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A Progress Report on the Control of Growth and Recruitment Overfishing in the Shrimp Trap Fishery in British Columbia

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Abstract

Management of growth and recruitment overfishing in the spot prawn (*Pandalus platyceros*) trap fishery in British Columbia is managed using size limits and a fixed escapement system. The fixed escapement is implemented using an index of the number of spawner/trap caught in the commercial fishery. The development and application of this system are reviewed, including a description of the theoretical basis for this method of management, the problems with implementation, and the implementation procedure.

The size limits were introduced in 1985 and implemented in 1988. Industry has recognised the benefits of the size limits and has recently suggested increases.

The fixed escapement system was initially based on empirical survey data. To evaluate the efficacy of this management system a number of experimental management areas were developed. This paper will review the present state of progress in the development of a more model-based rationale for this system using data gathered from one of these experimental management areas, Howe Sound.

Howe Sound has been closely monitored as an experimental prawn management area since 1985. Data available for the area includes catch records from the commercial fishery, biological sampling and catch composition monitoring of the fishery, and detailed information from pre- and post-fishery research surveys carried out every year. This paper reviews the findings and suggests directions for further work.

Résumé

La gestion de la croissance et de la surpêche des recrues chez la crevette tachetée (*Pandalus platyceros*) pêchée au moyen de trappes en Colombie-Britannique est effectuée en utilisant des limites de taille et un système fixe d’échappement, lequel repose sur un indice établi à partir du nombre de crevettes matures par trappe capturées commercialement. L’élaboration et l’utilisation de ce système sont examinées, notamment les fondements théoriques de cette méthode de gestion, les problèmes liés à son application et ses mécanismes de mise en œuvre.

Les limites de taille ont été introduites en 1985 et mises en application en 1988. L’industrie a reconnu les avantages de cette pratique et, récemment, a suggéré de hausser les limites.

Au départ, le système fixe d’échappement a été établi d’après des données empiriques. Un certain nombre de zones de gestion expérimentales ont été établies afin d’évaluer l’efficacité de ce système de gestion. Le présent document explique les derniers développements quant à l’élaboration d’une approche davantage basée sur un modèle et qui est fondée sur des données recueillies à Howe Sound, une des zones de gestion expérimentales.

En tant que zone d'expérimentation de la gestion de la crevette, Howe Sound a fait l'objet d'un contrôle suivi depuis 1985. Les données obtenues comprennent celles des registres des prises de la pêche commerciale, de l'échantillonnage biologique, et du contrôle de la composition des prises et des renseignements détaillés obtenus au cours des périodes qui ont précédé et qui ont suivi les relevés effectués chaque année. Le présent document fait état des conclusions et des propositions de travaux de recherche à venir.

Introduction

The shrimp fisheries on the West Coast of Canada target seven species of shrimp including: *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. The trawl fishery and its management and assessment framework was reviewed Harbo et al (in press). This paper will focus on the trap fishery for the spot prawn, *Pandalus platyceros*. The trap fishery accounts for 98% of the total landings of spot prawns (Morrison et al 1999) and represents the most valuable shrimp fishery in British Columbia (B.C.).

Key Biological Considerations

The spot prawn is the largest of seven commercial Pandalid shrimp species occurring in British Columbia waters with a reported maximum size 61.1 mm carapace length (Butler 1980). Their maximum age is considered to be 48 months old. They are protandrous hermaphrodites, functioning 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 fall 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. Once settled, however, tagging studies have shown that at least mature animals are relatively sedentary and remained within a mile or two of their release location over a period of several months (Boutillier, unpublished data). There are also significant differences in parasite loads and growth rates between stocks that are separated by 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 (Fig. 1). The suspected limited mobility of adult populations implies that there may be hundreds of separate stocks, however, the concept of meta-populations that share larvae may well apply to prawns because of their lengthy pelagic larval stage. Sequential south to north recruitment of populations of the smooth pink shrimp, *Pandalus jordani*, over time have shown potential indicators of meta-population trends off the west coast of Vancouver Island (Boutillier et al. 1997). Good recruitment of a single year-class over a fairly large area has occurred at times, (Boutillier, unpublished catch sampling data), however, this may be due to good environmental conditions over a large area having a positive effect on a number of populations, rather than a single population response. There are instances of a single year class settling in a particular area, spending its life there then leaving the area virtually barren when the year class dies off. Some of these cases have been documented via logbooks and catch sampling, in bays off the open waters of the West Coast of Vancouver Island.

History of the Prawn Trap Fishery

Prior to 1979 approximately 50 vessels fishing participated in the prawn fishery. The fleet had expanded to over 300 vessels by the mid-1980’s and in 1990 licence limitations were implemented and in 1998, 257 licences were issued to 223 licence holders. In 1995 trap limits were implemented which restricted single licensed vessels to 300 traps and double stacked licences to 450 traps.

No significant landings were reported from the north coast (Pacific Fisheries Management Areas (PFMA) 1-11) before 1979. The fishery moved into northern areas following exploratory surveys carried out in the mid 1970's (Boutillier and Cooke, 1976). The majority of the prawns are still landed in south coast waters (Fig. 2) (Morrison et al 1999). Coastwide landings peaked in 1996 and 1997 and currently, based on inseason sampling almost all inshore areas (PFMA 1 to 29) are 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 1990’s and the FAS market became predominant in the mid ‘90’s.

The landed value of the prawn fishery peaked in 1996 and 1997 with values exceeding $Cnd 26 million. Morrison et al (1999) carried out a post-season review of the 1997 fish slip data which revealed price records that were extremely low in comparison with the known average landed value. Their recalculation suggested that the true landed value was in the range of $28.5M to $32.5M. Subsequent inquiries confirmed that end-of-season adjustments are paid to fishers once the product has been marketed. Therefore, the reported landed value from fish slips appear to have always underestimated the actual landed value of the fishery.

History of the Biological Management Strategies

The prawn fishery in British Columbia is presently managed to meet two biological objectives: to prevent growth over-fishing and to prevent recruitment over-fishing.

Growth over-fishing is controlled through a combination of: 1) size-limits, which were introduced in 1985 and implemented in 1988, 2) trap escapement modifications and 3) manipulation of the opening times. Boutillier (1984) recommended a minimum size limit corresponding to an age at first capture of 25 months based on a Ricker yield per recruit analysis. This would allow the animals to be available to the fishery for two fishing seasons. A size limit of 30.0-mm carapace length (CL) was estimated to the average size of prawns at this age at first capture (Boutillier 1985) and this was suggested as a coast-wide limit. It was noted, however, that adopting a single coast-wide size limit did not take into account variations in growth rates between areas and between years. It should however be noted, that the growth rate of prawns is sufficiently high to insure that the 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 then to 33.0 mm in 1997 to take advantage of the increasing price-differential for larger animals (Morrison et al 1998). This increase in size limit basically increased the average age at first capture by a few months but most animals will still be available to the fishery over two fishing seasons.

Recruitment over-fishing has been managed using a fixed escapement policy since 1979. This policy was developed around the premise that the fishery would close for the remainder of the shrimp year once the number of female prawns caught per trap reached a minimum monthly threshold A series of these monthly indices was established which would account for natural mortality and allow the area to have an average of 1 female spawner per trap in March (the month of egg hatching). This biological reference point (BRP) was established by collecting assessment indices of the mean number of female spawners per trap in March from study sites within commercial fishing areas that produced the largest and most consistent catches. During the assessment cruises, effort was measured using a standard commercial trap (Pardiac trap) and overnight soak-times (18-24 hours). The assessment cruises were carried out at set locations, three or four times a year in the early to mid-1970's in Knight and Kingcome Inlets, the largest prawn producing areas on the B.C. coast (Boutillier 1988a, b, 1996). Minimum monthly spawner indices (MMI) for the months prior to March were back calculated using an estimated natural mortality rate of 1.3 (Boutillier 1987).

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. A number of problems needed to be addressed to implement this type of management system.

Assessment Data

Implementation of the fixed escapement strategy is addressed through an industry-funded program of at-sea monitoring biological sampling program which is carried out concurrently with enforcement of on-grounds effort controls. Using at-sea observers, commercial catches are sampled at the time the fishing gear is retrieved. The at-sea monitoring of the fishery provides sample spawner abundance indices from a number of traps per string and a number of strings over a broad area. The spawner-index sampling encompasses examination of sex and cohort composition of the commercial prawn catch on a per trap basis. The information is faxed to the assessment unit and the number of female spawners (3+ yr.) per trap is standardised to trap types. Observers attempt to sample traps which have been soaked overnight, to minimise biases that may occur with very short soaks (which tend to underestimate the female index) and very long soaks (which tend to overestimate the female index) (Boutillier, 1988a). The mean index of spawner abundance from the samples taken in any area within a week is then compared to an escapement threshold, minimum monthly index (MMI) of females/trap (Boutillier 1987). This MMI is based on CPUE figure from a standard conical trap (made by SAK industry) soaked overnight for 18-24 hours. Weekly management conference calls are held within the openings 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.

Other Considerations

There are two assumptions inherent with the implementation of the strategy in its present form. These are that effort could be standardized and the escapement targets were appropriate for the whole coast.

Effort Standardization

The first problem with implementing the fixed escapement strategy is to insure that you have an escapement index based on a standard unit of effort. The escapement index was developed from a measurement of standardized **survey effort**. The methods of fishing used by the **commercial industry** is constantly changing and may not be equivalent to the standard survey effort.

To address this issue, the effective efforts of various fishing methods were, and are, routinely being monitored in the commercial fishery. Fishing strategies which vary from our standard survey effort (conical trap with an overnight (18-24 hr) soak-time) are compared with standard effort in tightly controlled experiments (Boutillier 1988a) to determine if they produce significantly different catch rates. The results of the experiments indicate how and by how much the various fishing strategies need to be corrected to make them equivalent to the standard assessment fishing configuration and CPUE calculation. These correction factors are then applied to the at-sea-sampling results to determine the escapement indices.

Developing Escapement Targets

The application of a single fixed escapement target to the whole coast firstly assumes that all areas have equivalent production characteristics. The major danger with this assumption is that extrapolation of the results from the most productive area to the whole coast is that less productive areas may be in danger of overfishing.

The second assumption associated with the use of this empirical production data was that there would continue to be commercial production from the area if a certain number of females were left to complete spawning. These initial escapement targets were based on empirical measurements of production from a single area and do not reflect the complex production characteristics of a spawner/recruit relationship for the area.

To address these issues, experimental management areas (EMA's) were established in 1985. Six areas were chosen coastwide, three in the South coast (Howe Sound, Salmon/Sechelt Inlets, and Alberni Inlet) and three in the North coast (Rivers Inlet, Gardner Canal, and Work Channel). These areas were to be monitored through a series of commercial and research assessment programs. Because of logistical problems in terms of manpower and funding shortfalls, almost all effort to date has been focused in the South coast areas and in Howe Sound in particular. The objectives of this program were to improve the quality and efficiency of existing management practices, develop new practices for future use, and test the biological consequences of resource management decisions.

Prawn stock escapement indices in the EMA's 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. Specific experiments were also routinely conducted to provide information on effort standardisation and other biological characteristics such as immigration, larval distribution etc. When possible, these cruises were conducted during fishery closures to develop independent pre- and post-fishing assessments and to establish estimates of natural mortality and recruitment.

The main focus for this work was the Howe Sound EMA. Howe Sound provided a unique opportunity, in that Dioxin contamination closures in 1988 resulted in splitting the area so that 50% was closed to fishing (Sub-areas 3, 4, 5 and part of 1) and 50% of the area (most of Sub-area 1 and all of Sub-area 2) remaining open to fishing. Research cruises in the closed areas allowed us to study the rebuilding of the prawn populations in the area and develop a spawner/recruit relationship with data from the high population sizes.

Results to Date

Changing fishing techniques

The results of these gear-testing studies are used to develop correction factors to allow for standardisation of effective fishing effort. Table 1 shows the number of different traps used in the different years. Over time, a series of effort standardisation experiments have been completed so that most of the effort can now be standardised (Boutillier 1988a). In 1989, the MMI criteria were updated to a set of indices that reflected catches obtained using the most modern effective commercial fishing technologies.

Developing Escapement Targets

As previously described the initial BRP was established from a series of empirical survey observations. To estimate a more appropriate BRP a preliminary stock/recruitment analysis of the data from the closed area portion of Howe Sound was carried out in 1993 (Boutillier 1996). The closed area in Howe Sound provided a unique opportunity to collect observations from an area with extremely varied fishing patterns (Table 2). For the initial analysis there were only eight observations and the results were very preliminary. The present analysis allows us to evaluate the relationship with an additional six years of observations.

From the research cruises in the closed area, estimates of natural mortality were calculated for the combined age classes targeted by the fishery i.e. Age 2+ and 3+ animals, using the formula (Gulland, 1983):

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

where *t1* and *t2* are two points in time within the shrimp year (Apr-Mar) and *n1* and *n2* are relative estimates of abundance (#/standard trap) of the combined 2+ and 3+ animals in the experimental sampling locations at these two points in time (Table 4).

These calculations provided estimates of M for these two-combined age classes that ranged from 0.42 to 1.46. For calculations of cohort analysis and subsequent spawner recruit analysis the average value of M = 0.88 was used. It could be argued that some other value of M should have been used but due to the nature of cohort analysis, Hilborn and Walters (1992) felt that using soft values of M should not mask any strong age-time patterns in q.

The catch, effort and proportions at age data were used with the combined estimated value of M= 0.88 in the Catanal Cohort Analysis program (Hilborn and Walters 1992). The cohort estimates and patterns in q are seen in Tables 5 and 6 respectively.

The results of the cohort analysis were then used alone or in combination with other indices of abundance, such as the standard survey escapement index from March to estimate linear fits of Ricker stock recruitment models (Ricker 1975). All fits were calculated from models using S-plus estimation routines.

$$R=S*e^{a(1-S/b)} \text{ (Ricker Model)}$$

Linear parameter estimates (Table 7) were calculated for the spawner/recruit relationships based on recruits from the cohort analysis and spawners from either the cohort analysis or the spawner survey index data. Hilborn and Walters (1992) apply a correction factor the following correction factors to the ***a*** and ***b*** parameters when using a linear fit to the Ricker model.

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

$$b' = (a'/a)*b$$

where σ is the standard deviation of the residuals.

The estimated parameters for the Ricker spawner/recruit relationship allows us to estimate the Spawning stock for MSY (S_{MSY}) using Hilborn's approximation (Hilborn and Walters 1992).

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

Using this formula the spawning stock level at MSY is ~ 260,000 females for the area or a spawner index of 3.9 females per trap for the month of March (as calculated from a research cruise in the area) which is > 2 times larger then the present BRP for the month of March.

The absolute values obtained from these analyses must not be given to much emphasis, as there were problems with fitting the data. A plot of the residuals for the spawner index/recruit relationship in Fig. 7 shows some of the major anomalies. Another way of looking at the spawner/recruit relationship is the Markovian approach, shown in Table 8. This approach simply describes the data in tabular form by dividing the range of potential stocks and recruitment into intervals and computes the proportion of times that a spawning stock within any given interval produces a recruitment within each recruitment interval (Hilborn and Walters 1992). This technique does show that leaving more spawners reduces the probability of poor recruitment.

Discussion

Growth overfishing

Industry now has taken the lead on requesting size increases. They base their decisions on the price differential for different size prawns in the market. As size limits are increased to take advantage of price differentials, it will be important to understand the implications on production from a growth perspective. It will also be important to review the adequacy of the present escapement mechanisms, which have been built into the traps for release of undersize prawns, in relation to these new larger size limits.

Recruitment overfishing

Garcia (1996) reviewed the risks associated with fishing short-lived and late-maturing shrimp and found that the potential for drastically reducing the fecundity-per-recruit is very high. He concluded that it was absolutely necessary to have these fisheries controlled through recruitment-related reference points expressed in terms of spawning biomass, recruitment, fishing effort and other measurable and controllable fishery variables.

In general, a fixed escapement management system tends to maximise yield but it is subject to the largest variations in catch (Zheng et al 1993). Also this type of system is considered to be logistically difficult to implement. For example, salmon fisheries must take place before the escapement target on the spawning grounds can be assessed (Eggers 1993). This situation arises in salmon because the quality of the product is reduced substantially as the salmon nears the spawning grounds requiring that the fishery proceed well in advance of the escapement estimation procedure.

The British Columbia prawn trap fishery is one of the few non-salmonid fisheries that is actually being managed using fixed escapement targets. The system does appear to have been fairly successful over the last 20 years. Healthy populations of prawns and a healthy fishery have been maintained even during periods huge increases in fishing efficiencies (fishing times have been reduced from 230 days in 1994 to 93 days in 1998 while production has increased).

The present analysis does not provide us with the optimal BRP. The Fixed Escapement management system is still a long ways from being a perfect system that provides optimum production from all areas of the coast. The results of the stock/recruitment analyses do suggest that there is room to be more conservative in BRP criteria for closing areas. By allowing more spawners to escape (up to a point) the prawn populations should increase, which in turn would provide fishermen with a greater surplus of recruits to fish. In addition, a greater spawner index would provide a greater safety margin to take into account the variation in recruitment success caused by biotic and abiotic episodes such as disease or parasite outbreaks or unfavourable environmental conditions. The results also indicate that if the index is too high, then there is a chance of density-dependent depensatory mechanisms affecting survival. This may occur by factors such as: cannibalism, disease outbreaks etc. Prawns held in tanks are known to cannibalise other moulting prawns. This is also reflected in the apparent competition in traps (Boutillier and Sloan 1988) where small prawns enter the traps first but apparently leave the traps as larger prawns enter. This competition/predation may also explain some of the age-specific catchability differences evident in the results of the cohort analysis (Table 6).

Unfortunately the present analysis does not allow us to resolve important differences in area specific carrying capacity. There is a great deal more to learn about both the biotic and abiotic factors causing spatial variations in natural mortality, recruitment success and growth. New fishery independent data series need to be built in other areas of the coast and the data series needs to be expanded to collect information on the environmental conditions in these areas.

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References

Boutillier, J.A., K.D. Cooke. 1976. Prawn Trap Exploration, B.C. Northern and Central Coast September 1975 to December 1975. Fish. R. Board Can. MS Rept. No. 1388: 134 p.

Boutillier, J. A. 1984. Prawn - Minimum Size Limit. p. 11-24. In 1982 Shellfish Management Advice, Pacific Region. G.S. Jamieson (ed) Can. Ms Rep. Fish. Aquat. Sci. 1774: 71 p.

Boutillier, J. A. 1985. Effect of Variability in Growth rates on Minimum Size Restrictions for Prawns (Pandalus platyceros). in 1983 and 1984 Invertebrate Management Advice, Pacific Region. G.S. Jamieson (ed) Can. Ms Rep. Fish. Aquat. Sci. 1848: 107 p.

Boutillier, J.A. 1987. Prawn Trap Fishery and Fishery Monitoring. PSARC Working Paper S87-2.

Boutillier J., R. Harbo and B. Adkins. 1987. Mesh Selection Modifications in Wire Mesh Prawn Traps. PSARC Working Paper-I87-16. 13p.

Boutillier J.A. 1988a: Standardization of Effort in the Prawn Fishery as it Relates to Biological Sampling and Escapement Management. PSARC Working Paper No. I88-5.

Boutillier, J.A. 1988b. Review of studies in experimental prawn fishing areas. PSARC Working Paper I88-7.

Boutillier J.A. and N.A. Sloan. 1988. Trap mesh selectivity in relation to the legal size regulation for prawn, Pandalus platyceros in British Columbia. J. Shellfish Res. vol. 7, no. 3, 427-431.

Boutillier, J.A. 1996. 1993 Review of Experimental Prawn Fishing in Howe Sound. In Hand, C.M. and B.J. Waddell [eds.]. 1996. Invertebrate Working Papers Reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1993 and 1994. Can. Tech. Rep. Fish. Aquat. Sci. 2089: 303 p.

Boutillier, J.A., R.I. Perry, B. Waddell and J. Bond. 1997. Assessment of the Offshore *Pandalus jordani* Trawl Fishery Off the West Coast of Vancouver Island. PSARC Working Paper I-97-11.

Bower, S.M. and J.A. Boutillier. 1990. Sylon (Crustacea: Rhizocephala) Infections on the Shrimp in British Columbia. In Pathology in Marine Science. Edited by S.O. Perkins and T.C. Cheng. Academic Press. pp. 267-275.

Bower, S.M., G.R. Meyer and J.A. Boutillier. 1996. Stained prawn disease (SPD) of *Pandalus platyceros* in British Columbia, Canada, caused by a rickettsial infection. Diseases of Aquatic Organisms. Vol. 24: 41-54, Jan 1996.

Butler, T.H. 1980. Shrimps of the Pacific Coast of Canada. Can. Bull. Fish. Aquat. Sci. 202: 280 p.

Dawe, E.G., J.M. Hoenig, and X. Xu. 1993. Change-in-Ratio and Index-Removal Methods for Population Assessment and Their Application to Snow Crab *(Chionoecetes opilio).* Can. J. Fish. Aquat. Sci. 50: 1467-1476.

Eggers, D.M. 1993. Robust Harvest Policies for Pacific Salmon Fisheries. In Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations. Edited by G. Kruse, D.M. Eggers, R.J. Marasco, C. Pautzke, and T.J. Quinn, II. Alaska Sea Grant College Program Report No. 93-02. University of Alaska, Fairbanks, Alaska. pp. 85-106.

Gabriel, W.L. and P.M. Mace. 1998. A review of biological reference points in the context of the prcautionary approach. In V. Restrepo [ed.] Proceedings of the 5th National Stock Assessment Workshop. National Marine Fisheries Service, Office of Science and Technology, 1315 East-West Highway, Silver Spring, MD 20910.

Garcia, S.M. 1996. Stock-Recruitment Relationships and the Precautionary Approach to Management of Tropical Shrimp Fisheries. Mar. Freshwater Res. 47: 43-58.

Gulland, J. A. 1983. Fish stock assessment - A Manual of Basic Methods. FAO/Wiley series on food and agriculture, Vol.1.: 484p.

Hilborn. R. and C. J. Walters. 1992. Quantitative fish stock assessment: coice, dynamics and uncertainty. Chapman and Hall, New York. 570 p.

Morrison, J., M. Kattilakoski, I. Winther and J.Boutillier. 1998. The Prawn Trap Fishery 1996,1997. Prepared as a PSARC Fishery Update. January 1998.

Morrison, J., M. Kattilakoski, J.Boutillier and J. Bond. 1999. The Prawn Trap Fishery - 1998. Prepared as a PSARC Fishery Update. January 1999.

Orensanz, L., J. Armstrong, D. Armstrong and R. Hilborn. 1998. Crustacean resources are vulnerable to serial depletion – the multifaceted decline of crab and shrimp fisheries in the Greater Gulf of Alaska. Rev. in Fish Bio. and Fish. 8: 117-176.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res Board Can. 191: 382p.Boutillier, J. 1984. Prawn - Minimum Size Limit. p.

11-24. In 1982 Shellfish Management Advice, Pacific Region. G.S. Jamieson (ed.) Can. Ms. Rep. Fish. Aquat. Sci. 1774: 71 p.

International Council for the Exploration of the Sea (ICES). 1997. Report of the Study Group on the Precautionary Approach to Fisheries Management. ICES CM 1997/Assess:7. 37p.

Walters, C. and Parma, A.M. 1996. Fixed exploitation rate strategies for coping with effects of climate change. Can. J. Fish. Aquat. Sci. 53: 148-158.

Zheng, J., T.J. Quinn II, and G.H. Kruse. 1993. Comparison and Evaluation of Threshold Estimation Methods for Exploited Fish Populations. In Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations. Edited by G. Kruse, D.M. Eggers, R.J. Marasco, C. Pautzke, and T.J. Quinn, II. Alaska Sea Grant College Program Report No. 93-02. University of Alaska, Fairbanks, Alaska. pp. 267:290.

Year	# of different trap types recorded in logbooks	# of trap types for which efficiency is known	% of traps for which efficiency is known
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%

Table 1: The number of different types of traps fished in the Prawn Fishery by year, the number of trap types that have been standardised that year, and the percentage of total effort that can be standardised.

Year	Catch (number of prawns)	Effort (standard traps pulled)
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

Table 2. Catch and standardized effort for the Howe Sound areas **Closed** to commercial fishing, 1989 to 1994 inclusive (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 3. Proportions of catch at age for Areas 28-3, 28-4, 28-5, and a portion of 28-1.

Year	N_2 CPUE	N_1 CPUE	Months	M Annual
1989/90	15.9	25.6	6	0.96
1990/91	16.1	24.5	8	0.63
1991/92	20.9	27.3	5	0.64
1992/93	19.7	23.5	5	0.42
1993/94	22.2	36.1	5	1.17
1994/95	18.3	33.6	5	1.46

Table 4. CPUE's and months used to calculate the natural mortality rate, M.
NB: average is 0.88

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 5. Numbers at age from cohort analysis using constant M of 0.88.

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

Table 6. Average catchability coefficient by age.

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

Table 7. Linear fitted parameters for the Ricker model using: Recruits calculated from the cohort analysis and Spawners calculated from cohort analysis and Survey indices.

Recruitment (Million)	*Spawning Stock March BRP*		
	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

Table 8. Proportion of categories of spawner producing various levels of recruits.

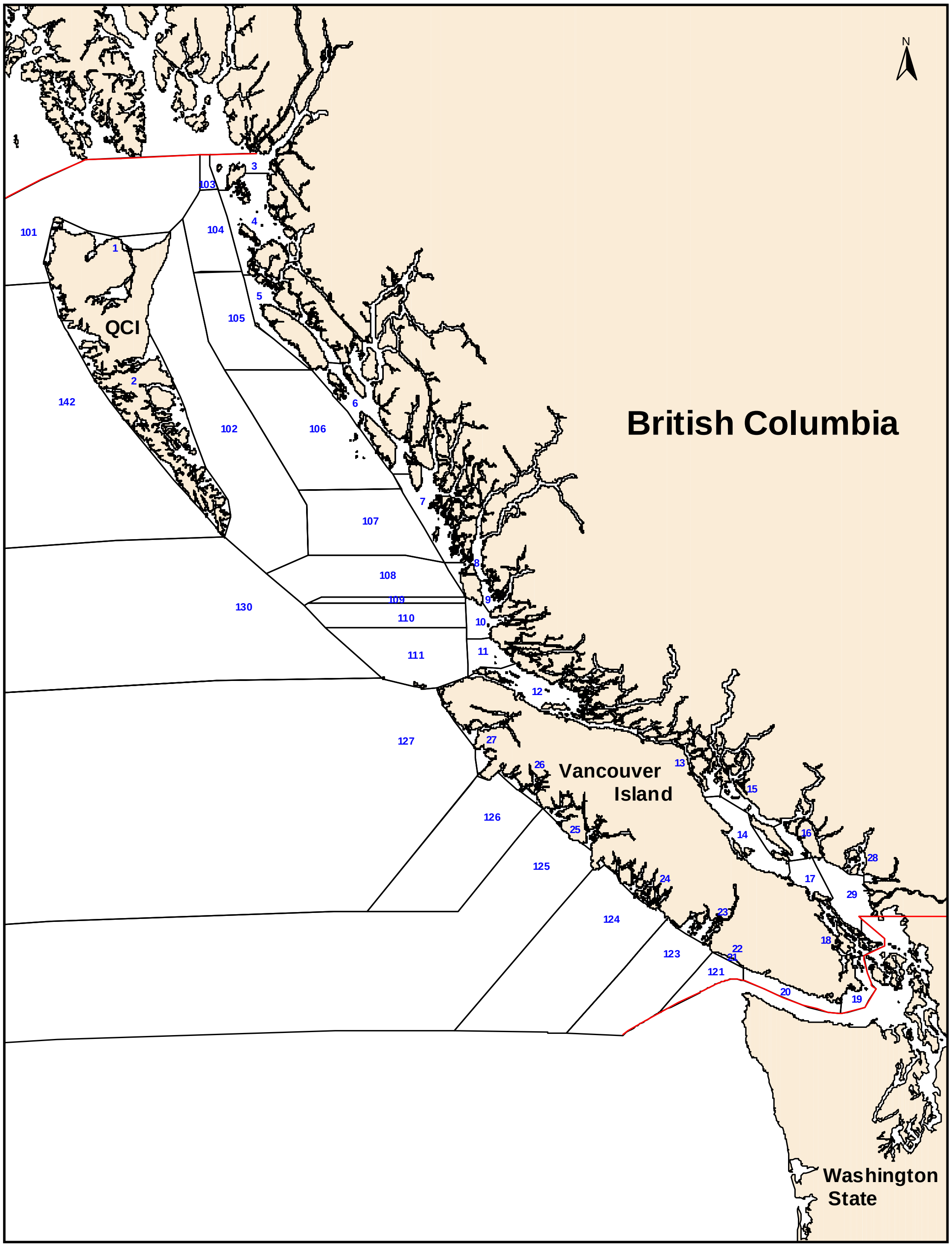

Figure 1. British Columbia Coast with PMFA.

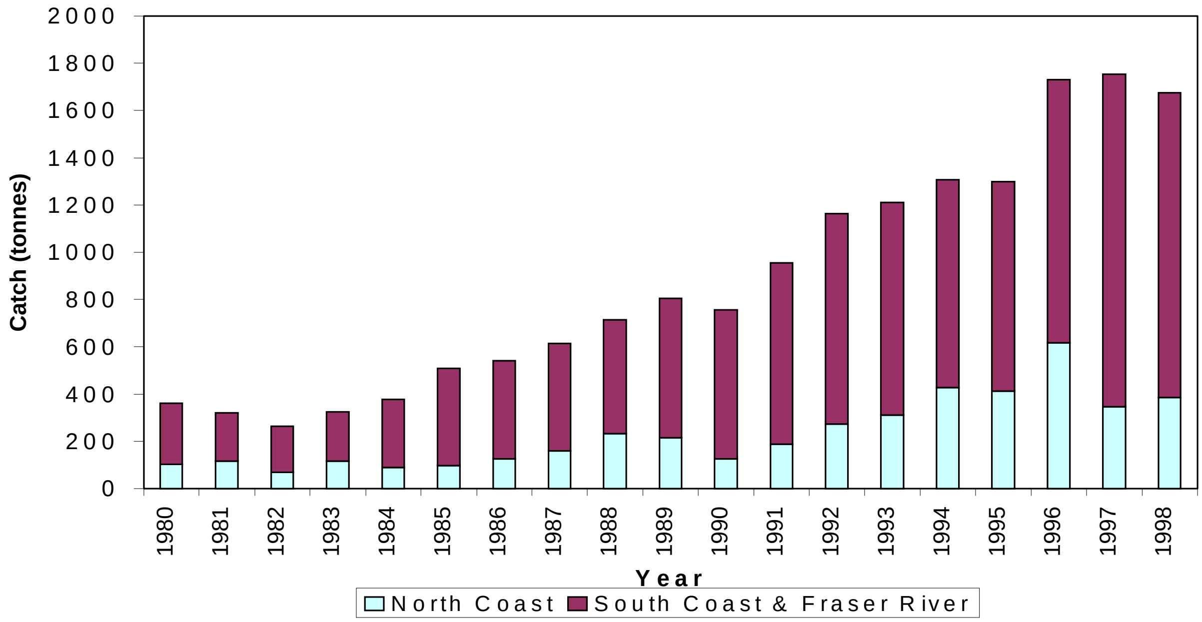

Figure 2. Catch (in tonnes) in the prawn trap fishery in British Columbia, 1980 to 1998.

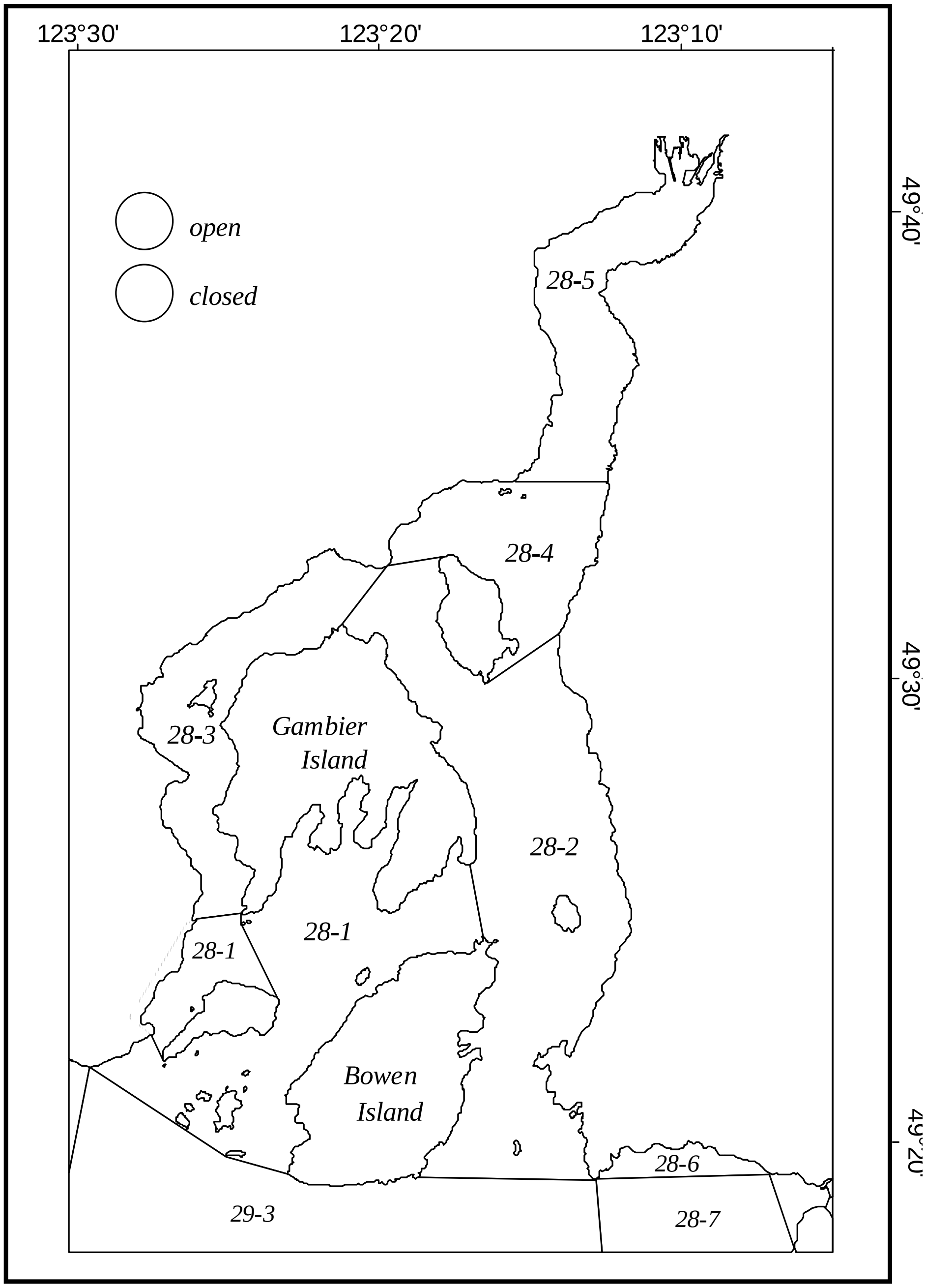

Figure 3. Howe Sound experimental management area with **Closed** (PFMA 28-3,4,5 and part of 1) and **Open** (PFMA 28- most of 1 and 2) indicated.

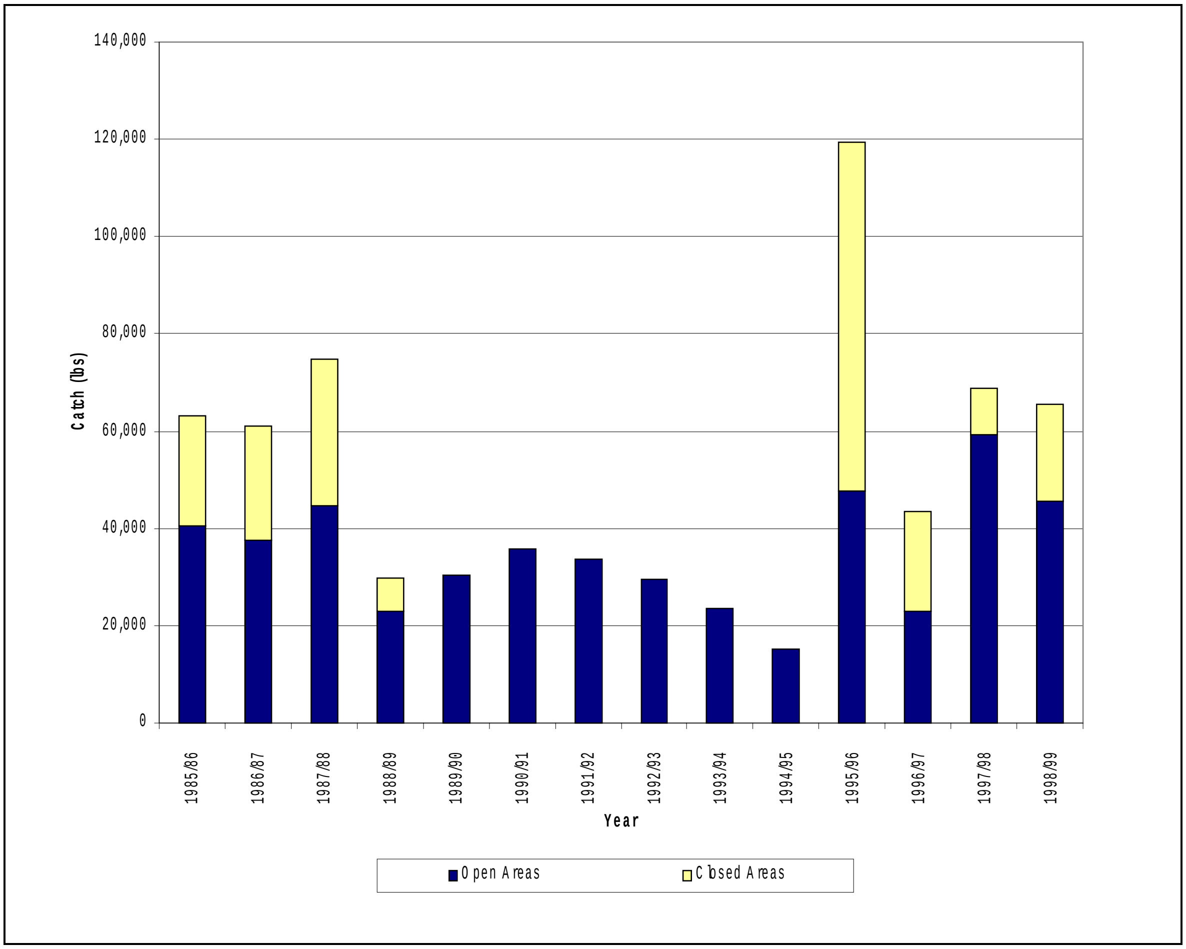

Figure 4. Catch of prawns from Howe Sound Experimental Management area (PFMA 28).

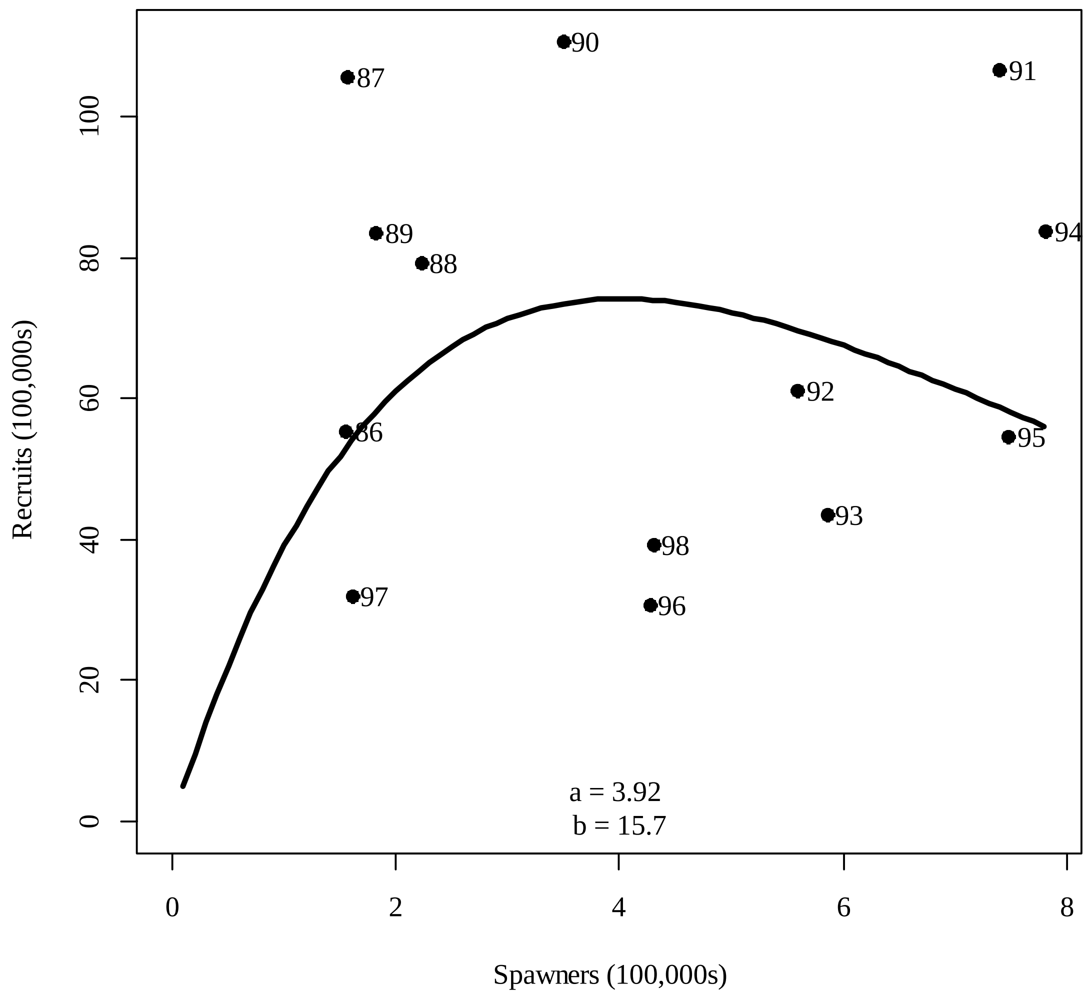

Figure 5. Results of the Ricker Spawner/Recruit relationship for Howe Sound Experimental Management area using the results from the cohort analysis.

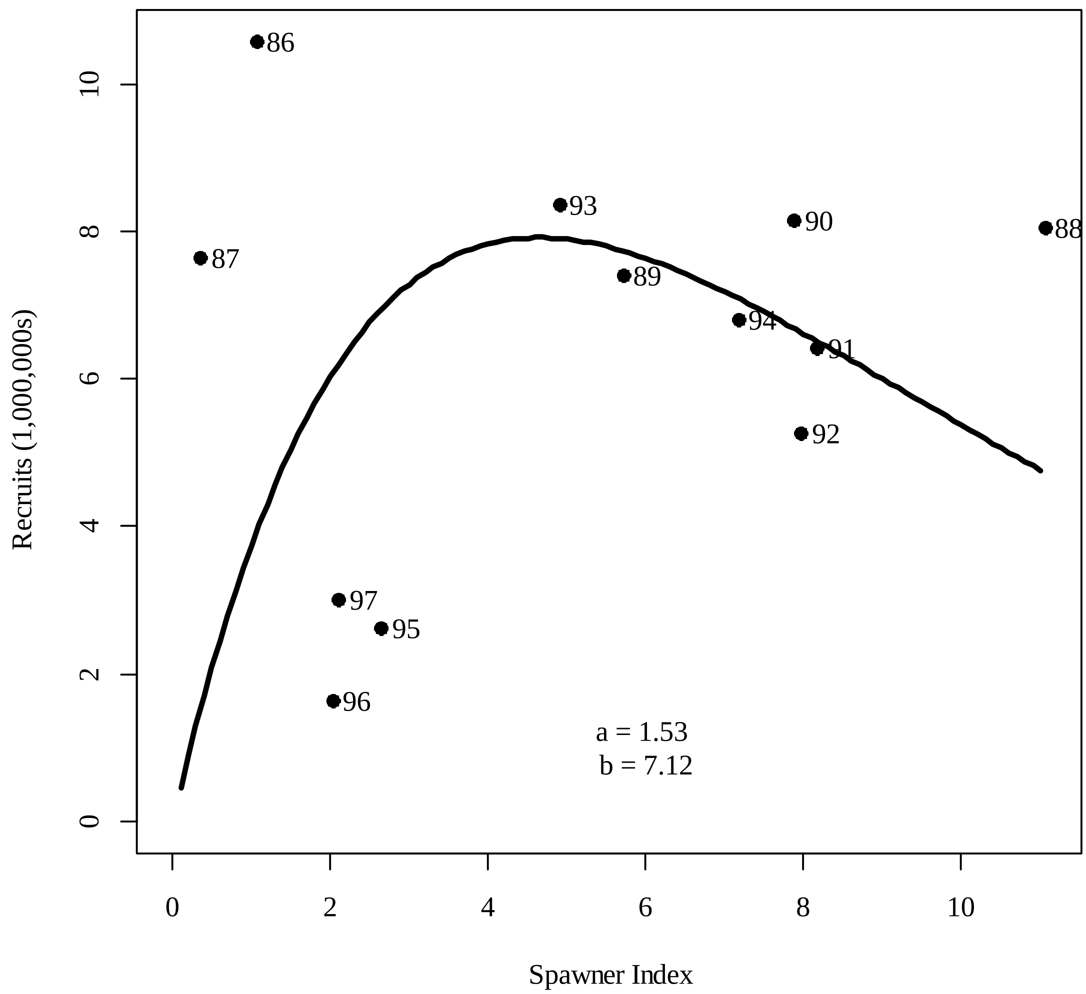

Figure 6. Ricker spawner recruit relationship with recruits from the cohort analysis and spawner from the survey spawner indices.

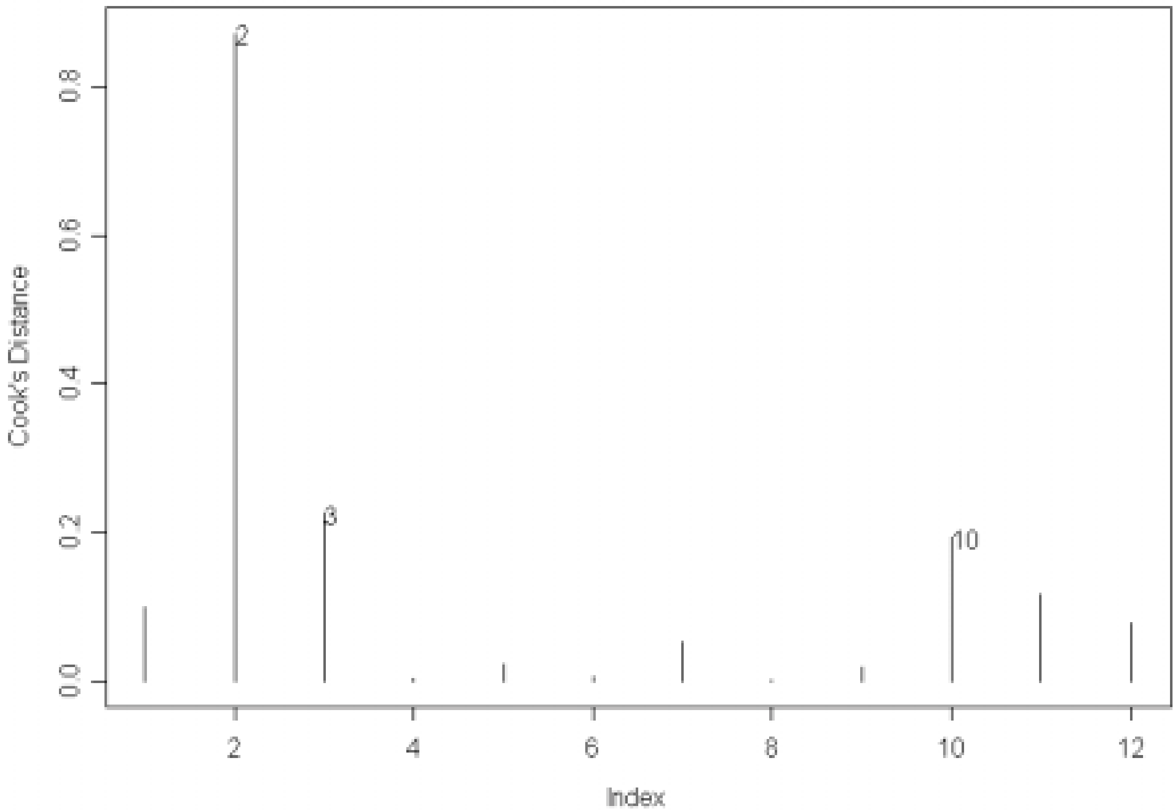

Figure 7. Cook's Analysis of the residuals showing the data points having the greatest effect on the residuals.