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Survey Design Considerations for Pacific Cod in Hecate Strait

Alan Sinclair

Pacific Biological Station
Fisheries and Oceans Canada
3390 Hammond Bay Road
Nanaimo, BC, Canada, V9R 5K6

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Abstract

This research document reviews aspects of the Hecate Strait groundfish assemblage survey design that may be modified to improve Pacific cod estimates while not compromising the main objectives of the survey. This included an analysis of past surveys and commercial fisheries data from the 1996-99 observer program. Consultations were held with Pacific cod fishermen on aspects of survey design and the interpretation of results. There are advantages to conducting bottom trawl surveys at times when the target species are dispersed throughout the survey area, to avoid seasons when the fish are highly aggregated, and to avoid periods when they have migrated out of the survey area. Cod spawning is reported in Hecate Strait between January and March. Commercial catch rates decline in the September – December period indicating that Pacific cod availability in Hecate Strait may be reduced then. It would appear that the month of June, when the survey has been conducted, is a good choice for this survey. Less than half the area of Hecate Strait is covered by the survey. A crab fishery occurs over a large portion of the Strait east of the Queen Charlotte Islands and the bottom conditions there are unfavorable for trawling. It would be illustrative to examine the fish by-catch in the crab traps for Pacific cod. If cod are present in significant numbers, then it may be worthwhile having the crab traps lifted at the time of the survey to allow fishing there. There appears to be a depth dependent pattern in Pacific cod distribution in Hecate Strait that would justify a stratified survey design to reduce variance. Having one station per stratum makes the estimation of sampling variance difficult. It would be useful to consider modifying the survey design where fewer strata and more stations per stratum are used. The basis for stratification should be further examined, taking into consideration other species for which the survey is now used (e.g. flatfish). Consideration should be given to trade-offs in station allocation and stratification. The current surveys have between 80 - 100 fishing sets. Increasing the number of sets would be expected to reduce the standard deviation of the mean in proportion to the square root of the number of observations. Roughly speaking, doubling the number of sets may result in a 30% reduction in the standard deviation. It is strongly recommended that length frequencies be taken for all Pacific cod catches made on the groundfish assemblage survey. Filling in for missing length frequencies introduces unnecessary uncertainties to the survey results.

Résumé

Le présent document de recherche traite de certains aspects de la conception du relevé des assemblages de poisson de fond du détroit d'Hecate qui peuvent être modifiés afin d'améliorer les estimations de la morue du Pacifique sans compromettre les principaux objectifs du relevé. On y trouve une analyse des données des relevés antérieurs et des pêches commerciales tirées du programme des observateurs de 1996 à 1999. Des consultations ont été tenues auprès des pêcheurs de morue du Pacifique relativement à certains aspects de la conception du relevé et à l'interprétation de ses résultats. Il est avantageux d'effectuer les relevés par chalutage des fonds au moment où les espèces visées sont dispersées dans toute la zone du relevé et ainsi éviter les saisons où les poissons sont fortement concentrés de même que les périodes où ils migrent à l'extérieur de la zone. Le frai de la morue est signalé dans le détroit d'Hecate de janvier à mars. Les taux de capture commerciaux diminuent entre septembre et décembre, ce qui porte à croire à une réduction de la disponibilité de l'espèce dans le détroit pour cette période. Il semble que le mois de juin, choisi pour le relevé, constitue un bon choix. Le relevé couvre moins que la moitié de la superficie du détroit d'Hecate. Une pêche du crabe est effectuée dans une grande partie du détroit à l'est des îles de la Reine-Charlotte et les conditions du fond y sont défavorables au chalutage. Il serait intéressant d'examiner les prises accidentelles de morue du Pacifique dans les casiers à crabe. Si des morues y sont présentes en nombre appréciable, il pourrait alors être valable de faire retirer les casiers au moment du relevé pour y permettre la pêche. La répartition de la morue du Pacifique dans le détroit d'Hecate semble être fonction de la profondeur et cela pourrait justifier la stratification du relevé afin d'en réduire la variance. Le fait de ne disposer que d'une station par strate complique l'estimation de la variance de l'échantillonnage. Il serait utile d'envisager la modification de la conception du relevé afin d'utiliser moins de strates mais plus de stations par strate. Les raisons de la stratification pourraient être examinées plus à fond en tenant compte des autres espèces aussi visées par le relevé (comme les poissons plats). Il faudrait tenir compte des compromis affectant le choix des stations et la stratification. Les relevés actuels comportent de 80 à 100 stations. L'augmentation du nombre de stations devrait donner lieu à une réduction de l'écart-type de la moyenne en fonction de la racine carrée du nombre d'observations. De façon générale, on peut dire que le fait de doubler le nombre de mouillages donnerait lieu à une baisse de 30 % de l'écart-type. Il est fortement recommandé d'obtenir les fréquences de longueur pour toutes les captures de morue du Pacifique faites pendant le relevé des assemblages de poissons de fond. Le fait de compenser pour les fréquences de longueur manquantes se traduit par des incertitudes inutiles affectant les résultats des relevés.

1. Introduction

Four stocks of Pacific cod are defined for management purposes on the BC coast, Strait of Georgia (4B), west coast Vancouver Island (3AB), Queen Charlotte Sound (5AB), and Hecate Strait (5CDE). The species is fished almost exclusively with trawl gear. Significant structural changes occurred recently in these fisheries which resulted in changes in the quality and comparability of data collected by the fisheries. A voluntary increase in mesh size was suggested for this fishery in 1991 and was then regulated in 1995. Prior to 1992, the fishery was managed with area and season closures. Total allowable catches were introduced in 1992 along with trip limits to prolong the fishing season. An individual transferable quota system was then adopted in 1996. These changes, and a reduction of catch sampling, has precluded the use of analytical assessments except in the Hecate Strait area.

The previous analytical assessment of Pacific cod in Hecate Strait (DFO 1999) was based on a catch-at-length model which included, for the first time, data from the Hecate Strait groundfish assemblage survey (Fargo et al. 1990). This new information improved the precision of recruitment estimates for the stock, but it was recommended that the utility of this survey be investigated further. The assessment indicated that stock biomass reached an historic low 1996-96 and there had been a slight increase since then. Recruitment estimates were low, with the last 9 year-classes being below the long term average (since 1956). Stock projections indicated the stock biomass would decline in the next 2 years.

Pacific cod are an important component of the multi-species groundfish fisheries off the BC coast and there is considerable interest on the part of the fishing industry to improve the quality and quantity of information on the resource. Since the ITQ system was established for the trawl fishery, fishery observers have been deployed on 100% of the fishing trips. This is a relatively new source of high quality information on fishing activities and it is hoped it will provide useful data for stock assessment. While the groundfish assemblage survey provides an important fishery-independent source of information on the Hecate Strait stock, it is conducted biennially. Preliminary analyses of these survey results indicated that Pacific cod were very patchy in distribution and there was considerable inter-annual variation in the location of heavy concentrations thus limiting their utility as an index of abundance. Nonetheless, the addition of the survey results to the assessment was thought to have been an improvement.

Last year, the PSARC Groundfish Subcommittee recommended "… that additional work on aspects of (the Hecate Strait) survey design be completed that may improve the cod estimates while not compromising the main objectives of the survey, (i.e. its use as an index of flatfish abundance). This work should focus on the spatial distribution of Pacific cod catches, the identification of juvenile areas, the possibility of adding more stations and possibly expanding survey coverage. Consultation and dialog with industry on aspects of survey design and the interpretation of results is also recommended. The effects of changes in survey design that may affect the consistency of the index need to be carefully considered. It was noted that there was a large percentage of survey tows

that did not catch Pacific cod, and some work on appropriate methods of calculating annual indices in such cases is warranted. Given the relatively short life history of the species, that both recruitment and biomass appear to be very low, and the importance of Pacific cod in the Hecate Strait groundfish fisheries, the Subcommittee encourages further survey work in Hecate Strait. This could be done under the existing Hecate Strait survey or the current observer program. The results should be included in a 1999 assessment." I have attempted to follow these guidelines in preparing this working paper.

The document contains a general description of the recent fisheries in all areas, the results of two meetings held with trawl fishermen to discuss the status of Pacific cod fisheries, a description of the groundfish assemblage survey results in Hecate Strait (1984 – 1998), a description of the observer data from Hecate Strait (1996 – 1999), and a comparison between the two in June of 1996 and 1998.

2. Description of the fishery

Pacific cod are landed almost exclusively by trawl gear. Of 3690 t landed in BC between 1996 – 1998, 13 were from fixed gear and the rest was from trawls.

2.1 Landings Data

Historical landings data from 1956 – 1995 for the 4 stocks were obtained from Haist and Fournier (1998) (Table 1). These were updated using information for trawl gear from the PACHARV database for the period 1996 - 1998. Landings estimates appear in 2 forms in PACHARV, set by set estimates by fisheries observers and trip by trip weights recorded at dockside. The observers also provide precise fishing locations while the dockside estimates are for the entire trip. Fishing trips often cross Pacific cod stock boundaries, thus the dockside estimates alone cannot be used to allocate landings to stock. It is assumed that the dockside weights are the most accurate source of information on landings since the fish are sorted by species and weighted coming off the vessel. The observes must do their estimations for each fishing set using a variety of volumetric and ad hoc methods. However, the observer estimates are the only source of information to prorate the trip landings to stock area. I used the following procedure to do so.

The first step was to compare the trip by trip estimates of landings. Three situations arose, trips for which there were both observer and dockside estimates (BOTH), those for which only dockside estimates were available (DOCK), and those for which only observer estimates were available (OBS). Where trips were found in both data tables, the observer estimates were 10 – 15% lower than the dockside estimates (Table 2). Closer examination of the trip by trip comparisons indicated that about 75% of the Pacific cod landings came from trip landings of 1 t or less, and half of the difference in observer and dockside estimates of the total landings came from trips of 1.5 t or less. The bias in observer estimates was greatest for small landings (< 0.5t, 45% underestimate) but much less at landings of 5t and greater (- 8%). There was 223t of Pacific cod landed by vessels that did not have observers aboard in 1996, mainly in the early part of the year. This was much lower in 1997 and 1998, 19t and 8 t respectively. There were 7t of Pacific cod reported on trips with observers which did not have a corresponding dockside estimate, most of this occurred in 1996.

The observer estimates were used to calculate the proportion of P. cod taken in each area in a trip. These proportions were used to allocated the dockside estimates of trip catch among areas as follows

$$C_{at} = \frac{D_t O_{at}}{\sum_{a=1}^{m} O_{at}} \quad if\ \ type = BOTH$$

$$C_{at} = O_{at} \quad if\ \ type = OBS$$

$$C_{ut} = D_t \quad if\ \ type = DOCK$$

were C_{at} = the estimated catch in stock area a in trip t
D_t = the dockside estimate of landings in trip t
O_{at} = the observer estimate of the catch in area a in trip t
C_{ut} = a special case where the area is unknown (u).
m = the number of stock areas

Discard information is also recorded by observers. Totals of 74t, 129t, and 65t were reported in 1996, 1997, and 1998 respectively.

2.2 Long Term Trends in Landings

Annual coastwide landings of Pacific cod have varied between a low of 667t in 1996 and a high of 15000t in 1966 (Fig. 2). Trends in the West Coast Vancouver Island, Queen Charlotte Sound and Hecate Strait areas have been similar with peak landings in the mid-1960s, the mid-1970s and the late 1980s – early 1990s. Landings from the Strait of Georgia were somewhat different, peaking around 1980 and again in 1988. Current landings in all four areas are the lowest on record.

2.3 Landings and quotas

The fishing year for management purposes currently runs from April to March. This change was made for the 1997/98 fishing year, prior to that the fishing year was a calendar year. Catch quotas have been used for the Hecate Strait (since 1992), west coast Vancouver Island (since 1994), and Queen Charlotte Sound (since 1997/98), but not for Strait of Georgia. A summary of the scientific advice, TACs and associated landings is given in Table 3. None of these quotas have been caught, with the exception of Hecate Strait in 1992. The average difference between TAC and landings is –61%.

3. Industry Input

Two meeting were held with fishers experienced in the Pacific cod fishery

3.1 Meeting in Prince Rupert

The first meeting was held in Prince Rupert on October 21, 1999. The main objective was to discuss aspects of cod distribution in Hecate Strait that are relevant to having a bottom

trawl survey of the area. I used material prepared for the PSARC working paper as speaking points. The following summarizes the discussion.

Attendees:

Bruce Turris (CGRCS)	Don Vaccher (Fisherman)
Todd Rhyno (Fisherman)	Scott Mark (Fisherman)
Carl Stace-Smith (Fisherman)	Adrian Rowlands (Fisherman)
Bobby Ingrham (Fisherman)	Dave Bill (Fisherman)
Steve Sviatko (DFO)	Todd Johanson (DFO)
Nev Venables (DFO)	Alan Sinclair (DFO)

- Small cod tend to be concentrated in relatively shallow water (20-40 fm.).
- The shallow area east of the Queen Charlotte Islands is generally covered with crab pots making fishing there almost impossible.
- January – March is seen as the main spawning time of cod in Hecate Strait.
- The fish are generally most spread out in June – August, but cod are spotty most of the year.
- Day time catch rates tend to be higher than night time catch rates.
- There were some complaints about observers not doing their jobs properly and not working as hard as the fishermen thought they should. The opinions varied among fishermen present.
- The participants felt there was little migration in and out of the Strait as cod can be found in the area year-round. But, later on some said that cod fishing is generally poor in the Strait in September-January, possibly because cod move out of the area. Other species such as halibut and rockfish are thought to leave the Strait at this time of year.
- Fishermen reported seeing signs of small P. cod and black cod in the Hecate Strait. However, with current mesh sizes they don't have the same access to information on fish size. Their observations are based on seeing fish escaping from the trawls as the gear is retrieved.
- Cod quotas tend to be limiting in terms of what other species can be harvested. The fishermen have to manage the cod quota to have enough for by-catch in fisheries for other species. This year, some are saving cod quota for rock sole and lemon sole fishing later in the fishing year.
- People who participated in an earlier industry survey initiative were interested in seeing results of the work and asked what had been done with the data.
- There was a general concern that there is too much of a delay between the Hecate Strait survey and when the quotas can be adjusted in case cod do show up in the area. A clear sign that cod have come back would be if the by-catch rates increased.
- The general feeling around the room was that cod abundance was currently low, no one asked for the quota to be increased. The main concern was that the fishermen would be the first to detect a change, and it would take DFO too long to react.
- Hydroacoustics were discussed as an alternative to trawl surveys for measuring abundance. The general feeling was that acoustics would not be very useful as cod are distributed close to bottom.

- It was suggested that we should look in areas currently covered by crab pots to see how much cod was there.
- At the end of the meeting, some interest was expressed in tagging fish. A considerable amount of tagging has been done in the past. It would be best to design experiments specifically for estimating abundance and take information on growth, age determination and migration as secondary benefits.

3.2 Meeting in Vancouver

The second meeting was held in Vancouver on November 10, 1999. Fishermen present had experience in both the Hecate Strait and Queen Charlotte Sound areas.

Attendees:

Don Murray (Fisherman)
Martin Carr (Fisherman)
Kirk Carr (Fisherman)
Per Englund (Fisherman)
Alan Sinclair (DFO)
Bob Morreau (Fisherman)
Dan McMillian (McMillian Seafoods)
Dave Dawson (Ocean Seafoods)
Nev Venables (DFO)

Hecate Strait

- Pacific cod are avoided due to low IVQs
- It is difficult to develop an opinion on the abundance of young fish because of the large mesh size currently used
- It was suggested that a survey should occur during the spawning period since this is when the resident fish will be in the area, and repeated 3 other times during the year in case fish are moving in and out of the area. If it is to be a Pacific cod survey, then the cod fishing gear should be used. Fishermen generally use gear designed for other species.
- It was mentioned that the earlier flatfish juvenile surveys may have fished in the area now covered by crab gear. The results of that work should be analysed for cod catches.
- Tides in Hecate Strait are very strong and influence catches.
- Cod catch rates are highest during the day. The impression among the fishermen at the meeting was that cod leave the bottom at night.
- Reference was made to earlier work by Westhheim that indicated water temperature affected cod catches.
- It was noted that there is a limited amount of cod directed fishing in June but very little later in the year. This may reflect a reduced availability of cod in the area in the late summer and fall. There was no strong opinion among participants about where the fish may go, whether they leave the Strait altogether, move off bottom, or enter the coastal inlets.
- It was suggested that some comparative fishing be conducted between the DFO research vessel and a commercial vessel at the time of the June survey.

- The low catch rates in the winter of 1999 may reflect the extremely poor weather. It may also have been a result of avoidance fishing as some fishermen may have had very low IVQs for the end of the 1998-99 fishing year.
- As was the case in Prince Rupert, the general feeling around the room was that cod abundance was currently low, no one asked for the quota to be increased. The main concern was that the fishermen would be the first to detect a change, and it would take DFO too long to react.

Other Areas
- It was noted that the low lingcod quota in area 3D restricts fishing for Pacific cod in this area. It was suggested that the area 3C and 3D lingcod quotas be combined, thus allowing a larger overall quota and more flexibility to fish other species.
- The basis for the 260t Pacific cod quota in area 5AB was questioned. This quota is so low it is not possible to fish for Pacific cod at all.
- Cod are abundant at around 52 fm. on Goose Island and fishermen avoid this depth range as a result.
- It was generally felt that silvergray rockfish were very plentiful in the 5AB area.

4. Hecate Strait Survey

This section presents an analysis of cod catches in the Hecate Strait groundfish assemblage survey. The focus of this analysis is on characteristics of cod distribution and survey design that may aid in developing a more precise relative abundance index for the species in this area. The following aspects have been considered;
- The survey design in terms of choice of sampling locations and the implications for estimating a population index;
- The statistical distribution of cod catches including the occurrence of zero catches, the frequency of zero catches may be a useful index of abundance on its own, i.e. a high number of zero catches in a given year may indicate low abundance;
- The spatial distribution of cod with respect to depth and size composition. This may indicate areas to concentrate future sampling effort.
- The use of bootstrapping to estimate the distribution of the population index.

Earlier examinations of Pacific cod catches in these surveys indicated that the catches were highly variable and possibly not suitable for a useful index (Fargo et al. 1990).

4.1 Survey Design and Set Locations

A series of multi-species groundfish surveys designed originally to map species assemblages was started in 1984. These surveys have been conducted in May-June of 1984, 1987, 1989, 1991, 1993, 1995, 1996, and 1998 (Westrheim et al. 1984, Fargo et al. 1984, Fargo et al. 1988, Wilson et al. 1991, Hand et al. 1994, Workman et al. 1996, Workman et al. 1997). Jeff Fargo, DFO PBS, kindly provided data files of fishing locations, depths, catches (kg) and length frequencies.

Fishing locations were allocated to strata determined by 10 fm. depth intervals within a 10 nm grid of Hecate Strait (Westrheim et al. 1984). The objective was to make at least 1

fishing set in each stratum, and these fishing locations were chosen based on suitable bottom conditions. Replicate hauls were made within selected strata when more than one vessel was used in the survey, to compare fishing power between vessels, and to compute inter-strata variance when one vessel was used. The main depth zone fished was 10 – 80 fm, although deeper stations were added occasionally. Thus, the survey design was depth-stratified within a spatial grid. Station locations were not chosen randomly thus introducing possible biases in the estimates. With one station per stratum, it is unclear what the best estimator of variance would be. Tow lengths varied between 30 minutes and 1 hour. Consequently, the catch data were analyzed as kg/hr fished.

The spatial distribution of set locations with respect to depth was relatively uniform (Table 4), as would be expected given the sampling design. The number of survey hours per 10 fm. interval varied between 45 – 54 hours in the first 5 intervals, and was somewhat lower in the 60 and 70 fm. intervals. There were occasional sets made in deeper depths in selected years. These sets have been excluded from the subsequent analyses because the depths were not covered in all years; the analysis was restricted to sets at depths less than 80 fm. Fishing stations were concentrated through the central portion of Hecate Strait and along the southern slope of Dixon Entrance (Fig. 3). These are areas of highest variation in depth.

The distribution of depth within the survey area was not uniform, however. The area of each 10 fm. depth interval was computed using a coast-wide database of bathymetry that gives mean depths on a 1 km^2 grid. (courtesy of N. Olsen, PBS, described in Schnute et al. (1999). The area in each depth interval was computed as follows. First, all the bathymetric data for areas 5CD (DFO Hecate Strait) were plotted. Then, an overlay of all the survey fishing locations at depths less than 80 fm. was added. The bathymetric data within the area fished were then selected. The data points, each representing 1 km^2, were then coded into 10 fm depth intervals, and the area in each interval was calculated. As shown in Table 4, the area of the 30, 40, 50, 60, and 70 fm. intervals was similar (range 866 – 910 km2), but the 10 and 20 fm. intervals were considerably larger. Consequently, the sampling rate of the survey, defined here as hours fished per km^2, was not constant among the depth intervals. The highest sampling rates were in the 30 – 59 fm. depth range, and the 10 – 29 fm. range was under-sampled (Fig. 4).

This uneven distribution of sampling with respect to depth could affect indices of relative abundance if fish distribution changes during the time period of the surveys. For example, let's say there was 10,000 t of fish in the survey area (depth range 10 – 79 fm.). The expected density would be 10,000 t / 9293 km^2 = 1.07 t/km^2. If all the fish were in the 50 – 59 fm. depth interval, we would expect a tow density of 11.5 t/km^2 in that area and 0 t/km^2 in all other areas. If the fish were all in the 10 – 19 fm. depth interval, the expected density would be 3.3 t/km^2 in that area and 0 t/km^2 in all other areas. Now, if the survey area is sampled as it has been in the past, the expected mean density ($\overline{A}$) would be

$$\overline{A} = \sum_{h=1}^{L} \overline{a}_h V_h \qquad 1)$$

where $\bar{a}_h$ is the mean density in depth interval h, V_h is the proportion of the sampling effort in depth interval h, and L is the number of depth intervals. The mean density would be 1.67 if all the fish were in the 50 – 59 fm. depth interval and 0.54 if all the fish were in the 10 – 19 depth interval. This is an undesirable outcome given that the absolute biomass of fish is the same in both cases, but the relative index would be 3 times higher in one than the other. A way around this problem is to calculate depth stratified mean density using the depth interval areas as weights (i.e. using equation 2, (Cochran 1977)).

$$\bar{A} = \sum_{h=1}^{L} \bar{a}_h W_h \qquad 2)$$

W_h is the proportion of the survey area in depth interval h.

A bootstrap method was used to investigate the variability of the annual stratified mean catch rates (Smith 1997). I used what Smith called the naïve approach, whereby for a given survey and within a depth strata, the observed catches were randomly sampled, with replacement, to obtain pseudo-replicates of size n, where n was the original number of sets within the stratum. The stratified annual mean was calculated from the bootstrap replicates, and this was repeated 1000 times for each survey. The distribution of the bootstrap means was used to estimate the distribution of the annual stratified means. Smith (1997) points out that the naïve approach will tend to underestimate the true variance. For the 8 Hecate Strait surveys, the bootstrap variance was about 8% less than the stratified variance on average.

Fargo et al.(1990) estimated the standing crop of several groundfish species in Hecate Strait using a swept area method applied to the 1984 and 1987 groundfish assemblage surveys. Pacific cod was excluded from the calculations due to the high variability in catches. While high variability may limit the utility of such an index for determining trends in population size, it does not invalidate the calculation. Provided we have some idea of the variance of the estimates, such calculations provide an indication of the possible range of biomass available in the survey area. Fargo et al.(1990) used a swept area of 0.0142 nm^2/hr. This converts to 0.0486 km^2/hr. The area covered by the survey was estimated to be 9293 km^2, giving the number of trawlable units in the survey as 9293 km^2/0.0486 km^2/hr = 191216 hr. Multiplying the annual depth stratified mean catch rate (kg/hr) by the number of trawlable units gives an estimate of the biomass of Pacific cod within the survey area. The same conversion was applied to the 95% confidence limits of the bootstrap means to obtain the confidence limits of the swept area estimates. I prefer to call this a biomass index since we do not know what fraction of the cod in the swept area are retained by the gear. The swept area is also calculated from the wingspread of the net. It is possible that the sweeplines and tawl doors hedr the fish and this may be an underestimate of the actual swept area.

Pacific cod catches are sampled for length on most of the fishing sets during these surveys. This was not always the case, however, and in some years, notably 1991, 1995, 1996, and 1998, a significant proportion of the total catch was not measured (Table 5)

due to operational restrictions. The following assumption was made to complete this analysis. It was assumed that the size composition of unsampled catches in a depth interval and survey was the same as the combined size composition of sampled caches in that survey and depth interval. This implies that the unsampled catches have the same mean fish weight (i.e. kg per fish caught), and that the numbers of fish caught in the unsampled catches would be $\frac{S_S * W_C}{W_S}$, where S_S is the number of fish caught in sampled sets, W_C is the weight of fish caught in the depth interval, and W_S is the weight of fish caught in sampled sets. It also occurred that when large catches of cod were made, a random subsample of the catch was taken for length measurement. The weight of the catch and the weight of the sample were recorded, and this ratio was used to "bump-up" the subsample to represent the total catch in the set. The length frequency samples within a survey and depth interval were combined and divided by the fishing effort in the depth interval to obtain a catch rate at length for the depth zone.

It should be noted that in the analyses that follow I have assumed the station locations were chosen at random and I have post-stratified the existing data by depth interval only. This will undoubtedly result in a bias in the estimates of population size. But, the extent of the bias is unknown. I have made this compromise to investigate the qualities of these survey results but by no means present these as absolute estimates for the purpose of stock assessment.

4.2 Cod Catches

Cod were caught throughout the survey area, but there was a high degree of variability in catch per set and catch per hour fished. Of the 801 survey sets, only 432 (54%) had cod. The mean catch per hour fished for all sets was 61 kg with a standard deviation of 271 kg. These two characteristics, a high number of fishing stations without cod and a high standard deviation of catches, suggest that Pacific cod will be difficult to evaluate with bottom trawl surveys. Nothing new, this was noted when the surveys were initiated.

4.2.1 Depth Distribution of Cod

Cod were found in all depth intervals but at different densities (Fig. 5). The frequency of occurrence was lowest in the 10 – 19 fm. interval (20%) and this increased to a maximum of about 75% in the 70-79 fm. interval. Cod densities (kg/hr) were low in both the shallowest and deepest depth intervals, and the highest densities were found in the 30 – 39 fm. depth interval. However, the 10 – 19 fm. depth interval is by far the largest in the survey area. An index of the distribution of the total cod biomass in the area was obtained by multiplying the density by the area. This indicates that the 20 – 29 fm. depth interval has the highest biomass and that 65% of the biomass is found in the 10 – 39 fm. depth range. The variability of cod catches, show here by the coefficient of variation of the mean, was highest in the 10 – 19 fm. interval (70%), and lowest in the deepest interval (20%). The coefficient of variation is an indication of patchiness, high values indicate a more clumped distribution than low values.

4.2.2 Spatial Distribution

The geographic distribution of cod catches varied considerably among the individual surveys making it difficult to generalize where the highest concentrations could be found. This lack of pattern was recognized in earlier reports on these surveys (Fargo et al. 1990). Null catches occurred more frequently in the southern range of the survey suggesting that the southern range of cod distribution in the Strait may have been delimited (Fig. 6). The largest catches occurred more frequently in the northern area. There were usually large catches made at the northern edge of the survey area, suggesting that the survey may have missed some fish in deeper water in this area. It is difficult to determine if the eastern and western distribution of cod was delimited by the survey. To the southeast, the bottom depths exceed 100 fm. and this may present a barrier to cod distribution. However, the western edge of the survey area is usually heavily occupied by crab traps making trawling difficult. In some years, there were several null sets along the western edge of the survey area. This was not the case in 1987, however.

4.2.3 Cod Size

The spatial and depth distribution of different size classes of cod was examined. This analysis may be helpful for directing survey sampling at specific size and age classes of cod.

The annual survey length frequencies of pacific cod showed, in all years except 1987, a dominant peak around 30 cm and a broader length distribution at lengths > 40 cm. (Fig. 7). The lower size interval probably represents age 1 cod (Westrheim 1996). Cod reach commercial size by age 2, thus this peak at 30 cm represents next year's recruitment. This lower size frequency was very "spikey" in 1996 due to the very small sample size available in the 20-29 fm. depth interval (only 5 kg of a total catch of 694 kg was measured).

The size frequencies were split into two size classes, <40 cm and >= 40 cm, to examine their depth distributions. Catch rates of these two size classes are presented by year and depth interval in Table 6. The <40 size class was found almost exclusively in the 20 – 39 fm. depth zone. The >= 40 cm size class was more widely distributed with the highest densities in the 30 – 39 fm. depth zone.

An abundance index was calculated for the size classes by multiplying the average density by the depth interval areas. This index indicates that about 70% of the <40 cm cod were caught in the 20 – 29 fm. depth zone. The >= 40 cm cod were much more evenly distributed with approximately equal numbers in the first 3 depth intervals and lower but significant numbers in the next 2 depth intervals (Fig. 8).

4.3 Trends in Population Measures

Some consideration needs to be given to the survey design when determining what estimator to use for developing an index of population trend, either in terms of biomass or abundance, from these survey results. As indicated above, the sampling rate has not been evenly distributed across the survey area (Fig. 4). Using a simple average as an index would result in biased annual indices if the spatial distribution of the stock changes over

time. That the spatial distribution would change seems inevitable given the apparent spatial segregation of small (<40cm) and large cod in Hecate Strait. In years of good recruitment, the stock would be more abundant in the 20 – 40 fm. depth range. The population would become more homogeneously distributed as the year-class ages. Given the current sampling rates, one would expect the index to be biased downward when the population is relatively young.

There are two other possible problems associated with station selection. The design placed one station within each depth interval and 10 nm area grid. It is not clear if the station locations were randomly selected and if they were selected each year. In addition, having only 1 observation within each grid/depth stratum makes estimating variance difficult.

My preference is to use a depth stratified estimator (equation 2) and ignoring the grid sampling design, at least for constructing an index of abundance and gaining a preliminary understanding of its variance from the existing data. This gives relatively high numbers of stations within each stratum (> 10 per year). The disadvantage is that the stations were not selected at random. Thus, one must accept an undefined amount of bias in the index. It would be worthwhile considering changing the survey design to select stations randomly within depth strata in future surveys.

The annual mean catch rate of Pacific cod in the Hecate Strait assemblage survey showed considerable variation with highest values in 1987, 1989, and 1998. In all years except 1998, the stratified means were lower than the simple means (Table 7). This is because cod catch rates tended to be lowest in the 10-19 fm. depth interval, and this interval has the highest area. The exception was in 1998 when there was an exceptionally high catch of cod (2252 kg/hr) was made in the 10-19 fm. depth interval.

Swept area estimates of biomass ranged from 4440t (2352 – 7151 05% CI) in 1991 to 19996t (6291 – 37134 95% CI) in 1989. The estimate for 1998 was close to the largest in the series at 19243t (5392 – 42010 95% CI). These biomass estimates have the same relative variability as the stratified means and we can see there is considerable overlap in the 95% confidence intervals of the lowest and highest estimates. Furthermore, in calculating a biomass index, we have assumed that the survey catchability is 1.0. At this time, no attempt has been made to confirm this assumption.

While there was considerable variation in the annual stratified mean catch rates (kg/hr), a factor of 4 between the lowest and highest, it was difficult to distinguish between them on a statistical basis. There was some overlap in the estimated 95% confidence intervals of all the annual means (Fig. 9).

The proportion of survey tows with cod varied between a low of 42% in 1993 and a high of 61% in 1991 (Fig.10). There was little similarity between this index and the survey mean catch rate of cod. Two years of relatively high proportions of sets with cod were among the lowest mean catch rates (1984 and 1991). On one hand, this indicates cod

were found throughout the survey area in all years. On the other, little can be said about their relative abundance based on percent occurrence.

5. Observer Data

Fisheries observers have been deployed on 100% of the groundfish trawl fleet fishing off the BC coast since 1996. Their set-by-set data on fishing operations have provided a wealth of information on the operations of this fleet and the distribution of the exploited species. The distribution of Pacific cod catches by the groundfish trawl fleet is discussed here. Of particular interest is the bathymetric and geographic distribution of cod in relation to other species, and if it appears possible to direct fishing effort specifically at cod.

Set by set records were extracted from the PACHARV database for the period January 1996 to July 1999. The selected fields included set date, position, depth, duration, fishing gear and catch of cod and all species. When cod catch rates were calculated, a depth stratified procedure was used similar to that described for the groundfish assemblage survey.

5.1 Coastwide Distribution of catches

Pacific cod have been caught in coastal waters all along the BC coast from the southwest coast of Vancouver Island, Queen Charlotte Sound, and Hecate Strait (Fig. 11). The largest catches in the 1996-99 period, have been taken in Hecate Strait and along the north shore of the Queen Charlotte Islands.

5.2 Hecate Strait (Area 5CD)

The trawl fishery in statistical districts 5CD is concentrated in depths of between 50 to 175 m (Fig. 12) along the north coast of the Queen Charlotte Islands and south through Hecate Strait. There is also a small amount of fishing at depths of 375 – 450 m in the Langara area off the northwest tip of the Charlottes and also some fishing in 175 – 250 m of water in the southern portion of Hecate Strait.

Pacific cod were found at highest densities between 50 – 125 m of depth (Fig. 13). However, cod were caught at relatively low densities compared to the catch of all species. The smoothed fit of cod catch rate vs. depth peaked at around 0.25 kg/hr at around 70 m. This was about half the catch rate off all species at the same depth. At depths in the range of 100 m, the cod catch rate was about 20% of the catch rate of all species combined. This suggests that cod is taken largely as by-catch in fisheries directed at other species.

There was some seasonal variation in the depths fished in the Hecate Strait area (Fig. 14). The fishery tended to be concentrated in shallower depths in the late winter/early spring, and at deeper depths in the fall. Similarly, there was seasonal variation in the occurrence of cod in individual fishing sets (Fig. 15). Cod were present in 70% of the fishing sets observed in this area. The highest occurrence was in the late-winter/early spring and the lowest in the fall. However, the percent occurrence never fell below 50% in any month

and most were above 60% indicating that cod were present in the area throughout the year.

On a set-by-set basis, cod made up 40% or greater of the catch in only 10% of the fishing sets made in the area (Fig. 16). Most of these sets occurred in the late-winter and early spring. The frequency of sets with a high proportion of cod during the late-winter early-spring was greater in 1997 and 1998 than in the other 2 years. Cod rarely exceeded 40% of the set catch in all other months.

The depth stratified mean catch rate of cod in Hecate Strait varied by a factor of 10 from a minimum in the fall of each year to a maximum in the winter-spring of 1997 and 1998 (Fig. 17). Catch rates increased somewhat later in the year in 1999 than the 2 pervious years. Several factors could contribute to this seasonal variation and it is difficult at this time to distinguish among them. One possibility is that cod migrate into and out of Hecate Strait thus changing their availability to the commercial fishery. A second and related possibility is that cod remain in the Strait but move in and out of the prime fishing areas. A third possibility is that the fishery moves relative to cod distribution. A fourth is that the catch rates reflect cycles of mortality (fishing and natural) followed by recruitment and growth.

Given the low fraction of the area that is actually fished, it is not possible, from the observer data, to rule out the possibility that the low catch rates in the fall are due to a movement of cod out of the fished areas or out of the Strait all together. Fishing in Hecate Strait is concentrated on a relatively small proportion of the total sea bottom along the southern edge of Dixon Entrance and along a corridor on the eastern portion of Hecate Strait (Fig. 18 – 21). A considerable portion of the western part of Hecate Strait is not fished.

The low catch rates in the winter of 1999 may reflect lower abundance of cod in the fishery area in that year. There is little difference in the spatial distribution of fishing effort in the winters of 1997, 1998, and 1999 (Fig. 18). It is possible, however, that the 1999 catch rates may have been deflated by subtle changes in the distribution of fishing that are not evident on these maps or the mean depths fished (Fig. 14). Similarly, there may have been changes to fishing gear and fishing strategies in order to avoid cod. On that note, the TAC for Pacific cod in Hecate Strait was the same in 1999-2000 as in 1998-1999.

6. Comparison of Hecate Strait Survey and Observer Data

6.1 Catch rates in June 1996 to 1999

It was possible to compare the mean catch rates (kg/hr) from the commercial fishery and the groundfish assemblage surveys in June of 1996 and 1998. Both were estimated using a depth stratified mean (equation 2) and the distribution of the means was estimated using a depth stratified bootstrap. The commercial catch rates were approximately twice the survey catch rates in the 2 years with the ratios of commercial / survey means being 2.2 in 1996 and 1.8 in 1998. The confidence intervals of the commercial mean catch rate

were much smaller than those from the survey estimates, probably reflecting the larger sample size for the former (336 and 511 sets in 1996 and 1998 respectively). The confidence intervals of the 1996 and 1998 commercial mean catch rate did not overlap while that for the survey estimates did. The difference in mean catch rates may be due to the size of trawl used in the survey (43 ft. wingspread) and commercial fishery.

7. Summary and Suggestions

This paper has investigated characteristics of the Hecate Strait groundfish assemblage surveys and the commercial fishery with the objective of drawing information on variations in abundance of Pacific cod in this area. The following section summarizes the main observations and provides suggestions of where to go from here.

7.1 Assemblage Survey Design Considerations

Do the groundfish assemblages surveys provide useful information about changes in abundance of Pacific cod in Hecate Strait and what can be done to improve them? The following section discusses certain aspects of the groundfish assemblage surveys that could be changed to improve survey performance.

7.1.1 Survey Timing

There are advantages to conducting bottom trawl surveys at times when the target species are dispersed throughout the survey area, to avoid seasons when the fish are highly aggregated, and to avoid periods when they have migrated out of the survey area. This would reduce the inter-haul variability, reduce sampling variance, and reduce inter-annual variability. Periods to avoid include spawning and migration periods. Favorable seasons include feeding periods. Westrheim (1996) reported that cod spawn in March in Hecate Strait and fishers reported seeing spawning aggregations in January – March. Fishers also reported that cod were more dispersed in June – August, but that catches tend to be "spotty" all year round. The lowest catch rates were noted in September-December. The commercial catch rates indicate cod may move out of the fishing and survey areas in the late summer and fall of the year. These periods may not be suitable for an abundance survey. Thus, the month of June appears to be a good choice for this survey.

7.1.2 Spatial Coverage

It is important that abundance surveys cover a large portion of the target species habitat in order to reduce biases associated with movements of fish between surveyed and unsurveyed areas. Less than half the area of Hecate Strait is covered by the survey. A crab fishery occurs over a large portion of the Strait east of the Queen Charlotte Islands. While the crab traps are in the water, it is very difficult to trawl there. One option is to examine the fish by-catch in the crab traps for Pacific cod. If cod are present in significant numbers, a second option is to investigate the possibility of having the crab traps lifted at the time of the survey to allow fishing there.

7.1.3 Stratification

There appears to be a depth dependent pattern in Pacific cod distribution in Hecate Strait, especially at younger ages. Thus, a depth stratified approach to sampling is justified to

reduce variance. The original intent of distributing stations using a grid design was to examine patterns of species assemblage. This does compromise the survey design to a certain extent, however. Having one station per stratum makes the estimation of sampling variance difficult, to say the least. And, one wonders how random the station selection really is.

It would be useful to consider modifying the survey design where fewer strata are used and station selection is randomized. For Pacific cod, there does not appear to be a significant amount of inter-annual spatial correlation in distribution. Thus, I would not expect much gain in using a fixed station design over an annual random station selection design. The basis for stratification should be further examined, taking into consideration other species for which the survey is now used (e.g. flatfish). Consideration should be given to trade offs in station allocation and stratification (Gavaris and Smith 1987).

7.1.4 Number of sets

The current surveys have between 80 - 100 fishing sets. Increasing the number of sets would be expected to reduce the standard deviation of the mean in proportion to the square root of the number of observations. Roughly speaking, doubling the number of sets may result in a 30% reduction in the standard deviation.

7.1.5 Sampling

It is strongly recommended that length frequencies be taken for all Pacific cod catches made on the groundfish assemblage survey. Filling in for missing length frequencies introduces unnecessary uncertainties to the survey results.

7.2 Commercial Catch Rates

Commercial catch rate has been used as an index of stock abundance in the past assessments of Pacific cod. But, changes in the fisheries management system and fishing strategies have allegedly resulted in fundamental changes in the relationship between the index and the population. The current TAC for Pacific cod is now very low. Fishers avoid catching it in order not to run out of their individual Pacific cod quotas, which would in turn reduce their ability to fish other species. Nonetheless, the depth stratified mean catch rates of cod in 1996 and 1998 showed a similar change in magnitude as those from the survey. Thus, the commercial index may still be of use in tracking changes in cod abundance. The following is a short discussion of some factors that need to be considered if this is to continue.

7.2.1 Seasonal changes in catch rate

The strong seasonal variation in commercial catch rate is of concern. It begs the question, where do the fish go. Do they leave Hecate Strait, do they move out of the fishing area, or is their abundance being reduced by exploitation and natural mortality? If this is a seasonal migration, how regular is it and how best to interpret an annual signal from the data?

7.2.2 Area weighting

This analysis of catch rates used few large depth strata. It was assumed that the average catch rates experienced in a stratum were representative of the entire strata. This could grossly overestimate biomass if fishing were concentrated only in areas of high local density. It would be interesting to investigate a smaller scale grid analysis as has been done for slope rockfish (Schnute et al. 1999). Indeed, this might reduce the strong seasonal signal.

7.2.3 Area fished

Another problem that may develop with this analysis is if the fishery covers variable amounts of the stock area from year to year. At the extreme, if the fishery stopped for a year, the stock index would be 0. The use of a designed commercial survey where a large portion of Pacific cod habitat was sampled every year, might avoid this problem.

7.2.4 Further changes in fishing strategy

A commercial catch rate index will always be vulnerable to changes in fleet fishing strategy. If pacific cod rebuild and TACs are increased, will the commercial fleet return to former fishing practices, thus again changing the relationship between catch rate and population abundance?

7.2.5 Relative fishing power among vessels

There are usually significant differences in fishing power of individual fishing vessels related to horsepower, vessel length, fishing gear, and the experience of the captain. No attempt has been made in this analysis to account for such variations. However, this is common practice in other areas. Fréchet (1996) provides several suggestions of how to control for inter vessel variations in fishing power in an industry based survey for Atlantic cod.

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10. Tables

Table 1: Annual landings of Pacific cod (t) by stock area, 1056-98

Year	Strait of Georgia	West Coast Vancouver Island	Queen Charlotte Sound	Hecate Strait
1956	578	1468	1753	1046
1957	607	1814	2744	1106
1958	650	850	1178	3058
1959	1047	907	946	2203
1960	744	635	618	2360
1961	415	420	240	1616
1962	478	633	422	1690
1963	675	1231	677	2927
1964	713	1221	1275	5228
1965	484	2768	1940	9119
1966	297	3136	1811	9519
1967	472	1941	1501	5112
1968	349	1425	960	5165
1969	388	1092	699	2987
1970	502	1095	299	1315
1971	740	3328	928	1477
1972	630	5629	2320	2696
1973	441	3712	1914	3996
1974	681	3474	2292	4766
1975	991	4000	2444	5036
1976	927	3797	2271	4993
1977	1148	2948	1268	3510
1978	1373	1998	1959	2103
1979	1202	1861	1904	4699
1980	1611	1126	1383	4542
1981	1749	896	853	3190
1982	1012	1123	596	2066
1983	904	694	183	2715
1984	652	675	383	1748
1985	463	492	299	1064
1986	804	498	241	2099
1987	1015	809	3243	8870
1988	1223	1807	1849	6199
1989	604	2991	763	4788
1990	114	1953	772	3607
1991	68	2177	2018	7655
1992	412	2773	2043	5103
1993	158	2527	1449	3965
1994	90	1211	679	1561
1995	24	652	345	1322
1996	3	92	170	402
1997	2	201	173	1596
1998	0	52	142	845

Table 2: Comparison of dockside and observer estimates of landings, 1996-99. For the type of landing, BOTH indicates that there were estimates for both sources, DOCK indicates only dockside estimates were available and OBS indicates only observer estimates were available.

Year	Type	Trips	Dockside	Observer	Discard
1996	BOTH	973	687.0	584.5	73.6
1997	BOTH	980	1971.4	1784.3	128.5
1998	BOTH	711	1039.4	920.8	64.9
1996	DOCK	245	222.6	0.0	0.0
1997	DOCK	563	19.1	0.0	0.0
1998	DOCK	328	7.9	0.0	0.0
1996	OBS	48	0.0	6.7	4.3
1997	OBS	11	0.0	0.1	0.0
1998	OBS	10	0.0	0.1	0.1

Table 3: Summary of recommended yields, TACs and landings (t) for Hecate Strait, West Coast Vancouver Island, and Queen Charlotte Sound Pacific cod stocks.

Year	Recommended Yield	TAC	Landings	Comments
	Hecate Strait			
1999/00	600-1500	1000	476	as of Oct. 20
1998/99	No directed fishery	1000	846	
1997/98	L: 1075 H:2165	1620	1074	
1996	0	by-catch only	403	
1995	L: 1870 M: 3040 H: 5520	1870	1322	
1994	L: 1670 M: 3850 H: 7790	3850	1561	
1993	L: 3200 H: 6500	5100	3965	
1992	L: 600 M: 2800 H: 3800	3400	5103	
	West Coast Vancouver Island			
1999/00	Consider spawning closure	694	52	as of Oct. 20
1998/99	No assessment/ no advice	694	56	
1997/98	0	696	126	
1996	L: 694 H: 916	by-catch only	109	
1995	L; 1300 M: 2200 H: 5330	1300	652	
1994	L: 650 M: 2170 H: 5880	2170	1211	
	Queen Charlotte Sound			
1999/00	no advice	260	100	
1998/99	no advice	260	138	

1997/98	no advice	260	149

Table 4: Comparison of the depth distribution of the Hecate Strait survey area and the number of fishing sets made in each 10 fm. depth interval during the groundfish assemblage surveys. The final column gives the sampling rate in each interval.

10 fm. interval	Survey area (km^2)	Hours Fished	Hours per km^2
0	56	0	0
10	3064	54.7	0.018
20	1745	51.1	0.029
30	910	45.0	0.049
40	946	48.7	0.051
50	866	45.4	0.052
60	868	38.7	0.045
70	894	28.8	0.032
80	526	0.5	0.001
90	322	1.5	0.005
100	191	0.6	0.003
110	91	0.6	0.007
120	93	1.3	0.014
130	43	0	0
140	6	0	0

Table 5: Catches (kg) of Pacific cod by depth stratum during the Hecate Strait groundfish assemblage surveys.

	Depth Interval (fm.)							
Year	10	20	30	40	50	60	70	Total
	Total Catch							
1984	56	315	105	196	294	430	119	1515
1987	73	778	1050	43	1154	35	271	3404
1989	13	760	1718	599	128	46	74	3338
1991	6	155	253	403	646	130	18	1611
1993	5	373	91	306	77	80	165	1097
1995	5	965	386	215	147	62	27	1807
1996	7	694	476	314	167	221	17	1896
1998	1418	67	389	618	919	184	43	3638
	Sampled Catch							
1984	56	315	104	196	294	412	119	1496
1987	73	778	1050	43	1154	35	271	3404
1989	13	760	1718	599	128	46	74	3338
1991	6	155	209	334	278	85	11	1078
1993	5	373	91	296	77	80	165	1087
1995	0	944	309	147	91	0	0	1491
1996	5	5	475	293	156	184	0	1118
1998	1418	65	338	93	913	178	42	3047
	Un-sampled Catch							
1984	0	0	1	0	0	18	0	19
1987	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0
1991	0	0	44	69	368	45	7	533
1993	0	0	0	10	0	0	0	10
1995	5	21	77	68	56	62	27	316
1996	2	689	1	21	11	37	17	778
1998	0	2	51	525	6	6	1	591

Table 6: Catch rates (U, number per hour) and fishing effort by depth interval and year for cod in the Hecate Strait groundfish assemblage surveys. Missing information in 1995 and 1996 were because no sampling was done of these catches.

	Depth Interval (Fm.)						
	10	20	30	40	50	60	70
U< 40 cm							
1984	3	86	16	6	2	2	1
1987	4	153	90	29	39	3	4
1989	9	527	446	11	3	0	1
1991	2	49	21	3	4	2	0
1993	1	64	16	4	0	0	2
1995		141	20	1	1		
1996	2	335	45	11	1	0	
1998	2	39	228	11	3	4	2
Mean	3	174	110	9	7	2	1
U>= 40 cm							
1984	6	4	9	12	29	35	14
1987	11	115	155	5	173	12	54
1989	0	8	168	42	15	11	8
1991	0	1	22	69	33	11	4
1993	0	30	11	38	6	7	22
1995		65	32	12	10		
1996	0	0	26	16	12	8	
1998	94	2	2	39	46	20	6
Mean	16	28	53	29	40	15	18
N Tows							
1984	18	20	21	28	21	23	15
1987	15	12	12	11	16	8	11
1989	16	13	12	15	12	10	12
1991	16	13	15	12	20	14	7
1993	14	19	14	12	13	10	12
1995	17	18	16	17	12	13	9
1996	24	22	13	17	9	12	4
1998	14	11	15	15	13	10	8
Hours Fished							
1984	5.6	6.0	6.4	8.5	6.3	6.9	4.5
1987	5.0	3.9	3.9	3.5	5.7	2.4	3.7
1989	4.8	4.0	3.6	4.5	3.7	3.0	3.6
1991	8.0	6.5	7.3	6.0	10.0	6.9	3.5
1993	4.1	5.5	4.1	3.6	4.0	3.0	3.6
1995	8.5	8.3	6.5	7.3	4.8	5.5	4.0
1996	11.9	11.2	6.5	8.5	4.5	6.0	2.1
1998	6.8	5.7	6.7	6.8	6.4	5.0	3.8

Table 7: Comparison of annual simple and depth-stratified catch rates (kg/hr) of Pacific cod during the Hecate Strait groundfish assemblage surveys. The final 3 columns give the swept area estimate of biomass with the 95% confidence limits determined with bootstrapping.

Year	Simple Mean	Stratified Mean	Biomass (t)	Upper Limit	Lower Limit
1984	34.4	29.5	5642	9790	2906
1987	119.7	91.8	17547	31092	6272
1989	123.7	104.6	19996	37134	6291
1991	33.4	23.2	4440	7151	2352
1993	38.9	32.2	6155	9580	3346
1995	41.2	35.4	6762	13997	2467
1996	37.5	30.7	5861	10727	2237
1998	85.3	100.6	19243	42010	5392

11. Figures

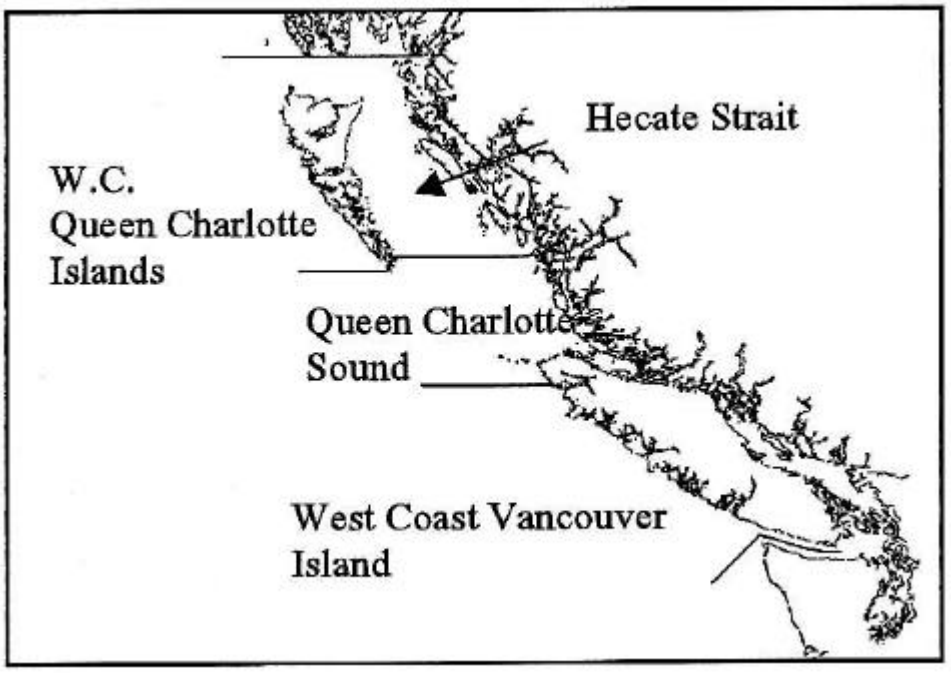

Figure 1: Pacific Cod stock areas on the BC coast.

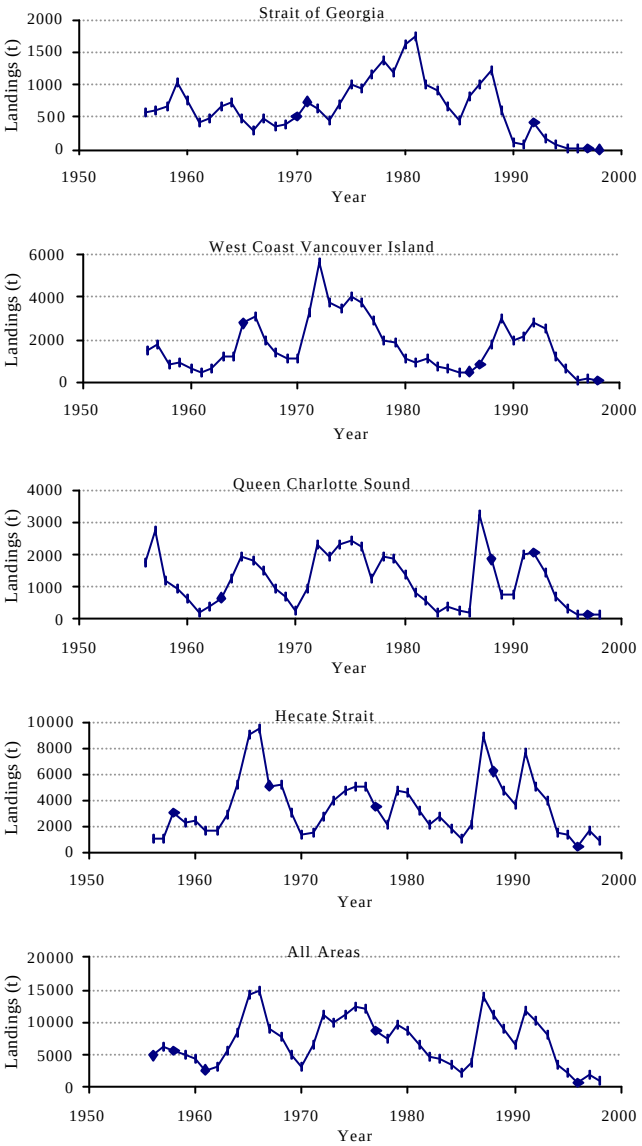

Figure 2: Annual landings of Pacific cod by stock area, 1956-98.

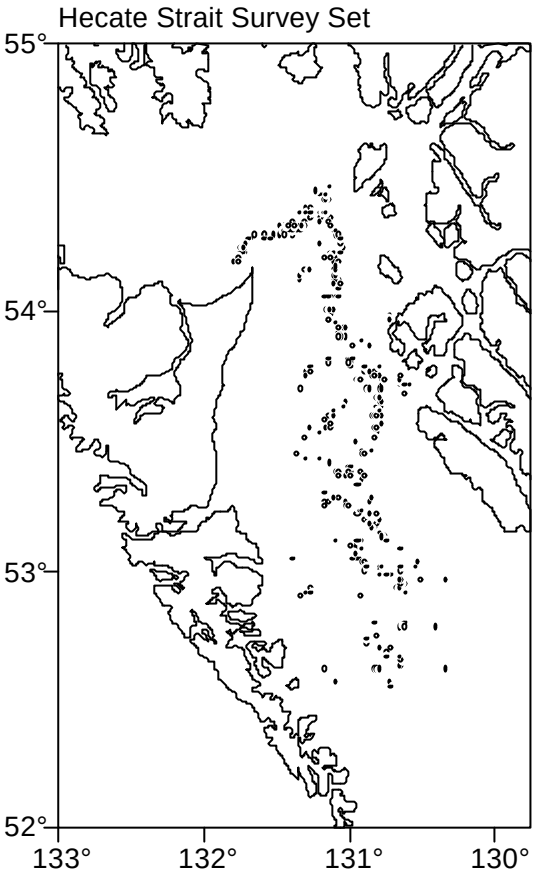

Figure 3: Map of fishing stations during the Hecate Strait groundfish assemblage surveys, 1984 – 98.

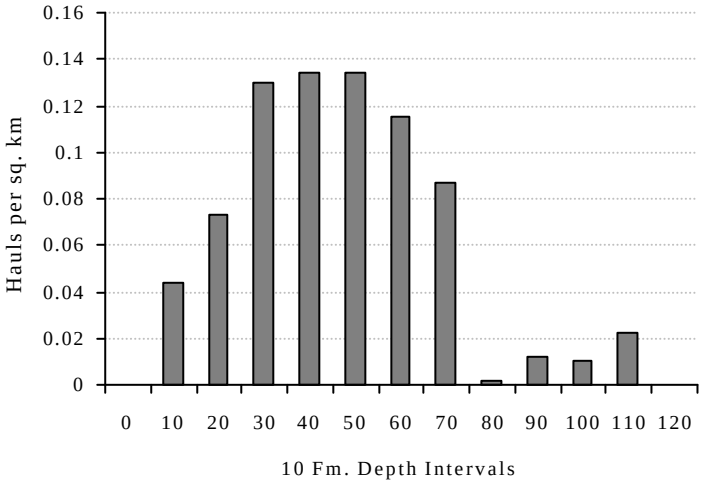

Figure 4: Sampling rate of the Hecate Strait survy by 10 fm. depth interval.

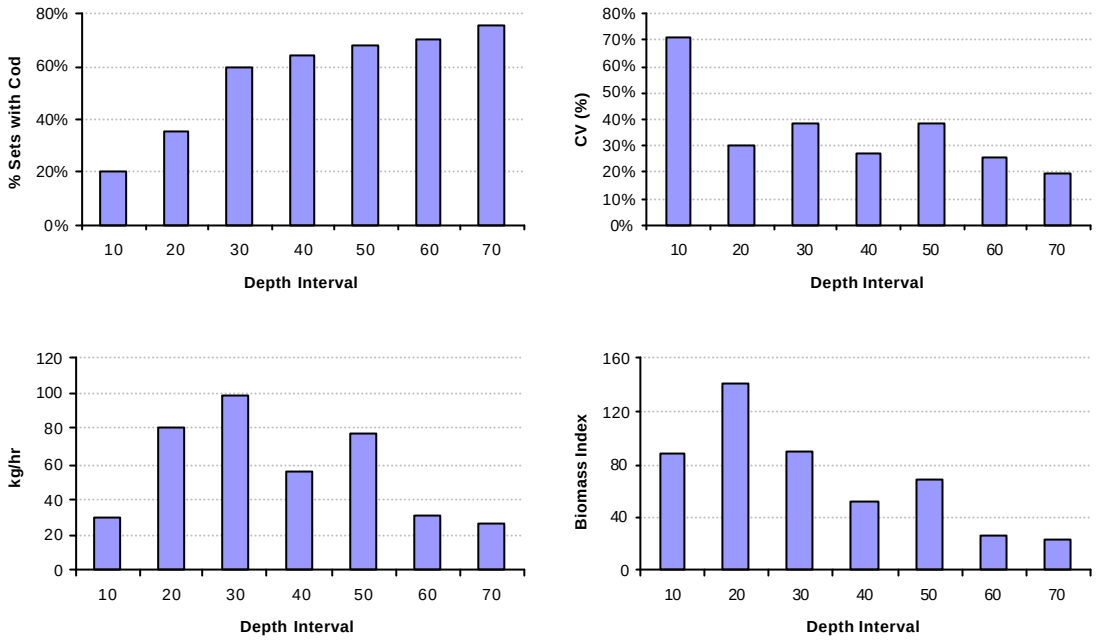

Figure 5: Indicators of cod distribution with respect to depth. Beginning at the upper left and going clockwise, the figures are for the percent of tows with cod, the coefficient of variation of mean catch rate, the biomass index (catch rate times area), and density, respectively.

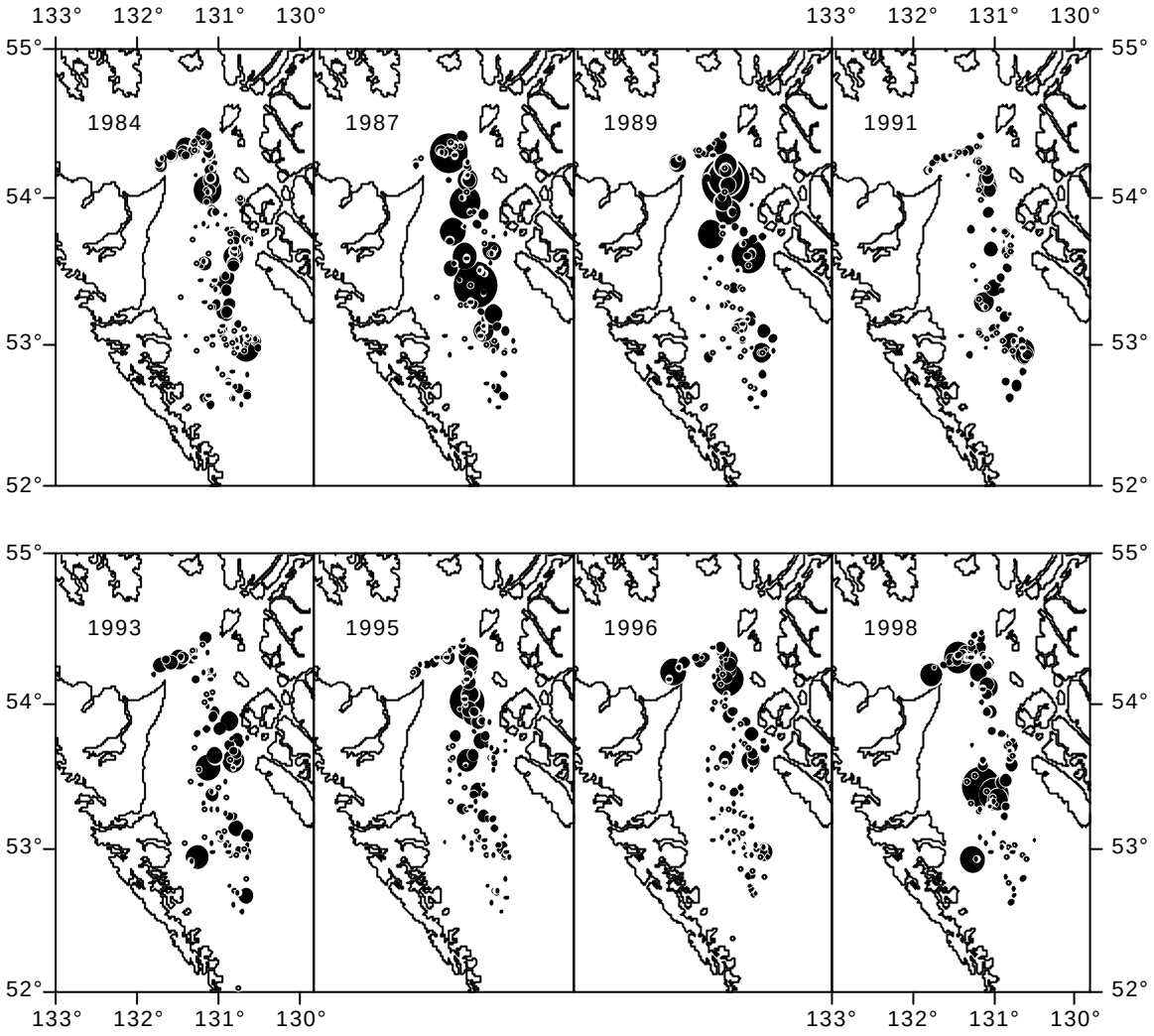

Figure 6: Catches of Pacific cod during the Hecate Strait groundfish assemblage surveys. The symbols represent catch rate (kg/hr), scaled to the area of the circle. The same scale is used for all maps.

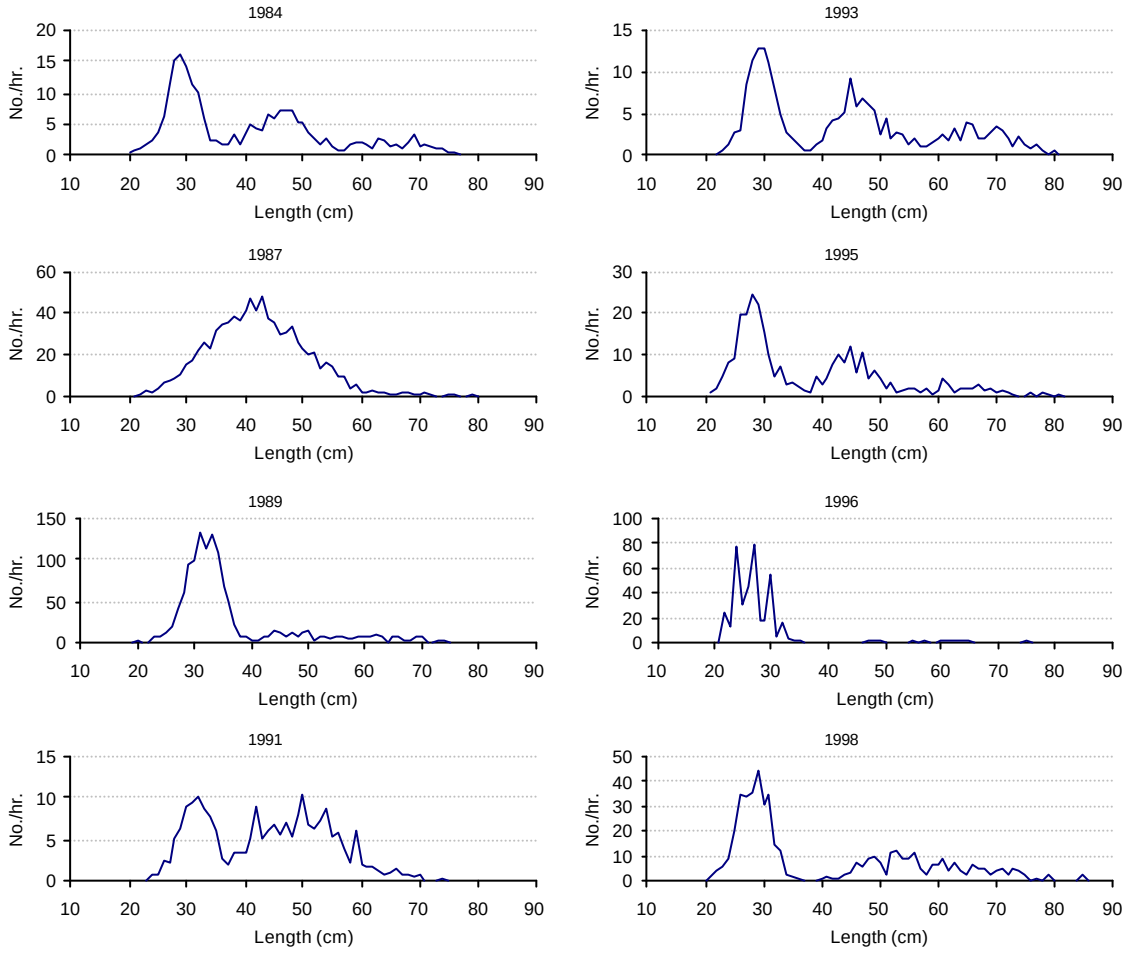

Figure 7: Length frequencies of Pacific cod caught in the Hecate Strait groundfish assemblage survey.

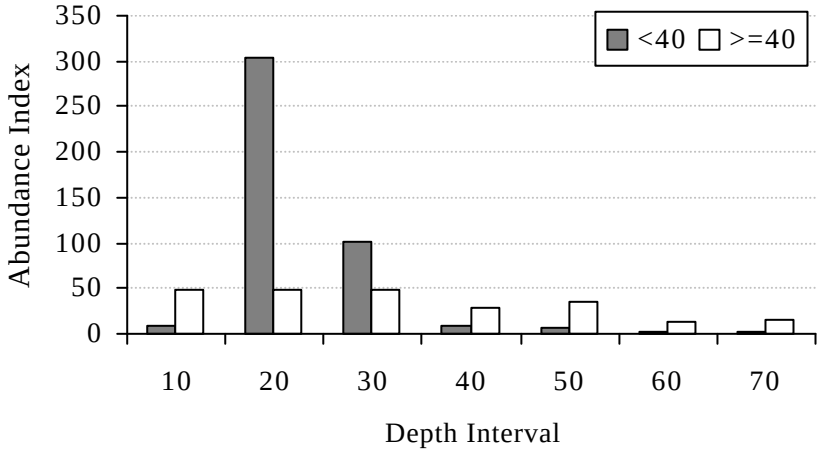

Figure 8: Average abundance of 2 size classes of cod in 10 fm. depth zones measured during the Hecate Strait groundfish assemblage surveys.

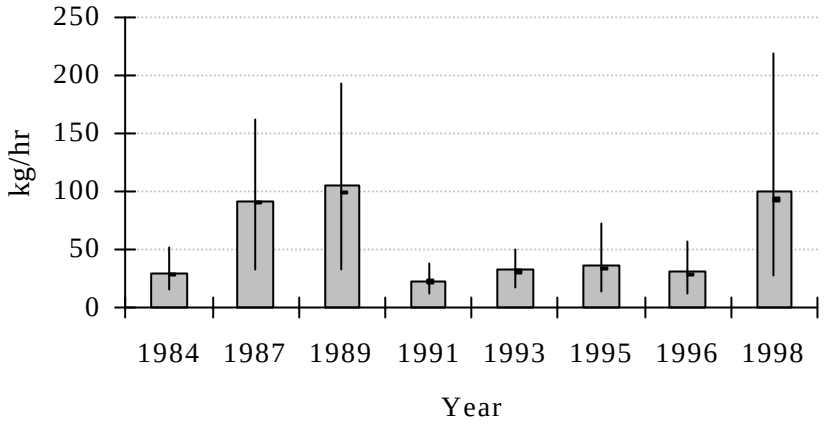

Figure 9: Annual depth-stratified mean catch rates (bars) of Pacific cod during the Hecate Strait groundfish assemblage surveys. The distributions of these means was estimated using bootstrapping. The vertical lines give the 95% confidence intervals and the tick marks indicate the medians.

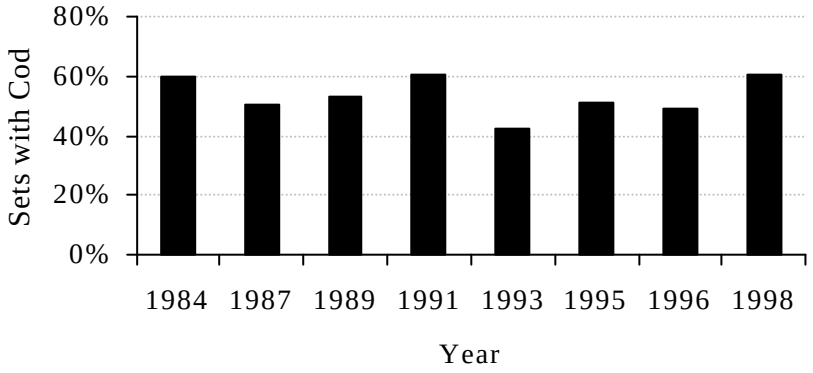

Figure 10: Annual proportions of sets with Pacific cod during the Hecate Strait groundfish assemblage surveys.

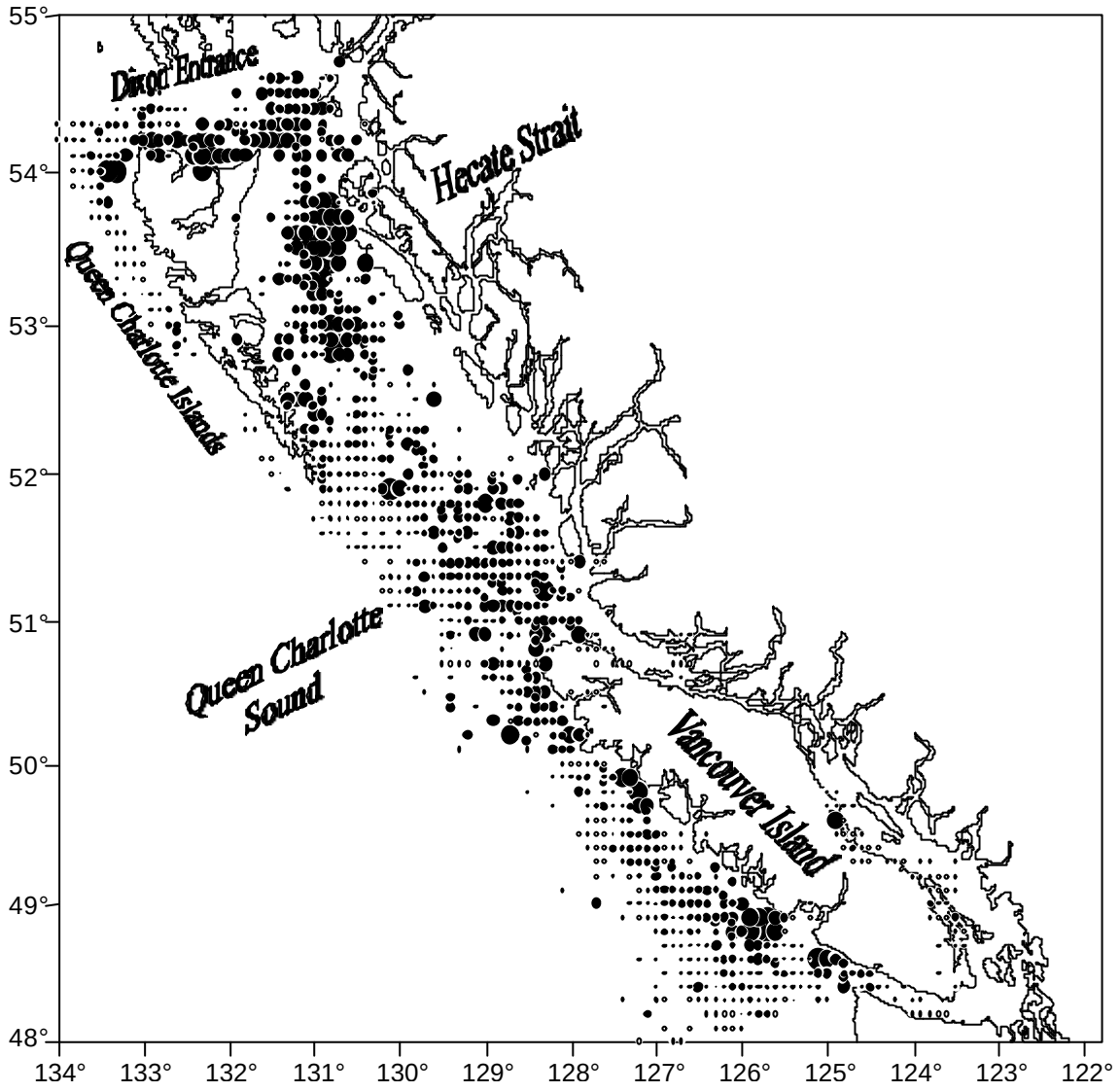

Figure 11: Distribution of Pacific cod catches by Canadian trawlers on the BC coast, 1996 – 1998. Open circles indicate locations where fishing occurred but no cod were caught. The area of the solid circles is proportional to the catch at that location. Source, DFO fisheries observers.

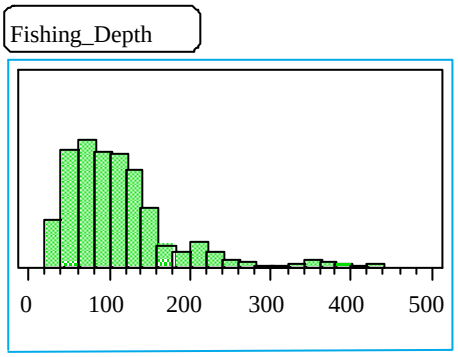

Figure 12: Depth (m) distribution of fishing sets by the groundfish trawl fleet recorded by fisheries observers deployed in statistical areas 5CD, 1996-1998.

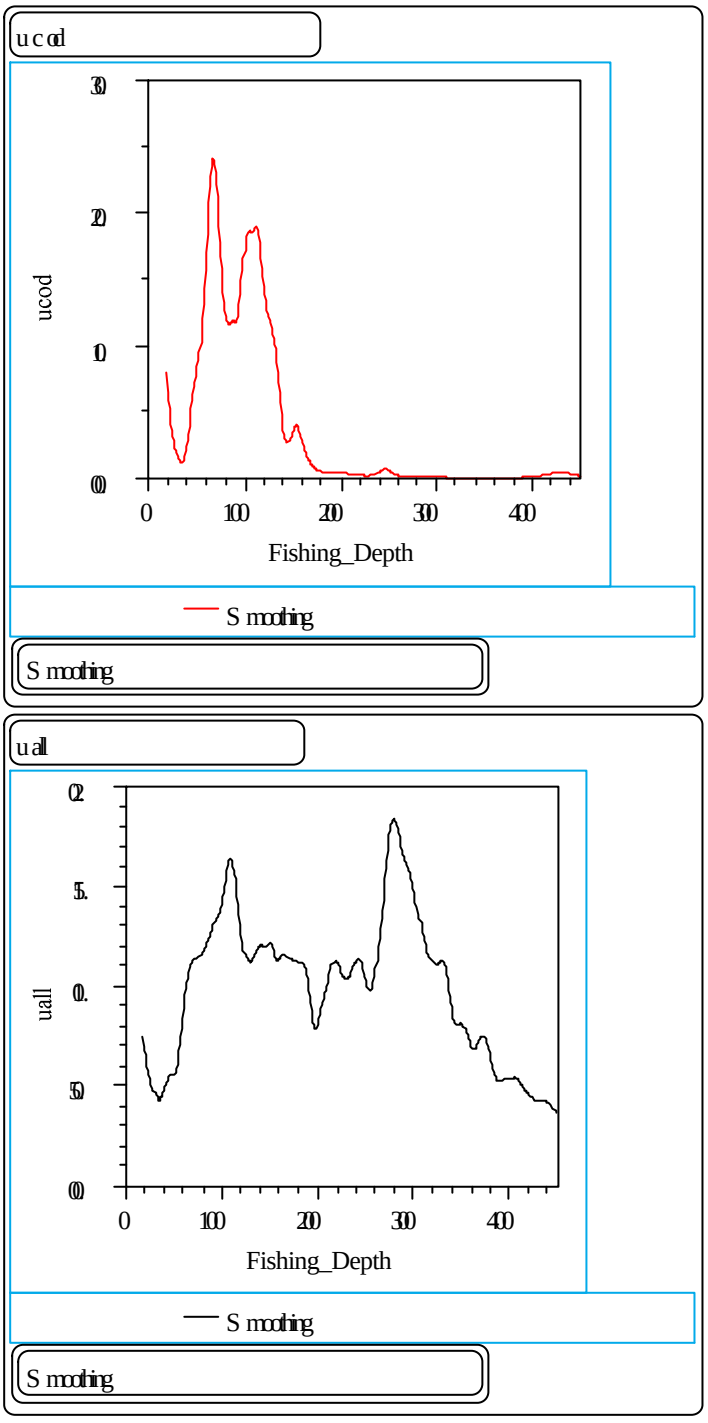

Figure 13: Catch rates (kg/hour) of Pacific cod (upper panel) and all species (lower panel) vs. fishing depth (m) by the groundfish rawl fleet in statistical areas 5CD. Data from the observer database.

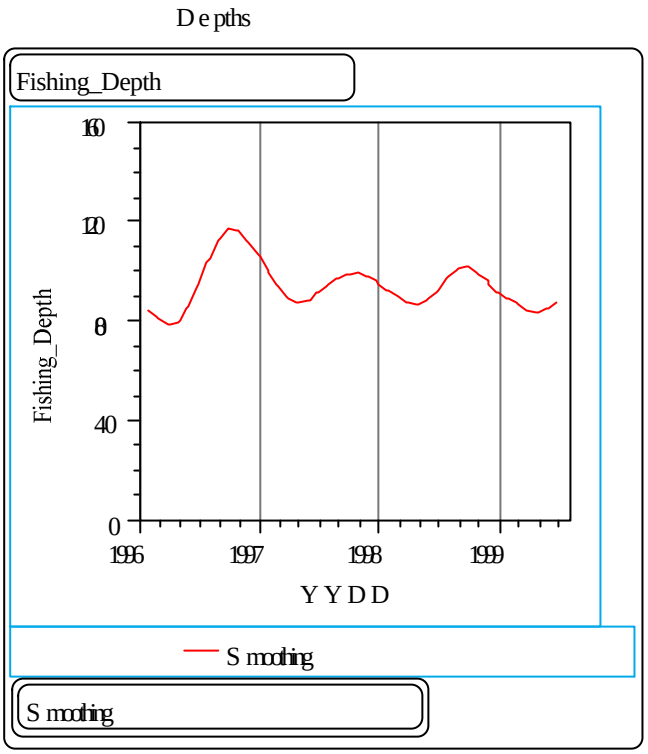

Figure 14: Seasonal variation in fishing depth (m) in statistical areas 5CD by the groundfish trawl fleet. The line is a spline smoother fitted throught the set-by-set observations. The data were limited to depths less than 200 m.

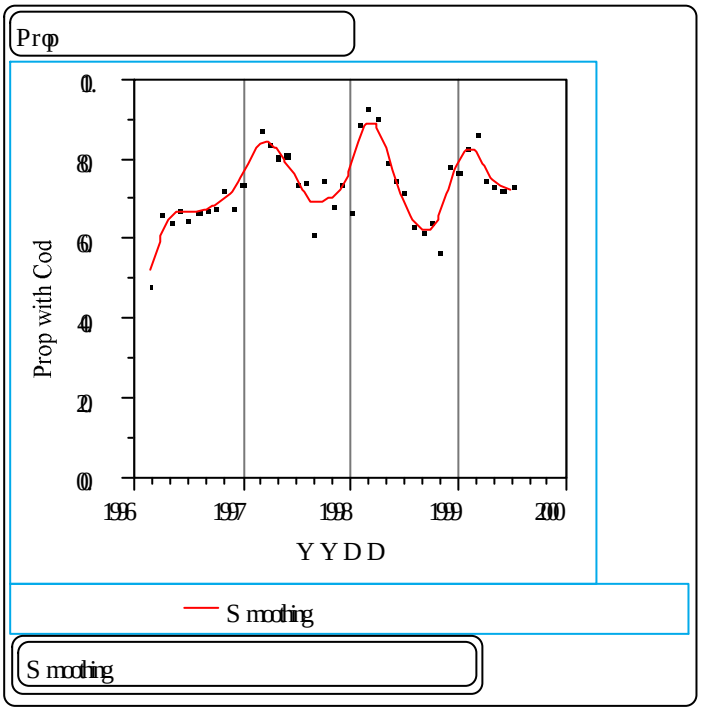

Figure 15: Seasonal variation in the proprotion of groundfish trawl fishing sets with cod in statistical areas 5CD. The data were limited to depths less than 200 m.

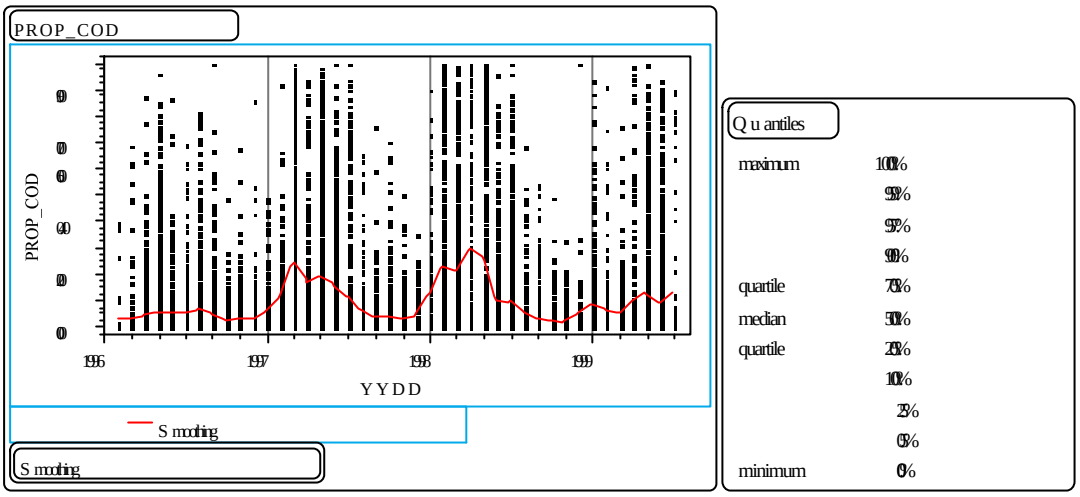

Figure 16: Seasonal variation (left panel) and the distribution of the set-by-set proportions of cod in sets by the groundfish trawl fleet, 1996-98. Each point represents a fishing set and the line is a spline smoother.

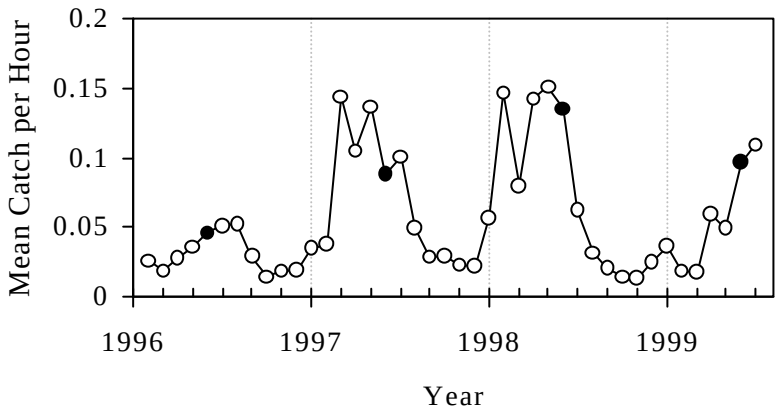

Figure 17: Monthly depth stratified mean catch rates of Pacific cod in Hecate Strait, 1996 – 1999. All sets in the area were included in the calculations.

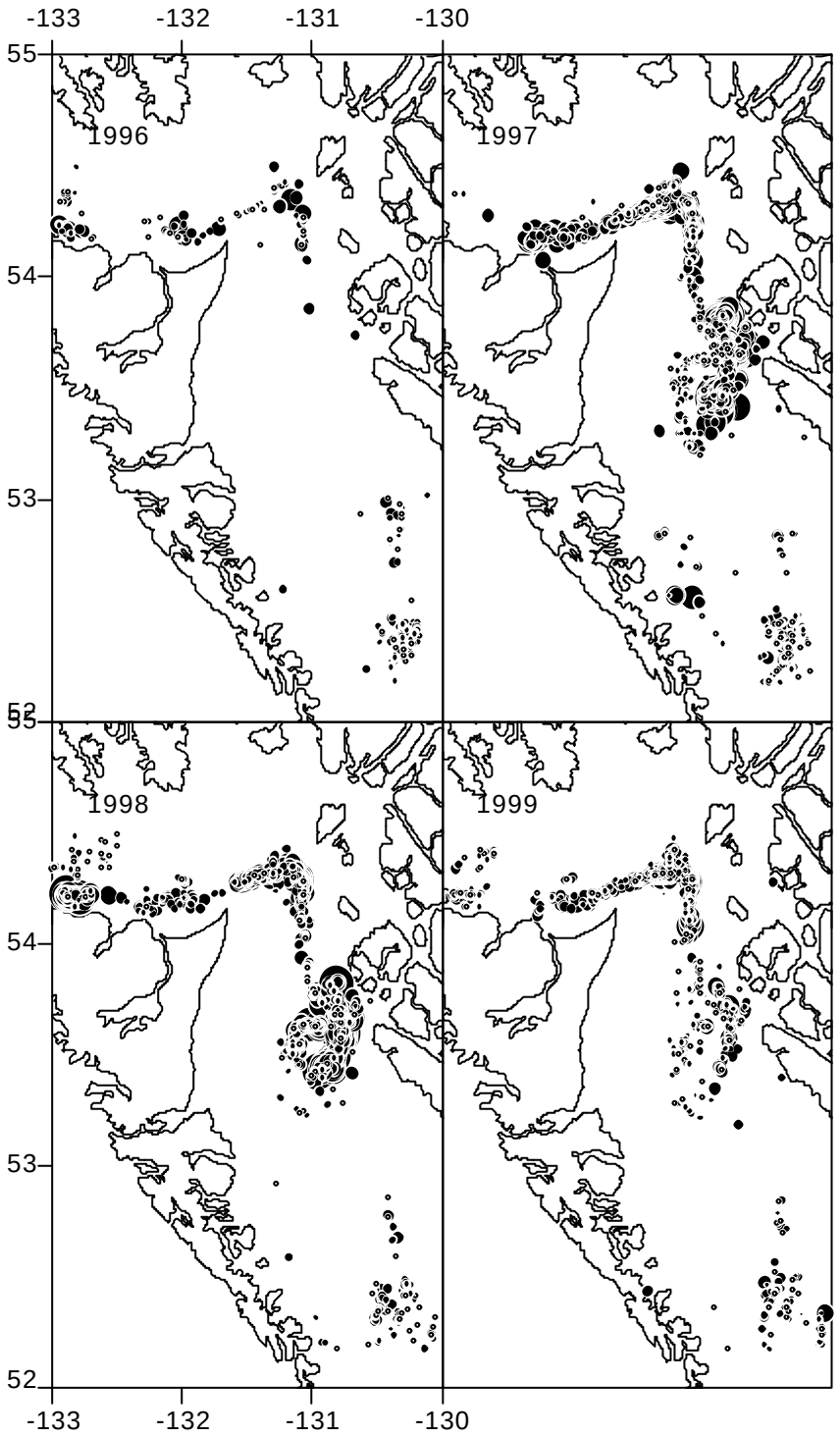

Figure 18: Fishing locations and catches of Pacific cod in Hecate Strait during January – March of 1996 – 1999. Open circles indicate sets where no cod were caught. The area of the black circles is proportional to the catch rate.

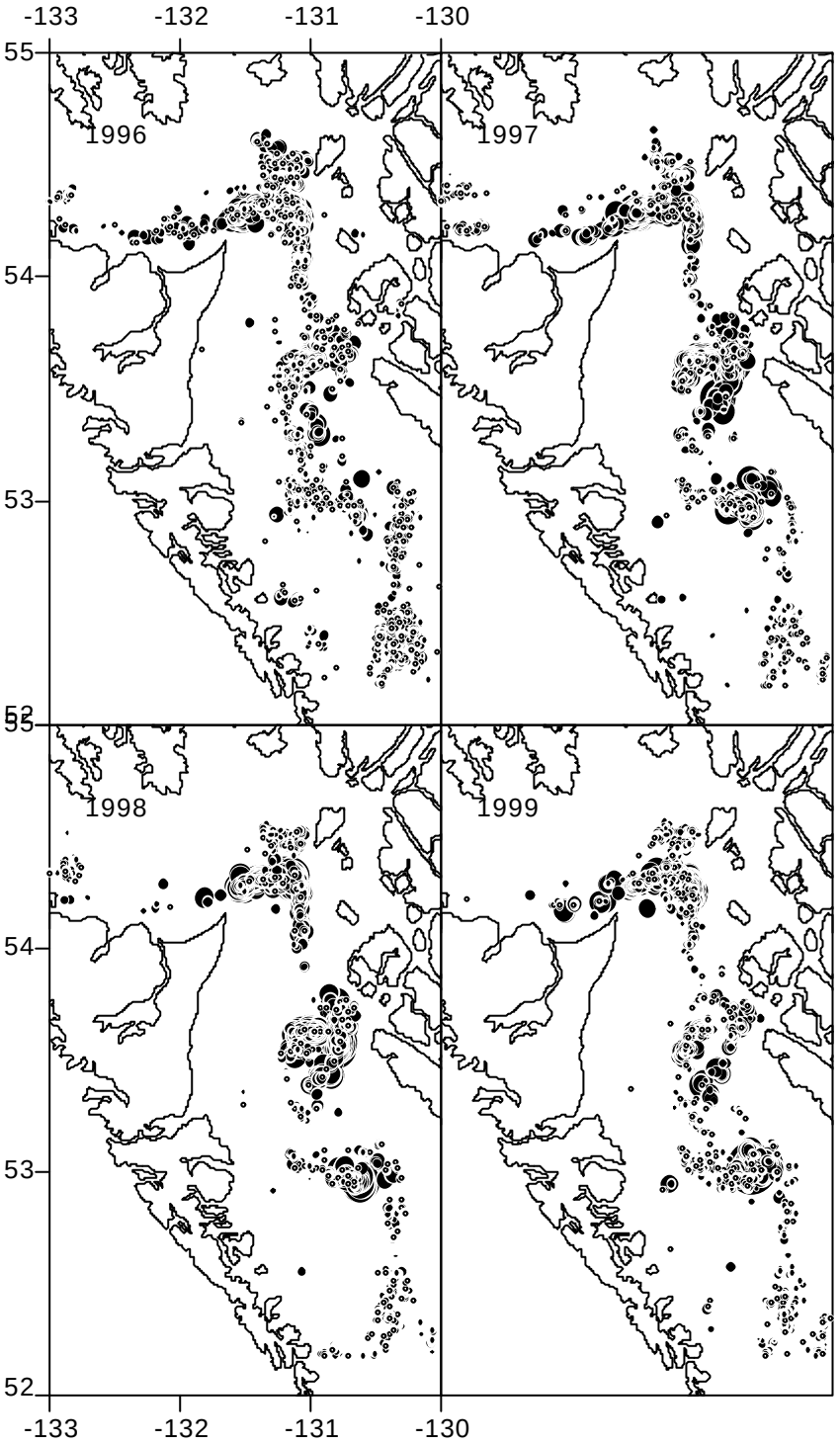

Figure 19: Fishing locations and catches of Pacific cod in Hecate Strait during April - June of 1996 – 1999. Open circles indicate sets where no cod were caught. The area of the black circles is proportional to the catch rate.

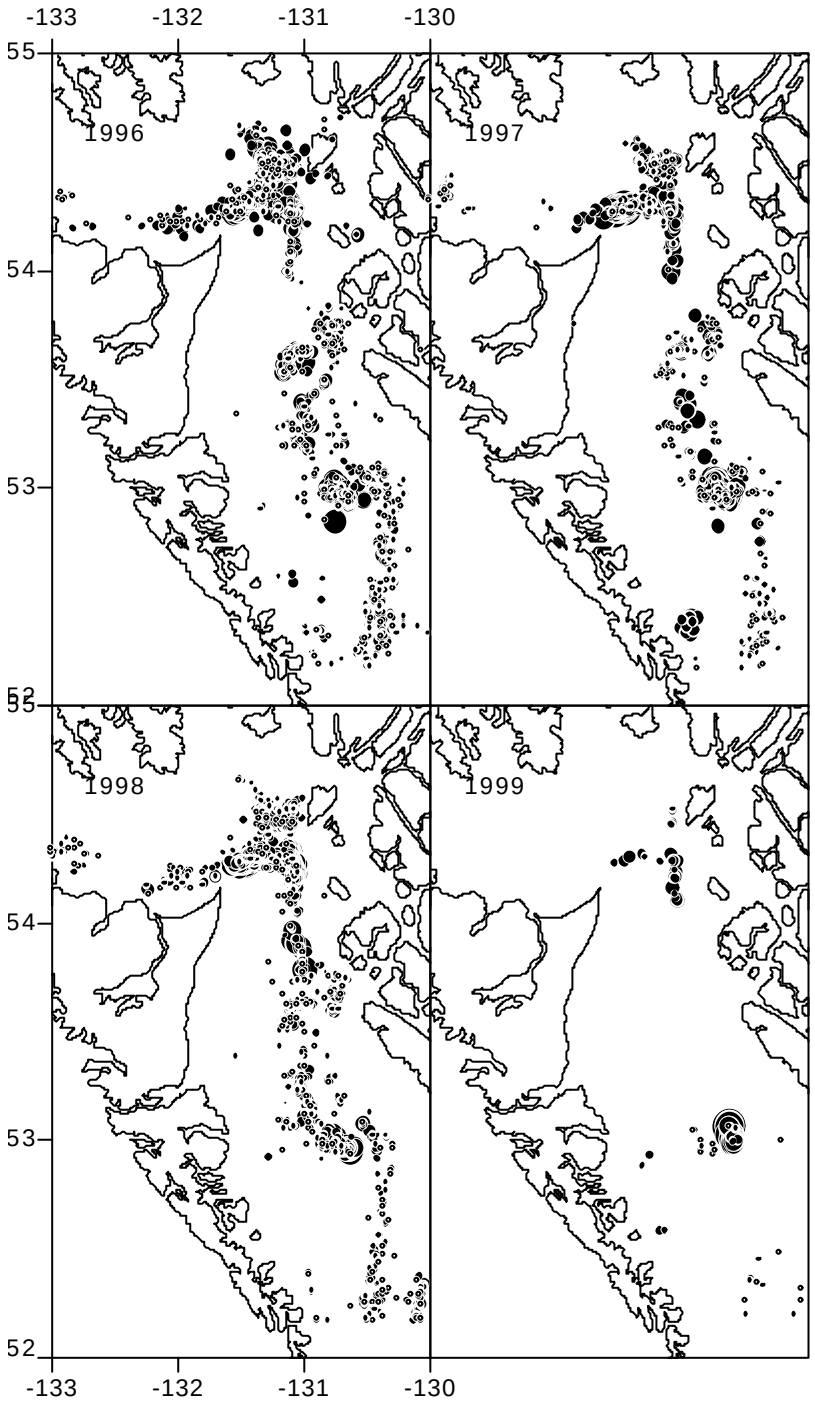

Figure 20: Fishing locations and catches of Pacific cod in Hecate Strait during July - September of 1996 – 1999. The low number of data points in 1999 is data only for early July were available at the time of writing. Open circles indicate sets where no cod were caught. The area of the black circles is proportional to the catch rate.

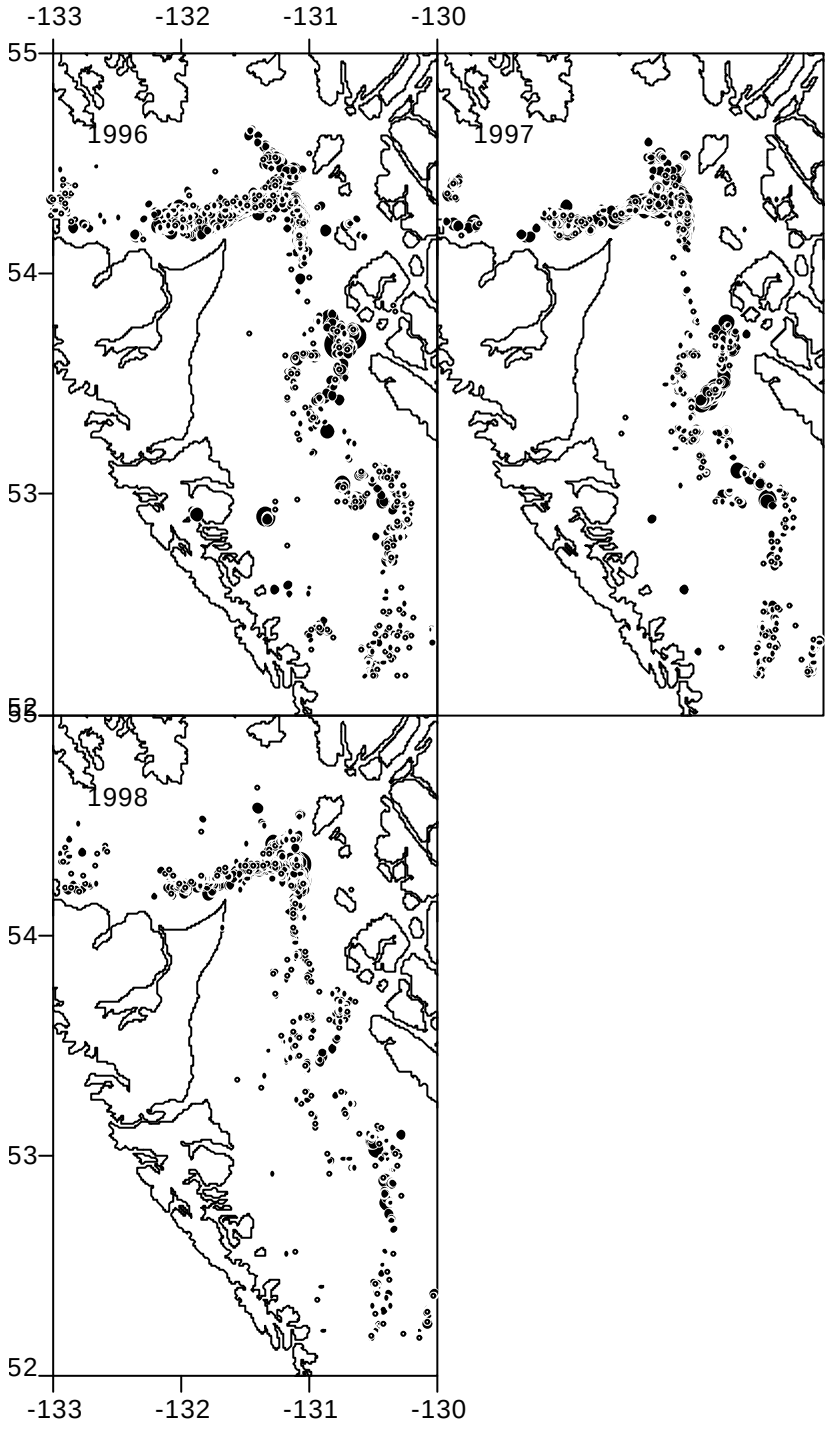

Figure 21: Fishing locations and catches of Pacific cod in Hecate Strait during October - December of 1996 – 1998. No data for 1999 were available at the time of writing. Open circles indicate sets where no cod were caught. The area of the black circles is proportional to the catch rate.

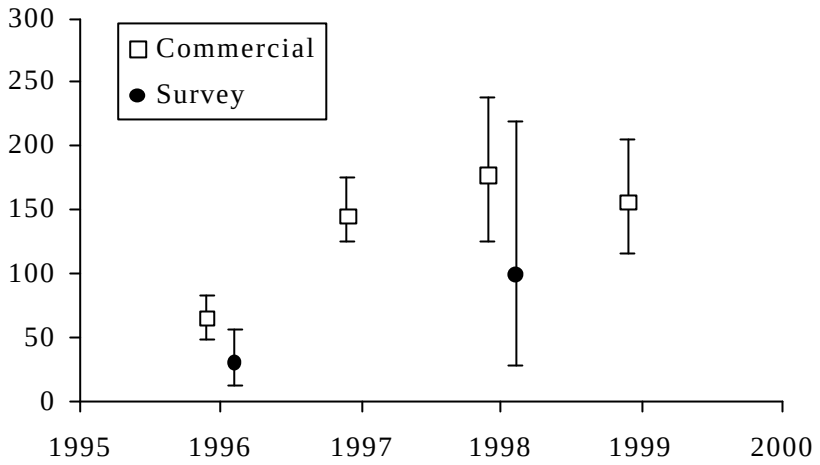

Figure 22: Comparison of mean catch rates (kg/hr) from commercial fishing and groundfish surveys in Hecate Strait during June. The error bars give the 95% confidence intervals of the means estimated with bootstraping.