STOCK ASSESSMENT OF THE INDUSTRIAL PINK SHRIMP (*Penaeus subtilis*) FISHERY IN NORTHERN BRAZIL

by

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1. INTRODUCTION

The shrimp fishery in northern Brazil is conducted along the coasts of the States of Amapá, Pará, Maranhão and Piauí by artisanal, small-scale, and industrial vessels. However, the main fishing grounds are located between the mouth of the Parnaiba River (at the border of the States of Maranhão and Piauí) and the border with French Guiana, hereinafter referred to as the Northern Region. The most important shrimp species caught in this fishery are pink shrimp (*Penaeus subtilis*), white shrimp (*Penaeus schmitti*), and sea-bob shrimp (*Xiphopenaeus kroyeri*).

Fishing operations by the artisanal and small-scale fleets are carried out in estuaries along the coast, mostly catching juvenile shrimps with artisanal fixed gear or hand-operated trawl nets. In the State of Maranhão, small motorized trawlers, with overall length between 7 to 11 m, are commonly used to catch sea-bob shrimp (*X. kroyeri*) and white shrimp (*P. schmitti*) on daily trips.

The industrial fleet consisted of about 200 vessels in 1994. Most of these vessels (159) are based in Belém and Macapá in the States of Pará and Amapá, respectively. However, a few industrial vessels are based in Fortaleza and Camocim in the State of Ceará, and a few others in Parnaíba, State of Piauí (Table 1). In general, the industrial vessels are Gulf of Mexico-type shrimp trawlers made of steel varying between 19 and 25 m in overall length. These vessels are powered with 235 to 710 HP main engines and operate with a double-rig shrimp trawl system. Some industrial vessels from Piauí, however, are smaller in size and a few of them operate with single trawls. It is estimated that over 95% of the shrimp landed by the industrial fleet are pink shrimp (Isaac *et al.*, 1992).

At present, the industrial fishing season is from February to October, with a closed season from November to January. The best yields are obtained from February to June, when fishing operations are conducted during day and night, with hauls lasting about 6 hours each. After this period the operations are concentrated during night hours as the shrimp densities in the main fishing grounds decrease. Towards the end of the season some vessels move to fish in the shallower grounds in the Maranhão area, which appear to be more productive during this time of the year.

The industrial fleet accounts for almost one hundred per cent of the pink shrimp landings. These landings increased significantly from 16,789 to 1,084,594 kg of tails during the period 1970-1973 as the fishing fleet expanded from 6 to 28 industrial vessels (Table 1). The maximum permitted fleet size imposed by Government regulation was attained during the period 1984-1987 when 246 to 287 industrial vessels were actively operating in the fishery. Landings during that period ranged between 5,493,466 kg tails in 1984 to the historic maximum of 6,435,427 kg of tails in 1987 and then 6,356,622 kg of tails in 1988. Following these atypically large landing years, a decreasing trend in landings was observed until 1992 when only 3,888,439 kg tails were realized by the industrial fishery (Table 1). However, in 1993 landings recovered to over 5 million kg of tails. During the period of decreasing landings, the industrial fleet remained almost unchanged at between 243 and 256 vessels, thus it is believed that the observed trends in landings were most likely the result of variability in the annual levels of shrimp abundance.

In what follows, we present the first comprehensive stock assessment of the pink shrimp resources in the Northern Region. The general biology and life cycle of the pink shrimp have been described elsewhere (e.g., Isaac *et al.*, 1992) and will not be revised here. However, the fundamental stock assessment parameters of growth and natural mortality are taken from those published in the literature concerning *P. subtilis* in Brazilian waters.

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2. MATERIALS AND METHODS

2.1 Data Sources

Annual tail landings and fishing effort given in number of vessels, fishing trips and days at sea were available for the period 1970 to 1994 for the fleet based in Belém and for the period 1970 to 1991 for the rest of the fleets. Also, total monthly weight of tails processed in plants in the States of Pará and Amapá during the period 1982 to 1994 was available for the analysis. Similarly, statistics on tail weight categorized according to 10 standard commercial size denominations were available for each month for the years 1982-85, 1987-1988, and 1991-1994.

Weight frequency statistics by sex, corresponding to tails in each of the 10 commercial size category denominations collected in each month of 1981 at processing plants in the States of Pará and Amapá, were also available for analysis. These data were used to convert monthly landings in weight by commercial size categories to landings in numbers by sex and by equally spaced tail length categories.

2.2 Data Integration

During the period 1982-1994, industrial landings in the States of Pará and Amapá accounted for 90.3% of the *P. subtilis* landed in the Northern Region. Statistics on monthly landings by processed commercial size categories were only available for shrimp landed in the States of Pará and Amapá, therefore, total monthly pink shrimp landed by commercial size categories in those two States were expanded to total pink shrimp landings in the entire Northern Region. This expansion was made under the assumption that the 9.7% of the remaining unclassified landings had the same commercial size category structure as the landings observed in Pará/Amapá. This was accomplished by developing monthly expansion factors defined as the ratio of total monthly landings in the Northern Region to the Pará/Amapá total monthly landings and then multiplying landings in each monthly commercial category by the appropriate monthly expansion factor.

Monthly weight frequency distributions by sex within each of the 10 commercial size categories sampled during 1980 were used to estimate the monthly sex ratios expected within commercial size categories. Thus, total Northern Region landings by commercial size categories were separated by sex in each month for the entire database. In this step of data re-construction it was necessary to assume that the sex compositions within commercial size categories vary within years but do not vary between the years. This same database was used to estimate monthly length frequency distributions within commercial size categories. For this purpose it was necessary to convert frequency by weight intervals to frequencies by tail length intervals. This was accomplished by utilizing a tail length-tail weight relationship given as $L = 38.7025 * W^{0.3111}$ obtained as a sex-compounded average function from available pink shrimp morphometric data. Since the length intervals estimated from weight intervals using the previous non-linear length-weight relationship resulted in unequal tail ranges, it was decided to reconstruct equally spaced length intervals with a 3-mm length class range starting at the lower length boundary of 53 mm tail length. The frequency distribution corresponding to each equally spaced length class was estimated as a fraction of the total frequency within an unequally spaced length range. Under the assumption of a uniform distribution of length frequencies within the unequally spaced class ranges, the fraction applied to the equally spaced intervals were estimated as simple proportions of the length range in the equally spaced classes to the range in the unequally spaced class intervals. As an example of this procedure consider the following:

Unequally Spaced Length Intervals From Equally Spaced Weight Intervals (mm)	Frequency	New Equally Spaced Length Intervals (mm)	Estimated Frequency
(3-4 g) 54,5-59,6	3	53-56	((56-54,5) / (59,6-54,5)) * 3
(4-5 g) 59,6-63,9	14	56-59	((59-56) / (59,6-54,5)) * 3
(5-6 g) 63,9-67,6	25	59-62	((59,6-59) / (59,6-54,5)) * 3 +((62-59,6) / (63,9-59,6)) * 14
………..		…….	

Some of the commercial size categories did not have weight frequency samples in some months of the 1980 weight frequency database by commercial size categories. Thus, samples corresponding to the U-15 commercial category in March and April, samples in commercial category 41/45 in October and commercial category >70 in January, February and July were not available. These samples were estimated as the average of the sample frequency distributions of the months immediately prior and after the month being estimated. In the case of the commercial category >70 in January and February, it was necessary to use the average of the frequency distributions in December and March.

Tail length frequencies by each commercial size category and month estimated for 1980 by the above procedure were used to reconstruct length frequencies in monthly landings expressed in weight per commercial size categories in the period 1982-1994. For this purpose the algorithm developed by Ehrhardt and Legault (1996) was used. The algorithm uses the average number of tails in a commercial size category to estimate the total number of tails landed in that category in a given month. For example, the 16/20 category contains an average of 18 tails per pound (or 452 g). Thus, in 1000 lb (or 452,000 g) there will be 18,000 tails landed. Then this total number of tails landed is distributed according to the tail length distribution estimated for that category and month in 1980. Once landed tail length frequency distributions in all the commercial categories have been estimated for a given month, the total frequencies corresponding to a tail length class are summed across all commercial size categories. This process was applied to males and females independently using an EXCEL template (CATLEN by Ehrhardt and Legault, 1996) specifically developed for this purpose.

2.3 Biological Parameters

The following natural mortality (M) and growth curve parameters K and L_∞ of the von Bertalanffy growth equation estimated as averages of similar parameters estimated by several methods given in Isaac *et al.* (1992) were used in the stock assessment procedures explained below:

Males:	M= 0.160/month;	K= 0.0974/month;	L_∞ = 110 mm tail length
Females:	M= 0.146/month;	K= 0.0885/month;	L_∞ = 136 mm tail length

2.4 Stock Assessment Methods

Most of the *P. subtilis* landed in Brazil are the result of fishing operations carried out by the industrial fleet since no other fleets land significant amounts of the species. Therefore, the assessments performed with statistics generated by the industrial fleet should reflect the status of exploitation of the entire *P. subtilis* stock inhabiting the Northern Region. Stock assessments were performed to evaluate monthly fishing mortality rates inflicted on the stock under various levels of fishing effort historically deployed by the fleets. Also, stock abundance in numbers and biomass and levels of recruitment abundance observed in each month were also estimated. For this purpose the data on monthly tail length frequencies in the landings were used in standard length based stock assessments. These consisted of applications of calibrated length cohort analysis to monthly data as suggested by the algorithm developed by Ehrhardt and Legault (1996). The algorithm may be explained as follows: a length converted catch curve analysis is performed first on the monthly tail length frequency data for each sex separately as to take into consideration the effects of sexual dimorphism observed in the species. An estimate of monthly fishing mortality rate (F) is obtained out of this process as the simple difference between the total mortality rate (Z) estimated as the slope in the catch curve and an estimate of the monthly natural mortality rate (M) assigned to the species. Estimated F-values are subsequently used as calibration indexes in a Jones-type length cohort analysis. Here, the initial F/Z required by the method to estimate abundance of the largest size group from catch is adjusted until the average fishing mortality rate for an input specified length class range equals that of the estimated fishing mortality rate obtained for the same length class range but from length converted catch curve analysis.

Thus, Z was estimated as the slope of a relative age restricted length catch curve given by

$$\log_e\left(\frac{N}{\Delta t_m}\right) = a + Z * t' \tag{1}$$

where t' is the relative age of the animals at the mid-length of the size class interval m. This median age t' is computed from a von Bertalanffy growth function as

$$t' = \frac{Ln\ (1 - \frac{L_m}{L_\infty})}{-K} \qquad (2)$$

and the time needed to grow through the length class (Δt_m) can be estimated as

$$\Delta\, t_m = t_{m+1} - t_m = \frac{1}{K}\,\mathrm{Ln}\,(\frac{L_\infty - L_m}{L_\infty - L_{m+1}})$$

In the previous equation t_m and t_{m+1} are the relative ages for L_m and L_{m+1}, the lower and upper size limits, respectively, of size interval m. These t values are estimated by equations similar to (2) but for m and m+1. In all the previous equations L_∞ is the asymptotic length that expresses the average maximum size the individuals may reach at an infinite age, and K is the growth coefficient.

Once Z had been estimated from the above procedure, the fishing mortality rate was estimated as the difference between the total mortality rate Z and the natural mortality rate M. The length converted catch curve analysis process was applied to males and females independently using an EXCEL template (LCCC by Ehrhardt and Legault, 1996) specifically developed for this purpose.

Tuned length cohort analysis is based on the Jones (1984) procedure. The basic cohort analysis equation using lengths is

$$N_m = (N_{m+1} X_m + C_m)\, X_m \qquad (3)$$

where m=1 to n are size intervals, N is population size in numbers, C is catch in numbers, and X_m is expressed as

$$X_m = (\frac{L_\infty - L_m}{L_\infty - L_{m+1}})^{\frac{M}{2K}}$$

where M is natural mortality rate.

Thus, once the number in the largest, and therefore oldest, size interval is known, the numbers in each successively smaller size interval can be estimated through application of equation (3) backward. The number in the largest size interval (n) can be estimated by

$$N_n = \frac{C_n}{(F/Z\,)_n}$$

where $(F/Z)_n$ is the ratio of fishing to total mortality for the largest, and therefore oldest, size group. The total mortality rate for each size interval (Z_m) can be estimated by

$$Z_m = \frac{M}{1-(F/Z\,)_m}$$

where $(F/Z)_m$ is estimated from the number of animals caught divided by the number dying for each size interval, that is,

$$(F/Z\ )_m = \frac{C_m}{N_m - N_{m+1}}\ .$$

The fishing mortality rates per size interval (F_m) are then estimated as F_m=Z_m-M.

The population numbers in each size interval (N_m) computed using equation (3) refer to the number of animals attaining the size during the time period of the catch, thus in order to estimate the standing stock, the average numbers in the sea per size interval can be computed under the assumption of steady state as

$$\overline{N_m} = \frac{N_m - N_{m+1}}{Z_m}\ .$$

According to Ehrhardt and Legault (1996) these population and fishing mortality estimates are highly sensitive to the $(F/Z)_n$ value entered for the largest animals. Therefore, they postulated that outside information should be used to tune length-based cohort analysis. For this purpose, the overall fishing mortality rate for a given time period can be estimated say from a total mortality rate estimated by length-catch-curves such as equation (1) and M, as described above. In the tuning of the length-based cohort analysis procedure, the overall fishing mortality rate derived from length catch curves is compared to a weighted average of the fishing mortality rates from the length-based cohort analysis. The tuning process thus consists of changing the F/Z value for the largest animals until the weighted F estimate from the size intervals is equal to the overall F from the length converted catch curve, that is,

$$\frac{\overline{N}_m F_m}{\overline{N}_m} = \overline{F}\ .$$

The tuned length cohort analysis algorithm programmed in an EXCEL template (TLCA programmed by Ehrhardt and Legault 1996) was used throughout these analyses.

3. RESULTS AND DISCUSSION

Monthly stock abundances estimated by calibrated length cohort analysis were transformed to average stock abundance using the corresponding monthly fishing mortality rate estimates and the adopted monthly natural mortality rate. These average stock abundance estimates were then compared to corresponding monthly catch per unit of fishing effort (CPUE), since CPUE is an index of the relative average stock abundance. The results are given in Figures 1 and 2 for females and males, respectively. It is observed in the figures that CPUE follows a generally increasing trend on average stock abundance as expected. Also 5 out of 108 monthly abundance estimates deviate considerably from the general observed trends. It is also noted that CPUE does not tend to increase proportionally with average stock abundance – an indication that the proportionality (catchability) coefficient may not be constant throughout the regressional range. On the other hand, Figures 3 and 4 show a markedly linearly increasing trend in catch and average stock abundance of females and males.

Further exploration of the results presented above showed that there was no clear relationship between fishing mortality rates and monthly fishing effort (Figs. 5 and 6). These trends would indicate therefore, that in this fishery, catch trends are the result of stock abundance trends and that fishing mortality rates reflect the amount retrieved by the fleets according to available stock abundance and not to fishing effort levels deployed by the fleets. In this regard, catchability should vary with levels of fishing effort since the fraction of the stock caught per unit of fishing effort will be more a function of gear competition and interaction than of stock abundance. In effect, a plot of catchability on fishing effort (Figs. 7 and 8) shows that this may be the case in the Northern Region shrimp fishery.

The slope of the line fitted to catch on average stock abundance in Figs 3 and 4 are estimators of the average monthly fishing mortality rates (F) for males and females. These rates are 0.091/mo for males and 0.077/mo for females. These averages correspond very well with the overall average monthly F's estimated from calibrated length cohort analysis for the entire period of analysis (0.0908 and 0.0754 for males and females, respectively). Seasonal variability of F is observed in Figs 9 and 10.

Seasonal F estimates for males and females appear to have been relatively higher during 1983 to 1985 and the general seasonal trends indicate that fishing mortality rates tend to be larger during the first semester of the year. These trends may be related to seasonal recruitment trends – when a more abundant population is available to the fleet. Also, a relatively stable trend in F is observed after 1987 in males while a relatively decreasing trend in F is observed in females during the same period. The maximum levels of seasonal F in both sexes (occurring during 1983 through 1985), never exceeded the level of natural mortality rates (M) corresponding to the sexes (M_{males} = 0.16/mo; $M_{females}$ = 0.146/mo). The exploitation rate (F/Z) corresponding to the overall average fishing mortality rates resulted in 0.345 for females and 0.36 for males. These results are indicative that the *P. subtilis* stocks in the Northern Region may have been subjected to moderate to full exploitation during the seasons analyzed.

Estimated stock abundance in numbers is presented in Figure 11 for males and females. Abundance of males is conspicuously lower than those observed in females with the exception of 1987, when the abundance by sex reaches similar levels. Generally, the months of peak abundance among females is March with some peak occurrences in April and May. Among males, seasonal abundance could be bimodal or sparse, with relatively larger abundance than females during the later months of the year. It is observed that seasonal abundance varies greatly among years with a significantly lower abundance observed in 1983 for both males and females. In general, stock abundance appears more stabilized during the period 1991-1994 relative to the other years analyzed.

Recruitment, defined here as those individuals that enter the exploitation phase at sizes between 53 and 71 mm tail length, is shown in Figs 12 and 13, for females and males respectively. Recruitment patterns between sexes show very different characteristics. Female recruitment shows a distinct maximum in every season, while among males there appears to be a rather protracted recruitment season with increased recruitment toward the later months of the year. Generally, female recruitment levels are 2 to 3 times larger than those observed for males, and inter annual recruitment levels appear to vary more conspicuously among males.

Total (male+female) recruitment anomalies (observation minus mean divided standard deviation) were estimated for each month and compared with rainfall anomalies for the Belem region. The resulting anomalies are presented in Figure 14. It is observed that recruitment is seasonally modulated by rainfall. In some years (1985, 1987 and 1988) recruitment variability follows strikingly similar patterns to rainfall.The relatively greater stability in rainfall pattern in the last four years of analysis may have been responsible for the greater stability in recruitment and population abundance during those years.

4. CONCLUSIONS

The analysis presented in this study used a large database of landings by commercial size categories and the weight frequency distribution of shrimp tails within those categories, which were not previously available for stock assessment purposes. The algorithm applied in the stock assessments incorporates several assumptions (such as equilibrium), which may not entirely justify its utilization with *P. subtilis*. In spite of this condition, the assessments reveal that recruitment abundance follows trends in seasonal rainfall, which would not be expected unless the results are congruent with the general dynamics of the environment and of the species. This is more strikingly so when one realizes the extraordinarily different sources of information used in these analyses and the methodologies applied to arrive at such a conclusion.

Landings in this fishery appear to be fundamentally driven by levels of seasonal abundance while catch per unit of fishing effort does not entirely reflect a direct proportionality to average stock abundance. Thus, under the levels of fishing effort observed during the study period, it appears that the fleet is able to retrieve an amount of biomass that is a function of the abundance and not of the amount of effort deployed. In these circumstances, catch per unit of fishing effort is related to the way an available catchable biomass was distributed among fishing effort units. This conclusion is also supported by the rather conspicuous decreasing trend in seasonal catchability as seasonal fishing effort increased. Furthermore, the constancy of the average seasonal F estimates observed in males and females (estimated as the slope of the line relating catch and average stock abundance), explains the lack of relationship between F and fishing effort. It also corroborates that under high levels of fishing effort, the amount of catch retrieved from the stock is proportional to stock size. This conclusion is significant when considering the economic consequences of open access policies or when determining optimum fleet size for this fishery.

The levels of exploitation observed during the study period appear well within the expected fishing mortality levels inflicted on an annual species exhibiting high natural mortality rates. In effect, the seasonal fishing mortality rates never exceeded the monthly natural mortality rates assigned to the species and sex.

5. RECOMMENDATIONS

The analyses presented here are based on a single year (1980) biological database consisting of sex ratios and tail weight frequency distributions by commercial size categories. These data were used to reconstruct tail length frequencies in the years included in this study. It is recommended that a search for similar historic biological data be made to establish whether changes in the biological condition of the shrimp have occurred through time, or if significant differences are observed between databases. If this database does not exist, then it is recommended that such database be formed with newly and objectively collected data.

The analyses in this report used a stock assessment algorithm under equilibrium conditions to estimate abundance and fishing mortality. It is recommended that the results obtained here are corroborated with age based stock assessment algorithms so as to include the dynamic linkages that might exist among monthly cohorts.

Further analysis on biomass production from cohort analysis should be attempted and compared with dynamic production modeling results. In this way some of the important non-linear relationships between CPUE and average stock abundance and between catchability and fishing effort may be elucidated.

The results of these analyses indicate the need to integrate economic data and economic analysis to the assessment of the *P. subtilis* fishery in the Northern Region. This is an important step to be taken in the future given findings in this report.

6. REFERENCES

Ehrhardt, N.M., and C.M. Legault. 1996. Crustacean Stock Assessment Techniques Incorporating Uncertainty. Paper presented at the FAO/CFRAMP Stock Assessment Workshop, 8-12 January 1996, Port of Spain, Trinidad and Tobago. *FAO Fish. Rep.* 544, Supplement: 111-131

Isaac, V.J., J. Dias-Nieto, F.G. Damasceno. 1992. Camarao rosa da costa norte: biologia, dinamica e administracao pesqueira. Coleção Meio Ambiente. Serie: Estudos-Pesca, 1. Brasilia, IBAMA. 191 p.

Jones, R. 1984. Assessing the effects of changes in exploitation pattern using length composition data (with notes on VPA and cohort analysis). *FAO Fish. Tech. Pap.* 256: 111 p.

Table 1: Licensed vessels operating in the shrimp fishery in northern Brazil and total landings

YEAR	FLEET				LANDINGS
	Pará/ Amapá	Ceará	Piauí (1)	Total	(kg tails)
1970	6			6	169789
1971	27			27	646485
1972	16			16	264864
1973	28			28	1084594
1974	34			34	716625
1975	26			26	495418
1976	39			39	871955
1977	48			48	1162124
1978	50			50	1718407
1979	73	2	11	86	2063529
1980	131	8	19	158	3571165
1981	121	6	23	150	4476648
1982	127	10	18	155	3770477
1983	137	24	18	179	3899217
1984	208	27	19	254	5493466
1985	224	41	22	287	5131828
1986	196	40	20	256	4574966
1987	198	36	12	246	6435427
1988	177	36	15	228	6356622
1989	183	42	17	242	4489849
1990	189	48	19	256	3918749
1991	180	47	16	243	4328753
1992	156	43	16	215	3888439
1993	170	20	16	206	5256404
1994	159	25	16	200	4071313

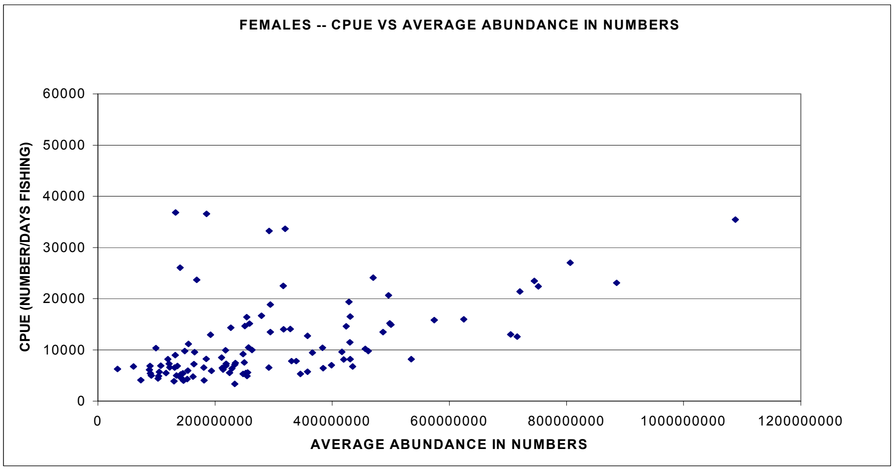
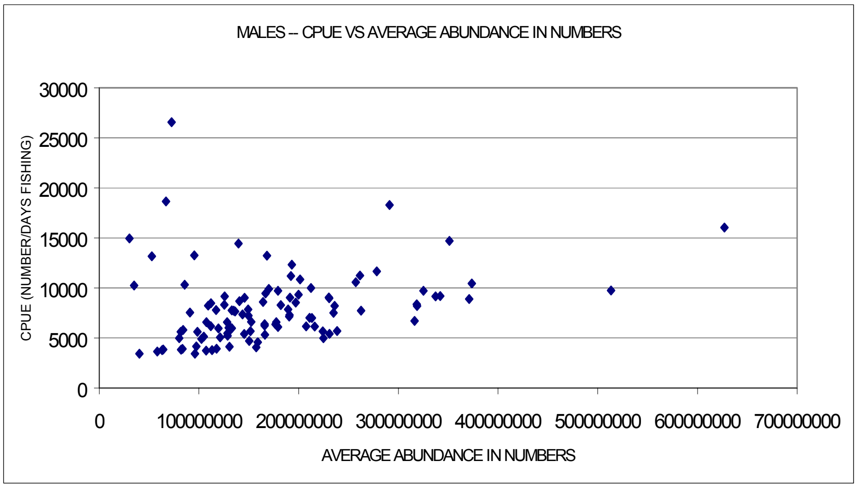


Figure 1



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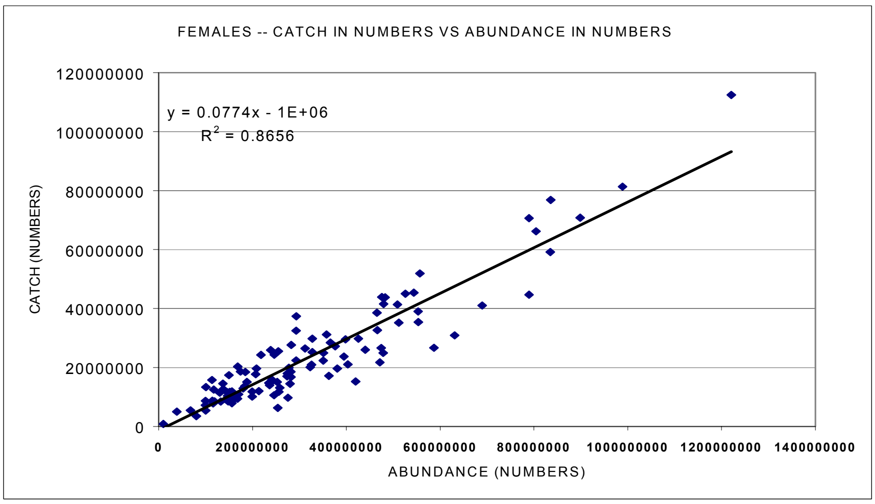

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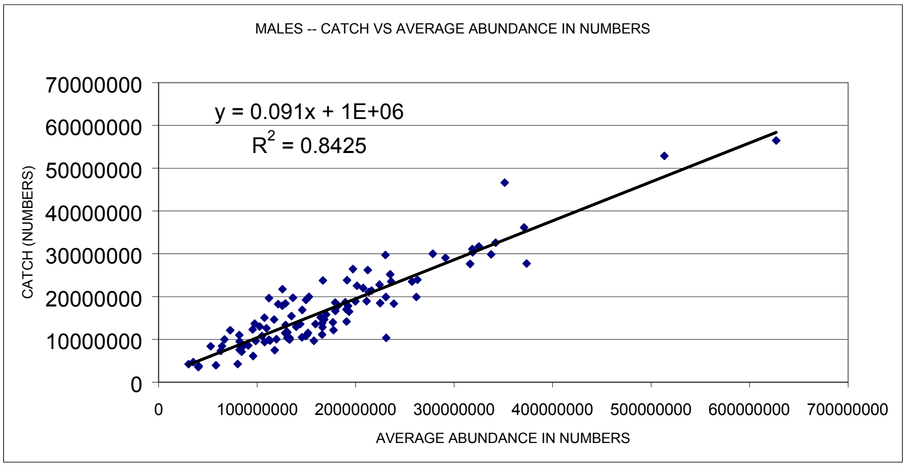

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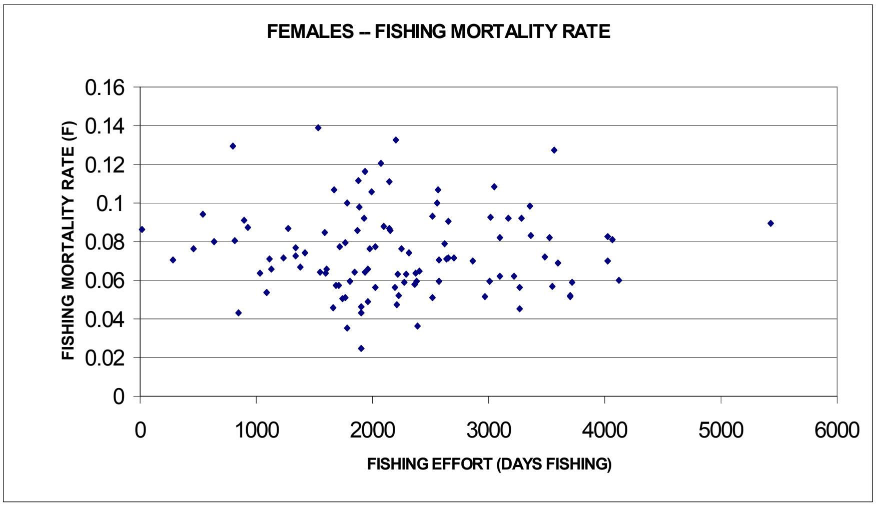

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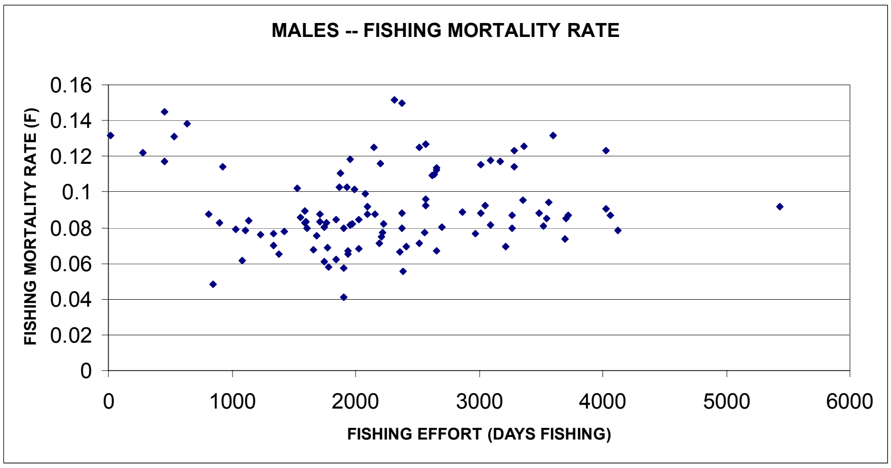

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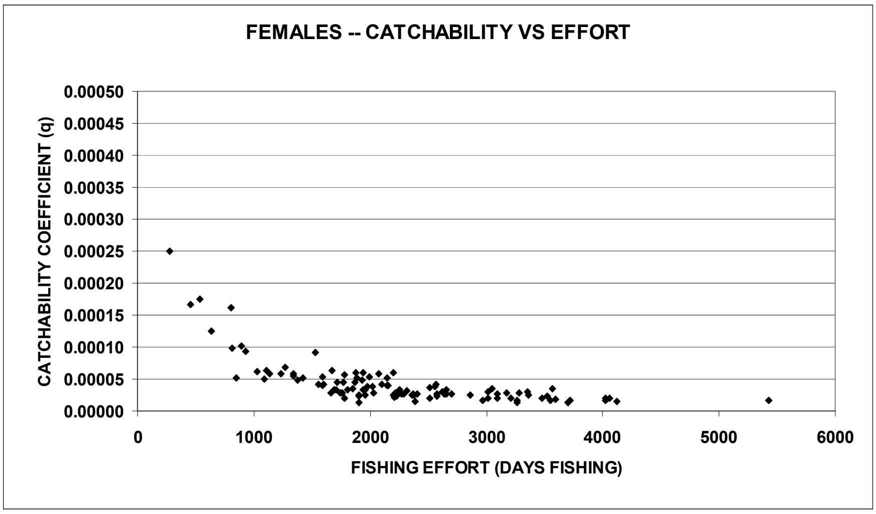

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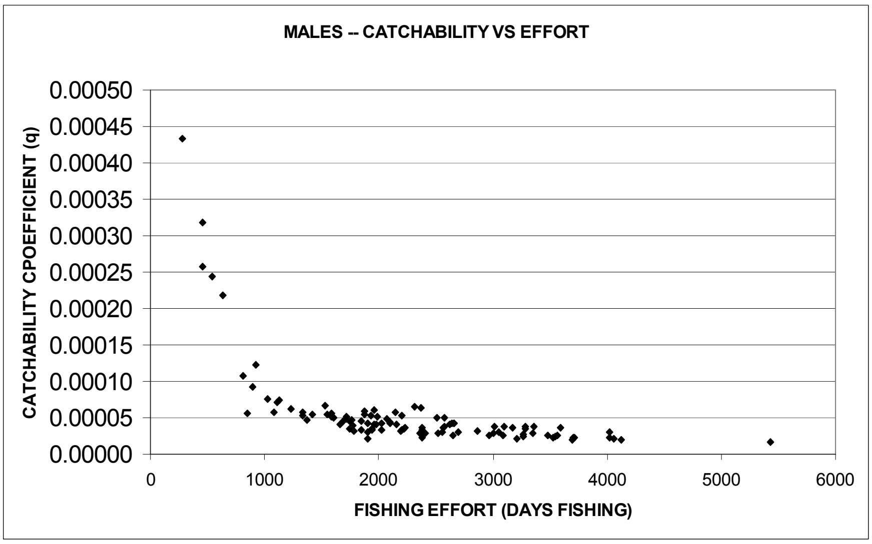

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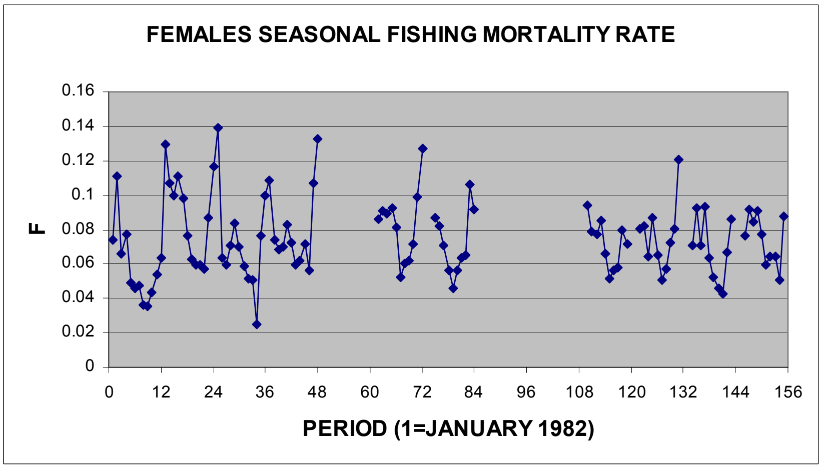

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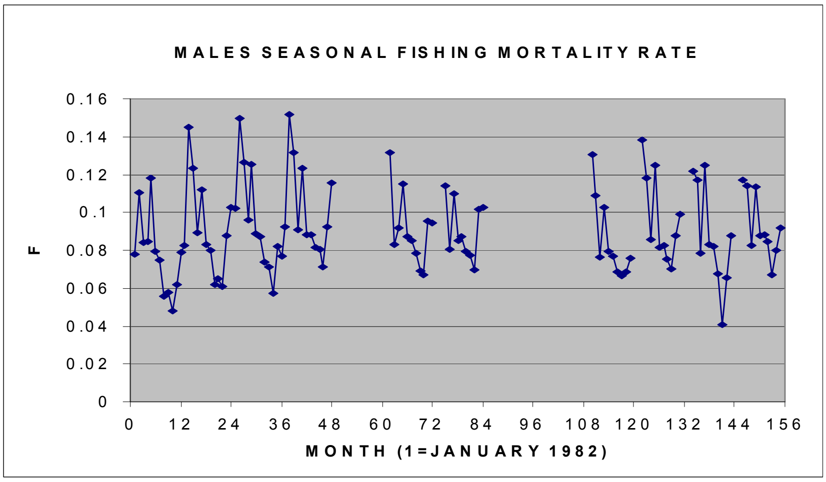

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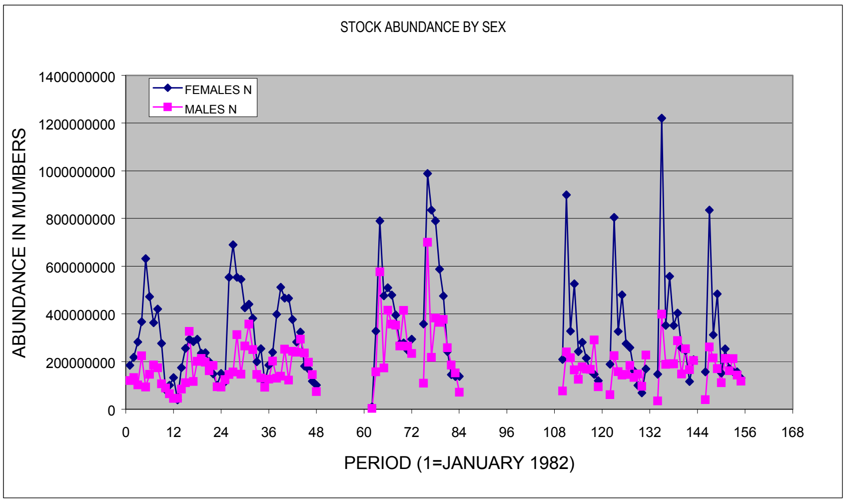


Figure 11

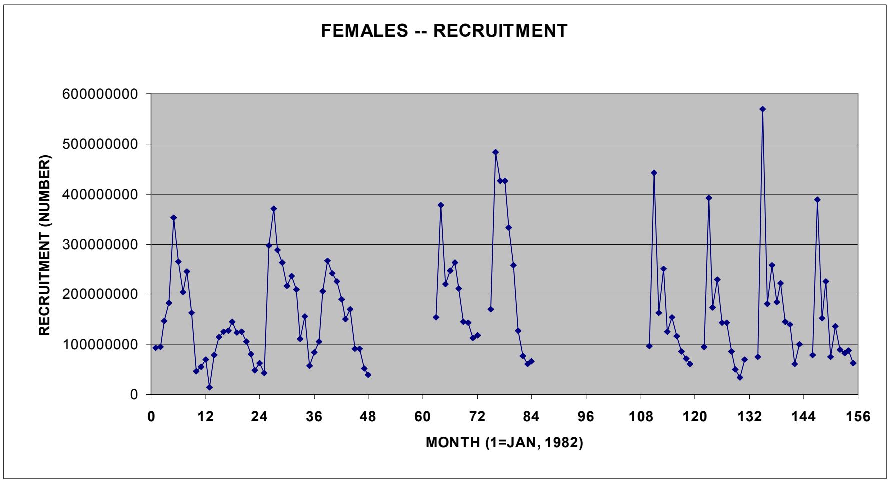
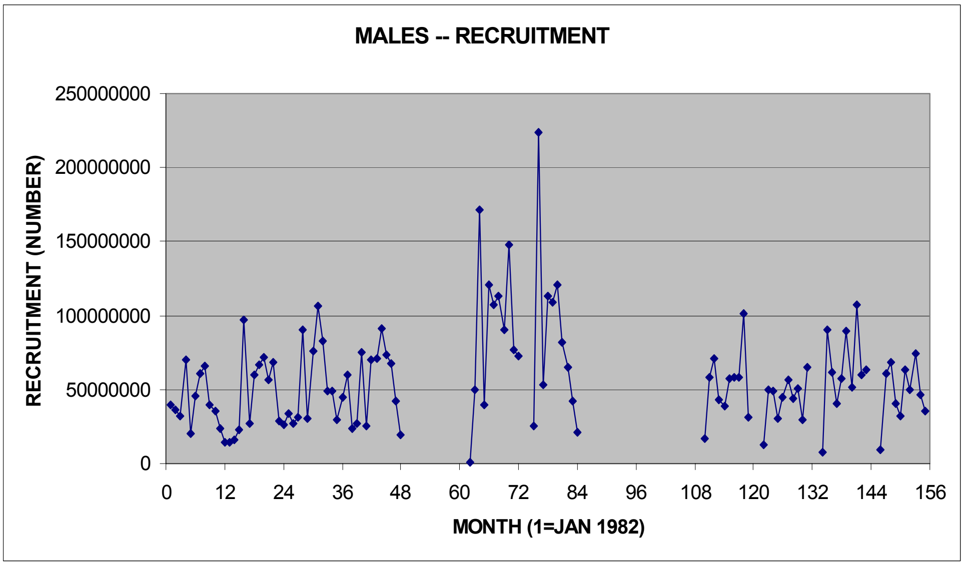


Figure. 12



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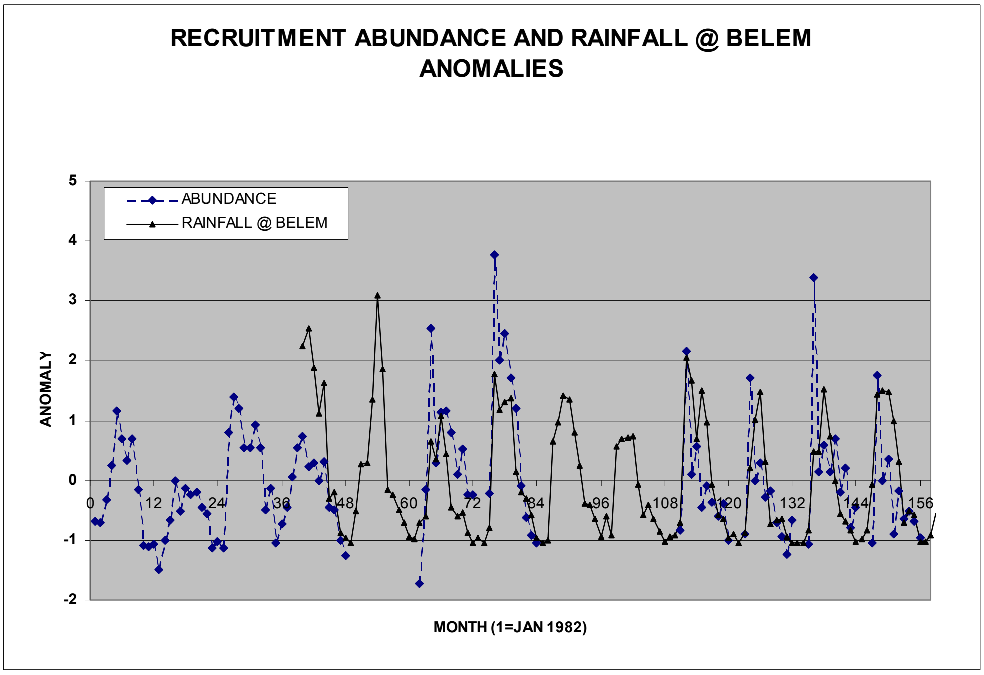

Figure 14