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ST LUCIA PENAEID PRAWNS. BIOLOGY AND MANAGEMENT OF PRAWN STOCKS AT ST LUCIA AND RICHARDS BAY.

Final Report

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Participation : P.J. Fielding
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INTRODUCTION

Natal supports the only commercially viable population of penaeid prawns in South Africa. Post-larval penaeids enter estuarine systems, grow to approximately 22 mm carapace length (C.L.), and emigrate to sea to mature and spawn (Champion, 1988; Benfield, et al., 1990). St Lucia (Figure 1) and Richards Bay (Figure 2) are two of the largest estuaries on the Natal coast, and together comprise about 80% of the estuarine area of Natal. They therefore provide important nursery areas for juvenile penaeids, which are exploited for bait purposes in both areas. The Natal Parks Board (N.P.B.) bait fisheries at St Lucia and Richards Bay form an integral part of the recreational infrastructure and the value of the prawn catch approaches half a million rand. Adult penaeids are caught for human consumption offshore on the Tugela and St Lucia banks and the catch value is in excess of R3 million. At present levels of exploitation neither the estuarine nor the offshore fisheries are able to meet demand, and fishing effort is likely to increase in the future. Although the nature of and interaction between the estuarine and offshore prawn fisheries in Natal is at present unknown, fears have been expressed by the offshore commercial enterprise that over-exploitation by the estuarine fisheries may lead to reduced catches offshore (see also Gunter, 1956). There have been conflicts in other parts of the world between these two types of fishery (Rothschild & Gulland, 1982). Published information on the penaeid prawns of Natal is minimal and it was considered important to gain some insight into the population dynamics of the estuarine prawn fishery. Recommendations could then be made regarding their management, and an estimate could be made of the effect this fishery may have on catches of adults that recruit to the offshore commercial fishing ground from the Richards Bay and St Lucia nursery areas.

KEY QUESTIONS

1. How has the estuarine prawn catch varied over the years?
2. What is the CPUE of the fisheries?
3. What is the extent of recruitment of prawns into the systems?
4. What is the prawn mortality from sources other than fishing?
5. What is the growth rate of prawns in the estuaries?
6. What is the sustainable yield of the estuarine prawn fisheries and the offshore fishery?

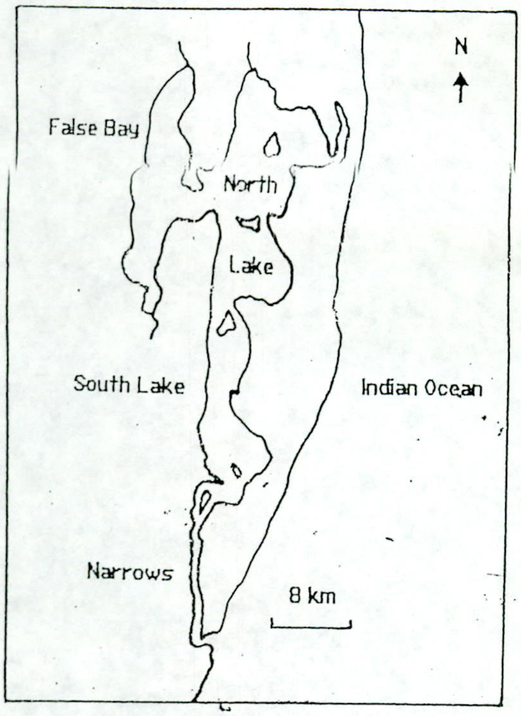

Figure 1. The St Lucia lake system on the north coast of Natal

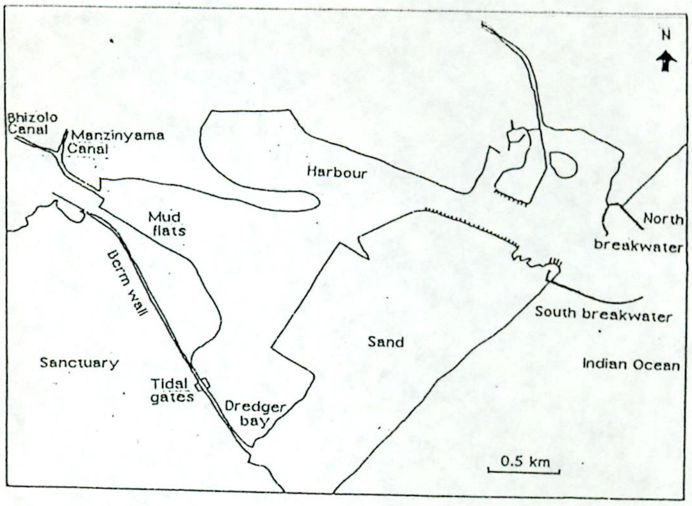

Figure 2. The Richards Bay harbour and part of the sanctuary area on the north coast of Natal.

METHODS

Catch records for the bait fisheries at St Lucia and Richards Bay were made available by the NPB, as were data from a previous St Lucia prawn sampling program (F. Joubert, 1969 - 1977) and from a current seine netting program. Weekly prawn samples supplied by the St Lucia and Richards Bay bait fisheries between 1987 and 1988 were used to determine size, composition and sex ratios of the catch.

An attempt to estimate natural mortality in estuarine penaeids was abandoned because of destruction of the enclosure netting by the portunid crab <u>Scylla serrata</u>. Mortalities were estimated from fisheries data and two tagging experiments (winter & summer) at Richards Bay. Tagging was only attempted at Richards Bay because it was felt that the St Lucia fishery operated over too large an area in relation to the number of prawns that could be tagged using home-made tags.

Prawn biomass at St Lucia was estimated by the "swept area" method from five lake-wide surveys. Two five minute trawls were made in opposite directions at each of 20 stations using a 1 m beam trawl described by Benfield <u>et al</u>., (1990). Distance covered by an average trawl was measured and trawl efficiency computed from five trawls through an enclosure containing a known number of prawns.

Growth rates of P. indicus at Richards Bay and St Lucia were obtained from tagging experiments and cage experiments. Growth over 8-10 weeks was measured fortnightly on animals caged individually in 1 m^2 cages during spring/early summer, late summer/autumn and winter at St Lucia. At Richards Bay growth was estimated from tag returns of P. indicus tagged in winter, spring/summer and late summer. Since age-length data for crustaceans in natural conditions are rarely available, growth equations were derived from the equation of Parrack (Chien & Condrey, 1988) as modified by Punt (1989), where

$$S_r = S_b - (S_b - S_m)^{-kdt}$$

S_m = size at mark
S_r = size at recapture
S_b = asymptotic size
dt = time between mark and recapture
k = Brody's growth coefficient

S_b and k were estimated using non-linear regression. It was not possible to statistically test the relative and absolute error growth models for homoscedasticity and randomness of residuals, so the error model with the smallest standard error was selected. Variance and 95% confidence interval estimation was performed using the conditioned parametric bootstrap procedure (Punt & Hughes, 1989). Yield per recruit analysis was performed using PC-Vonbert (Punt, 1989).

1. Species Composition

The species composition of the bait fisheries at St Lucia and Richards Bay is shown in Table 1. Natal Parks Board records of ± 1 kg monthly samples from 1969 - 1977 were examined together with monthly sample data collected by Dr A.T. Forbes from 1984 - 1987 and weekly samples between 1987 and 1988. These data were compared with the results of Joubert & Davies (1966) which covered a three year sampling period (1964 - 1966). It is evident that P. indicus is the major contributor to the fishery and that the species composition has remained relatively constant over the last 23 years. At Richards Bay the sampling period is relatively short and it appears that P. indicus makes up a slightly greater proportion of the catch (Table 1). On a weight basis catch composition is similar to that described by sample numbers. However, Penaeus monodon, because of their large size, make a slightly greater contribution, while Metapenaeus monoceros become less important, indicating a preponderance of small M. monoceros in the St Lucia and Richards Bay systems. This may be because they emigrate more quickly from the estuaries than P. indicus. Other data (Forbes pers comm.) suggest that this is the case.

Table 1. Species composition of the St Lucia and Richards Bay bait fisheries. Bait fishery samples were collected on a monthly basis from 1984 - 1986 and on a weekly basis from 1987 - 1988. N.P.B. samples were collected monthly.

	Percentage (numbers) of catch				
St Lucia	Pi	Mm	Pm	OP	M
Bait fishery samples 1984-1988	75	19	3	0,1	2,9
NPB samples 1969-1977	78	19	2	0,3	0,7
Joubert & Davies (1966)	84	11	5	-	-
Mean	79,0	16,0	3,0	0,2	1,8
SD	(±4,6)	(±4,6)	(±1,5)		
Richards Bay					
Bait fishery samples 1986-1988	86	10	3,7	0	0,3
	Percentage (weight) of catch				
	Pi	Mm	Pm	OP	M
St Lucia					
Bait fishery samples 1987-1988	82	9	7	0,1	1,9
Richards Bay					
Bait fishery samples 1987-1988	85	5,6	9	0	0,4

Pi = *P. indicus* Mm = *Metapenaeus monoceros* Pm = *P. monodon*
OP = Other penaeids M = *Macrobrachium*

2. Sex ratios

Sex ratios of St Lucia and Richards Bay *P. indicus* are shown in Table 2, together with significant differences in the ratio of males to females. It is not clear why there are more females than males at Richards Bay, while at St Lucia, number of males and females are equal. On a weight basis females comprise a significantly greater proportion of the catch at both Richards Bay and St Lucia, indicating that females grow larger than males.

Tables 2. Sex ratios of <u>P. indicus</u> at St Lucia and Richards Bay. Bait fishery samples (± 1 kg) were collected on a monthly basis from 1984 - 1986 and on a weekly basis from 1987 - 1988. N.P.B. samples (1-1,5 kg) were collected monthly.

	Males	Females	p
<u>Number of males to females</u>.			
Joubert and Davies (1966)	0.49	0.51	>0.05
NPB Samples 1969 - 1977	0.48	0.52	>0.05
St Lucia Bait Fishery 1984 - 1988	0.49	0.51	>0.05
Richards Bay Bait Fish 1986 - 1988	0.46	0.54	<0.05
<u>Weight of males to females</u>.			
St Lucia Bait Fishery 1987 - 1988	0.44	0.56	<0.01
Richards Bay Bait Fish. 1987 - 1988	0.44	0.56	<0.01

3. Fishing effort

The annual fishing effort measured as the number of boat days at St Lucia has declined since the 1960's although there are fluctuations from year to year (Figure 3). At Richards Bay fishing effort (number of boat days) has remained relatively constant since 1973 (Figure 3). Annual effort was considerably greater in the St Lucia fishery which generally operates 2-3 boats, compared with the Richards Bay fishery (1-2 boats).

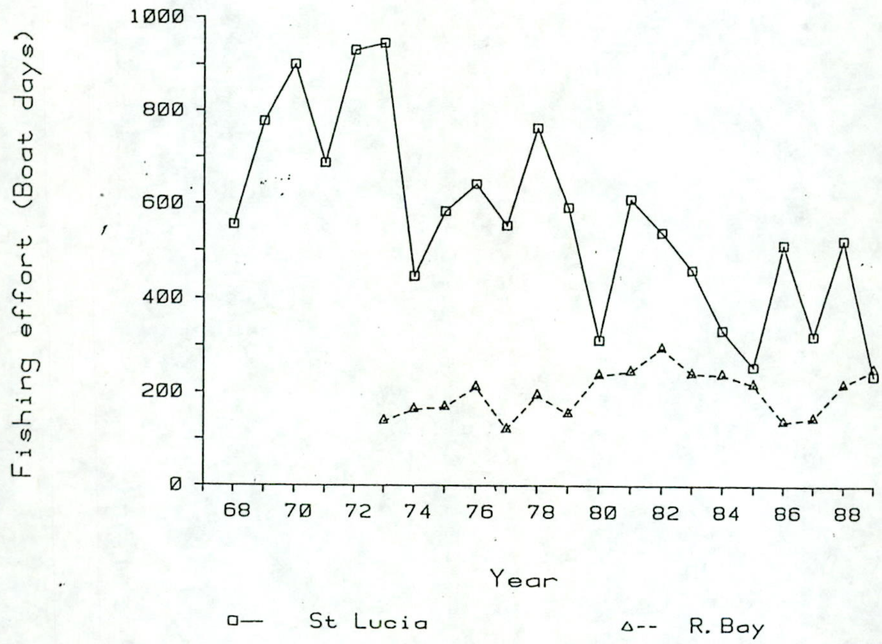

Figure 3. Annual fishing effort in the St Lucia and Richards Bay estuarine prawn fisheries.

There were reservations regarding existing measurements of effort in the bait fisheries because of a system of bonuses incorporated into the remuneration awarded the NPB prawn fishermen. Between September 1987 and March 1988 observation of the bait crews at St Lucia (4 days.month^{-1} for four months) showed a remarkably consistent fishing pattern. Boats left for the trawling grounds at 04h00 and returned promptly at 11h00, after which weighing and packaging of the catch ensued. A bonus of a day's pay is awarded to the crews when the day's catch exceeds 500 cartons. Each carton contains 200-250 g prawns. Approximately 110 kg of prawns must be caught to achieve a bonus. Catch records show that from September 1987 to February 1988 inclusive, bonus catches were made on 8 days only - an average of less than twice a month. The effect of these bonuses on effort is difficult to quantify. Catch records show that for approximately two months of the year (late summer and autumn) bonus catches may be achieved 10-15 times a month. For the rest of the year they are very seldom attained (< twice a month). Initially it was proposed that discrete observation of the bait fishermen be maintained from the shore for a number of days every month to standardise effort. Almost all trawling occurs in the Narrows of the St Lucia system. Because of the tortuous nature of the channel, the dense vegetation on the banks and the distances travelled by the boats when engaged in trawling operations, it is impossible to carry out shore based observations. Aside from actually observing operations while in sight of the boats, the only way of standardising effort is by noting times of departure and return of the boats, and for the 1987-1988 season this has been very consistent. At Richards Bays there are no records of the number of hours fished but since 1986 the prawn boats have fished for approximately five hours per day (N. Wright, pers comm.). For the purpose of this report the boat day has been used as a unit of effort.

4. Total catches

At St Lucia annual catches have ranged between 7 tonnes (1980) and 29 tonnes (1969), while at Richards Bay catches have fluctuated between 3 and 25 tonnes (Figure 4). Catch weight data exist only for St Lucia after 1980. Richards Bay and pre-1980 St Lucia catch weights have been calculated assuming the weight of prawn.carton^{-1} has remained constant in the fisheries. Monthly means of prawn weight.carton^{-1} ranged from 160 - 410 g (Mean = 240 g SD = 8 g) between 1980 and 1989, when data for both catch weight and the number of cartons were available. During 1988/9 20 cartons from the Richards Bay fishery had a mean prawn weight of 246 g (SD = 20 g) in summer and 245 g (SD = 16 g) in winter which was not significantly different from the prawn weight.carton^{-1} at St Lucia. Catch weights were therefore calculated on the basis of 240 g prawn.carton^{-1}.

Mean annual catches for the time period for which data exist (Figure 4) were 16,60 ($\pm$ 5,99) tonnes and 10,56 ($\pm$ 5,77) tonnes at St Lucia and Richards Bay respectively. Total catches at St Lucia showed cyclical fluctuations with peaks occurring every 4-5 years. A similar pattern was shown by the Richards Bay fishery but the period was 6-7 years (Figure 4).

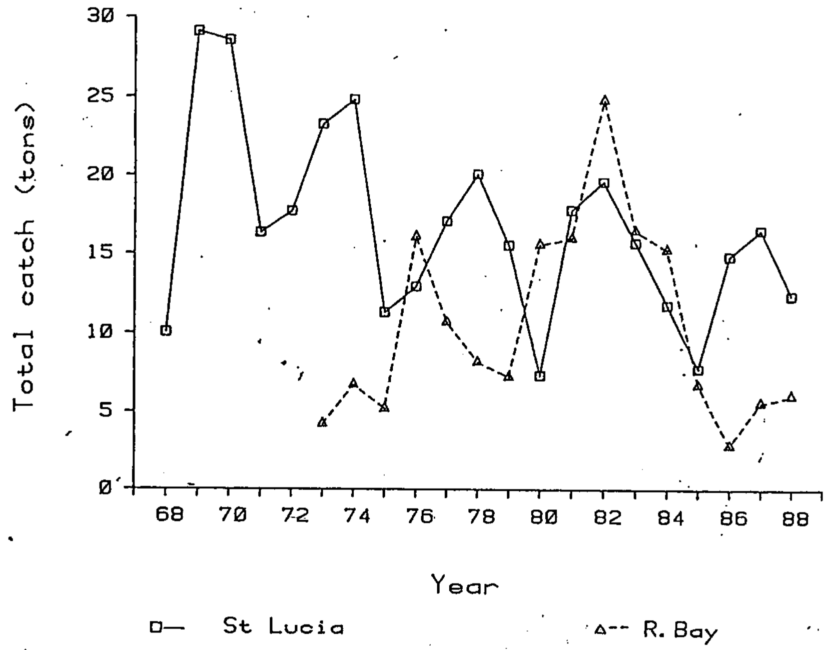

Figure 4. Total catches in the St Lucia and Richards Bay estuarine prawn fisheries.

5. Catch per unit effort

CPUE showed considerable fluctuations in both fisheries over the years, but these were more marked at Richards Bay than at St Lucia (Figure 5). There was no obvious cyclical pattern such as existed for total catches (Figure 4). CPUE at Richards Bay has been very much better than at St Lucia for most of the time for which records are available. Mean annual CPUE for St Lucia from 1968-1989 was 122,77 ($\pm$ 39,40) cartons.boat day^{-1} while the Richards Bay fishery CPUE (1973-1989) was almost twice that of St Lucia (213,27 $\pm$85,10 cartons.boat day^{-1}). Time series analysis showed that CPUE at St Lucia was significantly correlated with the salinity regime of the lake system (Fielding, et al, 1989). This is unlikely to be the case at Richards Bay because prawn netting occurs mainly in the harbour backwaters, where salinities are essentially marine. Lake levels at St Lucia do not affect prawn catches (Fielding, et al, 1989). Although there are sometimes quite large inter-annual fluctuations, CPUE at both Richards Bay and St Lucia does not show a declining trend (Figure 5) indicating that the fisheries are not over exploited.

The very much higher CPUE at Richards Bay compared with St Lucia is of considerable interest. The original Richards Bay estuary has been greatly degraded by the construction of harbour (Begg, 1978). NPB prawn netting has for some time been conducted almost exclusively in the harbour backwaters because siltation of the sanctuary area (Figure 2) has reduced water depth to the extent where boats can rarely operate. The opening of the harbour in 1976 appears to have had no deleterious effect on both CPUE and total catches (Figures 5 and 6), although it should be noted that data were only available for 3 years prior to harbour opening. Most of the prawns are caught in the Bhizolo and Manzinyama canals which are little more than effluent and drainage canals. (Figure 2)

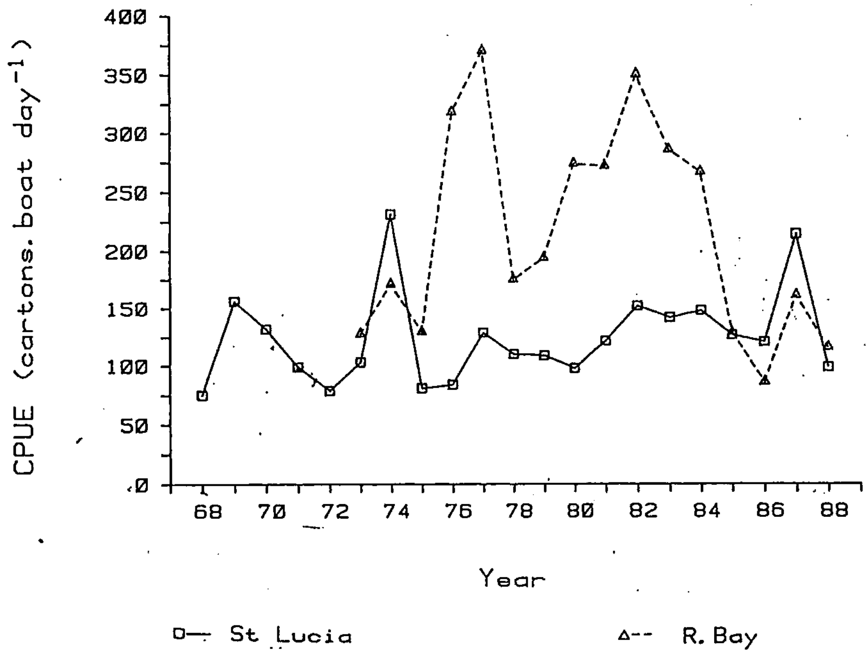

Figure 5. CPUE in the St Lucia and Richards Bay estuarine prawn fisheries.

The area in which netting occurs is ± 0,32 km^2 (Robertson, pers. comm.) so production is 32,8 g.m^{-2}. If the whole harbour area (11 km^2, Robertson, pers. comm.) is considered a suitable prawn habitat (which is unlikely as some of the harbour substrate is sandy and P. indicus prefers muddy substrates), then production is 0,96 g.m^{-2}. St Lucia is a sanctuary and although dredging activities have occurred in the Narrows, the estuary as a whole is relatively nondegraded. Prawns occur throughout the system which has a surface area of approximately 340 km^2 (Hutchison, 1974) of which about 250 km^2 is muddy substrate (Hutchison, 1974; Cyrus, 1983; De Kock, 1985). In spite of the greater effort, this system produces 16,6 tons p.a. - a production of 0,06 g.m^{-2}, which is 16 times less than even a very conservative estimate of Richards Bay production.

A combination of factors may account for differences in the St Lucia and Richards Bay fisheries CPUE. There may be less food available in the St Lucia system. The benthic meio and macro fauna in the St Lucia lakes are subjected to periodic salinity extremes which can result in low biomass (Boltt, 1975; Blaber, et al, 1983; Hay, 1985). However, the benthic fauna in the Richards Bay harbour appeared impoverished immediately after harbour development (Oliff, 1977) and species diversity and numbers were still low in 1985 (Connell, et al., 1985). Trawl data indicated greater quantities of plant detritus in the St Lucia Narrows than in the Richards Bay canals (own data) and the organic content of muddy substrates (<500 m fraction) in the St Lucia Narrows and lake system, and at Richards Bay, are similar (own data). Thus it seems unlikely that food availability accounts for differences in CPUE in the two fisheries.

The origin of prawn post-larvae recruiting to Richards Bay and St Lucia is uncertain. Post larvae may come down in the Agulhas current from Mozambique or may recruit from breeding stocks fished commercially on the Tugela bank, which is south of

Richards Bay. Eggs and larvae from both sources may be retained in the nearshore area of the northern Natal coast by eddy structures arising from the Agulhas current. Larvae spawned on the Tugela bank may be transported northwards by upstream retroflections of the Agulhas current (Wallace & van der Elst, 1974; Schumann, 1987; Lutjeharms & Connell, 1989). The shelf zone is wider at Richards Bay than at St Lucia, and the frequency and strength of the north going current is greater inshore, whereas at St Lucia, the inshore currents have a predominantly south-flowing tendency (Wallace & van der Elst, 1974). Thus prawn post-larvae would have a better chance of recruiting to Richards Bay than to St Lucia.

The volume of water transported in and out of an estuary at each tidal cycle will also play a crucial role in determining post-larval recruitment. The Richards Bay harbour mouth is 750 m wide and much of the central area accessing the main wharfs is dredged to 19 m, while secondary channels are $\pm$ 8 m deep. Other areas are generally about 2 m deep. From data on the depths of different harbour areas, supplied by W. Robertson (pers. comm.), a total harbour volume of 125 x 10^6 m^3 was estimated. Approximately 88% of water volume is exchanged each tidal cycle (Hughes, 1978). Thus 110 x 10^6 m^3 would be exchanged in a tidal cycle. The St Lucia mouth is rarely more than 100 m wide and tidal effects are evident as far as the top of the Narrows. The Narrows are on average 1,5 m deep and have a surface area of 14,6 km^2 (Hutchison, 1974). If the entire volume of the Narrows was exchanged each tidal cycle, water volume exchange would be 22 x 10^6 m^3. In practice water volume exchange is likely to be in the region of 0.59 - 1,23 x 10^6 m^3 per tidal cycle (Forbes unpublished data). Thus if prawn post-larval densities were the same in the nearshore zones of Richards Bay and St Lucia, many more would be washed into Richards Bay Harbour than into the St Lucia estuary over a tidal cycle. This may well account for the greater CPUE at Richards Bay.

6. Biomass

Prawn biomasses at St Lucia estimated from lakewide surveys and a more intense survey in the Narrows are shown in Tables 3 and 4. Beam trawls have a low catch efficiency (Zimmerman et al, 1984). Catch efficiency of the sampling gear was estimated as 23% and biomasses adjusted accordingly.

Table 3: Prawn biomass estimates in $g.m^{-2}$ ($\pm$ SE) from lakewide surveys using the swept area method at St Lucia. Catches were corrected for a beam trawl efficiency of 23%.

	P. indicus				Total Prawn				No of trawls
	Narrows	S.Lake	N.lake	F.Bay	Narrows	S.Lake	N.Lake	F.Bay	
Jan	0,809 (0,083)	0,009 (0,004)	0,300 (0,043)	0,043 (0,017)	1,222 (0,083)	0,043 (0,004)	0,639 (0,083)	0,048 (0,017)	32
Feb	0,539 (0,026)	0,187 (0,022)	0,096 (0,013)	0,300 (0,030)	1,161 (0,065)	0,230 (0,026)	0,096 (0,013)	0,300 (0,030)	40
Jul	0,435 (0,048)	0,001 (0,0004)	0,000	0,022 (0,004)	0,062 (0,074)	0,004 (0,001)	0,000	0,022 (0,004)	40
Aug	0,713 (0,070)	0,000	0,000	0,013 (0,004)	1,222 (0,117)	0,009 (0,004)	0,000	0,013 (0,004)	40
Oct	0,361 (0,030)	0,035 (0,004)	0,043 (0,004)	0,000	0,917 (0,057)	0,035 (0,004)	0,057 (0,009)	0,000	40

Table 4: Prawn biomass estimates in $g.m^{-2}$ ($\pm$ SE) in the St Lucia Narrows using the swept area method. Results are from a more intensive survey conducted independently of the lakewide surveys. Catches were corrected for a beam trawl efficiency of 23%.

	P. indicus	Total Prawn	No of trawls
Nov	0,578 (0,017)	1,222 (0,039)	24
Dec	0,926 (0,126)	1,343 (0,183)	10
Feb	0,622 (0,017)	1,852 (0,061)	17
Mar	0,139 (0,009)	0,761 (0,048)	19
Mean SD	0,566 0,324	1,295 0,448	

Prawns were present throughout the year in the Narrows but very few prawns were caught in the winter months in the lakes (Table 3). This was almost certainly a result of the autumn emigration to the sea of much of the prawn population. Independent estimates of prawn biomass in the Narrows during the summer months (Table 4) agree well with summer biomasses estimated from the lakewide surveys. Prawn biomasses in St Lucia can be compared with biomass in Richards Bay (Table 5) although it should be noted that the swept area method was used infrequently at Richards Bay and the data are for summer in the Bhizolo and Manzinyama canals only.

Table 5: Prawn biomass estimates ($g.m^{-2}$) from the Bhizolo and Manzinyama canals at Richards Bay. Estimates were corrected for a beam trawl efficiency of 23%.

	P. indicus	Total Prawn
Feb	4,970	4,978
Mar	3,178	3,665
Mar	2,152	3,000
Apr	5,074	6,522
Mean	3,844	4,541
SD	1,424	1,555

It is evident that biomass was considerably higher at Richards Bay than at St Lucia, in spite of the relatively degraded nature of the former habitat.

To obtain an estimate of total prawn biomass present in St Lucia, biomasses in Tables 3 and 4 were multiplied by areas available to prawns in the Narrows and lakes. Only areas with muddy substrates were considered suitable prawn habitats (see sediment analyses by Hutchison (1974), Cyrus (1983) and De Kock (1985)). Total biomass at Richards Bay (Table 7) was calculated for the canal area alone and for the canals and adjacent mudflats (data from W. Robertson, pers. comm.) Tables 6 and 7 give estimates of total prawn biomass in the two systems. These values are almost certainly underestimates since the beam trawl did not catch prawns with carapace lengths less than 6-7 mm, and the muddy substrate area available to prawns in the Richards Bay harbour area is greater than the 3,35 km^2 used here, which comprises only the canals and mudflats extending towards the tidal gates and dredger basin. (Figure 2).

Table 6: Prawn biomass estimates (tonnes) for St Lucia. Biomass ($g.m^{-2}$, see Tables 3 and 4) were multiplied by muddy substrate areas suitable for prawns.

Lakewide surveys

	P. indicus					Total Prawn				
	Narrows	S.Lake	N.Lake	F.Bay	T1	Narrows	S.Lake	N.Lake	F.Bay	T1
Jan	12	0,3	47	3		18	2	100	3	
Feb	8	7	15	18		17	8	15	18	
Jul	6	0	0	1		10	0,2	0	1	
Aug	10	0	0	1		18	0,3	0	1	
Oct	5	1	7	0		13	1	9	0	
Mean	8,2	1,7	13,8	4,6	28,3	15,2	2,3	24,8	4,6	46,9
SD	2,9	3,0	19.6	7,6		3,6	3,3	42,5	7,6	

Narrows survey

	P. indicus	Total Prawn
Nov	6	13
Dec	14	20
Feb	9	29
Mar	2	12
Mean	7,8	18,5
SD	5,1	7,9

Table 7: Prawn biomass estimates (tonnes) for the Bhizolo and Manzinyama canals, and for the canal and adjacent mudflats, at Richards Bay. Biomass ($g.m^{-2}$ see Table 5) were multiplied by the substrate area available.

	P. indicus		Total Prawn	
	Canals only	Canals & Mudflats	Canals only	Canals & Mudflats
Feb	1,0	10,7	1,2	12,3
Mar	1,6	16,7	2,0	21,1
Mar	0,7	7,2	1,0	10,1
Apr	1,6	17,0	2,1	21,8
Mean	1,2	12,9	1,6	16,3
SD	0,5	4,8	0,6	6,0

In two tagging experiments, 406 P. indicus were tagged in October and 526 in July in the Bhizolo and Manzinyama canals at Richards Bay. Tag returns from the NPB bait fishery were 41 and 66 in summer and winter respectively. Most recaptures occurred over a period of six weeks after tagging, although in the winter experiment, 3 animals were recaptured three months after release, and one animal tagged in spring/summer was recaptured 427 days later. Adjusted Petersen estimates (Ricker, 1975) of population biomass were made from the number of tag returns, the number of cartons caught by the bait fishery over the six week period after tagging, the average number of P. indicus in a carton (20 cartons) and the average weight of P. indicus individuals caught at this time. Biomass estimates together with 95% confidence limits are shown in Table 8.

Table 8: Estimates of P. indicus and total prawn biomass (tonnes) in the Bhizolo and Manzinyama canals at Richards Bay, from two tagging experiments. Total prawn biomass was calculated assuming P. indicus comprised 86% of the prawn population (see Table 1).

Tag Date	P. indicus biomass	95% C.I.	Total Prawn biomass	95% C.I.
10.10.88	5,37	3,97-7,49	6,24	4,60-8,71
23. 7.89	5,31	4,09-6,87	6,17	4,75-7,99

These biomass estimates lie between those for the canal area alone, and for the whole mudflat area, calculated from the the swept area method (Table 7), and are subject to the usual limitations of such tagging experiments (Ricker, 1975). Tag loss and tagging mortality over a three week period were negligible in the laboratory and tagged and untagged prawns were probably equally vulnerable to predation and fishing. It is likely that most recaptures were reported since NPB are the only fishing concern in the area, a reward was offered for tag returns, and prawns are sorted and packed into fairly small containers thus increasing the chance of tag discovery. Prawn movement with the strong tidal currents in the canals was considerable and the assumption was made that tagged animals rapidly become randomly distributed throughout the population. Recruitment into the fishery is likely to have been negligible in the winter experiment, since most subdults emigrate in the autumn and post-larvae mainly recruit in the later winter/spring. In the spring/summer experiment, recruitment may have resultcd in an overestimate of population size.

7. Growth:

Growth of P. indicus in the size range 13,80 - 26,10 mm CL was monitored in three caging experiments where animals were individually marked. The effect of density on growth is shown in Table 9. Survival in cages where the density was < 3 prawns.m^{-2} was high (80 - 100% over 6 weeks). At greater densities significant losses occurred probably as a result of cannibalism when the animals moult.

Table 9: Growth of P. indicus in 1 m^2 cages at different densities in the St Lucia estuary.

Density no.m^{-2}	Growth rate mm CL.d^{-1}
1	0,171
2	0,113
3	0,111
10	0,076
12	0,031

Estimates of von Bertalanffy growth curves for male and female P. indicus at St Lucia indicated no significant differences in growth rates of the two sexes (F = 0,349, d.of f. = 2,38, P >0,05) although Table 2 indicates that females grow larger and therefore probably slightly faster than males (assuming they stay in the system for the same length of time). Le Reste & Marcille (1976) show that P. indicus growth rates for both sexes are equal until the animals reach a carapace length of 18-20 mm. Thereafter, females grow faster and achieve a greater size than males. In St Lucia P. indicus migrate out of the estuary once they reach a CL of 18 mm, with most migration occuring between 20-25 mm CL (Joubert & Davies, 1966; Benfield, et al, 1990; Champion, unpublished data). Thus male and female prawns are just beginning to diverge in size when they leave the estuary and it is probable that for the estuarine phase, a single growth curve will suffice for both sexes.

The coefficient of variation in the data for winter growth was too large to allow meaningful seasonal comparison of growth rates. The influence of temperature on growth rates of P. indicus is uncertain (Benfield et al., 1990). Growth rates of caged P. indicus at St Lucia and tagged P. indicus at Richards Bay were not significantly different (F = 3,11 d.of f. = 2,81, P >0,05). Data for St Lucia and Richards Bay were therefore combined. Growth of P.indicus in the Richards Bay and St Lucia estuaries is described by the special von Bertalanffy equation.

$$L_t = 35,86\ (1 - e^{-0,164(t-0,24)})$$

where L is carapace length in mm at time t(months).

	L_∞	K
Coefficient of variation	13,47%	27,98%
Upper 95% confidence limit	49,57	0,256
Lower 95% Confidence limit	30,56	0,0823

8. Mortality

Several estimates of mortality were made using different methods. These are shown in Table 10, and briefly described.

1. Assuming recruitment in the winter months is negligible and there is no change in catchability, then the number of prawns caught per hour is proportional to the number available.

Thus $$Z = \text{Ln} \frac{(C/H)\ i-1}{(C/H)\, i}$$ Using 1989 catch data

from Richards Bay when the number of prawns per carton was known, the slope of Ln C/h v. month between May and September was -0,196.

Thus Z(monthly) = 0,20 (se = 0,18)

2. Since fishing effort was similar for the weeks following both tagging experiments, plots of Ln (N^0 of recaptures) against time gave estimates of Z(monthly) = 1,50 (se = 0,71) in summer and 0,42 (se = 0,08) in winter. Fishing mortality (monthly) calculated from:

$$\frac{n_1 .\ \ln (n_1/n_2)}{No\ (1-n_2/n_1)}$$ (Gulland, 1983) was 0,17

in summer and 0,07 in winter

3. Average tag return time t_r was 16,1 days in summer and 33,4 days in winter.

t_r = Z (Butterwoth, et al., 1989). Z (monthly) was thus 1,86 in summer and 0,90 in winter.

$$F = \frac{\text{no. captures}}{\text{no. tagged}} = 0,10\ (CV = 15,82\%)$$
in summer and 0,13 (CV = 21,31%) in winter.

Table 10. Monthly total (Z) and fishing mortality (F) estimates for P. indicus in the St Lucia and Richards Bay estuaries. Figures in parentheses are standard errors.

Z	F	Season	Source
0,20 (0,18)	-	Winter	Ultang et al., 1985
1,50 (0,18)	0,17	Summer	Gulland, 1983
0,42 (0,08)	0,07	Winter	Gulland, 1983
1,86	0,10	Summer	Butterworth et al., 1989
0,90	0,13	Winter	Butterworth et al., 1989

The estimates of Z based on tag return data vary widely and are subject to errors associated with tagging experiments. Unknown tagging mortality, tag loss rates, immigration and emigration all affect estimates of Z. Total mortalities estimated from other prawn fisheries vary widely. Monthly Z for 3 species of North American penaeids were 0,44 to 6,04 (Berry, 1969), while Kutkuhn (1966) estimated monthly Z values of 0,76 for unexploited and 1,39 for fully exploited penaeids in the Gulf of Mexico. Z values for P. indicus in Madagascar ranged between 1,32 and 0,48 (Le Reste & Marcille, 1976) and for P. indicus in Mozambique Ulltang et al. (1985) estimated Z (monthly) as 0,43 - 0,50. Thus values shown in Table 10 lie well within the range for penaeid total mortality estimates.

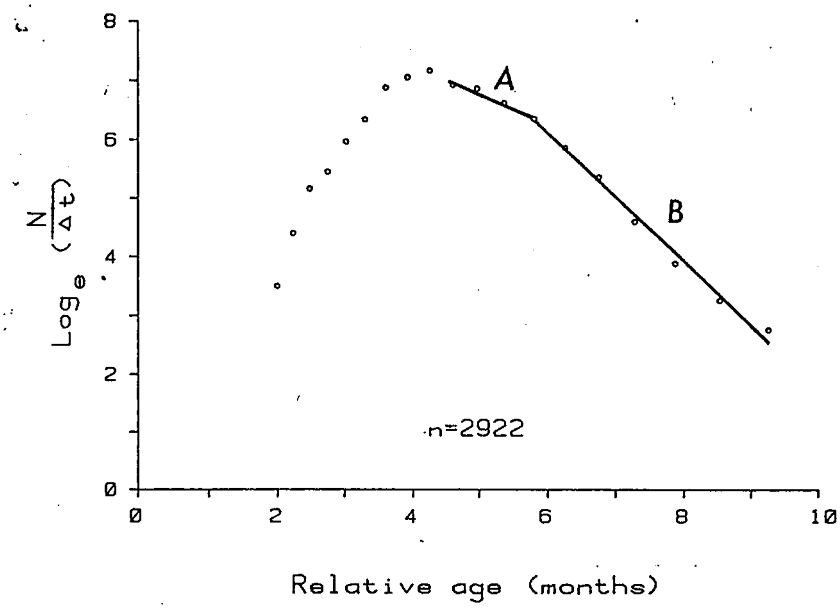

Figure 6. A length-converted catch curve for P. indicus. Data are from St Lucia bait fishery samples collected over 12 months.

In the estuarine phase any prawn mortality estimates are particularly confounded by emigration. This is more of a problem in summer than winter since major emigration from the nursery areas occurs in the summer months. This is evident in Table 10 where summer total mortality estimates are considerably higher than those for winter. Length-converted catch curves (Pauly, 1983) constructed from weekly prawn samples from the St Lucia bait fishery from January 1987 to February 1988 are shown in Figure 6. The slope of the descending limb was plotted in two parts since an increase in slope occurs after a relative age of 5,8 months (CL = 22 mm). This corresponds to the size at which prawns are emigrating rapidly from the estuary (Champion unpublished data; Benfield et al., 1990). Z before emigration size was reached was 0,50 (part A of Figure 6) and once prawns reached a C.L. of 22 mm, Z became 1,08 (part B of Figure 6). The slopes of A and B were significantly different ($p<0,05$, t =

2,365, 7 d. of f.). This allows an estimate of losses from emigration = X if the slope of A = -Z = M+F = 0,50 while the slope of B = -Z = M+F+X = 1,08. Monthly emigration after achieving 22 mm CL would thus be 0,58. Table 11 shows mortalities of P. indicus with losses due to emigration subtracted from summer values and estimates of M = Z-F. Rough estimates of fishing mortality from the relationship:

$$F = \frac{\text{Total annual catch}}{\text{Mean annual biomass}}$$

are also shown for the Richards bay fishery (1988) and the St Lucia (1987). For Richards Bay, mean biomass was calculated from the two tagging experiments (Table 9).

$$\text{F monthly: St Lucia} = \frac{14,6}{46,9} \div 12 = 0,03$$

and

$$\text{F monthly: Richards Bay} = \frac{6,06}{6,20} \div 12 = 0,08$$

Table 11. Estimates of monthly total mortality (Z), fishing mortality (F) and natural mortality (M) for P. indicus at Richards Bay and St Lucia. Summer total mortality estimates have been corrected for instantaneous emigration losses of 0,58 per month.

	Z	F	M=Z-F	Season	Place
	0,20			Winter	Richards Bay
	0,92	0,17	0,75	Summer	Richards Bay
	0,42	0,07	0,35	Winter	Richards bay
	1,28	0,10	1,18	Summer	Richards Bay
	0,90	0,13	0,77	Winter	Richards Bay
	0,50			Winter/Summer	St Lucia
		0,03		Winter/Summer	St Lucia
		0,08		Winter/Summer	Richards Bay
R.Bay Mean	0,74	0,11	0,63		
SD	0,43	0,04			
St Lucia	0,50	0,03	0,47		

Mean of estimates of M = 0,76 SD = 0,34

Values for M (monthly) are roughly the same as those estimated for P. indicus in Madagascar 0,20 - 0,98 (Le Reste & Marcille, 1976) but higher than those for P. indicus stocks in Mozambique (0,23 - 0,30; Ulltang et al., 1985). Fishing mortality at Richards Bay is probably higher than at St Lucia, although the estimate of F for St Lucia is relatively crude.

9. Management

Population parameters neccessary for determining the yield that can be expected from the prawn population are:

1. Growth. The growth of *P. indicus* is described by the equation:
   $L_t = 35{,}86\ (1 - e^{-0{,}164(t - 0{,}24)})$

   where L_t = Carapace length (mm) at t months.

2. Age at first capture. Few prawns <12 mm carapace length (CL) are found in bait fishery samples. Using the growth equation given above, age at first capture was calculated as 2,7 months.

3. Age at 50% maturity. Male *P. indicus* CL for 50% sexual maturity in St Lucia is 24-25 mm (Champion, 1988). Recalculated as age, 50% of male *P. indicus* are sexually mature at 7,2 months. There are no published data on maturity of female *P. indicus* in South African waters but they probably commence breeding when about 7 months old (Emmerson, 1980).

4. Weight to length function. This was calculated for *P. indicus* in Natal by Emmerson (1980).
   $$W = 0.00079L^{2.9813}$$

5. Estimates of natural and fishing mortality.
   To determine whether a fishery is over or under exploited it is useful to look at the fishing mortality at which maximum sustainable yield is obtained (F msy) in relation to current fishing mortality. A ratio of:

   $$\frac{F\ current}{F\ msy} > 1$$ constitutes overexploition while a value of < 1

   constitutes under exploitation. The penaeid Yield per Recruit curve (Y/R) showed a very flat maximum with similar yield values for a wide range of F values. Thus, $F_{0.1}$ (the F value where the slope of the Y/R curve is reduced to 10% of its initial value) is a more useful indicator of exploitation (Hughes, 1986). Table 12 shows ratios of F current (=0,11 monthly, see Table 11) to $F_{0,1}$ for a range of monthly natural mortality values at the estimated K value and the upper and lower 95% confidence limits of this estimate. $F_{current}$ = 0,11 may approach the fishing mortality in Richards Bay but is probably a high estimate for St Lucia (Table 11). M=0,63 is the value estimated in Table 11, M=0,30 is the value estimated for *P. indicus* in Mozambique, while M=0,2 is considered extremely low and M=0,8 is an arbitrarily set high value (Table 12).

Table 12. Ratios of $\frac{F_{current}}{F_{0,1}}$ where $F_{current} = 0,11$ for different values of M (monthly) and K for estuarine <u>P. indicus</u>. K values are for the estimate (0,164) ± 95% confidence limit.

	K values		
M values	0,082	0,164	0,256
0,20	1,12	0,80	0,64
0,30	0,73	0,55	0,43
0,63	0,28	0,22	0,18
0,80	0,19	0,16	0,13

It is clear that using present estimates of fishing mortality, for practically all values of M the prawn population is very underexploited. Only when M is reduced to 0,2 does the fishery approach maximum exploitation. Literature estimates of M for penaeid prawns are invariably higher than 0,2. Fishing mortality could be increased by a factor of almost 3 without significant overexploitation of the stock. Figure 7 is a Y/R response surface for the estuarine penaeid fishery at Richards Bay and St Lucia, given the growth rates estimated in this report. If the K values are varied between the upper and lower 95% confidence limits, the response surface changes very little. Clearly only at low values of natural mortality does fishing mortality have a marked effect on Y/R.

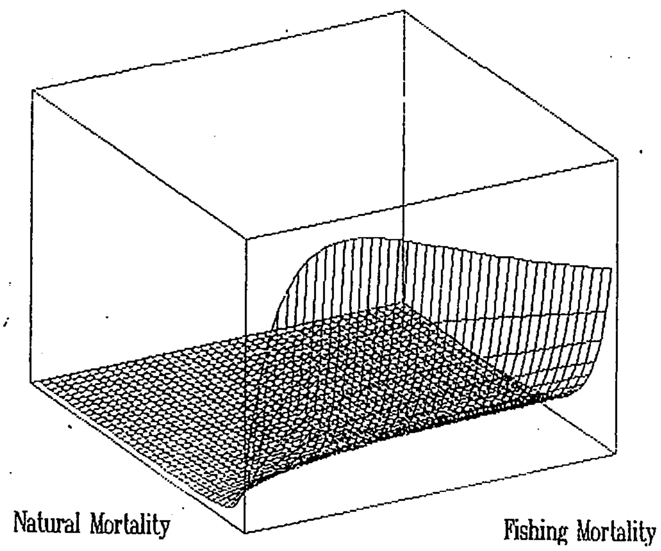

Figure 7. Yield-per-recruit response surface at varying fishing and natural mortality rates for the estuarine penaeid fishery at Richards bay and St Lucia.

In making management decisions based on a Y/R analysis it is important to consider spawning biomass per recruit in relation to F. If spawning biomass per recruit falls to less than half the unfished value then F is too great (Butterworth et al., 1989). There is little point in considering such a relationship for the estuarine penaeids since the animals move offshore to spawn and the spawning biomass is made up of penaeids from several Natal estuaries and probably Mozambique. Of interest to the offshore commercial fishery is the consideration of the percentage of recruits that will survive the estuarine phase of their life cycle and recruit to the offshore fishery. Figure 8 shows the percentage of estuarine recruits surviving at monthly natural mortality rates of 0,30 and 0,63 and fishing mortality values of 0,00, 0,11 and 0,33, given the growth rates estimated in this report. If prawns emigrate from the estuaries when they reach an age of 6 months, at M=0,63 the estuarine fishery has little effect on numbers recruiting to the offshore fishery (Figures 8a and 8b). Thus continuation of the estuarine fishery even at considerably increased fishing mortalities will not greatly affect yield from the Tugela Bank fishery. However, if natural mortality in the Richards Bay and St Lucia estuaries approaches that determined for P. indicus in Mozambique (Ulltang et al., 1985) the estuarine fishery will impact on numbers recruiting offshore, particularly at higher estuarine fishing mortalities (Figure 8c and 8d). A 23 mm CL P. indicus leaving the estuary weighs approximately 9g and this increases to 47 g by the time it is caught offshore at a CL of 40 mm. This is a five fold increase in weight between leaving the estuary and reaching modal size (Emmerson, 1980) offshore. If most of the prawns caught on the Tugela Bank recruit from the St Lucia and Richards Bay estuaries, at lower rates of natural mortality, fishing in the estuaries will considerably reduce offshore yield.

CONCLUSIONS AND RECOMMENDATIONS

Total catches and catch per unit effort of the St Lucia and Richards Bay estuarine prawn fisheries have been described. Measures of effort could not be refined beyond the number of cartons caught per boat day. There was considerable interannual fluctuation in CPUE. Regular weighing of the catch should be instituted at Richards Bay. Recruitment of prawns into the two estuaries was not measured but factors that might affect recruitment were described. Evidence of higher CPUE at Richards Bay compared with St Lucia indicated that prawns recruit more easily to the former estuary. The mouth of the St Lucia estuary should be maintained open and in good condition to assist post-larval recruitment to the estuary. Estimates of natural mortality rates of P. indicus in the estuaries varied widely but ranges were well within those described for other penaeid fisheries. Growth of P. indicus at Richards Bay and St Lucia is slightly slower than that described for Madagascan stocks of this species, probably as a result of lower water temperatures in Natal. Yield Per Recruit analysis indicated that the prawn populations are underexploited and considerable increases in fishing effort would not deleterious. One of the reasons for undertaking this research was that apparently demand for bait prawns frequently exceeded supply. Supply can be safely increased by greater fishing effort.

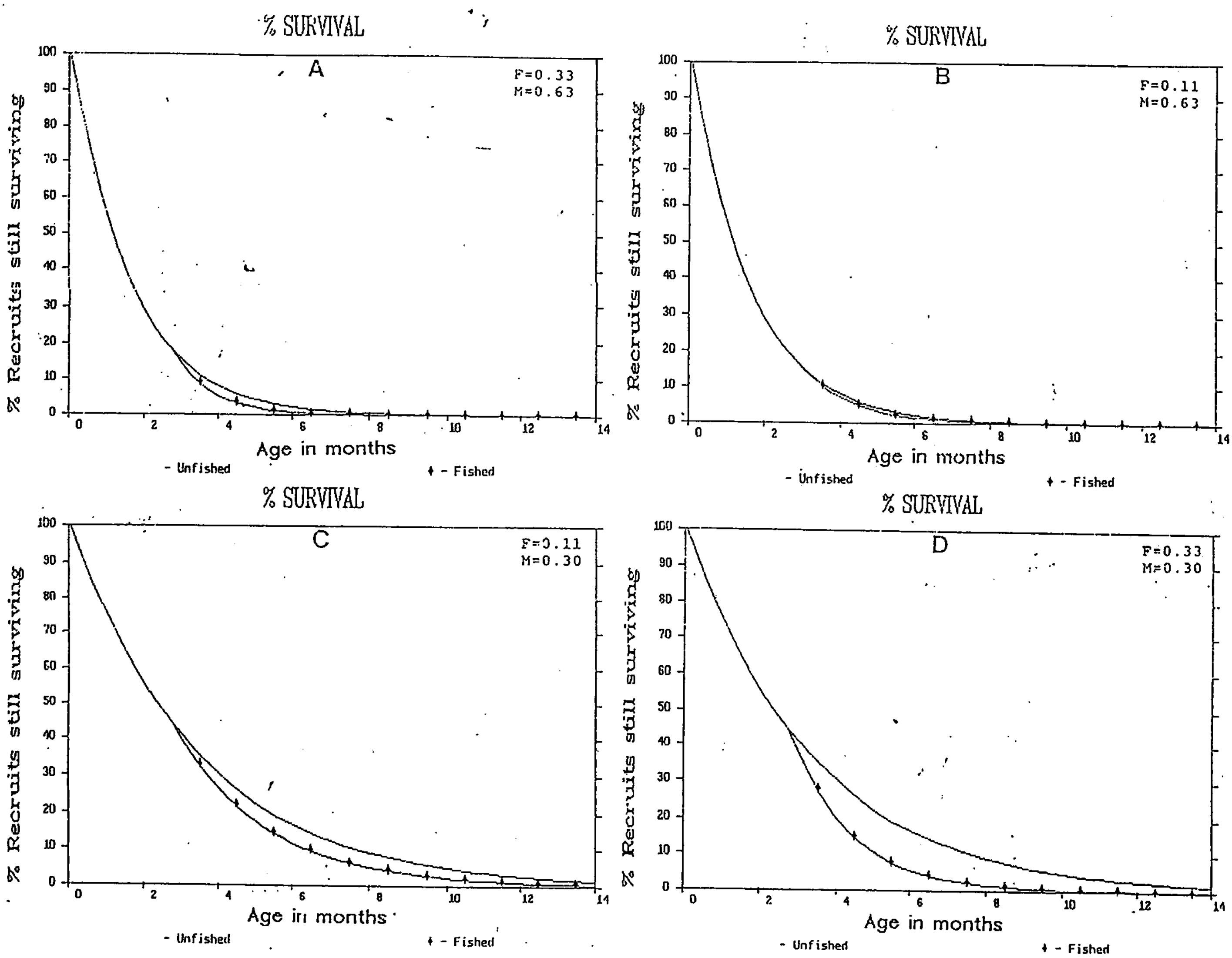

Figure 8. The percentage survival of P. indicus recruits with time, at different fishing and natural mortality rates.

The effect that the NPB bait fisheries have on the yield of the offshore fishery is highly dependent on the natural mortality rates of prawns in the estuaries and a concentrated effort should be made towards refining estimates of M. We suggest that M may approach values determined for the Mozambique fishery rather than the higher values determined in this report, because the extreme turbidity of both estuarine systems will limit effective predation on the prawn population. If this is so the estuarine fisheries will significantly impact on the yield of the offshore fishery.

Further effort and finance should be directed towards understanding the offshore prawn fishery. In particular, the origin of both post-larvae recruiting to the major Natal estuaries and subadults recruiting offshore to the Tugela Bank should be elucidated. It should be clearly determined whether the Natal prawn industry is a "closed" system or whether both the estuarine and offshore fisheries are substantially subsidised by recruits from further north. Recommendations made to both fisheries will be dependent on the outcome of such research. Other population parameters such as growth rates, natural and fishing mortality rates and age of first capture should be determined for the offshore fishery.

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