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Using a Fixed Escapement Strategy to Control Recruitment Overfishing in the Shrimp Trap Fishery in British Columbia

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Abstract

Recruitment overfishing in the spot prawn (*Pandalus platyceros*) trap fishery in British Columbia on the west coast of Canada is managed using a fixed escapement system. Fixed escapement targets in the fishery are set and implemented as the number of female spawners caught per trap in the commercial fishery. The development and application of this management system are reviewed, including the theoretical basis for the method, implementation procedures/problems, on-going research, results and implications.

Key words: *Pandalus*, management, recruitment overfishing, shrimp

Introduction

The shrimp fisheries in British Columbia (B.C.) on the west coast of Canada (Fig. 1) target seven species of shrimp; *Pandalus jordani, P. borealis eous, P. goniurus, P. danae, P. hypsinotus, P. platyceros and Pandalopsis dispar*. These species are harvested by trawl and trap gear. This paper focuses on the trap fishery for the spot prawn, *Pandalus platyceros* hereafter referred to as "prawn". The trap fishery accounts for 98% of the total landings of prawns (Morrison *et al*., MS 1999) and represents the most valuable shrimp fishery in British Columbia.

Key Biological Considerations

The prawn is the largest of the seven commercial Pandalid shrimp species occurring in B.C. waters with a reported maximum size of 61.1 mm carapace length (CL) (Butler, 1980). In B.C. waters the maximum age is considered to be 48 months but they have been reported to be much older elsewhere (Armstrong *et al.,* 1995). Prawns are protandrous hermaphrodites, which in B.C. means they function as mature males for one or two years and then as mature females in their final year of life (very few females will survive a second year). Spawning occurs in the autumn and the female carries the eggs on her abdominal pleopods until they hatch in the late spring. The resulting free-swimming larvae can spend up to 3 months in the plankton, where they may be subject to transportation by tides and currents. Tagging studies have shown that mature animals are relatively sedentary and remain within a mile or two of their release location over a period of several months (Boutillier, unpublished data). This is supported by significant differences in parasite loads and growth rates between stocks that are separated by only tens of kilometers (Bower and Boutillier, 1990; Bower *et al.,* 1996). Prawns have widespread distribution and are fished in most inshore fjord-like areas of the B.C. coast. Boutillier and Bond (MS 1999) suggested that with the limited mobility of the adult populations the fishery might be impacting on hundreds of separate stocks. They also noted that the concept of meta-populations, which share larvae, may apply since prawns have a lengthy pelagic larval stage. Sequential south to north recruitment suggests the presence of meta-populations of smooth pink shrimp, *Pandalus jordani* off the west coast of Vancouver Island (Boutillier *et al*., MS 1997). For prawns, good recruitment of a single year-class over a fairly large area has been reported (Boutillier, unpublished catch sampling data), but this may be due to favourable environmental conditions influencing a number of populations simultaneously. There are documented cases, based on logbook and catch sampling data, of a single year-class settling in a particular area, spending its life there, and then leaving the area virtually barren when the year-class dies off.

History of the Prawn Trap Fishery

Prior to 1979, approximately 50 vessels participated in the prawn fishery. The fleet had expanded to over 300 vessels by the mid-1980s. In 1990, licence

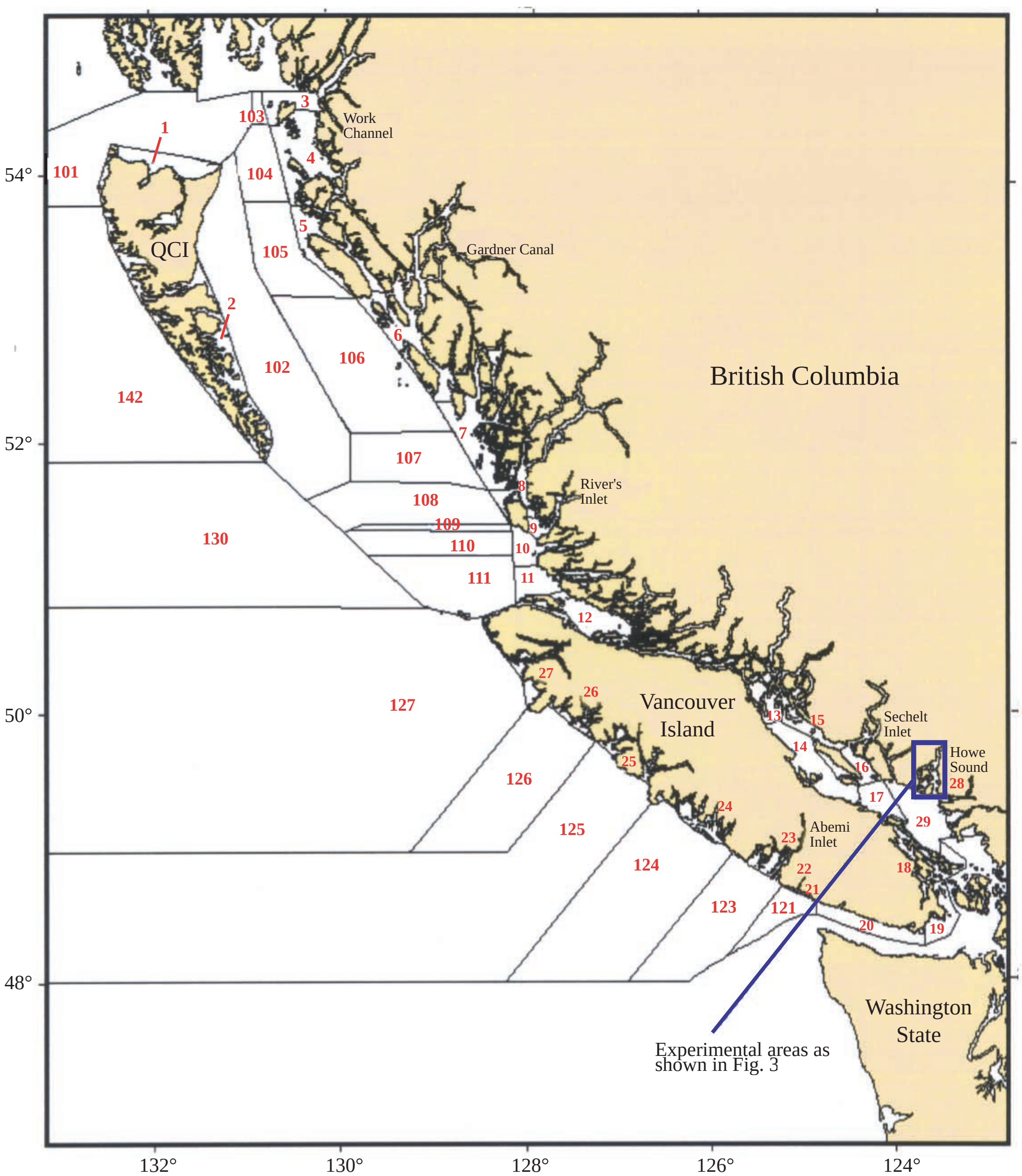

Fig. 1. Map of British Columbia Coastline showing Department of Fisheries and Oceans, Pacific Fisheries Management Areas.

limitations were implemented and in 1998, 257 licences were issued to 223 licence holders (some license holders held as many as 6 licenses). In 1995, trap limits were implemented which restricted single licensed vessels to 300 traps. For license holders that wanted to fish two licenses on a single vessel, a licence stacking provision allowed them to fish a maximum of 450 traps on a single vessel.

No significant landings were reported from the north coast Pacific Fisheries Management Areas (PFMA) 1–11 (Fig. 1) before 1979. The fishery moved into northern areas following exploratory surveys carried out in the mid-1970s (Boutillier and Cooke, 1976), although the majority of the prawns are still landed in south coast waters (Fig. 2) (Morrison *et al.*, MS 1999). Coastwide landings peaked in 1996 and

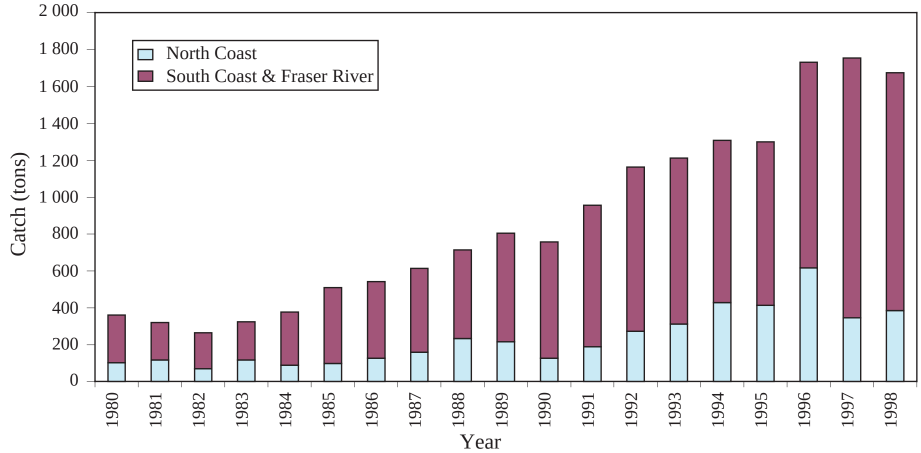

Fig. 2. Catch (in tons) in the prawn trap fishery in British Columbia, 1980 to 1998 (North Coast are all areas north of PMFA 11 and South Coast and Fraser River are all areas south of and including PFMA 11).

1997. In-season sampling indicates that the inshore areas (PFMA 1 to 29) are currently being fully exploited. The only opportunity for expansion of the fishery appears to be in the offshore waters (PFMA 101 to 130).

Prawns are landed live, fresh or frozen in whole or tailed form. Frozen at sea (FAS) product is produced in all areas by vessels with freezer capability and is marketed primarily to Japan. Many vessels added freezer capability in the 1990s and the FAS market became predominant in the mid-1990s. The landed value of the prawn fishery peaked in 1996 and 1997 with landed values in the range of $28.5M to $32.5M (Morrison *et al*., MS 1999).

History of Biological Management Strategies

The B.C. prawn fishery is presently managed by the Department of Fisheries and Oceans Canada (DFO) to prevent both growth and recruitment overfishing. Growth overfishing is controlled through a combination of: size limits, which were introduced in 1985 and implemented in 1988; trap escapement modifications (Boutillier and Sloan, 1988); and manipulation of the fishing season. With respect to size limits, Boutillier (1984) recommended a minimum size corresponding to an age at first capture of 25 months based on a Ricker yield-per-recruit analysis, allowing the animals to be available to the fishery for two fishing seasons. A size limit of 30.0 mm CL at first capture (Boutillier, 1985) was subsequently suggested as a coast-wide limit, although it was recognized that a single coast-wide size limit would not take into account variations in growth rates between areas and years. However, it was felt that the growth rate of prawns is sufficiently high and the length of season long enough to ensure that age 2+ animals would be available to the fishery in the first fishing season. At the request of the industry, the size limit was increased to 32.0 mm in 1996 and to 33.0 mm in 1997 to take advantage of the higher prices paid for larger animals (Morrison *et al*., MS 1998). This increased the average age at first capture by a few months but most animals were still available to the fishery over two fishing seasons.

Recruitment overfishing has been managed by DFO using a fixed escapement policy since 1979. This policy was developed around the premise that the fishery would close for the remainder of the fishing year once the female catch per trap reached a certain limit reference point. Annual minimum monthly indices (MMI) were established for each area to provide an average of 1 female spawner per trap at the time of egg hatch (generally March). MMI for the months prior to egg hatch were back calculated using an estimated natural mortality of 1.3 (Boutillier, MS 1987). The limit reference point (Gabriel and Mace, 1998) of 1 female spawner per trap was derived from a series of fishery independent surveys.

The assumption in the development of this management strategy was that the spawner-recruitment relationship for prawns would remain more or less the same as the relationship seen in the years of the assessment cruises. It was reasoned that, since good quantities of prawns had been produced historically at this spawner CPUE index, good recruitment would continue as long as the spawner index level was maintained.

Implementation of the fixed escapement strategy is carried out through an in-season, industry-funded monitoring program. At-sea observers sample commercial catches at the time the fishing gear is retrieved. The sampling provides estimates of female spawner abundance indices over a broad area as well as sex and cohort composition of the commercial catch on a per trap basis. Observers attempt to sample only traps which have been soaked overnight to minimise biases due to short soaks, which tend to underestimate the female index, and longer soaks, which tend to overestimate the index (Boutillier, MS 1988a). The information is faxed to the DFO assessment unit where the female spawners index per trap is standardised to trap types.

During the fishing season, weekly management conference calls are held between the DFO assessment unit and fisheries managers to discuss the sampling results and changing fishing patterns. Closures are implemented in management areas or subareas when the estimated sample mean of female spawner per standard trap is less than or equal to the MMI. Once a closure is implemented it remains in effect until the following April. This protects the remaining female spawning cohort until they have spawned and carried their eggs through to the end of the larval hatching period.

Implementation of the strategy requires ongoing research and evaluations to account for changing fishing patterns and insure the appropriateness of the management strategy. Ongoing research includes aspects of effort standardization and development of area specific escapement targets. A number of problems needed to be addressed to implement this type of management system, and this paper reviews them.

Methods

Effort Standardization

It is essential that an escapement index is based on a standard unit of effort. The escapement index was developed using standardized survey effort, however, commercial fishing methods are constantly changing and may not be equivalent to the standard survey effort, which has also changed since the 1970s surveys. To address this issue, the effective efforts of various commercial-fishing methods are routinely monitored. Fishing strategies, which vary from our present standard survey effort (conical trap with an overnight 18–24-hour soak-time), are compared to the standard in tightly controlled experiments (Boutillier, MS 1988a) and correction factors are developed if necessary. These correction factors are then applied to the at-sea-sampling results to determine the escapement indices (Table 1).

Developing Escapement Targets

The use of one fixed escapement target for the entire coast assumes that all areas have equivalent production characteristics. Extrapolation of results from more productive to less productive areas could result in overfishing the latter. In addition simple escapement targets do not reflect the complex production characteristics of a spawner/recruit relationship for the area. Experimental management areas (EMA) were established in 1985 to evaluate the appropriateness of the present escapement targets. Six areas were chosen coastwide, including three in the south coast (Howe Sound, Salmon/Sechelt Inlets, and Alberni Inlet) and three in the north (Rivers Inlet, Gardner Canal, and Work Channel) (Fig. 1). Funding shortfalls have restricted most effort to date to the south coast areas, particularly Howe Sound. Dioxin contamination closures in Howe Sound (Fig. 3) in 1988 resulted in 50% of the area being closed to fishing (Areas 3, 4, 5 and part of 1 within PFMA 28). This provided a unique opportunity to study the rebuilding of the prawn populations in the closed area and determine the spawner/recruit relationship at high population sizes (a proxy to virgin population sizes) using research vessel surveys.

Escapement indices in the EMA were monitored with fishery dependent logbook records and at-sea sampling. Fishery independent pre- and post-fishery survey cruises provided cohort abundance indices during non-fishing periods and independent verifications of commercial biological sampling information. Directed experiments were also conducted to provide additional information on effort standardization and other biological characteristics such as immigration and larval distribution.

Initial MMI were established using data from a limited series of survey observations. During these assessment cruises, effort was measured using a standard commercial (Pardiac) trap and overnight soak-times of 18–24 hours. Surveys were conducted at fixed locations, three or four times a year in the early to mid-1970s in PMFA 12, the largest prawn producing area on the B.C. coast (Boutillier MS

TABLE 1. The number of different types of traps fished (Trap Types) in the Prawn Fishery by year, the number of trap types that have been standardized that year (Standardized Traps), and the percentage of total effort that was standardized (Percentage of Total Effort).

Year	Trap Types	Standardized Traps	Percentage of Total Effort
1985/86	8	8	100.00%
1986/87	11	11	100.00%
1987/88	15	14	98.95%
1988/89	10	7	92.37%
1989/90	4	4	100.00%
1990/91	7	7	100.00%
1991/92	5	5	100.00%
1992/93	6	6	100.00%
1993/94	5	5	100.00%
1994/95	3	3	100.00%
1995/96	12	8	96.35%
1996/97	8	7	99.45%
1997/98	3	3	100.00%
1998/99	5	4	99.81%

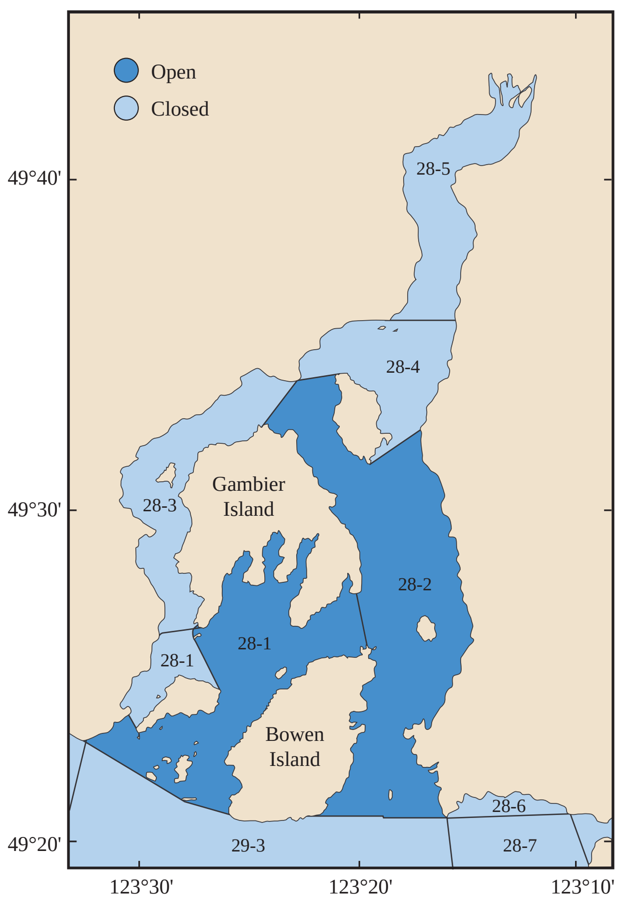

Fig. 3. Howe Sound experimental management area showing those areas closed to commercial fishing (PFMA 28-3,4,5 and part of 1) and those areas that remained open (PFMA 28- most of 1 and 2) during the period 1989 to 1994, inclusive.

1988a, b, 1996). To estimate a more appropriate MMI, a preliminary stock/recruitment analysis of the data from the closed portion of Howe Sound, which had experienced extremely varied fishing patterns (Table 2 and Fig. 4), was carried out in 1993 (Boutillier, 1996). The present analysis provides an additional six years of observations to better define the relationship.

Estimates of natural mortality were calculated for the abundance index for the combined age classes targeted by the fishery i.e. age 2+ and 3+ animals from the research survey data in the closed area, using the formula (Gulland, 1983):

$$Z=-(1/t2-t1))\cdot ln(n2/n1)$$

where $t1$ and $t2$ are two sampling times within the shrimp year (April to March) and $n1$ and $n2$ are the sum of age 2 and age 3 prawns per standard trap at these two sampling times (Table 4).

The catch, effort (Table 2) and proportions at age data (Table 3) were used with the average of the estimated value of M in the Catanal Cohort Analysis program (Hilborn and Walters, 1992). Stock-recruitment relationships were then estimated using traditional linear and non-linear fits of Beverton-Holt and Ricker stock recruitment relationships. In addition the stock-recruitment relationship was investigated using the Markovian approach which computes the proportion of times that a spawning stock within any given size interval produces recruits within various recruitment intervals (Hilborn and Walters, 1992). The

TABLE 2. Catch (number of prawns) and standardized effort (standard traps pulled) for the Howe Sound EMA closed to commercial fishing, 1989 to 1994 inclusive (Areas 28-3, 28-4, 28-5, and a portion of 28-1).

Year	Catch	Effort
1985/86	374 284	39 188
1986/87	403 046	38 327
1987/88	459 039	46 917
1988/89	88 160	12 593
1989/90	20 918	849
1990/91	27 917	1 082
1991/92	26 793	874
1992/93	26 580	921
1993/94	40 011	1 025
1994/95	23 494	690
1995/96	859 138	72 213
1996/97	288 347	33 551
1997/98	138 005	9 736
1998/99	222 871	20 910

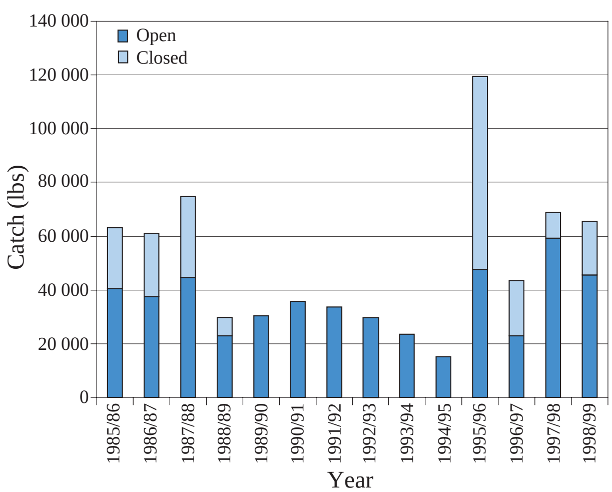

Fig. 4. Catch of prawns from the Howe Sound experimental management area (PFMA 28).

stock-recruitment relationships were calculated using recruits from the cohort analysis and spawners from either the cohort analysis or the spawner survey index data. All fits of the Beverton-Holt and Ricker models were calculated using S-plus estimation routines.

Hilborn and Walters (1992) apply the following correction factors to the a and b parameters when using a linear fit to the Ricker model.

$$a' = a + \sigma^2 / 2$$

$$b' = (a'/a) \cdot b$$

where σ is the standard deviation of the residuals.

The estimated parameters from the linear fitted Ricker stock-recruit relationship were then used to estimate the spawning stock at MSY (S_{MSY}). S_{MSY} was calculated using approximations given in Hilborn and Walters (1992).

$$S_{MSY} = b'(0.5 - 0.07a')$$

Results

Effort Standardization

The results of gear-testing studies were used to develop correction factors for standardization of effective fishing effort. Table 1 shows the number of different trap types used since 1985. Over time, a series of effort standardization experiments have been completed so that most of the effort can now be standardized (Boutillier, MS 1988a). In 1989, the MMI criteria were updated to reflect catches obtained with the latest and most effective commercial fishing technologies.

Developing Escapement Targets

Annual estimates of M for age 2+ and 3+ animals combined ranged from 0.42 to 1.46 with an overall average of 0.88. For calculations of cohort analysis and subsequent spawner recruit analysis the average of these calculated values (M = 0.88) was used. While some other value of M could have been used, Hilborn and Walters (1992) indicated that the use of "soft" values of M should not mask any strong age-time patterns in the catchability coefficient "q". The cohort

TABLE 3. Proportions of catch-at-age for prawns caught in Howe Sound EMA closed to commercial fishing, 1989 to 1994 (Areas 28-3, 28-4, 28-5, and a portion of 28-1.

Year	Age 0+	Age 1+	Age 2+	Age 3+
1985/86	0.03301	0.30773	0.45896	0.20030
1986/87	0.02518	0.50121	0.28886	0.18475
1987/88	0.01255	0.20758	0.51990	0.25997
1988/89	0.00025	0.21540	0.35911	0.42525
1989/90	0.01120	0.13976	0.58386	0.26518
1990/91	0.00640	0.18518	0.27371	0.53471
1991/92	0.01597	0.19225	0.45095	0.34084
1992/93	0.00758	0.22104	0.39271	0.37867
1993/94	0.00763	0.20718	0.41216	0.37303
1994/95	0.01054	0.20109	0.37734	0.41103
1995/96	0.00110	0.38167	0.28765	0.32958
1996/97	0.00059	0.29192	0.46362	0.24387
1997/98	0.00171	0.04944	0.43774	0.51112
1998/99	0.00551	0.18112	0.35291	0.46046

TABLE 4. The number of age 2 (n_1) and 3 (n_2) prawns caught per standardized trap from research cruises conducted in the autumn and winter from 1989 to 1995 in the Howe Sound EMA closed to commercial fishing. The number of months between the research cruises for each year and the calculated natural mortality rate, *M*. (NB: average is 0.88).

Year	n_1 CPUE	n_2 CPUE	Months	*M* Annual
1989/90	25.6	15.9	6	0.96
1990/91	24.5	16.1	8	0.63
1991/92	27.3	20.9	5	0.64
1992/93	23.5	19.7	5	0.42
1993/94	36.1	22.2	5	1.17
1994/95	33.6	18.3	5	1.46

estimates and patterns in average estimates of *q* by age are shown in Tables 5 and 6, respectively.

The linear Ricker stock recruitment models (Ricker, 1975) produced the best fits (Table 7) to the data with spawners estimated from both the cohort analysis (Fig. 5) and the research surveys (Fig. 6). This suggests a density dependent relationship where the highest levels of spawning stock reduce recruitment success. Although the residuals (Fig. 7) show anomalies in the application of the Ricker model, the results from the Markovian approach (Table 8) also suggested a density dependant relationship where there is a greater probability of poor recruitment at very high levels of spawner density.

The spawning stock level at MSY (S_{MSY}) for the linear fits of the cohort estimates and the survey indices were approximately 260 000 females and a spawner index of 3.9 females per trap for March, respectively. This is more than 2 times higher than the present MMI for March.

Discussion

Garcia (1996) reviewed the risks associated with fishing short-lived, late-maturing shrimp and found a high potential for drastically reducing the fecundity-per-recruit. He concluded that these fisheries must be controlled through measurable recruitment-related reference points such as spawning biomass, recruitment or fishing effort.

In general, a fixed escapement management system tends to maximize yield but it is subject to the largest variations in catch (Zheng *et al*., 1993). This

TABLE 5. Numbers-at-age from cohort analysis using constant M of 0.88 calculated for the Howe Sound EMA closed to commercial fishing.

Year	Age 0+	Age 1+	Age 2+	Age 3+
1985/86	5 307 572	1 879 520	626 674	155 502
1986/87	5 538 575	2 193 786	708 250	156 594
1987/88	10 563 980	2 290 978	785 280	222 589
1988/89	7 917 160	4 378 165	891 102	182 857
1989/90	8 331 326	3 283 889	1 804 150	349 945
1990/91	11 056 840	3 455 546	1 360 278	740 718
1991/92	10 646 470	4 586 075	1 430 077	559 457
1992/93	6 099 621	4 415 705	1 899 013	585 643
1993/94	4 338 098	2 529 893	1 827 895	781 172
1994/95	8 365 690	1 799 178	1 044 188	747 904
1995/96	5 461 324	3 469 791	743 323	427 587
1996/97	3 056 789	2 264 674	1 236 912	161 113
1997/98	3 184 701	1 267 798	887 059	430 706
1998/99	3 910 084	1 320 812	521 608	330 549

TABLE 6. Average catchability coefficient (q) by age of prawns caught in the Howe Sound EMA closed

Age	Catchability coefficient
Age 0+	4.57E-08
Age 1+	2.53E-06
Age 2+	1.06E-05
Age 3+	2.84E-05

TABLE 7. Linear fitted parameters for the Ricker model for the Howe Sound EMA closed to commercial fishing using: "R" recruits calculated from the cohort analysis and "S" spawners calculated from cohort analysis and research survey indices.

Equation	Fitting Method	Stnd. Dev. of residuals	Fitted "a" value	Fitted "b" value
$R = S \cdot e^{a(1-S/b)}$	Cohort spawner	1.74	3.92	15.7
	Survey Index	2.14	1.53	7.12

TABLE 8. Markovian analysis showing the proportion of categories of prawn spawning stock abundance in the Howe Sound EMA closed to commercial fishing which produced various levels of recruits.

Recruitment	Spawning Stock March BRP		
(Million)	0–3.9	4.0–7.9	8.0–11.9
0–3.7	0.4	0	0
3.8–7.4	0.2	0	0.5
7.5–11.1	0.4	1	0.5

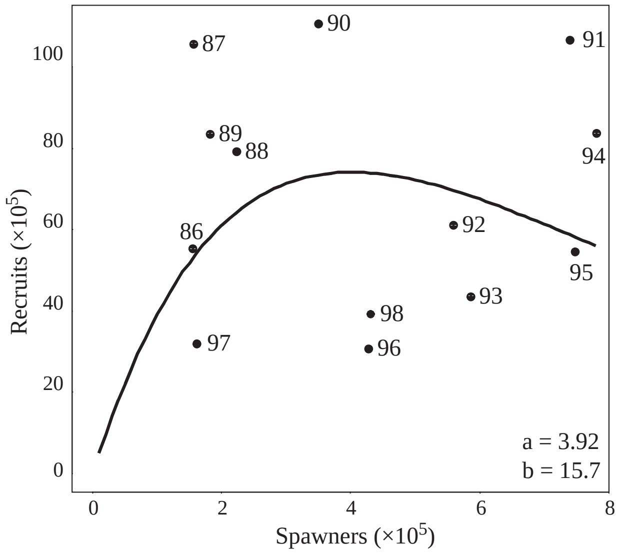

Fig. 5. Results of the linear fit of the Ricker Spawner-Recruit relationship for prawns in the Howe Sound EMA closed area using the estimated number of spawners from the cohort analysis.

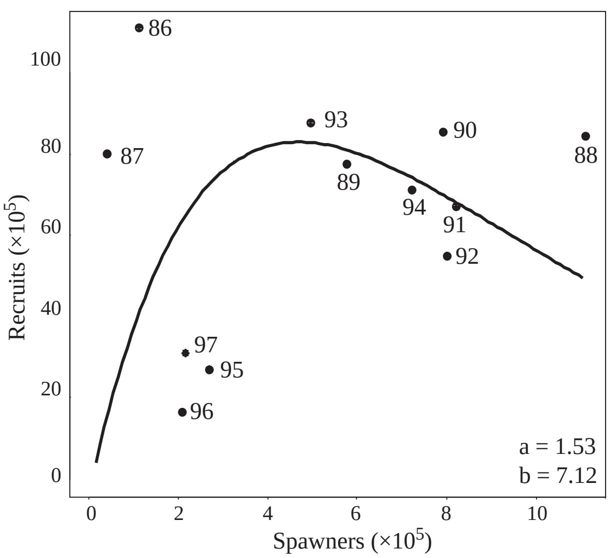

Fig. 6. Results of the linear fit of the Ricker Spawner-Recruit relationship for prawns in the Howe Sound EMA closed area using spawner estimates from research survey cruises.

type of system is also logistically difficult to implement. For example, salmon fisheries must take place well before the escapement target on the spawning grounds can be assessed (Eggers, 1993) because the quality of the product is reduced substantially as the salmon nears the spawning grounds.

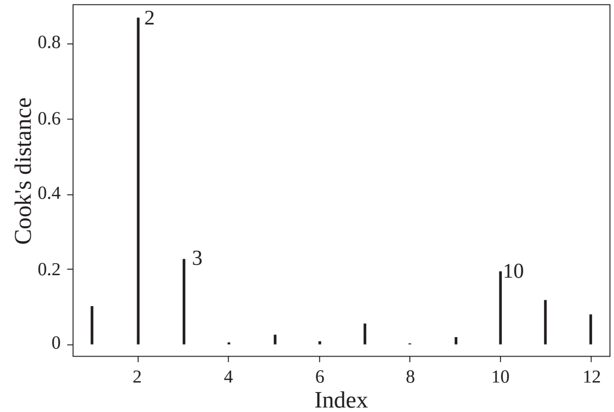

Fig. 7. Cook's Analysis of the residuals of the linear fit of the Ricker Spawner-Recruit analysis for the prawns in the Howe Sound EMA closed to fishing using the spawner index from the research cruises. The data points in this analysis show which points have the greatest effect on the residuals of the model fit.

The B.C. prawn trap fishery is one of the few non-salmonid fisheries that is managed using fixed escapement targets. The system appears to have been fairly successful over the last 20 years. A healthy prawn population and fishery have been sustained even during periods of huge increases in fishing efficiencies. Production has increased despite reductions on the fishing season from 230 days in 1994 to 93 days in 1998.

Despite its apparent success, the fixed escapement management system still requires improvements for optimum production from all areas of the coast. The present stock-recruitment analysis does not provide an optimum MMI although it does suggest that the current limit reference point for closing areas should be more conservative. By allowing more spawners to escape (up to a point), the prawn populations should increase and provide fishermen with a greater surplus of recruits. In addition, a higher spawner index would provide a greater safety margin for variations in recruitment success caused by biotic and abiotic influences such as disease, parasite outbreaks or unfavourable environmental conditions. The results also indicate that if the spawning stock size is too high there is a chance of density-dependent depensatory mechanisms such as cannibalism or disease, which affect recruitment survival. Prawns held in tanks are known to cannibalize molting prawns. Competition has been observed in traps (Boutillier and Sloan, 1988). This may also explain some of the age-specific catchability differences evident in the results of the cohort analysis (Table 6).

The present analysis does not resolve differences in area specific carrying capacity. There is a great deal more to learn about biotic and abiotic factors causing spatial variations in natural mortality, recruitment success and growth. New fishery independent data series are needed in other areas of the coast and data collection should include information on environmental conditions.

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