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Assessment of Pacific Cod in Hecate Strait, Nov. 2000

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Abstract

Annual total allowable catches (TACs) were introduced for this stock in 1992. The 1992 landings exceeded the TAC by about 50%. Since then, the landings have been below the TAC with between 41% (1994) and 85% (1998/1999) of the TAC being landed. In 1999/2000, 58% of the TAC was landed and so far in the current fishing year, only 31% of the TAC has been landed (as of Nov. 2). Two stock biomass indices were calculated using commercial fisheries data. One covered the period 1954-1995 and was based on quarterly commercial catch per unit effort, an index of stock density ($t \cdot hr^{-1}$). The second index covered the period 1994-2000 and was based on a swept area method and used estimates of both density and area fished to produce an index of stock biomass. The indices indicated three periods of high Pacific cod biomass in area 5CD, the mid-1960s, mid-1970s, and the late 1980s. The last peak was followed by a decline to a minimum in 2000. The set-by-set database of fishing activity in area 5CD between 1991-2000 was examined for evidence that the fleet had changed fishing location and depth to avoid cod habitat thus biasing the relationship between the commercial indices and stock biomass. There was little evidence that fishing effort has shifted away from areas preferred by cod. In fact, there may have been an increase in fishing effort in Pacific cod habitat in recent years. A surplus production model was used to estimate key stock parameters including biomass trends, fishing mortality, and biological reference points (F_{msy} and B_{msy}). The results indicate that the stock is currently at an extremely low biomass, about 3% of the optimal level. Despite low catches in recent years, the current level of exploitation may not be sustainable and will certainly not allow any appreciable stock recovery. Substantial reductions in catch are required to allow stock rebuilding.

Résumé

Un total annuel des captures (TAC) autorisé du stock de morue du Pacifique a été introduit en 1992. Cette année-là, les débarquements ont dépassé le TAC d'environ 50%, mais depuis, ils sont inférieurs à ce dernier, se chiffrant entre 41% (1994) et 85% (1998-1999). En 1999-2000, 58% du TAC a été débarqué, mais au 2 novembre cette année, seulement 31% du TAC avait été débarqué. Deux indices de la biomasse du stock ont été calculés à partir des données de la pêche commerciale. Le premier, un indice de la densité du stock ($t \cdot h^{-1}$) couvrant la période 1954-1995, repose sur les prises commerciales par unité d'effort par trimestre. Le second, un indice de la biomasse du stock couvrant la période 1994-2000, s'appuie sur la méthode des aires balayées et fait appel à des estimations de la densité et de la superficie pêchée. Les indices révèlent trois périodes de pointe de la biomasse dans la zone 5CD : le milieu des années 60, le milieu des années 70 et la fin des années 80. Le dernier pic a été suivi d'un déclin qui a atteint un creux en 2000. Un examen de la base de données sur les activités de pêche trait par trait menées dans 5CD de 1991 à 2000, visant à déterminer si la flottille pêchait à des profondeurs et des endroits différents afin d'éviter l'habitat de la morue, aurait biaisé la relation entre les indices de la pêche commerciale et la biomasse du stock. Ceci n'a pas révélé que les pêcheurs ont abandonné les eaux que privilégie la morue. De fait, l'effort de pêche dans l'habitat de la morue du Pacifique peut avoir augmenté dans les dernières années. Un modèle de production excédentaire a servi à estimer les paramètres clés du stock, y compris les tendances de la biomasse, la mortalité par pêche et des points de référence biologiques (F_{msy} et B_{msy}). Les résultats révèlent que la biomasse du stock est présentement très faible, se situant à environ 3% du niveau optimal. Malgré les faibles prises des dernières années, le niveau d'exploitation actuel peut ne pas être durable. Il ne permettra certainement pas un rétablissement notable du stock, une réduction substantielle des prises étant nécessaire pour lui permettre de se rétablir.

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 (5CD). 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 vessel quota (IVQ) 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 (Haist and Fournier 1998) was based on a catch-at-length model. The assessment indicated that stock biomass reached an historic low in 1996 followed by a slight increase to 1998. 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 to the year 2000.

This assessment will deal only with the Hecate Strait stock. It begins with a description of the fishery since the mid-1950s. A detailed analysis of the spatial and seasonal characteristics of the fishery since 1994 is then presented. A catch per unit effort time series is presented for the entire time period and it is subsequently used as an index of abundance for the stock in an analytical assessment. Results of the groundfish assemblage survey in Hecate Strait from 1984-1998 were analyzed in detail by (Sinclair 1999). New data from the 2000 survey are presented here. A surplus production analysis of stock status is presented and the results are discussed in relation to biological reference points for management. Assessment uncertainties are discussed.

Description of the Fishery

Annual Landings

Historical landings data from 1956 – 1995 for area 5CD were obtained from Haist and Fournier 1998 (Table 1). Landings data for 1996 – 2000 were obtained from the PacHarvest database. Landings estimates appear in 2 forms in PacHarvest, set by set estimates by fisheries observers and trip by trip weights measured at dockside. The observers also provide precise fishing locations while the dockside weights 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 weighed coming off the vessel. The observers 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 allocate the trip landings to stock area.

The following approach was used to prorate trip landings to area. 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 annual total observer estimates were 10 – 15% lower than the dockside estimates (Table 2). Closer examination of the trip by trip comparisons indicated about half of the difference in the observer and dockside estimates of the total landings came from trips of 2.0 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 219t 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 subsequent years. 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 Pacific 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

It should be noted that it is not possible to prorate landings of type DOCK to stock areas.

Annual landings of Pacific cod show considerable variability (Fig. 1). There were major peaks in landings in the mid-1960s (9519 t in 1966), the mid-1970s (5036 t in 1975), in 1987 (8870 t) and 1991 (7655 t). The minimum annual landing was recorded in 1996 (397 t), and landings since 1994 have been among the lowest on record.

Discard weights are also recorded by observers. Totals of 50 t, 78 t, 34 t, and 42 t were reported in 1996-1999 respectively. The amount reported in 1996 is likely to be an underestimate of the total discarding since only 68% of the landings were observed in that year. In subsequent years more than 98% of the reported landings were from vessels with observers and thus the discard estimates for these years are much closer to reality.

Landings and TAC

Annual total allowable catches (TACs) were introduced in the Hecate Strait area in 1992. These were managed on a calendar year basis until 1996. Beginning with the 1997-98 period, the fishing year was changed to April 1 to March 31. The 1992 landings exceeded the TAC by about 50% (Table 3). Since then, the landings have been below the TAC with between 41% (1994) and 85% (1998/1999) of the TAC being landed. In 1999/2000, 58% of the TAC was landed and so far in the current fishing year, only 31% of the TAC has been landed (as of Nov. 2).

Input Data

The basic data on trends in abundance of Pacific cod in area 5CD are presented in this section. Data come from 2 main sources, the trawl fishery and the groundfish assemblage survey. The main objective is to develop a relative index of Pacific cod biomass in the 5CD area for the period 1954 – 2000 that can be used in further analyses of trends in stock biomass and management targets.

The use of commercial catch per unit effort (U) as an index of stock biomass has several potential pitfalls. It has been suggested that changes in the management regime from an unrestricted fishery (prior to 1992) to global TACs (1992-1995) and then to individual vessel quotas (1996 – present) and the increase in regulated mesh size has affected the underlying relationship between commercial U and stock biomass. Of particular concern is that fishermen will avoid a potentially limiting species early in the fishing season in order not to run out of one quota before catching all available quotas. Presumably this would be apparent as shifts in fishing location and depth as well as the frequency of occurrence of cod in individual trawl catches. Another potential problem is that U may not be proportional to stock biomass due to the schooling behaviour of fish and the ability of fishermen to target concentrations (Paloheimo and Dickie 1963, Clark 1974). This will be discussed in the Uncertainties section of this paper.

Commercial

Data Sources

GFCATCH for 1954-1995. (Rutherford 1999)
This database contains landings slips and logbook information for groundfish fisheries between 1954-1995. These two sources of information were combined using a pre-defined algorithm to form "fishing event" records. From 1954-1990, these events were sub-components of individual fishing trips. Aggregation was made to fishing locality and depth zone within a trip. Fishing events consisted of set-by-set entries between 1991-1995. And for 1994-1995, fishing locations were recorded by latitude and longitude instead of broader fishing localities. While it is possible to record discard data in

GFCATCH, it is generally accepted that the existing observations are underestimates of what actually occurred.

PACHARVEST for 1996- present

This database consists of fishing data collected by fisheries observers and landings data collected by dockside monitoring. No attempt is made to combine these two data sources, this task is left to individual analysts. The fishing events are recorded set-by-set with position recorded as latitude and longitude. Catch by species is recorded for each set, and designation is made between kept and discards. It is possible to match the observer estimates of trip catch with the dockside weighouts. The weighouts may be pro-rated to stock area using the observer estimates (algorithm described above). Observers have been deployed on all groundfish trawl fishing trips, except those directed at hake, since July, 1996.

GF_BIO 1998-2000

This database contains size frequency samples collected by port samplers and by observers.

Comment on Data "Qualification"

Data on catch and fishing effort are available from 1954 to the present for the trawl fishery in Area 5CD. Catch per unit effort indices of cod biomass have been used in all previous analytical assessment of this stock. The indices have been calculated from a subset of "qualified" fishing events. For example, Haist and Fournier (1998) used the criterion that cod had to be at least 10% of the total nominal catch in the fishing event (e.g. sub-trip or fishing set depending on the aggregation of the data). The index was calculated by taking the median "qualified" event specific U for a given time period, which could have been a year or quarter. U data are highly skewed and taking a median will reduce undue influence of large observations on the index.

The "qualification" criterion will bias the index in three ways. First, all events with 0 catch will be eliminated from the index. This will bias the index upward since 0 catches can only indicate an absence of cod and nothing is done to eliminate observations that indicate high abundance of cod. Second, the qualification criterion will act differently depending on the level of data aggregation. From 1954-1990 the catch and effort data were aggregated by area and depth before entry to the database. Several fishing sets were included in the fishing event. As long as 10% of the total nominal catch was cod, the event would qualify for the index. Several catches with less than 10% cod could be included in the event U. With the set-by-set data that have been collected since 1991, all sets with less than 10% cod would be eliminated from the index. If one were to aggregate the qualified sets to the same level as had been done previously, the resulting U index would be higher than if the data had been aggregated then qualified. Third, the number of qualified events depends on the relative biomass of cod, not its absolute biomass, the quantity of interest. The absolute biomass of cod could remain constant but the number of qualified fishing events would change as the abundance of all other species changed.

In the following analysis I have used the sum of catch divided by sum of effort as the density index. This is an effort-weighted mean of the individual observations and tends to dampen the influence of large U values that come from observations with relatively little effort. All data are used to calculate the index. This could be problematic if the fishery shifts to habitat not occupied by cod. Maps of the spatial distribution of the fishery and plots of trends in mean fishing depth were examined to address this issue.

Spatial Distribution of the Fishery and Cod Catches

The groundfish trawl fishery in Areas 5CD occurs from Dixon Entrance, through Hecate Strait and Moresby Gully (Fig. 2). A large number of species are exploited and each is distributed widely throughout the area. Pacific cod ranked second in total catch during 1996-2000 in this multispecies groundfish fishery. Other species in the top 6 were arrowtooth flounder, rock sole, walleye pollock, English sole, and Dover sole respectively. The spatial and depth distribution of each species overlaps resulting in highly mixed catches.

The distribution of Pacific cod over the fishing grounds and how this varied seasonally was inferred from plots of catch per unit effort, i.e. density (U $kg \cdot hr^{-1}$) for the period 1994-2000. Catch and effort were summed by 0.025 degree rectangles of longitude and latitude based on the start position of individual tows. The ratio of sums was used as density measure. Monthly and quarterly plots were examined and the quarterly plots are presented in Fig. 3. No attempt was made here to distinguish among which species were sought.

Cod density was highest in the first and second quarters with the highest values on the White Rocks, Bonilla, and Horseshoe grounds. There were also relatively high values along the southern edge of Dixon Entrance and at Two Peaks during these periods. Cod density was very low or cod were absent from catches at depths over 150m in all areas. It should be noted that the Horseshoe and Reef Island grounds have been closed since 1996 during January 1 – April 15 to reduce harvests during the spawning season. The high densities in these areas shown in Fig. 3 were from 1994 and 1995. Cod density was considerably lower over the entire fishing area in the third and fourth quarters. During the third quarter, the highest density values were from the Two Peaks and Horseshoe areas.

The same data were plotted by year and quarter along with the distribution of fishing effort. These may be viewed in the media clip in Fig. 4. The spatial pattern of fishing was similar in each year. One exception was the absence of fishing effort in the closed area at Horseshoe and Reef Island in the winter from 1996-present. A second exception was that fishing effort was very low in the fourth quarter of 1995 and the first quarter of 1996, corresponding to the implementation of the IVQ program for this fleet. The seasonal pattern of high density in the first 2 quarters and low values in the third and fourth quarters was repeated in all years. A second pattern which appears in these maps is an easterly shift in cod density in the most northerly area, through Dixon Entrance to Two Peaks. This suggests a migration into the fishing area in the winter and spring. This apparent migration does not appear to continue in a southerly direction around Two

Peaks and toward White Rock. If anything, it appears that there may be movement from the mainland coast into the White Rock and Bonilla grounds in the winter and spring. A third pattern which emerges from the plots is a decline in cod density over all grounds in all seasons. This will be examined in more detail in the following section.

Depth Distribution of the Fishery and Cod Catches

The cumulative distributions of total fishing effort and cod catch were calculated with respect to depth. The middle 80% of fishing effort was concentrated between 40 – 240 m depth while the middle 80% of cod catch came from the 50 – 125 m depth range (Fig. 5). Trends in density, frequency of occurrence of cod, and mean depth fished were compared among depth zones. Three zones were defined for these comparisons, shallow (<50m), mid (50 – 125m), and deep (>125m). If cod were avoided in recent years due to restrictive quotas, one would expect the frequency of occurrence to decline and the fishery to shift away from depths favoured by cod.

The frequency of occurrence of cod in individual fishing sets declined from about 60% in 1991 to 25% in 1995 in the shallow depth zone (Fig. 6). There was a sharp increase to around 60% in 1996 and the value has remained steady since then. In the mid-depth range, there was a slight decrease in the frequency of occurrence from 1991 to 1995 (70% to 60%), followed by an increase to 80% in 1996 and a slight decline since then. The trend in frequency of occurrence in the deep zone was similar with a decline in the 1991 – 1995 period, then an increase to relatively high and stable values from 1996 to 2000. Overall, cod were present in 65% of the fishing tows in 5CD since 1996 and this was more than in the mid-1990s.

The annual average fishing depth was very stable in the mid depth zone (Fig. 7). Similarly, there was little variation in the mean depth fished in the shallow depth zone. There was an increase in mean fishing depth between 1992 and 1996 in the deep zone, from 160 – 220m.

The distribution of fishing effort among the 3 depth zones varied more than the average depth fished in each depth zone (Fig. 8). Fishing effort increased from 9400 hours in the mid-depth zone in 1991 to 11,800 hours in 1993. Effort declined to a minimum of 3300 hours in 1996 followed by an increase to 5600 hours in 1997-1999. The value for 2000 represents only half the year. There was an increase in fishing effort in the deep zone from 4200 hours 1991 to 7200 hours in 1995. This declined to 2900 hours in 1997 and was relatively stable in 1998 and 1999. In the shallow zone, fishing effort declined steadily from 8000 hours in 1991 to 1100 hours in 1998. There was a small increase in 1999. On a percentage basis, there were declines in effort in the shallow and mid-depth zones from 1991 to 1996, but the trend was reversed in 1997. From 1997 – 2000, the percentage of fishing effort in the mid-depth zone in 5CD was higher than in the previous years and the relative distribution of effort among depth zones was stable.

The trend in density in the shallow and mid depth zone were similar with a decline in the early 1990s , a slight increase in 1997-98, followed by a decline to 2000 (Fig. 9). The decline was larger in the shallow zone. Density in the deep zone was considerably lower than in the other 2 depth zones. The lowest values were recorded in 1996, 1999, and 2000. The low density values recorded in recent years in all 3 depth zones were accompanied by the highest frequency of occurrence of cod in individual fishing sets.

The shift in fishing effort among depth zones may influence the overall average density, even if there were no change in abundance. I computed the magnitude of this effect by first calculating the mean density in each depth zone over the period 1991-2000, then calculating an effort-weighted mean density (S_t) using the observed annual proportions of fishing effort in each depth zone.

$$S_t = \frac{\sum_i E_{it}\overline{U}_i}{\sum_i E_{it}}$$

Where E_{it} is the effort in zone i in year t and $\overline{U}_i$ is the mean density in zone i over the time period. The time series S_t is plotted with the annual mean density (U_t) in Fig. 10. The magnitude of change in the mean density is far greater than what could have been caused by the observed shifts in fishing effort among depth zones.

In summary, there is little evidence that fishing effort has shifted away from areas preferred by cod. In fact, there appears to have been an increase in fishing effort in Pacific cod habitat. The frequency of occurrence of cod in individual fishing sets was higher in the period 1998-2000 than in the mid-1990s. Of the total fishing effort in area 5CD, a higher proportion has been expended in the mid depth zone, i.e. that preferred by cod, in recent years than in earlier years.

Fishing Effort in Area 5CD

As mentioned above, Pacific cod are taken as one component of a multispecies groundfish fishery in Area 5CD. While fishermen can "direct" their fishing effort at one species or a subset of the available species in the area, the species composition of the individual fishing tows is relatively rich. Cod are taken in a high percentage of all tows and are vulnerable to fishing over 90% of the depth range fished. It is informative, therefore, to examine the overall trend in fishing effort in area 5CD as it would reflect, in general, the exploitation trend of Pacific cod, and several other groundfish species, in the area.

Not all catch in area 5CD was accompanied by fishing effort data. Therefore, an adjustment was made to the reported fishing effort data. The adjusted effort was the product of reported U and the sum of reported catch with and without effort. The reported and adjusted time series are shown in Fig. 11. The largest adjustment was 20 % of the total and the average adjustment was 10%. All catch had effort information in the years since 1996 when all trips were covered by observers.

The overall trend in fishing effort in area 5CD was upward until 1993. There were three peak periods, in the mid-1960s (12,000 hours), around 1980 (16,000 hours), and the early

1990s (29,000 hours). There was a five fold increase in fising effort from 1986 – 1993. This was followed by a decline to 10,000 hours in 1996, and fishing effort has remained at that level to 1999. This corresponds to the long term average.

Trend in Cod Density

There are strong seasonal and annual trends in area 5CD Pacific cod density. Similar trends are evident in both the "total" and "qualified" U (Fig. 12). An important difference is evident in the final years. The total index had values close to the lowest seen while the qualified index indicated an increase. This is likely an artifact of the qualification process as all the 0 and low cod U data were eliminated from the "qualified" index.

In order to obtain an annual density index, these quarterly data were analyzed with a multiplicative model (Gavaris 1980) of the form

$$\ln U_{qt} = \boldsymbol{b}_0 + \boldsymbol{b}_1\mathbf{Q} + \boldsymbol{b}_2\mathbf{T} + \boldsymbol{e}$$

where U_{qt} = catch per unit effort in quarter q and year t

$\mathbf{Q}$ = a matrix of 0 and 1 to distinguish quarters
$\mathbf{T}$ = a matrix of 0 and 1 to distinguish years

The parameter vector $\boldsymbol{b}_2$ was taken as the annual $\ln$ U index. The parameter vector $\boldsymbol{b}_1$ was taken as the U multiple for season. Antilogs of the least square means of the parameter vectors were used as the respective indices.

Both main effects were highly significant (Table 4). Three major peaks occurred in Pacific cod density (Fig. 13), in the mid-1960s, the mid-1970s, and the late 1980s. It was interesting to compare these peaks with those in total fishing effort (Fig. 13). Fishing effort peaked after the peaks in cod density. Furthermore, the high U values in the mid-1970s and late 1980s occurred after total effort declined. These trends would be expected when the fishery is having a significant effect on stock biomass.

The seasonal least square means are presented in Fig. 14. U was highest in the first quarter and lowest in the fourth.

Trend in Biomass

Catch per unit effort is a density measure, $t \cdot hr^{-1}$ in this case. When U is treated as a biomass index, an assumption is made that the area over which this density is measured remains constant from year to year. An alternative approach is to calculate both the density and the area fished. The product of density and area would be a more accurate index of biomass, provided the total area occupied by the stock is sampled (Beverton and Holt 1957). This is the basis of so called swept area measures of fish abundance and biomass (Kulka et al. 1996, Walters and Bonfil 1999, Schnute et al. 1999). The availability of precise fishing location data from logbooks (1994-95) and observers (1996-2000) allows such calculations to be done.

The approach taken here was to first divide area 5CD into a grid of equally sized rectangles. The effort weighted mean catch per unit effort (U t·hr-1) in each rectangle was calculated and assumed to represent the mean fish density in the grid. The fish biomass in the grid was calculated as the product of U, grid area (A km^2), and the number of hours needed to fish 1 km^2 (C $hr \cdot km^{-2}$).

$$B(t) = U(t \cdot hr^{-1}) \cdot A(km^2) \cdot C(hr \cdot km^{-2})$$

For the purposes of these calculations, it was assumed that 1 hour of trawling covers 0.05 km^2 of bottom and that the coverage rate is 20 $hr \cdot km^{-2}$. This corresponds to the dimensions of the trawl used in the Hecate Strait groundfish assemblage survey. Provided one fishing set was made in a grid, it was counted as being fished . The total area fished was assumed to be product of the grid area and the number of grids with at least one fishing set. The total biomass in the area was calculated as the sum of biomass estimates for each grid fished.

Clearly the assumed value of C is critical to the absolute biomass estimate. It is clear that the area covered by the average commercial trawl is larger than the area covered by the research trawl. However, since C is a scalar quantity, any error in its assumed value will have a proportional effect on B, thus affecting the absolute value but not the trend. A more important consideration is the differences in catching power of nets designed for different species, e.g. a flatfish trawl vs. a cod trawl. I was unable to make adjustments for net used because the relevant data were not recorded.

What also became evident was that the magnitude of the biomass index depended on the size of rectangle used. Five rectangles were used, 0.025, 0.05, 0.1, 0.2, 0.5, and 1.0 degrees of latitude and longitude on each side. The area of each rectangle was calculated assuming the rectangle was located at 53° N latitude (Table 5). Quarterly biomass indices were calculated for each rectangle size and the estimates from adjacent rectangle sizes were compared with linear regression. If the biomass index was independent of the rectangle size, one would expect the regression line to pass through the origin and the slope to equal 1.0.

The only case where the biomass estimates were of similar magnitude was between the 1.0 and 0.5 degree rectangles (Table 5). For progressively larger rectangle sizes, the biomass estimates approximately doubled as the rectangle size increased by a factor of 4. The reason for the increase was because the total area fished estimate increased as rectangle size increased. This is the result of the non-random distribution of fishing set locations. But, the mean fish density ($t \cdot km^{-2}$) was conserved. Nonetheless, the biomass time series were highly correlated indicating that the trend in biomass was consistently estimated regardless of rectangle size. The index from the smallest rectangle size was used in subsequent analyses.

It is clear that the biomass index for the last quarter of 1995 and the first quarter of 1996 is unreliable due to a lack of fishing effort (Fig. 15). What little fishing effort was reported in this period was concentrated in Dixon entrance and Moresby Channel. It is no coincidence that the cod biomass estimates for these 2 quarters are the lowest in the series, and this emphasizes the importance of full area coverage when using this swept area estimator. With the exception of these two quarters, the area over which cod were caught varied between 800 – 2200 km^2. There was little seasonal variation in the area estimates. The cod biomass estimates showed much greater variation from a low of 500 t in the last quarter of 1998 to 5600 t in the first quarter of 1994. The biomass index showed a strong seasonal pattern with the highest estimates in the first half of the year.

An annual biomass index was estimated from the quarterly estimates using the same type of multiplicative analysis as was used for the historical CPUE series. Both year and quarter main effects were highly significant (Table 6). The year main effect showed a declining trend from 1994-2000. Most of this decline occurred in the last 2 years (Fig. 16). The quarter main effect was somewhat different than in the historical analysis. For the period 1994-2000, the highest biomass index was in the second quarter where in the historical analysis the highest estimate was in the first quarter. The decline in the index between the second and fourth quarters was also higher in the more recent analysis, indicating a greater seasonal decline in relative biomass.

Size composition of Commercial Landings

The size composition of commercial landings of Pacific cod were examined for evidence of improved recruitment. Quarterly length frequencies for 1998 – 2000 were compared to those from 1987, the last time a significant year-class appeared in the stock. At sea observers collect “Keeper” and “Unsorted” samples. For this analysis, only “Keeper” samples were examined to be consistent with the port sampling done in 1987. There are no 1987 samples available that would be equivalent to the “Unsorted” samples collected by observers. Individual samples were weighted to the estimated kept catch in the tows from which the samples were taken.

The 1987 length compositions showed a large abundance of small fish, with a dominant mode in the high 40 and low 50 cm length classes (Fig. 17). The 1998, 1999, and 2000 length compositions were more broadly distributed. They were bi-modal in the latter periods of each year, indicating some recruitment. However, the lower mode was never dominant in the length composition. It should be noted that the commercial mesh size used in 1987 was smaller than in 1998-2000, and this would result in a shift in the commercial length compositions to larger lengths in recent years. But, it is doubtful that this change in mesh size would result in the suppression of a length frequency mode caused by the arrival of a large year-class.

This qualitative comparison of length frequency data indicates that there has not been a significant recruitment event in this stock during the period 1998-2000.

Research Vessel Surveys

A series of multi-species groundfish surveys have been conducted in area 5CD in May-June of 1984, 1987, 1989, 1991, 1993, 1995, 1996, 1998, and 2000 (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). 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 2000 Hecate Strait groundfish assemblage survey was conducted from May 31 – June 13. A total of 106 successful fishing stations were conducted. Fifty-four of these sets had Pacific cod.

Over the years, cod have been taken throughout the survey area. In 2000, catches were highest in the Two Peaks and White Rocks areas. Catches in the southern part of the survey area were small (Fig. 18). A qualitative scan of the catch data in Fig. 18 suggests that 2000 was a relatively poor year for Pacific cod in Hecate Strait.

The utility of this survey as an index of Pacific cod abundance and biomass was investigated by (Sinclair 1999). It was proposed that a depth stratified mean density using the 10 fm depth intervals as depth strata could be used to construct an index. The mean density ($\overline{A}$) would be calculated as

$$\overline{A} = \sum_{h=1}^{L} \overline{a}_h W_h$$

where $\overline{a}_h$ is the mean density in depth interval h and 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, where, 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 9 Hecate Strait surveys, the bootstrap variance was about 8% less than the stratified variance on average.

The mean U in the 2000 survey was the lowest of the 9 surveys since 1984 (Fig. 19). The annual means are highly variable, as shown by the confidence intervals determined by bootstrapping. High survey estimates were obtained in 1987, 1989, and 1998. However, it would be difficult to distinguish between the annual estimates on a statistical basis even though the means varied by a factor of 4. The 2000 survey was an exception in that the estimate is clearly less than most of the other values.

The size composition of these cod catches during the surveys were usually bi-modal with a dominant mode at approximately 30 cm and the second above 40 cm (Fig. 20). The 30 cm mode likely corresponds to age 1 fish at the time of the survey, pre-recruits for the following year's fishery. An exception was in 1987 where the mode was close to 40 cm. There is little continuity in size composition from survey to survey. For example, the 1989 survey had by far the largest abundance of pre-recruit cod. The adult abundance in the next survey (1991) 2 years later was only average. The pre-recruit mode in 1996 was among the smallest in the series. The adult abundance in the 1998 survey, 2 years later, was the second highest in the series next to 1987. The low biomass index in 2000 shown in Fig. 19 was reflected in very low abundance at all size classes in Fig. 20.

Analysis

Surplus Production Model

A surplus production model was used to estimate stock parameters relevant to management. The model and fitting procedure are described by Prager (1994) and a tested software package, ASPIC, was kindly supplied by the author. ASPIC is a non-equilibrium implementation of the symmetric Graham-Schaefer model. A time series of predicted stock biomass is calculated as a function of three parameters, and the annual catch biomass. The parameters are the ratio of initial biomass to B_{msy} (B1ratio), the intrinsic rate of increase (r), and the carrying capacity (K). The predictions are "conditioned" on catch, i.e. catch is assumed to be known without error. A constraint was placed on the annual instantaneous rate of fishing mortality (F) in order to avoid situations where the predicted biomass becomes negative. I used a constraint that $F < 8.0$. No attempt is made to account for age and size composition of the population or the catch. Nor is any attempt made to account for "environmental" or "biological" influences on production.

The model parameters are estimated using a non-linear search algorithm to minimize the sum of ln ratios of predicted and observed stock biomass indices. Part of the fitting procedure involved estimating the catchability coefficient (q) for each index, i.e. a proportionality coefficient used to scale stock biomass to the index. In this case, 2 indices were used. The first is the historical CPUE time series for the period 1960-1995. While CPUE estimates are available for 1954-59, these were eliminated from the analysis because these were the early years of the groundfish trawl fishery and one could expect some increases in CPUE due to learning. The historical series was terminated in 1995, the last year before the IVQ management system was introduced. The second series was the swept area CPUE series from 1994-2000. There were 2 years of overlap in the series which would help in estimating their relative catchabilities. The input data for the analysis are listed in Table 7.

A possible third index of stock biomass comes from the Hecate Strait groundfish assemblage survey. Its use in the model was investigated with trial runs. The index was highly variable and contributed little to the fitting process. Results from runs where the survey index was included were very similar to those where it was excluded. I elected not to use the survey index in the production model.

The software package has a bootstrapping module which may be used to estimate parameter bias and uncertainty. Quoting directly from (Prager 1994), "For each bootstrap trial … a set of synthetic observations is constructed by combining the ordered predictions from the original fit with residuals chosen at random (with replacement) from the set of residuals from the original fit. The model is then refit to this set of synthetic observations." Catch projections may also be performed from both the original model fit and all bootstrap estimates. A total of 600 bootstrap trials were used, the number recommended to obtain 80% confidence intervals for the parameter estimates.

Quantities of interest for management include $B_{msy} = 0.5K$, the stock biomass that produces maximum sustainable yield (MSY), $F_{msy} = 0.5r$, the instantaneous fishing mortality that produces MSY. Time series of B_t relative to B_{msy} and F_t relative to F_{msy} were examined to evaluate the performance of the fishery relative to the respective benchmarks.

Summary statistics of the model fit are given in Table 8. The model fit to the shorter recent swept area biomass index was better than the historical CPUE series, as indicated by the R2 values. This is likely due to the shortness of the recent series, that it declines over these few years, and this corresponds to the direction in the historical time series. The model predictions of stock biomass show three periods of population growth which correspond temporally to the high values of the historical U series (Fig. 21). However, the range of the predictions is less than what was observed in the tuning series. The temporal correlation of model residuals indicates the model did not fully capture the dynamics of the Pacific cod population. The periods of high residuals correspond to significant recruitment events to the stock (Haist and Fournier 1998). Growth production per unit biomass of young fish is higher than that of older fish and one would expect higher population growth (r) when recruitment is high than when recruitment is low. Given that r is assumed constant in this model and no consideration is made for population age structure, it is unlikely that all aspects of population dynamics can be described. Indeed, temporally correlated residual patterns are common in analyses of this type and periods of high residuals could well indicate good recruitment. In such a case, process error would be the dominant factor. The q-adjusted tuning series may be more accurate predictors of stock biomass than the model predictions.

A retrospective analysis of the model predictions was done to investigate the stability of the non-linear solution. Data points were eliminated successively from the end of the time series and the model was refit with shorter and shorter series. The trends in projected biomass from 8 of these analyses are compared in Fig. 22. The time series were robust to the length of the data series indicating the parameter estimates were stationary.

The use of commercial U as an index of stock biomass has been questioned for many reasons. Of particular concern to some is that fishing practices changed dramatically when catch quotas were introduced in 1992 and again when the current IVQ management system was introduced in 1996. I was interested to see what the results would have been if the U data since 1992 were not included in the analysis. Two trial runs were made. In the first, the time series included only the years 1960 – 1991. The resulting series of predicted stock biomass had the same trend as the entire analysis but was shifted downward (Fig 23). The second run used CPUE data from 1960 – 1991 and catch data from 1960 – 2000. In other words, the model parameters were estimated using data up to 1991 and the stock biomass was projected forward from then to the present using only the reported catches. The biomass trend was very close to that obtained when all CPUE data were used. The main difference was in the final year when the F constraint (i.e. F<8.0) became limiting. The only way the model could respect this constraint was to increase the starting biomass so enough fish would be left to justify the catches reported from 1991 – 2000.

How do the surplus production estimates of stock biomass compare to those from the previous analytical assessment of the stock? Haist and Fournier (1998) used Multifan, a length-based stock reconstruction model. Their stock biomass estimates are compared to the ASPIC estimates in (Fig. 24). The correspondence is remarkable considering how different the analysis procedures are. Both show three peaks in biomass with the peaks in ASPIC being slightly ahead of Multifan. A major difference, however, is the stock trajectory in the final years. The Multifan analysis indicated an increasing trend while ASPIC indicated a continuous decline. Two main reasons may explain much of this difference. The Multifan model was tuned with the "qualified" U index while the ASPIC model was tuned with the total U index. The qualified index indicates an increasing trend in the latter portion of the time series while the total series indicates a decline (Fig. 12). As discussed above, the qualified U series is likely biased upward in recent years. Secondly, Multifan also used the Hecate Strait groundfish assemblage survey index. The 1998 survey estimate, which is one of the highest in the series, was the last tuning index in the assessment. The 2000 survey estimate was the lowest in the time series. Given this high variability, the survey index must be treated with caution.

Biological Reference Points for Management

The so called Precautionary Approach (PA) to fisheries management has been the focus of attention of many national and international fisheries management bodies over the past 5 years (ICES (Anon 1997), NAFO (Anon 1999), USA (Restrepo 1999), Canada (Richards and Schnute 2000)). The use of biological reference points to establish fisheries management policies is emphasized in the defining document for the PA (Anon 1995). It is stated that:

- The fishing mortality rate that generates maximum sustainable yield should be regarded as a minimum standard for limit reference points.
- For overfished stocks, the biomass which will produce maximum sustainable yield can serve as a rebuilding target
- Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low and target reference points are not exceeded on average

Canada has committed itself to adopting the PA through the Oceans Act and signing the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks.

One of the main reasons for choosing a surplus production model for this assessment is that it's parameters are directly relevant to the first 2 elements of the PA by providing estimates of F_{msy} and B_{msy}. A framework for implementing the PA for groundfish fisheries was developed at a Canadian workshop held in 1999 (Richards and Schnute 2000, Appendix E). Consider the state of a fish stock in terms of B and F. The Target Zone for stock status would be where the B ($B > B_{msy}$) and F ($F < F_{msy}$) reference points are met (Fig. 25). If the B target was met but $F > F_{msy}$, the stock would be in a state of Overexploitation and steps would be needed to reduce exploitation. If $B < B_{msy}$, the stock would be in an Overexploited state and steps would be needed to promote stock rebuilding. There is a lower limit for stock biomass below which there would be serious concern for stock viability and this status would be Unacceptable. At this level, a serious commitment to stock rebuilding would be needed.

The third element of the PA deals with uncertainties. One could use estimates of model parameter uncertainty to ensure that the risk of exceeding limit reference points is low. A buffer could be placed between F_{msy} and the F target which is equivalent to the appropriate tail of the distribution of the F_{msy} estimate. The size of the buffer would correspond to the risk one is willing to accept of failing to meet a target or exceed a limit.

The model parameter estimates and their 80% confidence intervals for the area 5CD Pacific cod surplus production model are listed in Table 8. Of particular interest are the estimates of ratios of current biomass (B-ratio) and fishing mortality (F-ratio) relative to B_{msy} and F_{msy} respectively. The current biomass estimate is only 2% of B_{msy} (1.1% - 6.2%, 80% CI) and the fishing mortality estimate was twice F_{msy} (0.96 – 3.60, 80% CI). The deterministic trends B and F relative to B_{msy} and F_{msy} indicate that the stock has been outside the target zone throughout the entire history of the fishery (Fig. 26). The phase plot of F and B shows that the stock has been cycling through the overexploited, unacceptable, and unsustainable zones. For 9 of the last 10 years, F was greater than $2*F_{msy}$, i.e. greater than the intrinsic rate of increase (r). Such high Fs would be unsustainable in the long term. The trend through time has been toward lower B and Higher F. Since 1990, all points but 1 were in the unsustainable zone.

Uncertainties

A number of key assumptions have been made in this assessment and while I have attempted to support these with additional analyses, the possibility remains that they do not hold. The key assumptions are reviewed in the following section.

1) Total U is a proportional index of stock biomass in the period 1960-1995.

All previous analytical assessments of this stock have used "qualified" U as a proportional index of stock size. Qualification meant selecting only those events where cod was more than 10% of the total catch. The median U within the specified time period was used as the index. In this assessment, all data were used and the index was calculated as the ratio of sums of catch and effort. The two annual indices were very similar ($r = 0.98$). The main difference between the 2 indices was in the last 2 years (1994, 1995) where the "Qualified" index increased while the total index declined (Fig. 12). It is likely that the qualified index would be biased upward in these latter years since cod biomass was low, cod was likely a smaller proportion of the total fish biomass in the area, and therefore a large number of low U observations would be eliminated from the "qualified" data leaving only larger values.

A proportional relationship between U and B was assumed in the surplus production model. This assumption was supported by the symmetrical distribution of model residuals shown in Fig. 21. If U was not proportional to B but showed hyperstability as would be expected for a fishery targeting highly aggregated animals (Palohiemo and Dickie 1963), one would see a negative trend in Fig. 21. In addition, if hyperstability existed, one would expect the time series of U to have a lower dynamic range than population biomass. The dynamic range may be measured by the coefficient of variation of the time series (mean/standard deviation) or by the standard deviation of the ln values. These 2 measures of dynamic range for the stock biomass estimates from ASPIC, those from the MULTIFAN assessment of Haist and Fournier (1998) and the commercial total U index for the period 1960-1995 are compared in the text table below. The dynamic range of the U series was greater than both of the biomass series, again supporting the assumption of a proportional relationship.

	ASPIC	MULTIFAN	U
CV	0.37	0.54	0.61
std ln	0.51	0.53	0.63

2) The swept area estimator is a proportional index of stock biomass in the period 1994-2000.

There are clear advantages to using a biomass index that includes both fish density (U) and the area over which that density is measured (Beverton and Holt 1957, Walters and Bonfil 1999, Schnute et al. 1999). The availability of precise fishing location data for the groundfish trawl fishery in Area 5CD since 1994 makes these calculations possible. A fundamental requirement of the swept area method is that the fishery covers a constant proportion of the stock area throughout the time period. In the case of Pacific cod in area 5CD, it was clear that this was not the case in the last quarter of 1995 and the first quarter of 1996, and these data were not used in the index. The extent to which this may have occurred in other time periods is not known. It has been stated that fishermen have been practicing avoidance fishing since the implementation of the IVQ program and that the resulting CPUE data are not useful for tracking biomass. If Pacific cod were being avoided, one would expect the fishery to shift to depths where cod are not often found and that the frequency of occurrence of Pacific cod in individual fishing sets would decline. Neither of these situations were evident in the fishing data for recent years (Fig. 6 and 7). Furthermore, the annual TACs have not been taken since 1992.

3) A single species surplus production captures dynamics of Pacific cod in area 5CD.

There are clear shortfalls in the production analysis. The model predicts that stock biomass has not been above B_{msy} (i.e. half carrying capacity) in the time period of the analysis. This restricted dynamic range of stock biomass means that there is considerable uncertainty regarding model parameter estimates, in particular K. The model does not adequately account for recruitment variability as indicated by the temporal patterns of residuals in Fig. 21. The model is based on only 3 parameters, initial biomass, the intrinsic rate of increase (r), and carrying capacity (K). The population growth rate (i.e. surplus production/biomass) is assumed to be affected only by population size (density dependent). This simplistic representation of a much more complex reality is the basis for much criticism of the whole approach (Larkin 1977). In the 5CD Pacific cod example, it would be interesting to investigate incorporating additional environmental and biological variables to better explain recruitment, such as the transport mechanism proposed by Tyler and Crawford (1991). In the mean time, the results of the surplus production analysis provide some information on "average" conditions for this stock, and these should not be ignored.

Current Status and Prognosis

The ASPIC software has a module for making catch and population forecasts. One can specify future catch or fishing mortality. There is no indication that a significant recruitment event is currently occurring, either in the model residuals, the size composition of recent commercial catches, or the size composition of the 2000 groundfish assemblage survey. Consequently, projections were made using only the model parameters. The 600 bootstrap trials were used as input to the projections and the outputs included point estimates and 80% confidence intervals for stock biomass.

Two long term (10 year) scenarios were considered, zero catch and $F = 0.25 \cdot F_{msy}$. It should be noted that these are provided simply to illustrate what might occur if the population behaves precisely according to the assumptions and parameter estimates of the production model. Many things might happen that could invalidate these predictions such as recruitment failure or success, changes in individual growth rates caused by changes in food supply, changes in non-fishing mortality rates.

Zero catch: Given the extremely low biomass of cod and that the stock is is an unacceptable condition, a 10 year projection was made assuming no catch. Pacific cod are widely distributed throughout area 5CD and it would require almost complete cessation of trawl fishing to achieve zero catch. While this may be an unlikely scenario, the results may be useful to begin considering a recovery plan for this stock.

The projections indicate that after 10 years of no catch, there would be approximately 50% probability that stock biomass would not have recovered to the B_{msy} target or higher (Fig. 27).

$F = 0.25 \cdot F_{msy}$: The estimated fishing mortality on Pacific cod in area 5CD has been as high as 4 times F_{msy}. A reduction of F to 25% F_{msy} would require a 95% reduction in fishing effort over the main distribution of the species. This might be accomplished by the closure of fishing over the preferred depth range of the species, namely 50 – 125 m.

The projections indicate that after 10 years of $F = 0.25 \cdot F_{msy}$ there would be approximately 75% probability that stock biomass would not have recovered to the B_{msy} target or higher

(Fig. 27). Catches under this scenario would begin at about 40 t and increase gradually to about 800 t in the tenth year (Fig. 28).

It should be noted that if there is a major recruitment event in the next few years, stock recovery could occur much faster than projected. If this happens, it will be important not to squander the opportunity for more rapid stock recovery by catching the improvement.

A stochastic single year catch projection was also carried out. The 600 bootstrap estimates of stock size and production parameters were used as input. For each replicate, a single year projection was made for a range of TACs in 2001 of 0 – 700 t in 100 t increments. The probability of various stock levels not being achieved given specific catches in 2001 was then estimated. Three outcomes were considered, that stock biomass would decline, that stock biomass would not increase by 10%, and that stock biomass would not increase by 20%. These were chosen because of the extremely low stock biomass and the assumption that a management objective is to rebuild the stock. The catches associated with a 50% probability correspond to the respective deterministic catch projection. This analysis used output from the surplus production model and as such included uncertainties in the fitting procedure conditioned on the model assumptions. Uncertainties associated with model mispecification and errors in assumptions were not included.

A catch of approximately 250 t corresponded with a 50% probability of stock biomass declining (Fig. 29). A catch of 150 t had a 20% probability of stock decline. A catch of 135 t had a 50% probability of stock biomass not increasing by 20%, while a catch of 75 t had only a 20% probability of the biomass not increasing by 20%.

This presentation of yield options covers a much larger range than what has been presented in the past. Managers are free to determine what yields they consider to be of high or low risk.

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Tables

Table 1: Annual landings (t) of Pacific cod in the Hecate Strait area (5CDE), 1956-98.

Year	Landings (t)	Year	Landings (t)
1956	1046	1979	4699
1957	1106	1980	4542
1958	3058	1981	3190
1959	2203	1982	2066
1960	2360	1983	2715
1961	1616	1984	1748
1962	1690	1985	1064
1963	2927	1986	2099
1964	5228	1987	8870
1965	9119	1988	6199
1966	9519	1989	4788
1967	5112	1990	3607
1968	5165	1991	7655
1969	2987	1992	5103
1970	1315	1993	3965
1971	1477	1994	1561
1972	2696	1995	1322
1973	3996	1996	397
1974	4766	1997	1241
1975	5036	1998	1099
1976	4993	1999	629
1977	3510	2000*	445
1978	2103		

Table 2: Comparison of dockside and observer estimates of landings, 1996-2000. 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 (t)	Observer (t)	% Observer of Dockside
1996	BOTH	957	683.2	581.6	85%
1997	BOTH	848	1508.4	1368.0	91%
1998	BOTH	836	1382.6	1240.9	90%
1999	BOTH	743	817.9	705.0	86%
2000	BOTH	431	394.8	359.0	91%
1996	DOCK	252	218.8	0.0	
1997	DOCK	311	6.2	0.0	
1998	DOCK	288	4.5	0.0	
1999	DOCK	473	11.4	0.0	
2000	DOCK	175	5.0	0.0	
1996	OBS	48	0.0	6.7	
1997	OBS	21	0.0	0.2	
1998	OBS	13	0.0	0.1	
1999	OBS	7	0.0	0.1	
2000	OBS	8	0.0	0.2	

Table 3: Summary of recommended yields, TACs and landings (t) for Pacific cod in Hecate Strait.

Year	Recommended Yield	TAC	Landings	Percent Caught
2000/01	No new advice	1283	397	31% Nov. 2
1999/00	600-1500	1000	580	58%
1998/99	No directed fishery	1000	846	85%
1997/98	L: 1075	1620	1119	69%
	H:2165			
1996	0	by-catch only	403	
1995	L: 1870	1870	1322	71%
	M: 3040			
	H: 5520			
1994	L: 1670			
	M: 3850	3850	1561	41%
	H: 7790			
1993	L: 3200	5100	3965	78%
	H: 6500			
1992	L: 600	3400	5103	150%
	M: 2800			
	H: 3800			

Table 4: Summary statistics from a multiplicative analysis of quarterly total catch per nit effort data for Pacific cod in area 5CD, 1954-2000.

Summary of Fit

RSquare	0.807954
Root Mean Square Error	0.486196
Observations (or Sum Wgts)	186

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
year	46	46	115.42434	10.6149	<.0001
Q	3	3	22.02863	31.0630	<.0001

Table 5: Rectangle dimentions used to calculate quarterly biomass indices of area 5CD Pacific cod. The rectangles were based on fractions of degrees latitude and longitude. The final 3 columns summarize linear regressions of the biomass indices between rectangles of adjacent sizes. All regressions were highly significant. All slope estiates were significantally different than 1.0. None of the intercept estimates were significantly different than 0.0.

	Side Length (km)		Area			
Rec Size	Latitude	Longitude	km^2	R^2	Slope	Intercept
0.025	2.8	1.7	4.6	0.97	**1.90**	223
0.05	5.6	3.3	18.6	0.94	**1.77**	479
0.1	11.1	6.7	74.4	0.97	**2.01**	-1302
0.2	22.2	13.4	297.6	0.95	**4.10**	-4187
0.5	55.6	33.5	1859.8	0.85	**1.33**	-8810
1	111.2	66.9	7439.0	0.97		

Table 6: Summary statistics from a multiplicative analysis of quarterly total biomass index data for Pacific cod in area 5CD, 1994-2000.

Summary of Fit

RSquare	0.82736
Root Mean Square Error	0.384623
Observations (or Sum Wgts)	24

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Year	6	6	4.1812939	4.7107	0.0080
Q	3	3	6.3598834	14.3304	0.0002

Table 7: Input data for the ASPIC surplus production model.

Year	Catch	Historical CPUE	Swept Area Index	Year	Catch	Historical CPUE	Swept Area Index
1960	2360	0.272		1981	3190	0.245	
1961	1616	0.202		1982	2066	0.230	
1962	1690	0.222		1983	2715	0.304	
1963	2927	0.459		1984	1748	0.225	
1964	5228	0.741		1985	1064	0.129	
1965	9119	0.808		1986	2099	0.240	
1966	9519	0.607		1987	8870	0.896	
1967	5112	0.629		1988	6199	0.433	
1968	5165	0.309		1989	4788	0.252	
1969	2987	0.222		1990	3607	0.260	
1970	1315	0.126		1991	7655	0.332	
1971	1477	0.123		1992	5103	0.194	
1972	2696	0.340		1993	3965	0.144	
1973	3996	0.554		1994	1561	0.070	32.63
1974	4766	0.637		1995	1322	0.057	28.65
1975	5036	0.482		1996	397		21.22
1976	4993	0.377		1997	1241		28.92
1977	3510	0.281		1998	1099		23.05
1978	2103	0.237		1999	629		12.62
1979	4699	0.276		2000	283		8.14
1980	4542	0.279					

Table 8: Goodness of fit statistics and parameter estimates for the ASPIC surplus production model of Pacific cod in area 5CD.

Index	SSE	N	MSE	R^2
CPUE 1960-1995	6.987	36	0.2055	0.351
Biomass Index 1994-2000	0.180	7	0.0360	0.810
Objective Function	7.17			

Param name	Bias-corrected estimate	Ordinary estimate	Relative bias	App. 80% lower CL	App. 80% upper CL
B1ratio	0.487	0.506	3.80%	0.124	0.769
K	49070	48790	-0.59%	35710	140900
r	0.420	0.416	-0.97%	0.305	0.531
q(1)	2.71E-05	2.57E-05	-5.40%	2.23E-05	3.09E-05
q(2)	0.0151	0.0145	-3.83%	0.0113	0.0205
Bmsy	24540	24390	-0.59%	17850	70440
Fmsy	0.21	0.21	-0.97%	0.15	0.27
B-ratio	0.027	0.025	-6.24%	0.011	0.062
F-ratio	2.04	2.16	6.03%	0.96	3.60

Figures

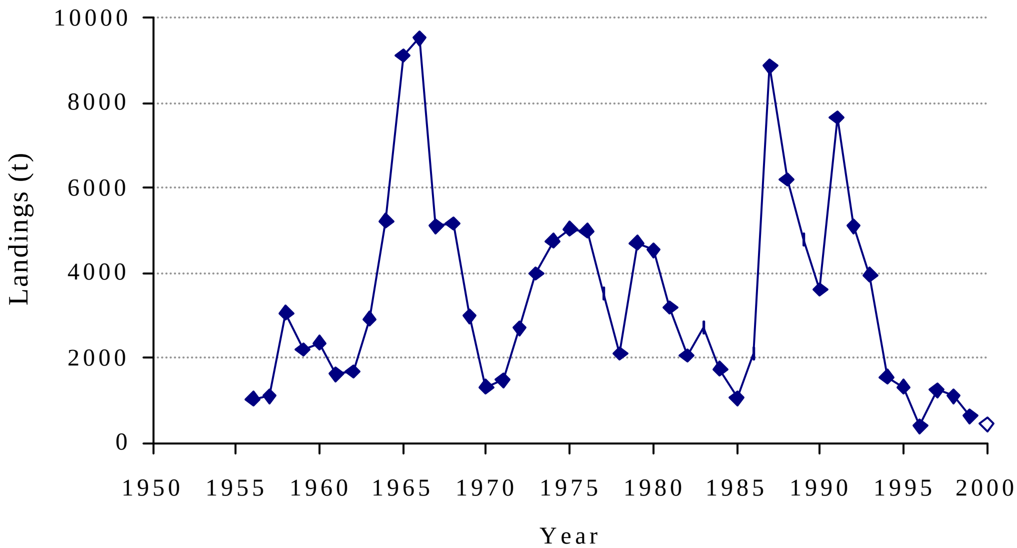

Figure 1: Annual landings (t) in the Hecate Strait area (5CDE) 1956-1999. The point for 2000 includes preliminary reports to November 2, 2000.

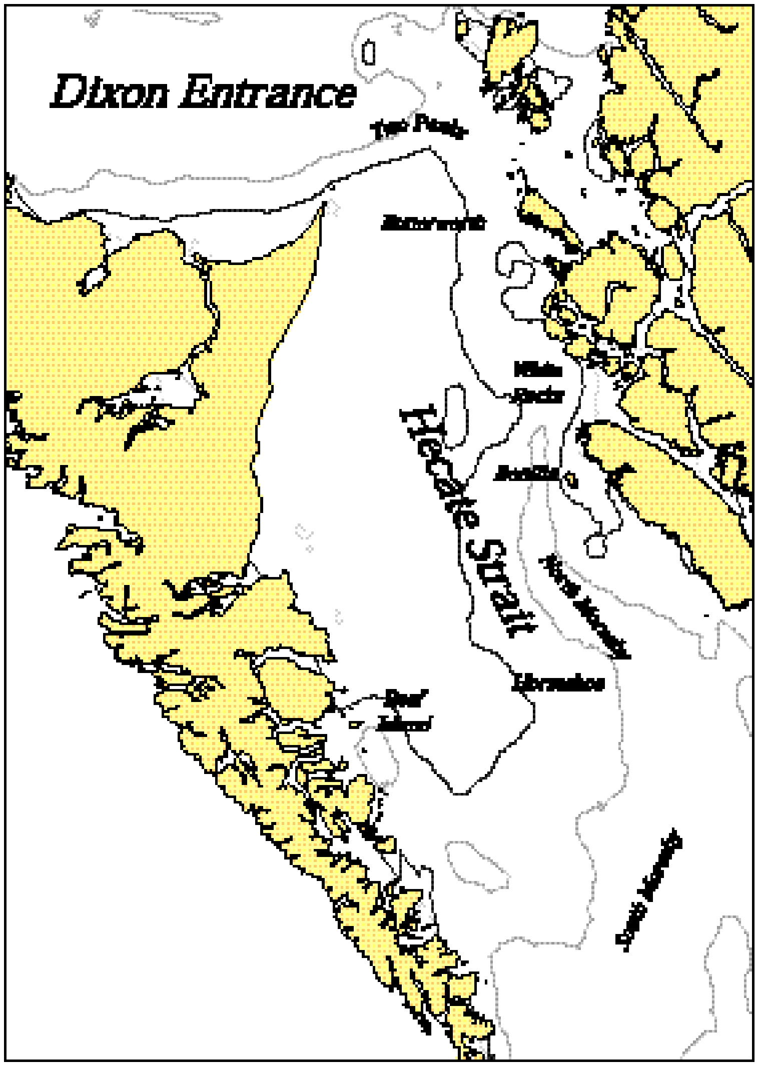

Figure 2: Major groundfish trawl fishing grounds in areas 5CD. The 50 m and 125 m depth contours are shown.

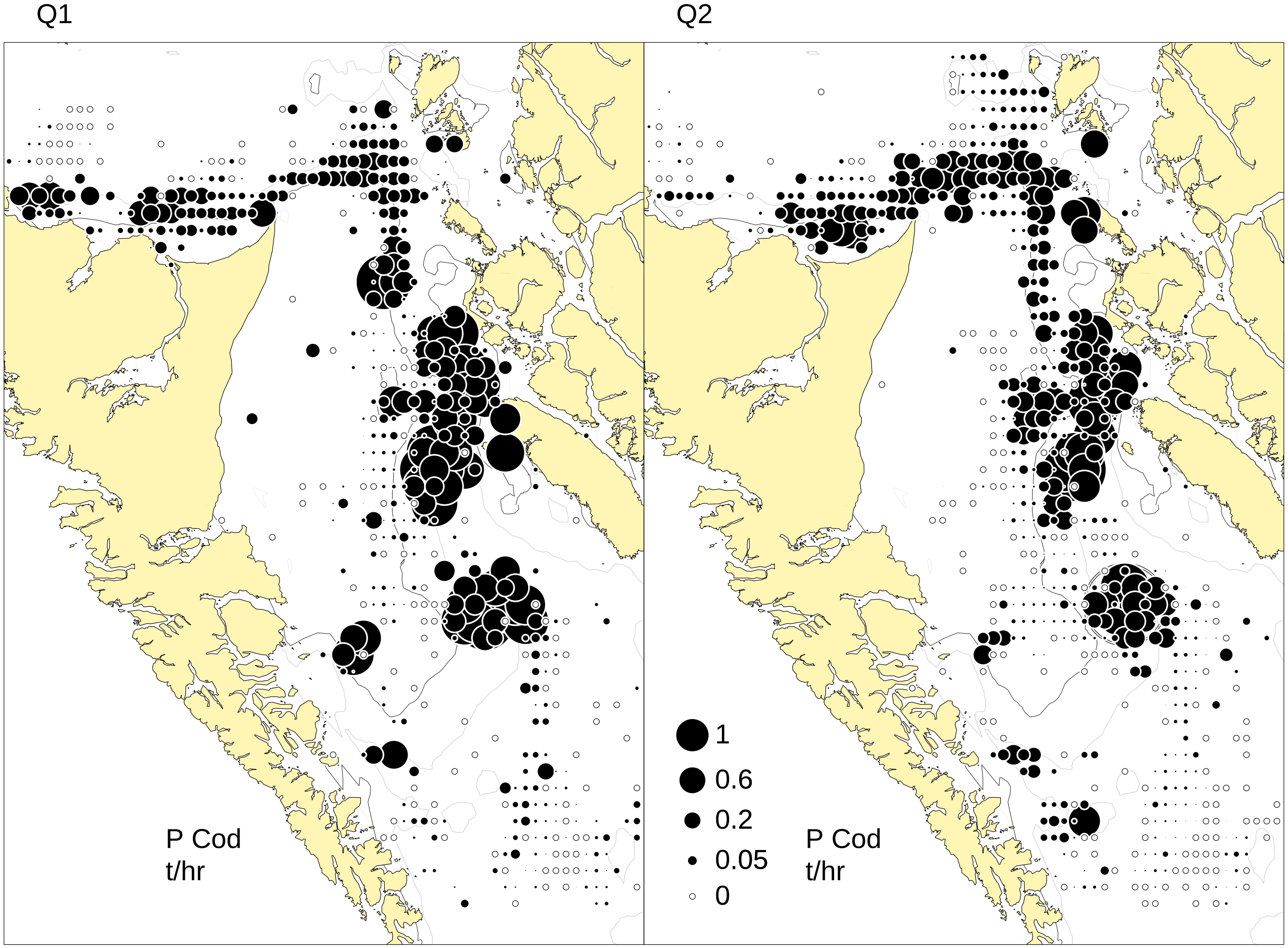

Figure 3: Spatial distribution of Pacific cod in areas 5CD. The expanding circles represent density (U t/hr). Catch and fishing effort data from logbooks (1994-1995) and observers (1996-2000) were summed by quarter (Q1 to Q4) and 1/20 ° rectangles of longitude and latitude to calculate U.

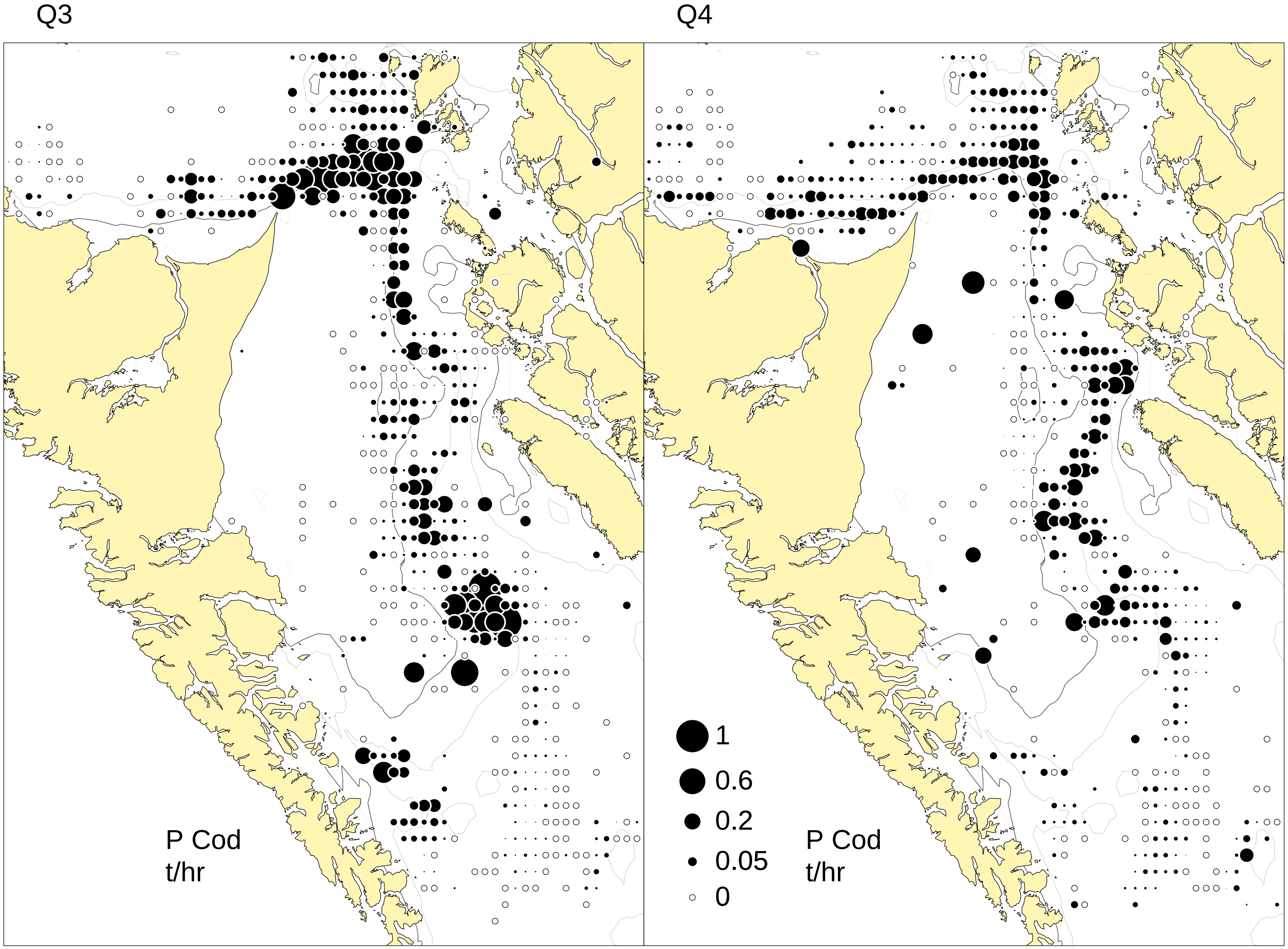

Figure 3: con't

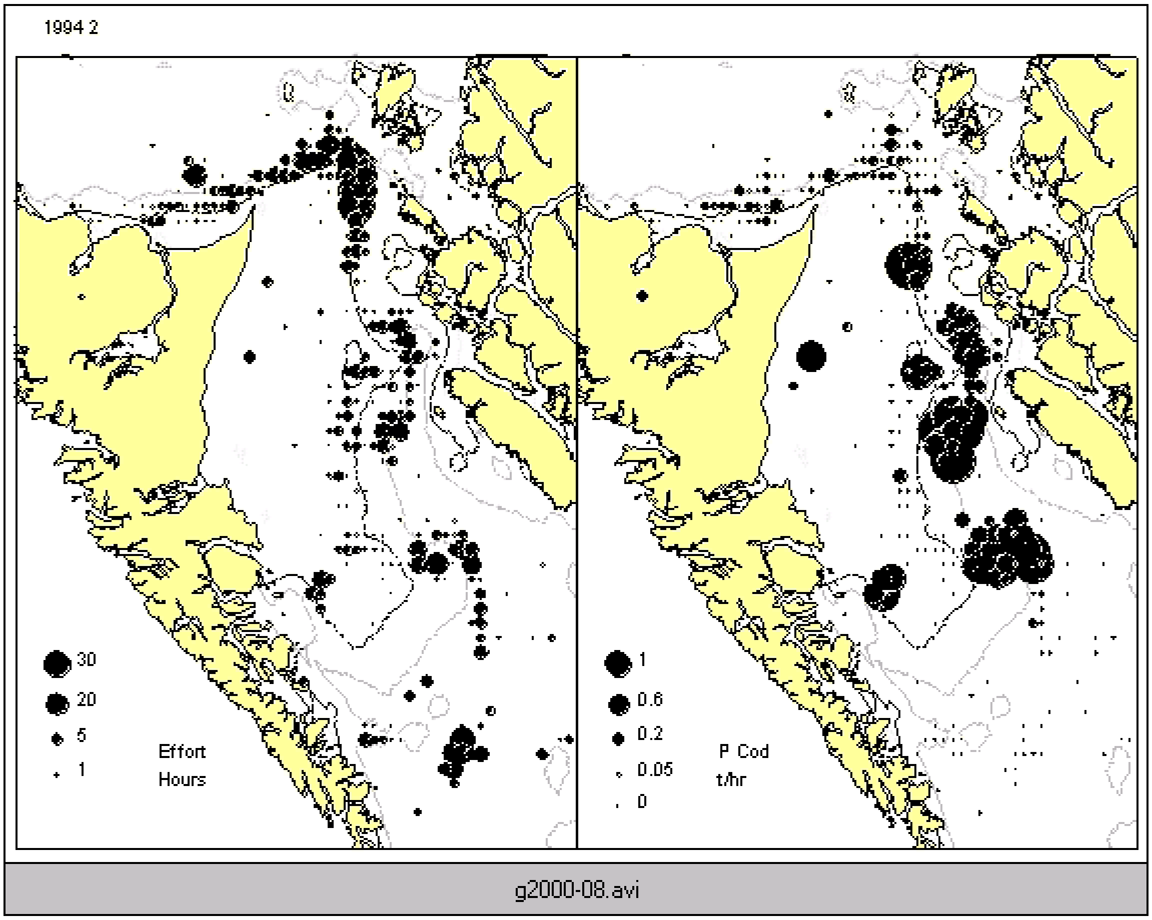

Figure 4: Maps of fishing effort (left) and Pacific cod U (right) in areas 5CD by quarter from 1994 – 2000. The maps are arranged by year and quarter. Quarters are indicated by the number of the middle month in the quarter, i.e. 2, 5, 8, 11. To play, right click on image: Play Object.

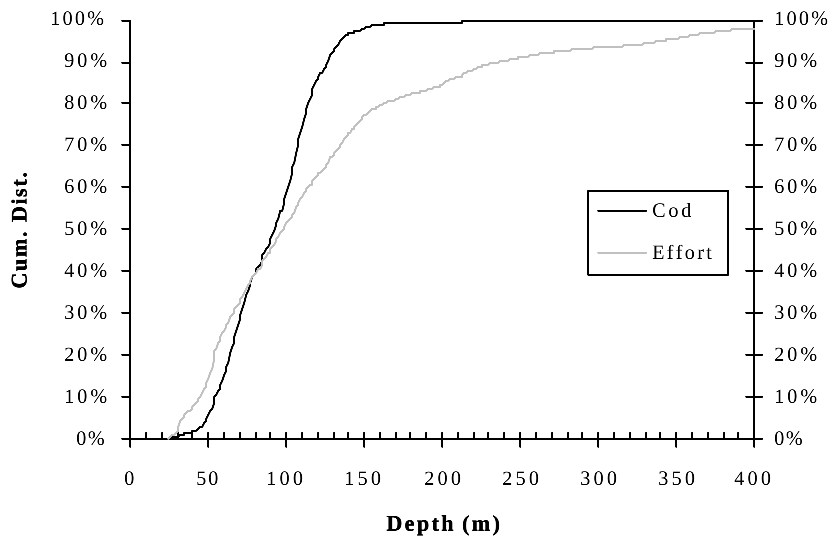

Figure 5: Cumulative distributions of fishing effort and Pacific cod catches in area 5CD, 1991-2000.

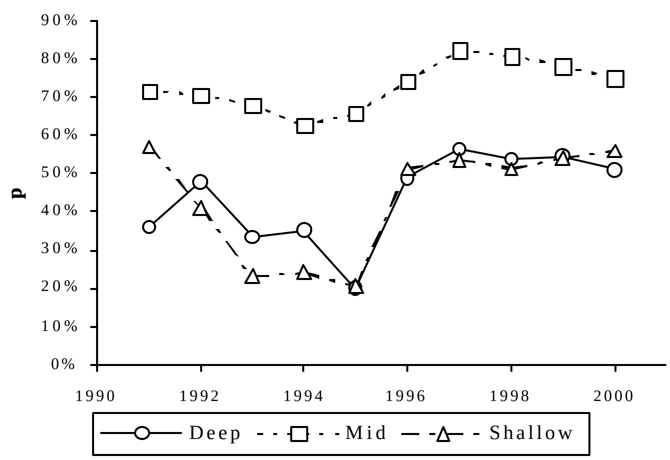

Figure 6: Frequency of occurrence of Pacific cod in individual fishing sets in area 5CD from 1991-2000, shown separately for 3 depth zones, Deep (>125 m), Mid (50-125 m) and Shallow (<50 m).

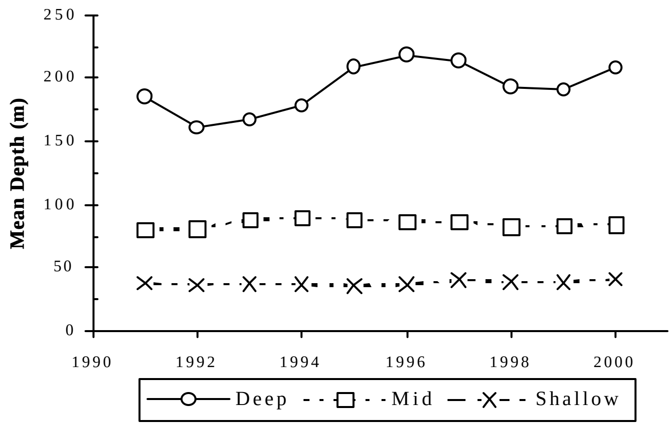

Figure 7: Annual average fishing depth in area 5CD from 1991-2000, shown separately for 3 depth zones, Deep (>125 m), Mid (50-125 m) and Shallow (<50 m).

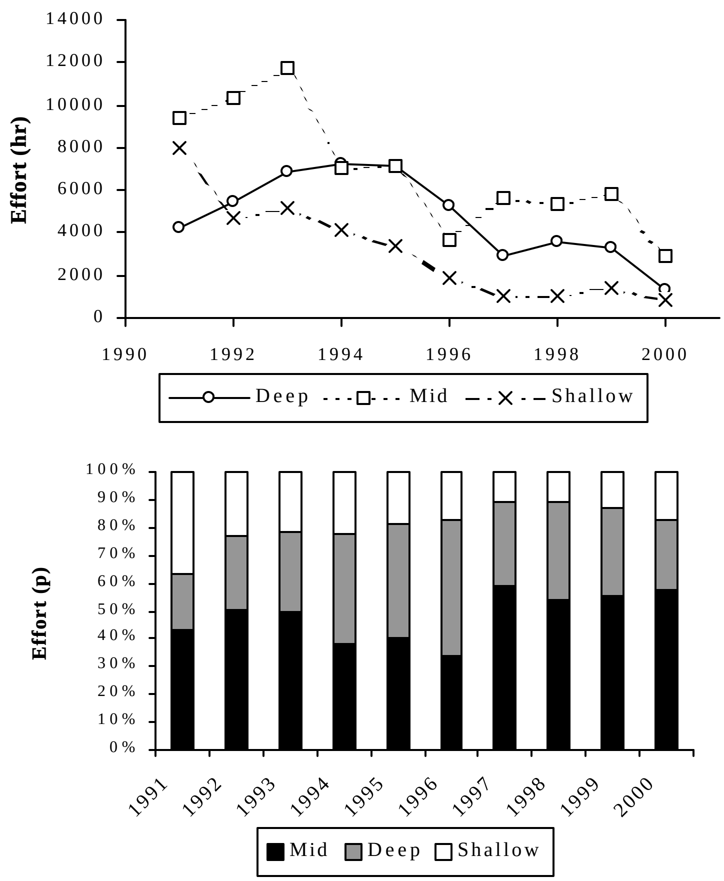

Figure 8: Distribution of fishing effort in area 5CD among 3 depth zones, Deep (>125 m), Mid (50-125 m) and Shallow (<50 m), 1991-2000. The upper panel shows the number of hours fished, the lower panel shows the percent distribution. Note that the values for 2000 include only the first half of the year.

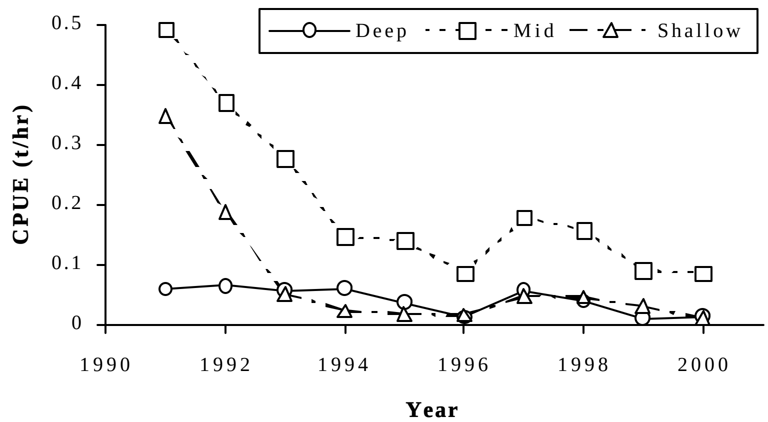

Figure 9: CPUE of Pacific cod in area 5CD shown separately for 3 depth zones, Deep (>125 m), Mid (50-125 m) and Shallow (<50 m), 1991-2000.

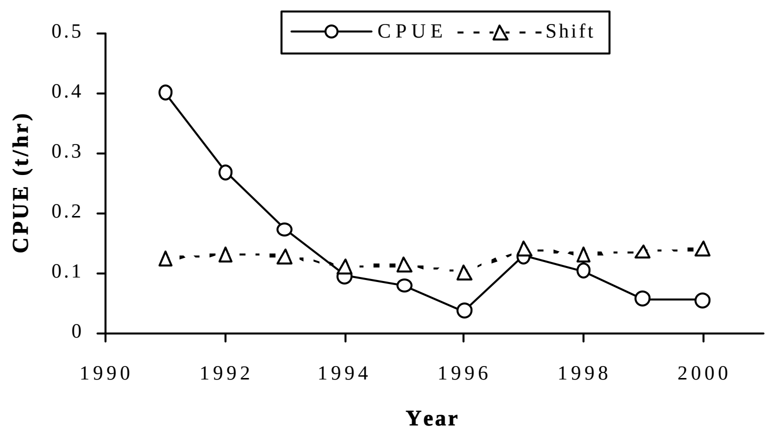

Figure 10: Comparison of the mean annual CPUE and the expected change in CPUE resulting from shifts in fishing effort among depth zones (Shift).

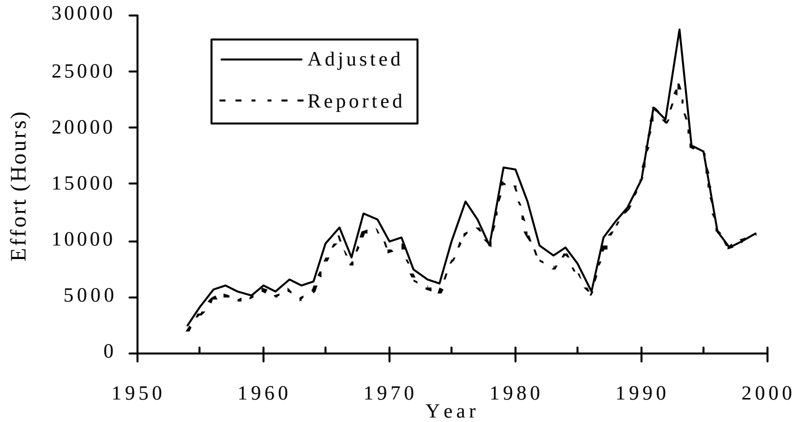

Figure 11: Trend in trawl fishing effort in area 5CD since 1954. Not all catch had fishing effort and it was necessary to adjust for non-reported effort. The adjustment method is described in the text.

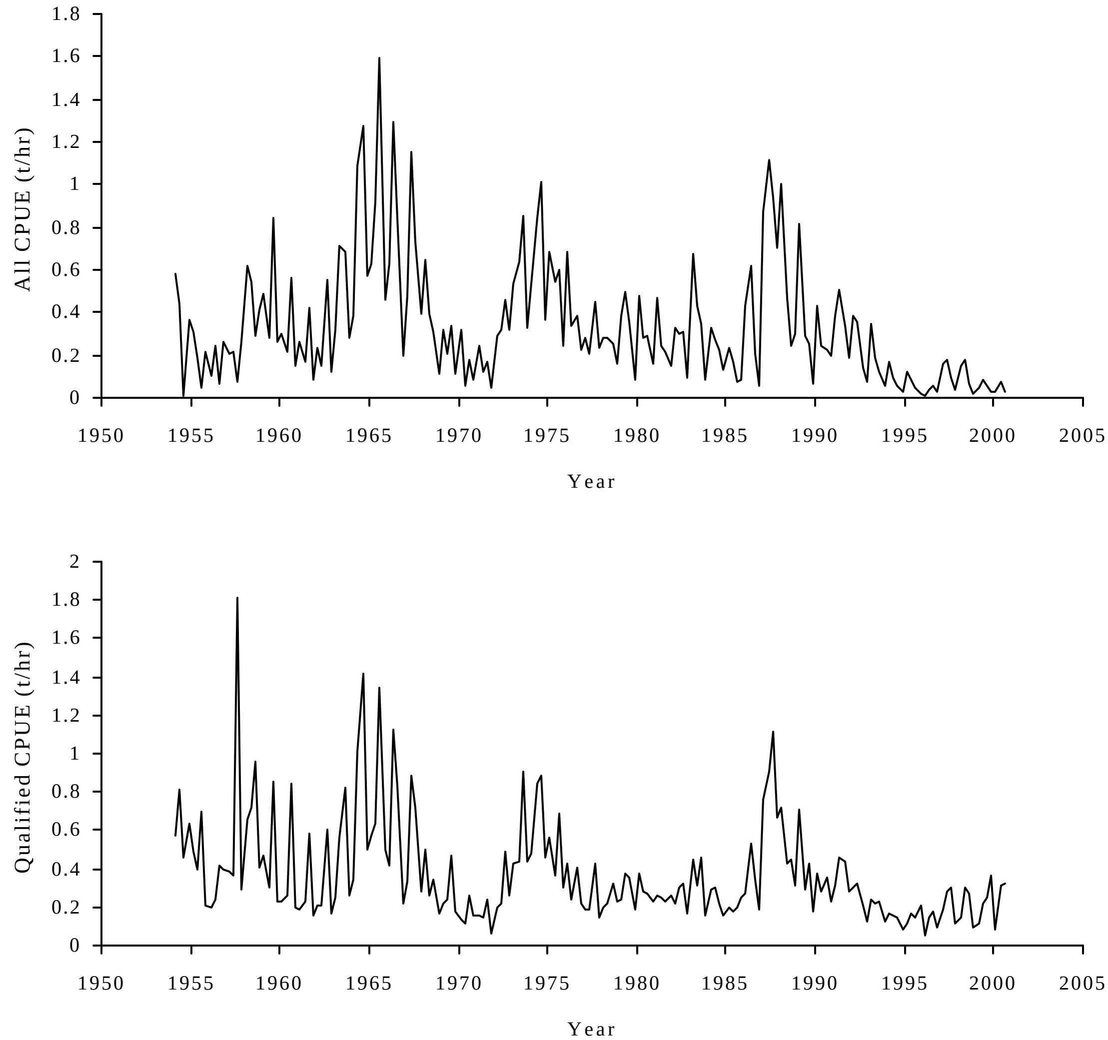

Figure 12: Quarterly CPUE for Pacific cod in area 5CD. The upper panel shows the ratio of catch divided by total effort, the lower is the median of "qualified" CPUE.

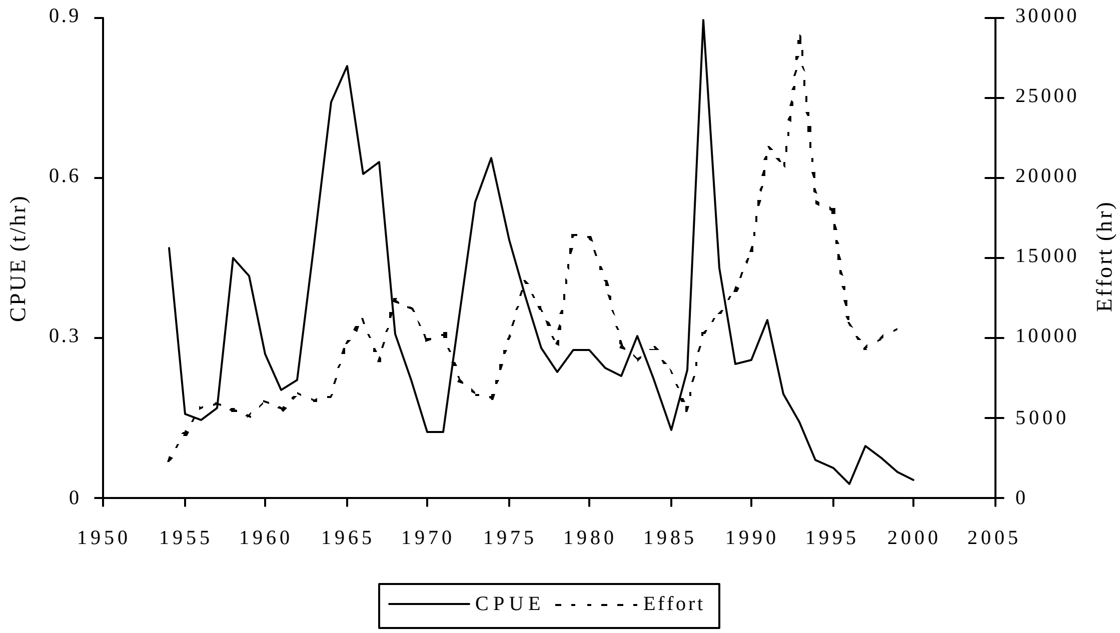

Figure 13: Trend in standardized CPUE for pacific cod in area 5CD. The index is compared with the trend in total fishing effort.

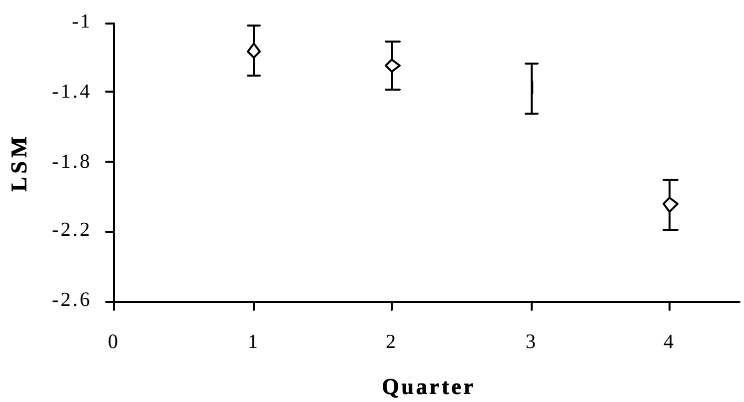

Figure 14: Parameter estimates for quarter in the multiplicative analysis of area 5CD Pacific cod CPUE. Error bars give 2 standard errors.

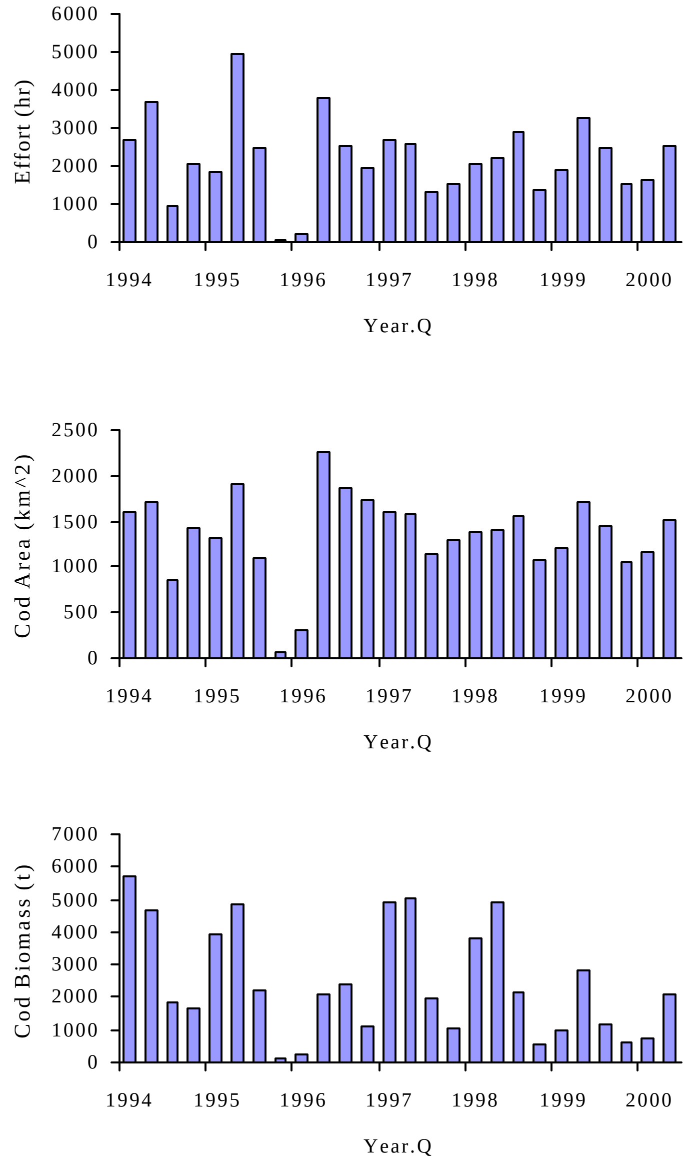

Figure 15: Quarterly estimates of fishing effort (hr), area (km^2), and biomass (t) of Pacific cod in 0.25 degree rectangles in area 5CD, 1994-2000.

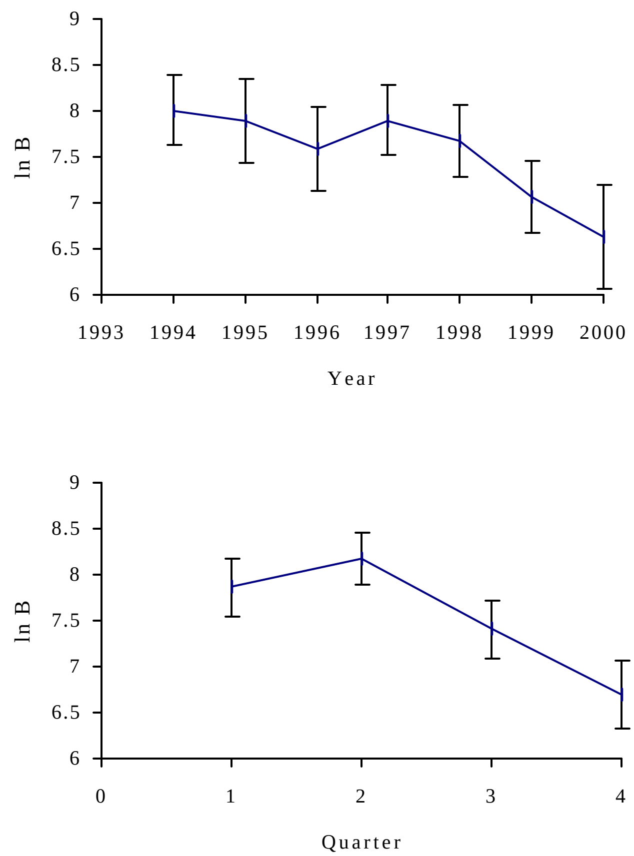

Figure 16: Main effects, year and quarter, from a multiplicative analysis of Pacific cod biomass index data for area 5CD. Error bars show 2 standard errors.

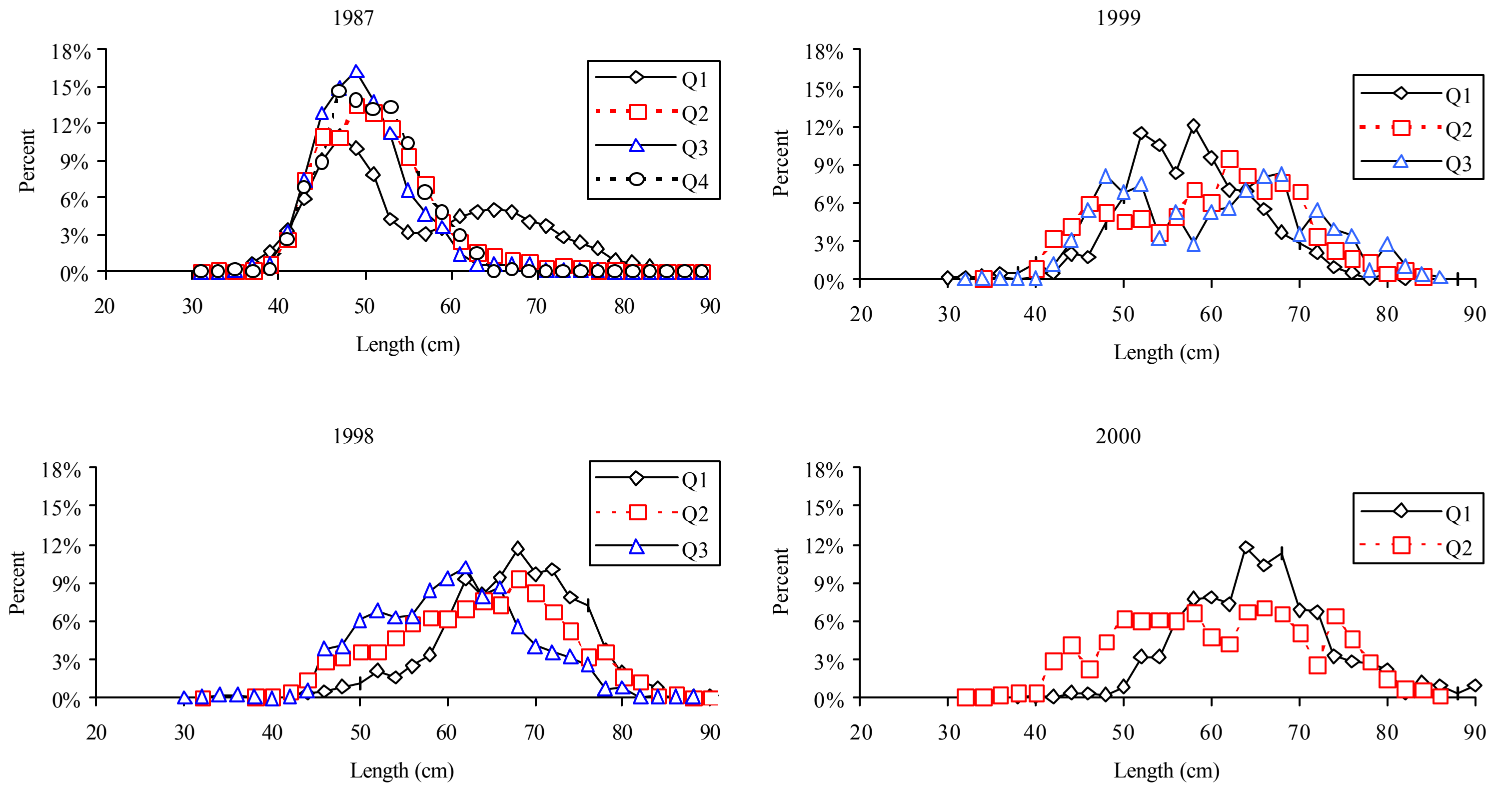

Figure 17: Quarterly length frequencies (percent) for Pacific cod in area 5CD, 1987, 1998-2000.

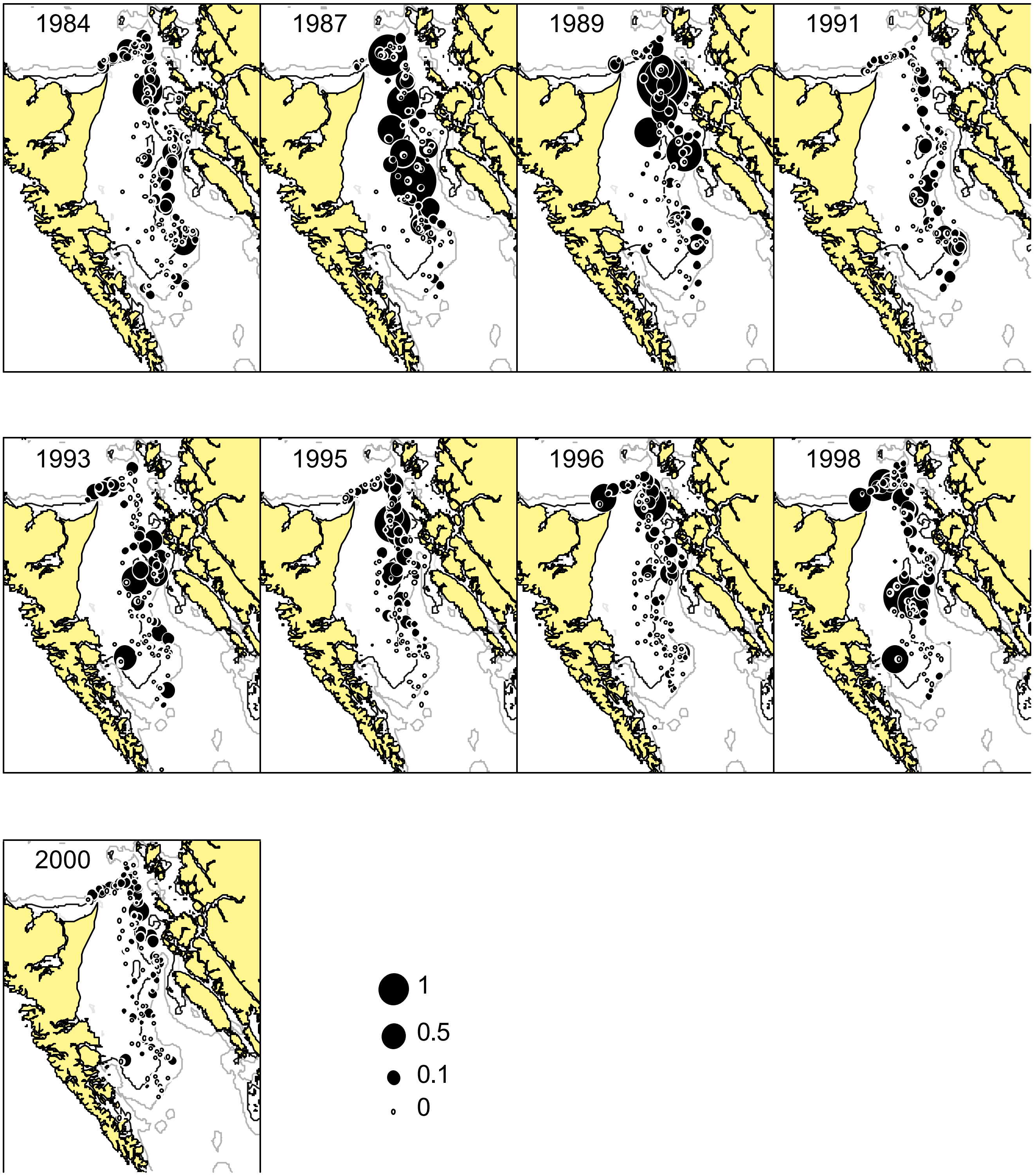

Figure 18: Catches of Pacific cod during the Hecate Strait groundfish assemblage surveys, 1984-2000. The symbols represent catch rates (t/hr). The 50 and 125 m depth contours are shown.

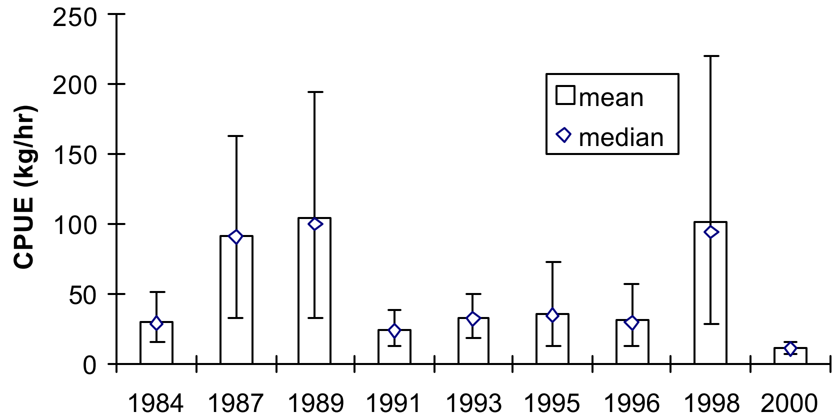

Figure 19: Annual depth stratified catch rates (bars) of Pacific cod in the Hecate Strait groundfish assemblage surveys. The distributions of these means were estimated using bootstrapping. The vertical lines give the 95% confidence intervals and the diamonds indicate the medians.

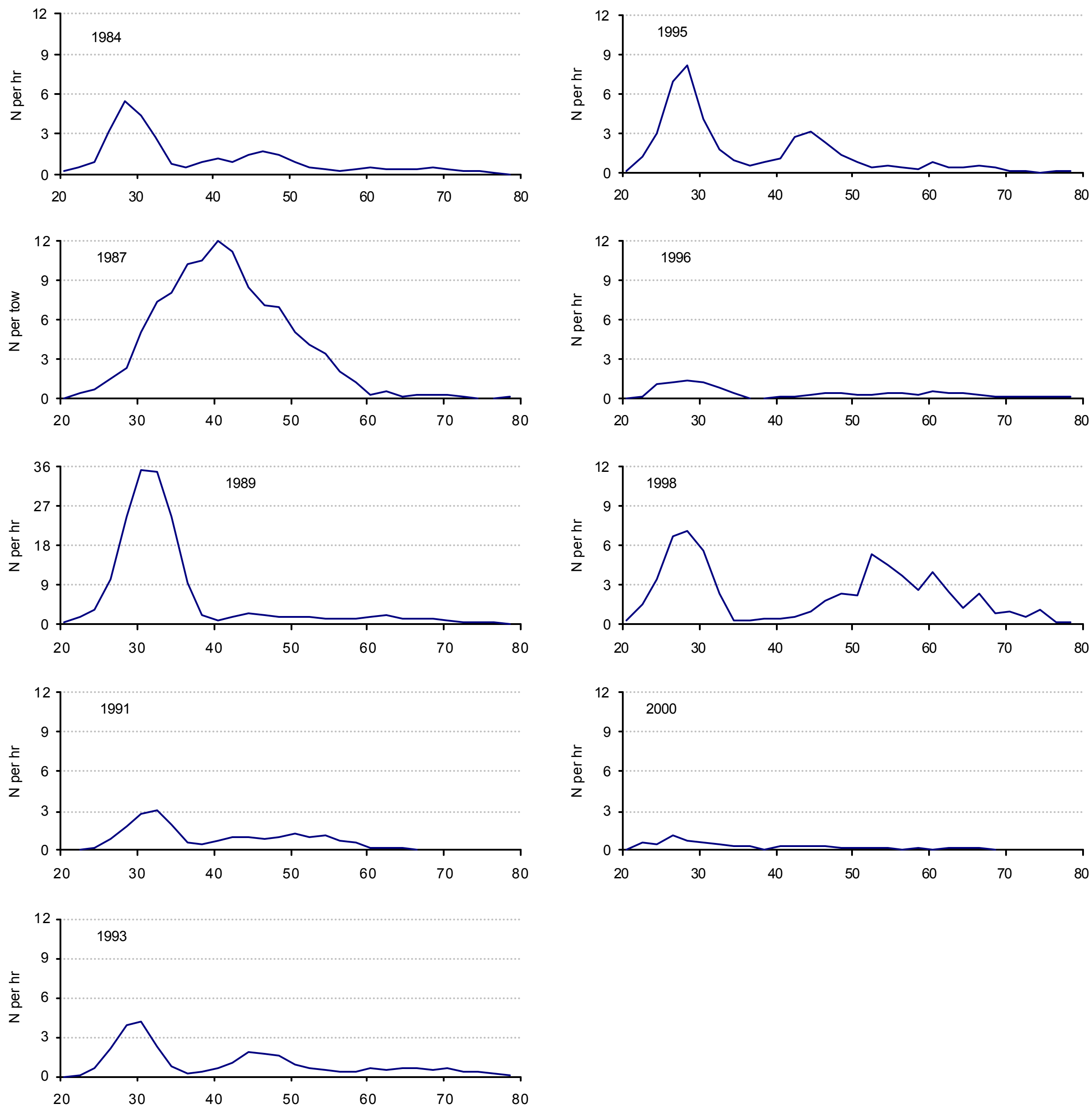

Figure 20: Estimated length composition of Pacific cod in Hecate Strait estimated during the groundfish assemblage surveys. The graphs are scaled to numbers per hour fished and indicate both size composition and relative abundance. Note that the scale on the 1989 panel is different than the others.

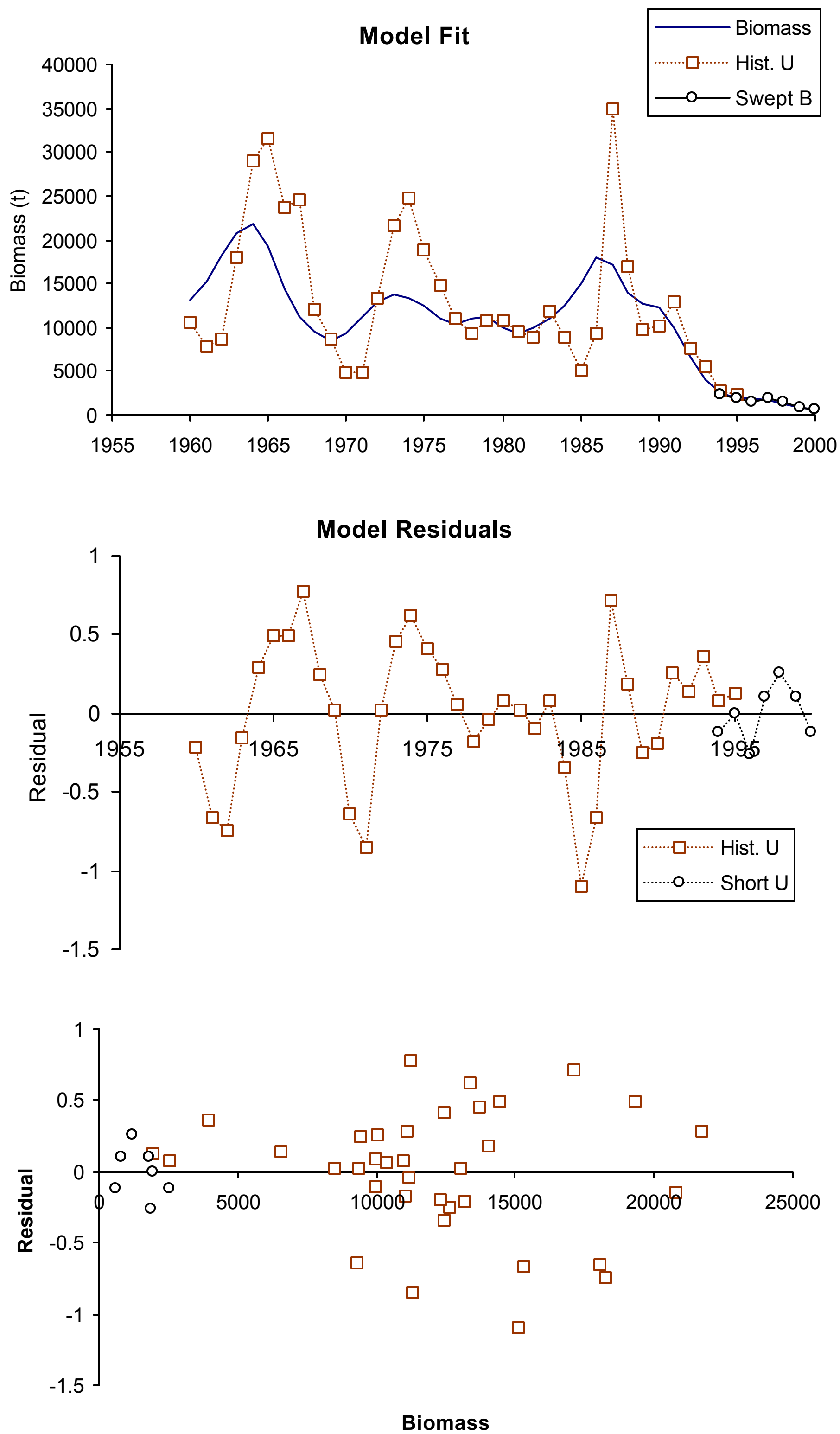

Figure 21: Model predictions, observations and resduals from a surplus production analysis of Pacific cod in area 5CD using the ASPIC software package.

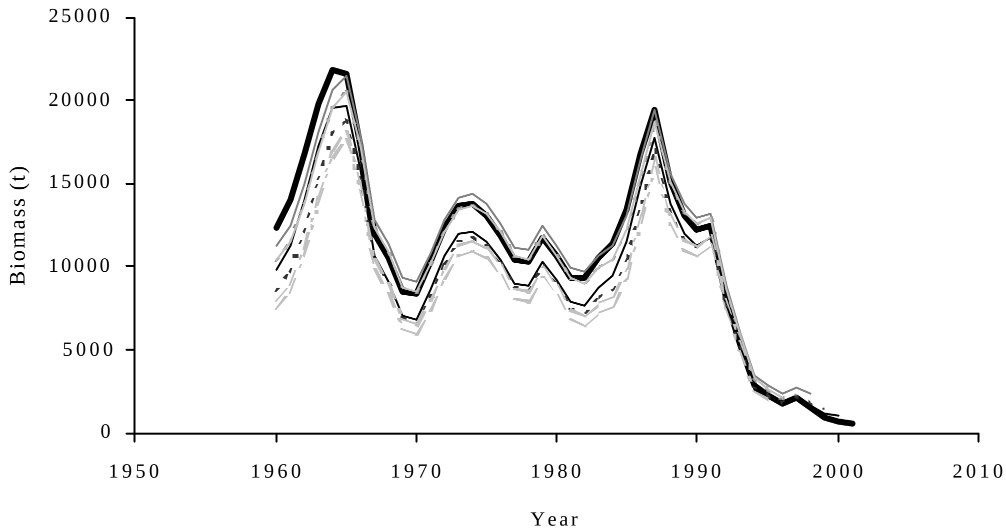

Figure 22: Retrospective analyses of area 5CD Pacific cod surplus production. The analyses were performed with successively shorter data series.

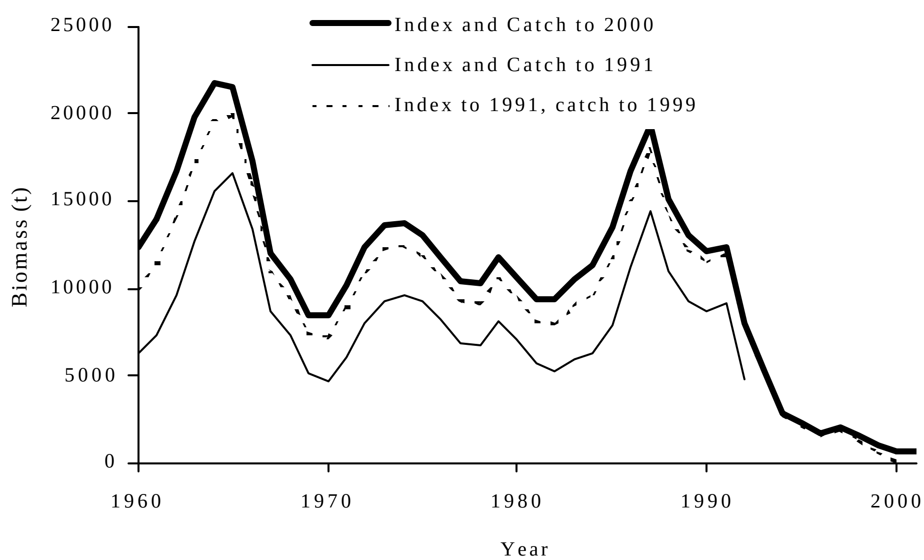

Figure 23: Three ASPIC analyses of Pacific cod in area 5CD were used to determine the impact of recent CPUE data on the solution.. The base run included index and catch from 1960-2000 (thick slolid line). The second run included only the years 1960-1991 (thin solid line). The third had CPUE data from 1960 – 1991 and catch from 1960 – 1999 (dashed line).

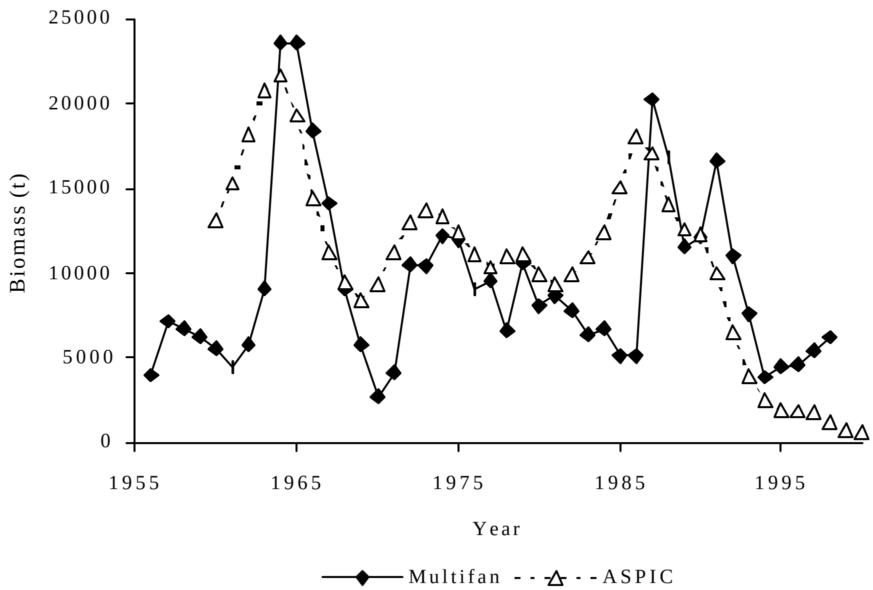

Figure 24: Comparison of area 5CD Pacific cod biomass estimates from the previous analytical assessment (Multifan) and this assessment.

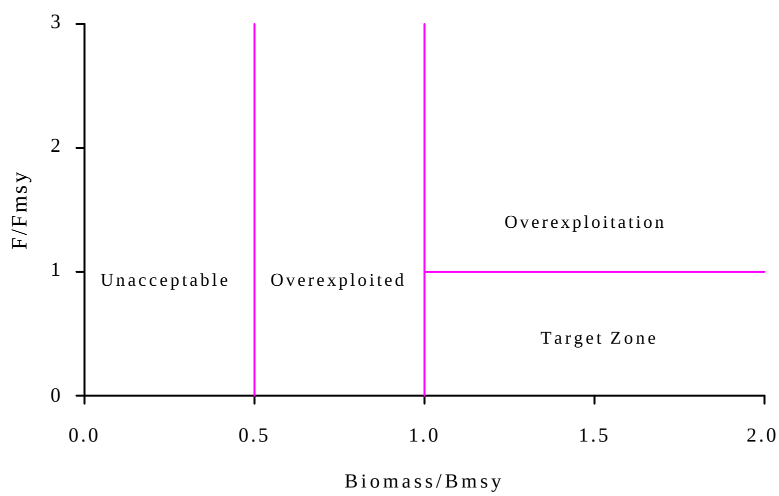

Figure 25: A harvest strategy framework consistent with the Precautionsry Approach modified from Richards and Schnute (2000), Appendix E.

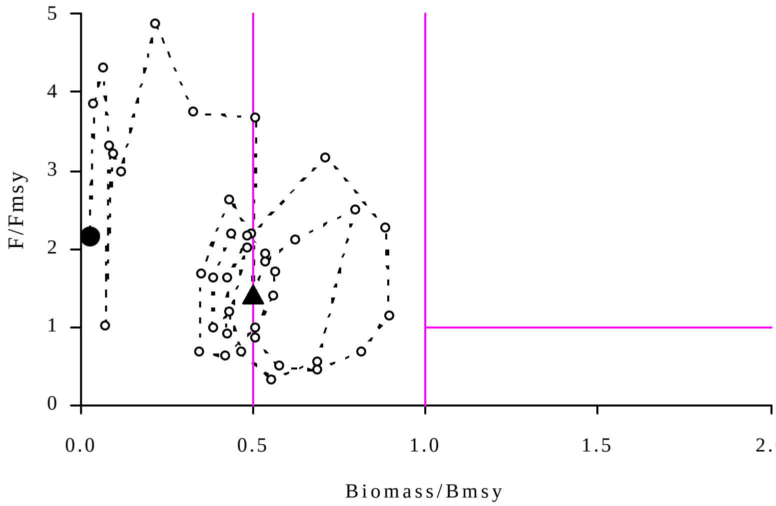

Figure 26: Phase plot of F and Biomass, relative to Fmsy and Bmsy, for area 5CD Pacific cod, 1960-2000. The solid triangular symbol is 1960 and the solid circle is 2000.

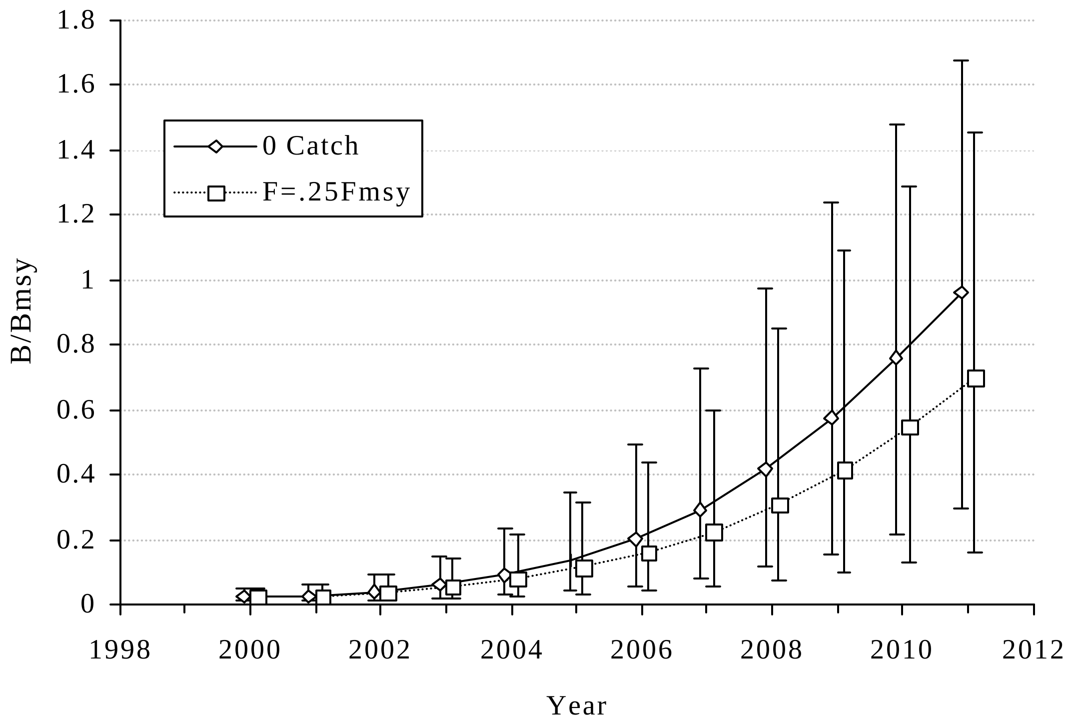

Figure 27: Biomass projections for Pacific cod in area 5CD, 2000-2011. Two catch scenarios were used, 0 catch and F = .25·F_{msy}. The error bars indicate 80% confidence intervals.

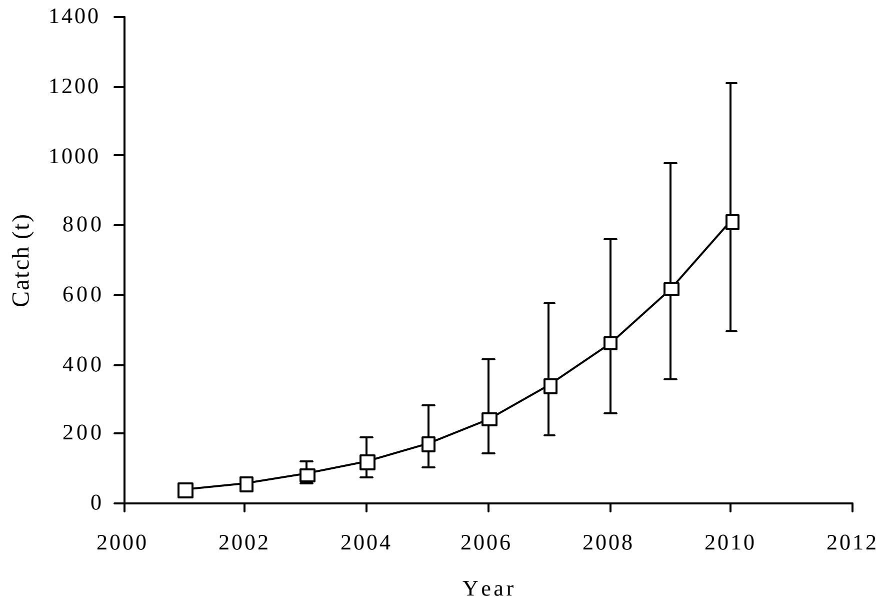

Figure 28: Projected catches of Pacific cod in area 5CD where F = .25·F_{msy}. for 10 years. The error bars indicate 80% confidence intervals.

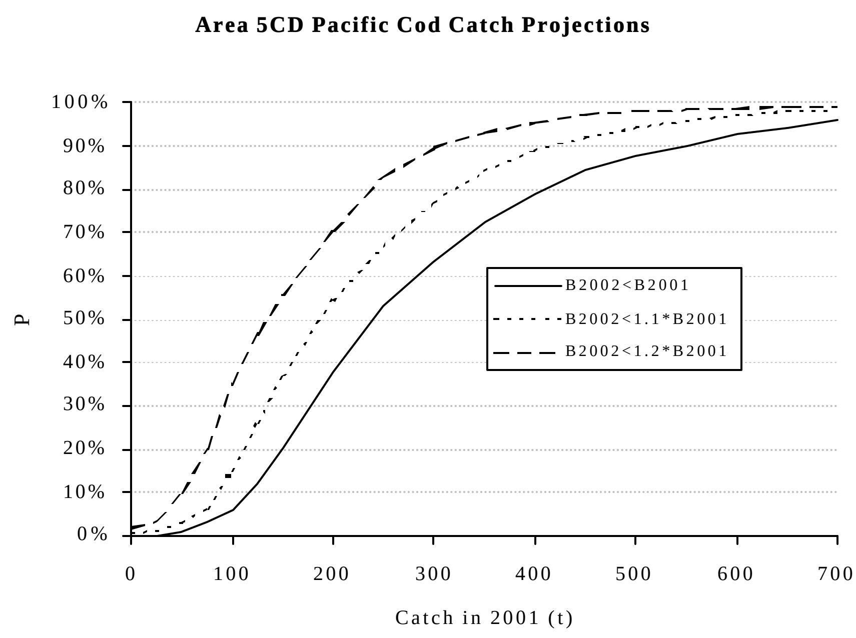

Figure 29: Probability of stock biomass declining (solid line), stock biomass not increasing by 10% (dotted line) and stock biomass not increasing by 20% as a result of a range of catches in 2001.

Annex 1: Output from ASPIC

```
ASPIC Pacific Cod Hecate Strait, proportional U                                                     Page 1
                                                                                      04 Oct 2000 at 12:01.48
ASPIC -- A Surplus-Production Model Including Covariates (Ver. 3.82)                              BOT Mode

Author: Michael H. Prager; NOAA/NMFS/S.E. Fisheries Science Center                         ASPIC User's Manual
        101 Pivers Island Road; Beaufort, North Carolina  28516  USA                       is available gratis
                                                                                              from the author.

Ref:    Prager, M. H.  1994.  A suite of extensions to a nonequilibrium
        surplus-production model.  Fishery Bulletin 92: 374-389.


CONTROL PARAMETERS USED (FROM INPUT FILE)
------------------------------------------------------------------------------------------------------------------
Number of years analyzed:                        41          Number of bootstrap trials:                      600
Number of data series:                            2          Lower bound on MSY:                        1.000E+03
Objective function computed:              in effort          Upper bound on MSY:                        1.000E+05
Relative conv. criterion (simplex):       1.000E-08          Lower bound on r:                          2.000E-02
Relative conv. criterion (restart):       3.000E-08          Upper bound on r:                          4.000E+00
Relative conv. criterion (effort):        1.000E-04          Random number seed:                          9126738
Maximum F allowed in fitting:                 8.000          Monte Carlo search mode, trials:          1    10000


PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS)                                                   code  0
------------------------------------------------------------------------------------------------------------------
Normal convergence.

CORRELATION AMONG INPUT SERIES EXPRESSED AS CPUE (NUMBER OF PAIRWISE OBSERVATIONS BELOW)
------------------------------------------------------------------------------------------------------------------
                                       |
 1  Hecate Strait P Cod long U         |   1.000
                                       |      36
                                       |
 2  Hecate Strait P Cod short U        |   1.000   1.000
                                       |       2       7
                                       --------------------------------------------------
                                               1       2


GOODNESS-OF-FIT AND WEIGHTING FOR NON-BOOTSTRAPPED ANALYSIS
------------------------------------------------------------------------------------------------------------------
                                                    Weighted            Weighted      Current    Suggested    R-squared
Loss component number and title                          SSE    N            MSE       weight       weight      in CPUE

Loss(-1)  SSE in yield                             0.000E+00
Loss( 0)  Penalty for B1R > 2                      0.000E+00    1            N/A    0.000E+00          N/A
Loss( 1)  Hecate Strait P Cod long U               6.987E+00   36      2.055E-01    1.000E+00    5.660E-01        0.351
Loss( 2)  Hecate Strait P Cod short U              1.800E-01    7      3.599E-02    1.000E+00    3.232E+00        0.810
TOTAL OBJECTIVE FUNCTION:                     7.16706206E+00

Number of restarts required for convergence:              39
Est. B-ratio coverage index (0 worst, 2 best):        0.8679            < These two measures are defined in Prager
Est. B-ratio nearness index (0 worst, 1 best):        0.8942            <     et al. (1996), Trans. A.F.S. 125:729


MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)
------------------------------------------------------------------------------------------------------------------
Parameter                                           Estimate     Starting guess    Estimated   User guess

B1R       Starting biomass ratio, year 1960        5.055E-01          5.000E-01            1            1
MSY       Maximum sustainable yield                5.075E+03          5.000E+03            1            1
r         Intrinsic rate of increase               4.161E-01          3.000E-01            1            1
........  Catchability coefficients by fishery:
q( 1)     Hecate Strait P Cod long U               2.565E-05          1.000E-05            1            1
q( 2)     Hecate Strait P Cod short U              1.454E-02          1.000E-02            1            1


MANAGEMENT PARAMETER ESTIMATES (NON-BOOTSTRAPPED)
------------------------------------------------------------------------------------------------------------------
Parameter                                           Estimate            Formula        Related quantity

MSY       Maximum sustainable yield                5.075E+03               Kr/4
K         Maximum stock biomass                    4.879E+04
Bmsy      Stock biomass at MSY                     2.439E+04                K/2
Fmsy      Fishing mortality at MSY                 2.081E-01                r/2

F(0.1)    Management benchmark                     1.873E-01           0.9*Fmsy
Y(0.1)    Equilibrium yield at F(0.1)              5.024E+03           0.99*MSY

B-ratio   Ratio of B(2001) to Bmsy                 2.531E-02
F-ratio   Ratio of F(2000) to Fmsy                 2.161E+00
F01-mult  Ratio of F(0.1) to F(2000)               4.165E-01
```

```
Y-ratio   Proportion of MSY avail in 2001          4.998E-02          2*Br-Br^2     Ye(2001) = 2.536E+02

........  Fishing effort at MSY in units of each fishery:
fmsy( 1)  Hecate Strait P Cod long U               8.113E+03           r/2q( 1)       f(0.1) = 7.302E+03
```

ESTIMATED POPULATION TRAJECTORY (NON-BOOTSTRAPPED)

Obs	Year or ID	Estimated total F mort	Estimated starting biomass	Estimated average biomass	Observed total yield	Model total yield	Estimated surplus production	Ratio of F mort to Fmsy	Ratio of biomass to Bmsy
1	1960	0.180	1.233E+04	1.315E+04	2.360E+03	2.360E+03	3.995E+03	8.628E-01	5.055E-01
2	1961	0.105	1.397E+04	1.533E+04	1.616E+03	1.616E+03	4.369E+03	5.066E-01	5.725E-01
3	1962	0.093	1.672E+04	1.824E+04	1.690E+03	1.690E+03	4.746E+03	4.452E-01	6.854E-01
4	1963	0.141	1.978E+04	2.081E+04	2.927E+03	2.927E+03	4.963E+03	6.761E-01	8.107E-01
5	1964	0.241	2.181E+04	2.170E+04	5.228E+03	5.228E+03	5.013E+03	1.158E+00	8.942E-01
6	1965	0.472	2.160E+04	1.932E+04	9.119E+03	9.119E+03	4.843E+03	2.268E+00	8.854E-01
7	1966	0.659	1.732E+04	1.445E+04	9.519E+03	9.519E+03	4.213E+03	3.166E+00	7.101E-01
8	1967	0.455	1.201E+04	1.123E+04	5.112E+03	5.112E+03	3.595E+03	2.189E+00	4.925E-01
9	1968	0.547	1.050E+04	9.450E+03	5.165E+03	5.165E+03	3.168E+03	2.627E+00	4.303E-01
10	1969	0.353	8.500E+03	8.461E+03	2.987E+03	2.987E+03	2.910E+03	1.697E+00	3.485E-01
11	1970	0.141	8.423E+03	9.314E+03	1.315E+03	1.315E+03	3.134E+03	6.785E-01	3.453E-01
12	1971	0.131	1.024E+04	1.129E+04	1.477E+03	1.477E+03	3.608E+03	6.287E-01	4.199E-01
13	1972	0.207	1.237E+04	1.301E+04	2.696E+03	2.696E+03	3.969E+03	9.960E-01	5.072E-01
14	1973	0.292	1.365E+04	1.370E+04	3.996E+03	3.996E+03	4.100E+03	1.402E+00	5.594E-01
15	1974	0.356	1.375E+04	1.338E+04	4.766E+03	4.766E+03	4.040E+03	1.713E+00	5.636E-01
16	1975	0.406	1.302E+04	1.241E+04	5.036E+03	5.036E+03	3.849E+03	1.950E+00	5.339E-01
17	1976	0.450	1.184E+04	1.110E+04	4.993E+03	4.993E+03	3.566E+03	2.163E+00	4.852E-01
18	1977	0.339	1.041E+04	1.035E+04	3.510E+03	3.510E+03	3.393E+03	1.630E+00	4.267E-01
19	1978	0.191	1.029E+04	1.101E+04	2.103E+03	2.103E+03	3.546E+03	9.182E-01	4.219E-01
20	1979	0.421	1.173E+04	1.116E+04	4.699E+03	4.699E+03	3.580E+03	2.024E+00	4.810E-01
21	1980	0.455	1.061E+04	9.972E+03	4.542E+03	4.542E+03	3.300E+03	2.189E+00	4.352E-01
22	1981	0.341	9.373E+03	9.351E+03	3.190E+03	3.190E+03	3.145E+03	1.640E+00	3.843E-01
23	1982	0.208	9.328E+03	9.937E+03	2.066E+03	2.066E+03	3.292E+03	9.992E-01	3.824E-01
24	1983	0.248	1.055E+04	1.097E+04	2.715E+03	2.715E+03	3.537E+03	1.190E+00	4.327E-01
25	1984	0.141	1.138E+04	1.242E+04	1.748E+03	1.748E+03	3.848E+03	6.767E-01	4.664E-01
26	1985	0.071	1.348E+04	1.509E+04	1.064E+03	1.064E+03	4.329E+03	3.390E-01	5.525E-01
27	1986	0.116	1.674E+04	1.806E+04	2.099E+03	2.099E+03	4.728E+03	5.587E-01	6.863E-01
28	1987	0.519	1.937E+04	1.710E+04	8.870E+03	8.870E+03	4.609E+03	2.493E+00	7.941E-01
29	1988	0.441	1.511E+04	1.404E+04	6.199E+03	6.199E+03	4.159E+03	2.121E+00	6.194E-01
30	1989	0.380	1.307E+04	1.261E+04	4.788E+03	4.788E+03	3.890E+03	1.825E+00	5.358E-01
31	1990	0.294	1.217E+04	1.228E+04	3.607E+03	3.607E+03	3.824E+03	1.412E+00	4.990E-01
32	1991	0.764	1.239E+04	1.002E+04	7.655E+03	7.655E+03	3.301E+03	3.670E+00	5.079E-01
33	1992	0.779	8.034E+03	6.552E+03	5.103E+03	5.103E+03	2.355E+03	3.743E+00	3.294E-01
34	1993	1.013	5.287E+03	3.916E+03	3.965E+03	3.965E+03	1.494E+03	4.867E+00	2.167E-01
35	1994	0.619	2.816E+03	2.521E+03	1.561E+03	1.561E+03	9.948E+02	2.976E+00	1.154E-01
36	1995	0.671	2.250E+03	1.969E+03	1.322E+03	1.322E+03	7.861E+02	3.227E+00	9.223E-02
37	1996	0.210	1.714E+03	1.888E+03	3.970E+02	3.970E+02	7.550E+02	1.011E+00	7.026E-02
38	1997	0.690	2.072E+03	1.798E+03	1.241E+03	1.241E+03	7.206E+02	3.316E+00	8.494E-02
39	1998	0.897	1.551E+03	1.225E+03	1.099E+03	1.099E+03	4.969E+02	4.311E+00	6.360E-02
40	1999	0.801	9.493E+02	7.854E+02	6.290E+02	6.290E+02	3.215E+02	3.849E+00	3.892E-02
41	2000	0.450	6.418E+02	6.295E+02	2.830E+02	2.830E+02	2.586E+02	2.161E+00	2.631E-02
42	2001		6.173E+02						2.531E-02

RESULTS FOR DATA SERIES # 1 (NON-BOOTSTRAPPED)   Hecate Strait P Cod long U

Data type CC: CPUE-catch series   Series weight: 1.000

Obs	Year	Observed CPUE	Estimated CPUE	Estim F	Observed yield	Model yield	Resid in log scale	Resid in yield
1	1960	2.717E-01	3.372E-01	0.1795	2.360E+03	2.360E+03	0.21604	0.000E+00
2	1961	2.021E-01	3.932E-01	0.1054	1.616E+03	1.616E+03	0.66569	0.000E+00
3	1962	2.223E-01	4.679E-01	0.0926	1.690E+03	1.690E+03	0.74424	0.000E+00
4	1963	4.590E-01	5.336E-01	0.1407	2.927E+03	2.927E+03	0.15060	0.000E+00
5	1964	7.414E-01	5.565E-01	0.2409	5.228E+03	5.228E+03	-0.28683	0.000E+00
6	1965	8.082E-01	4.955E-01	0.4720	9.119E+03	9.119E+03	-0.48918	0.000E+00
7	1966	6.068E-01	3.706E-01	0.6587	9.519E+03	9.519E+03	-0.49294	0.000E+00
8	1967	6.285E-01	2.879E-01	0.4554	5.112E+03	5.112E+03	-0.78075	0.000E+00
9	1968	3.085E-01	2.424E-01	0.5466	5.165E+03	5.165E+03	-0.24140	0.000E+00
10	1969	2.222E-01	2.170E-01	0.3530	2.987E+03	2.987E+03	-0.02368	0.000E+00
11	1970	1.256E-01	2.389E-01	0.1412	1.315E+03	1.315E+03	0.64261	0.000E+00
12	1971	1.231E-01	2.896E-01	0.1308	1.477E+03	1.477E+03	0.85503	0.000E+00
13	1972	3.399E-01	3.337E-01	0.2072	2.696E+03	2.696E+03	-0.01850	0.000E+00
14	1973	5.536E-01	3.513E-01	0.2917	3.996E+03	3.996E+03	-0.45483	0.000E+00
15	1974	6.375E-01	3.430E-01	0.3563	4.766E+03	4.766E+03	-0.61974	0.000E+00
16	1975	4.819E-01	3.182E-01	0.4058	5.036E+03	5.036E+03	-0.41487	0.000E+00
17	1976	3.774E-01	2.846E-01	0.4500	4.993E+03	4.993E+03	-0.28238	0.000E+00
18	1977	2.811E-01	2.654E-01	0.3392	3.510E+03	3.510E+03	-0.05729	0.000E+00
19	1978	2.365E-01	2.823E-01	0.1910	2.103E+03	2.103E+03	0.17700	0.000E+00
20	1979	2.755E-01	2.861E-01	0.4212	4.699E+03	4.699E+03	0.03775	0.000E+00
21	1980	2.786E-01	2.558E-01	0.4555	4.542E+03	4.542E+03	-0.08569	0.000E+00
22	1981	2.452E-01	2.398E-01	0.3412	3.190E+03	3.190E+03	-0.02240	0.000E+00
23	1982	2.304E-01	2.549E-01	0.2079	2.066E+03	2.066E+03	0.10096	0.000E+00
24	1983	3.043E-01	2.813E-01	0.2476	2.715E+03	2.715E+03	-0.07875	0.000E+00
25	1984	2.254E-01	3.184E-01	0.1408	1.748E+03	1.748E+03	0.34567	0.000E+00
26	1985	1.288E-01	3.869E-01	0.0705	1.064E+03	1.064E+03	1.10019	0.000E+00
27	1986	2.400E-01	4.631E-01	0.1162	2.099E+03	2.099E+03	0.65751	0.000E+00
28	1987	8.959E-01	4.386E-01	0.5187	8.870E+03	8.870E+03	-0.71427	0.000E+00
29	1988	4.326E-01	3.602E-01	0.4414	6.199E+03	6.199E+03	-0.18319	0.000E+00
30	1989	2.522E-01	3.233E-01	0.3798	4.788E+03	4.788E+03	0.24849	0.000E+00
31	1990	2.598E-01	3.150E-01	0.2937	3.607E+03	3.607E+03	0.19268	0.000E+00
32	1991	3.317E-01	2.571E-01	0.7637	7.655E+03	7.655E+03	-0.25486	0.000E+00
33	1992	1.936E-01	1.680E-01	0.7788	5.103E+03	5.103E+03	-0.14177	0.000E+00
34	1993	1.438E-01	1.004E-01	1.0126	3.965E+03	3.965E+03	-0.35880	0.000E+00
35	1994	6.978E-02	6.466E-02	0.6191	1.561E+03	1.561E+03	-0.07618	0.000E+00
36	1995	5.728E-02	5.050E-02	0.6714	1.322E+03	1.322E+03	-0.12610	0.000E+00
37	1996	*	4.841E-02	0.2103	3.970E+02	3.970E+02	0.00000	0.000E+00
38	1997	*	4.612E-02	0.6900	1.241E+03	1.241E+03	0.00000	0.000E+00
39	1998	*	3.142E-02	0.8969	1.099E+03	1.099E+03	0.00000	0.000E+00
40	1999	*	2.014E-02	0.8009	6.290E+02	6.290E+02	0.00000	0.000E+00
41	2000	*	1.614E-02	0.4496	2.830E+02	2.830E+02	0.00000	0.000E+00

* Asterisk indicates missing value(s).

```
UNWEIGHTED LOG RESIDUAL PLOT FOR DATA SERIES # 1
                   -2       -1.5       -1       -0.5        0       0.5        1       1.5        2
                    |    .    |    .    |    .    |    .    |    .    |    .    |    .    |    .    |
Year   Residual    -------------------------------------------------------------------------------------
1960     0.2160                                             |====
1961     0.6657                                             |=============
1962     0.7442                                             |===============
1963     0.1506                                             |===
1964    -0.2868                                       ======|
1965    -0.4892                                   ==========|
1966    -0.4929                                   ==========|
1967    -0.7807                             ================|
1968    -0.2414                                        =====|
1969    -0.0237                                             |
1970     0.6426                                             |=============
1971     0.8550                                             |=================
1972    -0.0185                                             |
1973    -0.4548                                    =========|
1974    -0.6197                                 ============|
1975    -0.4149                                     ========|
1976    -0.2824                                       ======|
1977    -0.0573                                            =|
1978     0.1770                                             |====
1979     0.0378                                             |=
1980    -0.0857                                           ==|
1981    -0.0224                                             |
1982     0.1010                                             |==
1983    -0.0787                                           ==|
1984     0.3457                                             |=======
1985     1.1002                                             |======================
1986     0.6575                                             |=============
1987    -0.7143                               ==============|
1988    -0.1832                                         ====|
1989     0.2485                                             |=====
1990     0.1927                                             |====
1991    -0.2549                                        =====|
1992    -0.1418                                          ===|
1993    -0.3588                                      =======|
1994    -0.0762                                           ==|
1995    -0.1261                                          ===|
1996     0.0000                                             |
1997     0.0000                                             |
1998     0.0000                                             |
1999     0.0000                                             |
2000     0.0000                                             |
                   -------------------------------------------------------------------------------------
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RESULTS FOR DATA SERIES # 2 (NON-BOOTSTRAPPED) Hecate Strait P Cod short U

Data type I1: Year-average biomass index Series weight: 1.000

Obs	Year	Observed effort	Estimated effort	Estim F	Observed index	Model index	Resid in log index	Resid in index
1	1960	0.000E+00	0.000E+00	0.0	*	1.911E+02	0.00000	0.0
2	1961	0.000E+00	0.000E+00	0.0	*	2.229E+02	0.00000	0.0
3	1962	0.000E+00	0.000E+00	0.0	*	2.652E+02	0.00000	0.0
4	1963	0.000E+00	0.000E+00	0.0	*	3.025E+02	0.00000	0.0
5	1964	0.000E+00	0.000E+00	0.0	*	3.155E+02	0.00000	0.0
6	1965	0.000E+00	0.000E+00	0.0	*	2.809E+02	0.00000	0.0
7	1966	0.000E+00	0.000E+00	0.0	*	2.101E+02	0.00000	0.0
8	1967	0.000E+00	0.000E+00	0.0	*	1.632E+02	0.00000	0.0
9	1968	0.000E+00	0.000E+00	0.0	*	1.374E+02	0.00000	0.0
10	1969	0.000E+00	0.000E+00	0.0	*	1.230E+02	0.00000	0.0
11	1970	0.000E+00	0.000E+00	0.0	*	1.354E+02	0.00000	0.0
12	1971	0.000E+00	0.000E+00	0.0	*	1.641E+02	0.00000	0.0
13	1972	0.000E+00	0.000E+00	0.0	*	1.891E+02	0.00000	0.0
14	1973	0.000E+00	0.000E+00	0.0	*	1.991E+02	0.00000	0.0
15	1974	0.000E+00	0.000E+00	0.0	*	1.944E+02	0.00000	0.0
16	1975	0.000E+00	0.000E+00	0.0	*	1.804E+02	0.00000	0.0
17	1976	0.000E+00	0.000E+00	0.0	*	1.613E+02	0.00000	0.0
18	1977	0.000E+00	0.000E+00	0.0	*	1.504E+02	0.00000	0.0
19	1978	0.000E+00	0.000E+00	0.0	*	1.600E+02	0.00000	0.0
20	1979	0.000E+00	0.000E+00	0.0	*	1.622E+02	0.00000	0.0
21	1980	0.000E+00	0.000E+00	0.0	*	1.450E+02	0.00000	0.0
22	1981	0.000E+00	0.000E+00	0.0	*	1.359E+02	0.00000	0.0
23	1982	0.000E+00	0.000E+00	0.0	*	1.445E+02	0.00000	0.0
24	1983	0.000E+00	0.000E+00	0.0	*	1.594E+02	0.00000	0.0
25	1984	0.000E+00	0.000E+00	0.0	*	1.805E+02	0.00000	0.0
26	1985	0.000E+00	0.000E+00	0.0	*	2.193E+02	0.00000	0.0
27	1986	0.000E+00	0.000E+00	0.0	*	2.625E+02	0.00000	0.0
28	1987	0.000E+00	0.000E+00	0.0	*	2.486E+02	0.00000	0.0
29	1988	0.000E+00	0.000E+00	0.0	*	2.042E+02	0.00000	0.0
30	1989	0.000E+00	0.000E+00	0.0	*	1.833E+02	0.00000	0.0
31	1990	0.000E+00	0.000E+00	0.0	*	1.785E+02	0.00000	0.0
32	1991	0.000E+00	0.000E+00	0.0	*	1.457E+02	0.00000	0.0
33	1992	0.000E+00	0.000E+00	0.0	*	9.525E+01	0.00000	0.0
34	1993	0.000E+00	0.000E+00	0.0	*	5.692E+01	0.00000	0.0
35	1994	1.000E+00	1.000E+00	0.0	3.263E+01	3.665E+01	-0.11617	-4.020E+00
36	1995	1.000E+00	1.000E+00	0.0	2.865E+01	2.862E+01	0.00080	2.298E-02
37	1996	1.000E+00	1.000E+00	0.0	2.122E+01	2.744E+01	-0.25716	-6.222E+00
38	1997	1.000E+00	1.000E+00	0.0	2.892E+01	2.614E+01	0.10076	2.772E+00
39	1998	1.000E+00	1.000E+00	0.0	2.305E+01	1.781E+01	0.25768	5.235E+00
40	1999	1.000E+00	1.000E+00	0.0	1.262E+01	1.142E+01	0.10029	1.204E+00
41	2000	1.000E+00	1.000E+00	0.0	8.139E+00	9.150E+00	-0.11713	-1.011E+00

* Asterisk indicates missing value(s).

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UNWEIGHTED LOG RESIDUAL PLOT FOR DATA SERIES # 2
                   -1       -0.75     -0.5      -0.25       0        0.25      0.5       0.75       1
                    |    .    |    .    |    .    |    .    |    .    |    .    |    .    |    .    |
Year   Residual    ------------------------------------------------------------------------------------
1960     0.0000                                             |
1961     0.0000                                             |
1962     0.0000                                             |
1963     0.0000                                             |
1964     0.0000                                             |
1965     0.0000                                             |
1966     0.0000                                             |
1967     0.0000                                             |
1968     0.0000                                             |
1969     0.0000                                             |
1970     0.0000                                             |
1971     0.0000                                             |
1972     0.0000                                             |
1973     0.0000                                             |
1974     0.0000                                             |
1975     0.0000                                             |
1976     0.0000                                             |
1977     0.0000                                             |
1978     0.0000                                             |
1979     0.0000                                             |
1980     0.0000                                             |
1981     0.0000                                             |
1982     0.0000                                             |
1983     0.0000                                             |
1984     0.0000                                             |
1985     0.0000                                             |
1986     0.0000                                             |
1987     0.0000                                             |
1988     0.0000                                             |
1989     0.0000                                             |
1990     0.0000                                             |
1991     0.0000                                             |
1992     0.0000                                             |
1993     0.0000                                             |
1994    -0.1162                                        =====|
1995     0.0008                                             |
1996    -0.2572                                   ==========|
1997     0.1008                                             |====
1998     0.2577                                             |==========
1999     0.1003                                             |====
2000    -0.1171                                        =====|
                   ------------------------------------------------------------------------------------
```

RESULTS OF BOOTSTRAPPED ANALYSIS

Param name	Bias-corrected estimate	Ordinary estimate	Relative bias	Approx 80% lower CL	Approx 80% upper CL	Approx 50% lower CL	Approx 50% upper CL	Inter-quartile range	Relative IQ range
B1ratio	4.870E-01	5.055E-01	3.80%	1.239E-01	7.694E-01	3.130E-01	5.560E-01	2.430E-01	0.499
K	4.907E+04	4.879E+04	-0.59%	3.571E+04	1.409E+05	4.367E+04	6.462E+04	2.096E+04	0.427
r	4.202E-01	4.161E-01	-0.97%	3.052E-01	5.313E-01	3.748E-01	4.667E-01	9.190E-02	0.219
q(1)	2.711E-05	2.565E-05	-5.40%	2.231E-05	3.092E-05	2.486E-05	2.853E-05	3.666E-06	0.135
q(2)	1.512E-02	1.454E-02	-3.83%	1.127E-02	2.049E-02	1.313E-02	1.766E-02	4.534E-03	0.300
MSY	5.143E+03	5.075E+03	-1.32%	4.361E+03	1.372E+04	4.852E+03	6.866E+03	2.014E+03	0.392
Ye(2001)	2.695E+02	2.536E+02	-5.88%	1.314E+02	6.122E+02	1.792E+02	4.144E+02	2.352E+02	0.873
Bmsy	2.454E+04	2.439E+04	-0.59%	1.785E+04	7.044E+04	2.183E+04	3.231E+04	1.048E+04	0.427
Fmsy	2.101E-01	2.081E-01	-0.97%	1.526E-01	2.657E-01	1.874E-01	2.333E-01	4.595E-02	0.219
fmsy(1)	7.966E+03	8.113E+03	1.84%	6.444E+03	9.534E+03	7.277E+03	8.613E+03	1.335E+03	0.168
fmsy(2)	1.431E+01	1.431E+01	0.03%	1.069E+01	1.881E+01	1.234E+01	1.661E+01	4.278E+00	0.299
F(0.1)	1.891E-01	1.873E-01	-0.88%	1.373E-01	2.391E-01	1.687E-01	2.100E-01	4.135E-02	0.219
Y(0.1)	5.092E+03	5.024E+03	-1.31%	4.318E+03	1.358E+04	4.803E+03	6.797E+03	1.994E+03	0.392
B-ratio	2.699E-02	2.531E-02	-6.24%	1.115E-02	6.219E-02	1.703E-02	4.215E-02	2.512E-02	0.931
F-ratio	2.038E+00	2.161E+00	6.03%	9.641E-01	3.595E+00	1.406E+00	2.867E+00	1.461E+00	0.717
Y-ratio	5.351E-02	4.998E-02	-6.60%	2.254E-02	1.192E-01	3.398E-02	8.252E-02	4.854E-02	0.907
f0.1(1)	7.169E+03	7.302E+03	1.66%	5.799E+03	8.581E+03	6.550E+03	7.751E+03	1.202E+03	0.168
f0.1(2)	1.288E+01	1.288E+01	0.03%	9.625E+00	1.693E+01	1.110E+01	1.495E+01	3.850E+00	0.299
q2/q1	5.586E+02	5.668E+02	1.47%	4.165E+02	7.793E+02	4.870E+02	6.627E+02	1.757E+02	0.315

NOTES ON BOOTSTRAPPED ESTIMATES

- The bootstrapped results shown were computed from 600 trials.
- These results are conditional on the constraints placed upon MSY and r in the input file (ASPIC.INP).
- All bootstrapped intervals are approximate. The statistical literature recommends using at least 1000 trials for accurate 95% intervals. The 80% intervals used by ASPIC should require fewer trials for equivalent accuracy. Using at least 500 trials is recommended.
- The bias corrections used here are based on medians. This is an accepted statistical procedure, but may estimate nonzero bias for unbiased, skewed estimators.

Trials replaced for lack of convergence:	45
Trials replaced for MSY out-of-bounds:	8
Trials replaced for r out-of-bounds:	40
Residual-adjustment factor:	1.0638