J. Fish. Sci. Tech. 5(2), 114~121, 2002

JOURNAL OF
FISHERIES SCIENCE
AND TECHNOLOGY

Seasonal Variation in Catchability of Penaeid Prawns in the Night-time Prawn Fishery in Albatross Bay, Gulf of Carpentaria, Australia

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(Received September 2001, Accepted June 2002)

A correction index of catchability (CIC) was derived using a 6 year research data set to examine the seasonal variation in catchability for the night time prawn fishery in Albatross Bay. CIC reflects the composite effect of the monthly variation in size selectivity, emergence-burying behaviour and population density variation of prawn populations. The values of CIC for four dominant species, *Metapenaeus endeavouri, M. ensis, Penaeus semisulcatus* and *P. esculentus,* were examined. The value of CIC for *M. endeavouri* varied substantially and was the highest in August. The values of CIC for *M. ensis* were high during November to March and the seasonality was weaker than that for *M. endeavouri.* The monthly variation in CIC for *P. semisulcatus* reflected the seasonal variation in population density, being high during November to February. These results suggest that the catchability of *P. esculentus* is steady throughout the year but it varies greatly on a seasonal basis for *M. endeavouri.*

Key words: Catchability coefficient, Size selectivity, Emergence behaviour, Population density

Introduction

Four penaeid prawns, *Metapenaeus endeavouri, M. ensis, Penaeus semisulcatus* and *P. esculentus,* are commercially important species in Australia and in the Indo-West Pacific region. They comprise over 95% of the catches in the night time Northern Prawn Fishery (NPF) which is one of the most profitable fisheries in Australia. Albatross Bay region is one of the most important fishing grounds in the NPF.

The NPF is managed by input controls set on the basis of the advice provided by scientists on the status of penaeid shrimp stocks. This advice is based on stock assessments (Somers, 1994; Wang and Die, 1996; Somers and Wang, 1997) that rely upon the knowledge on biological and fishery parameters. One of these parameters is catchability (normally denoted by q), which is usually assumed to relate linearly the fishing mortality (F) of an exploited stock to a given unit of fishing effort (f): thus, $F = qf$. The yield from the fishery can then be represented as FB, where B is the exploitable biomass. In general, estimates of the catchability coefficient derived from most existing methods are assumed to be constant during a year. However catchability is affected by various biological factors that have strong seasonality such as emergence-burying behaviour, seasonal population density and size distributions. Factors affecting the relationships between prawn behaviour and catchability have been studied by Penn (1984), Hill (1985) and Park and Loneragan (1999). They suggested that catchability varies with behavioural characteristics such as emergence and aggregation activity in relation to environmental factors. From previous studies on emergence behaviour and movement (Hill, 1985; Somers and Kirkwood, 1991), Somers and Wang (1997) derived a catchability index for two tiger prawn species, *P.*

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*Corresponding author: youngyl96@yahoo.com *semisulcatus* and *P. esculentus* that reflects the seasonal changes in catchability. Catchability may also be size-dependant. In the case of *M. endeavouri* and *M. ensis*, which have more slender and shorter bodies than *P. semisulcatus* and *P. esculentus*, size selection by fishing gear can be a significant factor in determining catchability.

In this study, a correction index of catchability (CIC) was derived using data collected at 45 stations during the 6 year research period. CIC reflects the composite effect of the monthly variation in size selectivity, emergence and population density variation of prawn populations. The values of CIC for four commercial species, *M. endeavouri*, *M. ensis*, *P. semisulcatus* and *P. esculentus*, were examined.

Materials and Methods

Research survey data

Monthly length-frequency distributions and catch per unit fishing effort for the four prawn species were obtained from research surveys carried out at 45 stations over 66 lunar months during 6 years (March 1986 to March 1992; Fig. 1; full details on study area and sampling stations are found in Crocos and Van der Velde, 1995). Trawling stations covered a depth rage of 5 to 65 m while the commercial fishery was mostly confined to depths of 15 to 35 m. Four groups of stations were sampled during this study. Station types 1 (5 to 20 m) and 2 (20 to 40 m) were sampled monthly over the whole 6 year period. Type 3 was sampled monthly for the first 2 years and Type 4 (40 to 65 m) was sampled in May, July and November 1987 and in February 1990. In each survey four 9 m (headrope length) nets were used at towing speed of 3.2 knots. The stretched-mesh size of each net was 50 mm for the body and 44 mm for the cod-end, which the mesh combinations are common in the NPF. Catch per unit fishing effort was standardized to the number of prawns caught per 60 net-minutes (4 nets 15 minutes) and was used as a measure of density of

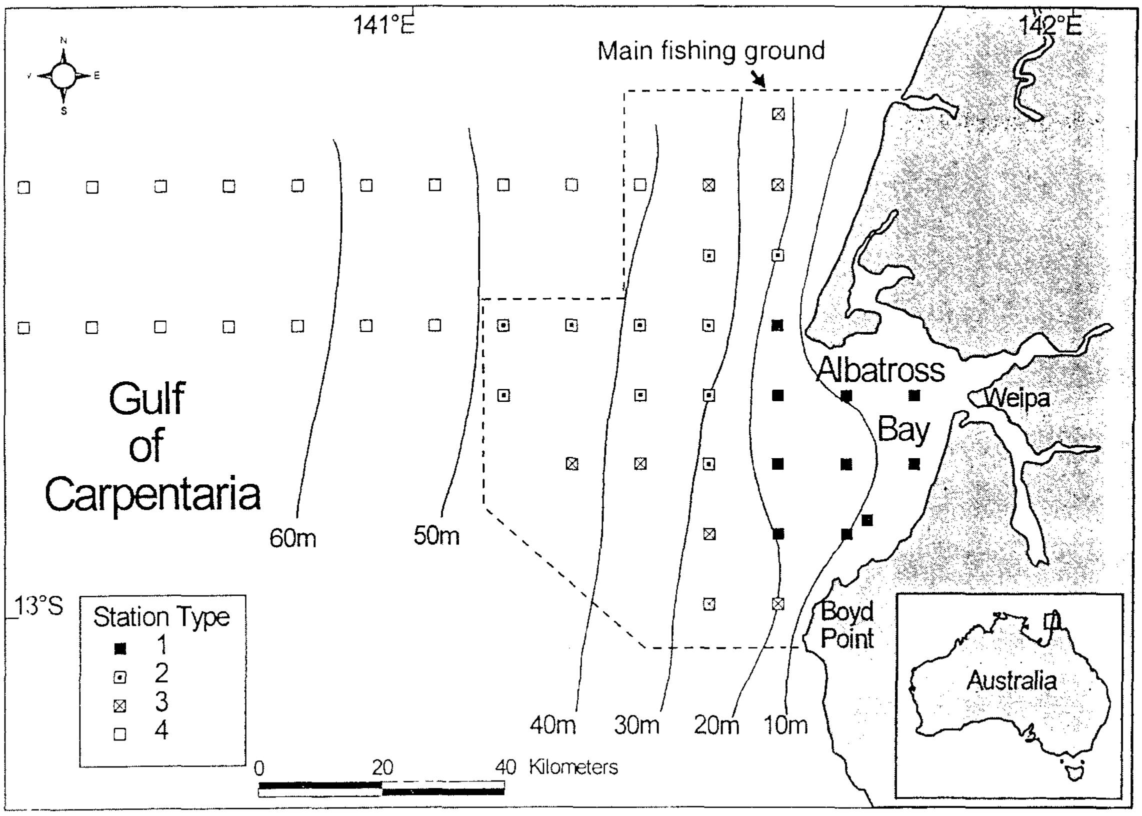

Fig. 1. Study area in Albatross Bay region of northeastern Gulf of Carpentaria, Australia, showing the main fishing ground, sampling stations and station groups (Types 1 to 4) used to determine spatio-temporal spawning activity (this figure is quoted from Crocos et al. (2001), Fig. 1).

prawn populations. All trawls were made at night. Total number of individuals monthly sampled ranges between 37 and 221 (*M. endeavouri*), 13 and 556 (*M. ensis*), 29 and 252 (*P. esculentus*), 35 and 1034 (*P. semisulcatus*).

Size selectivity

Pauly's (1984) length-converted catch curve method was used to estimate size selectivity from the length frequency data. This method develops a curve that describes the combined effect of recruitment and gear selection for a stock, i.e.

$$S_t = C_t/C'_t = C_t/[\Delta t \exp(\Phi - Zt)] \qquad (1)$$

$$\ln(C_t/\Delta t) = \Phi - Z(t_1 + \Delta t/2) \qquad (2)$$

$$\Delta t = t_2 - t_1 = (1/K)\ln\{(L_\infty - L_1)/(L_\infty - L_2)\} \qquad (3)$$

$$t_1 + \Delta t/2 \cong t_{(L_1+L_2)/2} = t_0 + (-1/K) \ln[1-(L_1+L_2)/(2L_\infty)] \qquad (4)$$

where S_t is size selectivity during t (i.e. from age t_1 to t_2), C_t is the catch in number between relative age t_1 and t_2, C'_t is the expected number in the catch from age t_1 to t_2, Φ is a constant that is estimated from Equation (2) using regression analysis, K and L_∞ are von Bertalanffy growth parameters, Z is the overall value of total mortality, t_0 is the hypothetical age at length zero and L_1 and L_2 are the lower and upper limits of a given length class. This approach assumes that Z is constant, t_0 is zero and age $t_1 + \Delta t/2$ is the same to that at length $(L_1 + L_2)/2$ (i.e. Equation (4)).

The selectivity of a net during a single haul can be described by a logistic curve, namely

$$S_t = 1/[1+\exp(T_1 - T_2 t)] \qquad (5)$$

$$\ln[1/S_t - 1] = T_1 - T_2 t \qquad (6)$$

where S_t is gear selectivity in terms of relative age t and T_1 and T_2 are constants. If the resultant curve for a penaeid prawn is assumed to be a logistic curve such as equation (5), from Equations (1) and (6),

$$\ln[\{t \exp(\Phi - Zt)/C_t\} - 1] = T_1 - T_2 t \qquad (7)$$

T_1 and T_2 were estimated from Equation (7) which is a linear equation that has a form, $Y = a + bX$ ($a = T_1$, $b = T_2$) using regression analysis. The size selectivity at length $L_t(S_{Lt})$ was then estimated from equation (5), namely

$$S_{Lt} = 1/[1+\exp\{T_1 - T_2(t_0 - \ln(1 - L_t/L_\infty)/K)\}] \qquad (8)$$

Emergence-temperature relationship

The seasonal variation in prawn emergence behaviour affects the monthly catchability coefficient. The emergence-temperature relationship for *M. endeavouri* was examined by Park and Loneragan (1999) and used to estimate the seasonal variability in the mean daily duration of emergence (i.e. $E_i = \exp(3.50 + 0.24T_i - 0.005T_i^2)$ where E_i is the mean daily duration of emergence in month i and T_i is the mean temperature in month i).

For the months that the mean temperature is below 27℃, Hill's (1985) emergence-temperature relationship, $E_i = 34.7T_i - 488$ (when $14 \leq T_i < 27$C), was used to calculate the extent of seasonal variation in emergence for *P. esculentus*. For the months when the mean water temperature is 27℃ or higher, the duration of emergence was assumed to be the same as the maximum value for the months that the water temperature is below 27℃. The duration of emergence for *M. ensis* did not differ with temperature (see Park and Loneragan, 1999).

Seasonal variation in population density

Crocos and Van der Velde (1995) found that *P. semisulcatus* in Albatross Bay move to offshore waters (>40 m) outside of the commercial prawn fishing ground after February (i.e. after the peak of recruitment) and they move back to shallower waters (<40 m) after July. *M. endeavouri* and *M. ensis* showed a similar pattern to *P. semisulcatus* in Albatross Bay (Crocos et al., 2001). *M. endeavouri* move offshore (>40 m) and dispersed after February and move inshore after July (Crocos et al., 2001). *M. ensis* move offshore (>40 m) after April or May, which is the peak of recruitment, and appear to reaggregate in inshore waters (<35 m) from August or September (Crocos et al., 2001). Offshore migration by *P. esculentus* has not been reported in Albatross Bay. Somers et al. (1987) found that most subadult (21~28 mm CL) and adult (>28 mm CL) *P. esculentus* were in shallow waters (<40 m) in the north-western Gulf of Carpentaria. For *P. esculentus*, therefore, the population density variation due to the seasonal migration was assumed to be zero. Although the distance of the migration for *P. semisulcatus* and the two endeavour prawn species in Albatross Bay is only about 40~100 km, seasonal effects of the population density on catchability in the commercial prawn fishing ground may be significant.

Monthly variation in population density was calculated from the catch per unit effort (CPUE) distribution of the two endeavour species and *P. semisulcatus* in Albatross Bay in May, July, November 1987 and February 1990. A relative density index (A) was used to estimate the seasonal variation in population density, namely

$$A = mCPUE_s / mCPUE_T \qquad (9)$$

where $mCPUE_s$ is the mean CPUE in the shallow waters (Fig. 1, station group 1, 2 and 3) and $mCPUE_T$ is the mean CPUE in the total research area (Fig. 1, station group 1, 2, 3 and 4). The values of A for the three species in the other months were then calculated by linear interpolation from the estimated values of A in February, May, July and November. The index A then reflects the proportion of seasonal density variation.

Correction index of catchability (CIC)

A correction index of catchability (CIC) was derived from (I) the size selectivity estimates (Equation (8)), (II) the emergence-temperature relationships (Hill, 1985; Park and Loneragan, 1999) and (III) the relative density index that reflects the seasonal density variations (Crocos and Van der Velde, 1995; Crocos et al., 2001). Therefore, CIC for species g in month i (CIC_{gi}) can be expressed as

$$CIC_{gi} = (S_{\lambda gi} / mS_{\lambda g})(E_{gi} / mE_g)(A_{gi} / mA_g) \qquad (10)$$

where $S_{\lambda gi}$ is the size selectivity at the mean carapace length $\lambda$for species g in month i, $mS_{\lambda g}$ is the mean value of $S_{\lambda gi}$, E_{gi} is the mean daily duration of emergence for species g in month i, mE_g is the mean value of E_{gi}, A_{gi} is the relative density index for species g in month i and mA_g is the mean value of A_{gi}. In the present study, we assumed that the seasonal spatial distributions of CPUE for each species in a given research area (station groups 1, 2 and 3) reflect those in the real fishing area in the Albatross Bay.

Results

The estimates of carapace length at which size selectivity is 0.5 ($L_{0.5}$) for endeavour prawn species were about 20 mm (*Metapenaeus endeavouri*) and 25 mm (*M. ensis*) while those for tiger prawns were 19 mm (*Penaeus esculentus*) and 21 mm (*P. semisulcatus*) (Fig. 2).

The relative size selectivity for *M. endeavouri* was higher than the annual mean value from March to

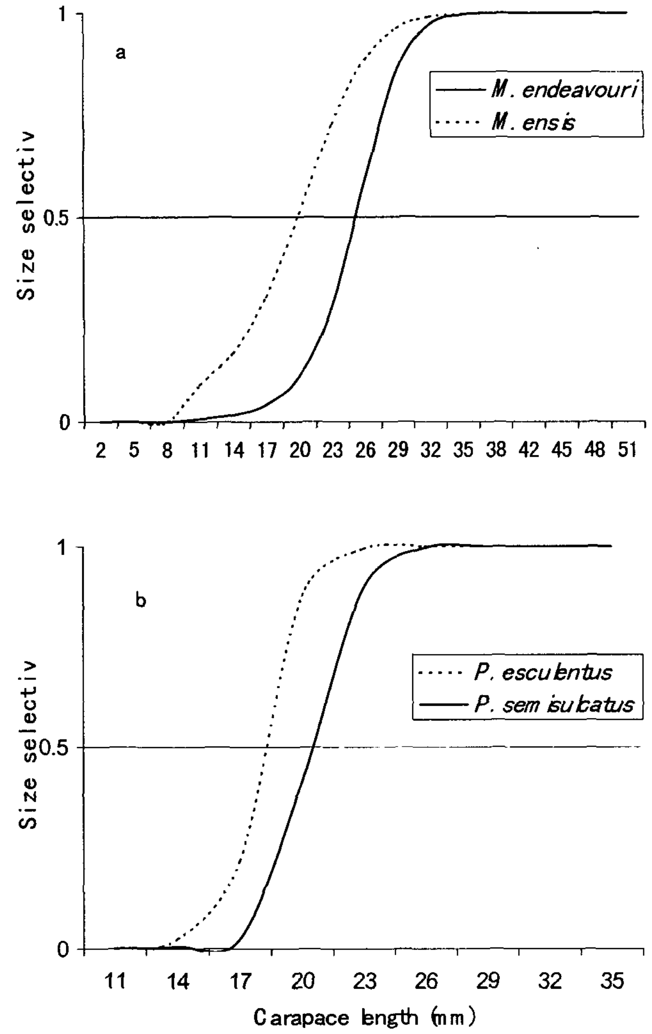

Fig. 2. Size selectivity curves for (a) endeavour prawns, *Metapenaeus endeavouri* (L_∞=49 mm, K=1.8 yr^{-1}, Z=5.09 yr^{-1} (R^2=0.73); T_1=7.63, T_2=19.04 (R^2=0.89)) and *M. ensis* (L=48.3 mm, K=2.3 yr^{-1}, Z=5.12 yr^{-1} (R^2=0.65); T_1=4.5, T_2=19.54 (R^2=0.71)), and (b) tiger prawns, *Penaeus esculentus* (L_∞=48 mm, K=2.7 yr^{-1}, Z=3.71 yr^{-1} (R^2=0.69); T_1=14.22, T_2=80.94 (R^2=0.87)) and *P. semisulcatus* (L_∞=56 mm, K=2.5 yr^{-1}, Z=5.25 yr^{-1} (R^2=0.79); T_1=15.36, T_2=83.45 (R^2=0.92)), in the night time prawn fishery in Albatross Bay.

October and lower during November to February. The relative size selectivity for *M. endeavouri* was lowest in December (Fig. 3a). For *M. ensis*, the relative size selectivity was lower than the annual mean value during January to April but remained higher during the rest of the year (Fig. 4a). The relative size selectivity for *P. semisulcatus* remained constant at around the annual mean value through the year (Fig. 5a).

The relative value of duration of emergence for *M. endeavouri* was slightly higher than the annual mean during June to October and lower during December to April (Fig. 3b). The relative emergence for *P. esculentus* was constant through the year. The relative density index reflects the extent of migration of prawn population into the fishing ground: i.e. as the extent of migration increases, the relative population density within the fishing ground increases. The value of the monthly density index for *M. endeavouri* remained relatively constant at around 1.3 from July to November and decreased to 0.4 in February (Fig. 3c). In contrast, the value of the relative density index for *M. ensis* was the highest in February and the lowest in July (Fig. 4b). For *P. semisulcatus*, the relative density index was higher than the mean value during October to March (Fig. 5b).

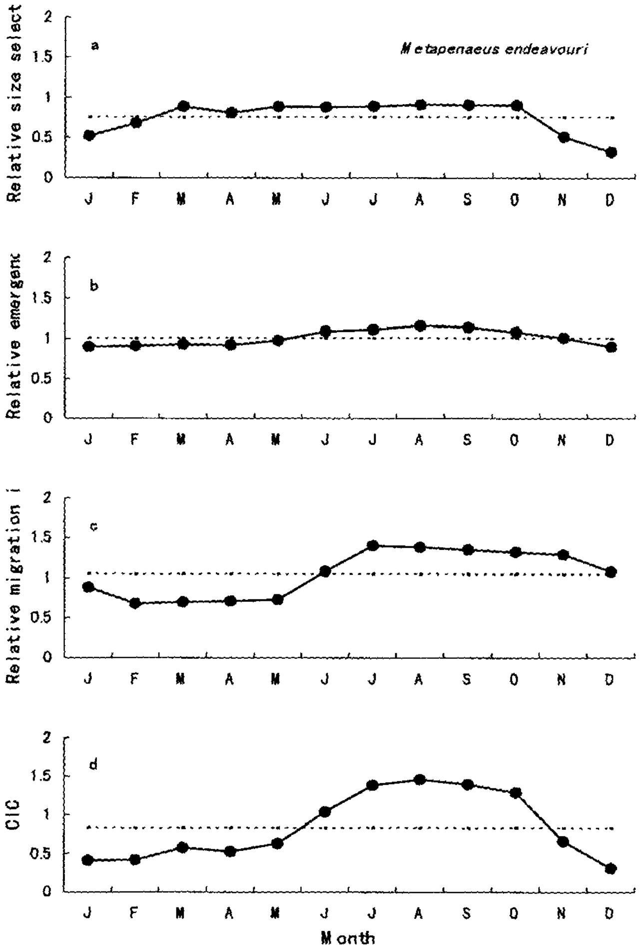

Fig. 3. Monthly variation in (a) relative size selectivity, (b) relative emergence, (c) relative density index and (c) correction index of catchability coefficient (combined result of (a), (b) and (c)) for *Metapenaeus endeavouri* in Albatross Bay over 6 years (March 1986 to March 1992). Dotted line=Mean values.

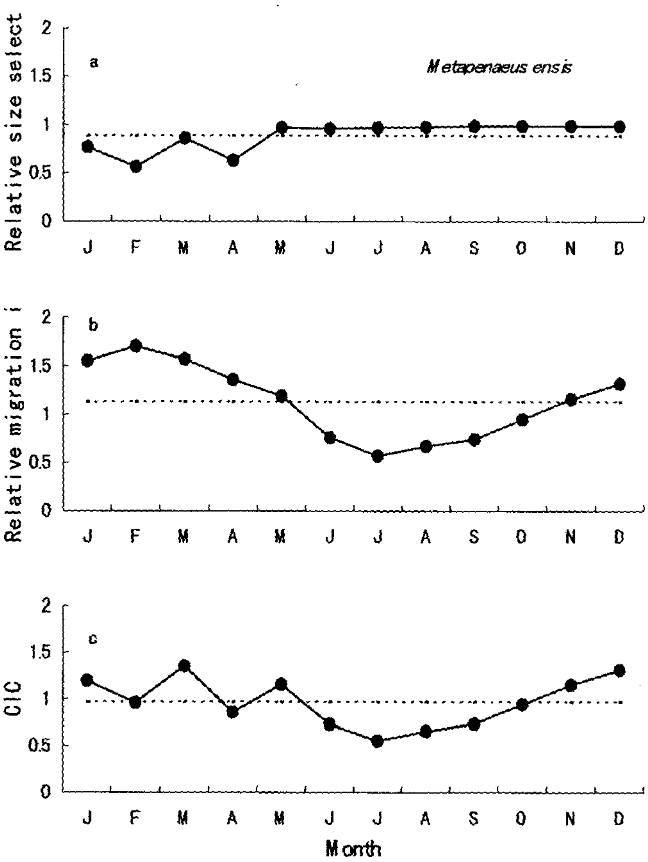

Fig. 4. Monthly variation in (a) relative size selectivity, (b) relative density index and (c) correction index of catchability coefficient (combined result of (a) and (b)) for *Metapenaeus ensis* in Albatross Bay over 6 years (March 1986 to March 1992). Dotted line=Mean values.

Monthly variation pattern in CIC differed between species. The value of CIC for *M. endeavouri* varied substantially and was the highest in August.

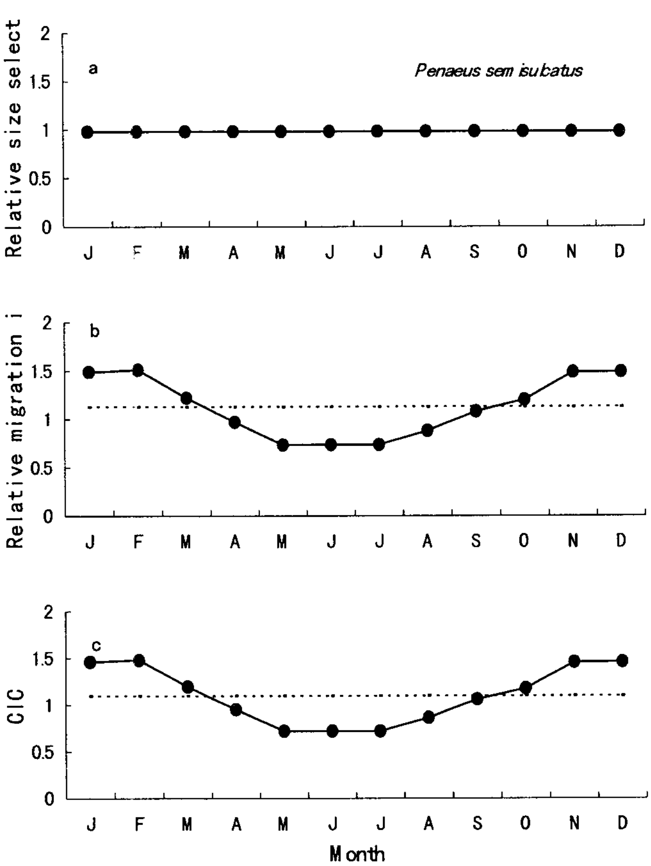

Fig. 5. Monthly variation in (a) relative size selectivity, (b) relative density index and (c) correction index of catchability coefficient (combined result of (a) and (b)) for *Penaeus semisulcatus* in Albatross Bay over 6 years (March 1986 to March 1992). Dotted line=Mean values.

The CIC value was higher than the annual mean during June to October (Winter~Spring) and lower during November to March (summer-early autumn; Fig. 3d). The value of CIC for *M. ensis* was generally low in winter and early spring (June~September) and high in summer and early autumn (November~March) but the seasonal trend was weaker than that for *M. endeavouri* (Fig. 4c). For *P. semisulcatus*, the monthly variation pattern in CIC was very similar to that of the relative density index, being highest during November to February (Summer; Fig. 5c). In contrast, the value of CIC for *P. esculentus* remained constant at around the annual mean value through the year.

Discussion

The determination of the catchability is one of the most difficult subjects in fisheries science. The value of catchability may vary seasonally because of interactions between a species and the physical environment that the species belongs as well as its own behaviour.

The monthly variation in the relative size selectivity for prawns reflects the monthly size composition that in turn affects the seasonal catchability and catch variation. These results were consistent with length frequency distributions for the two endeavour and tiger species: e.g., for *M. endeavouri*, the month that the proportion of the small size group is at a maximum is the same month that the relative size selectivity is the lowest (December; see Crocos et al., 2001, Fig. 3). The range of monthly variation in the relative size selectivity of the two endeavour species was larger that that for the two tiger prawns, which suggests that size selectivity has a greater impact on catchability in the case of endeavour prawns in Albatross Bay. This may be because of the difference in the body shape between endeavour and tiger species: i.e. endeavour species are more slender than tiger species. *P. esculentus* was likely to have a higher vulnerability to trawl capture than other species. Nevertheless the body form of *M. ensis* is finer than that of *P. semisulcatus*, size selectivity for *M. ensis* was higher than that for *P. semisulcatus* at the same carapace length. It is possible that the size selectivity for *M. ensis* was overestimated due to a lack of observations of intermediate size class (see Crocos et al., 2001, Fig. 4).

The range of monthly variation in the relative emergence for *M. endeavouri* was low relative to other factors affecting catchability and the emergence index for *P. esculentus* was also very constant during a year, suggesting that the emergence behaviour did not significantly affect catchability in Albatross Bay. This can be because Albatross Bay is located in the tropical zone, where the water temperature is relatively constant during a year (Hill, 1985; Crocos and Van der Velde, 1995).

Seasonal density distribution appears to be a major factor affecting the catchability to trawl capture. The present results indicated that seasonal variation in population density can significantly affect the monthly variation in catchability for *M. endeavouri*, *M. ensis* and *P. semisulcatus*, and that *M. ensis* may be more susceptible to trawl fishing pressure than other species. Somers and Kirkwood (1991) found that *P. semisulcatus* in the north-western Gulf of Carpentaria dispersed into offshore waters in midwinter (July) and by November (early summer). They had shifted slightly shoreward into depths of 25~35 m, which is consistent with the results of the present study.

The other factor that affects prawn catchability to trawl capture is aggregation behaviour. Penaeids do not aggregate as much as the banana prawn, *P. merguiensis* (Die and Ellis, 1999). Penn (1984) suggested that the aggregation behaviour makes *P. merguiensis* more vulnerable than tiger prawns to trawl capture. Table 1 shows the expected effects of various factors on catchability. Spawning of *P. merguensis* in spring (September) produces the main pulse of recruitment during January~March. Adult *P. merguiensis* spawn in the open sea and larvae move onshore (Somers, 1994). After several months in these nursery grounds, the juveniles move offshore and join the adult population (in January). The biomass of *P. merguiensis* recruiting to the fishery peaks between mid-March and mid-April (Somers, 1994), about two weeks earlier than the main fishing season (April~June). Therefore, the seasonal migration of *P. merguiensis* prerecruits increases their vulnerability during the main fishing season (Table 1).

The correction index of catchability (CIC) reflects the composite effect of the monthly variation in size selectivity, duration of emergence and seasonal variation in population density. The monthly variation of the CIC suggests that the catchability of *P. esculentus* is almost constant through a year but it varies greatly for *M. endeavouri* on a seasonal basis. Somers and Wang (1997) developed monthly trends in catchability for *P. esculentus* and *P. semisulcatus* in the NPF using Hill's (1985) temperature-emergence relationship and monthly CPUE for the two tiger species in the north-western Gulf of Carpentaria (Somers and Kirkwood, 1991). They found that catchability for the two tiger species was lowest in July. The present results are slightly different from these of Somers and Wang (1997); the catchability in Albatross Bay was lowest in August (*P. esculentus*) and from May to July (*P. semisulcatus*). This is because of differences in water temperature between Albatross Bay and the whole Gulf of Carpentaria, and the fact that the seasonal distribution for the two tiger species in the north-western Gulf of Carpentaria may be slightly different to those in Albatross Bay.

The seasonal variation in CIC measured in the

Table 1. Expected effects of ecological factors on catchability for Australian commercial prawns

Factors	Overall effect on q				
	ME (non-target sp; Albatross Bay)	MS (non-target sp.; Albatross Bay)	PE (target sp.; Albatross Bay)	PS (target sp.; Albatross Bay)	PM (target sp.; NPF)
Distribution relative to fishery	–#	–#	+#	+#	+#
Seasonal population density during main fishing season	++*	–*	NC*	+*	+#
Aggregation	NC#	NC#	NC#	NC#	++#
Avoidance of fishing gear (e.g. swimming, burying)	NC*	NC*	NC*		
Size selectivity (combined effect of gear selectivity and recruitment) during main fishing season	+*+*	NC*	NC*		

ME=*Metapenaeus endeavouri;* MS=*M. ensis;* PE=*Penaeus esculentus;* PS=*P. semisulcatus;* PM=*P. merguiensis;* '–'=Decrease effect; '+'=increase; '++'=great increase; SI=Similar; NC=Not clear; *Present study; #Expected results.

present study can be used as an important information to estimate seasonal catchability coefficient. If the seasonal catchability coefficients can be estimated, they could be used as the index for seasonal management for prawn stocks in Albatross Bay.

Acknowledgments

We thank Neil Loneragan, Ann Grant, Hiyama Yoshiaki, Sung-kwon Soh and Chul-woong Oh for their useful advice and comments.

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