (39)		4.14 (19)	6.65 (5)	1.57 (5)	2.46 (157)
MTC	0.50 (1)		1.50 (5)	1.55 (2)	1.91 (4)	0.81 (3)	1.70 (2)	1.14 (8)		1.34 (6)	0.91 (4)	0.91 (12)	1.20 (47)
NMTC	0.27 (2)		0.71 (3)	1.85 (1)	0.71 (4)	0.45 (8)	0.72 (5)	1.05 (6)		1.81 (8)	1.05 (4)	0.78 (14)	0.92 (55)

Note: FRP are motorised fibreglass boats, MTC are motorised traditional craft, and NMTC are non-motorised traditional craft.
The fishery was closed in February and September.

BIOMASS

Introduction

The data enabling biomass estimation were from the 'fishery-independent' diving survey conducted in February and March, 2009. Commercial SCUBA divers were employed for the purpose. At each dive site they were required to swim a measured 100 m, making observations within a measured 2 m track along the swim line. This was done at a total of 223 sites, although not all sites were on reef habitat. The data used here to determine lobster abundance were in respect to the 149 dive sites on reef. There were 110 sites where the dives were during night time, and 39 day time dive sites. According to divers the lobsters were more readily observed at night.

The relevant information recorded at each site was the number of lobster seen and the species. In the analysis it was assumed that the efficiency of observation was 100 %; that is every lobster of exploitable size within each 200 m^2 was seen. In reality the efficiency of observation is likely to be less, particularly during day time dives. Notwithstanding, the density of lobster at each site was determined by dividing the lobster count by the 200 m^2 of seabed area covered.

In order to estimate biomass, it was necessary to convert the number densities to biomass densities. A mean individual weight for each species was used for this purpose. These were previously determined from the length frequencies for 2007 shown in the previous section and the weight to length constants also previously determined. Biomass values were then estimated as the product of reef areas and biomass densities.

This was done for each of four separate reef complexes. Little Basses Ridge, Middle Ground, and Great Basses Ridge exist offshore. Coastal refers to the near-shore reefs. It is the area that is almost exclusively fished for *P. homarus*. The seabed area of each complex had previously been determined from a topography survey using echo-sounders. The exception was the area east of Kirinde, where for security reasons no survey work was permitted. The reef area for the grounds not able to be surveyed was determined from charts. The worksheet used for estimating biomass values is shown in Table 4. The actual dive locations and associated lobster counts are shown in Figures 8 and 9.

Biomass Estimates

The all species biomass was estimated at 235 tonnes using data from the combined day and night time dives, and 239 tonnes using the data from the night time dives. The contributions to these totals from *P. homarus* were 100 and 121 tonnes respectively; mostly from the coastal reefs as expected. As a percentage of the standing stock, the estimates for this species were 50 % and 58 % respectively. These are less than the 86 % observed in fishermen's catches during 2007. It was necessary to assume that the estimates of density for the reefs west of Kirinde, were applicable to all the coastal reefs. This may, at least in part, explain the under-representation of *P. homarus*. The other species were found mostly on the offshore reefs, particularly on the Little Basses and Great Basses Ridges.

Discussion

There is uncertainty attached to the biomass values. Concerning the assumption of 100 % efficiency of observation, there were no data upon which this could be tested. Assuming a lower efficiency has the consequence of increasing the estimates of biomass. Also of concern was the inability to survey the coastal reefs east of Kirinde. These reefs are large and productive, particularly for *P. homarus*. *P. ornatus* were not encountered during the survey dives. This was somewhat surprising having in mind its presence in fishermen’s catches.

Table 6: Biomass worksheet.

			Little Basses Ridge	Middle Ground	Great Basses Ridge	Coastal	Reefs Combined
Area of Reef (km^2)			8.1	12.25	17.56	34.17	72.08
Obs. Area per Dive (m^2)			200	200	200	200	200
No.of Dive Sites (day and night dives)			45	8	68	28	149
No.of Dive Sites (night dives only)			43	2	42	23	110
Obs. Lobster Count	*P. homarus*		21	0	1	54	76
(day and night dives)	*P. versicolour*		46	12	31	3	92
	P. penicillatus		6	0	27	0	33
	P. ornatus		0	0	0	0	0
	P. longipes		44	0	55	0	99
		sums	117	12	114	57	300
Est. Stock Number	*P. homarus*		18,900	0	1,291	329,496	349,688
(day and night dives)	*P. versicolour*		41,400	91,875	40,026	18,305	191,607
	P. penicillatus		5,400	0	34,862	0	40,262
	P. ornatus		0	0	0	0	0
	P. longipes		39,600	0	71,015	0	110,615
		sums	105,300	91,875	147,194	347,802	692,171
Est.Biomass	*P. homarus*		5,424	0	371	94,565	100,360
(day and night dives)	*P. versicolour*		17,057	37,853	16,491	7,542	78,942
	P. penicillatus		2,506	0	16,176	0	18,681
	P. ornatus		0	0	0	0	0
	P. longipes		13,226	0	23,719	0	36,945
		sums	38,213	37,853	56,756	102,107	234,929
Obs. Lobster Count	*P. homarus*		21	0	1	54	76
(night dives only)	*P. versicolour*		46	0	25	1	72
	P. penicillatus		6	0	27	0	33
	P. ornatus		0	0	0	0	0
	P. longipes		44	0	47	0	91
		sums	117	0	100	55	272
Est. Stock Number	*P. homarus*		19,779	0	2,090	401,126	422,996
(night dives only)	*P. versicolour*		43,326	0	52,262	7,428	103,016

	P. penicillatus		5,651	0	56,443	0	62,094
	P. ornatus		0	0	0	0	0
	P. longipes		41,442	0	98,252	0	139,694
		sums	110,198	0	209,048	408,554	727,800
Est.Biomass	*P. homarus*		5,677	0	600	115,123	121,400
(night dives only)	*P. versicolour*		17,850	0	21,532	3,060	42,442
	P. penicillatus		2,622	0	26,189	0	28,812
	P. ornatus		0	0	0	0	0
	P. longipes		13,842	0	32,816	0	46,658
		sums	39,990	0	81,138	118,184	239,312
Inputs:							
Mean Weight							
(gm/lobster)	*P. homarus*	*287*					
	P. versicolour	*412*					
	P. penicillatus	*464*					
	P. ornatus	*510*					
	P. longipes	*334*					

Figure 8: Lobster counts from day and night time dives.

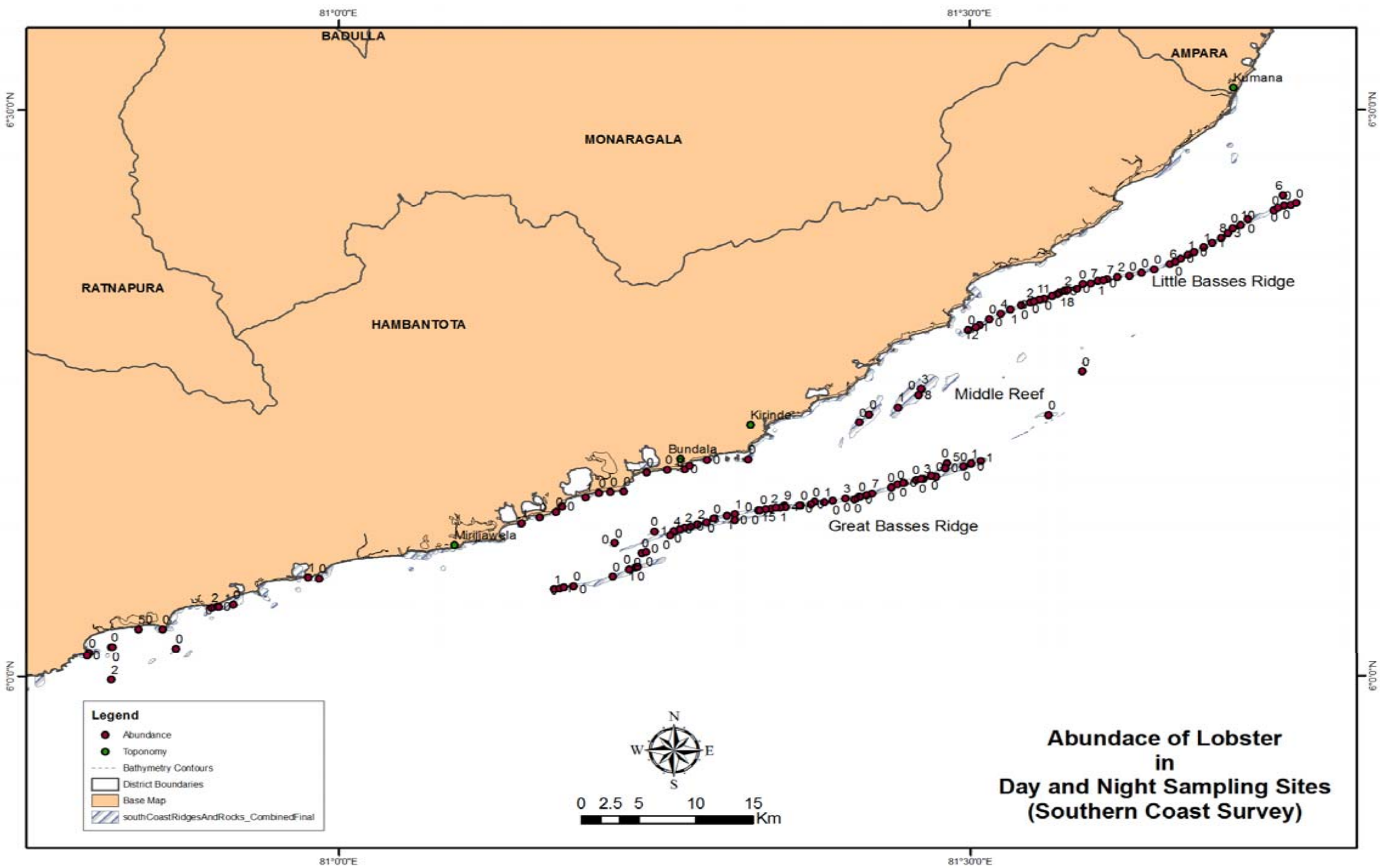
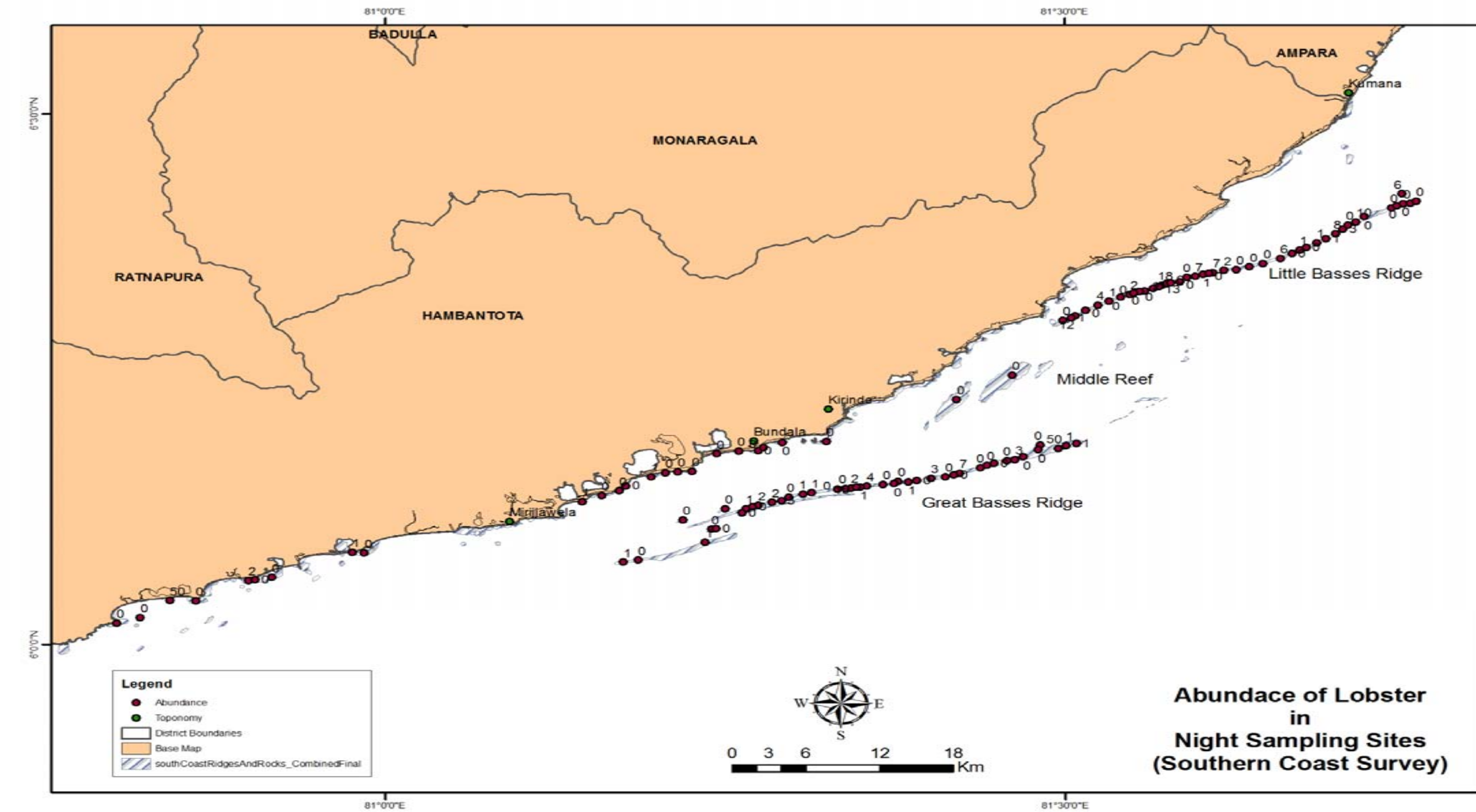


Figure 9: Lobster counts from night time dives.



YIELD ASSESSMENT

Introduction

This section seeks a more comprehensive examination of the current exploitation levels. It involved formulating a mathematical model of the fishery. The biological inputs are those previously determined for *P. homarus*. They included those concerned with growth in length (Lα and K), the conversion of length to individual whole weight (a and b), the individual fecundity at length constants (u and v), and natural mortality with age constants (A and B). The probability of capture ogive included in the model assumes trawl net type gear selection. Two important inputs were determined internally. These were the annual recruitment of zero-aged lobster (R), and the catchability coefficients(q). The remaining input was the annual fishing effort (X) as number of 'standard' fishing days.

The outputs from the model were estimated catch numbers, catch weights, CPUEs, population fecundities, and lobster length frequencies. In raising the output to include the other species of lobster, it was assumed their proportion by number was 14 % as determined from the sampling of catches in 2007, and that their average individual weights would be the same as for *P. homarus*. A worksheet showing the model structure, associated equations, input values and example output are shown in Appendix 1.

Internal Estimation of Inputs

The internal estimation of model inputs involved iteration (ie. trial and error). After inputting the 'observed' fishing effort for the year, the 'best choice' values for the catchability coefficients were those for which the estimated and observed length frequencies (as percentages) were in closest agreement. The latter was when the sum of the squared differences between the estimated and observed length frequencies were minimised. The iterations were undertaken using the Solver routine in EXCEL. Following this internal estimation of the catchability coefficients, the annual number of zero-aged recruits was determined by iteration as when the estimated and observed catch weights were in closest agreement.

Application of the Model

Following inclusion of all the inputs, the model was used to estimate how the fishery might perform in the event of more or less fishing effort, and with different lengths at first capture (ie. minimum lengths). In the first analysis the probability of capture ogive reflecting present fishing practice (as shown in Appendix 1) was kept constant, and the fishing effort varied over a range to twice the contemporary level. The analysis was then repeated with probability of capture ogives reflecting minimum sizes of 6 cm, 7 cm and 8 cm. In each of these 'knife-edge' selection was assumed. All analyses were repeated for each of the assumed annual contemporary catch weights (ie. 90, 110, and 130 tonnes).The outputs of interest in respect to each combination are shown in Figures 10, 11 and 12.

Predictions of Yield

The shape of the yield plots are essentially the same irrespective of the choice of assumed annual catch weight. Fishing efforts above the contemporary level (multiplier 1) would lead to very little additional yield. This is particularly so where there is no effective minimum size as at present. While reduced yields would be associated with any reduction in fishing effort, the latter could be reduced as much as 40 % without much loss of yield. In respect to identifying a 'best choice' minimum size, there seems little difference, in the sense of achieving increased yields, between no effective minimum size and minimum lengths of 6 cm and 7 cm. There would be significantly less yield if an 8 cm minimum size were adopted.

Individual Whole Weights

The plots of mean individual whole weights are exactly the same irrespective of the assumed annual catch weight. Increased fishing efforts would have the effect of reducing the mean size of the lobster in the catches, and vice versa. In respect to the choice of minimum size, as this is increased so also are the mean individual weights. This is as expected and has substantial relevance, as product prices are dependent on lobster size in this fishery. Prices quoted recently at a major lobster collection centre are given in Appendix 3.

Population Fecundities

The plots of population fecundity are also exactly the same irrespective of the assumed annual catch weight. They are as percentages of the population fecundities when the fishing efforts are zero (multiplier 0). With the contemporary fishing effort and no effective minimum size, the estimated population fecundities are 38 % of those prior to the commencement of the fishery. Increased fishing efforts would be associated with lower population fecundities. As the choice of minimum size is increased, so also are the population fecundities. With the fishing effort as at present, the estimated population fecundity percentages for minimum sizes of 6 cm, 7 cm, and 8 cm are respectively 43 %, 52 %, and 63 %.

Discussion

These findings indicate that the fishery is heavily exploited. They provide no justification for increase in fishing effort. Such would be associated with no or little increase in yield, the lobster in the catches would be smaller, and population fecundities would be further reduced. A modest reduction in the fishing effort on the other hand, would cause only a small reduction in yield. Catch rates would be significantly higher, and there would be an increase in the size of the lobsters caught and in the population fecundities.

The findings provide strong justification for having a minimum size, provided there is compliance. This is not in the sense of achieving increased yields. Rather, it is in the sense that the lobster caught would be larger and more valuable, and the population fecundities would be higher, hence reducing the risk of future recruitment failure. It is not possible to judge whether population fecundities are now dangerously low, although they may well be.

Figure 10: Yield plots.

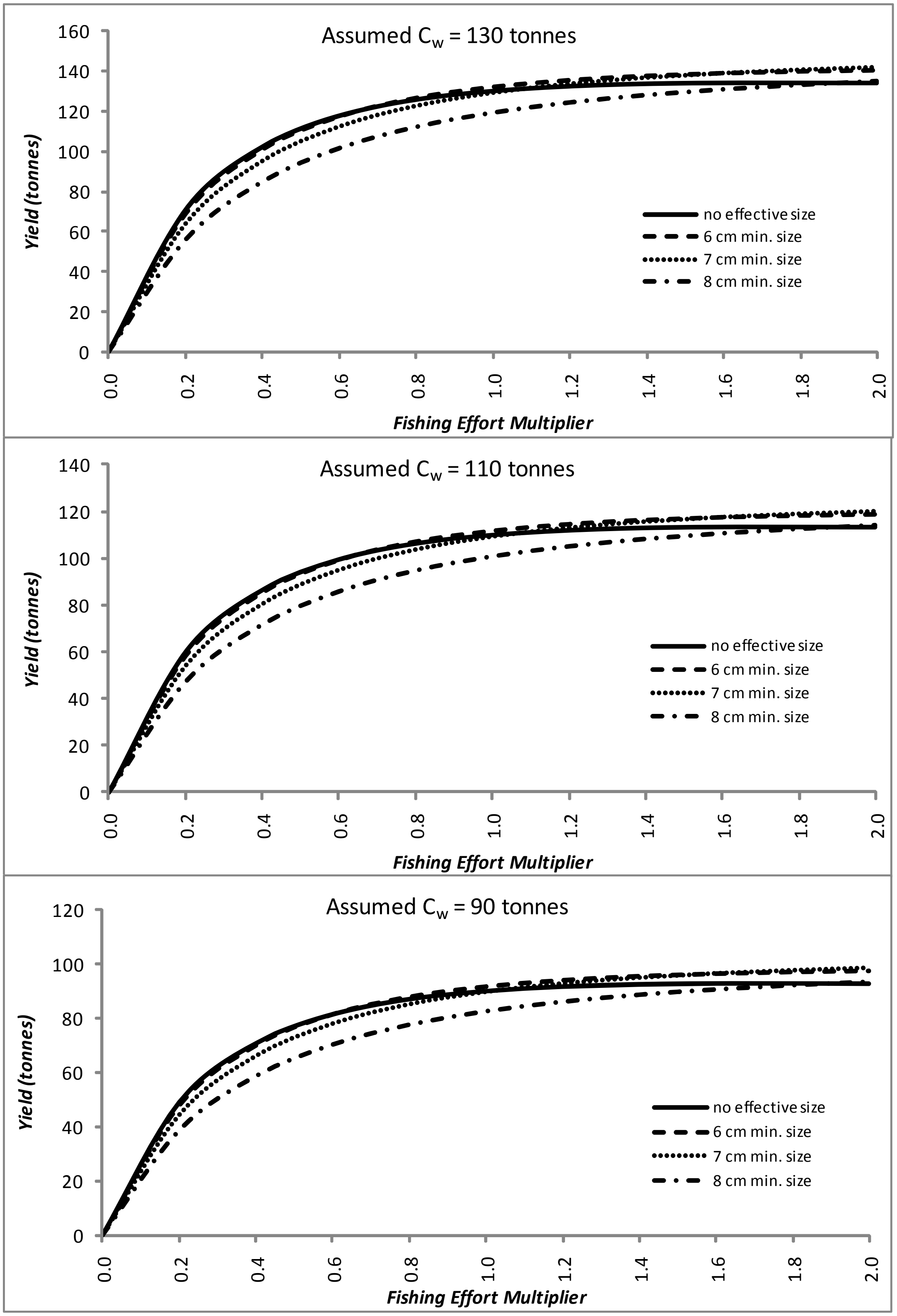


Figure 11: Mean individual weight plots.

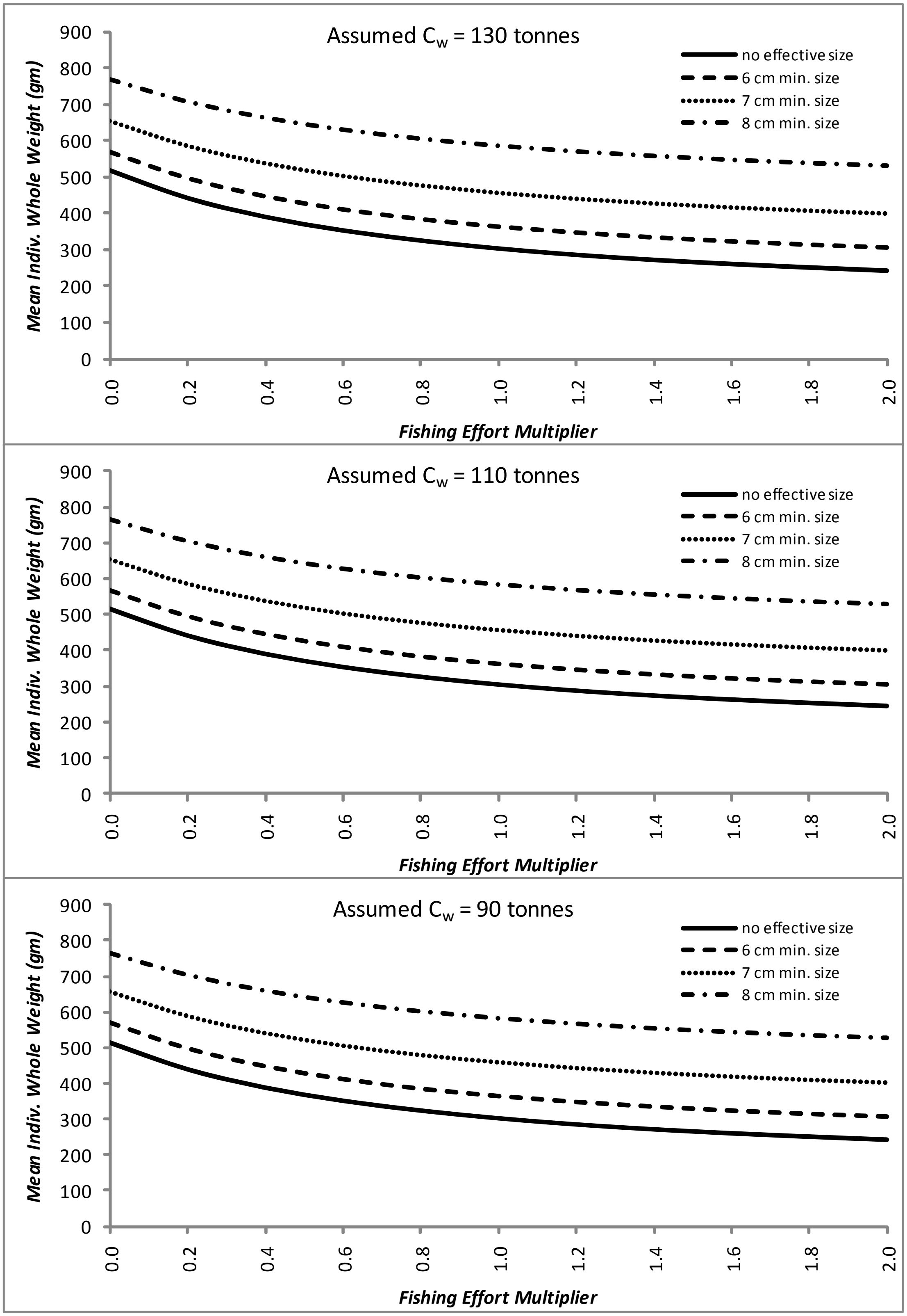
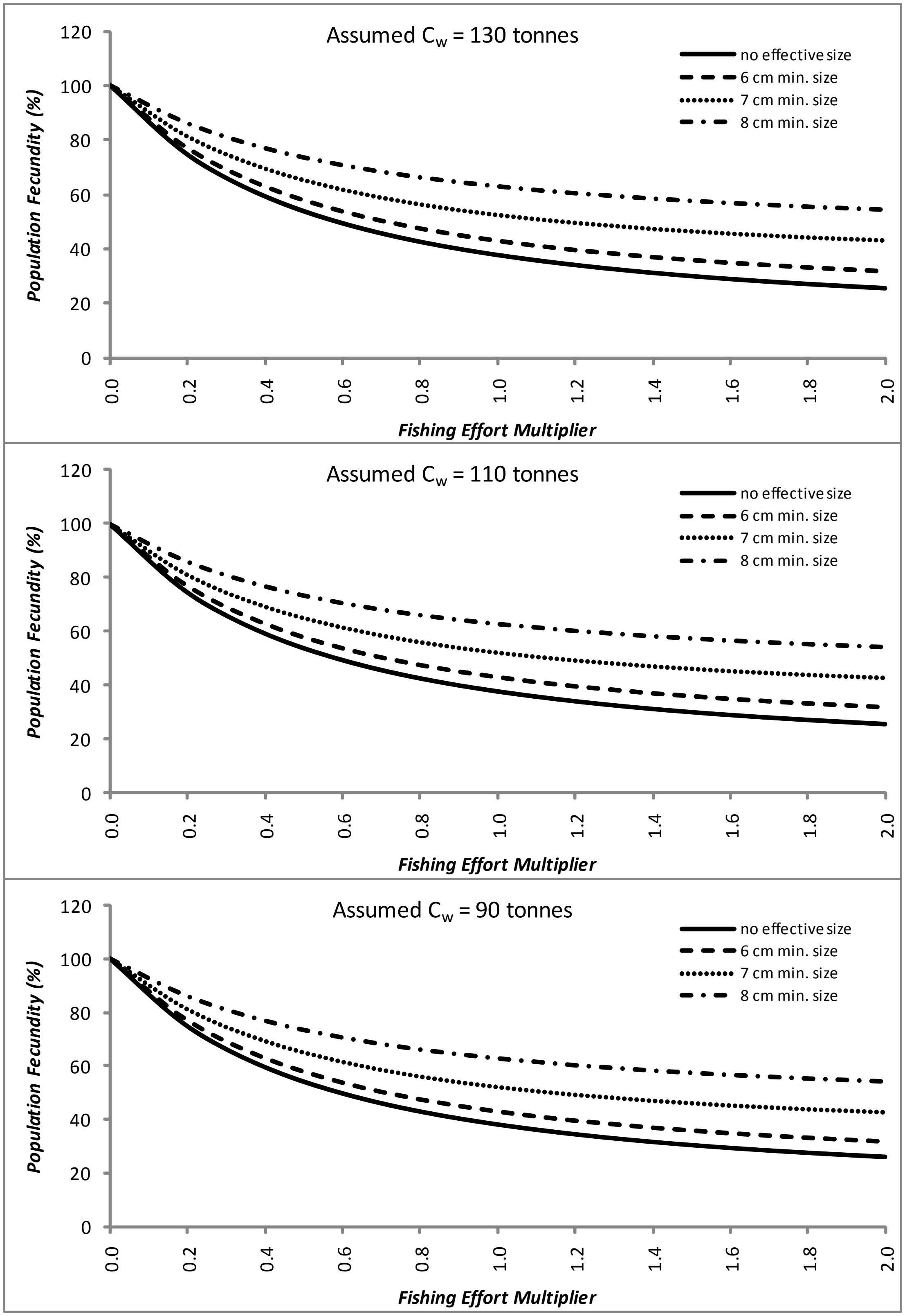


Figure 12: Population fecundity plots.



FINANCIAL ANALYSIS

Introduction

This section concerns the financial viability of lobster fishing. A cash flow analysis was undertaken for each of the three types of fishing craft, all operated with gill nets. It was assumed that the FRP and MTC were used to catch lobster for 20 days in each of 7 months. The NMTC was assumed to be operated for 20 days in each of 6 months. The sea conditions in May to August are generally acknowledged as too rough for most boats. February, September, and October for the first time this year, are closed months for fishing.

Lobster prices and the costs of fishing operations and investments were obtained from recent interviews with owners and crews. The catch composition and CPUEs were from the sampling undertaken in 2007. The results are presented as cash flows over a 10 year period, with each of the fishing operations, CPUEs, product prices and costs assumed to remain constant. Annual net remuneration to each of the owner and crew were the outputs of principal concern. In all cases it was assumed that the owner was also a crew member. Internal rates of return (IRR) and the net present value (NPV) were estimated. The cash flow spreadsheets are shown in Tables 7, 8 and 9.

Gross Revenues

The estimates of gross revenue for the 'standard' FRP, MTC, and NMTC fishing units are Rs 1,009,000, Rs 403,000, and Rs 249,000 respectively. These are equivalent to US$ 8,851, US$ 3,535, and US$ 2,184, assuming the current exchange rate for changing rupees into dollars of US$ 1 = Rs 114. The product prices used for *P. homarus* ranged from 1,400 Rs/kg (100-200 gm sizes) to 2,400 Rs/kg (> 500 gm sizes). The prices used for the other species were lower, ranging from 700 Rs/kg (100-200 gm sizes) to 1,900 Rs/kg (>500 gm sizes). The mean individual weight of a just legal size lobster is about 200 gm. As such essentially all of the 100-200 gm size category will be under-size.

Total Costs

The estimates of total costs for the FRP, MTC, and NMTC are Rs 948,000, Rs 478,000, and Rs 284,000 respectively. These are greater than the associated gross revenues for each of the traditional craft. The major items of cost were for payments to crew (including owner), fuel and oil in the case of the motorised craft, and the cost of purchasing and replacing gill nets. The percentages of total costs required to meet crew payments were 60 %, 54 % and 70 % for the FRP, MTC and NMTC respectively , for purchasing gillnets they were 15 %, 21 % and 28 % respectively, and for fuel and oil they were 16 %, 17 % and 0 % respectively. According to interviews gillnets require substantial repair and often replacement after a month of use.

Remunerations

In the scenarios depicted here the FRP is crewed by 3 persons, and the MTC and NMTC by 2 persons. The estimated remunerations per crew member for each of the FRP, MTC, and NMTC are 27,000, 18,000, and 17,000 Rs/month respectively. These are modest to poor and less than had been anticipated. This is particularly so for the crew member who is also the boat owner. The estimated returns to the owners' investment and management are positive 3,000 Rs/month for the FRP, and negative 5,000 and 3,000 Rs/month for the MTC and NMTC respectively. The annual cash flows (when no allowance is made for depreciation) are also negative for the traditional craft. These negative returns would need to be met from the owners' return to labour.

Discussion

These findings if believed indicate that the fishery is hardly viable. This was unexpected. During interviews with fishermen and owners when they were asked to identify management issues, the possibility of the fishery lacking viability was not raised. It will be important to quickly confirm these findings or otherwise. Local consultants have been recruited to undertake a follow-up study, and this work is expected to commence in early 2010.

Table 7: Cash flow worksheet for FRP.

						Year 0	1	2	3	4	5	6	7	8	9	10
1. Definition of fishery change scenarios																
assumed annual change in catch rates				0	%											
estimated catch rate index							100	100	100	100	100	100	100	100	100	100
projected catch rates	*P. homarus*		100-200 gm	0.427	kg/boat day		0.427	0.427	0.427	0.427	0.427	0.427	0.427	0.427	0.427	0.427
			200-500 gm	2.161	kg/boat day		2.161	2.161	2.161	2.161	2.161	2.161	2.161	2.161	2.161	2.161
			>500 gm	0.643	kg/boat day		0.643	0.643	0.643	0.643	0.643	0.643	0.643	0.643	0.643	0.643
	other lobsters		100-200 gm	0.070	kg/boat day		0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070
			200-500 gm	0.353	kg/boat day		0.353	0.353	0.353	0.353	0.353	0.353	0.353	0.353	0.353	0.353
			>500 gm	0.106	kg/boat day		0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106
			sum	3.760	kg/boat day											
assumed annual change in product price				0	%											
estimated price index							100	100	100	100	100	100	100	100	100	100
observed product prices	*P. homarus*		100-200 gm	1,400	Rs/kg		1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400
			200-500 gm	2,050	Rs/kg		2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050
			>500 gm	2,400	Rs/kg		2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
	other lobsters		100-200 gm	700	Rs/kg		700	700	700	700	700	700	700	700	700	700
			200-500 gm	1,100	Rs/kg		1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100
			>500 gm	1,900	Rs/kg		1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
2. Efforts and estimated catch weights																
months fishing				7	/yr											
boat days/month				20	boat days											
catch weights (kg)	*P. homarus*		100-200 gm				60	60	60	60	60	60	60	60	60	60
			200-500 gm				303	303	303	303	303	303	303	303	303	303
			>500 gm				90	90	90	90	90	90	90	90	90	90
	other lobsters		100-200 gm				10	10	10	10	10	10	10	10	10	10
			200-500 gm				49	49	49	49	49	49	49	49	49	49
			>500 gm				15	15	15	15	15	15	15	15	15	15
3. Gross revenue (Rs'000)																
	P. homarus		100-200 gm				84	84	84	84	84	84	84	84	84	84
			200-500 gm				620	620	620	620	620	620	620	620	620	620
			>500 gm				216	216	216	216	216	216	216	216	216	216
	other lobsters		100-200 gm				7	7	7	7	7	7	7	7	7	7
			200-500 gm				54	54	54	54	54	54	54	54	54	54
			>500 gm				28	28	28	28	28	28	28	28	28	28
	total						1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009
4. Investment (Rs'000)																
	FRP boat					150										
	engine (25 HP outboard)					320										
	total					470										
5. Fuel & oil costs (Rs'000)																
kerosene	consumption	kerosene		15	litres/boat day		105	105	105	105	105	105	105	105	105	105
petrol	price	kerosene		50	Rs/litre		19	19	19	19	19	19	19	19	19	19
oil	consumption	petrol		1	litres/boat day		26	26	26	26	26	26	26	26	26	26
	price	petrol		135	Rs/litre											
	consumption	oil		1	litre/20 litres kerosene											
	price	oil		250	Rs/litre											
6. Other trip costs (Rs'000)																
	food			0	Rs/boat day		0	0	0	0	0	0	0	0	0	0

7. Crew payments (Rs'000)														
	Crew share (shared by 3 persons)	66.7	% of net trip revenue		573	573	573	573	573	573	573	573	573	573
	Crew (incl. owner)	3	persons											
8. Repairs/Maintenance/Replacement Costs (Rs'000)														
	boat	5,000	Rs/yr		5	5	5	5	5	5	5	5	5	5
	engine	40,000	Rs/yr		40	40	40	40	40	40	40	40	40	40
	fishing gear (35 nets @ Rs 4,000)	140,000	Rs/yr		140	140	140	140	140	140	140	140	140	140
9. Registration and licences (Rs'000)														
	lobster fishing permit	250	Rs/yr		0	0	0	0	0	0	0	0	0	0
10. Insurance costs (Rs'000)														
	insurance	0	Rs/yr		0	0	0	0	0	0	0	0	0	0
11. Depreciation costs (Rs'000)														
	boat	5	% of investment		8	8	8	8	8	8	8	8	8	8
	engine	10	% of investment		32	32	32	32	32	32	32	32	32	32
12. Total costs					948	948	948	948	948	948	948	948	948	948
13. Return to owners investment and management (Rs'000)					61	61	61	61	61	61	61	61	61	61
14. Discounted cash flow analysis (Rs'000)														
inflow														
	gross revenue				1009	1009	1009	1009	1009	1009	1009	1009	1009	1009
	capital recovery													395
	total inflow				1009	1009	1009	1009	1009	1009	1009	1009	1009	1404
outflow														
	investment			470	0	0	0	0	0	0	0	0	0	0
	fuel & oil costs				150	150	150	150	150	150	150	150	150	150
	other trip costs				0	0	0	0	0	0	0	0	0	0
	crew costs (incl. owner)				573	573	573	573	573	573	573	573	573	573
	repairs/maintenance/replacement				185	185	185	185	185	185	185	185	185	185
	registration and fishing licences				0	0	0	0	0	0	0	0	0	0
	insurance				0	0	0	0	0	0	0	0	0	0
	total outflow				908	908	908	908	908	908	908	908	908	908
net cash flow to investment				-470	101	101	101	101	101	101	101	101	101	496
internal rate of return (IRR)	21%													
net present value (NPV)	227 Rs'000	(assumed rate =	12.00%)											

Table 8: Cash flow worksheet for MTC.

1. Definition of fishery change scenarios				Year 0	1	2	3	4	5	6	7	8	9	10
assumed annual change in catch rates			0 %											
estimated catch rate index					100	100	100	100	100	100	100	100	100	100
projected catch rates	*P. homarus*	100-200 gm	0.170 kg/boat day		0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170
		200-500 gm	0.863 kg/boat day		0.863	0.863	0.863	0.863	0.863	0.863	0.863	0.863	0.863	0.863
		>500 gm	0.257 kg/boat day		0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257
	other lobsters	100-200 gm	0.028 kg/boat day		0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
		200-500 gm	0.140 kg/boat day		0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140
		>500 gm	0.042 kg/boat day		0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
		sum	1.500 kg/boat day											
assumed annual change in product price			0 %											
estimated price index					100	100	100	100	100	100	100	100	100	100
observed product prices	*P. homarus*	100-200 gm	1,400 Rs/kg		1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400
		200-500 gm	2,050 Rs/kg		2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050
		>500 gm	2,400 Rs/kg		2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
	other lobsters	100-200 gm	700 Rs/kg		700	700	700	700	700	700	700	700	700	700
		200-500 gm	1,100 Rs/kg		1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100
		>500 gm	1,900 Rs/kg		1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
2. Efforts and estimated catch weights														
months fishing			7 /yr											
boat days/month			20 boat days											
catch weights (kg)	*P. homarus*	100-200 gm			24	24	24	24	24	24	24	24	24	24
		200-500 gm			121	121	121	121	121	121	121	121	121	121
		>500 gm			36	36	36	36	36	36	36	36	36	36
	other lobsters	100-200 gm			4	4	4	4	4	4	4	4	4	4
		200-500 gm			20	20	20	20	20	20	20	20	20	20
		>500 gm			6	6	6	6	6	6	6	6	6	6
3. Gross revenue (Rs'000)														
	P. homarus	100-200 gm			33	33	33	33	33	33	33	33	33	33
		200-500 gm			248	248	248	248	248	248	248	248	248	248
		>500 gm			86	86	86	86	86	86	86	86	86	86
	other lobsters	100-200 gm			3	3	3	3	3	3	3	3	3	3
		200-500 gm			22	22	22	22	22	22	22	22	22	22
		>500 gm			11	11	11	11	11	11	11	11	11	11
	total				403	403	403	403	403	403	403	403	403	403
4. Investment (Rs'000)														
	FRP boat			40										
	engine (25 HP outboard)			150										
	total			190										
5. Fuel & oil costs (Rs'000)														
kerosene	consumption	kerosene	8 litres/boat day		56	56	56	56	56	56	56	56	56	56
petrol	price	kerosene	50 Rs/litre		9	9	9	9	9	9	9	9	9	9
oil	consumption	petrol	0.5 litres/boat day		14	14	14	14	14	14	14	14	14	14
	price	petrol	135 Rs/litre											
	consumption	oil	1 litre/20 litres kerosene											
	price	oil	250 Rs/litre											
6. Other trip costs (Rs'000)														
	food		0 Rs/boat day		0	0	0	0	0	0	0	0	0	0

7. Crew payments (Rs'000)														
	Crew share (shared by 2 persons)	80	% of net trip revenue		259	259	259	259	259	259	259	259	259	259
	Crew (incl. owner)	2	persons											
8. Repairs/Maintenance/Replacement Costs (Rs'000)														
	boat	3,000	Rs/yr		3	3	3	3	3	3	3	3	3	3
	engine	20,000	Rs/yr		20	20	20	20	20	20	20	20	20	20
	fishing gear (25 nets @ Rs 4,000)	100,000	Rs/yr		100	100	100	100	100	100	100	100	100	100
9. Registration and licences (Rs'000)														
	lobster fishing permit	105	Rs/yr		0	0	0	0	0	0	0	0	0	0
10. Insurance costs (Rs'000)														
	insurance	0	Rs/yr		0	0	0	0	0	0	0	0	0	0
11. Depreciation costs (Rs'000)														
	boat	5	% of investment		2	2	2	2	2	2	2	2	2	2
	engine	10	% of investment		15	15	15	15	15	15	15	15	15	15
12. Total costs					478	478	478	478	478	478	478	478	478	478
13. Return to owners investment and management (Rs'000)					-75	-75	-75	-75	-75	-75	-75	-75	-75	-75
14. Discounted cash flow analysis (Rs'000)														
inflow														
	gross revenue				403	403	403	403	403	403	403	403	403	403
	capital recovery													170
	total inflow				403	403	403	403	403	403	403	403	403	573
outflow														
	investment			190	0	0	0	0	0	0	0	0	0	0
	fuel & oil costs				79	79	79	79	79	79	79	79	79	79
	other trip costs				0	0	0	0	0	0	0	0	0	0
	crew costs (incl. owner)				259	259	259	259	259	259	259	259	259	259
	repairs/maintenance/replacement				123	123	123	123	123	123	123	123	123	123
	registration and fishing licences				0	0	0	0	0	0	0	0	0	0
	insurance				0	0	0	0	0	0	0	0	0	0
	total outflow				461	461	461	461	461	461	461	461	461	461
net cash flow to investment				-190	-58	-58	-58	-58	-58	-58	-58	-58	-58	112

internal rate of return (IRR) #DIV/0!

net present value (NPV) -465 Rs'000 (assumed rate = 12.00%)

Table 9: Cash flow worksheet for NMTC.

Item		Size	Value	Unit	Year 0	1	2	3	4	5	6	7	8	9	10
1. Definition of fishery change scenarios															
assumed annual change in catch rates			0	%											
estimated catch rate index						100	100	100	100	100	100	100	100	100	100
projected catch rates	*P. homarus*	100-200 gm	0.123	kg/boat day		0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123
		200-500 gm	0.621	kg/boat day		0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621
		>500 gm	0.185	kg/boat day		0.185	0.185	0.185	0.185	0.185	0.185	0.185	0.185	0.185	0.185
	other lobsters	100-200 gm	0.020	kg/boat day		0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
		200-500 gm	0.101	kg/boat day		0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101
		>500 gm	0.030	kg/boat day		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
		sum	1.080	kg/boat day											
assumed annual change in product price			0	%											
estimated price index						100	100	100	100	100	100	100	100	100	100
observed product prices	*P. homarus*	100-200 gm	1,400	Rs/kg		1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400
		200-500 gm	2,050	Rs/kg		2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050
		>500 gm	2,400	Rs/kg		2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
	other lobsters	100-200 gm	700	Rs/kg		700	700	700	700	700	700	700	700	700	700
		200-500 gm	1,100	Rs/kg		1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100
		>500 gm	1,900	Rs/kg		1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
2. Efforts and estimated catch weights															
months fishing			6	/yr											
boat days/month			20	boat days											
catch weights (kg)	*P. homarus*	100-200 gm				15	15	15	15	15	15	15	15	15	15
		200-500 gm				75	75	75	75	75	75	75	75	75	75
		>500 gm				22	22	22	22	22	22	22	22	22	22
	other lobsters	100-200 gm				2	2	2	2	2	2	2	2	2	2
		200-500 gm				12	12	12	12	12	12	12	12	12	12
		>500 gm				4	4	4	4	4	4	4	4	4	4
3. Gross revenue (Rs'000)															
	P. homarus	100-200 gm				21	21	21	21	21	21	21	21	21	21
		200-500 gm				153	153	153	153	153	153	153	153	153	153
		>500 gm				53	53	53	53	53	53	53	53	53	53
	other lobsters	100-200 gm				2	2	2	2	2	2	2	2	2	2
		200-500 gm				13	13	13	13	13	13	13	13	13	13
		>500 gm				7	7	7	7	7	7	7	7	7	7
	total					249	249	249	249	249	249	249	249	249	249
4. Investment (Rs'000)															
	FRP boat				40										
	total				40										
5. Trip costs (Rs'000)															
	food		0	Rs/boat day		0	0	0	0	0	0	0	0	0	0
6. Crew payments (Rs'000)															
	Crew share (shared by 2 persons)		80	% of net trip revenue		199	199	199	199	199	199	199	199	199	199
	Crew (incl. owner)		2	persons											
7. Repairs/Maintenance/Replacement Costs (Rs'000)															
	boat		3,000	Rs/yr		3	3	3	3	3	3	3	3	3	3
	fishing gear (20 nets @ Rs 4,000)		80,000	Rs/yr		80	80	80	80	80	80	80	80	80	80
8. Registration and licences (Rs'000)															
	lobster fishing permit		105	Rs/yr		0	0	0	0	0	0	0	0	0	0

9. Insurance costs (Rs'000)													
	insurance	0 Rs/yr		0	0	0	0	0	0	0	0	0	0
10. Depreciation costs (Rs'000)													
	boat	5 % of investment		2	2	2	2	2	2	2	2	2	2
11. Total costs				284	284	284	284	284	284	284	284	284	284
12. Return to owners investment and management (Rs'000)				-35	-35	-35	-35	-35	-35	-35	-35	-35	-35
13. Discounted cash flow analysis (Rs'000)													
inflow													
	gross revenue			249	249	249	249	249	249	249	249	249	249
	capital recovery												20
	total inflow			249	249	249	249	249	249	249	249	249	269
outflow													
	investment		40	0	0	0	0	0	0	0	0	0	0
	trip costs			0	0	0	0	0	0	0	0	0	0
	crew costs (incl. owner)			199	199	199	199	199	199	199	199	199	199
	repairs/maintenance/replacement			83	83	83	83	83	83	83	83	83	83
	registration and fishing licences			0	0	0	0	0	0	0	0	0	0
	insurance			0	0	0	0	0	0	0	0	0	0
	total outflow			282	282	282	282	282	282	282	282	282	282
net cash flow to investment			-40	-33	-33	-33	-33	-33	-33	-33	-33	-33	-13

internal rate of return (IRR) #DIV/0!

net present value (NPV) -222 Rs'000 (assumed rate = 12.00%)

CONCLUDING COMMENTS AND RECOMMENDATIONS

The opportunities to increase catches are negligible. Any increase in fishing effort would merely reduce catch rates, and hence remunerations unless offset by increased product prices. The trend to increase the numbers of nets per boat and the landing of under-sized lobster are symptomatic of the fishermen seeking to offset declining catch rates. Notwithstanding, the lobster stocks have shown resilience, with annual catches thought to have remained steady at somewhere between 90 and 130 tonnes for the last decade. This resilience is aided by the lobster becoming sexually mature at a young age, and from having two spawning periods in each year. The finding that the population fecundity might be some 38 % of the pre-fishery values is nevertheless worrying. Increased fishing effort, especially if small lobsters continue to be targeted, would further decrease the population fecundity.

It is crucially important that the exploitation of small lobster be stopped. The management measures adopted so far have included minimum sizes and closure of the fishery during months when small lobsters are abundant. Fishing is now prohibited in each of February, September, and October. The 'best choice' minimum size for *P. homarus* (and the other species apart from *P. ornatus*) at least in the short-term is 6 cm carapace length, as presently legislated but not enforced. This is not in the sense of achieving an increase in yields, as these would be little different from no effective minimum size. The virtue is increasing the mean size and hence value of the lobsters caught, and to reduce the risk of future recruitment failure, by increasing the population fecundity.

Having in mind the practical difficulties being experienced with enforcing any size limit, it seems necessary to increase the duration of the monthly closures, as a means of avoiding the capture of small lobster. The months when the recruitment of young lobsters into the fishery is most prevalent are September, October, November, December and January. Closing all these months, along with the present closure of February, is likely to be resisted by boat owners and fishermen. Many would likely have difficulty in meeting financial commitments for such a long period. A compromise might be to close the fishery during September and October, and from mid-December to the end of February, a total period of 4.5 months. This is 1.5 months more than at present, and would be compensated by greatly improved CPUEs and catch values during the open months.

A shortcoming at present is that the fishery makes no contribution to its costs of research and management. Furthermore, there is no credible collection and compilation of catch and fishing effort statistics, as essential to research and proper management. Assessments of the performance of the fishery as undertaken here are also associated with costs. There would be costs in order to conduct a continuation of the fishery-independent diving surveys, if these are to continue into the future. These types of costs are 'attributable' in the sense that they would not exist in the absence of the fishery. The direct beneficiaries of the fishery would normally be expected to contribute in part or fully to meeting 'attributable' costs.

The failure to have catch and fishing effort statistics for the fishery is an old problem. Fisheries officers in the districts, who have responsibility for the collection of catch data, appear insufficiently motivated. The work is not given sufficient priority, and the officers are seriously hampered by lack of adequate transport to get to landing and lobster collection sites. The provision of additional vehicles is not imminent. A new approach is required.

It is proposed here that lobster export companies be enlisted to arrange the collection of these data, as a contribution to co-management of the fishery. There are two major exporters and a few others who purchase lobster along the south coast, and relatively few places where the lobster are bought either directly from fishermen or intermediaries. Receipts are provided upon purchase that identifies the supplier, the number and weight by species and size grade, and the moneys paid in respect of each purchase. In the case of purchases from intermediaries, it would be helpful if the receipt docket books also identified how many fishermen had contributed to each quantity of lobster being sold. Already at some of these centres the information on the dockets is compiled onto daily log sheets. It would be relatively inexpensive for this practice to be established at all purchasing centres.

Recommendations

The recommendations that follow are principally aimed at the South Coast Lobster Fishery Management Committees. These are newly formed entities under the umbrella of an 'Interim Committee'. The latter has broad responsibilities for management of the South Coast Fisheries Management Area, established under the *Fisheries and Aquatic Resources Act of 1996*.

Governance:

As the initial priority task the Lobster Fishery Management Committees must formulate the management objectives for the fishery, as would be incorporated in a management plan. These need not be long-term objectives, but rather the objectives to be achieved within the life of the management plan. This might be for a period of three years from the commencement of the plan. In association it is proposed that each 'fishery management' year commence at the first opening of the fishery following the September and October closure.

> Recommendation 1: Management objectives to be formulated by the South Coast Lobster Fishery Management Committees.
>
> Recommendation 2: The initial management plan for the fishery to be for a 3-year period.
>
> Recommendation 3: The management year for the fishery commence immediately following the September and October closure.

In association with the formulation of management objectives, the Management Committees should decide on the performance indicators, target and trigger reference points, in order to monitor the future performance of the fishery. Having in mind the need to reduce (and hopefully eliminate) the incidence of undersize lobster in the landings, the important performance indicator relevant to the well-being of the lobster stock would be the percentage of undersize. The target reference point would be for the percentage of undersize to be reduced. If fishery-independent diving surveys are to be continued into the future, lobster density could be another useful performance indicator. Annual remunerations to owners and crews, as determined from cash flow analysis, could be the indicator of economic performance, being directly relevant to the well-being of the fishery participants.

Recommendation 4: Performance indicators and reference points relevant to the initial management plan to be decided by the South Coast Lobster Fishery Management Committees.

Recommendation 5: Choose percentage of undersize lobster in the landings, and lobster density from fishery-independent diving surveys as the performance indicators relevant to the well being of the lobster stock.

Recommendation 6: Choose annual remunerations to owners and crews determined from cash flow analysis, as the performance indicator relevant to the well being of the fishery participants.

The process of monitoring fishery performance should be clearly identified within the management plan. It is proposed here that NARA be assigned responsibility for an annual assessment report, to be prepared during September in each year. At least in the first few years this should follow the methodology utilised in this report, and include the findings from updated catch and effort statistics, stock assessment, cash flow analyses, and all related issues. This assessment report and any other relevant documentation should be available to the Management Committees by early October. The Committees would presumably meet shortly after to decide details of the management regime to apply in the coming year.

Recommendation 7: An annual assessment report to be prepared by NARA and lodged with the South Coast Lobster Fishery Management Committees in early October.

Recommendation 8: The South Coast Lobster Fishery Management Committees to meet during October to decide the management regime for the coming fishery year.

It would be important for the South Coast Lobster Fishery Management Committees to consider the co-funding of the research and management needs of the fishery. As indicated earlier, it seems highly reasonable that the fishery contribute either in part or fully to its ‘attributable’ costs. The approach recommended here is for the relevant lobster exporting companies to lodge funds into a joint trust account, to be to be managed at their discretion for the purpose of co-funding research and management.

Recommendation 9: The South Coast Lobster Fishery Management Committees consider how to achieve the co-funding of research and management in this fishery.

Recommendation 10: The exporting companies engaged in purchasing south coast lobster establish a joint account to be utilised for funding at least part of the fishery research and management costs.

Recommendation 11: As an initial contribution, funds to be made available from the account as necessary to enable full enumeration and collation of the lobster landings statistics, based on the purchase receipts issued at the lobster collection centres within the south coast. Any persons employed for this task would be responsible directly to the exporters.

The quality of the assessment advice to the South Coast Lobster Fishery Management Committees will be dependent on the continuation and strengthening of the data collection systems presently in place. The total enumeration of catches and fishing efforts by local persons at the purchasing sites as recommended above would be a great contribution. In respect to length frequencies and other data NARA must continue the sampling of landings, and the interviewing of boat owners and crew. The collection of product prices and costs data relevant to cash flow analysis must continue. The continuation of the 'fishery-independent' surveys is problematical, in the absence of a future funding source.

> Recommendation 12: NARA staff to take responsibility for the monthly collation and tabulation of the catch and fishing effort data, utilising the enumeration records to be made available from the exporting companies.

> Recommendation 13: During monthly field trips within the south coast, NARA staff to sample landings and collect length frequency data, and in the process interview fishermen for information on fishing costs.

> Recommendation 14: The South Coast Lobster Fishery Management Committees to consider whether the 'fishery independent' diving surveys are to continue, and how these might be financed.

Lobster Stock:

The fishery is presently characterised by high exploitation levels, large numbers of undersize lobster being landed, and seemingly poor remunerations to the fishermen. It is nevertheless a very important fishery, generating substantial export earnings and employing many people. There is little or no possibility to increase annual catches or provide additional employment opportunities within the fishery. The immediate task for managers is to substantially reduce or eliminate the landing of undersize lobster. In doing this it will be necessary to have consideration to the financial needs of the fishermen. The proposal here is to do this by further extending the periods when the fishery is closed, for an additional 1.5 months. This would be expected to be offset by a substantial increase in the CPUEs and the value of the catches during the periods when fishing is permitted.

> Recommendation 15: The South Coast Lobster Fishery Management Committees agree to an extension of the fishery closures to include September, October, the second half of December, January, and February; a total of 4.5 months.

> Recommendation 16: The South Coast Lobster Fishery Management Committees commit to achieving full compliance by the fishermen to the present legal minimum sizes.

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Appendix I

Yield Assessment Worksheet.

Inputs:		
Observed fishing effort (st. boat days)		120,000
Fishing effort Multiplier		1
Annual fishing effort (st. boat days)	X =	120,000
P. homarus (male)		
No. of zero length recruits	R =	30,426,552,697
Natural mortality at age constants	A =	0.5343
(when age in years)	B =	0.9771
Catchability coefficient	q =	0.00001118
Asymptotic carapace length (cm)	L_{α} =	13.39
Curvature coefficient (/yr)	K =	0.51
Carapace length/whole weight constant	a =	0.00150
(when l in cm. and w in kg.)	b =	2.709
P. homarus (female)		
No. of zero length recruits	R =	30,426,552,697
Natural mortality at age constants	A =	0.5343
(when age in years)	B =	0.9771
Catchability coefficient (trammel net)	q =	0.00001118
Asymptotic carapace length (cm)	L_{α} =	13.00
Curvature coefficient (/yr)	K =	0.48
Carapace length/whole weight constant	a =	0.00220
(when l in cm. and w in kg.)	b =	2.539
Individual fecundity at length constants	u =	2.228
(when l in cm.)	v =	2.348

Outputs:		***P. homarus***	**All species**
Catch weight (tonnes)	Cw =	95	110
CPUE (kg/st. boat day)	Cw/X =	0.79	0.92
Catch number ('000)	Cn =	323	375
Av. individ. weight (gm)	w =	293	293
Population fecundity ('000,000,000)	PF =	73	85

Equations:

$t1' = -(1/K).LN(1-L1/L_{\alpha})$

$t' = (t2-t1)/LN(t2/t1)$

$F' = (t2-t1).O'.q.X$

$M' = (t2-t1).(A+(B/(t2-t1)).LN(t2/t1))$

$N2' = N1'.exp(-(F'+M'))$

$N' = (N2-N1)/(F'+M')$

$Cn' = F'.N'$

$Dn' = M'.N'$

$w' = (1/(LT2'-LT1')).(a/(b+1)).(LT2'\wedge(b+1)-LT1'\wedge(b+1))$

$Cw' = Cn'.w'$

$Cw = sum(Cw')$

$Cn = sum(Cn')$

$w = Cw/Cn$

$PF' = N'.(u.((L1'+L2')/2)\wedge v)$

$PF = sum(PF')$

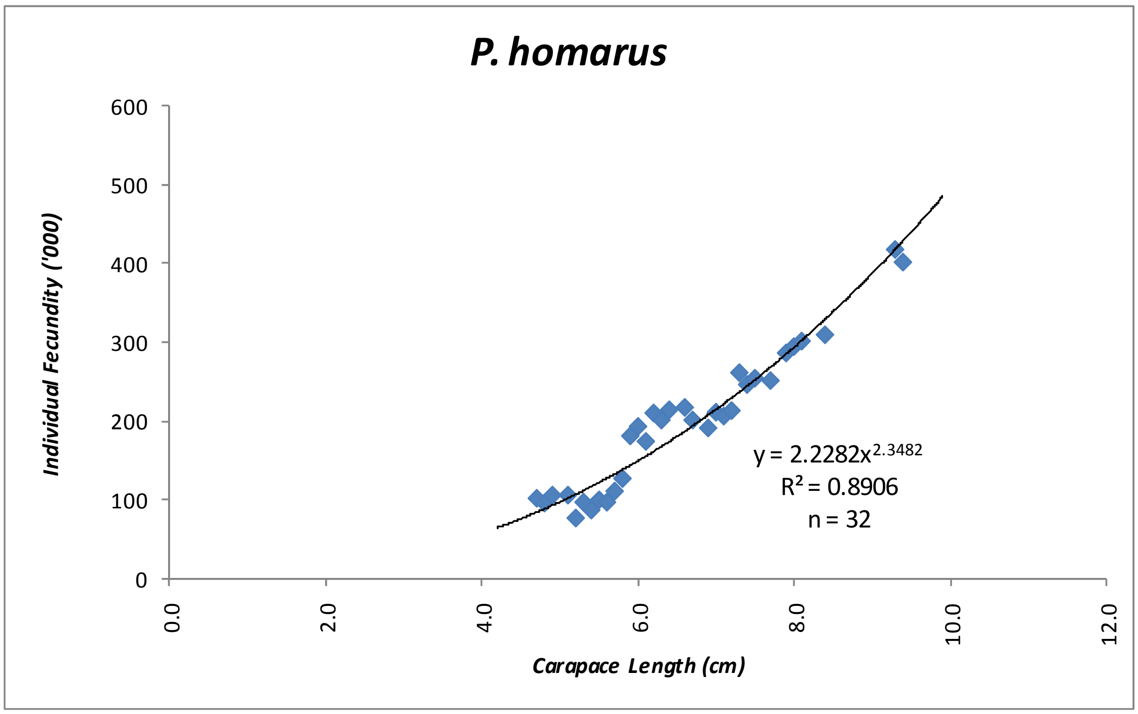
Male *(P. homarus)*:

Carapace Length Interval (cm) L1'	L2'	Start Age (yr) t1, t2	Mean Age (yr) t'	Probability of Capture Ogive O'	Fishing Mortality Coef. F'	Natural Mortality Coef. M'	Population Number Start N1'	Population Number End N2'	Population Number Mean N'	Catch Number C'	Natural Death Number D'	Av. Indiv. Whole Weight (kg) w'	Catch Weight (tonnes) Cw'
0.0	0.5	0.000	0.009	0.00	0.0000	8.3805	30,426,552,697	6,976,378	3,629,786,675	0	30,419,576,319	0.000	0.0
0.5	1.0	0.075	0.109	0.00	0.0000	0.7379	6,976,378	3,335,648	4,934,155	0	3,640,730	0.001	0.0
1.0	1.5	0.152	0.190	0.00	0.0000	0.4591	3,335,648	2,107,683	2,674,852	0	1,227,965	0.003	0.0
1.5	2.0	0.233	0.273	0.00	0.0000	0.3466	2,107,683	1,490,346	1,781,220	0	617,337	0.007	0.0
2.0	2.5	0.317	0.359	0.00	0.0000	0.2863	1,490,346	1,119,299	1,295,982	0	371,047	0.014	0.0
2.5	3.0	0.405	0.450	0.00	0.0000	0.2495	1,119,299	872,185	990,610	0	247,113	0.023	0.0
3.0	3.5	0.497	0.544	0.00	0.0000	0.2253	872,185	696,276	780,931	0	175,910	0.037	0.0
3.5	4.0	0.594	0.644	0.00	0.0000	0.2088	696,276	565,085	628,400	0	131,191	0.054	0.0
4.0	4.5	0.696	0.748	0.00	0.0000	0.1974	565,085	463,842	512,799	0	101,243	0.076	0.0
4.5	5.0	0.803	0.859	0.10	0.0152	0.1898	463,842	377,860	419,383	6,385	79,598	0.102	0.7
5.0	5.5	0.917	0.975	0.40	0.0646	0.1850	377,860	294,378	334,384	21,614	61,868	0.134	2.9
5.5	6.0	1.037	1.100	0.50	0.0861	0.1826	294,378	225,018	258,147	22,223	47,137	0.172	3.8
6.0	6.5	1.165	1.233	0.70	0.1290	0.1822	225,018	164,839	193,370	24,939	35,241	0.215	5.4
6.5	7.0	1.303	1.375	1.00	0.1981	0.1838	164,839	112,505	137,010	27,145	25,189	0.265	7.2
7.0	7.5	1.450	1.529	1.00	0.2143	0.1874	112,505	75,286	92,653	19,853	17,366	0.321	6.4
7.5	8.0	1.610	1.696	1.00	0.2333	0.1931	75,286	49,150	61,292	14,299	11,838	0.385	5.5
8.0	8.5	1.784	1.878	1.00	0.2560	0.2013	49,150	31,112	39,446	10,099	7,939	0.456	4.6
8.5	9.0	1.975	2.079	1.00	0.2836	0.2124	31,112	18,946	24,528	6,957	5,209	0.535	3.7
9.0	9.5	2.186	2.303	1.00	0.3180	0.2272	18,946	10,984	14,605	4,644	3,319	0.622	2.9
9.5	10.0	2.423	2.556	1.00	0.3618	0.2472	10,984	5,974	8,226	2,976	2,033	0.717	2.1
10.0	10.5	2.693	2.846	1.00	0.4196	0.2745	5,974	2,985	4,308	1,807	1,182	0.821	1.5
10.5	11.0	3.006	3.188	1.00	0.4994	0.3130	2,985	1,324	2,043	1,020	640	0.934	1.0
11.0	11.5	3.378	3.603	1.00	0.6170	0.3705	1,324	493	842	519	312	1.056	0.5
11.5	12.0	3.838	4.132	1.00	0.8076	0.4640	493	138	279	225	130	1.188	0.3
12.0	12.5	4.440	5.652	1.00	3.5227	1.8571	138	1	26	90	48	1.330	0.1
sums		7.066								164,795			49

Female (*P. homarus*):

Carapace Length Interval (cm)		Start Age (yr)	Mean Age (yr)	Probability of Capture Ogive	Fishing Mortality Coef.	Mortality Coef.	Population Number Start	End	Mean	Catch Number	Natural Death Number	Av. Indiv. Whole Weight (kg)	Catch Weight (tonnes)	Population Fecundity (10^{-9})
L1'	L2'	t1, t2	t'	O'	F'	M'	N1'	N2'	N'	Ct'	D'	w'	Cw'	PF'
0.0	0.5	0.000	0.010	0.00	0.0000	8.3849	30,426,552,697	6,946,081	3,627,906,203	0	30,419,606,616	0.000	0.0	
0.5	1.0	0.082	0.119	0.00	0.0000	0.7425	6,946,081	3,305,931	4,902,826	0	3,640,150	0.001	0.0	
1.0	1.5	0.167	0.208	0.00	0.0000	0.4640	3,305,931	2,078,658	2,645,010	0	1,227,273	0.004	0.0	
1.5	2.0	0.255	0.299	0.00	0.0000	0.3517	2,078,658	1,462,327	1,752,466	0	616,331	0.009	0.0	
2.0	2.5	0.348	0.394	0.00	0.0000	0.2918	1,462,327	1,092,231	1,268,292	0	370,096	0.017	0.0	
2.5	3.0	0.445	0.494	0.00	0.0000	0.2553	1,092,231	846,095	963,931	0	246,136	0.029	0.0	
3.0	3.5	0.547	0.598	0.00	0.0000	0.2316	846,095	671,202	755,277	0	174,893	0.044	0.0	
3.5	4.0	0.653	0.708	0.00	0.0000	0.2156	671,202	541,048	603,789	0	130,154	0.063	0.0	
4.0	4.5	0.766	0.824	0.00	0.0000	0.2048	541,048	440,859	489,245	0	100,189	0.087	0.0	
4.5	5.0	0.885	0.947	0.10	0.0169	0.1978	440,859	355,665	396,739	6,721	78,473	0.115	0.8	
5.0	5.5	1.011	1.077	0.40	0.0721	0.1938	355,665	272,620	312,305	22,529	60,516	0.148	3.3	34
5.5	6.0	1.146	1.216	0.50	0.0964	0.1922	272,620	204,271	236,804	22,826	45,523	0.187	4.3	
6.0	6.5	1.290	1.365	0.70	0.1450	0.1930	204,271	145,698	173,338	25,126	33,447	0.231	5.8	
6.5	7.0	1.444	1.526	1.00	0.2237	0.1959	145,698	95,777	118,997	26,615	23,306	0.281	7.5	23
7.0	7.5	1.611	1.700	1.00	0.2431	0.2010	95,777	61,428	77,335	18,802	15,547	0.337	6.3	
7.5	8.0	1.792	1.889	1.00	0.2663	0.2087	61,428	38,199	48,898	13,022	10,207	0.399	5.2	
8.0	8.5	1.990	2.098	1.00	0.2944	0.2194	38,199	22,851	29,871	8,794	6,555	0.467	4.1	9
8.5	9.0	2.210	2.330	1.00	0.3291	0.2339	22,851	13,013	17,473	5,750	4,087	0.542	3.1	
9.0	9.5	2.455	2.592	1.00	0.3731	0.2534	13,013	6,955	9,670	3,608	2,451	0.625	2.3	4
9.5	10.0	2.733	2.891	1.00	0.4307	0.2800	6,955	3,417	4,978	2,144	1,394	0.714	1.5	
10.0	10.5	3.054	3.240	1.00	0.5093	0.3174	3,417	1,495	2,325	1,184	738	0.811	1.0	1
10.5	11.0	3.434	3.661	1.00	0.6233	0.3723	1,495	552	947	590	352	0.915	0.5	1
11.0	11.5	3.899	4.191	1.00	0.8035	0.4597	552	156	314	252	144	1.027	0.3	0
11.5	12.0	4.498	4.907	1.00	1.1321	0.6190	156	27	74	83	46	1.146	0.1	0
12.0	12.1	5.342	8.335	1.00	9.3077	4.5206	27	0	2	18	9	1.222	0.0	0
sums		12.280								158,064			46	73

Individual Fecundity at Length.



Note: Data from Jayakody (1991).

Appendix III

Lobster Prices.

P. homarus		
100-200 gm	1,500	Rs/kg
200-500 gm	2,150	Rs/kg
>500 gm	2,500	Rs/kg
P. versicolor & P. longipes		
100-200 gm	800	Rs/kg
200-300 gm	1,100	Rs/kg
300-500 gm	1,300	Rs/kg
>500 gm	2,000	Rs/kg
P. penicillatus		
100-200 gm	700	Rs/kg
200-300 gm	900	Rs/kg
>300 gm	1,200	Rs/kg
P. ornatus		
100-200 gm	1,100	Rs/kg
200-500 gm	1,900	Rs/kg
500-900 gm	3,300	Rs/kg
00-2,000 gm	4,400	Rs/kg
>2,000 gm	4,200	Rs/kg

Note: Fishermen are paid less when selling through an intermediary.