An analysis of variation in catchability of green tiger prawn, *Penaeus semisulcatus*, in waters off Kuwait

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Abstract.–A method for assessing variation in catchability of single cohort fisheries based on catch and effort statistics was developed. The results of its application to the Kuwait shrimp, *Penaeus semisulcatus*, fishery showed that catchability declined gradually with progress of fishing in general, but there was a rise in December or January. The pattern of variation was associated with possible schooling behavior at the beginning of a fishing season. Initially, catchability was high, but, as intensive fishing dispersed the schools, or reduced population density, catchability declined. The midwinter increase in catchability was probably due to an inshore spawning migration. There were also substantial interseasonal variations in catchability because schooling was associated with strong recruitment and environmental conditions.

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Most fishery management regulations are based on estimation of resource abundance and fishing mortality, of which catchability is an essential element. The existing literature on population dynamics rarely deals directly with catchability *per se*. For most production models and cohort models that use abundance indices, catchability is usually taken as constant and, subsequently, catch per unit of effort (CPUE) from commercial catch and effort statistics is used as an index of stock abundance.

The assumption of constant catchability is rarely, if ever, valid within a fishing season (Garcia, 1988; Atran and Loesch, 1995; Hannah, 1995; Arreguin-Sanchez, 1996), particularly for short-lived species such as certain shrimp in Kuwait's waters. Catchability depends on many factors: sensory capabilities, behavioral response of the target species (Penn, 1984; Wassenberg and Hill, 1990), environmental factors including temperature (Chittelborough, 1970; Morgan, 1974; Hill, 1985) and wind (Ehrich and Groger[1]), stock area, the relative distribution of fish and fishing (Winters and Wheeler, 1985; Hannah, 1995), and stock abundance (MacCall, 1976, 1990; Murphy, 1977; Csirke, 1989). Ricker (1975) stated that variation in catchability is likely to be the greatest source of error in models based on CPUE with constant catchability.

Shrimp fisheries are often managed by a minimum spawning stock strategy to prevent overfishing of stocks. Under such a strategy, CPUE during a spawning season is usually used as an index of spawning stock abundance, and fishing is closed when CPUE falls below a certain level (Penn, 1984; Morgan, 1989). If catchability is highly variable, indices of spawning stocks and the underlying stock recruitment relationship could be obscured and perhaps lead to erroneous management decisions (Hannah, 1995).

Studies on catchability are essential for relating stock abundance to observed CPUE. By investigating within-season changes in catchability, properties of a stock that are not apparent when only annual data are examined, can be understood better. The objective of this paper is to develop a method to estimate changes in catchability from commercial catch and effort data.

Materials and methods

The model

The *Penaeus semisulcatus* fishery in waters off Kuwait has a single major recruitment in June and July,

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[1] Ehrich, S., and D. Groger. 1989. Diurnal variation in catchability of several fish species in the North Sea. ICES Council Meeting (CM) 1989/B:35, 10 p.

which, depending on the year, may be supplemented by a second, late-summer recruitment in August or early September (Mohammed et al., 1996). The success of the second recruitment was responsible for record landings, for example, in the 1988–89 and 1989–90 seasons (Siddeek et al., 1994). Total landings of *P. semisulcatus* in 1994–95 and 1995–96 were 699.7 and 925.0 tonnes, respectively, about 14% and 19% of the 1988–89 season's *P. semisulcatus* catch of 5022.4 tonnes (Siddeek et al., 1994).

Kuwait's opening date for shrimping has been set at 1 September since 1987 (Gulland, 1989; Siddeek and Abdul-Ghaffar, 1989). The season is closed when the CPUE for combined species of the industrial fleet falls below 80–120 kg/boat-day (Xu et al., 1995). In this case, shrimp trawling is a process that depletes a single cohort.

We start with three basic equations. The first equation is the relation between fishing mortality and fishing effort:

$$F_t = q_j f_t, \tag{1}$$

where q_j = catchability in month *j*;
F_t = fishing mortality in time interval *t* (5 days per interval); and
f_t = fishing effort in time interval *t*.

The second relates the population number at time *t* to the initial cohort number and cumulative fishing and natural mortalities:

$$N_t = Re^{-\sum_{i=1}^{t} F_i - tM}, \tag{2}$$

where R = initial stock number;
N_t = population number at time *t*;
i = time interval; and
M = natural mortality.

The final equation relates catch to current abundance and fishing as well as to natural mortalities, and we assume that fishing mortality acts independently of natural mortality, taking a fraction of $F/(F+M)$ of the total mortality, so

$$C_t = N_t \frac{F}{F_t + M}\left(1 - e^{-(F_t+M)}\right), \tag{3}$$

where C_t = catch in time interval *t*.

The three equations describe an exponential decay process of a single cohort with fishing and natural mortalitites. Natural morality is assumed to be independent of time throughout the season and catchability is assumed to remain constant within a month.

Given catch and effort data, the initial population number (*R*), natural mortality rate (*M*), and six monthly catchability rates (q_j), a total of eight parameters can be estimated in theory by a time-series fitting method of least squares between observed and predicted catches. There exists, however, a problem of confounding the initial stock number, natural mortality, and catchabilities. A high initial population number with high natural mortality and low catchability rates gives as good a fit as does a low initial population number with a low natural mortality and high catchability rates. The following three measures were taken to solve this problem.

1) We assumed that

$$R = \frac{1}{q_1} \sum_{t=1}^{3} C'_t \Big/ \sum_{t=1}^{3} f_t, \tag{4}$$

where C'_t = observed catch at time *t*.

This assumption says, in effect, that for a given estimate of q_1, we have an estimate of the initial population number (*R*) from the average catch and effort over the first three time intervals (Hilborn and Walters, 1992). 2) It was presumed that natural mortality was available from other sources. 3) Auxiliary abundance index was used in the time series fitting as follows:

$$SS = \sum_{t=1}^{T}\left[\ln(C_t) - \ln(C'_t)\right]^2 + W\sum_{j=1}^{J}\left[\ln(X_j) - \ln(X'_j)\right]^2, \tag{5}$$

where C_t = predicted catch at time *t* by Equation 3;
C_t' = observed catch at time *t*;
X_j' = observed index of stock number in month *j* in relation to the beginning point of a fishing season;
X_j = predicted relative stock abundance in the middle of month *j*, i.e. predicted stock number in month *j* divided by the predicted stock number of the middle point of the beginning month; and
W = the weight given to the deviation between the predicted and the observed stock indices.

This procedure reduced the number of parameters to be estimated to six. Monthly CPUE of the United Fisheries of Kuwait (UFK) fleet was used as auxiliary information about stock abundance.

The data

The shrimp fishery in Kuwait consists of two sectors: industrial trawlers and dhow trawlers (for a review see Mathews and Samuel, 1991; Mathews, 1994; Ye et al., 1996). The main species caught are *P. semisulcatus*, *Metapenaeus affinis*, and *Parapenaeopsis stylifera*. *Penaeus semisulcatus* dominates in the central and southern waters, and the other two species are mainly distributed in northern waters. The dhow boats trawl in relatively shallow waters, and their catches are auctioned at local fish markets (Abdul-Ghaffar and Al-Ghunaim, 1994; Ye et al., 1996). Species composition of the dhow catch varies with changes in fishing grounds and with seasonal migration. The monthly percentages of *P. semisulcatus* in the dhow landings change greatly within a season, for example, from 29.6 to 87.1% in 1993–94. Owing to the difficulty in collecting reliable effort data from the dhow sector, effort is usually standardized in relation to that of the industrial sector in reporting Kuwait's shrimp fishery statistics. The dhow effort is thus calculated by dividing the total catch of combined species of the dhow sector by the CPUE of combined species from the industry sector (Mathews, 1994), which ignores the change in target species. The catchability of *P. semisulcatus* under such a standardized effort would change simply because of the variation in target species.

The industry sector comprises three companies: United Fisheries of Kuwait (UFK), Bubiyan Fishing Company, and National Fishing Company. The shrimp catch landed by UFK is mainly exported. Fishing operations of the UFK fleet are mainly in the southern and central Kuwait waters, where *P. semisulcatus* dominates (Siddeek et al., 1989); this occurs because *P. semisulcatus* is individually larger and much more valuable in international markets than the other two species (Siddeek et al., 1989; Ye et al., 1996). Consequently, the percentage of *P. semisulcatus* in the UFK catch remains relatively less variable within a season, for example between 59.5% and 84.5% in the 1993–94 season (Ye et al., 1996).

Seasonal landing data from the dhow boats were recorded every five days (Mohammed et al., 1996); however, industrial fleets reported their catches and fishing effort monthly. To estimate monthly variations in catchability, we assumed a uniform distribution of the industrial catch within any month and added this to dhow catches for that month. This obscured the within-month variation in catch. The dhow landings constituted about 53% of the total *P. semisulcatus* landings in the 1994–95 and 1995–96 seasons (Ye et al., 1996); therefore such an assumption would not affect the estimates of monthly catchability significantly. In our study, catchability was assumed to be constant within a month, and the fishing effort data of the *P. semisulcatus* fishery were standardized by using the entire industrial shrimping fleet catch rates, as is customary (Gulland, 1983; Mohammed et al., 1996). The total catch, fishing effort, and abundance index are shown in Table 1.

Table 1

Time series catch, effort, and relative abundance index data of the Kuwait *P. semisulcatus* fishery in the 1994–95 and 1995–96 seasons.

	Catch (10^3number)		Effort (boat-day)		Abundance index	
Time	1994	1995	1994	1995	1994	1995
5 Sep	2007	3752	266.2	357.7	1.000	1.000
10 Sep	2212	3165	316.3	325.4		
15 Sep	1565	3201	239.9	352.8		
20 Sep	1592	4502	260.0	528.8		
25 Sep	1704	1868	295.0	232.5		
30/Sep	1549	1805	282.9	237.1		
5 Oct	1589	1707	490.8	386.0	0.621	0.613
10 Oct	782	1342	252.5	316.8		
15 Oct	925	1126	310.9	276.5		
20 Oct	921	1397	321.1	356.3		
25 Oct	914	1354	329.3	356.9		
30 Oct	724	1051	268.8	285.1		
4 Nov	421	42	199.7	210.6	0.500	0.383
9 Nov	396	331	192.0	151.5		
14 Nov	337	411	167.3	191.9		
19 Nov	287	486	145.4	231.5		
24 Nov	292	404	150.0	195.8		
29 Nov	239	398	124.7	195.7		
4 Dec	460	424	211.5	398.2	0.574	0.202
9 Dec	371	369	172.9	350.3		
14 Dec	448	409	210.7	392.1		
19 Dec	496	311	235.4	301.1		
24 Dec	354	268	169.3	260.6		
29 Dec	703	395	337.8	387.6		
3 Jan	487	383	588.1	378.4	0.229	0.201
8 Jan	260	243	315.3	240.9		
13 Jan	347	482	422.3	478.8		
18 Jan	339	397	413.3	395.0		
23 Jan	339	285	413.6	283.6		
28 Jan	346	272	423.3	271.2		
3 Feb	233	93	529.9	330.2	0.123	0.057
8 Feb	45	204	102.3	726.8		
13 Feb	177	219	402.8	782.2		

Catchability by the UFK fleet is relatively stable within a fishing season. From Equations 1 and 3, $CPUE \cong qN$. CPUE can be an indicator of variation in stock abundance only when catchability q is constant. Figure 1 shows q estimates calculated by simply dividing UFK CPUE data (Siddeek et al., 1989) by the shrimp stock abundance, represented by catch

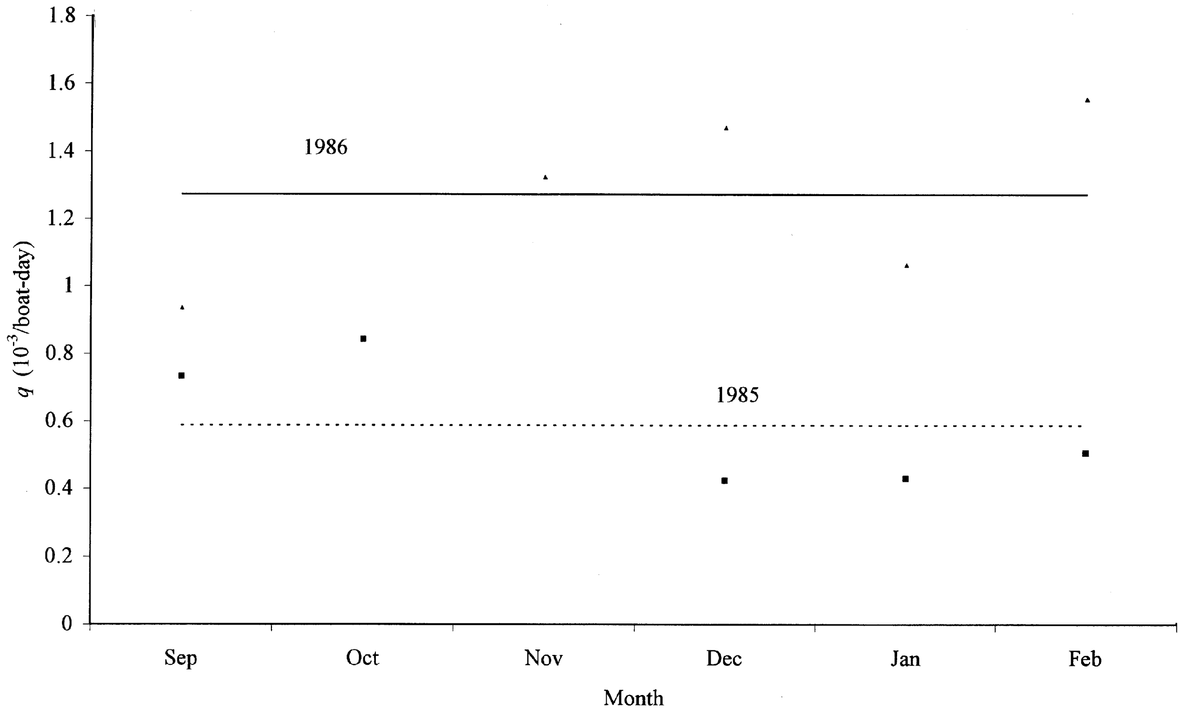

Figure 1

The catchability estimates of the UFK fleet in 1985 (■) and 1986 (▲). The survey catch rates in November 1985 and October 1986 were missing because the whole data set of five year-round surveys was destroyed during the Iraqi occupation in 1991.

rate (kg per haul of 45 minutes) of a survey vessel in 1985 and 1986. There are no survey catch rates in number available, but using catch rate in weight would not introduce any great bias in the investigation of catchability here. The catchability, q, is relatively stable within the period of the investigation, although a great difference can be seen between 1985 and 1986. Therefore, the UFK CPUE was used as an index of stock abundance of *P. semisulcatus* within a fishing season in our study.

Results

Natural mortality is supposed to be known and independent of time within a fishing season, which may violate reality, but this is a more conservative assumption than assuming that natural mortality is constant over periods of years (Hannah, 1995). The natural mortality rate of Kuwait's *P. semisulcatus* has been investigated by a number of authors (Mathews et al., 1987; Siddeek et al., 1989; Xu et al., 1995; Mohammed et al., 1996; FAO[2]; Al-Hossaini[3]); these results range from 1.8 to 4.0/yr. In this study, we used the minimum, median, and maximum estimates of natural mortality rates for our estimation of catchability.

The fits of the above developed depletion model to catch data are shown in Figure 2, in which we used a median natural mortality rate (M=2.9/yr) and produced 95% confidence intervals by the parametric bootstrap (BC) method (Efron and Tibshirani, 1986). The predicted catches for the 1994–95 and 1995–96 seasons are very close to the observed values in general. There is relatively greater discrepancy at the beginning of the seasons, however. The predicted catches are lower than the observed ones in the first month for both seasons (Fig. 2). This is caused by the assumption of Equation 4.

The calculated stock abundance indices also followed the pattern of observed population indices (Fig. 3), showing an exponential depletion of a single co-

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[2] FAO (Food and Agriculture Organization of the United Nations). 1982. Assessment of the shrimp stocks of the west coast of the Gulf between Iran and the Arabian Peninsula. Food and Agriculture Organization. FAO Rep. FI:DP/RbyAB/80/015, Rome, Italy, 162 p.

[3] Al-Hossaini, M. 1993. Finfish fisheries and shrimp fisheries management. Tech. Rep., Kuwait Institute for Scientific Research. Food-4 KISR 4367, 53 p.

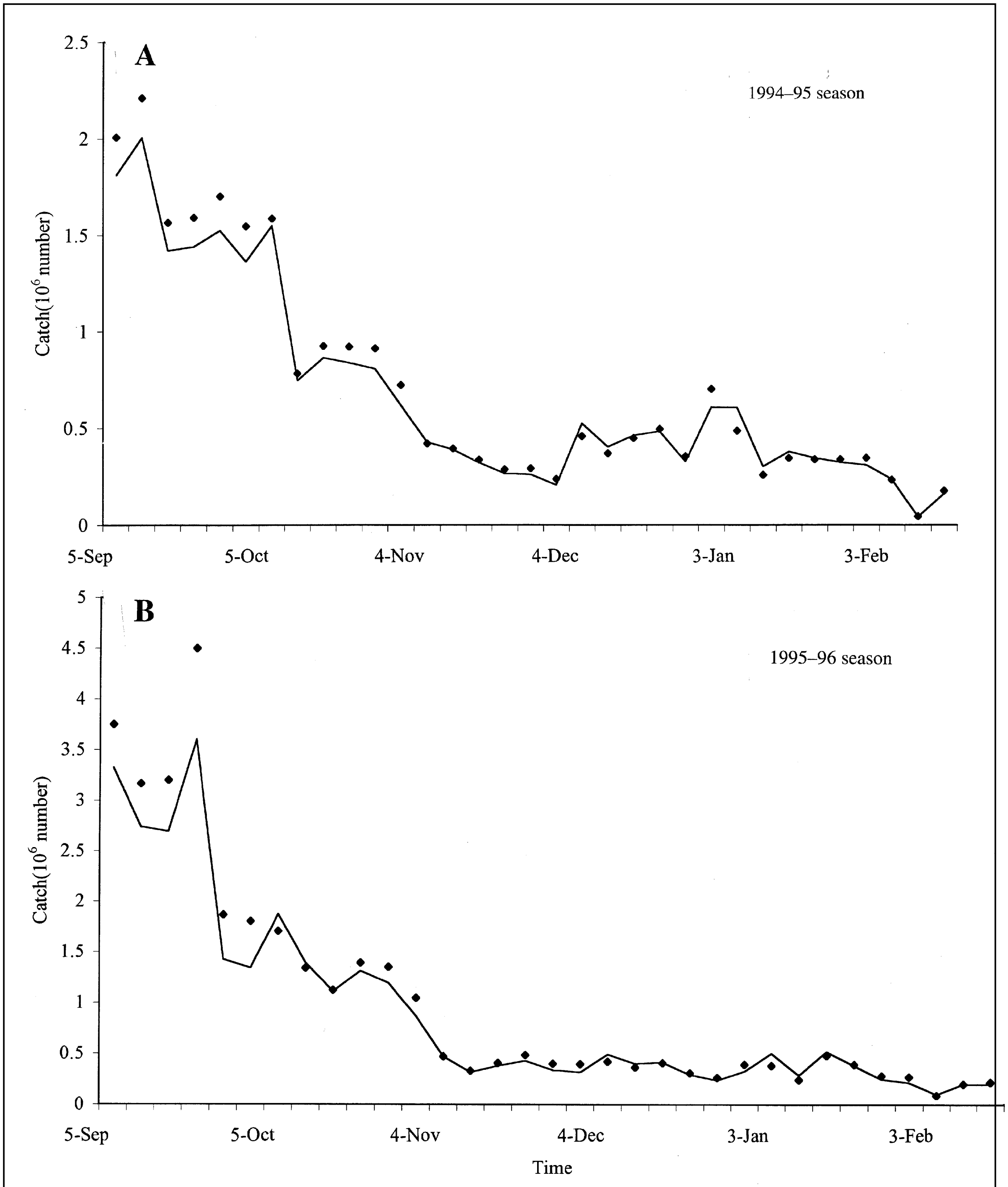

Figure 2

The fit of the model to the catch data (◆ observed data, - fit) for Kuwait's 1994–95 and 1995–96 shrimp landings from 1 September to 15 February.

hort stock. The model fit for the 1995–96 season was better than that for the 1994–95 season. A comparison of these two fits of stock abundance indices showed that the stock experienced a greater decline during the1995–96 season. Figures 2 and 3 demonstrate the goodness of the model fit.

The monthly estimates of catchability in the 1994–95 and 1995–96 seasons exhibit a declining trend as

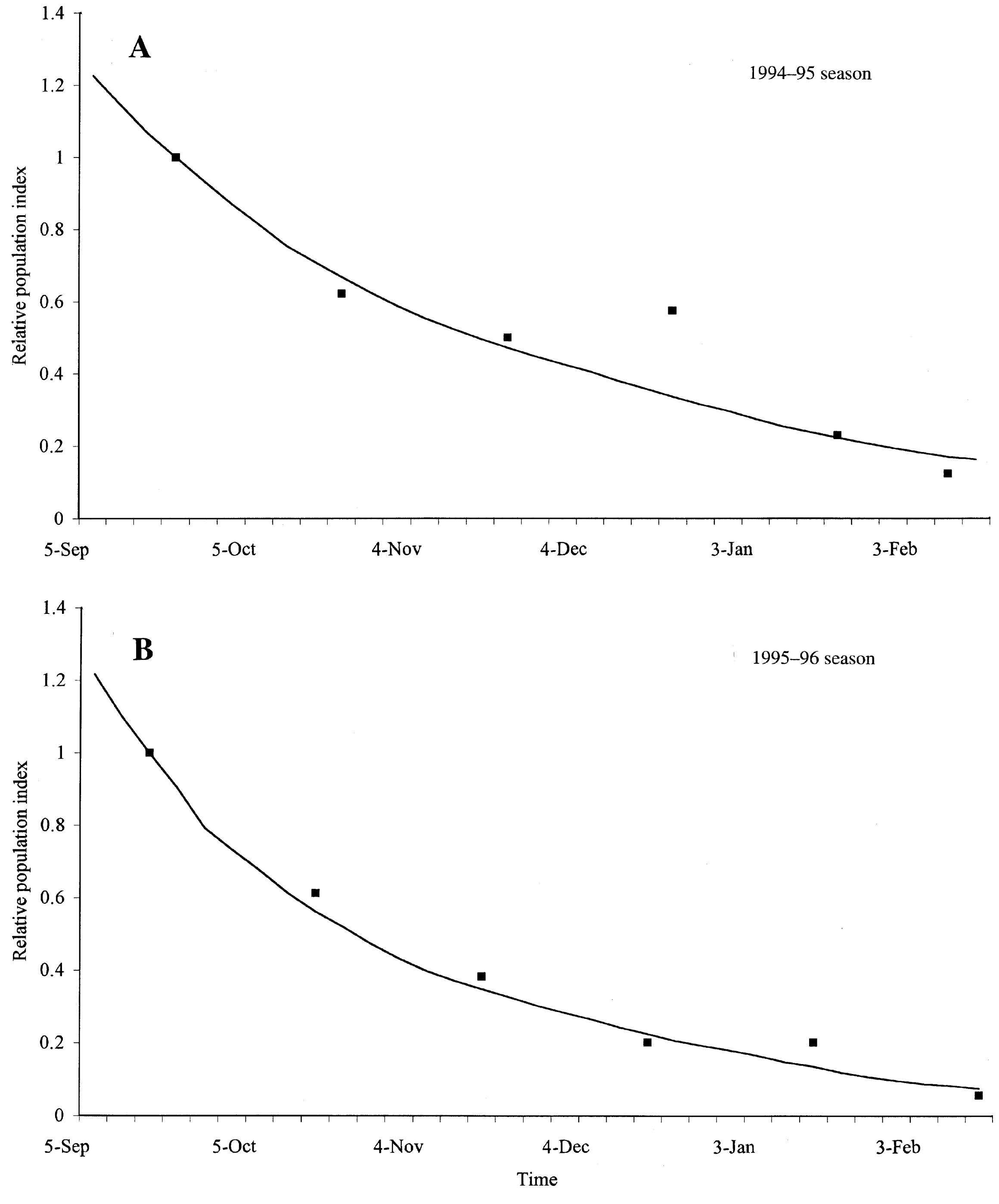

Figure 3

The fit of the model to the relative stock abundance indices (◆ observed data, - fit) for the 1994–95 and 1995–96 seasons.

the season progressed (Fig. 4). From season opening to closing, catchability decreased from 10.40×10^{-5}/boat-day to 4.63×10^{-5}/boat-day in 1994–95, and 17.05×10^{-4}/boat-day to 7.77×10^{-5}/boat-day in 1995–96, respectively (Fig. 4). Comparison between these two seasons shows that shrimp catchability at the beginning of the 1994–95 season was only about 60% of the catchability at the start of the 1995–96 sea-

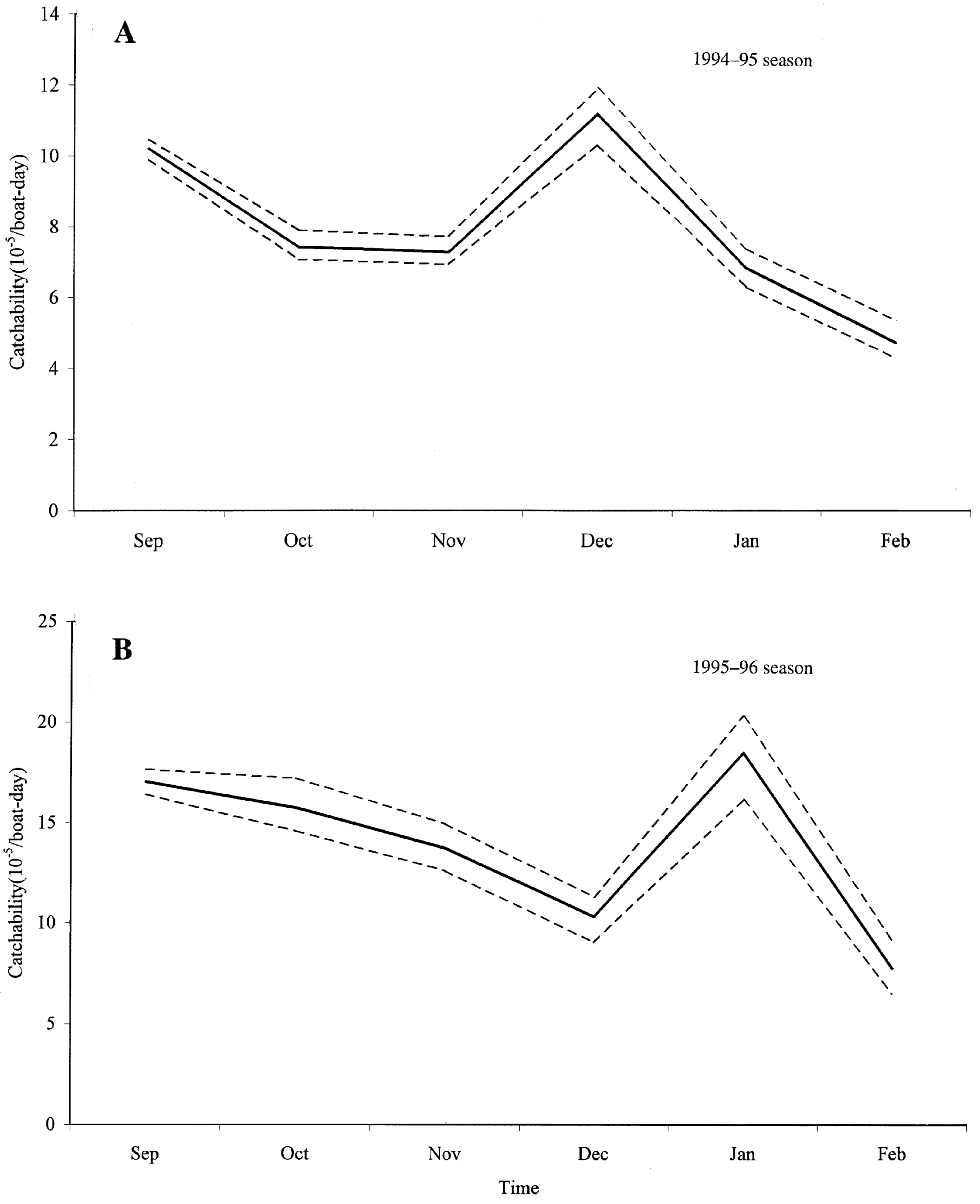

Figure 4

The monthly catchability rates estimated by the model. Dash lines indicate 95% confidence intervals derived by the 200 bootstrap assessments and percentile methods.

son. The estimates of catchability at the end of these two seasons exhibited a similar difference. The catches at the beginning of the 1995–96 season were much higher than those in the same period of the 1994–95 season (Fig. 2). High catchability rates may be associated with abundant stocks. Thus, it can be concluded that high catchability is expected when recruitment is good.

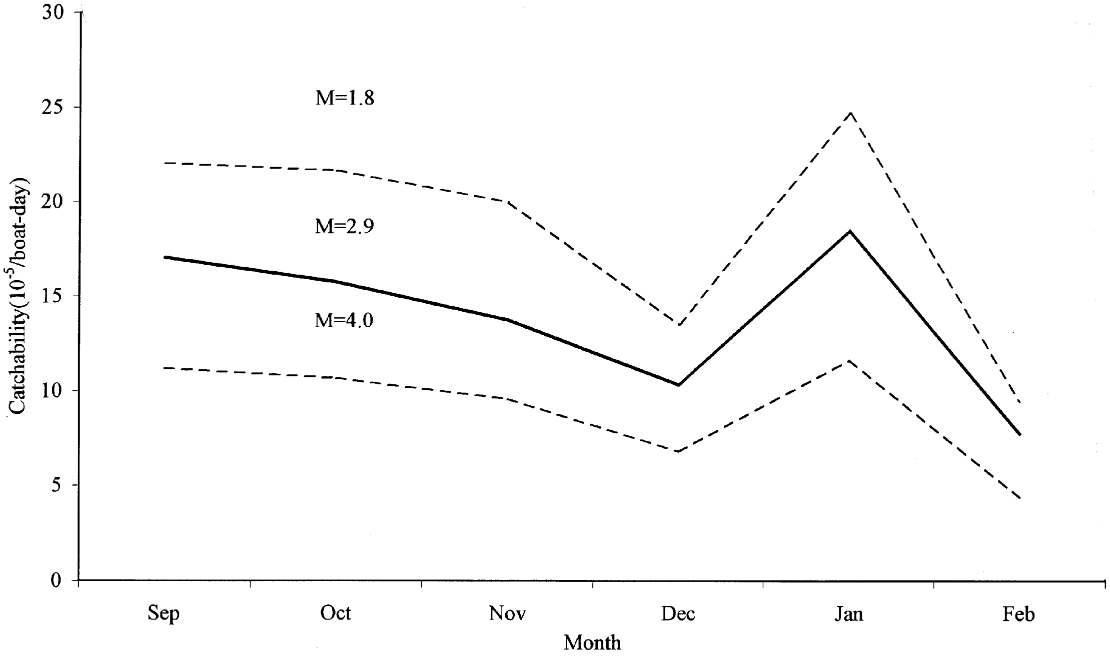

Figure 5

The effect of natural mortality on the estimation of catchability derived from Kuwait's 1995–96 season data.

Another interesting point is that there was a rise in catchability in December for the 1994–95 season, in January for the 1995–96 season. The second catchability rate peak was even slightly higher than the first one in both seasons. All these results show that catchability in the *P. semisulcatus* fishery varies within a fishing season and from year to year, but that the variation patterns in different seasons are similar, with two peaks (Fig. 4).

There are many biases in the estimation of natural morality (Vetter, 1988). The natural mortality rate used in this analysis was the median value of estimates from various sources. Different values of natural mortality will result in different estimates of catchability. Figure 5 shows comparison of the results derived from the seasonal 1995–96 data when the minimum (M=1.8/yr), median (M=2.9/yr), and maximum (M=4.0/yr) estimates of natural mortality were used. The variation of the pattern of catchability was similar within this range of natural mortality. A lower natural morality results in higher catchabilities and a relatively large variation in catchability within a fishing season, demonstrating the correlation between natural mortality and catchability. Therefore, we suggest that the variation pattern derived by this method is reliable, although absolute values may be biased by the natural mortality used.

The weight, W in Equation 5, can be assigned a high or low value depending on the reliability of the auxiliary information compared with the catch data (Hilborn and Walters, 1992). Here, we set W to 6 simply because there were six points of catch and effort data each month, but the auxiliary index had only a single datum point each month. Actually, the auxiliary information was used to constrain the predicted stock's declining track, and thus control total mortality within a certain level. A sensitivity analysis showed that reducing W by 50% resulted in an average decrease of 3.5% in catchability, ranging from 2.1% to 4.8%; increasing W by 50% leads to an increase in catchability of 7.4% on average, with a range of 5.3% to 9.6% (Fig. 6). The primary concern here is the pattern of catchability variation; it is not sensitive to the weighting factor in the case of Kuwait's *P. semisulcatus* fishery (Fig. 6). One method to determine a suitable value for W is by comparing the geometric fits of both the catch and abundance index in the case of unknown reliability over either set of data.

Discussion

An analytical framework to estimate changes in catchability of single cohort fisheries has been pro-

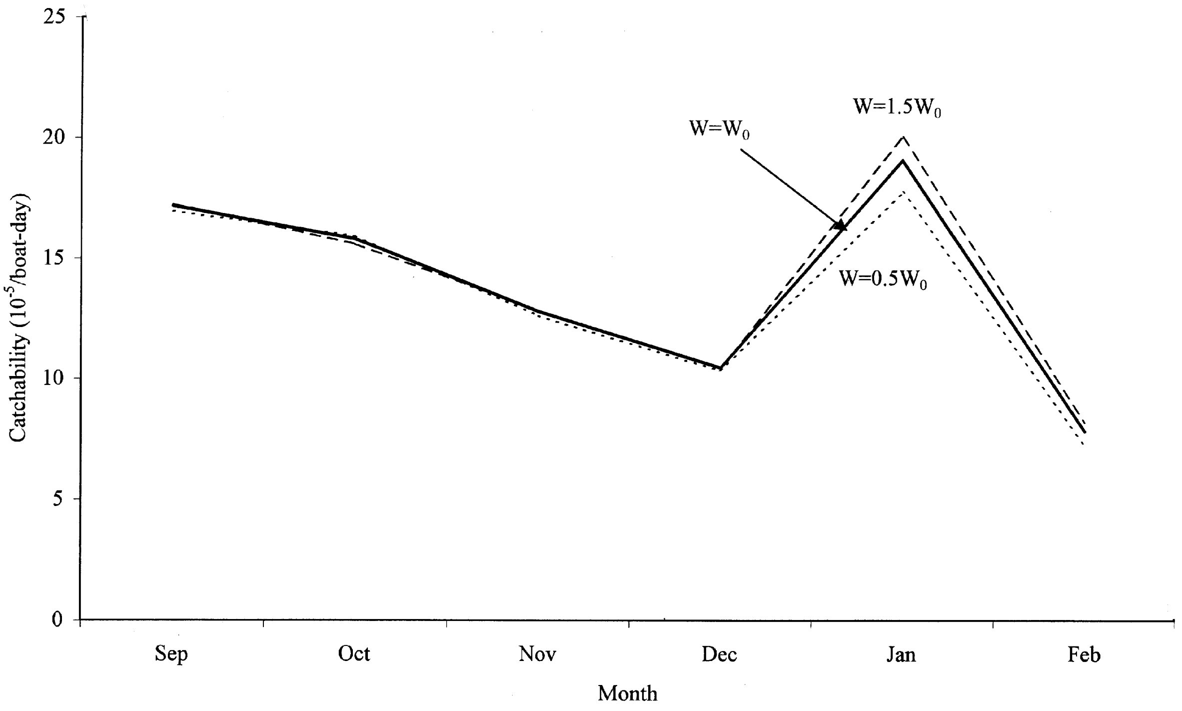

Figure 6

The effect of weighting fact, *W*, on the estimation of catchability for the 1995–96 season.

vided. The results of our study show that the catchability of the Kuwait shrimp fishery is not constant; there were high values at the beginning of the fishing season, lowest values at the end. The two-peak pattern of catchability may be associated with schooling behavior at the time of recruitment to the fishery and the spawning migration of the species. There is also great variation in catchability on an interannual basis because schooling is associated with high recruitment (Mathews et al., 1994) and certain environmental conditions (Penn, 1984).

The general declining trend in catchability may be attributed to schooling behavior. As fishing progressed, shrimp schools were depleted or dispersed, and catchability declined (Drobisheva and Aseev, 1976; Garcia and Reste, 1981; van Zalinge, 1984; Mathews et al., 1994). Reduced activity caused by low temperature is another identified cause for the decline of catchability of Spencer Gulf prawns (*Penaeus latisulcatus*) in Australia during the winter months (June to August) (Sluczanowski, 1984) and *P. semisulcatus* in Kuwait (Mathews and Al-Hossaini, 1982). Both schooling and effects of decreasing temperature likely contributed to the variation of catchability in the Kuwait shrimp fishery.

The major spawning season for *P. semisulcatus* is from December to April (Drobisheva and Aseev, 1976; Siddeek et al., 1989). Many penaeids undertake a short shoreward migration before spawning (Garcia, 1988; Ye, 1984). *Penaeus semisulcatus* in the Gulf of Carpentaria migrate from offshore into shallow waters in the spring before spawning (Dall et al., 1990). Drobisheva and Aseev (1976) reported that *P. semisulcatus* in the Arabian Gulf forms prespawning schools or aggregations in the spawning area. Although the migration pattern of *P. semisulcatus* in watters off Kuwait is still not clear, the pattern of catchability strongly indicates that this species may return to Kuwait waters before spawning season and concentrate in certain areas. Such shoreward movement by spawning schools resulted in the highest catchability, and a peak in December or January (Fig. 4), which rapidly decreased as fishing progressed.

There is also the possibility that shrimp of non-Kuwait origin migrate to Kuwait waters. El-Musa (1982) analyzed mark-recapture data and concluded that the *P. semisulcatus* released in February 1979 at Dohat Al-Zaur, close to the border with Saudi Arabia, exhibited a strong northward movement. The timing of such a migration could be affected significantly by environmental conditions associated with a spawning migration, resulting in an apparent increase in catchability earlier in some years than in others.

The schooling behavior of *P. semisulcatus* was associated with years of higher catches (van Zalinge, 1984; Mathews et al., 1994). When recruitment to the fishery was good, larger schools, and thus higher catchability, could be expected. The catches at the beginning of the 1995–96 season were much higher than those of the same period in the 1994–95 season (Fig. 2); catchability in 1995–96 was also much higher (Fig. 4). With intensive fishing effort, the shrimp stock was reduced to a very low level by the end of the fishing season, despite its initial abundance. Therefore, catchability is associated with stock abundance.

Although the variation in total mortality and catch cannot be explained by variation in natural mortality, violation of the assumption that natural mortality remains constant within a season may still be the source for biases in the estimation of monthly catchability. The relatively larger discrepancy between predicted and observed catches, the predicted being always lower than the observed, in the first month (Fig. 2) may result from a departure from the natural mortality rate that is generally used. An inflated natural mortality for the first month will give lower predicted catches because the first month's catchability was related to the initial population number, which in turn was connected to all the other estimates of catchability in the fitting scheme used in this study. The fit cannot be improved by adjusting catchability for the first month. Although it may be true that natural mortality is constant during a fishing season, a possible second recruitment in early September, which was not considered in our study and is probably rather weak, may compensate natural death to some extent and lead to a lower net natural mortality than the value we used.

This study reports apparent changes in catchability of Kuwait's *P. semisulcatus* fishery. It should be noted that M, q, CPUE, and schooling must be interrelated to a certain extent. Schooling may bias CPUE with respect to years in which it does not occur, and M estimates from any method applied in Kuwait may also be influenced if schooling occurs only in certain seasons. Changes in catchability to a fishery may be associated with both fishing power and population characteristics. A better understanding of the mechanisms underlying these results will improve stock assessment. The variations in catchability suggest that changes in catch-rate indices may not actually reflect variations in abundance. Although other results support the conclusion of this study, functional relationships among catchability and population characteristics, fleet characteristics, and environmental conditions should be studied further.

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