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Identifying Tropical Penaeid Recruitment Patterns

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Abstract. Knowledge of recruitment patterns is a requisite for modern fisheries management. These patterns can range in complexity from a single pulse of identically sized and aged prawns, which is often assumed in fisheries models, to continuous recruitment by prawns of several ages. Existing techniques used to identify recruitment patterns range from the *ad hoc* use of size limits to more complex methods that examine changes in length–frequency modes through time.

A model that allowed variable growth of individuals was used to simulate monthly length–frequency fisheries data from a range of recruitment patterns of varying complexity. The effectiveness of a range of methods to identify these underlying recruitment patterns was examined. Length–frequency survey data from tropical penaeid fisheries for *Penaeus esculentus*, the brown tiger prawn, in two locations off north-eastern Australia (Torres Strait and Turtle Island Group) were also subjected to these methods.

Methods that employed simple truncation by length successfully identified simple recruitment patterns but were not effective for multi-age recruitment patterns. Only the length-cohort and age-cohort methods could identify the presence of older recruits in multi-age patterns. All methods were sensitive to estimates of growth parameters, particularly the cohort-based methods. Results suggest that *P. esculentus* from the two fisheries examined had different recruitment patterns requiring different management approaches.

Extra keywords: shrimp, simulation.

Introduction

Gulland (1983) defined recruitment as the process whereby animals become potentially vulnerable to fishing as a result of growth, change of behaviour, or movement onto the fishing grounds. We define recruitment as the process that makes prawns available to fishers through the developmental migration onto the fishing grounds. Recruits are those prawns that reach the trawling grounds regardless of size or age. In a similar way, numbers of prawns with known ages and sizes can be introduced or 'recruited' to computer models in a fixed schedule. Subsequent processes such as gear selectivity that also control the catch of prawns can then be modelled separately.

Knowing the relationship between the numbers or biomass of spawning stock and that of subsequent recruits is critical to the management of many fisheries. Recruitment overfishing is a possible consequence if this relationship is ignored. Study of this relationship first requires that recruits be identified. For animals that cannot be accurately aged, such as penaeid prawns, recruits are usually identified by size from length–frequency data. It is difficult to do this in a fashion that allows for the possibility of recruits of a wide range of sizes. Usually, prawn researchers must arbitrarily choose a value for the largest-sized animals that will be classed as recruits. Buckworth (1985), Somers *et al.* (1987), and Blyth *et al.* (1990) used prawns less than 'export' size (<26 mm carapace length, CL) as an index of recruitment for the penaeid *Penaeus esculentus*, the brown tiger prawn. Gribble and Dredge (1994) and Glaister *et al.* (1990) used prawns of 20 mm CL as an index of recruitment for *P. esculentus* and *P. plebejus* respectively. Somers (1990) used an age-based criteria to describe recruits. He used prawns that were four months of age as an index of recruitment for *P. esculentus*.

Inferring recruitment from monthly length–frequency data is difficult because four separate processes may operate simultaneously to affect the number and size of prawns at a site between one sampling period and the next. These processes are growth, natural mortality, emigration and immigration. The last of these processes, immigration, is essentially recruitment; as defined above, it is the process that brings the prawns into the area of the fishery. Recruits can arrive as a single cohort of small prawns at one time of the year only. This would be an example of simple recruitment and is the pattern most commonly assumed in fisheries modelling. Blyth *et al.* (1990) described a more complex recruitment pattern for *P. esculentus* in Torres Strait, where recruits arrived during several different months of the year and at different ages.

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Penaeids and other groups that increase in value rapidly with size are vulnerable to growth overfishing. Management of these species often includes seasonal and spatial closures of the fishery to protect prawns until they are the optimum size for harvest in order to maximize the value of the harvest. Design of an effective closure requires information not just on the numbers of recruiting prawns but also on the pattern of recruitment over time and space. Seasonal closures of tropical penaeid fisheries can improve yields up to 40% for fisheries with only one recruiting cohort; however, this is reduced to less than 7% if recruitment involves multiple cohorts (Watson and Restrepo 1994). Carothers and Grant (1987) found significant differences in the expected performance of alternative management policies as measured by simulated harvests, depending on the way in which they represented the recruitment process.

A computer simulation study of penaeid fisheries along the Queensland coast included a project to identify the pattern of recruitment for a variety of commercial penaeids. A range of methods were tested for their ability to identify the original recruitment patterns from a series of simulated variable-growth length–frequency data. We also compared their sensitivity to the growth and mortality parameter estimates that these procedures required. These recruitment identification methods were then applied to length–frequency data from two commercial penaeid fisheries in northern Queensland, Australia. Although both of these fisheries targeted *P. esculentus*, the size structure of the catch suggested that they had different recruitment patterns and that these patterns would affect the use of closed seasons in their management.

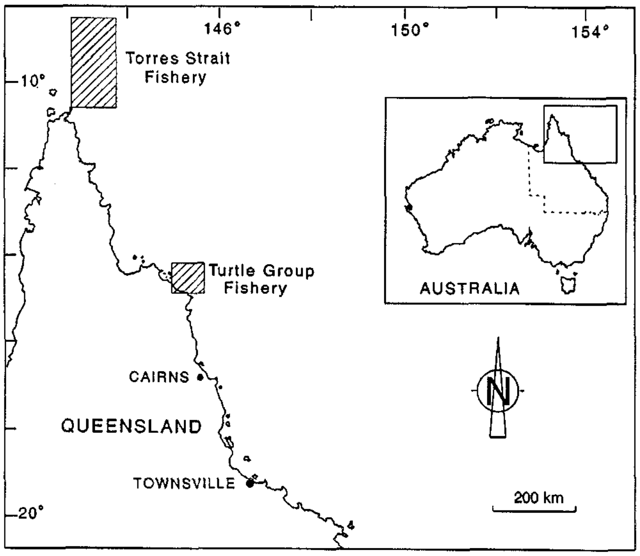

Fig. 1. Location of the Turtle Group and Torres Strait penaeid fisheries.

Methods

Several recruitment patterns were chosen that represented the range observed with wild stocks of penaeids off northern Australia. Length–frequency catch data were simulated on the basis of these recruitment patterns. The simulated length–frequency data were based on normally distributed growth rates, as these produced a more realistic reflection of these fisheries. A variety of computer methods was then used to identify the underlying recruitment pattern used to simulate the data initially. The success of these methods was assessed with the aid of a calculated index of deviation between the expected and observed recruitment patterns. These methods were then used to examine the recruitment patterns of real length–frequency data collected through monthly surveys of two penaeid fisheries (Fig. 1).

The initial number of simulated prawns in each group was 5000 to ensure adequate numbers following losses due to the mortality process modelled. For the sensitivity analysis, values of each growth parameter were varied in 11 steps from –50% to 150% of the chosen mean.

Simulated Catch Data

A realistic simulation of length–frequency data requires growth to be modelled as a stochastic process in which the growth of each individual is subjected to random changes to the common growth process (Cohen and Fishman 1980). Those authors modelled the length of an individual at time t as

$$L_t = \alpha + \rho L_{t-1} + U_t \ ,$$

where U_t is an independent, normally distributed random variable with a mean of zero and a variance of σ^2. The Brody coefficient ρ is $\exp(-K)$ and α is $L_\infty(1-\rho)$ where L_∞ is the asymptotic length and K is the slope constant of the von Bertalanffy (1938) equation

$$L_t = L_\infty[1-\exp[-K(t-t_0)]].$$

The value of t_0, the age of zero length, is assumed to be zero.

The growth parameters and variance of growth used in the simulation were estimated from tagging data from female *P. esculentus* from the Torres Strait fishery (Fig. 1), where $K = 0{\cdot}21$ month^{-1}, $L_\infty = 44$ mm, and $\sigma^2 = 0{\cdot}26$ mm^2 after Watson and Turnbull (1993). For simplicity, only female prawns were modelled.

Prawn mortality was modelled by the equation for exponential decline, where N_{t+1}, the number existing at time $t+1$, is

$$N_{t+1} = N_t e^{-Z} \ ,$$

where $Z = 0{\cdot}3$ month^{-1}, a value approximating that used by Die and Watson (1992) to model *P. esculentus* in the Torres Strait fishery.

In order to more closely approximate the catch of an actual fishery, the simulated length–frequency data were adjusted for net selectivity. The frequency at each length was multiplied by the selectivity at that length, S, calculated as

$$S = \frac{1}{1+e^{-\lambda(L-L_{50})}} \ , \qquad (1)$$

where λ is the slope of the selectivity curve, L is the length, and L_{50} is the length at 50% selection. Values of these parameters were taken from the commercial prawn fishery in Torres Strait (Watson *et al.* 1993), where $\lambda = 0{\cdot}3$ mm^{-1} and $L_{50} = 21{\cdot}5$ mm.

Simulated Recruitment Patterns

Simulated length–frequency data were generated on the basis of three different recruitment patterns of increasing complexity. These were, in order of complexity: a pattern with a single pulse of recruitment, a pattern with two pulses of recruitment, and a multi-age pattern.

Single pulse. A single recruitment age was assumed in the generation of length–frequency data for the single-pulse and double-pulse recruitment patterns. The multi-age recruitment pattern assumed recruits of two ages. For the single-pulse pattern, it was assumed that all prawns were born in January and recruited to the fishery in March at age two months (Fig. 2*a*). Prawns younger than two months were not considered available to the fishery and represented those still in the unfished seagrass nursery areas described by Turnbull and Mellors (1990). Although simulated recruitment was in March, the prawn numbers in the catch data were highest in May because of the net-selectivity adjustments made, which delayed capture of small recruits.

Double pulse. Recruitment was simulated as described above for the single pulse, except that only half the prawns were born in January and recruited to the fishery in March at age two months. The other half were born in October and recruited in December at age two months (Fig. 2*b*). Highest catch numbers in the simulated data lagged behind recruitment dates because of net-selectivity adjustments.

Multi-age. For these simulations, one-third of the prawns were assumed to be born in February and the balance in September. One-third of prawns recruit in April and a further third in November, all at two months of age. The remainder recruit in February at five months of age (Fig. 2*c*). Highest catch numbers in the simulated data lagged behind recruitment dates because of net-selectivity adjustments.

Case Histories of Turtle Group and Torres Strait P. esculentus Fisheries

During 1993, an 18-m research trawler towing commercial (50 mm mesh) otter trawls collected monthly catch samples of brown tiger prawns, *P. esculentus*, from 27 sites throughout the Turtle Group off the north-eastern Queensland coast (Figs 1 and 3*a*). Similarly, from 1986 to 1991, monthly catch samples of *P. esculentus* were collected from 30 sites across the Torres Strait fishery off the northern tip of Australia (Figs 1 and 3*b*). The study was focused not on interannual variations in recruitment patterns but rather on the prevailing annual pattern, so the data from the Torres Strait fishery were pooled by month across sampling years (Fig. 3*b*).

Recruitment Identification Methods

A range of methods included in the trawl fishery simulation program Simsys Version 3.6 (described in Watson *et al.* 1993) was used to identify recruitment patterns from simulated and actual length–frequency catch data. To correct for species-specific net selectivity, frequency at length was divided by the length-dependent selectivity S (Eqn 1). As before, values of these parameters were taken from the commercial prawn fishery in Torres Strait (Watson *et al.* 1993), where $\lambda = 0{\cdot}3$ mm^{-1} and $L_{50} = 21{\cdot}5$ mm carapace length (CL).

In all methods except the age-cohort method, recruits were identified by their length from length–frequency data and pooled by age after length–age conversion using growth parameters. Growth parameters used for Torres Strait prawns were: $K = 0{\cdot}21$ month^{-1}, $L_\infty = 44$ mm for females, and $K = 0{\cdot}3$ month^{-1}, $L_\infty = 34$ mm for males, after Watson and Turnbull (1993). For the Turtle Group fishery, these growth parameters were: $K = 0{\cdot}2$ month^{-1}, $L_\infty = 42$ mm for females, and $K = 0{\cdot}24$ month^{-1}, $L_\infty = 35$ mm for males (Derbyshire, unpublished data). For all prawns from both locations, the value of t_0 was assumed to be zero.

Simple-cut-off method. This method employs an arbitrarily chosen length class (carapace length groups to nearest 1 mm) as the criterion for accepting or rejecting prawns as recruits. For every month, all prawns

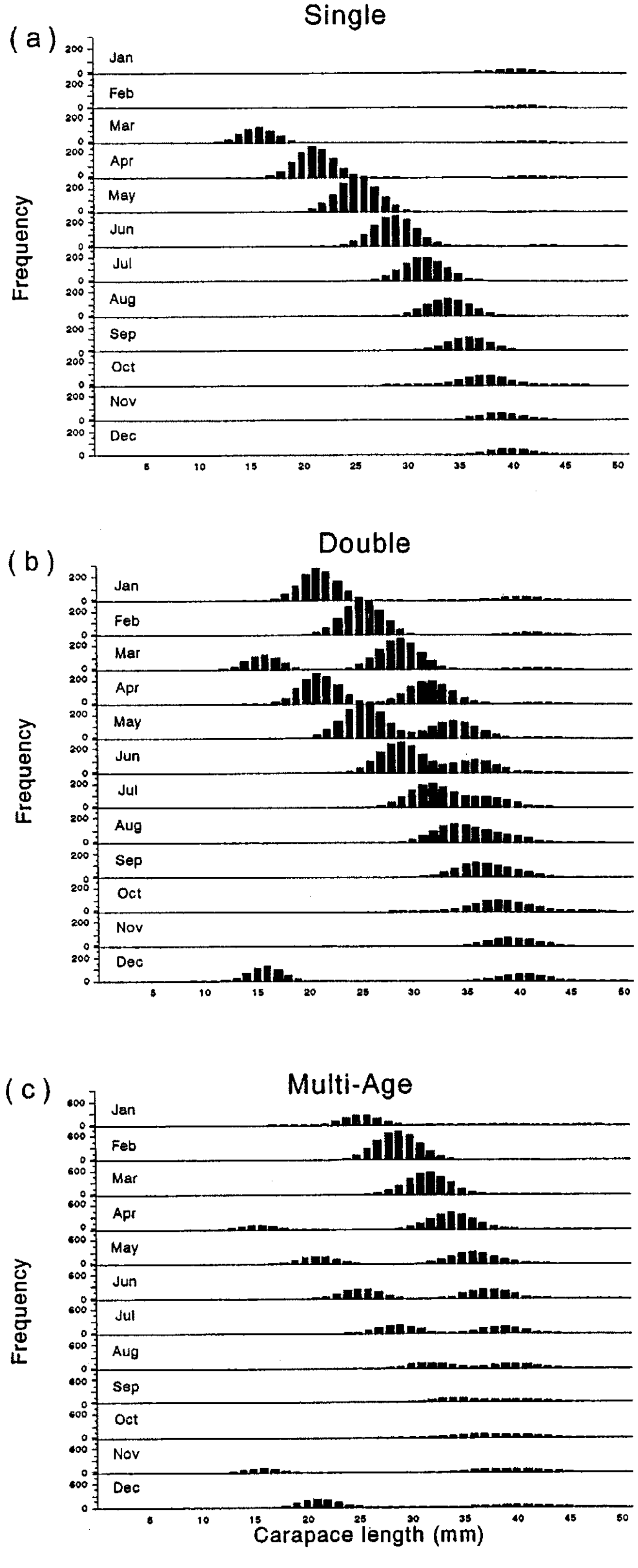

Fig. 2. Simulated length–frequency catch data for *(a)* single, *(b)* double and *(c)* multi-age recruitment patterns used to evaluate recruitment identification methods.

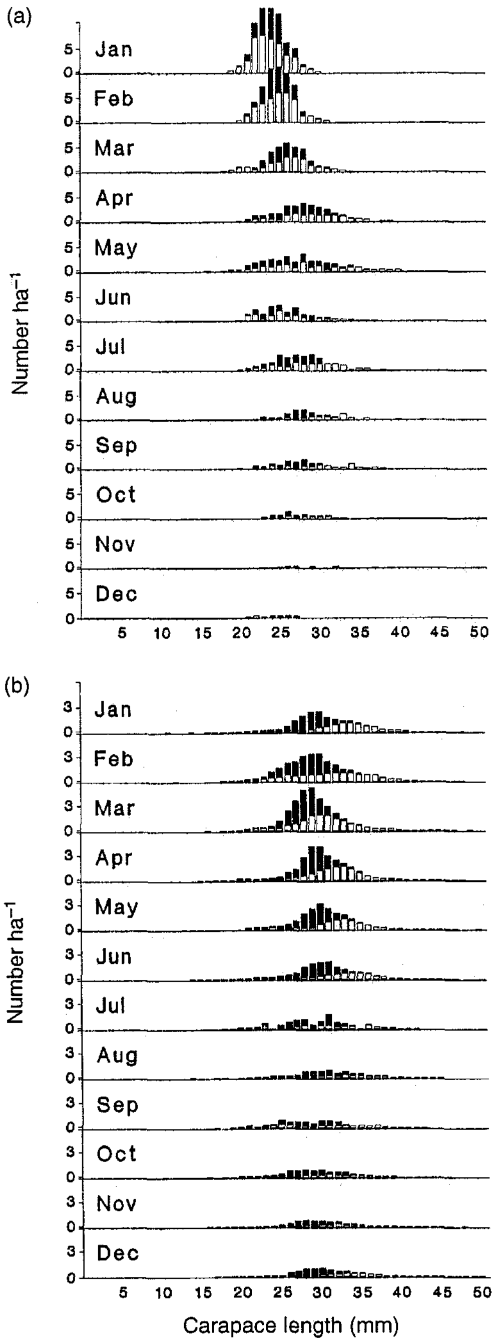

Fig. 3. Length–frequency fisheries data from *(a)* Turtle Group and *(b)* Torres Strait fisheries for *Penaeus esculentus*. Stacked bar graph: females are represented by the white portion of each bar, males by the black portion.

smaller than this chosen length class were defined as recruits. This was the only method used that did not assume that all prawns grow equally. This method assumes that prawns identified as recruits in one month will have grown beyond the cut-off length by the time of the next sample the following month. The estimated growth rates and net-selectivity factors for these prawns make this assumption likely to be true. The value used for the cut-off length, *C*, was 16 mm CL (approximately two months of age).

Maximum-of-monthly-minima method. The minimum length class represented in each month was determined. The largest of these monthly minima over the entire set of monthly samples considered was used as the value with which to truncate the length-frequency data for each month. All prawns less than this length were identified as recruits. This method assumes that recruitment can occur in all but one month of the year.

Minimum-grown method. For every month, the minimum length class represented in the previous month was determined. The length of this class, predicted deterministically from the growth curve for the current month, was used as a cut-off, and all prawns less than this size were identified as recruits. The previous month for January was considered to be December of the same year. This method identifies recruits as those prawns that are too small to have recruited in the previous month.

Length-cohort method. The length of each length class predicted from the growth curve from the length–frequency data for the previous month was determined. After adjusting for the effect of total mortality, the frequencies in corresponding length classes were compared. If the frequency of prawns in a length class in the current month was greater than that expected from the previous month on the basis of our estimate of total mortality (0·3), then the difference was attributed to recruitment. If this difference was negative, then no recruits were identified.

Age-cohort method. The age of each length class in the length–frequency data for the previous month and the projected length of prawns in this length class after one month of growth were calculated. For each monthly cohort, if the frequency of the prawns in the current month was greater than our estimate of total mortality would predict from the previous month, then these prawns were identified as new recruits. By application of the same logic as in the length-cohort method, those prawns that could not be accounted for according to their size/age and abundance were identified as recruits.

Analysis

Recruitment patterns determined from the simulated length–frequency data by the methods described above were compared with the original recruitment pattern used to simulate the data. For example, for the simulated double-pulse recruitment data, 50% of prawns were expected to recruit in March at age two months and the balance in December at the same age because of the parameter values used to simulate the data. The pattern of recruitment observed (percentage by month and age), as identified by each method described above, was then compared with the expected recruitment pattern. An index of deviation, *D*, was calculated as

$$D=\sum_{i=1}^{12}\sum_{j=1}^{12}\frac{\left(Observed_{i,j}-Expected_{i,j}\right)^2}{Expected_{i,j}},$$

where $Expected_{i,j} > 0$, i is the age of prawns (from 1 to 12 months) in the original and simulated data, and j is the month of the year. Expected values are the percentage of all recruits found at age i in month j, so values of D can vary from 0 to 100.

The index of deviation was used to indicate the degree of agreement between the expected and observed results. Parameter values applied in the methods to identify recruitment patterns were varied from those values used originally to simulate the catch data so that the effects of parameter values on the index of deviation could be observed. For the same simulated data, one parameter was varied at a time from –50% to 150% of the original value used to simulate the data, allowing a sensitivity evaluation of parameters.

Results and Discussion

Simple-cut-off Method

This method resulted in good fits between expected and observed single and double recruitment patterns, but the deviation was considerably greater for the multi-age recruitment pattern, with values exceeding 40% (Figs 4*a*–4*c*). The results were comparatively insensitive to the value of the cut-off (after a threshold of –20% of the length corresponding to the true age of recruitment). Results were sensitive to the value of K used, with the best results recorded when K was 10% greater than that used to generate the simulated data. This higher value of K more closely matched the 16 mm cut-off with the recruitment age of two months that was used when the data were generated.

There were two values for each of K and L_∞ that yielded reduced deviation for the multi-age pattern (Fig. 4*c*). With the original parameter values, there were too many recruits identified from the two groups of young recruits (two months of age) and none from the older recruits (five months of age) (Table 1). As parameter values were increased or decreased from the true values, the number of younger recruits identified was reduced. At points above and below the true parameter values, the lowest deviation occurred when the observed proportion of young recruits most closely matched that expected. Similarly, there were two minima resulting from the range of cut-off lengths used. One value best identifies the young recruits and the other the older recruits.

Table 1. Results of the analysis of simulated multi-age recruitment data, comparing the expected and observed percentages of recruits by age group and method used

'Young' recruits represent those aged two months in April and November, and 'old' recruits were aged five months in February

	Young recruits	Old recruits
Expected	67	33
Observed		
Simple-cut-off	98	0
Maximum-of-minima	42	0
Minimum-grown	96	0
Length-cohort	30	10
Age-cohort	42	14

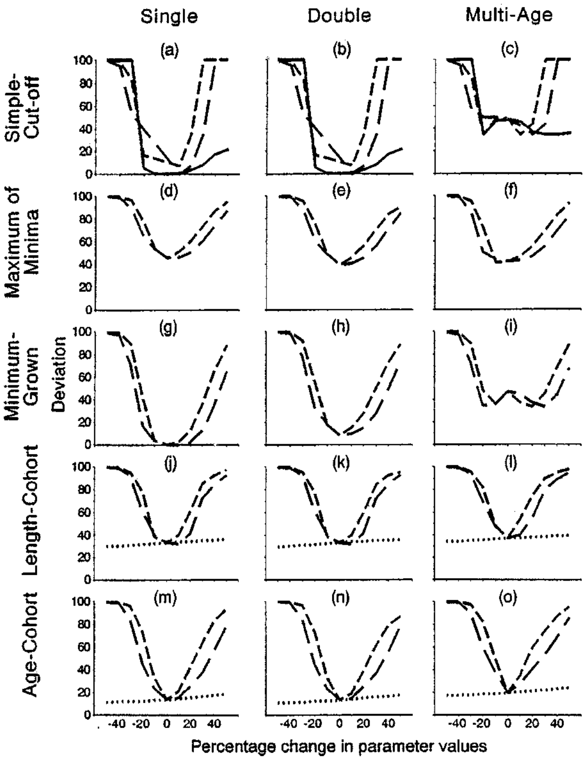

Fig. 4. Sensitivity, to change in original parameter values, of deviation between expected and observed single, double and multi-age recruitment patterns identified by *(a–c)* simple-cut-off, *(d–f)* maximum-of-minima, *(g–i)* minimum-grown, *(j–l)* length-cohort, and *(m–o)* age-cohort methods. Deviation varies from 0 to 100 (percent of recruits). Parameters that are varied are identified in the plots as: cut-off, solid line; asymptotic length (L_∞), short-dashed line; slope constant (K), long-dashed line; and total mortality (Z), dotted line.

Maximum-of-minima Method

Unlike the simple-cut-off method, this method does not rely on an estimate of an appropriate cut-off length. Fits between expected and observed values with this method were similar for the three recruitment patterns (Figs 4*d*–4*f*). Although deviation values were generally large, fits with this method were slightly better when recruitment occurred in more than one month (double and multi-age patterns) because the critical assumption underlying this method is that recruitment occurs in all but one month of the year. None of the older recruits were identified from the multi-age recruitment pattern (Table 1). The method was moderately sensitive to changes in the value of K and L_∞.

For many prawns, the month for which recruitment was simulated was incorrectly identified, or they were assigned the wrong ages owing to the variable growth function used. This scattering of recruits into adjacent age and month cells in the recruitment pattern matrix contributed to higher deviation values than those for the other methods.

Minimum-grown Method

Fits with this method were good for the single and double recruitment patterns but poor for the multi-age recruitment pattern, as older recruits were not detected (Table 1). As with the simple-cut-off method, two set of parameters yielded reduced deviation values (Figs 4*g*–4*i*). These values corresponded to combinations where the proportion of recruits from the two younger recruit groups most closely matched that expected; performance in that case was comparatively insensitive to changes in K and L_∞.

Length-cohort Method

This method produced moderately good fits for all recruitment patterns (Figs 4*j*–4*l*) and correctly identified the main recruitment times and ages. This method identified older recruits in the multi-age pattern (Table 1) and found these in the expected ratio to younger recruits; however, the proportion of expected recruits identified was lower than that for any other method. The variable growth function used caused misassignment of recruit ages and contributed to the relatively high deviation values. The values were moderately sensitive to changes in K and L_∞ but insensitive to estimates of Z. Although the value of Z controlled the number of recruits identified with each recruitment group, the use of percentages to describe the recruitment pattern greatly reduced its influence on deviation values.

Age-cohort Method

This method produced moderately good fits for all recruitment patterns (Figs 4*m*–4*o*). Like the length-cohort method, it detected the older recruits in the multi-age pattern (Table 1) and in the expected proportion to younger recruits. This method, however, detected 16% more of the actual recruits than did the length-cohort method. Greater accuracy may be possible because this method does not require the repeated use of an inverse von Bertalanffy calculation to assign lengths to age groups of prawns, so less error was induced in the calculations.

The reason that more of the actual recruits in the multi-age pattern were not detected was that prawns aged five months could not be readily separated from those of age four or six months because of their slow growth and because of the cumulative effects of variable growth of individuals. We estimated that up to 10% of recruits were assigned to the wrong age because of this problem. Results from this method were moderately sensitive to K and L_∞, but as with the length-cohort method they were insensitive to changes in Z.

Turtle Group Prawn Fishery

The simple-cut-off, maximum-of-minima, and minimum-grown methods failed to identify any older recruits in *P. esculentus* length–frequency sample data from the Turtle Group (Figs 5*a*, 5*c* and 5*e*). Most recruitment was identified as occurring in January at approximately four months of age.

The minimum-grown method produced the most concentrated pattern of recruitment, with 40% of all recruits occurring in January at age four months (Fig. 5*e*). Although there were similar results from the length-cohort and age-cohort methods, they suggested that the main recruitment period took place in January at ages four to five months (Figs 5*g* and 5*i*). The maximum-of-minima method indicated that the maximum recruitment occurred at age three months in January (Fig. 5*c*).

Recruitment patterns identified by these methods were supported by examination of histograms of length–frequency data from surveys overlaid with appropriate prawn growth curves. These suggested that recruitment occurred in January and February with females at age four months and males at age five months. This recruitment pattern suggests a spawning period from August to October.

Torres Strait Prawn Fishery

There was a clear dichotomy in the results between the methods used with *P. esculentus* length–frequency sample data from the Torres Strait. The length cut-off methods—simple-cut-off, maximum-of-minima, and minimum-grown (Figs 5*b*, 5*d* and 5*f*)— all indicated that there was recruitment of prawns from two to four months of age during most of the year. The simple-cut-off method indicated that recruitment occurred at three to four months of age, whereas the other two methods suggested it occurred at ages two to three months. The maximum-of-minima method indicated that recruitment occurred throughout the year at age two months. In contrast, the length-cohort and age-cohort methods detected only a small numbers of recruits at age three months in most months but indicated that the main recruitment occurred in February and March with prawns aged five to six months (Figs 5*h* and 5*j*). This difference in the interpretation of recruitment patterns from fisheries data is significant because *P. esculentus* grows and increases in commercial value rapidly with age.

The recruitment of older, more mature prawns in the Torres Strait fishery is supported by other research. Tagging experiments and other length–frequency data from research surveys indicate that *P. esculentus* moves eastward into this fishery during February and March. On the basis of growth parameters from Watson and Turnbull (1993), these prawns are estimated to be between five and six months of age when they arrive at the fishing grounds.

General Discussion

The length-cohort and age-cohort methods were the only methods that detected older recruits in the presence of younger recruits in simulated length–frequency data. Unless the recruitment pattern was single, i.e. consisting of a single pulse of young prawns, most methods underestimated the expected numbers of recruits and assigned the wrong ages to prawns identified as recruits. Underestimation of recruits resulted because most methods ignored older recruits. Recruits were assigned to the wrong ages because individuals had variable growth and because it was especially difficult to calculate ages for prawns approaching L_∞. Prawns larger than L_∞ had to be assigned the age of prawns at L_∞ because their age could not be calculated by the inverse von Bertalanffy formula. It is actually inappropriate to predict ages from a formula developed to

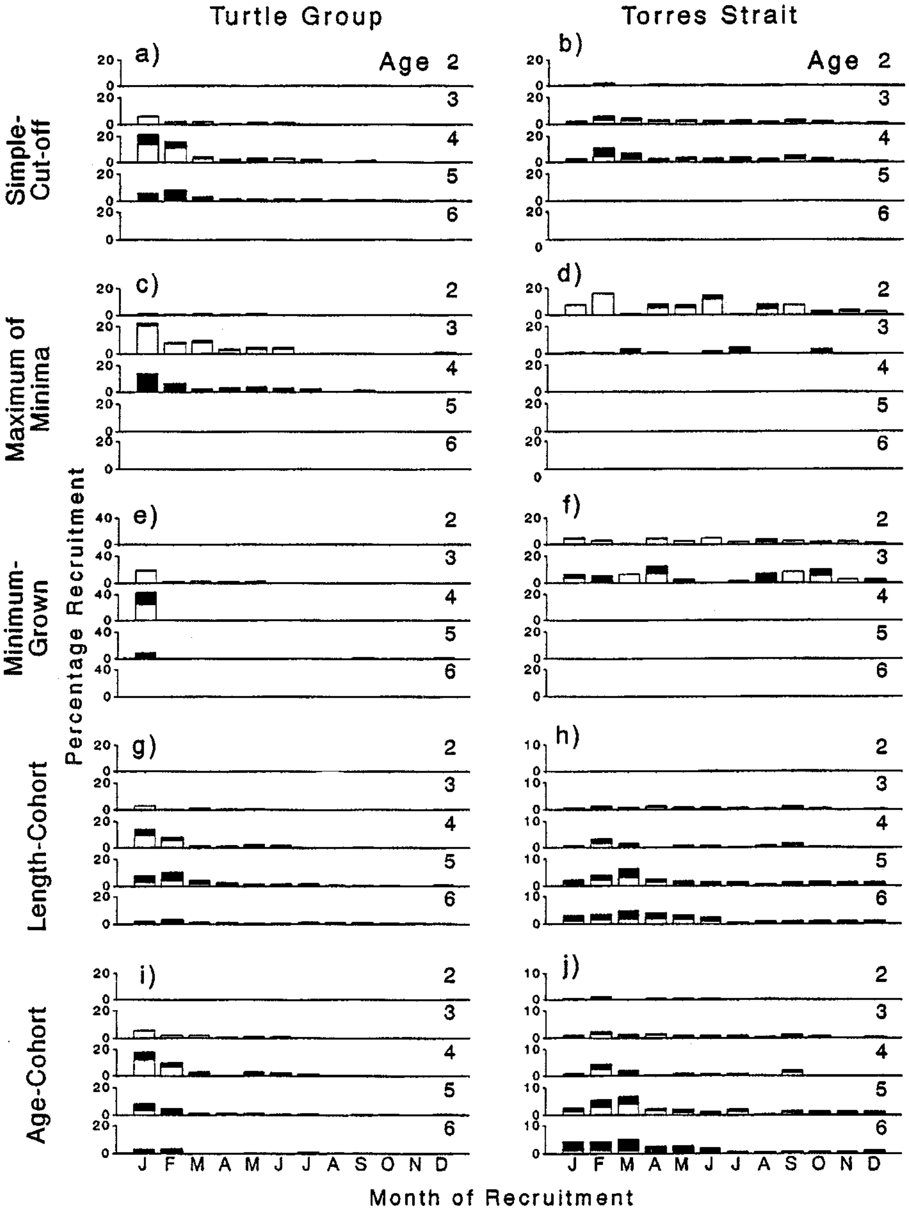

Fig. 5. Recruitment patterns identified from Turtle Group and Torres Strait fisheries data by *(a, b)* simple-cut-off, *(c, d)* maximum-of-minima, *(e, f)* minimum-grown, *(g, h)* length-cohort, and *(i, j)* age-cohort methods. Stacked bar graph: females are represented by the white portion of each bar, males by the black portion. Ages shown are in months.

predict length from age, which suggests that future work must address the problem of estimating age from length, especially for larger prawns.

The length-cohort and age-cohort methods could correctly identify the groups of recruiting prawns if estimates of growth parameters were within 20% of their true values. If the variance of individual growth was less than that used in the present simulations, then it might be possible to correctly identify groups of recruits even if the estimates of growth parameters deviated more than 20% from the actual values.

The inability to assign ages to prawns as they approach the asymptotic length is a major problem of the two cohort-based methods. This problem is most acute for species that cease growing before they are fully recruited into the fishery or for times when the size of recruits approaches L_∞. If the estimate of total mortality is too high, then prawns will be identified as recruits that existed in the fishery the previous month.

The same species in two different locations or fisheries appears to exhibit different recruitment patterns. This means that in some fisheries like the Turtle Group, species such as *P. esculentus* recruit at a relatively young age and are still growing rapidly at this time, whereas in other fisheries such as the Torres Strait, some prawns do not enter the fishery until they are older and slower-growing.

Differences in the recruitment patterns between *P. esculentus* in the Turtle Group and those in Torres Strait could be related to the differences in the bathymetry of the areas. In the area of the Turtle Group fishery, the depth increases gradually with distance from the nearshore seagrass areas that *P. esculentus* use as juveniles before they recruit into the fishery. This relatively simple bathymetry may allow a gradual migration offshore into the fishery with increasing age. Under these conditions, prawns would be expected to recruit into the fishery at the same age. The date at which they recruit into the fishery would be closely related to the spawning period.

Courtney *et al.* (1989) found that the distribution of small and large *Metapenaeus endeavouri* off central Queensland differed from that reported for the Torres Strait by Somers *et al.* (1987), and he suggested that the more complex bathymetry of the Torres Strait was an explanation. The complex bathymetry of Torres Strait can also explain the unusual recruitment pattern of *P. esculentus*. The area has an extensive reef system to the west of the fishery. These shallow reefs support seagrass that is an important juvenile habitat for *P. esculentus* (Turnbull and Mellors 1990). The area away from the fishery to the west of the reef system is quite shallow (10 to 20 m). Evidence from tagging studies and length–frequency data from research surveys suggest that although some prawns migrate toward the fishery and recruit at a young age, others migrate to the west, away from the fishery (Watson and Turnbull 1993). These western migrants grow in the unfished area to the west of the reef and subsequently migrate eastward, passing through channels in the reef and recruiting into the fishery at mature ages. These movements have been confirmed by tagging studies (Watson and Turnbull 1993) and monthly surveys of the area. The complex bathymetry of the Torres Strait likely explains the complex recruitment pattern found in this fishery, characterized by recruitment of both younger and older prawns in different months. It is important that this recruitment pattern be understood and included in any assessment of the relative advantages of seasonal and area closures to prevent overfishing. It is also important that all recruits resulting from a spawning be enumerated if stock and recruitment relationships are to be examined and recruitment overfishing avoided.

Conclusions

Although simple methods, which are used to identify recruits in many fisheries, may work extremely well if recruitment can be characterized by a single pulse consisting of prawns of the same age, they fail to detect older recruits even though such detection may be important for the best management of the fishery. For the purpose of identifying the basic recruitment pattern for use in computer modelling, the simple-cut-off method was adequate except when the size of recruits was mixed. In contrast, length-cohort and age-cohort methods proved comparatively insensitive to the complexity of the recruitment pattern and therefore identified older recruits. These methods were, however, sensitive to errors in the estimation of growth parameters. Therefore, when identification of older recruits is important, such as in modelling management closures of fisheries, use of the cohort-based methods is recommended, but only if growth parameters are well known. In the absence of methods to age prawns, however, it is important to attempt a range of methods to establish recruitment patterns so that dangerous assumptions can be avoided.

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