12. PRAWN FISHERY SIMULATION YIELD MODEL

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12.1 Introduction

Managers of fisheries have always sought to predict the consequences of any management measure before it is introduced. Even broad predictions have proven extremely difficult to make and, mistakes in predictions can be costly to the industry and possibly the long term durability of the fishery. The industry expects management measures to be precise. For example the optimum dates for seasonal closures are expected to have an accuracy measured in weeks, if not days.

Many of the management measures being employed on prawn fisheries in Northern Australia are novel in their application, for example, seasonal closures to protect small prawns have been in use for less than ten years in northern Australia. Few if any experimental controls have been used to establish the effectiveness of these measures. Large inter-year variations in prawn numbers occur naturally and can complicate long-term assessments. In response to industry concern, several different management regimes have been used in successive years, making the explanation of results extremely difficult because of their possible interactions.

To assess the response and elasticity of a fisheries' potential to withstand fishing pressure it is usually necessary to employ widely varying levels of exploitation and then observe the response. This means some degree of calculated under fishing exploitation and over fishing exploitation within the fishery. To be successful these 'experiments' have to be large in scale and extend for several years. The very idea of costly manipulation of a viable important fishery is, at least for the present, politically unacceptable. This means that researchers are asked to help managers decide on strategies without the benefit of the type of data from the system which would allow statistical predictions to be made. They must therefore employ data from other fisheries. Fisheries from which data is available are often from temperate regions , and all too often are failed fisheries and not ideal for comparison with a tropical prawn fishery.

There is one other tool researchers and managers can employ. This tool is simulation modelling. A fisheries biologist can estimate a number of important biological and population parameters from direct measurement, experimentation, or from the scientific literature. These can be combined with information gathered from economists, commercial processors and fishermen to produce a series of rules and relationships. Such controls often govern the fishery through various limiting factors such as the number of vessels, the available searching time, the biology of the key species, or the economics of the products. One or more of these aspects can be combined using the computational powers of computers in a simulation of the fishery. These computer simulations often allow for graphical or tabular display of the results so that all potential users can visualise the results and gain some understanding of the interplay between the many complex relationships underlying the model.

Several types of computer simulation models exist. As the name implies they are meant to simulate the fishery. Given suitable input such as the numbers and sizes of animals recruiting into the fishery, models can produce estimates of potential outcomes. These may be landings, numbers of animals the following year, or even net profits. Most of these simulation programs are based on dynamic models. Dynamic models attempt to model the passage of time in the life of the fishery. Some programs model time on a continuous basis, while most models use discrete time units. Units of years are applicable only to comparitively long-lived animals. For prawns, units of months or even weeks are more appropriate. The time scale most appropriate is dependent on the generation time of the key species as well as the detail available in the input data, and the precision required of the predictions.

Many models use fixed rules to relate the input data to outcomes and do not allow for chance circumstances, these are deterministic models. Others attempt to simulate the natural uncertainty in the reaction of one factor in the fishery to others, or the certainty or potential error in the input data. These models allow for random or pseudo-random processes to occur. These stochastic models produce different results every time they are used even if the same input data is used. While this produces a more realistic approximation of the natural situation, it requires additional information on the rules which regulate how this variation or randomness occurs. When stochastic models are used, it is common to reuse the computer model a number of times, through the process of Monte Carlo simulations, in order to extract the average result. In addition to the average outcome, stochastic models also allow the range of expected results to be determined.

Models can be either extremely complex or 'reductionist' in nature and attempt to describe all knowable aspects of the animals' biology and the fishery in fine detail, or they can be general or 'holistic' in approach and deal with only the generalised net or overall affects. They can attempt to explain the relationship between all parameters that can be measured and attempt to predict all aspects of the fishery, or they can use only some of the available data to predict only one result such as the net profit.

Modelling has been employed to great effect by Somers (1985) to predict the optimum opening date for the *Penaeus merguiensis,* banana prawn fishery in the Gulf of Carpentaria. Somers (1985) used information on prawn prices and prawn growth rates, together with weekly size surveys, to predict when harvest would maximise the gross profits of prawn fishermen. Sluczanowski (1984) used historical catch data and existing fisheries models to optimise (through modelling) population parameters for the Spencer Gulf prawn fishery of *P. latisulcatus,* the western king prawn. These parameters were then used in a subsequent model, which had an economic framework, to find management measures which would optimise total industry profits.

The deterministic model that will be described below is not as complex as that used by Sluczanowski (1984) in the Spencer Gulf, and as yet has not been elaborated to produce economic parameters other than gross catch values. This model was originally developed to simulate the growth, immigration, emigration and mortality processes of juvenile *P. esculentus,* brown tiger prawns, in nursery areas of Torres Strait. It was then extended to include the adult or commercial phase of the life cycle, and to include the other two commercial species in Torres Strait, *Metapenaeus endeavouri,* endeavour prawn, and *P. longistylus,* redspot king prawn. It has already been employed to make crude predictions of the effects of differing seasonal closure periods on prawn catch values. With modification and further sophistication this model can be used to meet many of the prawn fishery managers future needs.

12.2 Materials and Methods

12.2.1 General model description

The initial input data used in this deterministic simulation model are the numbers of prawns km^{-2} at 1 mm size classes (length density values). These prawns are subjected to size-specific natural mortality (Figure 1), then they are fished according to schedules of fishing effort. In the simulation, prawns are caught at varying rates in accordance with experimentally-established size-selectivity relationships (Section 11). Some prawns are harvested and their abundance, sex and carapace lengths are recorded. The weight and value of this catch is then calculated using sex and species-specific weight-length relationships, as well as size-specific price schedules.

Prawns remaining at the end of a one monthly cycle are joined by new recruits, whose numbers are calculated by changes in the length frequency data, before the process is repeated. The model was usually used to simulate twelve months in the fishery and can be used, in the absence of recruitment data, to follow a group of prawns until extinction. The three prawn species were modelled separately before their results were combined.

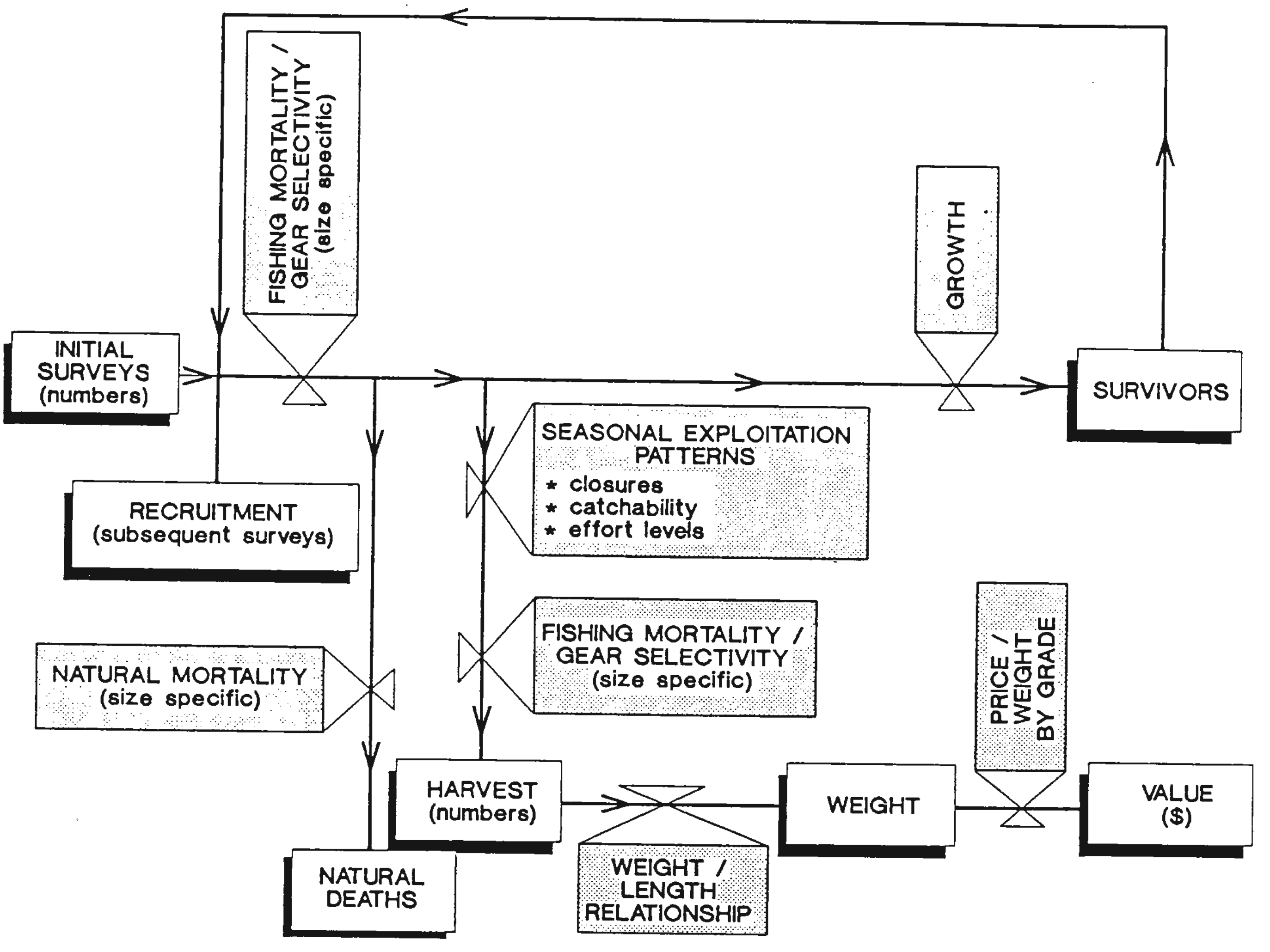

Figure 1. Schematic representation of the simulation model.

12.2.2 Description of sub-models

Weight-length. Parameters were fitted to the relationship:

$$W = aL^b$$

where W is a total wet weight of a prawn (g)
and L is its carapace length (mm)

Parameter values varied for different prawn species and sex (Table 1). The values used were derived from laboratory measurements.

Table 1. Coefficient values for the weight-length relationship used for commercial prawn species from Torres Strait.

Species	a		b	
	Male	Female	Male	Female
Penaeus esculentus	0.0024	0.0026	2.72	2.67
Metapenaeus endeavouri	0.0017	0.0015	2.79	2.81
Penaeus longistylus	0.0017	0.0015	2.79	2.81

Growth. Parameters were fitted to the von Bertalanffy growth curve from tagging experiments or derived from the literature (Table 2). This curve has the form:

$$L_t = L_\infty [1 - e^{-k(t - t_0)}]$$

Table 2. Coefficient values for the von Bertalanffy growth model used for commercial prawn species from Torres Strait.

Species	k		L_∞	
	Male	Female	Male	Female
Penaeus esculentus	0.22	0.22	35	43
Metapenaeus endeavouri	0.14	0.16	37	45
Penaeus longistylus	0.10	0.17	43	48

Natural mortality. A size-specific mortality schedule was created for each species (Table 3) based on extrapolations of average literature values for Australian prawn species (Garcia 1985). The assumption was made that at smaller, non-commercial sizes and at sizes approaching L_∞, natural mortality values exceed that for the mean size.

Table 3. Values for the annual coefficient of natural mortality used for all commercial prawn species from Torres Strait.

Carapace length range	Value
0 - 9 mm	0.3
10 - 14	0.25
15 - 44	0.2
45 - 55	0.3

Gear selectivity. Based on trawl gear experiments (Section 11) an asymptotic relationship was used to describe the vulnerability of prawns to trawling in each 1 mm length class. Insufficient information is available at this time to assign separate selection curves to different species of prawn.
The relationship used was:

$$Y = x_1 / [1 + e^{(x_2 L - x_3)}]$$

where Y is the proportion of prawns vulnerable to capture at any length L (mm),
x_1 is the upper asymptote of the curve,
x_2 is the slope of the ascending limb of the curve, and
x_3 is the carapace limb (mm) at which 50% of prawns would be caught.

Parameters used for all species were: x_1 = 0.812, x_2 = -0.452 and x_3 = 20.0 mm (Section 11).

Seasonal exploitation. The annual fishing mortality was set equal to the annual natural mortality. This assumption has been used before with Australian prawn fisheries (Haynes and Pascoe 1988). A percentage of this annual fishing mortality was apportioned to each month based on the Northern Prawn Fishery logbook records from Torres Strait vessels (Section 2). The distribution of fishing effort throughout the year differed depending on the presence and timing of seasonal closures (Table 4). The simulation program allowed different seasonal closure scenarios to be chosen, with each scenario using different seasonal fishing effort schedules.

Table 4. Proportion of annual fishing each month for different closure period in Torres Strait.

Month	No Closure	Dec 15 Feb 1	Dec 15 Feb 15	Dec 15 Mar 1	Dec 15 Mar 15	Dec 15 Apr 1	Dec 15 Apr 15
January	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Febrary	0.13	0.16	0.26	0.00	0.00	0.00	0.00
March	0.17	0.22	0.15	0.38	0.18	0.00	0.00
April	0.07	0.09	0.09	0.07	0.27	0.45	0.25
May	0.13	0.08	0.05	0.10	0.10	0.10	0.30
June	0.07	0.05	0.05	0.05	0.05	0.05	0.05
July	0.05	0.07	0.07	0.07	0.07	0.07	0.07
August	0.12	0.14	0.14	0.14	0.14	0.13	0.13
September	0.09	0.06	0.06	0.06	0.06	0.06	0.06
October	0.05	0.07	0.07	0.07	0.07	0.07	0.07
November	0.04	0.05	0.05	0.05	0.05	0.05	0.05
December	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Prawn prices. The wholesale purchase prices of the three commercial species were obtained from Cairns buyers at the time the analysis was performed. Buyers informed us at the time that prices did not exhibit a predictable seasonal pattern. We therefore, did not attempt to make seasonal adjustments to the price structure in Table 5. Larger sized prawns were higher priced and smaller sizes which are not exported, are much less valuable. Consequently the price schedule used had a stepped format. Price is not directly related to prawn carapace length but rather to prawn weight or count (number per unit of weight). Counts are often given in units of the number of prawns which weigh one kilogram. Prices were supplied as $AUS kg^{-1} for different ranges of prawn counts. These ranges of prawn counts by weight were calculated for ranges of prawn carapace lengths using species and sex-dependent weight-length relationships (Table 1).

Table 5. Prawn prices used for commercial prawn species from Torres Strait.

Species	Range of carapace lengths (mm)	Price ($ kg^{-1})
Penaeus esculentus	0 - 20	0.00
	21 - 24	6.00
	25 - 29	10.80
	30 - 38	15.90
	39 and above	19.40
Metapenaeus endeavouri	0 - 19	0.00
	20 - 24	5.50
	25 - 29	7.30
	30 and above	9.30
Penaeus longistylus	0 - 19	0.00
	20 - 28	5.00
	29 - 33	9.80
	34 and above	12.00

12.2.3 Input data

Trawl stations in Torres Strait were surveyed monthly from January 1986 to January 1988. The catch of prawns caught from each hectare of the bottom swept by the survey trawl gear was recorded in 1 mm carapace length class intervals. The January 1986 survey results were used as the initial estimates of prawn numbers for the model. All sizes of prawns from this initial month were introduced into the model as new recruits. In subsequent months, the length frequency data was examined, but only those prawns which could not already have been included from the previous months surveys were added as new recruits. A conservative approach was adopted when new recruits were calculated. To determine which prawns could not have been included previously, a maximum size limit or cut-off size was calculated. An increase in length equivalent to one month of growth was added to the smallest sized prawns surviving from the previous months survey results. Prawns equal to or greater than this projected size were not included as they could already have been included as new recruits into the model from the previous month.

12.2.4 Output data

There are two types of output: graphical and text. Text output can be directed to a printer as well as to the computer screen. Graphical and text output is produced for each species of prawn separately. These outputs are followed by a text summary which combines all commercial species. It is possible to combine text and graphical output in several formats.

Text output. For each species the text format produces a table, each row representing the results from one month of simulation (Table 6). The columns in Table 6 represent: the month, the proportion of total annual fishing effort for a non-closure year, the number of prawns ha^{-1} remaining alive and free, the ratio of deaths from fishing to those from natural mortality, the number of new recruits ha^{-1}, the number of deaths from natural causes ha^{-1}, the number of deaths from fishing or the number caught ha^{-1}, the cumulative value of the catch, the monthly or incremental value of the catch, the weight (kg) of the catch, the average weight of a prawn (g) for the month, the average value per prawn for the month, and the ratio of fishing to natural mortality rates. Below the rows representing monthly results are the averages and totals for the species over the total simulation period which is usually one year. These include: the total catch in weight (kg) and value, the average price kg^{-1} and per prawn, the total number of deaths by natural causes and through fishing, the average prawn weight (g) and carapace length (mm), and the yield per recruit by weight (g) and by dollar value. These statistics are also repeated for all species combined over the simulation period (Table 7).

Table 6. An example of text output for *P. esculentus* from the simulation model.

```
******************************************************************************
*                                                                            *
*     STATION: 9   P. ESCULENTUS    STARTING MONTH: JANUARY, 1986            *
******************************************************************************
```

	MONTHLY	PRAWNS	RATIO	NEW	DEATHS		CATCH VALUE ($)		CATCH	WT(G)/	$/	MORT R
	EFFORT	LEFT	F/M	REC	NAT	FISH	CUMULAT	INCREM	(KG)	PRAWN	PRAWN	F/N
JA	NIL	7229	0.64	7229	1310	0	0.00	***** No Catch *****				
FE	NIL	5927	0.64	231	1114	0	0.00	***** No Catch *****				
MA	0.38	5044	0.63	0	618	2691	1051.20	1051.20	75.02	27.89	0.40	4.36
AP	0.07	1736	0.61	599	392	300	1172.59	121.38	8.39	27.99	0.41	0.77
MA	0.10	1643	0.77	226	303	339	1315.62	143.03	9.79	28.89	0.43	1.12
JU	0.05	1227	1.03	1168	410	227	1396.10	80.48	6.00	26.44	0.36	0.56
JU	0.07	1758	0.71	0	293	236	1499.13	103.03	6.93	29.38	0.44	0.81
AU	0.14	1229	0.71	260	231	369	1668.45	169.32	11.11	30.12	0.46	1.60
SE	0.06	889	0.72	0	149	104	1722.08	53.63	3.41	32.69	0.52	0.70
OC	0.07	635	0.72	0	105	86	1770.78	48.70	3.01	34.85	0.57	0.83
NO	0.05	444	0.72	379	140	81	1809.02	38.24	2.52	31.12	0.48	0.58
DE	0.01	602	0.66	113	127	14	1816.08	7.05	0.45	31.35	0.50	0.12

```
CATCH TOTAL: (KG)  126.7     PRICE AVERAGE ($): (KG)  14.35
             ($)  1816.08                    (EACH)   0.41

DEATHS  NATURAL:   5192      AVG PRAWN WT (G): 28.48
        FISHING:   4447                LT (CM): 31.74

YIELD/RECRUIT: (g)  12.41
               ($)   0.18
```

Table 7. An example of text output for all species from the simulation model.

```
******************************************************************************
*                                                                            *
*     STATION: 9   ALL SPECIES      STARTING MONTH: JANUARY, 1987            *
******************************************************************************


CATCH TOTAL: (KG)  269.3      PRICE AVERAGE ($): (KG)  10.92
              ($)  2939.10                    (EACH)    0.25

DEATHS  NATURAL:  16034       AVG PRAWN WT (G): 22.78
        FISHING:  11822             LT (CM): 29.48

YIELD/RECRUIT: (g)   8.04
               ($)   0.09
```

Graphical output. Graphical output takes up only one half of the computer screen. The graphical output is currently designed for use with computers with Extended Graphics (EGA) or Video Graphics Adaptor capabilities. Text output can be used with or without graphical output as it does not require graphics capabilities. By itself, text display will use the entire computer screen. When used with a graphics display the text utilises only the lower half of the screen but scrolls as this area is filled.

There are two graphical displays possible and each is designed to use half of the computer's display area. These displays can be used together or singly with the text display. The first graphics display is basically a length-frequency histogram for each month of the simulation. These histograms show the number of prawns ha^{-1} at 1 mm carapace length classes. The histograms are colour coded to indicate the number of male prawns surviving, female prawns surviving, prawns caught, prawns dead from natural causes and new recruits. The second graphical display shows an entire year of data. For each month the weight of prawns caught is colour coded to show the proportion under and over the minimum export size. The cumulative value of the catch is also shown in the background.

12.2.5 Program options

Through a series of questions at the beginning of the program, the user can choose between many different options. In each case there is a default choice displayed in parenthesis.

Output format. The first series of questions establishes what type of output display is desired. At this point there is an opportunity to have the text output sent to a printer and a general title can be entered.

Input data. Users can choose the first calendar month of the simulation as well as which trawl stations to include.

Fishing pattern. The annual level of fishing mortality is selected. If the level of fishing mortality is set to zero then no fishing will occur but the standing value of the prawn stocks will still be reported monthly. If fishing effort is applied, different seasonal effort patterns are available for a variety of seasonal closure periods.

Recursive option. It is possible to save the length frequency information for prawns still surviving after one year of the simulation - these are termed 'the leftovers'. It is also possible to begin a simulation by adding the leftovers from a previous simulation to the new recruits. This allows a more realistic simulation, especially if the total value of the fishery for a single year is the most important output parameter.

12.3 Results and Discussion

12.3.1 Potential catch value vs seasonal closures

It is possible to model the prawn fishery under different seasonal closure regimes and make estimates of the gross annual value of the prawn catch per area of the bottom trawled. This gross value is related to the level of fishing activity or fishing mortality coefficient, F. In our simulation we used a value for F equal to the literature value of natural mortality, M, of 2.4. We also used values of F equal to 1.2 and 3.6 to represent units of instantaneous fishing mortality that has been halved and increased by half respectively.

The simulation was based on a station just east of Warrior Reef (station 9 - Section 5) and used survey data from 1986 when there was a seasonal closure in effect (Section 1). The model predicts an increase to the annual gross value of the fishery if a seasonal closure is enforced, unless the closure period extends beyond April 15 (Figure 2). Seasonal closures longer than this period have little positive effect. Closures cause a comparative increase to the value of the fishery at higher levels of exploitation (the curve is more arched). At low levels of fishing effort the model predicts that closures have little effect. At high levels, closure timing is critical if maximum catch values are to be attained.

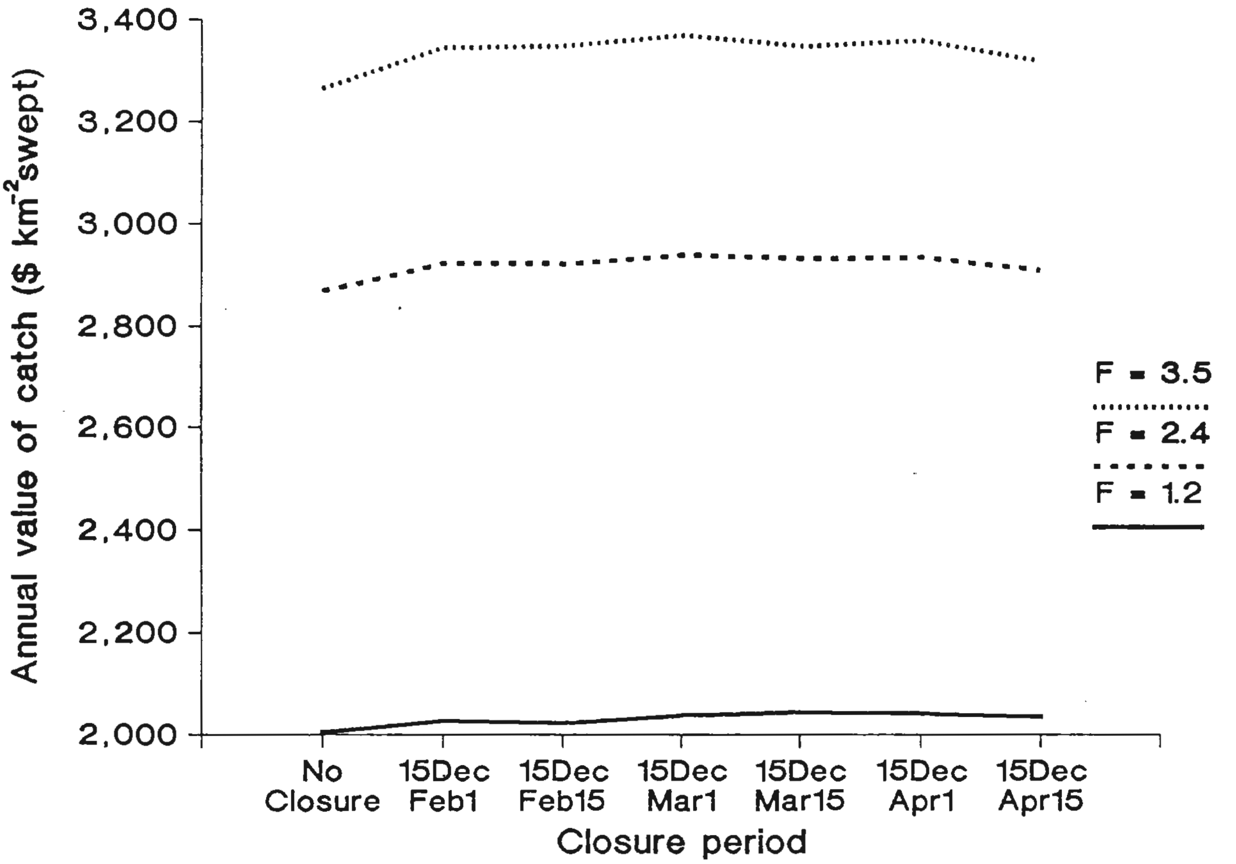

Figure 2. Annual catch values of all commercial prawns predicted by model and coeffecients of fiahing mortality for different closure periods.

In the future we can model other stations in Torres Strait and years, however, indications are that the results will be similar. It is difficult to use survey data from years when seasonal closures did not occur, as the effect of commercial fishing alters our survey data and makes predictions of unfished recruitment nearly impossible.

12.3.2 Stochastic recruitment processes

Recruitment into a prawn fishery varies widely from year to year. The number of recruiting prawns in any one year is extremely difficult to predict. A deterministic model does not allow for this interannual variation and relies directly on survey data to establish recruitment levels. A more realistic approach would be to examine several years of recruitment data in order to establish the timing and magnitude of recruitment peaks and, more importantly, their variance. The recruitment peaks established using the criteria described for the model occur twice a year (Figure 3). These recruitment peaks vary in their timing and magnitude. If we assume that the peaks are similar to the normal gaussian curve in shape then we can estimate the means and variance of these recruitment peaks.

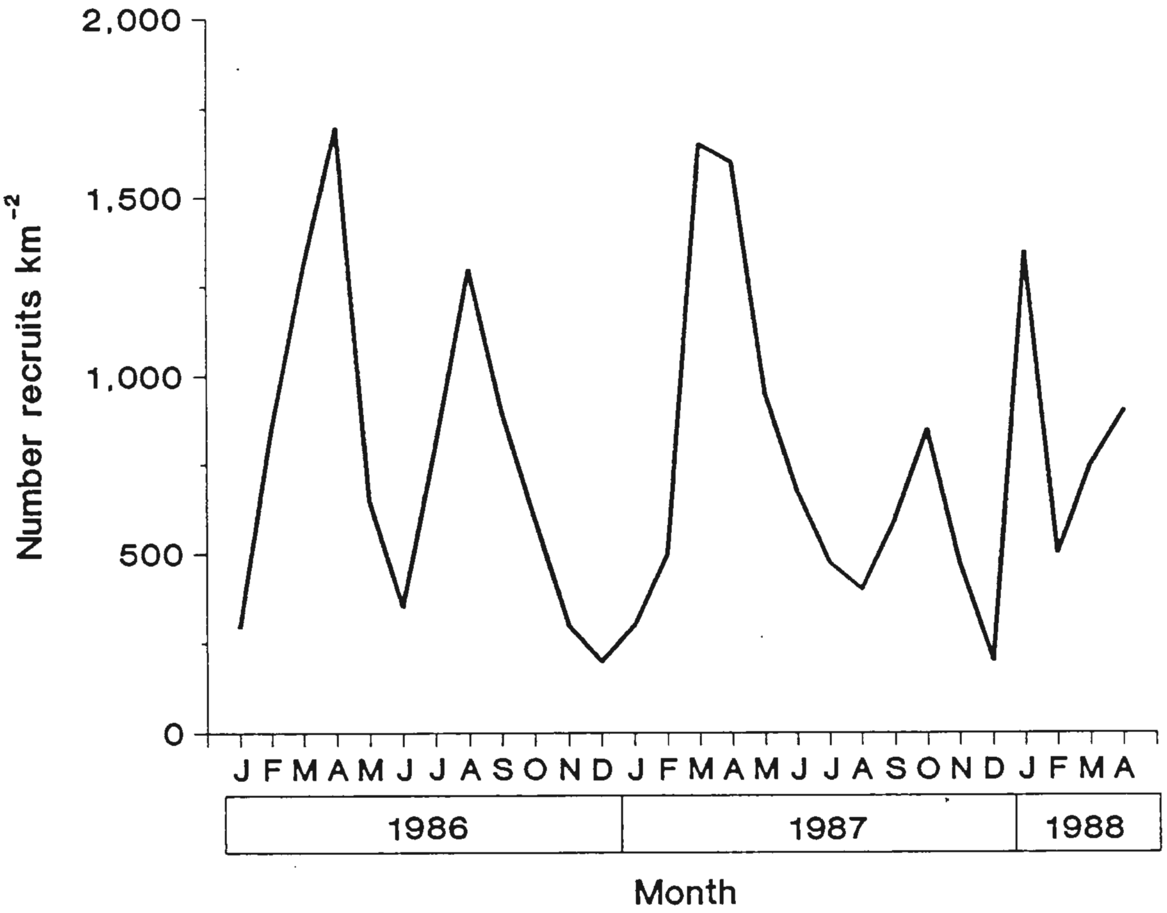

Figure 3. Recruitment peaks of *P. esculentus* produced by the simulation model from survey data.

In the future we plan to use these means and variance to establish recruitment peaks that vary randomly around these values for the simulation. Recruitment will vary about the means as predicted by the variance and as a result each simulation run will produce different results. The mean of a series of Monte Carlo trials will establish long term average estimates. This process is more realistic than simple deterministic models as it includes a range of natural variation. It also allows some idea of the range of results that a management measure may have, and allow experimentation with the variability of recruitment itself.

12.3.4 Future model uses

In the future the model will be extended to include fleet dynamics - the interaction between the rate of fishing and such factors as prawn prices, prawn catches, interest rates etc. If fisheries managers want to predict the effects of these factors on prawn catches then a submodel of fleet dynamics must be included. This submodel would also allow managers to study the possible effects of changing the fleet size or altering its catching power.

The model will also be elaborated into a spatial model which will directly incorporate survey data from prawn tagging experiments and juvenile prawn studies. If managers were to consider additional or altered spatial closures then the model must have a spatial component.

The model can be elaborated or simplified in many ways. The model already allows for prawns to grow at random rates relative to the overall mean predicted by the von Bertalanffy growth curve. This random growth is more realistic, however, this effect increases the computer time necessary to make predictions without greatly modifying the predictions. The computer code which simulates random growth has been disabled in our simulation. This in an example of how different processes or submodels can be added or abandoned as needed to maintain the simplest model consistent with our needs and understanding.

12.4 Acknowledgments

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12.5 References

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