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Assessment of the Area A Crab (*Cancer magister*) Fishery in British Columbia

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Abstract

This paper is an assessment of the crab (*Cancer magister*) populations for British Columbia Crab Fishing Area A and adjacent offshore areas in Hecate Straits. The paper conducted three types of analyses: (1) a review of the various fishery dependant abundance indices and biological data. (2) biomass dynamic modeling of the various abundance indices and (3) a yield per recruit analysis of the theoretical growth, natural mortality and value data. There were a number of findings indicated that were quite different trends depending on the abundance index used and that care must be taken to determine the most appropriate index. In general however there were some findings which were consistent throughout. These included:

1. That the fisheries in McIntyre Bay and Hecate Strait have quite different dynamic behaviour.
2. That present effort levels are higher than E_{opt} in both the biomass dynamic models and the yield per recruit models.

As a result of the various findings the following recommendations were made:

1. Improve the logbook data and fish slip data with respect to reporting of area, soak time and gear used. This should be done in consultation with the industry to determine ways of improving reporting.
2. Consider the implications of managing McIntyre Bay and Hecate Strait together. Be aware that McIntyre Bay crab populations do not go through the same degree of fluctuations as Hecate Strait crab populations. Also be aware that even analyses which are considered to overestimate E_{opt} , indicate that effort in both areas already exceeds E_{opt} .
3. There is a need to develop a fishery independent assessment program that will provide checks as to the most appropriate fishery dependent index and allow us to gather information on the population that is not targeted on e.g. females and juveniles.
4. There is a need to collect biological data from fishery dependent and independent sources that are more consistent in frequency and cover critical biological periods (minimum spring and fall i.e. pre- and post-moulting) and more detailed with respect to the biological information gathered (an objective shell condition criteria must be developed).
5. Industry should be discouraged from leaving gear soak for excessive periods of time as the impact in terms of mortality of crabs is probably significant.

Résumé

Le présent document est une évaluation des populations de crabe (*Cancer magister*) de la zone de pêche du crabe A de la Colombie-Britannique et des régions voisines du détroit d'Hecate. On y trouve trois types d'analyse : 1) un examen de divers indices d'abondance et de données biologiques dépendants de la pêche; 2) une modélisation par dynamique de la biomasse des divers indices d'abondance et 3) une analyse du rendement par recrue de la croissance théorique, de la mortalité naturelle et des données. Les résultats obtenus indiquaient des allures passablement différentes tout dépendant de l'indice d'abondance utilisé et qu'il s'avérait nécessaire de faire preuve de prudence pour la détermination de l'indice le plus approprié. Certains des résultats obtenus étaient cependant cohérents, notamment :

1. Les dynamiques des pêches de la baie McIntyre et du détroit d'Hecate sont passablement différentes.

2. Tant les modèles de la dynamique de la biomasse que ceux du rendement par recrue font état d'efforts de pêche actuels supérieurs à E_{opt}.

Les résultats obtenus ont donné lieu aux recommandations suivantes :

1. Améliorer les données des registres et des bordereaux en ce qui a trait à la zone, au temps de mouillage et à l'engin utilisé. Cela devrait être fait en collaboration avec l'industrie afin de trouver les meilleurs moyens d'améliorer les rapports.

2. Examiner les incidences d'une gestion réunie de la baie McIntyre et du détroit d'Hecate. Tenir compte du fait que les populations de crabes de la baie McIntyre ne fluctuent pas autant que celles du détroit d'Hecate et que même les analyses qui sont jugées surestimer la valeur de E_{opt} indiquent que l'effort est déjà supérieur à cette valeur dans ces deux zones.

3. Il s'avère nécessaire d'élaborer un programme d'évaluation indépendante des pêches permettant de cerner l'indice dépendant des pêches le plus approprié et d'obtenir des renseignements sur la population qui n'est pas ciblée, notamment les femelles et les juvéniles.

4. Il faut obtenir des données biologiques de sources dépendantes ou indépendantes des pêches cela d'une façon plus régulière et de manière à couvrir les périodes biologiques critiques (au moins au printemps et à l'automne, c'est-à-dire avant et après la mue) et avec plus de détails (un critère objectif de l'état des carapaces doit être élaboré).

5. Il faudrait dissuader les pêcheurs de laisser leurs engins mouillés pendant de trop longues périodes car cela accroît sans doute de façon appréciable la mortalité chez les crabes.

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Problem

Increases in Dungeness crab *(Cancer magister)* catches from commercial fisheries around the Queen Charlotte Islands (Area A)[1](Fig. 1) have led to an unprecedented increase in effort over the last five years. More vessels opted to fish Area A and operators increased their trap inventories as catches increased. Managers questioned whether the current regime of size limits, sex restrictions and seasonal closures were adequate to meet conservation goals for crab populations given the increased effort. Managers are concerned about the impact of the fishery on the overall future production and about the effects of over-capitalization given the likelihood of population declines. Also they wanted to know how the present management system might affect product availability and economic optimization of the landed product.

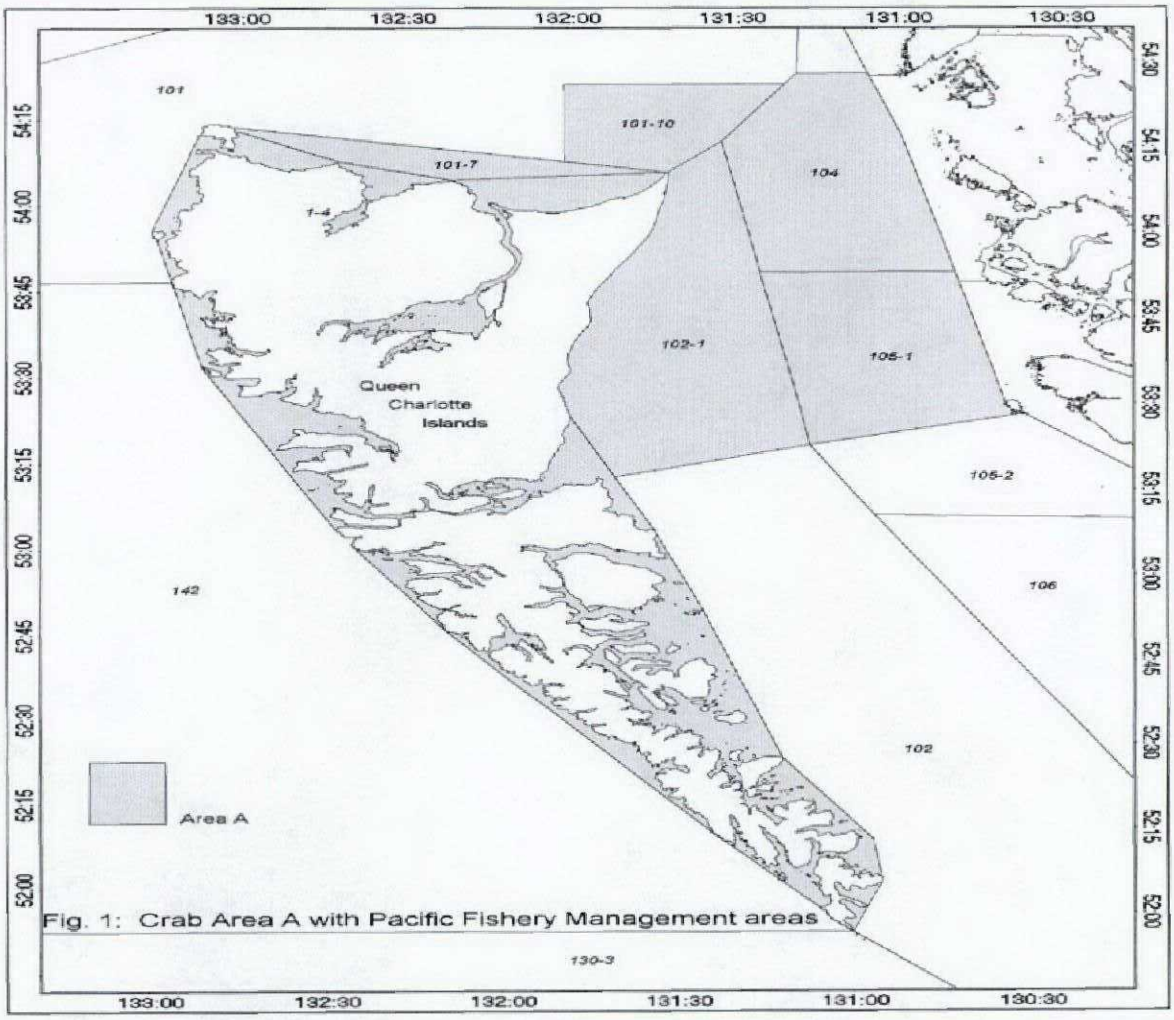


Fig. 1: Crab Area A with Pacific Fishery Management areas

[1] For the purposes of this paper we are including offshore areas 106 and 105-2 in Area A.

Purpose

The purpose of this paper is to collect the available data for the Dungeness crab fishery from this area and analyze it to see what if any information is available to address the problems poised above. Three types of analyses will be completed: an evaluation of historic trends, biomass dynamic models, and yield per recruit models.

Introduction

History of Area A

Dungeness crabs support one of the major commercial fisheries in British Columbia (B.C.). Commercial crab fisheries have been established in B.C. for over 100 years. In 1996 this important shellfish fishery landed 4900 tonnes of live product coast wide for a landed value of $23.4 million. This was 18.8% of the total B.C. landed value of all shellfish species.

For the purposes of this report the Area A crab fishery will be treated as two distinct fisheries: McIntyre Bay (Pacific Fishery Management Area (PFMA) 1 and 101 excluding sub area 4), and Hecate Straits (PFMA 2, 102, 104, 105, 106). Naden Harbour (PMFA 1-04), was not included in the analysis as the fishery is conducted in an entirely different manner to the offshore fisheries. Naden Harbour is fished using ring nets that are hauled after 1-3 hours while the offshore fishery uses traps with soak time measured in days.

The first fishery was conducted in Naden Harbour, where crabs were canned from 1920 to the late 1940's. This fishery would have been impracticable without the canning operation. During 1920 to 1937 catch from the Queen Charlotte Islands was canned in Naden Harbour. This was the first crab cannery in Canada and the only cannery in operation in Canada during the early years of the fishery. In 1933, 17 fishers were employed to fish Naden Habour for the cannery, and thereafter until the end of World War II their numbers varied from none (1943-1945) to 26 (1935). After the war the numbers increased to a high of 32 in 1947-48 but decreased after that due to retirements and deaths.

A ground in Virago Sound was fished intermittently, by rings and circular traps, from 1946 to 1954. Use of the circular trap enabled fishermen to move out of Naden Harbour to the open waters of McIntyre Bay beginning in 1938, and operating with three vessels late in 1939. From 1946 to 1957 the fishing season normally lasted from May to October. Beginning in 1958, the season in McIntyre Bay and Naden Harbour was split by a closure from July 10 to September 20 to protect soft crabs. This closure has continued to the present.

The fishery in Hecate Strait started in 1946 involving two or three vessels from Masset. From 1949 to 1955, vessels from Oregon and Washington also fished this area with the U.S. vessels accounting for 29-75% of the catch. The catch from the US vessels was landed in Washington and Alaskan ports. This presence brought about changes in Canadian trap gear and opened up new ground in Hecate Strait (Stocker and Butler 1990). The depressed state of crab stocks in Hecate Straits in the 1970s and 1980s, caused over half the fleet to turn to other fishing ventures.

Landings from Area A averaged 25.4% of the total B.C. crab landings from 1980-1989 and 60.6% in the years 1990-1995 (Winther et al 1996). The greatest proportion of landings made from this area was in 1993 when 76% of the total B.C. crab landings came from Area A.

Compared to Dungeness crab fisheries along the Pacific coast of North America, Canadian production during 1996 (the latest year for which figures are available) ranked fourth with 15% of the total landings or 5126 tonnes, behind Washington with 32%, Oregon with 24%, and California with 21%. Alaska ranked fifth with 8%. When considering 10 year average harvests, British Columbia places last behind all the four west coast American States (Didier 1997, INPFC an. rep. 1996).

Biology

Crabs mate during the summer and females extrude fertilized eggs in the fall. The eggs are carried until hatching in late March or April. The young then spend the next 3-5 months as pelagic larvae going through 5 zoeae stages and one megalopal stage. In Area A the young crabs metamorphose from July to September, earlier in Hecate Strait than in McIntyre Bay. As juveniles these animals moult fairly frequently in their first two years (10 times) but after they have become sexually mature at 2 or 3 years of age the frequency of moulting decreases to once a year and even less frequently as they get older. In Area A, moulting season varies from late spring through summer depending on the area and the year. After moulting, it requires about 6-8 weeks for crab meat recovery to become optimal.

Regulations

The Dominion British Columbia Fisheries Commission, in existence from 1905 to 1907, recommended a minimum size limit for Dungeness crabs of 152 mm (Prince 1908) spine to spine width measurement at the widest part of the shell. This limit was in place in 1914 (Weymouth, 1915) and was raised to the present day limit of 165 mm prior to 1926. Other measures included prohibition of the harvest of soft-shelled crabs and ovigerous females (Spencer 1932). These latter two restrictions were revoked in 1957, because of the lack of practicable criterion of shell hardness and the fact that females, whether berried or not, usually do not reach the minimum size limit. Nonetheless, female retention was prohibited altogether in 1991. A regulation requiring an escape port of 100 mm minimum diameter for the release of undersize crabs was introduced in 1990.

During the years of low production in the 1970s, fishers began to leave traps unattended for long periods of time, some for as long as a month or more. Long soaks and occasional abandonment of traps resulted in undue crab mortality. To address this issue in 1978 a regulation was established that requires fishers to haul traps after fourteen consecutive fishing days. In practice it has given officers authority to confiscate abandoned traps. To prevent ghost fishing in lost or abandoned traps, the introduction of biodegradable twine to secure the hinged lid of crab traps was instituted in 1992.

Specifications for marking crab traps by surface buoys appeared in 1983; with an exemption two years later permitting operation of traps without floating markers on Roberts Bank during salmon net seasons. Also in 1985: a new regulation enjoined fishers to remove traps from grounds closed to crab fishing. There have also been a number of area specific closures, trap limits and gear restrictions implemented. In 1983 the only lawful crab gear specified were traps, dip nets, and ring nets. Retention of crabs as bycatch in any other fishery is prohibited.

Data

Landing, effort and biological data comes from a variety of sources, including historic landing interviews and plant records from T.H. Butler and various Prince Rupert port samplers, fish slip data from 1951 broken down by major PFMAs[2], logbook records from 1990 to present, and sporadic biological sampling.

Historical landing and effort data from fish slips

Prior to 1951 the data from the area was reconstructed by T.H. Butler from historical plant records and interviews of dockside monitors. After 1951 the main source of data was from fish slips. However fish slip data have a number of problems associated with them such as the inability to capture area properly. For example Hecate Straits covers a number of PFMAs including 2, 102, 104, 105 and 106, and the fish slips can often be assigned to the wrong area e.g. area 104 would fall into area 4 catch because the offshore areas have not been separated. Since 1990, the fish slip data have been corrected by assigning catch to area A from fish slip data where the vessels are licensed for area. Another problem of fish slips is the lack of precision associated with the unit of effort captured in the data. The data is collected at the processing plants at the time of off-loading and the plant records the general area and total days fished. It is unclear in many cases whether fishing day refers to the total trip length or the actual days on which the gear was hauled.

[2] Major PFMA's do not distinguish between inshore areas e.g. 2 and offshore areas e.g. 102.

The historic fish slip data used in this paper was presented in two ways. One with the correction as indicated above and a second in which the file of catch and days fished was corrected with the logbook information from 1990 to 1997. When correcting with logbook information the location was more accurately identified, often down to the sub-area level. The difference in the way "days fished" data are collected is that on the fish slips the reported number is collected at the time of landing, while days fished in the logs refer to the actual calendar day that traps were pulled. We know of errors in both sets of data. For instance, there were numerous examples in logbook records where it was evident that fishers had lumped a number of days fishing under one entry; similarly the collection of days fished at the time landing is fraught with problems. All we can do at this point is to assume that errors are consistent between years. We don't feel that this is correct but going back and correcting data would be impossible.

Historical landing and effort data from logbooks

The logbook information is a data series that runs from 1990 to present. The data collected provides daily information on specific area fished, the number of traps hauled, the type of traps, the length of time the gear was soaked, the number of crabs retained and the estimated weight of crabs retained. A number of problems arise with the data series when the numbers and weights are not filled in, when vessels have multiple types of traps and when entries are not filled out daily. This last problem in particular leads to difficulty in interpretation of soak times.

Biological data

Biological data analyzed in this work comes from a number of sources over the years. There has been changes in the way the data was collected over the years. The most notable change that has occurred is the way the measurement of carapace width at its widest part has changed from point to point (PTP) measurement taken from the tips of the spines to a notch to notch (NTN) measurement taken at the base of these spines. The sources of data that were used included: pre- and post-moult studies conducted in the early 1950s, PTP and NTN measurements taken from the same animals in a 1993 commercial sample, size, sex and shell condition data from the commercial fishery that were collected in the summer of 1993 and logbook information which contained both catches in numbers and weight. There is more size and sex data available than just the 1993 sample, however, the quantity of data and the types of information collected varied considerably. The size of the data sets ranged from only a few hundred measurements of unsexed animals to thousands of measurements of sexed animals with extensive records of shell condition. The 1993 commercial biological sampling data includes information on the width of the animal as measured from notch to notch (NTN) of the widest part of the shell, the sex of the animal, and the shell condition, as rated on a 7 point scale with conditions 1-5 representing various stages of hardness of newly moulted crabs and stages 6 and 7 stages of old moult crabs.

Other data

In addition to the catch, effort and biological data, parameter estimates of growth and natural mortality were collected from published studies. Price data were obtained from interviews with the plants that bought crabs. Abundance and effort trend information was also obtained from an interview with a fisherman (Captain Bob Wylie) who has an extensive history fishing crab in area A.

METHODS

Descriptive Data Analysis

Landing trends

Plots of catch from fish slip and log book data were made for both McIntyre Bay and Hecate Strait.

Effort trends

In this analysis we review how fishing effort and practices have changed over time. For example the effort from fish slips is measured in a very general sense as days fished. Stocker and Butler (1990) point out that this measurement of effort does not reflect fishing changes in numbers of traps pulled, variations in soak time, and variations in the type of gear used. Comparisons of all three of these aspects were carried out using historic data, interviews and logbooks. For the effort analysis portion of this review only log records with traps and soak times > 0 were included.

CPUE trends

In this analysis we compare the various indices of abundance in two ways : with respect to consistency of variation in magnitude of the indices and with respect to the observed trends among data sources. As most of the abundance indices were based on effort measurements from logbooks, this comparison could only be carried out over the time frame that logbooks data were available (1990-1997). In particular, we considered the logbooks, fish slip records, and interview data and compared them with respect to landings and various catch per unit effort (CPUE) indices. Landings and the various CPUE indices for McIntyre Bay and Hecate Strait can be seen in Appendix Tables 1A and 1B.

CPUE indices were also compared to see if the abundance trends between McIntyre Bay and Hecate Strait were similar. For this between area comparison, one of the

CPUE indices was from historic catch data and effort measured in days fished, thus the comparison could be made for the time frame from 1946-1996 (excluding 1949 and 1950). A shorter 1990-1997 time frame was used for the between area comparison when the measurement of effort came from logbooks.

Biological information

We also analyzed the biological samples to determine if there is information on cohort strength or growth that would help explain any of the trends seen in the abundance indices. As with most crustaceans, the only way to age crabs is to analyze the size structure of the population and break out the various modes which would then be assigned to age classes. To understand something about how crabs grow we looked first at data that could give us information as to how big a change in carapace size we would expect after a moult. Growth increments were calculated from the pre- and post moult crab measurements. Since this data was originally measured PTP, the next analysis that was conducted was a regression of relationship of PTP and NTN measurements. This allowed us to compare the various data sets. Next, plots of the 1993 biological data were made in two ways to look at the problems with separating size frequency modes: a plot of the complete data set and plots of the data divided by new and old shell ratings. In additon logbook information was analyzed to determine the average annual size of animals captured in the fishery. This gives us a feeling for the complexity of the problem of variations in growth rates, variations in the number of cohorts exploited in the fishery, or a combination of both.

Biomass Dynamic Models

Biomass dynamic models are considered the simplest of stock assessment production models because of their assumptions. They describe the production dynamics of the stock in terms of its biomass, rather than the numbers at age which are used in age structured models (this latter set of models have much greater data requirements). The concept behind the biomass dynamic model is that the next biomass is equal to the last biomass plus increases due to production i.e. new recruits and growth and minus two sources of loss i.e. catch and natural mortality. Surplus production is the difference between production gains and natural mortality losses. The models are fit to the various indices of abundance that were evaluated from the fish slip and log book information. The assumption when using this type of index is that the catchability coefficient (q) remains constant. Basically two models were used: the Schaefer model and the Walters and Hilborn difference model.

We used the three approaches outlined by Hilborn and Walters (1992) to estimate the parameters in these models when using indices of abundance: an equilibrium approach, a non-equilibrium approach using linear regression and a non-equilibrium approach using time-series analysis.

Equilibrium Approach

In this model we use the assumption of the stock being at equilibrium which makes the relationship between CPUE and effort linear. Hilborn and Walters (1992) warn that the logic is seldom if ever true and warn not to use this method as it usually overestimates surplus production and optimal fishing effort whenever they are applied to data gathered during a stock decline. We conducted this analysis of surplus production in the same manner as Stocker and Butler (1990). The approach was to initially conduct an exploratory analysis of the data and for those data sets meeting the criteria for further analysis we conducted two equilibrium models using different forms of the error structure.

Exploratory analysis

Using two simple fishery models we conducted an exploratory data analysis to investigate the information content of the effort and catch data series described above.

The first model used was a special case of Schnute's biomass index model (Schnute et al., 1989, P. 748, eqn. [9]) which we term Model 1:

$$CPUE_{t+1} = A + \tau * CPUE_t$$

where $CPUE_{t+1}$ is the catch biomass per unit effort in year t+1, $CPUE_t$ is the catch biomass per unit effort in year *t* , A is the catch biomass of newly recruited crab and τ is the survival parameter (which is a function of natural mortality, M, fishing mortality, F, and growth). If the null hypothesis (slope, τ=0) is rejected then there is evidence that $CPUE_{t+1}$ is dependant on the survival of animals in year t and not just the new recruits.

The second model, which we term Model 2, is a simple version of the Schaefer model which assumes that there is a linear relationship between effort (E) and catch per unit effort (CPUE).

$$CPUE_t = \alpha - \beta * E_t$$

When the α and β values are positive the equilibrium model states that, in general, higher effort values result in lower CPUE. This again is tested with a linear regression with the null hypothesis that β is 0 ie. that there is no relationship. If the hypothesis is rejected and β is positive then there is evidence that higher effort generally results in lower CPUE.

Equilibrium models

For those data sets which met the acceptance criteria for Model 1 and Model 2, we continued in the same manner as Stocker and Butler (1990) and formulated two equilibrium models which describe the long term effect of effort on the crab population.

With these models they considered two possible forms of the error around the effort term: normal (Model 3) and log-normal (Model 4).

Model 3

$$E_t = E_{opt}\{2 - E_{opt} / MSY * CPUE_t\} + \in_t$$

Where $\in_t$ is the random error component, assumed to be normally independently distributed (NID) with mean 0.

Model 4

The equivalent to Model 3 with log-normal error is

$$\log(E_t) = \log(E_{opt}) + \log(2 - E_{opt}/MSY * CPUE_t) + \varepsilon_t$$

where $\in_t$ is the random error component, assumed to be normally independently distributed (NID) with mean 0.

Estimates of MSY and E_{opt}, and 95% confidence intervals of these parameters were obtained using non-linear parameter estimation procedures using the "nls function" in S-plus (StatSci 1993).

Non-equilibrium Approach - using linear regression

The second approach was to transform the Schaefer model into a linear form and then fit it using a linear regression (Model 5). Walters and Hilborn (1992) comment that the format is computationally easy but unless the data reflects a very informative perturbation history the procedure will be unlikely to provide reliable parameter estimates.

Model 5

First, we considered the difference equation suggested by Hilborn and Walters (1992):

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{k}\right) - C_t$$

where B_t is the biomass at time t, r and k are as in the Schaefer model, and C_t is the catch during time t.

Using the difference equation above and the relationship

$$B_t = \frac{U_t}{q}$$

where U_t is the catch per unit effort at time t, and rearranging, we can get the following equation:

$$U_{t+1} = (r+1)U_t - \frac{r}{kq}U_t^2 - qE_tU_t$$

where E_t is effort at time t, and U_t, r, k, and q are as above. Using this equation, we estimate the parameters of the Schaefer model employing a multiple linear regression with $r+1$, $-r/kq$, and $-q$ as the parameters of the regression, and no intercept term.

Non-equilibrium Approach - using time series analysis

Rather fit the non-equilibrium model using a multiple linear regression (Model 5) we used a time series model, which we term Model 6. The basic procedure in fitting this model involves estimating not only k, q, and r, but also the biomass at the start of the data series. These values can then be used to predict the entire biomass time series. The parameter values are estimated by using nonlinear techniques to fit the best predicted-to-observed time series of relative abundance indices or catches. There are options in using this model with respect to the most appropriate starting stock size. It can be very time consuming in fitting a wide range of time-series options and there is no systematic survey of the relative performance of the various alternative forms.

For Model 6 we used the following discrete form of the Schaefer model as described by Hilborn and Walters (1992) p. 310:

$$U_t = q\left(B_{t-1} + rB_{t-1}\left(1 - \frac{B_{t-1}}{k}\right) - C_{t-1}\right) + \varepsilon_t$$

where ε_t is the error term and all other variables are as above.

A non-linear regression was performed using the "nls function" in S Plus (StatSci 1993) to estimate the values of k, q, r, and the starting biomass B_0.

Yield per Recruit Models

Finally, we conducted a yield per recruit analysis (Ricker 1975). We used estimates of instantaneous natural mortality rates from the literature (Butler and Hankin 1992) as well as moult increment data from a series of pre- and post-moult studies conducted by

Butler (1961) in the 1950s using data obtained from crabs in live wells at canneries, in traps of fishing boats and from tag recoveries. The carapace size of the crabs were converted to weights using two equations that Butler calculated for: 1) male crabs (50-199 mm PTP) from Hecate Strait and 2) legal male crabs only from a southern population of crabs off Points Roberts. These equations are show below.

Butler 1:

$$LogWt = 2.943 * Log(WidthPTP) - 3.769$$

Butler 2:

$$LogWt = 3.167 * Log(WidthPTP) - 4.249$$

The model incorporated price per kilogram information from interviews of plant managers in Masset and Prince Rupert. Values used try to reflect the differences in prices paid for crabs from the area in 1997. The prices used in our calculations are shown in Table 1.

Table 1: Price/kg used for various sizes of crabs in the yield per recruit model.

Size range (g)	571-933	934-1423	1424-2057	2058+
$/kg	$4.41	$6.06	$7.72	$9.37

The yield per recruit analysis was completed in two ways to reflect the variability in the vulnerability of the recruiting cohort to the fishery. The first was to consider a population in which the recruiting cohort was only 50% vulnerable to the fishery. In this case the mean carapace width would be 165 mm PTP and subsequent means would be 195, 225, and 255 mm PTP. The second was to consider a population in which the recruiting cohort was completely vulnerable to the fishery. In this case the first mode of animals was 180 mm PTP with subsequent modes at 210, 240, and 270 mm PTP respecitvely.

The results were measured as both yield in weight and yield in dollars. The populations are assumed to have levels of M ranging from 0.6 to 1.4 and be subjected to varying rates of instanteous fishing mortality (F). These values were then modelled and the $F_{0.1}$ for the various values of M were calculated for both weight and dollar yields. The reference point $F_{0.1}$ is the value of the F at which the slope of the yield per recruit function is 10% of the slope at the origin. It is a more conservative value than F_{max} and is widely used as a fishery management reference point (Hilborn and Walters, 1992).

RESULTS

Descriptive Data Analysis

Landing Trends

In the interview with Captain Bob Wylie, he stated that the major increase in production in 1993 was in Hecate Strait and that an increase of the same magnitude was not experienced to the same extent in McIntyre Bay. This observation is confirmed by a plot of fish slip (FS) catches from both McIntyre Bay and Hecate Strait (Figure 2A).

Similarity of trends from fish slips and logbook information for years 1990-1996 is shown to be quite different for the areas depending on whether they are treated separately or in combination (Figures 2B, 2C and 2D).

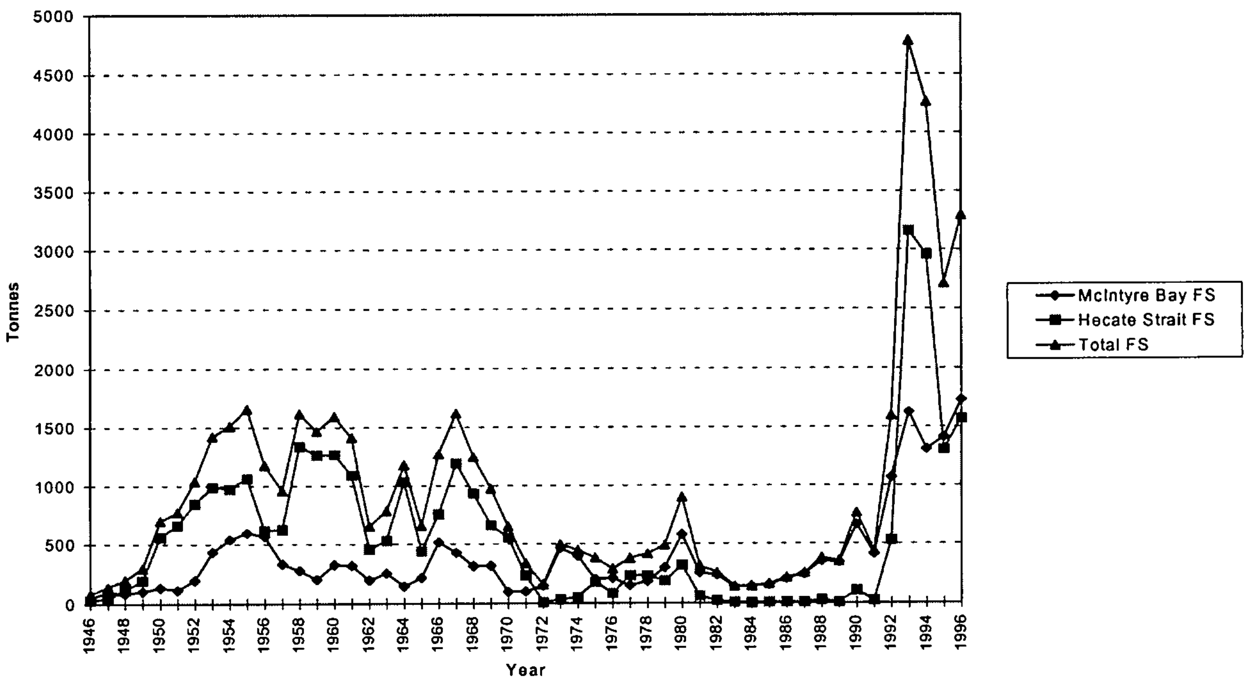


Fig 2A: Fish slip landings from McIntyre Bay and Hecate Strait and both areas combined.

Fig 2B: Comparison of log and fish slip data for Hecate Strait.

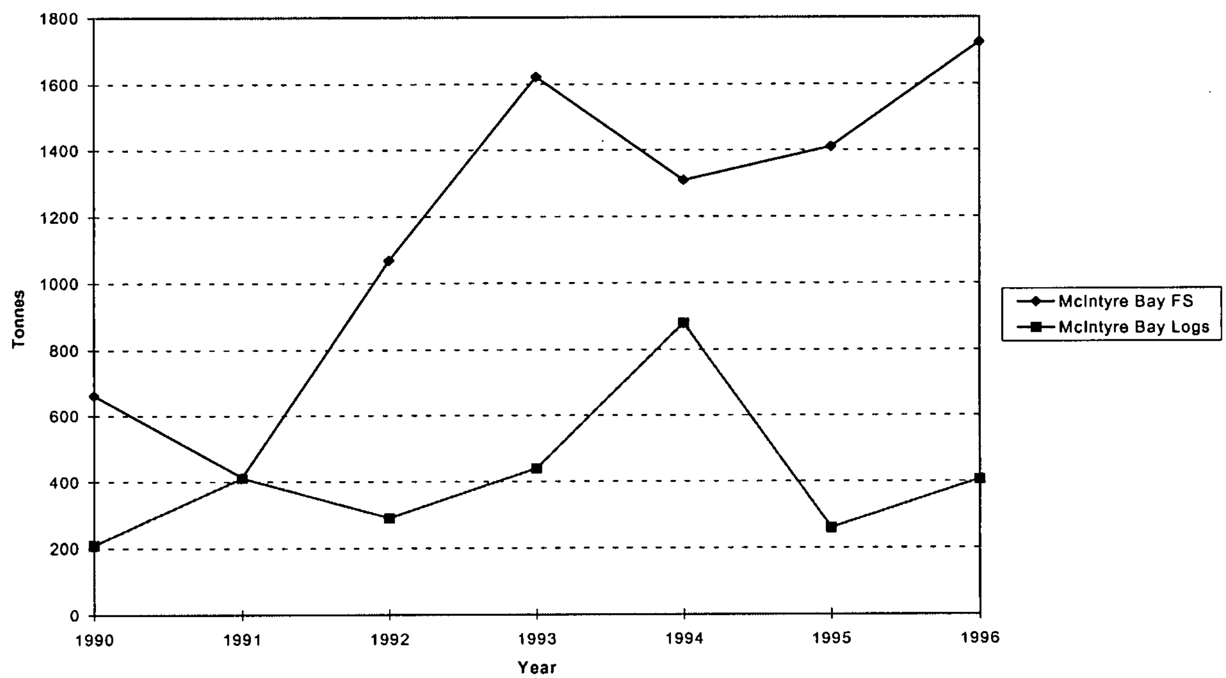


Fig. 2C: Comparison of logbook and fish slip data for McIntyre Bay.

Fig. 2D: Comparison of logbook and fish slip data for both areas combined.

Effort Trends

The number of vessels reported fishing in Area A from logbook records has increased by approximately 4 fold from 1990 to 1996 (see Table 2 below).

Table 2: Number of vessels fishing in each major PFMA and in Area A combined.

Year	McIntyre Bay vessels	Hecate Strait vessels	Combined Areas
1990	13	3	13
1991	11	5	11
1992	10	7	11
1993	18	14	21
1994	17	25	33
1995	16	35	38
1996	22	45	51

The number of traps pulled per fishing day for McIntyre Bay and Hecate Strait are in shown in Table 3 below.

Table 3: Average number of traps run per day by area and year.

Year	McIntyre Bay	Hecate Strait	Combined Areas
1990	255	771	333
1991	285	389	305
1992	275	370	316
1993	265	296	287
1994	388	294	325
1995	177	291	273
1996	213	236	232
1997	246	226	229

Soak time (annual average hours soaked) was also compared for the years when logbook data were available. The soak times range from 1 to 50 days in McIntyre Bay and 1 to 99 days in Hecate Strait. The average hours the traps were soaked is shown by area and year in Table 4 below.

Table 4: Average soak time by area and year

Year	McIntyre Bay (Average Hours Soaked)	Hecate Strait (Average Hours Soaked)
1990	188	201
1991	150	206
1992	144	193
1993	152	143
1994	166	237
1995	220	258
1996	228	257
1997	205	286

It also became obvious that the use of soak times in excess of the 14 day limit is becoming increasingly prevalent as the cpue indices decline. This can be seen in Table 5 below which shows, for each year since 1990, the traps pulled, the overall average catch per trap and %catch taken from soak times in excess of 14 days.

Table 5: Total number of traps pulled with soak times in excess of 14 days, the catch per trap for that year, and the % of total catch taken from those traps for each year for McIntyre Bay and Hecate Strait.

Year	McIntyre			Hecate Strait		
	Traps	Kg/trap	%Catch	Traps	Kg/trap	%Catch
1990	2000	2.8	2.1%	325	2.8	2.3%
1991	209	3.7	0.1%	1520	4.1	3.9%
1992	1280	4.2	3.6%	1365	10.2	7.2%
1993	111	5.4	0.2%	1934	13.0	0.8%

Year	McIntyre			Hecate Strait		
1994	450	4.2	0.1%	21391	7.0	6.4%
1995	4094	4.1	9.4%	45009	4.5	9.0%
1996	10303	3.8	12.4%	44285	4.6	6.9%
1997	3192*	2.4	6.9%*	25435*	2.5	5.9%*

* 1997 data are incomplete

Gear type was also investigated through logbooks and an interview with a long time fisherman from the region (Capt. Bob Wylie). To quote Capt. Wylie, "the newer trap, used after early 1950s is basically unchanged to present". Prior to that time the trap was a 36 inch circular trap which was 16-17 inches high (McMynn 1948). These rather high steep sided traps did not have any triggers in the tunnels. The web was a coarse copper wire which was large enough that any crab under the legal size limit could escape. In the 1950s the traps were shallower and the openings were triggered to prevent crabs from escaping. The gear in the early 1990s was basically the 42 inch diameter trap used in the offshore areas while some smaller gear (i.e. 36 inch traps were used in the nearshore/inshore areas such as Masset Inlet. In the mid 1990s there was an increase in the number of vessels reportedly using 36-38 inch traps in the offshore areas. This increase was associated with a number of new vessels fishing the area. Variations in catch rates (Kg/trap) can be seen by year and major area in Tables 6A and B below.

Table 6A: CPUE (Kg/trap hauled) for major trap types for McIntyre Bay by year.

	36"	38"	40"	42"
1991	na	2.8	3.2	na
1992	1.8	2.4	4.3	4.3
1993	na	4.5	7.3	8.7
1994	na	3.6	4.5	4.6
1995	na	na	3.0	4.0
1996	2.4	na	na	5.4
1997	na	na	na	3.0

Table 6B: CPUE (Kg/trap hauled) for major trap types for Hecate Strait by year.

	36"	38"	40"	42"
1991	na	na	na	4.1
1992	7.2	na	na	10.8
1993	na	11.6	8.4	14.7
1994	6.6	7.6	6.8	6.8
1995	3.0	3.3	3.7	5.1
1996	3.2	4.7	3.4	4.9
1997	1.8	1.4	2.4	2.8

CPUE Trends

The abundance indices in Appendix table 1A and 1B and the catch history of the areas tell a different story with respect to when the population peaked and the magnitude of the difference between the highs and lows. The peak high and low index years and the difference factor between the extremes are shown in Table 7 below:

Table 7: Comparison of peak years and the degree of difference between these factors.

	McIntryre Bay		Hecate Strait	
CPUE index	Peak years High/low	Difference factor	Peak years High/low	Difference factor
Tonnes/day	1994/1997	2.8	1993/1997	6.9
Kg/trap (Unstand.)	1993/1997	2.3	1993/1997	5.2
Kg/trap (mode soak)	1993/1991	2.2	1993/1997	5.6
Kg/trap (42 in. trap)	1993/1997	2.9	1993/1997	5.3

The correlations between the catch from fish slips, the catch from log books and the four indices of CPUE from logbooks: tonnes/fishing day (from the combined fish slip and log book information), kg/trap, kg/trap for the soak time mode (in this case the mode is 4 days for McIntyre Bay and 7 days for Hecate Strait), kg/trap for the most common trap (42 in. diameter traps) are seen in Table 8 below.

Table 8: Correlations between the various indices of abundance for McIntyre Bay and Hecate Straits.

	McIntyre Bay		Hecate Strait	
Indices	Correlation Coefficient	p-value	Correlation Coefficient	p-value
Tonnes per day & Kg per trap	0.731	0.0260	0.887	0.0833
Tonnes per day & Kg per trap std. to soak time mode	0.392	0.5330	0.886	0.0478
Tonnes per day & Kg per 42 in trap	0.540	0.0909	0.948	0.0107
Tonnes per day & Catch	0.186	0.7639	0.236	0.6523
Tonnes per day & Catch adjusted for logs	0.886	0.0355	0.311	0.8806
Kg per trap & Kg per trap std. to soak time mode	0.752	0.0615	0.992	0.0013
Kg per trap & Kg per 42 in trap	0.838	0.1329	0.995	0.0043

	McIntyre Bay		Hecate Strait	
Kg per trap & Catch	0.611	0.3675	0.592	0.0509
Kg per trap & Catch adjusted for logs	0.427	0.1331	0.661	0.0985
Kg per trap std. to soak time mode & Kg per 42 in trap	0.772	0.7021	0.987	0.0016
Kg per trap std. to soak time mode & Catch	0.495	0.2296	0.639	0.0985
Kg per trap std. to soak time mode & Catch adjusted for logs	0.013	1.0000	0.708	0.0509
Kg per 42 in trap & Catch	0.581	0.3272	0.496	0.1885
Kg per 42 in trap & Catch adjusted for logs	0.148	0.1416	0.613	0.1885
Catch & Catch adjusted for logs	0.291	0.4527	0.900	0.0243

Comparisons between crab abundance indices in McIntyre Bay and Hecate Strait over the time frame 1946-1996 are seen in Table 9 below using the fish slip index corrected with logbook information, Tonnes/day, and over the time fram 1990-1997 using both the log index, Kg/trap and the fish slip index, Tonnes per day.

Table 9: Correlations of crab abundance between McIntyre Bay and Hecate Strait using Tonnes/day and Kg/trap.

	1990-1997		1946-1996 excluding (1949/50)	
Indices	Correlation Coefficient	p-value	Correlation Coefficient	p-value
Tonnes/day (McIntyre Bay)& Tonnes/day (Hecate Strait)	0.623	0.0635	0.391	0.0027
Kg/trap (McIntyre Bay) & Kg/trap (Hecate Strait)	0.876	0.0020	N/A	N/A

Biological information

The analysis of pre- and post-moult size data was conducted on animals with a pre-moult size in excess of 135 mm PTP. Pre-moult sizes were collected for animals in the final stages of the moulting process. The pre-moult sizes were regressed against their post-moult carapace size increment increase. If the slope of the line is significantly different from 0 then there is evidence of a relationship between the pre-moult size and the moult increment size. As it turned out, for the size range of animals examined, there was no significant difference in moult size increment regardless of the pre-moulting size. In other words, for the size range of animals examined, they all grew the same amount no matter what size they started at. The mean increment for PTP measurements was 29.9 mm with bootstrapped 95% confidence limits of 29.4 to 30.3.

The pre- and post-moult PTP sizes were converted to NTN measurement using the following regression which was taken from NTN and PTP comparisons made from Hecate Strait crabs in June of 1997. The R^2 value for the regression was 0.99.

$$NTN = 0.8942PTP + 6.7232$$

The mean increment for NTN measurements was 26.7 mm with bootsrapped 95% confidence limit of 26.3 to 27.1.

Size frequency data is seen in the following figures 3A and 3B. Here the data is shown as NTN measurements with legal size being 154 mm NTN. The data are shown in two ways: the first is a histogram of the complete data set and the second is with the data separated by shell condition into new moult measurements and old moult measurements.

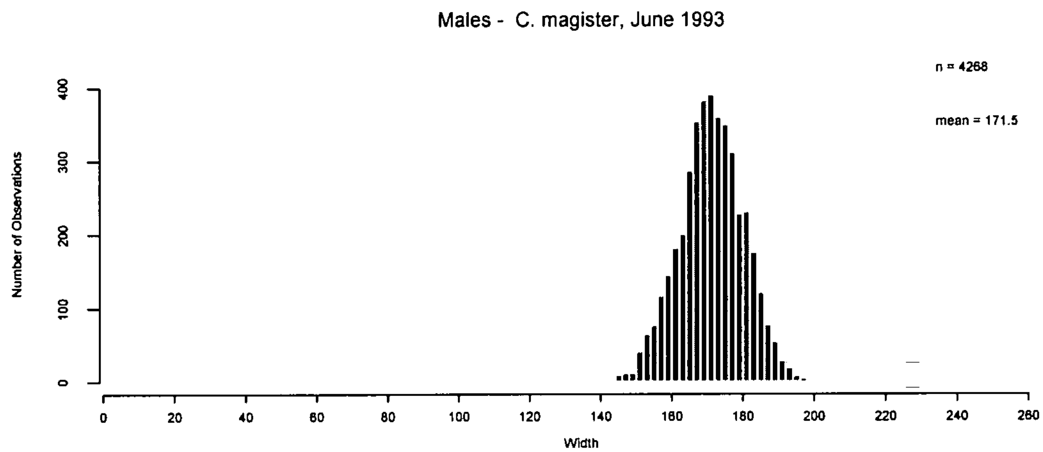
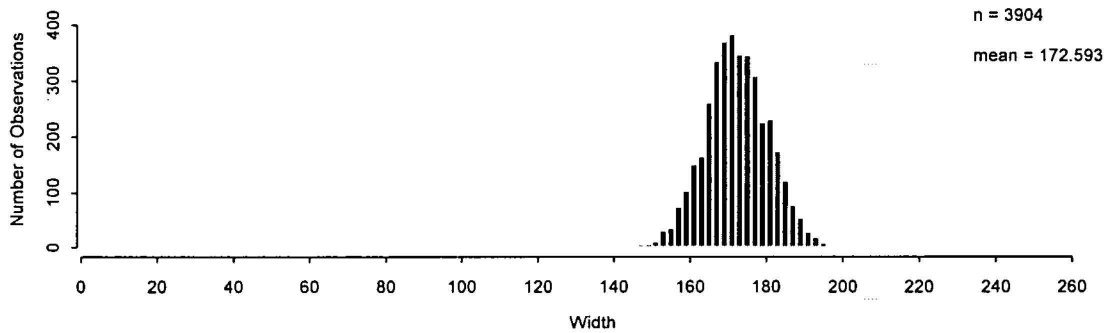


Fig. 3A: Size frequency of all male crabs from Hecate Strait from June 1993.

New Shells - C. magister, June 1993



Old Shells - C. magister, June 1993

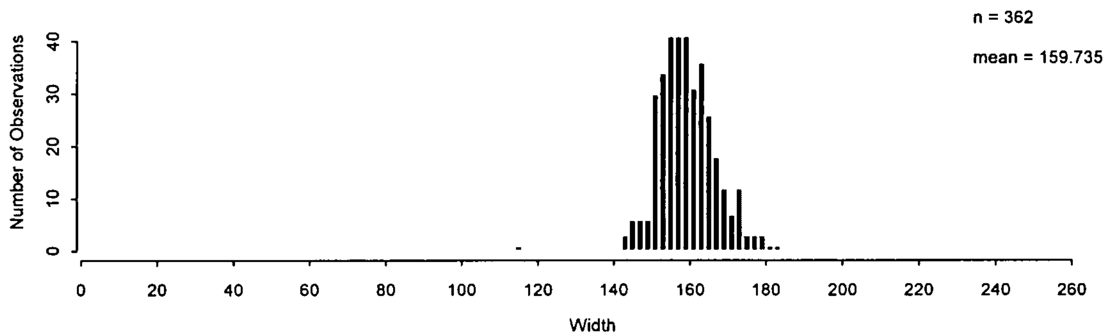


Fig. 3B: Size frequency data from male crabs sampled from Hecate Strait from June 1993, divided up according to shell condition.

A comparison of the average weight of crabs landed was conducted using logbook information. For records where fishers supplied both catch data in terms of numbers and weight of crabs, the average size of the animals was determined for each entry. The data were summarized by area and year to determine the average annual size of crabs. An interview with Captain Bob Wylie was as conducted in which he stated that "in the first year of the run (1992) the crabs were under 2 pounds while in the following year the crabs were larger, suggesting a large number of crabs survived to moult in the interim." The results of the logbook analysis are shown in the table below.

Table 10: Average weight of crabs (g) from logbooks with both numbers and weights recorded.

Average wt (g)	year								
Area	90	91	92	93	94	95	96	97	Grand Total
1	787	783	873	870	906	827	789	811	825
2	818	823	na	na	962	na	na	872	847
101	na	831	776	889	900	817	781	896	877

Average wt (g)	year								
102	na	771	780	885	917	881	867	874	877
104	na	na	748	908	954	819	857	893	868
105	na	na	na	na	923	881	914	889	908
106	na	na	na	na	na	na	na	na	na
Grand Total	792	785	807	890	917	862	862	882	868

Surplus Production Analysis

The results are presented below for the three approaches used for estimating the parameters.

Equilibrium Approach

Exploratory analysis

The results of this analysis are seen in the following table. As with Stocker and Butler (1990), if the data meet the following three criteria, then the data set will have sufficient information for statistical analysis using the Schaefer surplus production model:

Criteria for further analysis

I. Model 1: H_0: τ=0 is rejected;
II. Model 2: H_0: β=0 is rejected; and
III. Model 2: β is non-negative.

Table 11: Results of exploratory data analysis for various CPUE indices by area.

Area	n (sample size)	Parameter	t-ratio	P(two-tail)	H_0: slope=0	Criteria for further analysis
McIntyre Bay Fish Slips (FS) Catch/day	59	τ .5485 β .0002	3.427121 .0000962	0.0000 0.0396	reject reject	1: Yes 2: Yes 3: Yes
McIntyre Bay FS & Logs Catch/day	59	τ .5763 β .0008	5.021521 0.000205	0.0000 0.0004	reject reject	1: Yes 2: Yes 3: Yes
McIntyre Bay (logs) Catch/trap stnd mode soak time	7	τ -0.049 β .00001	-0.106 -0.797	0.9199 0.4560	accept accept	1: No 2: No 3: Yes
McIntyre Bay	7					

Area	n (sample size)	Parameter	t-ratio	P(two-tail)	H_0: slope=0	Criteria for further analysis
(logs) Catch/trap standard to trap 42		τ -.31118 β .000006	-.60158 -0.30546	.5799 .7723	accept accept	1: No 2: No 3: Yes
Hecate Strait (FS) Catch/day	51	τ .69423 β -.00037	6.63300 1.30366	0.0000 0.1984	reject accept	1: Yes 2: No 3: No
Hecate Strait (FS & logs) Catch/day	51	τ .71856 β -.00036	7.08442 1.23266	0.0000 0.2236	reject accept	1: Yes 2: No 3: No
Hecate Strait (logs) Catch/trap stnd soak = 7 days	7	τ 0.389 β .000009	0.793976 -0.52206	0.4717 0.6239	accept accept	1: No 2: No 3: Yes
Hecate Strait (logs) Catch/trap stand trap 42	7	τ .71856 β .00001	0.64599 -0.56378	0.5535 0.5972	accept accept	1: No 2: No 3: Yes
Combined Areas FS Catch/day	51	τ .70042 β .000003	6.97313 -0.03236	0.0000 0.9743	reject accept	1: Yes 2: No 3: Yes

Equilibrium Models

Table 12: Results of equilibrium models for those indices which met the exploratory analysis criteria.

Area/model	MSY(t) estimate	95% CI	E_{opt} estimate (days)	95% CI
McIntyre Bay FS				
Model 3	488	331-4013	432	280-583
Model 4	344	276-457	333	243-434
McIntyre Bay FS&log				
Model 3	364	290-543	316	250-381
Model 4	326	264-578	248	185-321

For the McIntyre Bay fish slip data residual analysis suggest that Model 4 is more reasonable, while for McIntyre Bay fish slip & log data, Model 3 is the most appropriate.

Non-equilibrium Approach - using linear regression

The results are shown in the table below, as well as MSY and the effort at MSY, calculated from the estimated values of r, k, and q. Parameter estimates were considered acceptable only if :

I. k was positive;
II. q was positive; and
III. r was between 0 and 1.

Table 13: Results of model 5 non-equilibrium biomass dynamic model.

	r	q	k	MSY (tonnes)	Eopt	Acceptable
McIntyre Bay FS Data	0.624	0.000119	8886.274	1386	2622 (days)	Yes
Hecate Strait FS Data	0.475	0.000325	8179.879	971	730 (days)	Yes
Both Areas Combined FS Data	0.464	0.000042	33613.74	3903	5465 (days)	Yes
McIntyre Bay FS/log Data	0.516	-0.00009	-10954.17	-1414	-2852 (days)	No, q & k negative
McIntyre Bay log Data Stnd 4 day soak	0.602	-0.000002	-4810246	-329	-177240	No, q & k negative
Hecate Strait FS/log Data	0.382	0.000375	8,598.571	821	508 (days)	Yes
Hecate Strait log Data	1.386	0.000002	15180683	2386	307871 (traps)	No, r > 1
McIntyre Bay log Data	0.844	0.000001	8179525	783	287983 (traps)	Yes
Hecate Strait log Data Stnd to 7 day soak	1.5896	0.0000026	14064930	2535	307561 (traps)	No, r>1
Hecate Strait log Data Stand. to 42"	1.910	0.00000	12,400,791	2685	340804 (traps)	No, r > 1

	r	q	k	MSY (tonnes)	Eopt	Acceptable
trap						
McIntyre Bay log Data Stand. to 42" trap	1.501	0.000003	4577064	779	253074 (traps)	No, r>1

Non-equilibrium Approach - using time series analysis

Parameter estimates were considered acceptable only if :

I. k was positive;
II. b_0 was positive;
III. q was positive; and
IV. r was between 0 and 1.

The results are shown in the table below, as well as MSY and the effort at MSY, calculated from the estimated values of r, k, and q.

Table 14: Results of Model 6 time series fitting for different areas using different CPUE indices.

	b_0 (tonnes)	r	k	q	MSY (tonnes)	Eopt	Accept
McIntyre Bay FS Data	3736	0.769	11463.78	0.00008	2203	5028 (days)	Yes
Hecate Strait FS Data	682	.498	6802.13	-0.00017	847	-1455	No, q<0
Both Area Combined FS Data	1410	0.548	43557.3	0.00016	5966	1744 (days)	Yes
McIntyre Bay FS/log Data	-1420	0.127	-1289.76	-0.00036	-41.0688	-173.627	No, b_0 ,k.q,< 0
Hecate Strait FS/log Data	2479	0.165	> 1.8×10^9	0.00008	> 7.4×10^7	971 (days)	Yes
Hecate Strait log Data	1234	17.62	2269320	0.00001	4536	641580 (traps)	No, r > 1
McIntyre Bay log Data	1.8	15.12	462133	0.00003	793	242035 (traps)	No, r > 1
Hecate Strait	1363743	1.649	12971077	0.000003	2425	280024	No,

	b_0 (tonnes)	r	k	q	MSY (tonnes)	Eopt	Accept
log Data Stnd to 7 day soak						(traps)	r>1
Hecate Strait log Data Stand. to 42" trap	13.5	5.447	6214785	0.115	3839	23.6764	No, r > 1
McIntyre Bay log Data Stnd to 4 day soak	1684384	3.030	5287637	0.000002	1816	774077	No, r>1
McIntyre Bay log Data Stand. to 42" trap	795	0.892	4558911	0.000004	461	112976 (traps)	Yes

Yield per Recruit Analysis

The results of the Yield per Recruit analysis are presented in Tables 15 and 16 below. In Table 15, the assumption is that only 50% the first year class of crabs have recruited to the fishery. Yield is measured both in terms of weight and value. The reference point reported in the table to compare the different values of M is $F_{0.1}$.

Table 15: Yield per recruit analysis using paritally available first year class with a mean size of 165 mm (PTP).

Butler 1				Butler 2		
M	Yield Kg $F_{0.1}$	Value$ $F_{0.1}$		M	Yield Kg $F_{0.1}$	Value$ $F_{0.1}$
0.6	0.763573	0.540930		0.6	0.727644	0.521253
0.7	0.898290	0.615713		0.7	0.853981	0.590585
0.8	1.062281	0.711122		0.8	1.009790	0.679029
0.9	1.254128	0.832635		0.9	1.195102	0.791991
1.0	1.469155	0.985509		1.0	1.406182	0.935177
1.1	1.701425	1.172835		1.1	1.637140	1.112914
1.2	1.945451	1.393611		1.2	1.881981	1.325916
1.3	2.196775	1.642610		1.3	2.135627	1.570230
1.4	2.451963	1.912215		1.4	2.394086	1.838505

The second set of numbers used were those where the first mode of animals completely available to the fishery was 180 mm PTP. Subsequent growth increments for the 2nd, 3rd and 4th years of availability to the fishery were 210, 240 and 270 mm respectively. Again the $F_{0.1}$ for the various levels of M were calculated as shown below.

Table 16: Yield per recruit analysis using a fully recruited first year class with a mean size of 180 mm (PTP).

Butler 1				Butler 2		
M	Yield Kg $F_{0.1}$	Value$ $F_{0.1}$		M	Yield Kg $F_{0.1}$	Value$ $F_{0.1}$
0.6	0.799578	0.560425		0.6	0.763939	0.540696
0.7	0.942519	0.640830		0.7	0.899167	0.615635
0.8	1.114176	0.743412		0.8	1.063801	0.711322
0.9	1.311785	0.873621		0.9	1.256316	0.833285
1.0	1.530004	1.036062		1.0	1.471907	0.986803
1.1	1.763052	1.232410		1.1	1.704565	1.174912
1.2	2.005979	1.460029		1.2	1.948797	1.396468
1.3	2.254909	1.712732		1.3	2.200181	1.646082
1.4	2.506902	1.982927		1.4	2.455322	1.916058

Discussion

Descriptive Data Analysis

Landing Trends

It is evident that there there are problems with the landing data and a different picture emerges from the fish slips than from logbooks or fishers' comments. In particular fish slips attribute a much greater proportion of the Area A catch to McIntyre Bay, than indicated by either the logbooks or the comments from the fishers. If the fish slips are correct then the catches from McIntyre Bay are at levels 2 or 3 times greater than historical levels while logs show a increase in 1993 but a return to historic levels of production in the more recent years. According to the fish slips, the production characteristics of McIntyre Bay and Hecate Strait showed similar magnitudes of increase and that these catches continue to increase in Hecate Strait. If the logs are used then the pattern agrees with the fishers comments in that a increase was seen in 1993 in McIntyre Bay but not to the same extent as in Hecate Strait and the landings have gone back to historic levels, while landings have continued to be very high in Hecate Strait. If the data from both areas are combined than the resulting catches are nearly identical indicating that it is probably a simple misreporting of catch taken from one area but reported from another.

Effort Trends

There has been a substantial increase in the number of vessels fishing Area A. Most of this increase has been directed in Hecate Straits.

There have also been a number of changes in traps pulled per day which confounds the CPUE comparisons using the index "days fished". Using the annual averages from logs in Table 6, there is approximately a two and three fold difference between high and low years for McIntyre Bay and Hecate Strait respectively. If the areas are combined, the difference between the extremes is reduced to a factor of approximately 1.5. There are declining trends in number of traps pulled in the more recent years. This may be due to a number of factors including more accurate reporting of fishing activity by day or the large influx of smaller capacity vessels fishing the area.

The interannual average annual soak time also varied considerably. Table 4 showed that the high/low interannual difference could vary by as much as a factor of 1.6 and 2 for McIntyre Bay and Hecate Strait respectively. The shortest soak times occurred in years with high catch per trap and longest soak times in years with low catch per trap indices. Smith and Jamieson (1989 a) found that both soak time and bait effectiveness are extremely important in standardizing effort. They felt it was necessary to model (1) agonistic interactions, (2) changes in bait effectiveness, and (3) escapement, to understand and interpret changes in catch rates as well as size frequency distributions from trap samples for *C.magister*. Rather then try to model a standard effort for all the data, we chose data with a constant soak time to provide a standardized CPUE index which was not confounded by the effects of soak time on effective effort. We did not choose a one day soak as it was obvious in the logbooks that there have been problems with fishers confusing the length of time that a trap is fishing in the water with the time it takes to retrieve the trap. This has been a more prevalent problem with some of the newer entrants to the fishery in recent years. We did however choose the soak time which was most commonly used in each area and felt that most but not all of the issues cited by Smith and Jamieson could be addressed in this way.

The increasing use of soak times in excess of 14 days may pose a significant risk of incidental mortality loss to the fishery. Breen (1985) reported on the mortality of crabs in traps that were abandoned. In this work, he found that 55% of the crabs that entered the trap over a year died in the trap. He further broke this down and catalogued when the mortalities took place. This can be seen in Table 17 below.

Table 17: Estimates of mortality of crabs in traps proportioned by soak time (original data from Breen 1985).

Days soaked	% of total death
0-25	10%
26-50	40%
51-75	12%
76-100	12%
100+	26%

Again there is there is considerable difference seen in the catch rates of crabs depending on the size of the gear used. The difference between the average annual CPUE of different gear types were shown to vary by as much as 2.7 and 1.5 times within a single year for McIntyre Bay and Hecate Strait respectively. We generally observe increasing trends in catch rates as we go to larger traps, however, this trend is not consistent between years as is seen in Tables 6A and 6B. However differences of this magnitude will have significant effects on CPUE abundance indices that use unstandardized effective effort.

CPUE trends

The choice of CPUE index can affect the resulting picture of stock trends. We desire a CPUE index that tracks the true trends in population and the magnitude of these trends. For the two areas studied, the magnitude of the changes and the correlations in trends of the abundance indices chosen tell different stories depending on the area.

For McIntyre Bay the correlation coefficients between these abundance indices in Table 8 showed that the trends were only significantly correlated in two instances: Tonnes per day vs Kg per trap and Tonnes per day vs Catch adjusted from logbooks. McIntyre Bay catch peaked in 1994 and was at a low in 1997 similar to Tonnes per day but different than Kg/trap which peaked in 1993. Besides the timing of the trends, the magnitude of the differences between between the high and low catches varied by a factor of 6.8[3]. The magnitude of difference factor between the high/low values for the CPUE indices reported in Table 7 were only 32%-43% of those seen for the catches. There does not

[3] The difference will be overestimated because the landing data is from the logbooks and there are still 1997 logs coming in.

seem to be a consistent trend emerging from the CPUE indices chosen for McIntyre Bay and it is therefore unclear at this time which indices if any reflect the true population trend.

In Hecate Strait the picture is somewhat different in that good correlation was found between almost all the CPUE indices however there was poor correlation in most instances between CPUE and catch. In terms of timing and magnitude of variation between the high and low index, catches peaked in 1993 and were at a low in 1990 with the differences varying by a factor of 32.0. The CPUE indices in Appendix Table 1B indicate that the population was at a low in 1997 while the magnitude difference factors for the high/low ranges (Table 7) were only 16%-22% of the magnitude found in the difference factor for the catch ranges.

In the comparison of trends between areas, it was found that there were some significant correlations between the areas although the correlations were rather weak for the long time series. The pattern of the trends seems to be the same between areas. The magnitude of differences are not totally reliable since the CPUE indices in this analysis are from logbooks and the 1997 logbooks are incomplete, however, there are some notable trends.

The magnitude in the fluctuations experienced in the fishery in McIntyre Bay are consistently lower than the magnitudes experienced in Hecate Strait. Hilborn and Walters (1992) might describe McIntyre Bay as either predictable or cyclical and Hecate Strait as unstable. They go on to describe how a system can be made unstable if the fleet response time is very rapid. Instability in this case is defined as a system that does not return to its original state if perturbed and leads to extinction of some element of the system such as the fleet or the biomass. There is quite a difference between the 1950s' peak fishery and the one in the 1990s with respect to the fleet response. In 1958, with a saturated crab market, companies put a limit on the landings which controlled effort. In 1959 effort was again controlled when there was a strike which closed the fishery down completely for two weeks.

All indications, except for Hecate Strait landings and McIntyre Bay Kg/trap for 4 day soaks, suggest that the 1997 population levels are the lowest level since measuring CPUE in 1990, while the highest population indices occurred in 1993 with the exception of catch and catch per day in McIntyre Bay which peaked in 1994.

In terms of historic trends, the catch rates (kg/trap unstandardized) for Hecate Strait peaked at a high of 13.0 in 1993. This was the third highest rate on record and was only exceeded in 1952 (14.2 kg/trap) and in 1958 (15.3 kg/trap). The decline from the peaks in 1952 and 1958 were relatively gradual in the following two years (10.5 and 7.7 in 1953 and 1954 respectively and 12.6 and 10.4 in 1959 and 1960 respectively). In comparison, this same index declined in 1994 and 1995 to 7.0 and 4.5 respectively. The reason for this apparent difference in trends between the 1950s and the 1990s was either due to continued good recruitment in the 1950s or the extreme effort increase in 1994 and 1995.

Biological information

From the moult increment data that were presented, it was notable how consistent (29.9 mm PTP and 26.7 mm NTN) the moult increment was regardless of the pre-moult width. If these increments hold true from year to year then it is possible to separate crabs with somewhat more confidence. What appears to be a constant growth rate in terms of moult increment, is however not constant at all with respect to weight increases. With a constant carapace increase at moulting, as an animal get larger it must put on an increasing amount of weight to fill in the new carapace (see Table 18 below).

Table 18: Using a constant moult increment of 30 mm PTP, the resulting weight gains required by various sized animals.

Pre Width (mm PTP)	Post Width (mm PTP)	Pre Weight [4](g)	Post Weight (g)	Weight gain
165	195	572	934	362
195	225	934	1424	490
225	255	1424	2058	634

The results of the regression of PTP and NTN measurements allow us to interpret the PTP analysis and put them into perspective with respect to NTN data.

When we look at the Hecate Strait size frequency data from 1993, there are very different interpretations depending on how the data is broken up. When the data are presented as a single histogram of male crabs, there appears to be a single mode representing a cohort for crabs above 143 mm. When we break the data up by shell condition, it is evident that there is a second mode of old shell individuals with a mean size of 160 mm NTN and a mode of new shell crabs with a mean size of 173 mm NTN. If the moult increment holds true then the 160 mm NTN mode of old shell crabs would not moult into the mode of 173 mm NTN new shell crabs, they would (if they moult), grow up to a mode with a mean of approximately 187 mm NTN. There is also the possibility that a fair proportion of the old shell animals may miss the annual molt completely. This makes interpretation of size frequency data to distinguish separate cohorts very complex without the ability of assigning of shell condition to size frequency data.

From the results of the comparison of average weights in Table 10, it is evident that the maximum variation that occurs between areas is approximately 10% while the between year variances can be as high as 15%. A recent sample of crabs from Hecate Strait when analyzed by fishing banks (in this case a comparison of samples from 104-1 and 105-1) showed differences in average weights of crabs in samples of ~18% (104-1

[4] Weight calculations from PTP measurements using size/weight relationship described as Butler 1 in methods section.

average weight was 719 gms and 105-1 average weight was 849 gms)[5]. This in part may be a function of either variations in moulting and growth or a function of different fishing pressures and varying proportions of different year classes. However it does show that collection of appropriate data is necessary if we are to understand the dynamics driving these different populations.

Surplus Production Analysis

From the exploratory analysis under the equilibrium approach, only two data sets met the criteria necessary for further analysis in the equilibrium models. These were both sets of data showing the 59 years of catch from McIntyre Bay and consisted of the catch per day information from the fish slip records only and the combined fish slip/logbook records. As discussed above in catch trends, this second series of data are probably more accurate with respect to area and effort and also provides trends that are more consistent with the information that was received from the fisher interview.

The results of equilibrium models 3 and 4 for both sets of the McIntyre Bay data showed that the combined fish slip/logbook data provides the more conservative estimates of MSY and Eopt. This is not surprising since the record high catches seen in recent years in fish slips but not logbooks would drive the models to give higher equilbrium values. Comparing the estimated E_{opt} from Models 3 and 4 with the effort expended in the fishery according to the logbooks, it can be seen that the upper 95% CI of E_{opt} for model 3 has been exceeded in 5 of the years since 1990-1996 and the upper 95% CI of E_{opt} for model 4 has been exceeded every year since 1990.

The results of the non-equilibrium model 5 had acceptable results in five instances. Three of these were from the 51 to 59 year fish slip data series, which as as was noted previously is questionable as it disagrees with the more detailed location and effort information from the logbooks and the fisher interview. The fourth acceptable result came from catch per day information from the 51 year combination of fish slip/logbook data series for Hecate Strait. The estimated E_{opt} for this model has been exceeded in the commercial fishery in every year since 1993. The fifth acceptable response came from 1990-1996 unstandardized catch per trap data for McIntyre Bay. The estimated E_{opt} in this case was higher than any previously recorded effort.

The results from the non-equilibrium time series model 6 had acceptable results from three of the data sets analyzed. Again fish slip data produced acceptable results for McIntyre Bay and the combined areas. The third positive result was the Hecate Strait catch per day data from the fish slip/logbook combination. The resulting E_{opt} was almost twice as high as the E_{opt} value from model 5, however, this value is still exceeded in fishery in every year since 1993.

[5] Weights were calculated by converting NTN measurement to PTP and using the Butler 1 equation to determine the weight of the animal.

The only result from any of the short time series logbook based abundance indices that met any of the models acceptance criteria, produced estimates of MSY and E_{opt} beyond those seen in the data series. This is likely because the data series is too short and is not that informative. The data would probably be classified by Hilborn and Walters as a one way street which shows a constant decline with increasing effort. The other acceptable responses all occurred when the models were applied to longer time series in which the measure of effort is quite unreliable. It is interesting to note that the equilibrium models, which generally are considered not to be useful because of their assumptions about equilibrium and because they generally produce overestimates of MSY etc., resulted in the most conservative estimates of MSY and optimal effort for this area.

Yield per Recruit

The yield per recruit analysis produces a range of estimated fishing strategies depending on the estimated M used. There are reported estimates of M both in excess of the range of values we selected (Smith and Jamieson 1989b) as well as less then the values used (Armstrong et al 1987; Botsford and Wickham 1978). The interesting finding is that with the differential pricing used, the optimal F value is lower to optimize the economic response than it is to optimize catch which indicates that there may be potential for growth overfishing and loss of income if one only tries to optimize the total weight from the stock. It should be noted, however, that the crab market can be quite volatile with prices changing by as much as 300% in a season. Also, there are not always price differentials by size. These factors could affect the model results.

Exploitation rates for the fishery in recent years were estimated using a Leslie analysis of the catch and effort data from the fall of $year_t$ to the spring of $year_{t+1}$. It was felt that there would be no further recruitment into the fishery after the fall period. Data from many of the years did not produce positive estimates of N_0, but for those that did the estimated exploitation rates for McIntyre Bay varied from 33 to 68% while for Hecate Strait, they ranged from 41-54%. If one were to believe the lowest estimate of M we used, then the resulting $F_{0.1}$ for both weight and value was exceeded in McIntyre Bay in at least 3 of the last 7 years.

Can we answer the questions posed?

As framed in the Problem section above there are two basic questions.

Is the current regime of size limits, sex restriction and seasonal closures adequate to protect crab populations (meet conservation goals) given the increased fishing effort?

The first thing we have to do is define what is meant by "adequate to protect" or "conservation goals". Do we mean by this to protect the stock from recruitment overfishing or do we mean to protect the stocks so that the system is stable over long periods of time? The key findings that can be used to start to address this question (these questions) are:

- Area A may need to be thought of as at least two different fisheries which have quite different dynamics. McIntyre Bay may be characterized as being more consistent or perhaps cyclical while Hecate Strait seems to be quite unstable.
- The large effort increases that were experienced in Hecate Strait in the 1990s will theoretically make the unstable population dynamics even worse and shorten the time frame that the fishery will probably be available.
- The results from the biomass dynamic models, albeit questionable, indicate that the current management practices allow effort in the fishery above calculated levels of E_{opt}.

These all indicate that there is probably more management options which should be considered however to answer the question completely from a recruitment over-fishing perspective there are a number of key pieces of information missing. In particular we need to know what is happening to the female component of the stock. In addition the biological information is so weak that it is impossible to determine when a strong recruitment event took place so that we can not determine the effects of abiotic factors on the population.

Do current management practices optimize the return for the product being delivered?

The yield per recruit information shows that the answer to this question is very dependent on the price structure and the natural mortality estimates for these older year classes. To address this question we need better information on these components. Getting a handle on M is critical and requires information on the cohort strengths. Considering the complexity of the analysis of the size frequency data this can not be done at this time, but we do see that the $F_{0.1}$ of the lower range of M is exceeded with the present management system.

Recommendations

1. Improve the logbook data and fish slip data with respect to reporting of area, soak time and gear used. This should be done in consultation with the industry to determine ways of improving reporting.
2. Consider the implications of managing McIntyre Bay and Hecate Strait together. Be aware that McIntyre Bay crab populations do not go through the same degree of fluctuations as Hecate Strait crab populations. Also be aware that even analyses which are considered to overestimate E_{opt}, indicate that effort in both areas already exceeds E_{opt}.
3. There is a need to develop a fishery independent assessment program that will provide checks as to the most appropriate fishery dependent index and allow us to gather information on the population that is not targeted on e.g. females and juveniles.

4. There is a need to collect biological data from fishery dependent and independent sources that are more consistent in frequency and cover critical biological periods (minimum spring and fall i.e. pre- and post-moulting) and more detailed with respect to the biological information gathered (an objective shell condition criteria must be developed).
5. Industry should be discouraged from leaving gear soak for excessive periods of time as the impact in terms of mortality of crabs is probably significant.

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Appendix Table 1A: Landings and indices of catch per effort for McIntyre Bay.

	Landings (tonnes) from FS	Landings (tonnes) from FS & Logs	Tonnes/ day	Kg/trap Unstnd.	Kg/trap Mode = (4 day soak)	Kg/trap (42 in. dia. trap)
1990	661.3	235.88	0.72	2.8	4.1	na
1991	413.1	434.65	1.06	3.7	3.1	na
1992	1068.1	379.61	1.16	4.2	4.5	4.3
1993	1621.7	550.39	1.43	5.4	6.9	8.7
1994	1308.5	927.29	1.65	4.2	4.1	4.6
1995	1409.4	263.87	0.72	4.1	5.2	4.0
1996	1725.4	455.46	0.82	3.8	3.4	5.4
1997[6]			0.59	2.4	3.4	3.0

Appendix Table 1B: Landings and indices of catch per effort for Hecate Strait.

	Landings (tonnes) from FS	Landings (tonnes) from FS & Logs	Tonnes/ day	Kg/trap	Kg/trap Mode = (7 day soak)	Kg/trap (42 in. dia. trap)
1990	105.3	127.10	2.19	2.8	3.2	na
1991	21.6	154.98	1.61	4.1	3.4	4.1
1992	528.4	969.28	3.79	10.2	10.4	10.7
1993	3160.6	4068.81	3.85	13.0	13.5	14.7
1994	2953.6	2355.01	2.06	7.0	7.8	6.8
1995	1303.2	2570.78	1.34	4.5	5.2	5.1
1996	1569.9	1569.90	1.10	4.6	4.3	4.9
1997			0.56	2.5	2.4	2.8

[6] 1997 log book data is preliminary.