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Research Document 2000/154

Document de recherche 2000/154

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Assessment of the Canadian longspine thornyhead (*Sebastolobus altivelis*) for 2000

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ISSN 1480-4883
Ottawa, 2000
Canadä

1. ABSTRACT

A detailed compilation and analysis of the available data for longspine thornyheads (*Sebastolobus altivelis*) found in west coast Canadian waters is presented. This analysis was prompted by concerns over the rapid development of a new bottom trawl fishery directed at this species since 1996. An analysis of the available length frequency data from the commercial fishery showed that these distributions have been quite stationary over the four years of the fishery. Relative abundance indices estimated from CPUE data using general linear modelling methods showed a 16% decline in biomass over the four year history of the fishery. Population modelling using a dynamic age-structured model fitted to the estimated relative biomass indices and the annual observations of length structure in the commercial fishery estimate that the population has declined between 10 and 30% over the four years of the fishery. These estimates are unreliable due to the lack of a validated growth function and uncertain estimates for natural mortality. This report recommends the development of an independent biomass survey for this species and further research on growth rates. This report also hypothesises that this species may have very wide stock boundaries due to its extended pelagic larval phase (18-20 months) and the consequent opportunity for wide dispersal due to prevailing ocean currents.

1.2. RÉSUMÉ

Ce rapport présente une compilation et une analyse détaillées des données disponibles sur le sébastolobe à longues épines (*Sebastolobus altivelis*) des eaux de la côte ouest canadienne. L’analyse a été réalisée pour donner suite aux préoccupations concernant le développement rapide d’une nouvelle pêche dirigée de cette espèce au chalut de fond depuis 1996. L’analyse des fréquences de longueurs disponibles des prises commerciales indique que ces distributions sont restés stables au cours de cette pêche qui dure depuis quatre ans. Les indices d’abondance relative estimés à partir des données de CPUE à l’aide de modèles linéaires généraux montrent que la biomasse a baissé de 16 % durant ces quatre années. Selon un modèle dynamique de structure par âge ajusté aux estimations d'indices de biomasse relative et aux observations annuelles de la structure par longueur de l'estimation des prises commerciales, la taille de la population aurait diminué de 10 à 30 % depuis le début de cette pêche. Toutefois, ces estimations ne sont pas fiables, car la fonction de croissance n’est pas validée et les estimations de la mortalité naturelle sont incertaines. Ce rapport recommande d’effectuer un relevé indépendant de la biomasse de cette espèce ainsi que des études approfondies sur ses taux de croissance. En outre, le rapport émet l’hypothèse que les aires des stocks de l’espèce seraient très vastes en raison de la longue durée de son stade de larve pélagique (de 18 à 20 mois) et donc de la possibilité d’une grande dispersion par les courants marins dominants.

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2. INTRODUCTION AND BACKGROUND

The fishery for longspine thornyheads (*Sebastolobus altivelis*) has had a relatively short history on the Canadian west coast, with the fishery on this species beginning only in early 1996. Prior to that year, it is likely that this species was taken in small amounts coincidentally with its congener *Sebastolobus alascanus* (shortspine thornyheads), but the identification of thornyhead catch at the species level was not available until the introduction of comprehensive observer coverage in early 1996. Both species are most abundant in the depth ranges from 600 to 1200 m (Wakefield 1990) and the fishery at these depths did not develop until recently.

The largest catches for this species have been taken in waters off the south-west coast of Vancouver Island, but the fishery is presently expanding northward to the northern sections of Vancouver Island, the west coast of the Queen Charlotte Islands and to Dixon Entrance through an exploratory fishing program implemented by DFO in 2000. A coastwide quota of 860 t was set for this species in 1997 at the same time as the introduction of “individual vessel quotas” which are used to manage all slope rockfish species (Schnute et al. 1999). This coastwide quota was reduced to 425 t on 1 April 2000. However, an additional 425 t of “exploratory” quota was allocated for longspines for those areas “north and west of a line drawn 230° true from the light located on Lookout Island located at 49°59’52.1” north latitude and 127°26’57.3” west longitude on the upper west coast of Vancouver Island” (Anonymous 2000). This new regulation has maintained the same coastwide quota but has effectively halved the catch south of Nootka Sound where previously the large majority of fishing has taken place.

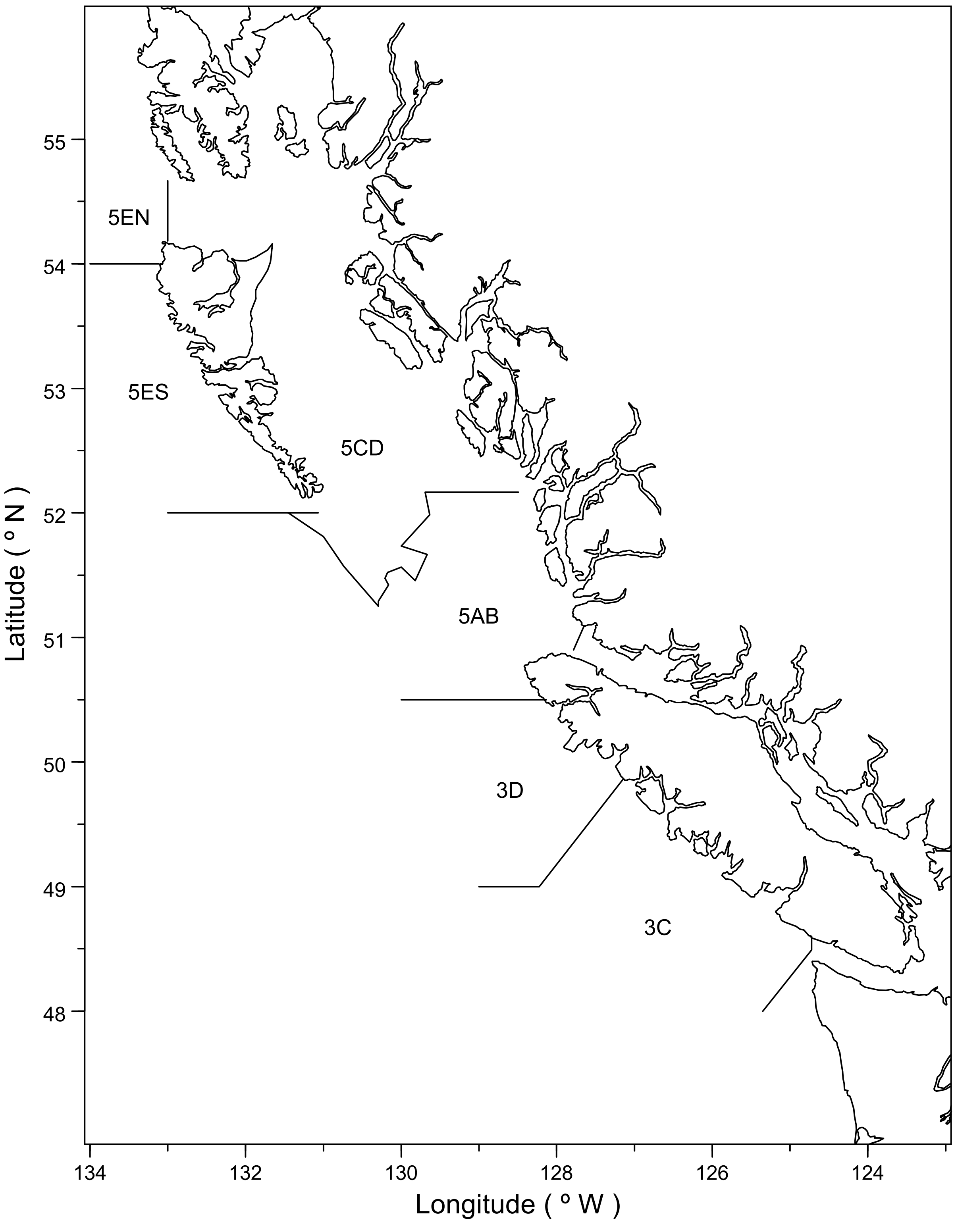


Figure 1. Map of the Pacific west coast of Canada showing the locations of the SRF_Areas (=slope rockfish management areas) referred to in the text.

The two *Sebastolobus* species overlap in distribution and appear morphologically similar. Both species of thornyheads have a long pelagic larval phase where they will be subject to considerable dispersion due to the prevailing ocean currents. Shortspines appear to settle at shallower depths and migrate to deeper depths (Jacobson and Vetter 1996) while longspines settle immediately at the deeper depths (Wakefield 1990). The effect of this behavioural difference is that shortspines are considerably larger than most longspines in the depths where they overlap. Jacobson and Vetter (1996) point out that both species have similar peak reproductive depths.

Neither thornyhead species is found in aggregated schools but instead both are distributed uniformly over soft sediments (Wakefield 1990). This distribution leads to relatively low catch rates in the fishery and commercial vessels typically tow for long periods (up to 16 hours) to catch sufficient product.

Approximately 10% of both sexes have reached sexual maturity at 190 mm (Ianelli et al. 1994), which is also the retention size for this species in the commercial fishery. This size equates to approximately age 12 using the growth function provided in Kline (1996) and which has been adopted for this assessment. The modal size in the commercial fishery is 240 mm, corresponding to age 20 (~80% mature) using the same growth function.

Presently about 12 to 15 bottom trawl vessels specialise in taking the two *Sebastolobus* species in a fishery that extends from early spring to late autumn. The fish are sorted by size and the smaller fish are frozen whole at sea for export to Japan. The larger fish (primarily shortspine thornyheads) are headed and gutted before freezing. The tows are long (often 12 or more hours in length) and frequently double back on themselves so that a vessel tends to begin and end its tows in the same general location.

The Canadian Groundfish Research and Conservation Society, in support of its commitment towards the sustainable use of the resource on which its members depend, has commissioned this report. The intent of this report is to compile all available information pertinent to Canadian longspine thornyheads and to assess the status of this species given the quality and quantity of information available.

3. DATA SOURCES AND PREPARATION

Details regarding the preparation and analysis of the length frequency and catch and effort data used in this report are provided in Appendix 2 (page 55). A detailed analysis of the available weight-at-length data for this species is presented in Appendix 3 (page 61).

3.1 GROWTH RATES

There is no reliable growth rate information available for this species (J. Ianelli – NOAA, Alaska Fisheries Centre, pers. comm.; Waldo Wakefield – NOAA, Northwest Fisheries Science Centre, Newport, Oregon, pers. comm.). Growth rates have been estimated from unvalidated counts of rings in sectioned otoliths (Ianelli et al. 1994) and attempts have been made to validate these counts using radiometric techniques (Kline 1996; Cailliet et al. 1996). It is commonly thought that this species is slow growing with an apparent maximum age of 45+ years (Ianelli et al. 1994; Kline 1996; Cailliet et al. 1996).

A growth curve for this species has been developed (Jacobson 1991: cited in Ianelli et al. 1994). Unfortunately the parameters for the growth equation are not given in the paper. However, the same growth curve appears to be reproduced in Kline (1996: Figure 17), with parameter estimates provided and which have been used in the population model developed in this paper.

3.2 NATURAL MORTALITY

Ianelli et al. (1994) use a value of 0.1 yr^{-1} for this parameter which they say is consistent with values used in previous assessments of this species. This value is derived using the method of Hoenig (1983) using a maximum age of 45 years.

3.3 MATURITY

A maturity-at-length ogive is provided in Ianelli et al. (1994). This function was converted to maturity-at-age using the age-length function described in Section 3.1.

4. METHODS

4.1 GENERAL LINEAR MODEL

A stepwise multiple linear regression (where data are modelled assuming lognormal variability) was used to estimate trends in abundance from CPUE data derived from the commercial catch and effort database (see Section 10.2.4 for how these data were generated). This approach is commonly used to analyse fisheries catch and effort data (for examples of this approach being applied in fisheries situations, see Vignaux 1993 and 1994).

A forward stepwise multiple regression fitting algorithm was employed. The algorithm generates a regression model iteratively, starting with the simplest model (a single variable). The relative reduction in residual deviance (denoted R^2) is calculated for each single term addition to the base model. The term that results in the greatest reduction in residual deviance is added to the base model if this generates a relative improvement in the residual deviance of at least 5%. The algorithm then repeats this process, updating the base model, until no new terms are added.

4.2 LENGTH-BASED AGE-STRUCTURED MODEL

A generalised age-structured model described by Hilborn et al. (in prep.) was used to model the population dynamics of longspine thornyheads. Model equations and the general specifications are provided in Hilborn et al. (in prep.) and are attached as Appendix 1 (Page 44). The model was run for the short history of the fishery (1996-1999), using varying assumptions regarding the available data, recruitment and biological parameters described later in this document.

The model was able to make use of the length frequency data available from the commercial fishery by converting the predicted age distributions to expected length distributions using the von-Bertalanffy growth parameters and on the estimated standard deviations of length at age (Appendix 1. Section 9.5; page 46). Each set of annual length frequency data has been given an effective sample size of ‘100’ per year. This represented a compromise between the actual sample sizes, which are usually much larger, and the fact that sample sizes below 100 represent little effective data, given the number of size classes in the model.

Model results reported in this paper are based on the mode of the joint posterior distribution which is used as an estimate of the model parameters (PME – Posterior Mode Estimate). These estimates include information from both the data, through the likelihoods, and the information contained in the priors (i.e. the log-normal prior on the initial recruitment multipliers). The PME is used in the same manner as a maximum likelihood estimate (MLE). The PME is found using the automatic differentiation minimiser supplied with ADModel Builder (™ Otter Research).

5. RESULTS

5.1 COMMERCIAL LENGTH FREQUENCIES

5.1.1 AVAILABLE DATA

Catch-at-length samples have been obtained for longspine thornyheads from 19 different vessels during 124 trips in the four year history of the fishery to the end of March 2000 (Table 1). There were 374 samples comprising 58,000 length measurements taken over the four years of the fishery (Table 17). The number of useable samples and length measurements were reduced to 192 and 29,000 respectively under the "total catch" analysis option (Table 19), or to 282 and 41,000 respectively under the "retained catch" option (Table 20). The bases for choosing these options are described in Section 10.1.1.3.

Table 1. Number of sampled trips by standardised fishing year (1 April – 31 March) by participating vessel. Data for the 1996-97 fishing year have not been presented to preserve confidentiality

Vessel Name	1997-98	1998-99	1999-2000	Total
CAPE MORIEN		10	10	20
CARMANAH I		1	3	4
CHALLENGER			1	1
E.J. SAFARIK	1	4	4	9
FREE ENTERPRISE #1		3	1	4
FROSTI		6	3	9
HOPE BAY		4		4
JEANNA MARIE	2	6	6	14
KNIGHT DRAGON	1	3		4
MISS TATUM		3		3
NEMESIS		2	3	5
NOOTKA MARINER	1			1
OCEAN REBEL		2	7	9
OCEAN SELECTOR	1	2	5	8
PACIFIC VIKING		4	7	11
VIKING MOON	1	3	5	9
VIKING SKY	2			2
VIKING STORM	2	1	3	6
Total	11	54	58	124[1]

[1] Includes one trip sampled in 1996-97

5.1.2 COVERAGE OF THE FISHERY

The summary statistics provided in this section are based on the complete set of samples which were linked to tows in the PacHarvest database (Table 17).

Table 2. Number of trips and the representative catch from those trips by standardised fishing year which have had at least one length sample taken during the trip

Fishing Year	Number trips with samples	% of trips with samples	Total trips	Total Catch of trips with samples	% catch of trips with samples	Total catch (t)
1996	1	0.1%	723	10.4	0.9%	1166.7
1997	11	4.7%	236	140.3	24.7%	567.0
1998	54	28.0%	193	495.6	59.9%	826.8
1999	58	28.6%	203	623.9	68.0%	917.6
Total	124	9.2%	1355	1270.2	36.5%	3478.1

Table 3. Number of tows and the representative catch from those tows by standardised fishing year that were sampled for longspine thornyheads

Fishing Year	Number tows with samples	% of tows with samples	Total tows	Total Catch (t) of tows with samples	% catch of tows with samples	Total Catch (t)
1996	15	0.4%	4168	6.8	0.6%	1166.7
1997	16	0.8%	2042	12.8	2.3%	567.0
1998	113	5.2%	2172	60.9	7.4%	826.8
1999	205	9.3%	2206	115.7	12.6%	917.6
Total	349	3.3%	10588	196.2	5.6%	3478.1

Table 4. Frequency of the number of tows sampled per trip in each of the four standardised fishing years.

```
------------+------------------------------
Number tows |    Standardised fishing year
sampled     | 1996  1997  1998  1999  Total
------------+------------------------------
          1 |          8    28    16     52
          2 |          1    16    22     39
          3 |          2     7     3     12
          4 |                      7      7
          5 |                1     3      4
          6 |                      2      2
          7 |                      1      1
          8 |                      1      1
         10 |                      1      1
         13 |                1            1
         14 |                1            1
         15 |    1                        1
         28 |                      2      2
            |
      Total |    1    11    54    58    124
------------+------------------------------
```

5.1.2.1 Amount of coverage

Sampling of the commercial fishery for lengths has been sporadic through the four year history of this fishery. Only one trip representing about 10 t of catch was sampled in the first standardised fishing year (Table 2). Sampling has improved considerably since then, with over fifty sampled trips in the two most recent fishing years, representing 60% or more of the total catch (Table 2).

When coverage is examined at the level of tows per trip, only 9% of the total tows and 13% of the total catch of longspines were examined during the 1999 fishing year (Table 3). This low degree of coverage at the tow-by-tow level is the result of only sampling one or two tows per trip (Table 4) even though most trips consisted of twenty or more tows (Table 5).

Table 5. Minimum, median, mean, standard deviation and maximum number of tows per trip for each of the four standardised fishing years and for the entire period

```
-------------+-----------------------------------------------------------
Standardised |                   Number of tows per trip
fishing year |        min      median         mean     std dev          max
-------------+-----------------------------------------------------------
        1996 |          1          13           17          13           51
        1997 |          1          17           19          13           46
        1998 |          1          22           23          13           65
        1999 |          1          23           23          13           52
             |
       Total |          1          19           20          13           65
-------------+-----------------------------------------------------------
```

5.1.2.2 Distribution of coverage

While the level of coverage is not high, it appears to match the catch distribution reasonably well, particularly in the two most recent fishing years. This reflects the sampling strategy which is designed to cover most of the fishery, even though at low levels (one to two tows per trip as shown in Table 4).

The distribution of samples by month approximates the true distribution in both of the fishing years examined (Figure 2), but oversampling is evident in the summer (August in 1998/1999 and July in 1999/2000) and undersampling in the spring. The distribution of sampling by SRF_Area is very close to the true distribution (Figure 3) and has captured the northern shift in catches which occurred in the most recent fishing year. Finally, the distribution of sampling by depth is close to the actual distribution, particularly in the most recent fishing year (Figure 4). Depth coverage of the sampling was particularly poor in the 1997/1998 fishing year and was intermediate in quality in the remaining two fishing years.

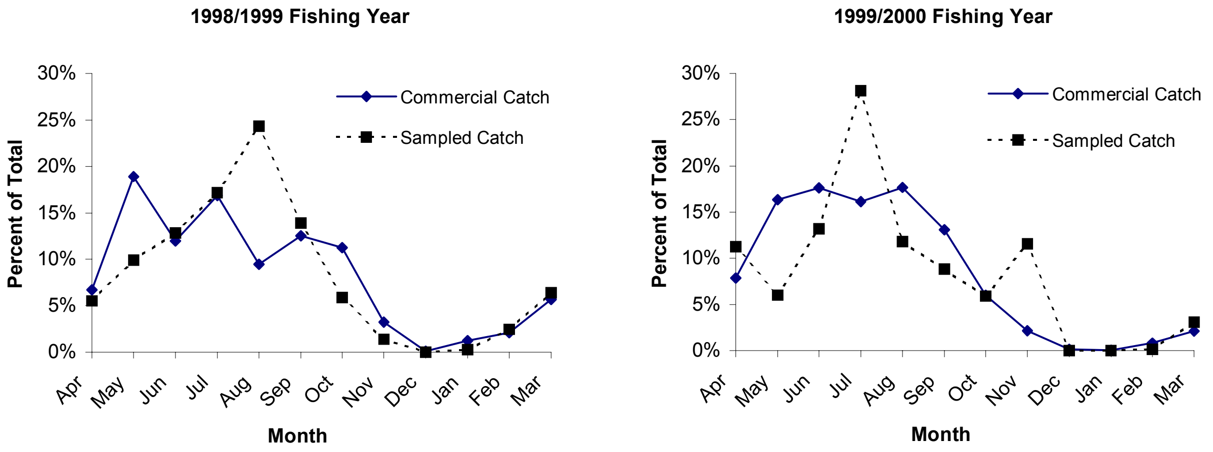


Figure 2. Distribution of sample coverage by month for the two most recent fishing years compared to the actual distribution of catch by month for the same periods.

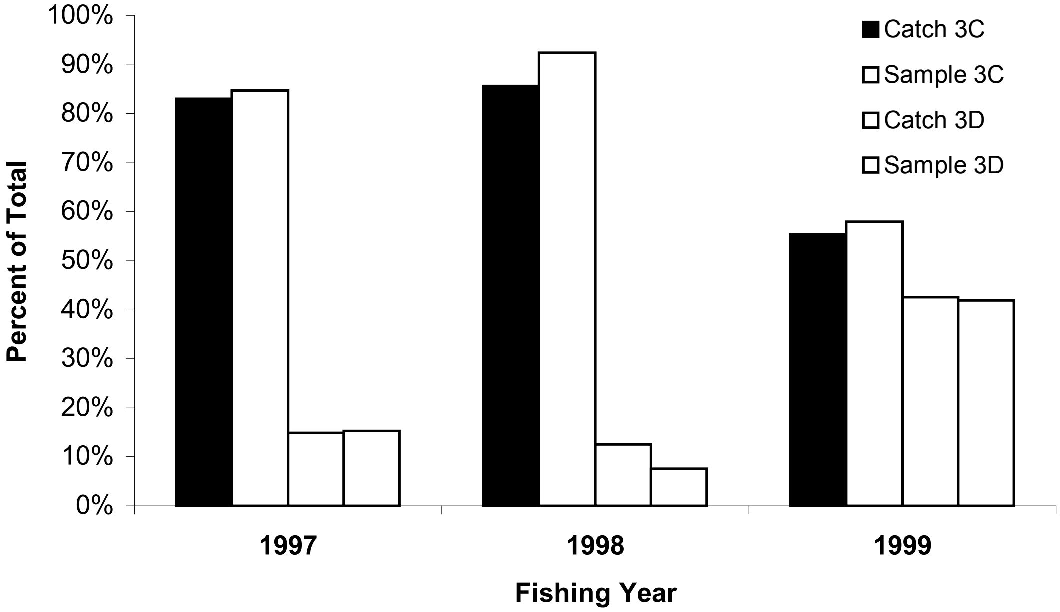


Figure 3. Distribution of sample coverage by SRF_Area for the three most recent fishing years compared to the actual distribution of catch by SRF_Area for the same periods. Only SRF_Areas 3C and 3D are compared as there was no sampling in the other areas (apart from 2 samples in 5ES in the 1999/2000 fishing year).

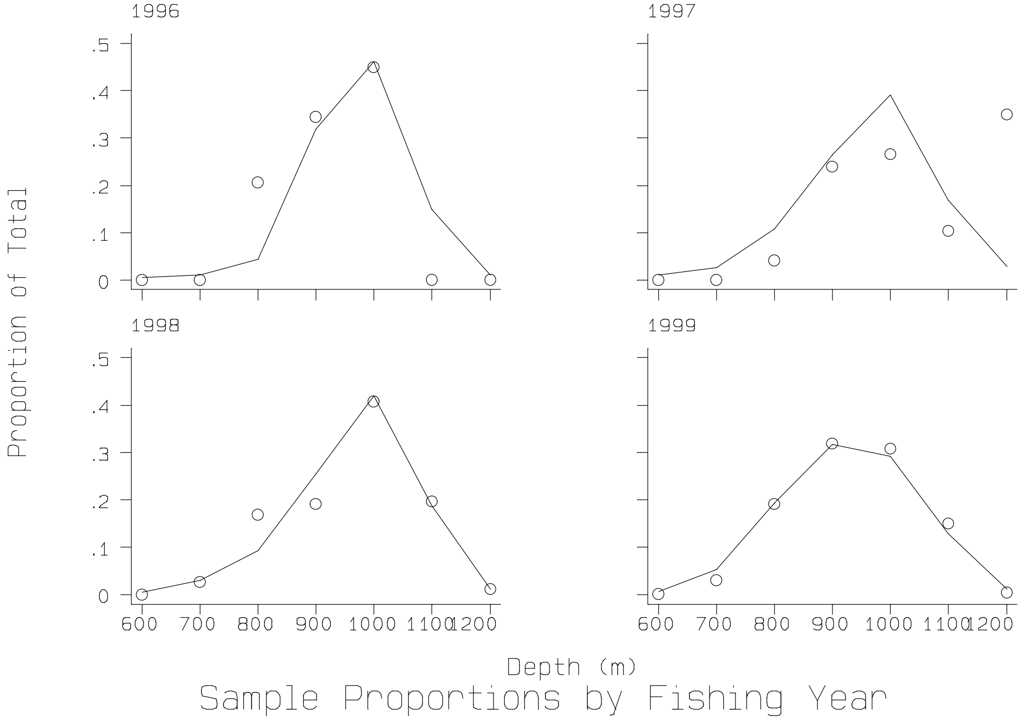


Figure 4. Distribution of sample coverage by 100 m depth bands for the four standardised fishing years compared to the actual distribution of catch by 100 m depth bands. Catch distribution is shown by the solid line and sample distribution is shown by the open circles.

5.1.3 LENGTH FREQUENCY DISTRIBUTIONS

Length frequency data were summarised under the two assumptions detailed in Section 10.1.1.3.

5.1.3.1 "Retained" catch option

When length frequency data are summarised under the "retained" catch assumption, frequency distributions by length class do not differ much between the weighting options investigated. Unweighted samples give a very similar distribution to the options that were weighted by either the retained catch from the sampled tow or the retained catch of the entire trip (Figure 5 and Figure 6). Length frequency distributions from the catch above 190 mm for this species are very stable across 1) the entire fishery within a year and 2) the main geographical areas being fished. This is particularly true for the two most recent fishing years, which also appear very similar to each other. The 1996 and 1997 fishing years seem to be more variable and likely reflect the very low and intermittent sampling achieved in those years.

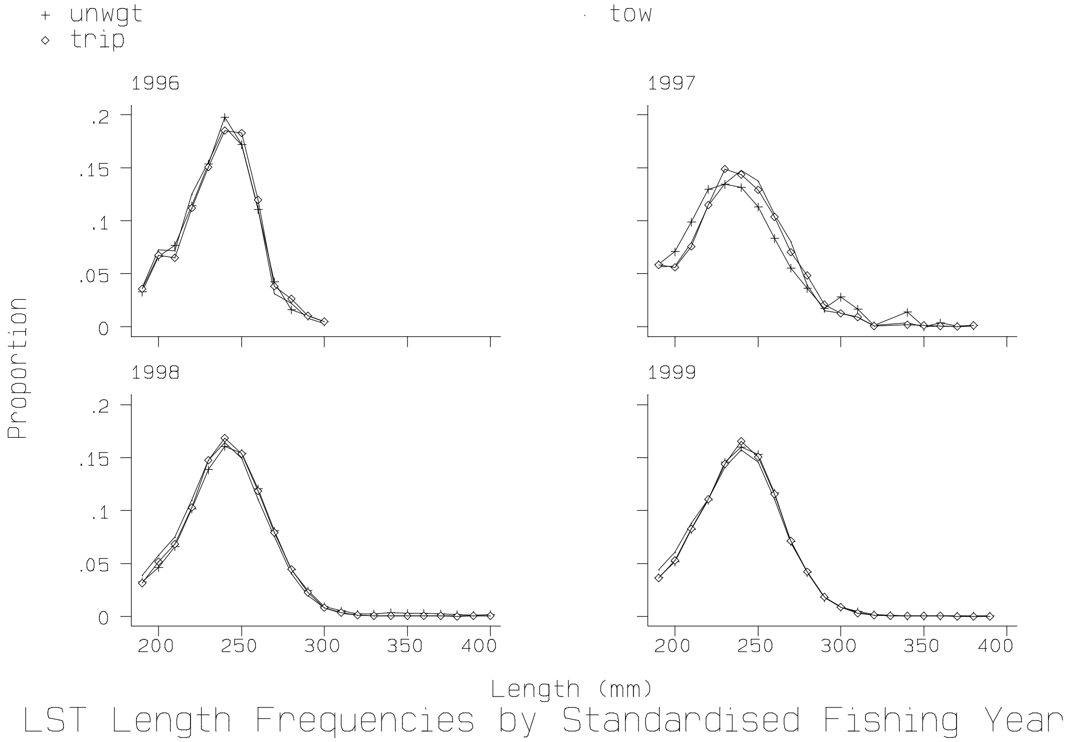
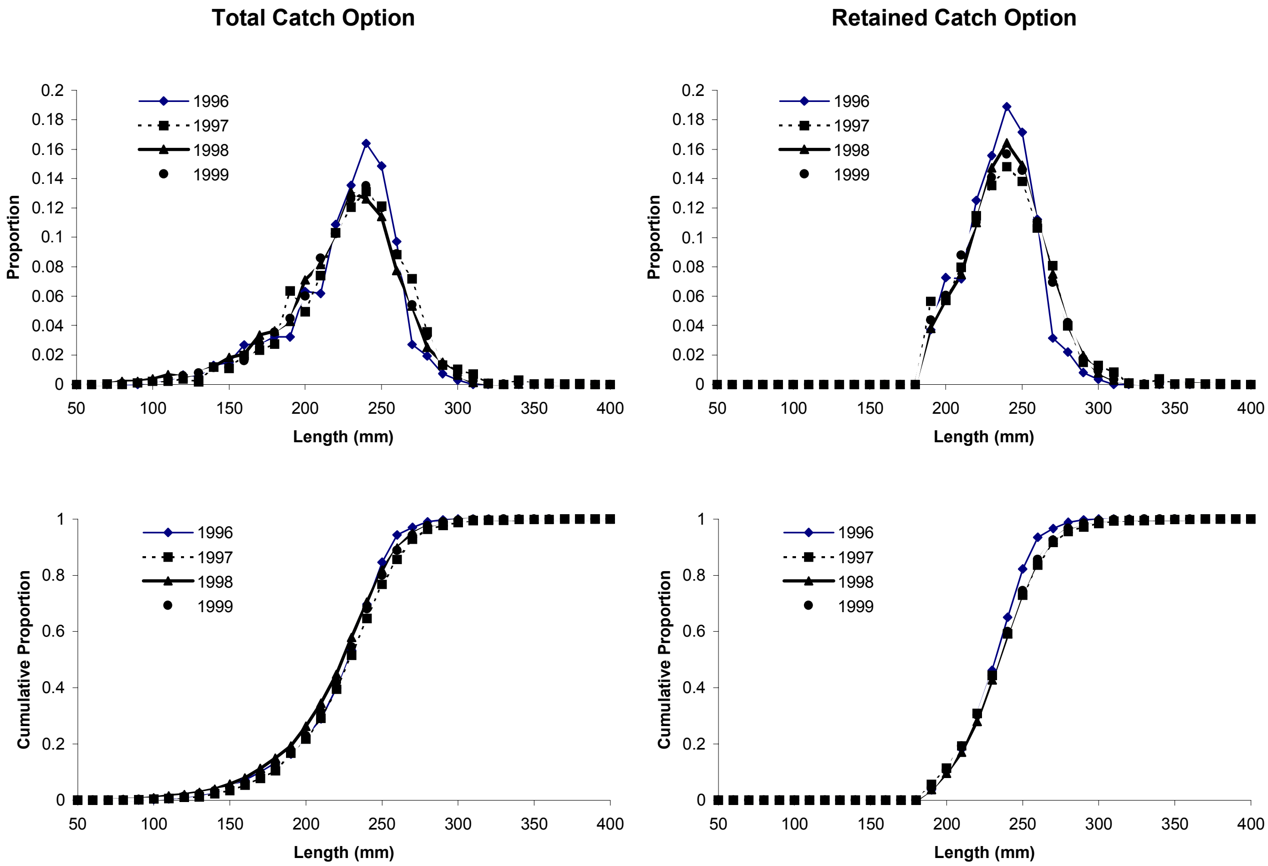


Figure 5. Length frequency distributions by standardised fishing year under the "retained" catch option (all samples used except discard samples and truncated at 190 mm). Three plots are shown: summed across samples without weighting ("unwgt"); summed across samples weighted by the retained catch in the tow sampled ("tow"); summed across samples weighted by the retained catch for the entire sampled trip ("trip").



Total Catch Option

Retained Catch Option

Figure 6. Superimposed by year length frequency distributions and cumulative frequency distributions by standardised fishing year under the both the “total” and “retained” catch option.

5.1.3.2 “Total” catch option

When the length frequency data are summarised under the “total” catch assumption, the frequency distributions by length class show a bit more variability between the weighting options investigated than under the “retained” catch assumption. However, the distributions are broadly similar and the conclusion of stable length composition over time and space appears to be robust (Figure 6 and Figure 7). Fishing years other than the 1999 show more variation between the weighting assumptions, probably reflecting the lack of coverage with “total” samples in those years (Table 19).

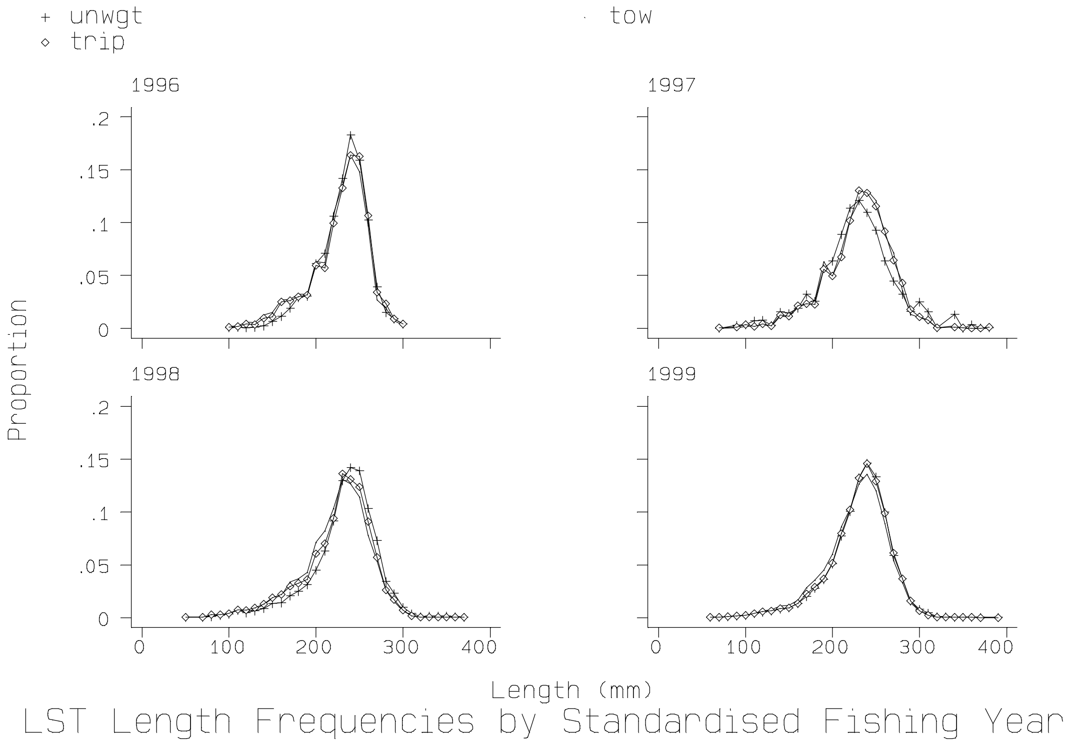


Figure 7. Length frequency distributions by standardised fishing year under the “total” catch option (only those samples categorised as “total” were used). Three plots are shown: summed across samples without weighting (“unwgt”); summed across samples weighted by the retained catch in the tow sampled (“tow”); summed across samples weighted by the retained catch for the entire sampled trip (“trip”).

5.1.4 LENGTH FREQUENCIES FROM NMFS “SLOPE” SURVEYS

Length frequencies of population biomass from surveys conducted by NMFS along the US Pacific west coast were summarised in Section 10.1.2. These summaries were analysed by sex, depth and survey year to determine the amount of variation in these categories for this species.

5.1.4.1 Length frequencies by sex

Visual comparison shows little difference in the biomass length frequencies between the distributions of those fish with a known sex designation (Figure 8). Simple non-parametric tests are not able to detect a significant difference between the empirical distributions for the two sexes (Table 6).

Table 6. Probability that the cumulative biomass length frequency distributions (combined over the 1995, 1997 and 1999 surveys and over all sampled depth strata) for the sex categories paired at each column and row intersection are different using a Kolomogorov-Smirnov test for equality of distribution functions

	2nd Sex Category	
1st Sex Category	**Male**	**Female**
Unknown	0.002	0.030
Male		0.791

This result is consistent with the conclusion reached in Section 11.3.3.1 that both sexes have a similar weight-at-length relationship. The biomass length distribution for the "unknown" sex category is significantly different from the other two distributions (Table 6) because it was composed almost entirely of small fish (Figure 8 and Table 25).

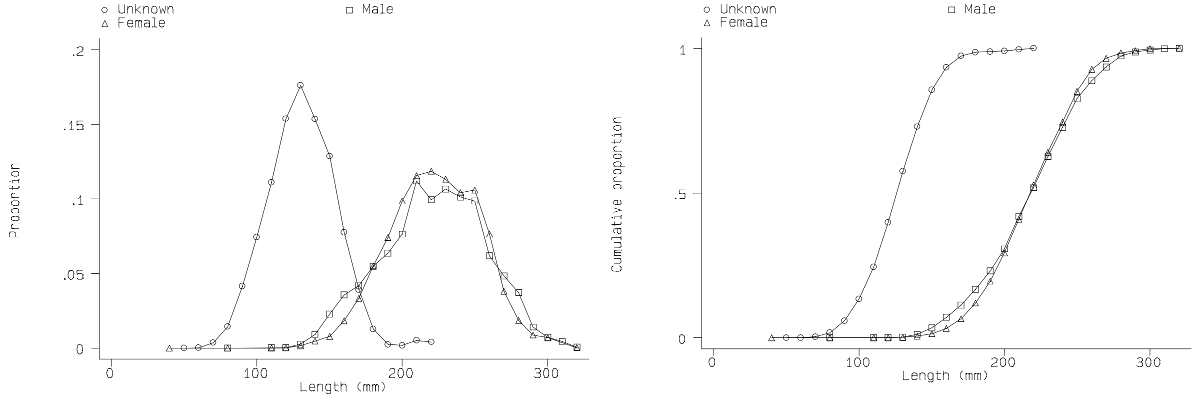


Figure 8. Proportional and cumulative length frequency distributions for each sex from the "slope" survey biomass estimates by 1 cm length class combined over the 1995, 1997 and 1999 surveys and over all sampled depth strata.

5.1.4.2 Length frequencies by depth

Visual comparison showed considerable difference in the biomass length frequencies between the four deepest strata sampled (Figure 9). However, the simple non-parametric test employed could not detect a significant difference between any of the paired empirical distributions among the four deepest strata, even when comparing the 550-732 m stratum with the three deeper strata (Table 7). Significant differences were detected between the two most shallow strata and all of the four deeper strata, probably because there were very few large fish in the two shallow strata (Table 7 and Figure 9).

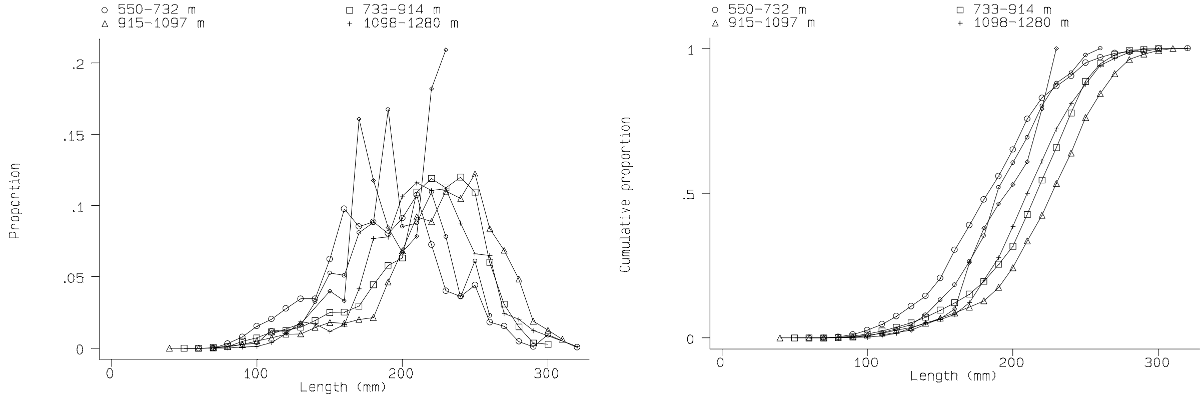


Figure 9. Proportional and cumulative length frequency distributions for each of the six depth strata from the "slope" survey biomass estimates by 1 cm length class combined over the 1995, 1997 and 1999 surveys and over all sampled depth strata. The two most shallow strata (183-366 m and 367-549 m) are not labelled in the graph and are marked with a diamond and a small 'o' respectively.

Table 7. Probability that the cumulative biomass length frequency distributions (combined over the 1995, 1997 and 1999 surveys and over all sexes) for the depth categories paired at each column and row intersection are different using a Kolomogorov-Smirnov test for equality of distribution functions

	2nd Depth Interval:				
1st Depth Interval:	**367-549 m**	**550-732 m**	**733-914 m**	**915-1097 m**	**1098-1280 m**
183-366 m	0.013	0.000	0.000	0.000	0.000
367-549 m		0.000	0.000	0.000	0.000
550-732 m			0.222	0.123	0.222
733-914 m				0.791	0.791
915-1097 m					0.572

5.1.4.3 Length frequencies by year

Visual comparison showed an apparent difference in the biomass length frequencies between the 1997 survey and the other two surveys (Figure 10), but the simple non-parametric test employed could not detect a significant difference among any of the survey years (Table 8).

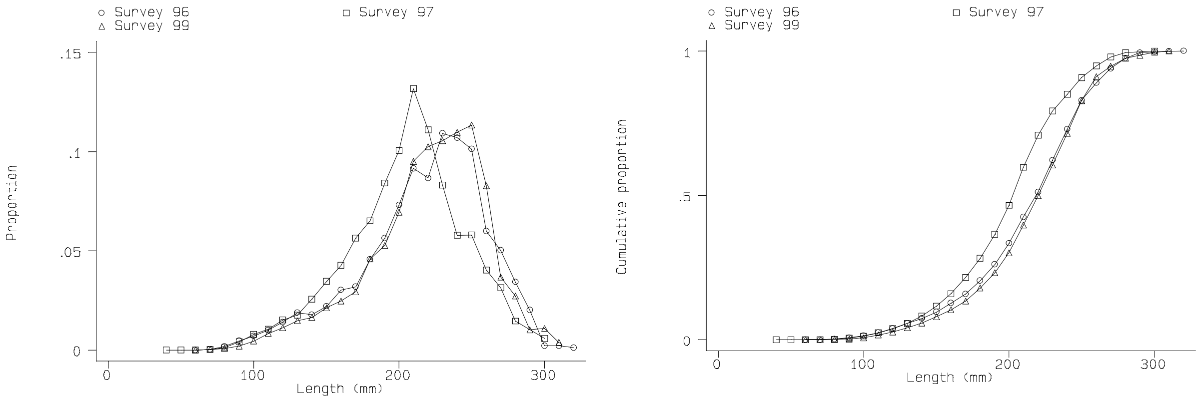


Figure 10. Proportional and cumulative length frequency distributions by year of survey for the “slope” survey biomass estimates by 1 cm length class combined over the 1995, 1997 and 1999 surveys and over all sampled depth strata.

Table 8. Probability that the cumulative biomass length frequency distributions (combined over all depths and all sexes) for each of the survey years paired at each column and row intersection are different using a Kolomogorov-Smirnov test for equality of distribution functions

	2nd Survey year	
1st Survey year	**1997**	**1999**
1995	0.791	0.791
1997		0.791

5.1.5 COMPARISON OF SURVEY AND COMMERCIAL LENGTH FREQUENCIES

A comparison of the commercial length frequency distributions presented in Figure 6 with length frequencies from the US NMFS trawl survey data described in Section 5.1.4 show little difference between the two sets of distributions (Figure 11). The 1997 survey data which appeared to be different from the 1995 and 1999 surveys (Figure 10) also appears to have more small fish than any of the commercial data sets. There are slightly more small fish in the research survey data compared to the commercial catch data, which is likely due to the use of a fine mesh cod-end liner in the research tows (32 mm stretched mesh size – Lauth 2000).

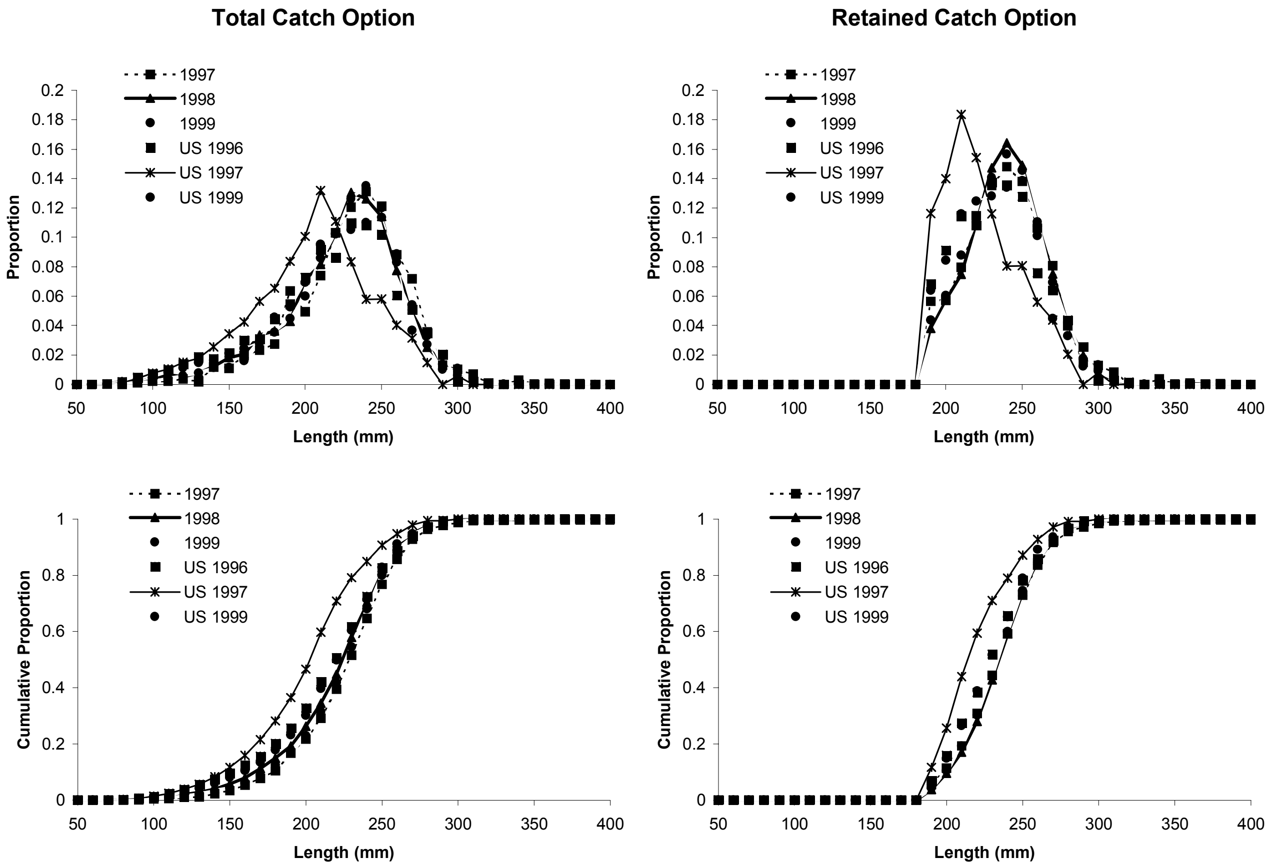


Figure 11. Comparison of length frequency distributions and cumulative length frequency distributions for commercial data from the west coast of Vancouver Island and US NMFS trawl survey data off the coast of Washington. The survey data are presented by year and the commercial data by standardised fishing year under both the “total” and “retained” catch option.

5.2 CATCH AND EFFORT ANALYSIS

5.2.1 SELECTION OF TOP VESSELS

Total longspine catch and effort was summarised for every vessel in the PacHarvest database to identify those vessels specialising in the fishery for thornyheads. Twenty-five vessels accounted for 98% of the total longspine catch accumulated over the four year period from 1 April 1996 to 31 March 2000 (Figure 12) while 80% of the total catch was caught by only 12 vessels. The top vessel alone accounted for ~10% of the total four-year catch (Figure 12). Simple CPUE trends by ranked vessel all appear to be declining slightly over the four-year period (Figure 13). Figure 13 also shows that the vessels ranked 13 to 16 all appear to have left the fishery in recent years. Due to reports of improved catch rates in the most recent year (since 1 April 2000), plots which compare the catch rates in the first four months of each of 5 standardised fishing years (April-July) show that 6 of the 12 vessels fishing in the most recent fishing year have shown an improvement over the previous four months, while the other 6 have remained the same or declined slightly (Figure 14).

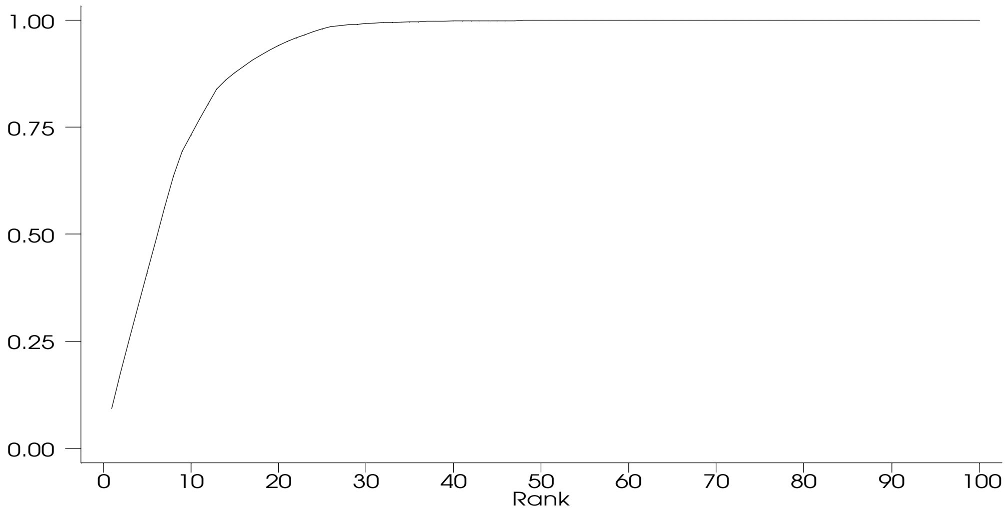


Figure 12. Cumulative proportion of total four-year longspine catch by vessel ranked according to its total catch from 1 April 1996 to 31 March 2000.

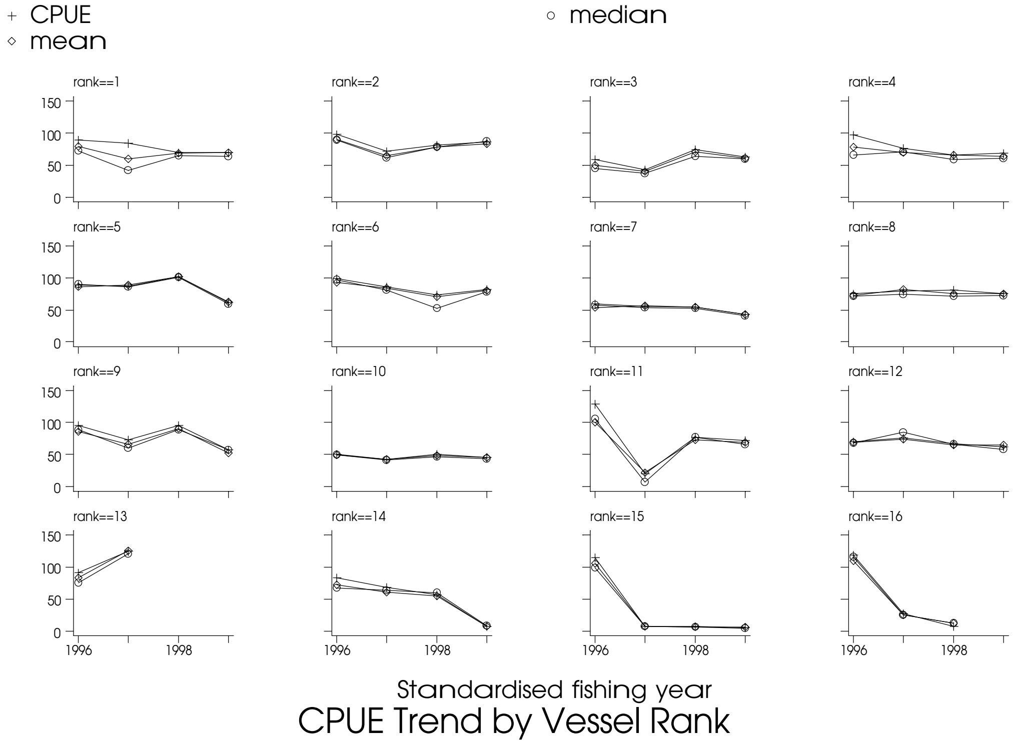


Figure 13. CPUE trends for each of the 16 vessels with the largest cumulative catch of longspine thornyheads in four successive standardised (April-March) fishing years. Plotted lines are (i) mean; (ii) median of the “tow-by-tow” catch per hour and (iii) total period catch divided by the total period effort.

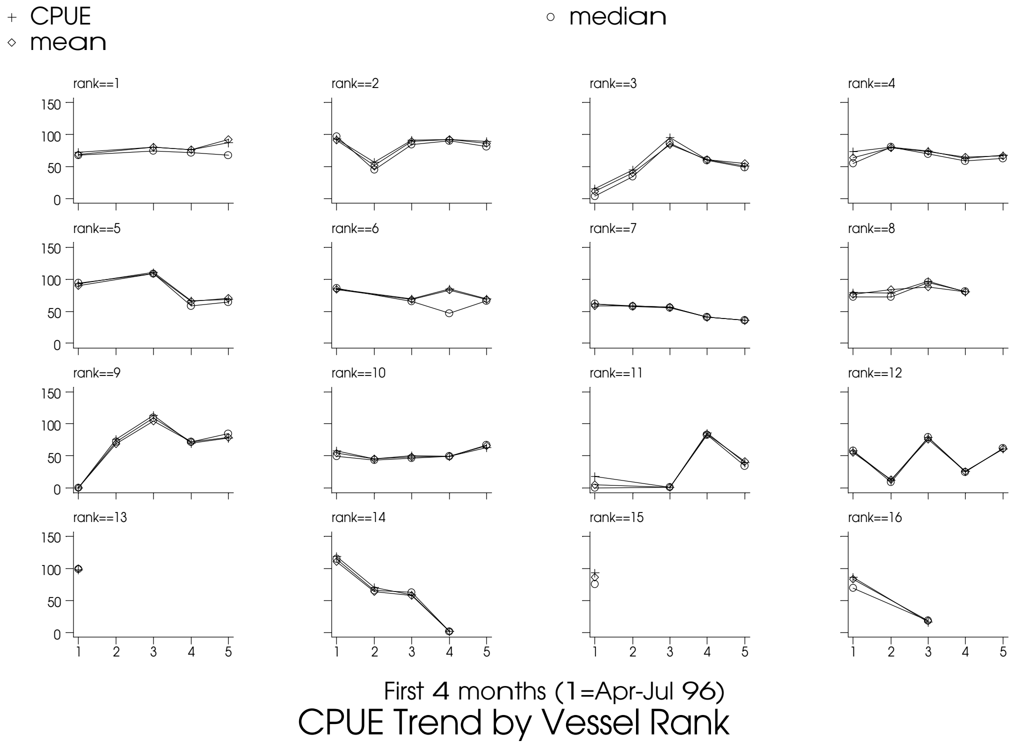


Figure 14. CPUE trends for each of the 16 vessels with the largest cumulative catch of longspine thornyheads in the first four months (April-July) of each standardised fishing year. Plotted lines are (i) mean; (ii) median of the "tow-by-tow" catch per hour and (iii) total period catch divided by the total period effort.

5.2.2 TRENDS IN CATCH AND EFFORT

5.2.2.1 Catch and effort totals by Slope Rockfish area

Catches in the longspine fishery approached 1,200 t in the first full year of the fishery and have since dropped due to limitations imposed by a quota management system (Table 9). Total longspine catch by standardised fishing year has been highest in every year in SRF area 3C (Table 9 and Figure 15), although the relative importance of this area is dropping as the fishery moves northward.

Table 9. Summary statistics for total catch, discards and effort in the Canadian longspine thornyhead fishery for four standardised fishing years (1 April 1996 to 31 March 2000). Note that the catch and effort data have been groomed as described in Section 10.2.2 and as a result these totals may differ slightly from previously published totals.

```
-------------+---------------------------------------------------------------
Standardised |                              SRF_Area
fishing year |      3C       3D   5AB_GI   5AB_MI   5CD_MR      5EN      5ES    Total
-------------+---------------------------------------------------------------
Total Catch
        1996 |   924.7    231.6      2.4      0.3      4.8      1.4      1.5   1166.7
        1997 |   470.6     84.6      9.1               1.3      0.9      0.5    567.0
        1998 |   708.1    103.9      5.9               1.8      2.1      5.0    826.8
        1999 |   507.6    391.1      0.2               1.9      4.0     12.9    917.6
             |
       Total |  2610.9    811.2     17.6      0.3      9.8      8.3     20.0   3478.1
-------------+---------------------------------------------------------------
```

```
-------------+---------------------------------------------------------------
Standardised |                              SRF_Area
fishing year |      3C       3D   5AB_GI   5AB_MI   5CD_MR      5EN      5ES    Total
-------------+---------------------------------------------------------------
Discard Catch
        1996 |    86.0     20.3      0.4      0.0      0.7      0.1      0.1    107.6
        1997 |    60.5      8.7      1.6               0.2      0.0      0.1     71.1
        1998 |    93.6     18.3      1.8               0.2      0.0      0.2    114.1
        1999 |    57.0     38.2      0.1               0.3      1.1      2.3     99.0
             |
       Total |   297.0     85.5      4.0      0.0      1.4      1.3      2.6    391.8
-------------+---------------------------------------------------------------
Retained Catch
        1996 |   838.7    211.4      2.0      0.2      4.1      1.2      1.5   1059.1
        1997 |   410.2     75.9      7.5               1.1      0.8      0.4    495.9
        1998 |   614.5     85.6      4.1               1.5      2.1      4.9    712.7
        1999 |   450.6    352.9      0.1               1.6      2.9     10.6    818.7
             |
       Total |  2314.0    725.8     13.6      0.2      8.3      7.0     17.4   3086.3
-------------+---------------------------------------------------------------
Effort (hours towed)
        1996 |   12072     2592      451       65      669      107      181    16136
        1997 |    7380     1366      429                61       86       20     9343
        1998 |    9935     1367      130               161      124      225    11942
        1999 |    8569     5692       30                65      154      407    14917
             |
       Total |   37956    11016     1040       65      956      471      833    52338
-------------+---------------------------------------------------------------
Effort (number tows)
        1996 |    2677      575      282       40      432       51      111     4168
        1997 |    1565      278      126                34       29       10     2042
        1998 |    1773      241       35                53       28       42     2172
        1999 |    1212      820       11                26       65       72     2206
             |
       Total |    7227     1914      454       40      545      173      235    10588
-------------+---------------------------------------------------------------
CPUE (kg/hour towed)
        1996 |    76.6     89.4      5.3      4.1      7.2     12.7      8.6     72.3
        1997 |    63.8     61.9     21.2              21.5     10.0     23.7     60.7
        1998 |    71.3     76.1     45.6              11.0     16.8     22.2     69.2
        1999 |    59.2     68.7      6.5              28.5     25.9     31.8     61.5
             |
       Total |    68.8     73.6     16.9      4.1     10.2     17.6     24.0     66.5
-------------+---------------------------------------------------------------
```

Discard rates in this area has averaged about 11% of the total catch which is similar to the average for the entire coast. SRF area 3D comprised a much larger proportion of the total catch in the 1999/2000 fishing year while the longspine fisheries in Queen Charlotte Sound and off the west coast of the Queen Charlottes remained negligible (Table 9 and Figure 15).

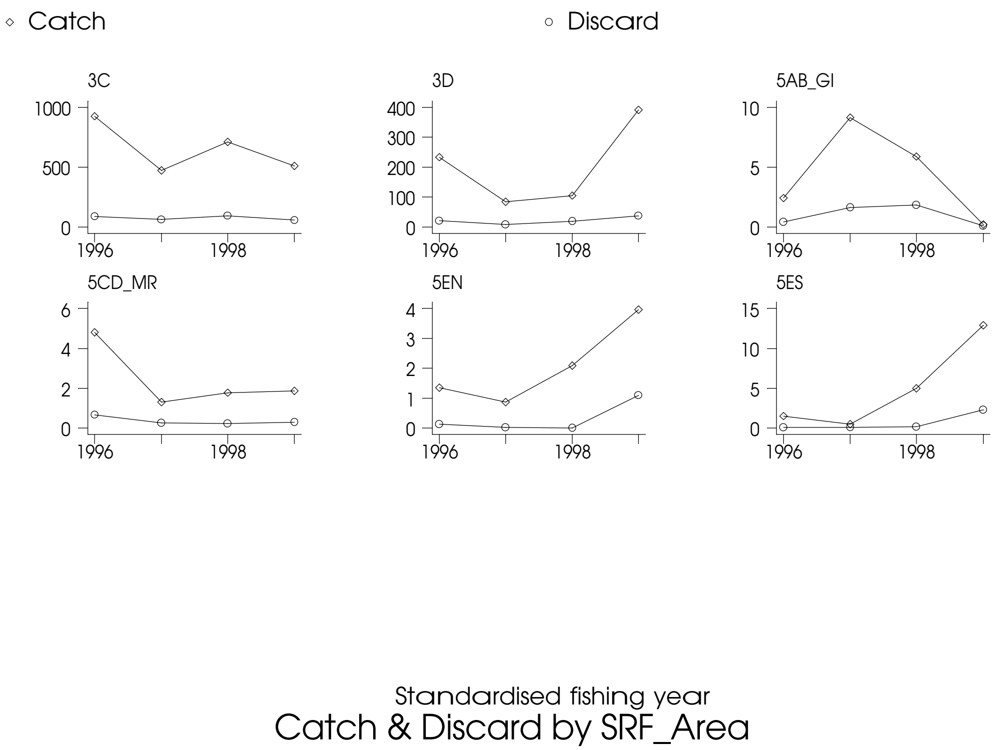


Figure 15. Catch and discards for longspine thornyheads by standardised fishing year (1 April – 31 March) and by SRF_Area. Note: 5AB_GI= Goose Island Gully; 5CD_MR = Moresby Gully

5.2.2.2 Catch and effort totals in the first four months of the fishing year

To demonstrate changes that may have occurred in the longspine fishery in the current fishing year, data from the first four months (April – July) for each of five standardised fishing years were compared (Figure 16). Each SRF area with the exception of Area 3C shows a substantial increase in catch. However, it is known that fishing in Area 3C has increased since July 2000, as the weather has worsened in the more northern areas. Fishing strategies in the 2000 fishing year have incorporated the provisions of the recently introduced (1 April 2000) exploratory quota management programme by choosing to fish the more exposed Queen Charlotte areas during the more clement summer months, expecting to shift later to the west coast of Vancouver Island. This shift in fishing behaviour illustrates why it is difficult to interpret catch data from partial years under a quota system.

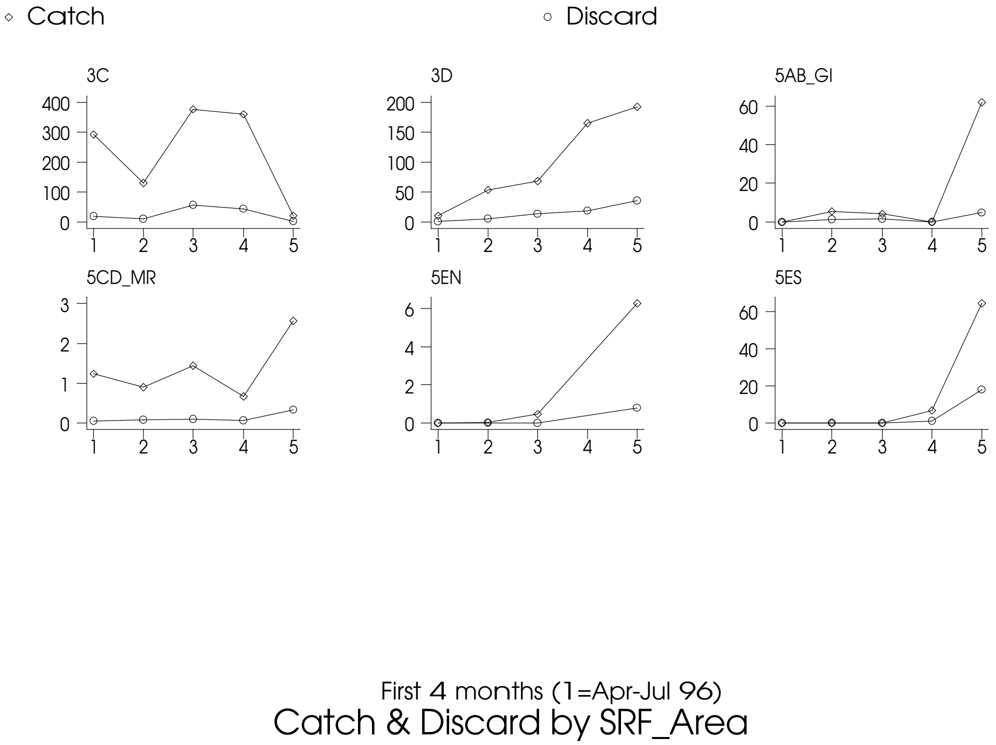
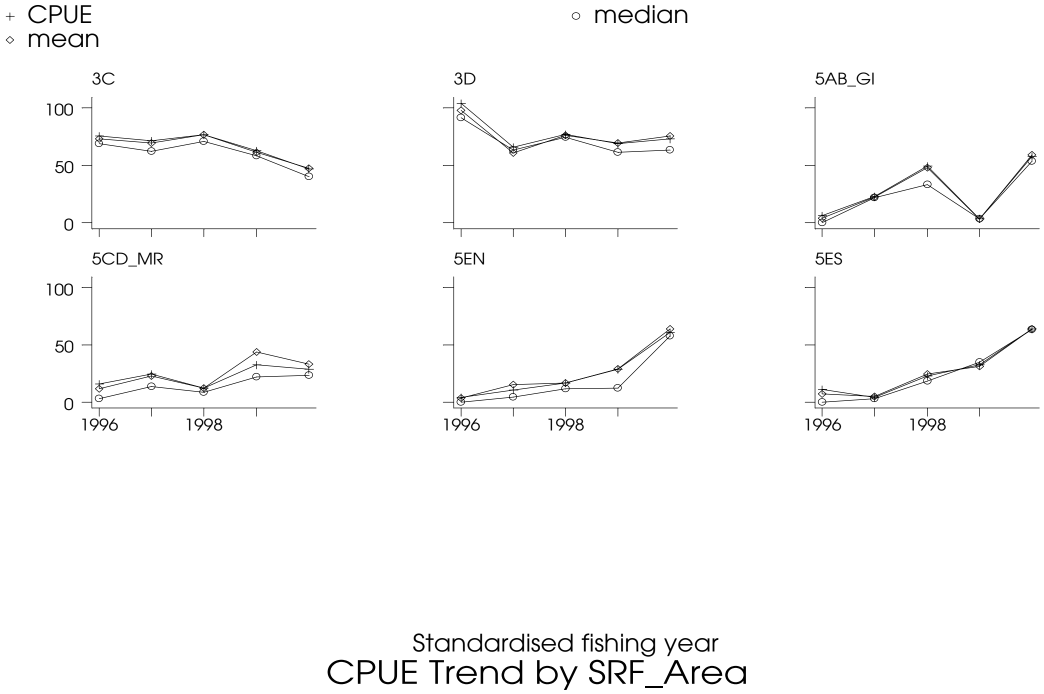


Figure 16. Catch and discards for longspine thornyheads for the first four months (April – July) in each standardised fishing year (1 April – 31 March) and by SRF_Area. Note: 5AB_GI= Goose Island Gully; 5CD_MR = Moresby Gully

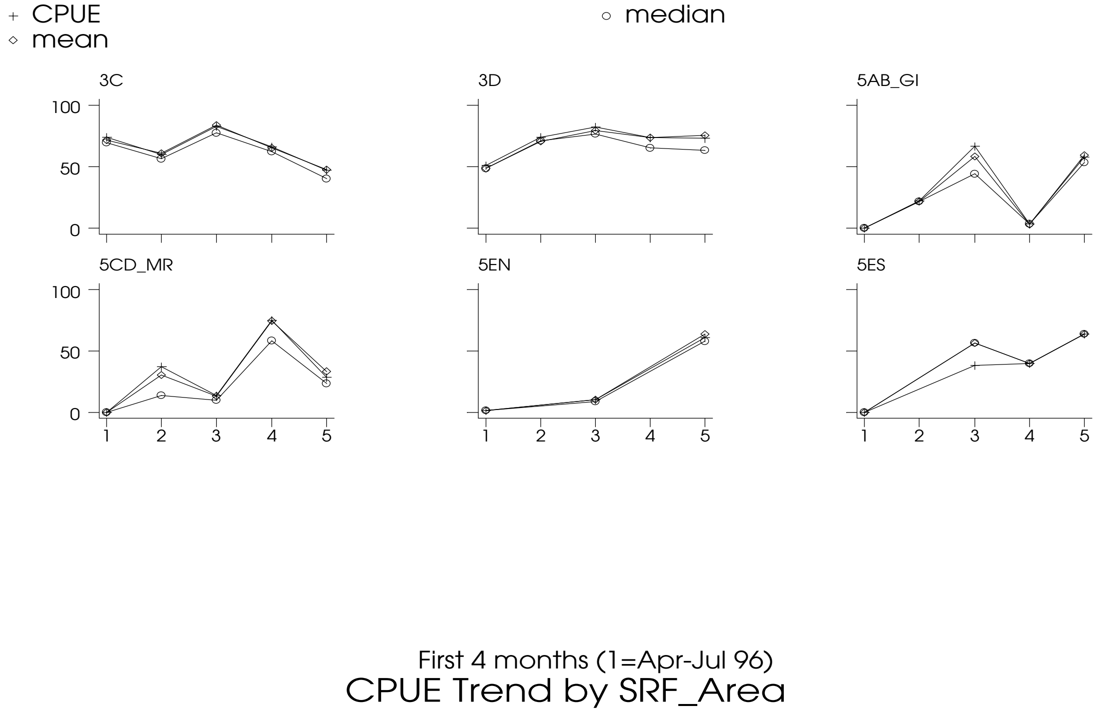
5.2.3 TRENDS IN SIMPLE CPUE

Trends in simple CPUE for the combined catch and effort by the top 12 vessels (Section 5.2.1) have generally been slightly downward for SRF_Area 3C (Figure 17 and Table 9). SRF_Area 3D has had no trend since an initial decline from the first year and there has been a general upward trend in the northern areas skippers are discovering new areas (Figure 17). These conclusions remain unchanged when the catches from only the first four months (April – July) of the fishing year are considered (Figure 18).



CPUE Trend by SRF_Area

Figure 17. CPUE trends for longspine thornyheads by standardised fishing year (1 April – 31 March) and by SRF_Area for the top 12 vessels in the fishery (Section 5.2.1). Plotted lines are (i) mean; (ii) median of the “tow-by-tow” catch per hour and (iii) total period catch divided by the total period effort (labelled CPUE). Note: 5AB_GI= Goose Island Gully; 5CD_MR = Moresby Gully



CPUE Trend by SRF_Area

Figure 18. CPUE trends for longspine thornyheads for the first four months (April – July) in each standardised fishing year (1 April – 31 March) and by SRF_Area for the top 12 vessels in the fishery (Section 5.2.1). Plotted lines are (i) mean; (ii) median of the “tow-by-tow” catch per hour and (iii) total period catch divided by the total period effort (labelled CPUE). Note: 5AB_GI= Goose Island Gully; 5CD_MR = Moresby Gully

5.3 GENERAL LINEAR MODEL

5.3.1 CHOICE OF VARIABLES TO INCLUDE IN MODEL

Seven explanatory variables were available to the model (Table 10), including a vessel variable that categorised for variations in fishing practises among vessels. Many of the vessels have alternated between skippers, but a skipper categorical variable was not included because the quality of this field in PacHarvest was unclear (this field was null in ~30% of the tow-by-tow records).

Table 10. Variables chosen for inclusion in the GLM model. All variables are categorical except for time of day set which is a continuous variable included as a 7th order polynomial

Variable	Type	Description
Time	Polynomial (Order 7)	Time of day tow set
Depth_band	Categorical (4)	100 m depth bands (from 800 to 1100)
Month	Categorical (12)	Month of year (April to March)
Fishing Year	Categorical (4)	1996-1999
Latitude_band	Categorical (18)	From 48.2° to 49.9°
SRF_Area	Categorical (2)	SRF_Areas 3C & 3D
Vessel	Categorical (12)	12 vessels

5.3.2 MODEL RESULTS

The model was selected by regressing the natural log(catch/hour) successively against each of the available explanatory variables in Table 10 and selecting the variable with the greatest explanatory power in terms of R^2 (Table 11). The next iteration repeated this process while including the variable chosen in the first iteration in the regression. This process was continued until the incremental improvement in the explanatory power of the model (R^2) dropped to below a 5% increase over the previous R^2. Variables chosen for the model were, in order of importance: vessel, latitude, depth and month (Table 11). Fishing year was not chosen under the specified criteria but was forced, as this is the variable which indicates relative abundance. The estimate of total change over the four fishing years is –16% which is interpreted as a relative index of population abundance (Figure 19 and Table 12). This interpretation should be treated with caution as this variable did not satisfy the inclusion criteria specified by the analysis, \ and therefore has a very weak effect compared to those effects from the other explanatory variables.

Table 11. Variables included in the stepwise regression of LN(catch/hour) in order of importance.

	R^2 At Iteration				
Variable (in order of acceptance in model)	**1**	**2**	**3**	**4**	**5**
Vessel	0.1065				
Latitude band	0.0619	0.1485			
Depth band	0.0482	0.1457	0.1928		
Month	0.0154	0.1243	0.1632	0.2075	
Fishing year	0.0092	0.1133	0.1556	0.1959	0.2118
Time of day set	0.0018	0.1085	0.1504	0.1943	0.209
SRF_Area	0.0004	0.1072	0.1527	0.1932	0.2081
% Improvement		39%	30%	8%	2%

Table 12. Year coefficients from the GLM analysis which are interpreted as relative indices of abundance in the stock assessment model. Confidence bounds are ± 1.96 SE (N/A: not applicable)

Fishing year	Index	Lower Bound	Upper Bound
1996/97	1.000	N/A	N/A
1997/98	0.975	0.922	1.030
1998/99	0.974	0.923	1.027
1999/00	0.861	0.813	0.912

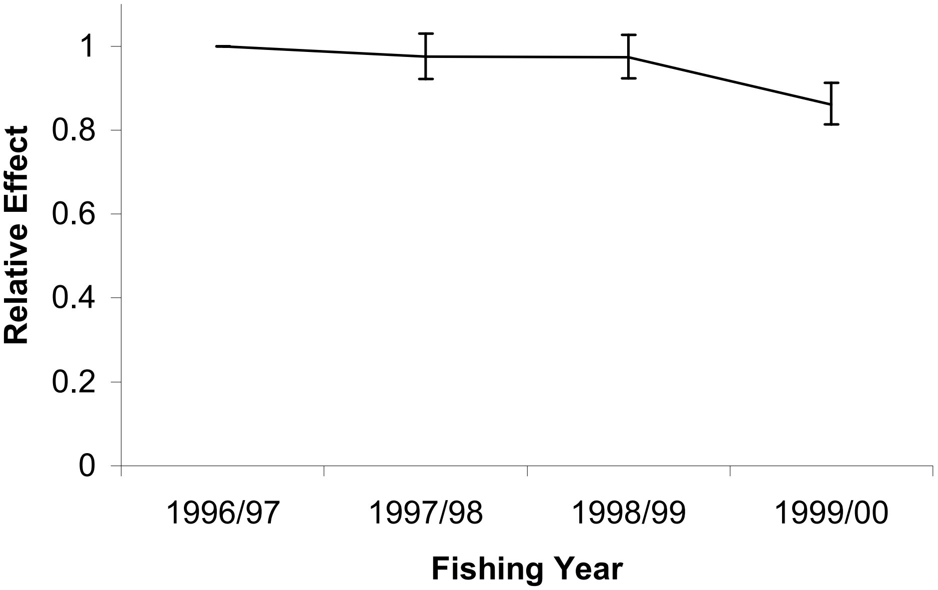


Figure 19. Fishing year coefficients from full model. Error bars are +/- 1.96*SE Note: the coefficient for 1996/97= 1.

5.3.3 ANALYSIS OF OTHER MODEL COEFFICIENTS

The validity of such a model can sometimes be better understood if the coefficients of some of the other explanatory variables are examined. For instance, the coefficients for month show that the best relative fishing is in summer as there is a strong decline in relative catching power in December and January which is, coincidentally, the period when poor weather reduces fishing activity (Figure 20). Note that the relative monthly CPUE rises again to nearly 1.0 in March, even though there is usually not much fishing in this month, as this is the end of the quota management period.

The latitude coefficients show a steady decline from south to north towards the centre of Vancouver Island (the low point is located at approximately 49.3°N) , followed by a gradual increase to the upper boundary of SRF_Area 3D (Figure 21). The error bars on this increasing trend are large, probably reflecting the general lack of data along northern Vancouver Island. Overall, the minimum relative CPUE is less than ½ of the maximum CPUE, depending on where fishing takes place. The explanatory power of this variable is likely the reason that the simple SRF_Area variable (two categories) was not selected.

Similarly, there appears to be a considerable variation in the catching power of the vessels, where at least two vessels have ~½ the fishing power of the best vessels (Figure 22). This difference in the catching power among vessels is well known in the fleet and appears to be the result of a combination of factors, including vessel size, engine power, vessel hydraulics and type of net used.

Finally, the effect of depth is also quite strong, with an increase of ~70% in relative CPUE over the range of depths investigated (Figure 23). The depth effect is also well known to the fleet and explains why there is a push to fish at greater depths. The increase in relative catchability is obviously offset by the greater difficulty and cost in fishing at these great depths.

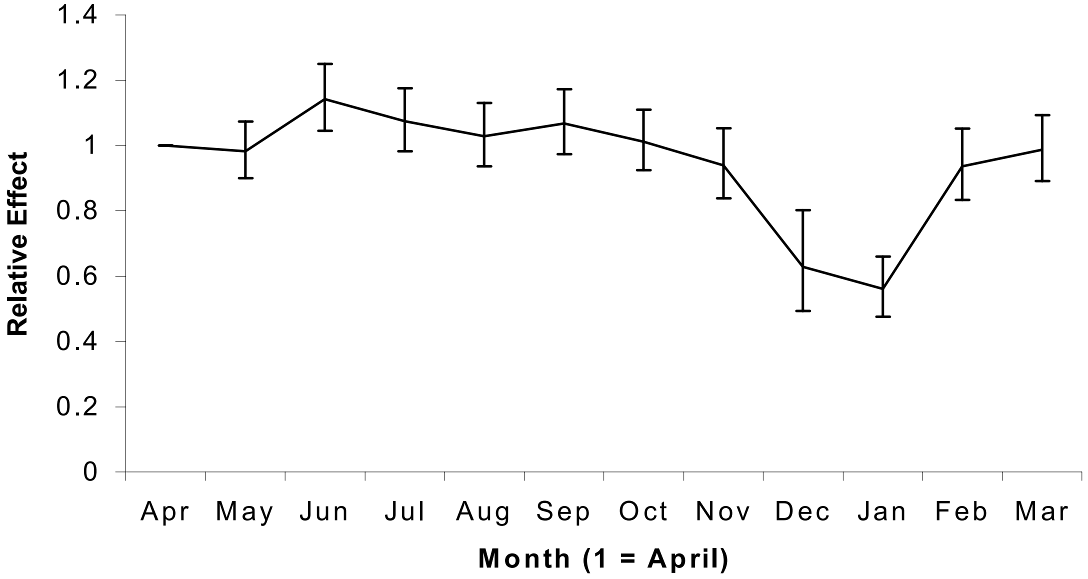


Figure 20. Month coefficients from the full model. Error bars are +/- 1.96 SE Note: coefficient for April = 1

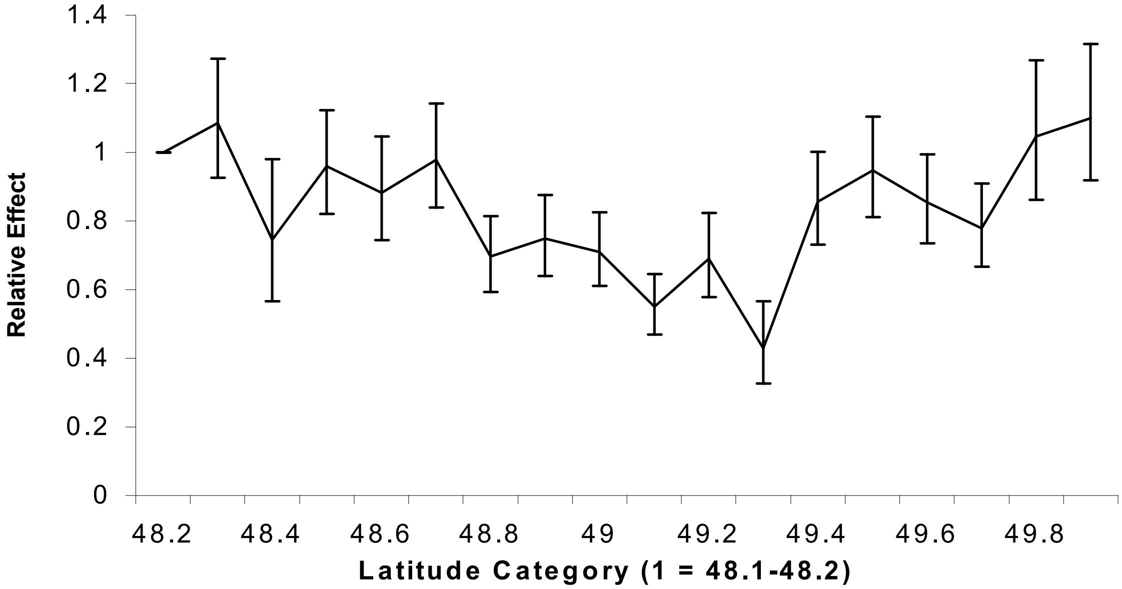


Figure 21. Latitude coefficients from the full model. Error bars are +/- 1.96SE Note: the coefficient for the band between 48.1°N and 48.2°N = 1

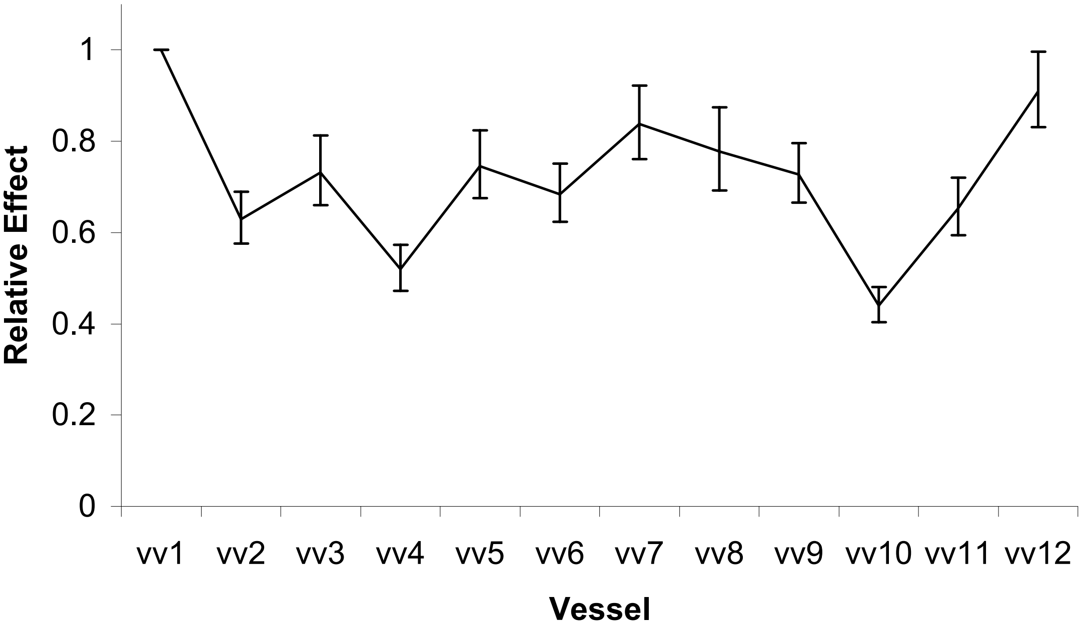


Figure 22. Vessel coefficients from the full model. Error bars are +/- 1.96 SE The coefficient for Vessel_1= 1

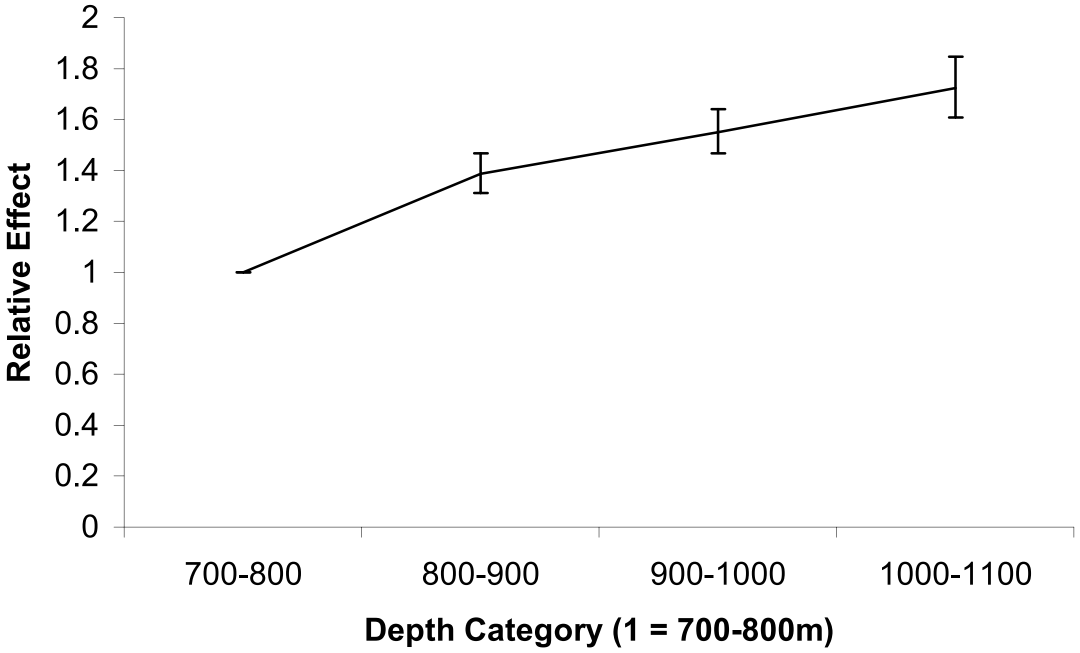


Figure 23. Depth band coefficients from the full model. Error bars are +/- 1.96 SE The coefficient for the 700-800 m depth band = 1

5.3.4 MODEL RESIDUALS

The residuals to the model fit are reasonably well distributed, with a noticeable negative tail, indicating that the model tends to overestimate the observed values (Figure 24). Since the underlying assumption of the model is that CPUE is log-normally distributed, it is useful to determine how closely the residuals conform to this assumption. A quantile-quantile plot comparing the cumulative residuals to a normal distribution shows that it is in the tails (both the upper and lower ends) where the model fails to fit the observed data (Figure 24). The relatively small amount of data available in these regions and the model assumptions are probably the cause of the poor fits.

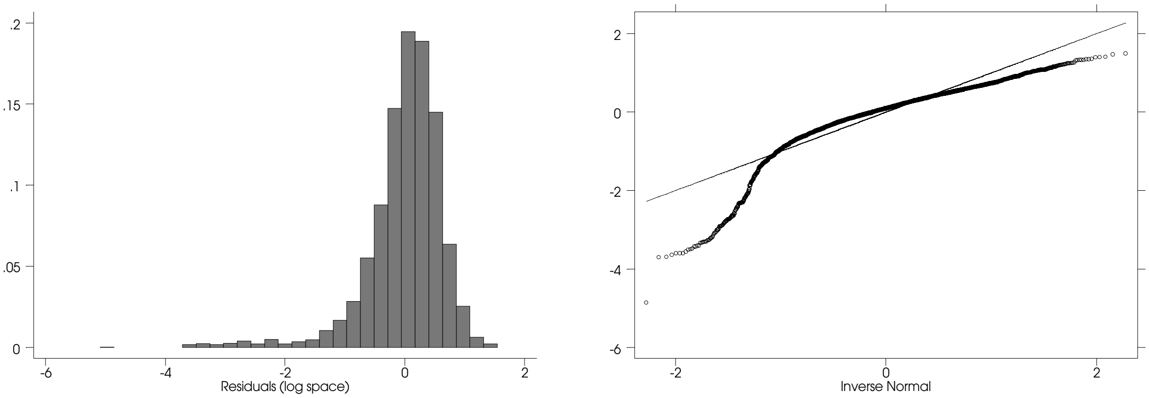


Figure 24. (left panel): Frequency histogram of residuals from the fit to the full GLM model. (right panel): QQ plot of residuals (in log space) from the fit to the final model plotted against a cumulative normal distribution.

5.4 LENGTH-BASED AGE-STRUCTURED MODEL

5.4.1 DATA SOURCES AND MODEL ASSUMPTIONS

Slope rockfish, including longspine thornyheads, have been assessed in Canada over the last three years (Richards et al. 1997; Schnute et al. 1999a; Schnute et al. 1999b) and there have been several stock assessments for this species in the United States (Jacobson 1991; Ianelli et al. 1994). Biological parameters for this assessment have been collected from a number of sources, including original work presented in this paper (Table 13). A single sex model was chosen for this assessment as there appears to be little difference between the sexes in terms of weight-at-size (Section 11.3.3.1) and size distribution (Section 5.1.4.1). The US longspine stock assessments prepared for the Pacific Management Council have also used single sex models (Jacobson 1991; Ianelli et al. 1994).

Table 13. Summary of parameters used for modelling Canadian longspine thornyheads. s.d.: standard deviation

Parameter	**Value Used**	**Source**
M (natural mortality)	0.10	Ianelli 1994
Maximum age used in model	45	Kline 1996
Maximum length used in model	400	Max. in US survey data
Age at full maturity	23	Ianelli 1994
Age at 50% maturity	17	Ianelli 1994
Von Bertalanffy L_∞ (mm)	301	Kline 1996
Von Bertalanffy k	0.072	Kline 1996
Von Bertalanffy t_0	-1.90	Kline 1996

Parameter	Value Used	Source
Length-weight *a*	4.85 E-06	Section 11.3/Table 26
Length-weight *b*	3.163	Section 11.3/Table 26
s.d. of right side of vulnerability ogive	Fixed at 30	No descending limb
Recruitment variability	0.6	Default value[1]
Steepness	0.75	Default value[2]
s.d. of age 1 fish (mm)	6	10% of mean length
s.d. of age 45 fish (mm)	30	10% of mean length
CV of relative abundance index (Table 12)	0.3	Arbitrary

[1] Beddington & Cooke (1983)

[2] Francis (1992)

Two models were investigated in this report. The first was a "retained catch" model fitted to the "retained catch" length frequencies (Section 5.1.3.1) and using the retained catch data from SRF_Areas 3C and 3D (Table 9). The second was a "total catch" model which was fitted to "total catch" commercial length frequencies (Section 5.1.3.2) and using the total catch (discards plus retained catch) from SRF_Areas 3C and 3D (Table 9). These two models were investigated to detect differences in model estimates from these data sets. Both models assumed that the relative abundance indices from the GLM analysis (Table 12) were estimates of the trend in the vulnerable biomass, mediated through the model selectivity function.

The effect of doubling or halving the value for M (natural mortality) was also investigated in this model. Some of the fixed parameters (Table 13) were modified to match the implied changes in length-at-age in the maturity and selectivity ogives to maintain the same relationship of size, maturity and selectivity in Table 13. This included modifying the von-Bertalanffy *k* and *t0* parameters to suit the changed M value while the L_∞ parameter was left unchanged.

5.4.2 PRIORS FOR ESTIMATED PARAMETERS

A list of priors used in this analysis is presented in Table 14. Note that the only informed prior used was that for the recruitment deviations which were restricted to ± 10 times the mean recruitment deviation. The rest of the priors were made uniform with wide bounds.

Table 14. Priors used in the longspine thornyhead modelling.

Parameter	Lower Bound	Upper Bound	Prior Type	Mean	CV	Initial Value
R_0	1	100,000	Uniform	NA	NA	100
Log CPUE q	-12	12	Uniform	NA	NA	-10
Log recruitment deviations for initial population	-2.3	2.3	Normal	0	0.6	0
Commercial Selectivity Parameters:						
Age at full vulnerability	7	60	Uniform	NA	NA	16[1]
Log left side variance	-30	15	Uniform	NA	NA	3.1[1]

[1] increased to 32 and 4.5 respectively for runs where M=0.05

5.4.3 MODEL SPECIFICATIONS

The runs explored in this assessment can be classified in several ways: (i) data that were included in the likelihood, (ii) parameters that were estimated, and (iii) the assumptions made for several key parameters that were difficult to estimate. With respect to the data used, the main options considered were (i) to include/exclude the length frequencies; and (ii) to fit the model using the length frequencies from the entire catch taken (including discards) or from the retained catch.

With respect to the model parameters, in all cases R_0 (average recruitment) and the relative CPUE q were estimated. In some instances, the parameters of the selectivity ogive for the commercial gear were estimated. The recruitment deviations which can create a non-equilibrium initial age structure were estimated in some runs. In these cases, the recruitment deviations were bounded at ±2.3 (Table 14), yielding minimum and maximum year-class-strength multipliers of ±10.

The sample size for each set of annual commercial length frequency data was set at '100'. This represented a compromise between the actual sample sizes, which are usually much larger, and the fact that sample sizes below 100 have little effect in these models, given the limited number of size classes and the large amounts of other data available.

5.4.4 MODEL RESULTS USING INITIAL PARAMETER VALUES AND WEIGHTS

Posterior mode estimates using the initial parameter values, weights and priors described in Sections 5.4.1 to 5.4.3 are presented in Table 15 and are discussed in Sections 5.4.4.1 and 5.4.4.2. Note that all these results assume that growth is known without error. As this is clearly incorrect, the interpretation of these model results should consider how varying growth rates would affect the conclusions.

Table 15. Description of model runs reported, including the data used, the parameters estimated, the assumed parameters. Results are presented for two sets of input data: (i) "retained" catch and the appropriate length frequencies and (ii) "total" catch and the appropriate length frequencies. See Section 5.4.1 for a description of the data used. Effective sample sizes of 100 were used for the annual length frequency distributions as described in Section 5.4.3. Posterior mode (PME) parameter estimates and likelihood components for the PME fit are presented. Biomass levels are for the beginning of the year

	Retained Catch				**Total Catch**			
	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Data Used								
CPUE	yes	yes	yes	yes	yes	yes	yes	yes
Length Frequency Data	no	yes	yes	yes	no	yes	yes	yes
Parameters Estimated								
R0	yes	yes	yes	yes	yes	yes	yes	yes
CPUE q	yes	yes	yes	yes	yes	yes	yes	yes
Selectivity (2 params)	no	no	yes	yes	no	no	yes	yes
Recruitment Deviations (48)	no	yes	no	yes	no	yes	no	yes
Assumed Parameters								
M	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Steepness	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Growth Function Used	Kline	Kline	Kline	Kline	Kline	Kline	Kline	Kline
Likelihoods								
CPUE	0.0203	0.0164	0.0444	0.1239	0.0195	0.0187	0.0638	0.0169
Commercial LFs	-211.9	-298.2	-266.3	-317.6	-264.8	-294.7	-268.4	-297.4
Penalties	0.0	31.3	0.0	16.7	0.0	10.1	0.0	10.1
Total Likelihood	-211.9	-266.9	-266.3	-300.8	-264.8	-284.6	-268.3	-287.3

	Retained Catch				Total Catch			
	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Parameter Estimates								
R0	28.15	164.50	20.43	11.86	31.53	43.23	299.51	37.31
CPUE q	6.69E-05	6.14E-06	1.11E-04	1.34E-04	5.97E-05	3.50E-05	6.15E-06	4.13E-05
Sfull_commercial	16.0	16.0	14.3	16.0	16.0	16.0	18.5	19.4
VarL_commercial	3.1	3.1	-14.2	-16.1	3.1	3.1	3.8	4.1
Mean Recruitment Multipliers	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Derived Parameters								
$Vuln\_Biomass_{1996}$	15,265	164,770	9,682	8,400	17,096	28,973	155,377	24,544
$Vuln\_Biomass_{2000}$	12,657	138,230	7,077	5,212	14,159	24,384	152,501	20,447
$\frac{Vuln\_Biomass_{1996}}{Vuln\_Biomass_{2000}}$	82.9%	83.9%	73.1%	62.0%	82.8%	84.2%	98.1%	83.3%
$Spawning\_Biomass_{1996}$	12,501	132,677	9,069	7,809	14,001	23,136	132,984	20,026
$Spawning\_Biomass_{2000}$	10,165	135,736	6,552	5,503	11,370	21,494	130,297	18,462
$\frac{Spawning\_Biomass_{1996}}{Spawning\_Biomass_{2000}}$	81.3%	102.3%	72.2%	70.5%	81.2%	92.9%	98.0%	92.2%
Number Parameters Estimated	2	50	4	52	2	50	4	52
Akaike Information Criterion[1]	-419.73	-433.81	-524.59	-497.52	-525.52	-469.11	-528.62	-470.69

[1] Hilborn & Mangel 1997

5.4.4.1 “Retained” catch model

Model results indicated that the available data were not very informative to the parameter estimates. This can be seen from the widely varying estimates of initial population size and the level of depletion that was obtained when the available data and model assumptions were varied (Table 15). For instance, the model termed “Case 2” estimated an initial population biomass which was an order of magnitude larger than the estimates made by the other three models (Cases 1, 3 and 4). This model also estimated that there had been a large drop in absolute biomass, well in excess of the catch taken over four years (Table 15). The loss in biomass was likely due to the natural mortality of the large spike of recruitment estimated by the model to have occurred in the late 1960s and early 1970s (Figure 25). Note that the cumulative length frequencies of “Case 2” were shifted well to the right of “Case 1”, indicating the population size distribution for “Case 2” was much larger than for “Case 1”. The “Case 2” size distribution appears to shift further to the right in each successive year, indicating the rapid ageing of the population (Figure 26). The other “cases” estimated that the reduction in biomass was approximately equal to the total catch taken in the four years (3,000 t), a more credible result than estimated by “Case 2”.

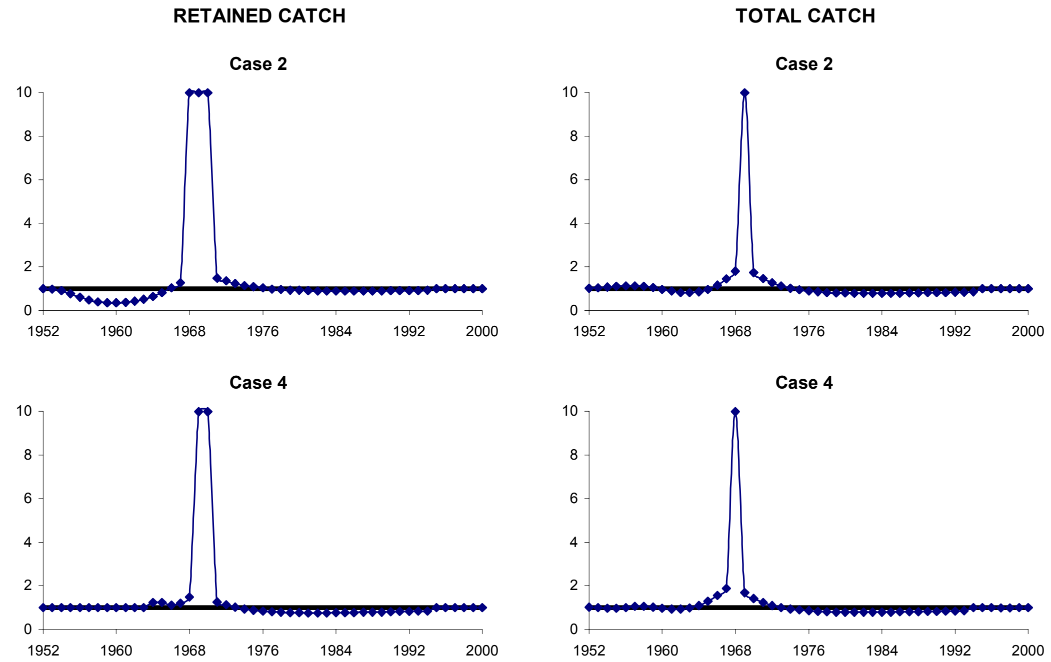


Figure 25. Estimated recruitment deviations for the two “cases” defined in Table 15 which estimated recruitment for both the “retained” and “total” catch and length frequency data inputs.

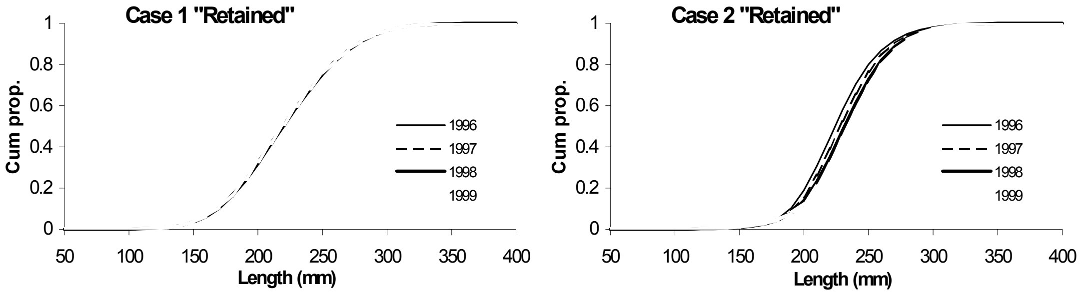


Figure 26. Cumulative frequency distributions for the predicted lengths from “Case 1” and “Case 2” (“Retained catch option” – Table 15) by model year.

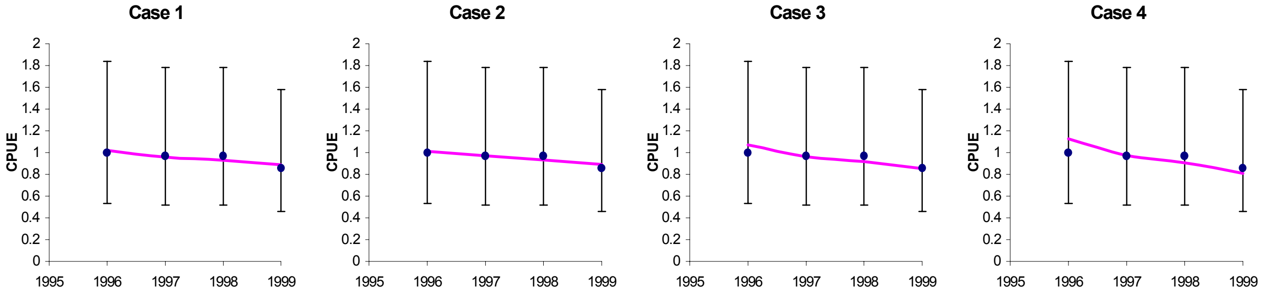


Figure 27. Fitted CPUE biomass indices for the four “cases” defined in Table 15 using “retained” catch and length frequency data as inputs.

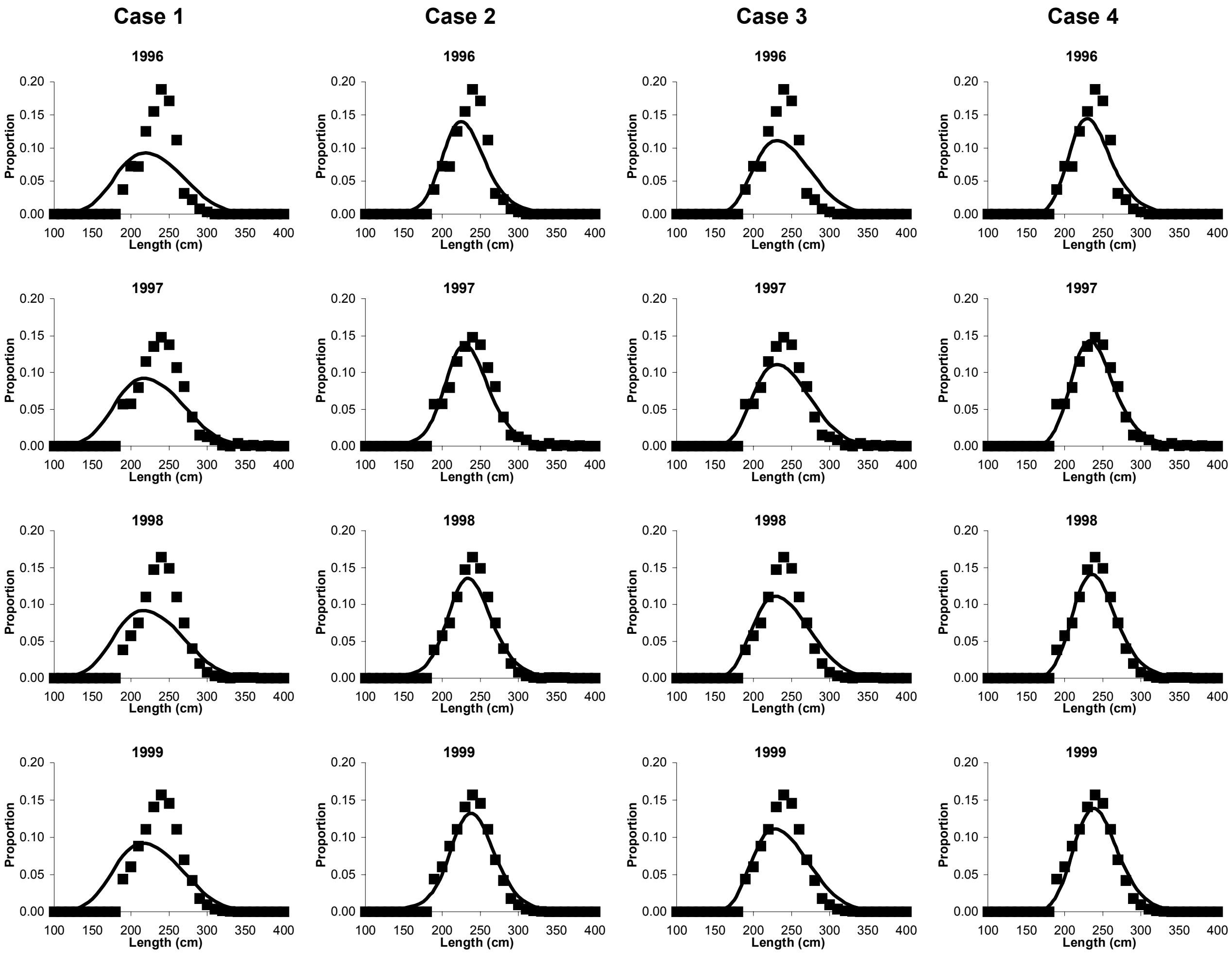


Figure 28. Fitted length frequencies for the four "cases" defined in Table 15 using "retained" catch and length frequency data as inputs.

All the models investigated fitted easily within the error bounds of the relative abundance indices (Figure 27). However, models designated "Case 3" and "Case 4" had exaggerated slopes relative to the observed data, indicating that there may be a possible inconsistency between the length frequency data and the CPUE abundance data. The relative likelihoods presented in Table 15 suggest that a better fit is obtained to the CPUE abundance indices if the stock is large, but the relative gain over fits from smaller stock sizes is not great. The model is able to achieve a relatively better fit in terms of likelihood by fitting the length frequency data by adjusting either the recruitment deviations or the selectivity parameters. This may be an indication that the relative weighting between the two data sources disproportionately favours the length frequency data.

A comparison of the fits to the length frequency data (Figure 28) shows the effect of altering different processes within the model to achieve a fit to these data. In "Case 1", it is clear that this simple model had no capacity to fit the observed data, given the fixed growth rates and natural mortality. "Case 2" illustrates that it is possible to fit the current observed length frequency distributions reasonably well by adjusting the historical recruitment pattern. Although the estimated recruitment pattern is not credible (Figure 25), the fit to the observed data is quite good. An equally good fit to the leading edge of the observed length frequency distributions was obtained by adjusting the selectivity parameters ("Case 3"; Figure 28) but this model was unable to match the magnitude of the peak in the observed distribution using only deterministic recruitment. Finally, "Case 4" obtained an even better fit to the observed distributions by being able to alter both the selectivity function and the recruitment deviations (Figure 28). This was at the expense of adding 48 more parameters to the model relative to "Case 3" and the AIC (Table 15) indicates that the gain in likelihood did not justify the improvement in the overall fit of the model. However, the poor fit to the length frequency data obtained by "Case 3" indicates that it fails to adequately explain the observed data and that a more complex model is required for management advice.

5.4.4.2 "Total" catch model

A comparison of the fits obtained using the "total" catch data to those obtained using the "retained" catch indicates that the results were broadly comparable between the two data sets (Table 15). The fits to the biomass indices (Figure 29) and the length frequency data (Figure 30) follow very similar patterns to those described in the previous section (5.4.4.1) and the recruitment deviation trajectories are similar in timing, but the peaks are not as broad (Figure 25).

As for the "retained" data option, the model "Case 3" was, based on the AIC (Table 15), the most parsimonious choice in terms of fit to the data. But this fit may not be very credible as it estimated an extremely large initial biomass. The simplest model ("Case 1") fitted the observed length frequencies surprising well, with only a slight improvement in the fit when the selectivity parameters were estimated in "Case 3". Based on the AIC, the models using deterministic recruitment appeared to perform better than the models which estimated a non-equilibrium initial population. Three of the four models investigated estimated similar biomass trajectories (Figure 29). The fourth model ("Case 3") estimated such a large initial biomass that the relative change attributable to the fishery was small.

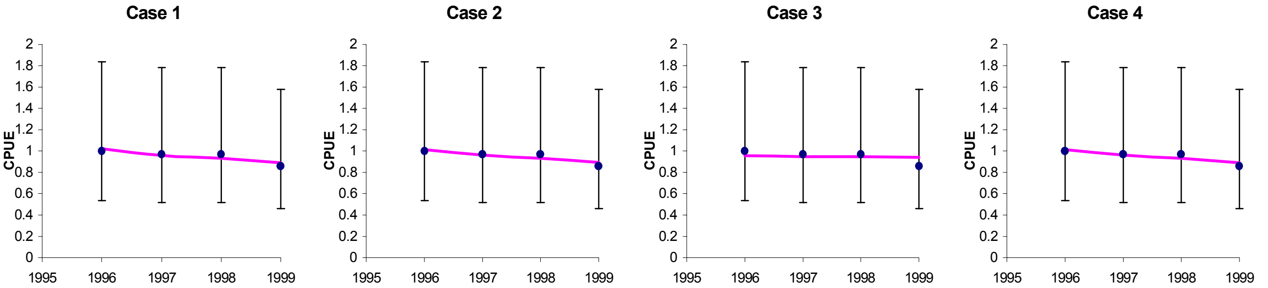


Figure 29. Fitted CPUE biomass indices for the four "cases" defined in Table 15 using "total" catch and length frequency data as inputs.

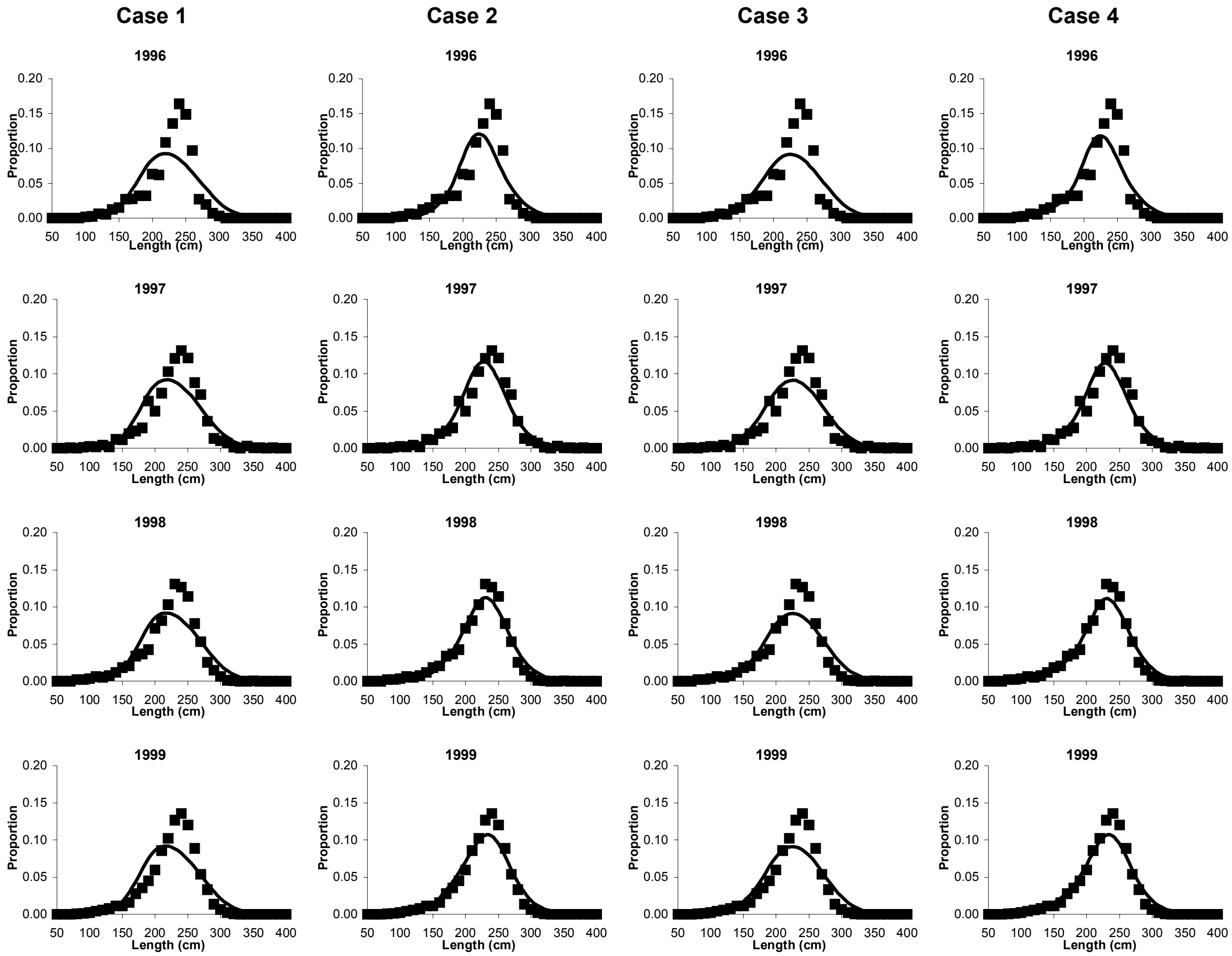


Figure 30. Fitted length frequencies for the four "cases" defined in Table 15 using "total" catch and length frequency data as inputs.

5.4.5 MODEL RESULTS INVESTIGATING THE EFFECT OF CHANGED NATURAL MORTALITY (M)

The results presented in the previous section were based on models which fixed a number of important parameters that are poorly known, including growth rate parameters and natural mortality. Model sensitivity to the fixed natural mortality parameter was investigated by refitting the model using different values for M (M=0.05 and M=0.20). In order to make the comparisons valid, the growth rates, maturity schedule, and seed values for the selectivity function needed to be adjusted to reflect the different age-at-length relationships implied by changing M. Model runs were made using the full selection of parameters used in "Case 4" of the initial model fitting and are presented with that "case" for comparison. Again, the interpretation of these results must consider that growth rates, although poorly known, are modelled without error.

Table 16. Description of model runs investigating different values of M, including the data used, the parameters estimated, and the assumed parameters. Results are presented for two sets of input data: (i) "retained" catch and associated length frequencies and (ii) "total" catch and associated length frequencies. See Section 5.4.1 for a description of the data used. An effective sample size of '100' was used for the annual length frequency distributions as described in Section 5.4.3. Posterior mode (PME) parameter estimates and likelihood components for the PME fit are presented. Biomass levels are for the beginning of the year

	Retained Catch			**Total Catch**		
	Case 4	**Case 5**	**Case 6**	**Case 4**	**Case 5**	**Case 6**
Data Used						
CPUE	Yes	yes	yes	yes	yes	yes
Length Frequency Data	Yes	yes	yes	yes	yes	yes
Parameters Estimated						
R0	Yes	yes	yes	yes	yes	yes
CPUE q	Yes	yes	yes	yes	yes	yes
Selectivity (2 params)	Yes	yes	yes	yes	yes	yes
Recruitment Deviations (48)	Yes	yes	yes	yes	yes	yes
Assumed Parameters						
M	0.1	0.05	0.2	0.1	0.05	0.2
Steepness	0.75	0.75	0.75	0.75	0.75	0.75
Growth Function Used	Kline 96	Kline 96	Kline 96	Kline 96	Kline 96	Kline 96
Likelihoods						
CPUE	0.1239	0.0415	0.0443	0.0169	0.0539	0.3819
Commercial LFs	-317.6	-325.0	-317.7	-297.4	-308.9	-300.8
Penalties	16.7	0.3	10.7	10.1	0.1	9.1
Total Likelihood	-300.8	-324.7	-307.0	-287.3	-308.7	-291.3
Parameter Estimates						
R0	11.86	110.01	72.92	37.31	207.40	15.38
CPUE q	1.34E-04	1.34E-05	4.07E-05	4.13E-05	6.16E-06	2.29E-04
Sfull_commercial	16.0	34.0	8.2	19.4	45.6	11.2
VarL_commercial	-16.1	-24.0	-6.3	4.1	5.8	2.9
Mean Recruitment Multipliers	1.0	1.0	1.0	1.0	1.0	1.0
Derived Parameters						
Vuln_Biomass$_{1996}$	8,400	73,178	23,980	24,544	156,150	5,303
Vuln_Biomass$_{2000}$	5,212	68,465	20,978	20,447	150,447	2,492
$\frac{\text{Vuln\_Biomass}_{1996}}{\text{Vuln\_Biomass}_{2000}}$	62.0%	93.6%	87.5%	83.3%	96.3%	47.0%
Spawning_Biomass$_{1996}$	7,809	80,588	22,822	20,026	149,136	4,736
Spawning_Biomass$_{2000}$	5,503	76,664	22,417	18,462	143,467	2,336
$\frac{\text{Spawning\_Biomass}_{1996}}{\text{Spawning\_Biomass}_{2000}}$	70.5%	95.1%	98.2%	92.2%	96.2%	49.3%
Number Parameters Estimated	52	52	52	52	52	52
Akaike Information Criterion[1]	-497.52	-545.31	-510.00	-470.69	-513.46	-478.64

[1] Hilborn & Mangel 1997

Model fits appeared to be better with the lower M (=0.05) under both catch options ("retained" and "total" – Table 16). Surprisingly, the AIC was better for M=0.20 than for M=0.10 under both catch options. Model fits with M=0.05 estimated a large standing stock biomass and consequently lower levels of depletion. Also, the lower M value allowed for relatively more large fish in the population; this resulted in no large spikes of recruitment compared to the model runs when M=0.10 ("Case 4": Figure 25 and "Cases 5": Figure 31).

Similarly, model fits with M=0.20 estimated a large spike of recruitment in the early 1960s (Figure 31). The most likely explanation for this model behaviour is that the length frequency data suggest that more large fish should be available in the catch than would be expected when M=0.20. Therefore, the model obtains a better fit to the length frequency data by increasing recruitment for the appropriate age classes. Initial stock sizes vary under the M=0.20 assumption between the "retained" and "total" catch data options, with a large stock size estimated when fitting to the "retained" catch data and a quite small stock size when the "total" catch data are used.

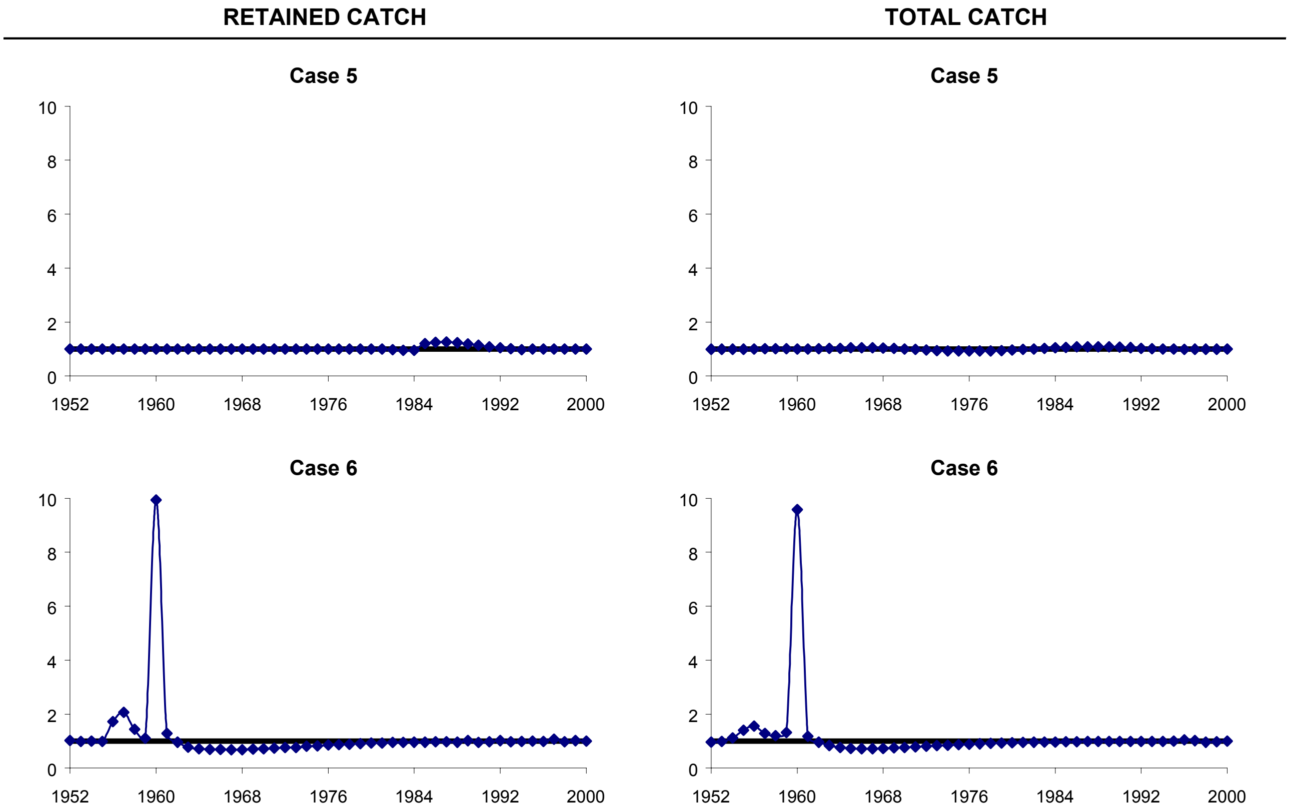


Figure 31. Estimated recruitment deviations for the two additional "cases" investigating the effect of alternative values of M as defined in Table 16 for both the "retained" and "total" catch and length frequency data inputs. "Case 4" (Figure 25) is the equivalent model run with M=0.10.

6. DISCUSSION AND CONCLUSIONS

This paper has attempted to collect and interpret all the information available for Canadian longspine thornyheads. The data sources that were identified included:

- The DFO PacHarvest database for catch and effort data
- The DFO GFBio database for research and commercial length frequency data
- Length frequency and relative biomass estimates by sex from a random trawl survey undertaken by NMFS off the US Pacific coast. This survey does not extend into Canada
- Biological data (weight at length) from Canadian and US research surveys

- Age at length data were not obtainable at this time (Ianelli NOAA-Alaska Fisheries Centre, pers. comm.) so a published growth function was used without verification
- Maturity data were also not available so a published growth function was also used
- Stock boundary information for this species are completely unavailable

6.1 STATUS OF AVAILABLE INFORMATION

It is clear that good information pertaining to this species is scarce. Population modelling undertaken in this paper indicates that the available information is inadequate to determine population status or available yields for this stock. This inability to assess the current status of Canadian longspine thornyheads is related to two factors: 1) the short time period over which the fishery has existed and 2) the lack of useable information for this species. Because the fishery targeting this species is still in its development stage, this summary of available information can be used to identify key areas where data are lacking and where further analyses are required.

The analyses presented in this paper have shown that catch and effort data are available at a very detailed level and the high quality of this information is adequate for stock assessment. Some associated data (e.g. tow speed, vessel and net characteristics) which would improve the use of catch and effort data in fishery stock assessments have not been routinely collected in the past. This lack of information can be overcome by analysing each vessel individually as was done in Section 5.3, but this option becomes less feasible as the fishery develops and matures. It is also likely that the relative fishing power of bottom trawl gear will improve substantially over time. Future analyses will need to take this improvement into account as this trend will be confounded with abundance changes. The possibility of adding additional data fields to data collection procedures is currently being considered.

A progressively exploited population generally shows a shift in the population age structure as the average age drops. As the ageing of this species is presently uncertain, population length structures must serve as a surrogate measure for this expected change, although at a lesser level of confidence. This paper has identified that length sampling during the first two years of the commercial fishery was at very low levels. More recent sampling in the fishery would also be considered low (at 12% of the catch in the most recent year – Table 2) in most fisheries, but appears adequate given the restricted area being fished and the extraordinary stability apparent in the length structure of the population. However, this level of sampling should be improved as the fishery expands and matures.

Possibly the most important area of required research for this species is further investigation into growth rates which underpin the modelling. Stock assessments for longspine thornyheads done for the Pacific Management Council (Jacobson 1991; Ianelli et al. 1994) also emphasise the lack of information on this issue and other papers (e.g. Cailliet et al. 1997) underscore the uncertainty in the present ageing technology. It is thought that these fish are relatively old (or non-productive) due to the great depths at which they live and the likely low productivity of the anoxic layer between 800 and 1100 m in depth (Jacobson & Vetter 1996). An unpublished M.Sc. thesis by Kline (1996) used radiometric techniques to independently age the two *Sebastolobus* species. The method measures levels of (^{210}Pb:^{226}Ra) disequilibria in otolith cores to estimate the age of the otolith. Results from this study estimated that the maximum age for *Sebastolobus altivelis* was 45 years. However, this method is extremely sensitive to contamination and errors in the ^{226}Ra measurements and the results should be considered provisional until confirmed. Adequate age and growth information are required before stock assessments can be done for this species with any degree of confidence.

6.2 STOCK STATUS CONCLUSIONS

The modelling results presented in Section 5.4 are clearly equivocal, particularly when considered in the context of uncertain growth rates. The amount of information presently available is insufficient to assess this stock and the results indicate that stock size could be either large or small, depending on the assumptions and the data set used. Consequently sustainable yields are unknown and cannot be presently estimated with confidence.

The modelling results indicated that current spawning biomass levels were in the range of 70 to 90% of the 1996 level after four years of fishing, regardless of the assumptions made (with the exception of one run with M=0.20). This result is driven by the estimate of depletion from the analysis of the catch and effort data (Table 12: this analysis estimates a cumulative decline of approximately 15% over the first four years of the fishery, corresponding to about 4% reduction of biomass per year). While the stock assessments using this series of CPUE biomass indices are not reliable, the CPUE analysis indicates that it is likely that the current level of fishing is not causing this stock to decline rapidly in the near future. However, if the stock is to continue being fished at the current levels, it is also important to continue collecting base line information to closely monitor its annual progress.

The hypothesised low productivity for this species and experience in deepwater fisheries in other parts of the world suggest a high degree of caution when fishing such a population. Model results presented in Table 15 and Table 16 indicate that the change in biomass over the four-year period is approximately equal to the total removals from the fishery. This observation is a function of the slow growth rates used in the modelling and the fact that most of the population is found in the flat section of the growth curve (as the population will be made up primarily of older individuals). This also implies that there will be a phase of “fishing down” as the population equilibrates to lower abundance levels associated with higher yields. These levels of higher productivity are usually characterised by populations made up of smaller fish and commercial CPUEs will often be lower than when fishing an unfished population. Given the catch rates which presently characterise this species, it may be that lower catch rates combined with a prevalence of smaller fish will tend to make the fishery uneconomic before biomass levels become depleted.

An important component of any stock assessment is having an index of biomass to track the progress of the population as it is being fished. Indices of absolute biomass are always more powerful than relative indices, but such absolute indices are difficult to obtain. Relative indices of abundance can be obtained from the commercial catch and effort data (Section 5.3 is an example of this), but such indices are always potentially biased as the commercial fishing effort is necessarily targeted and not randomly allocated. Therefore a series of fishery-independent indices are preferred to monitor this fishery. Such a survey is presently proposed (Starr & Schwarz 2000).

6.3 STOCK BOUNDARY ISSUES

A consideration for further research is the extent of the stock boundaries for this species. Wakefield (1990) indicates that this species has an extended larval pelagic phase of about 18 – 20 months. This implies that, given the extensive and strong currents which are present along the edge of the eastern Pacific, there is a strong possibility that the effective spawning biomass could extend over a large area of the coast. It is possible that future assessments may require the consideration of catches and biomass levels over a much larger area than simply the west coast of Vancouver Island.

6.4 RECOMMENDATIONS

The following recommendations flow from this work:

1. Review the information being collected on this species from the commercial fishery. This includes information associated with the catch (including tow speed, vessel and net characteristics) and the biological information (length frequency, age frequency, sex and maturity). Recommend improvements to the collection of data based on this review.
2. Review available information on growth and ageing for this species. Commission further research on growth and ageing based on this review.
3. Design and develop a fishery-independent biomass survey.
4. Review available information on stock identification for this species. Commission research as required to determine the effective stock boundaries for this species.
5. Allow the current level of removals to continue for at least another year as there is little evidence that the fishery is having a large impact on the vulnerable biomass of this species. Continue the present policy of spreading the catches throughout the entire coast.
6. Update for the 2001 PSARC meeting the monitoring analyses (length frequency and GLM) presented in this report for the southern fisheries. In addition, summarise the length frequencies and catch rates from the exploratory fishery and compare these with those from the established southern fishery.

7. ACKNOWLEDGEMENTS

The authors wish to acknowledge the support and encouragement of the directors and staff of the Canadian Research and Conservation Society and particularly Doug March for his vision of the future of Canadian groundfish research. The authors also acknowledge the assistance of Mark Wilkins from the NOAA Alaska Fisheries Centre who so kindly provided the US survey data used in this analysis. Waldo Wakefield and Kevin Piner (NOAA – Northwest Fisheries Centre), and Jim Ianelli (NOAA – Alaska Fisheries Centre) all provided support and advice in the preparation of this paper. Lastly, Jon Schnute has provided continuous and generous support in the discussions which have led to the completion of this paper.

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9. APPENDIX 1: MODEL DESCRIPTION AND EQUATIONS FOR THE LENGTH-BASED AGE-STRUCTURED MODEL

The following set of equations and documentation have been extracted from Hilborn et al. (in prep.) to describe the population model used in Section 5.4. Note that referenced "sections" preceded with a '#' are referring to sections of the input procedures when implementing the model.

9.1 NOTATION

A general description of the different components of the estimation model (*Colerain.exe*) is presented in the next sections of this manual. The following notation is used throughout this section:

Subscripts:	*a*	Age
	l	Length
	t	Time
Superscripts	*g*	Gear (Fishery or Survey)
	s	Sex

9.2 ABUNDANCE DYNAMICS BY SEX

Abundance at age and sex is propagated according to the following difference equations

$$\boldsymbol{N^s_{a,t+1} = N^s_{a-1,t}\mathrm{e}^{-M}\left(1-u^s_{a-1,t}\right) \quad \text{for } a = 1,\cdots,A-1}, \qquad \text{Eq 1}$$

$$\boldsymbol{N^s_{a,t+1} = N^s_{a-1,t}\mathrm{e}^{-M}\left(1-u^s_{a-1,t}\right) + N^s_{a,t}\mathrm{e}^{-M}\left(1-u^s_{a,t}\right) \quad \text{for } a = A} \qquad \text{Eq 2}$$

where M is the instantaneous rate of natural mortality, age A is a "plus" group, and $u^s_{a,t}$ is the exploitation rate for all gears combined obtained by summing over all gear-types

$$u^s_{a,t} = \sum_g u^{s,g}_{a,t} \qquad \text{Eq 3}$$

The exploitation rate for each gear is a product of its age-specific selectivity, $s^{s,g}_{a,t}$, and the exploitation rate of fully-selected fish

$$u^{s,g}_{a,t} = s^{s,g}_{a,t}\, u^g_t \qquad \text{Eq 4}$$

Formulations below are identical whether *g* refers to a fishery component or to a survey, except that the mortality induced by the surveys is negligible and can be ignored. The alternative approaches used for the selectivity function are explained in a later section.

Assuming that the total commercial catches in biomass for each gear C_t^g are known without error, and that fishing takes place in a short time interval in the middle of the year, the annual exploitation rate by gear is given by

$$u_t^g = \frac{C_t^g}{\mathrm{e}^{-0.5M} \sum_s \sum_a s_{a,t}^{s,g} \, N_{a,t}^s \, w_{a,t}^{s,g}} \qquad \text{Eq 5}$$

which is basically equal to the ratio of total catch to vulnerable biomass at the middle of the year.

9.3 INITIAL CONDITIONS

The initial condition assumptions built in to the model allow for the estimation of two parameters, namely $N_{1,1}$ and u_0. The initial vulnerability at age pattern by sex has to be incorporated by the user in the "Fixed Parameter" section (# 13) and the fraction of $N_{1,1}$ and more generally $N_{1,j}$ (*j* = year) that recruits to each sex is represented by a user defined constant (λ). Thus the initial population age structure is represented by

$$N_{a,1}^s = \lambda N_{1,1} \, \mathrm{e}^{-M(a-1)} \prod_{i=1}^{i=a-1} (1 - s_{i,1}^{s,g} u_0^s) \quad \text{for} \quad a = 1, \cdots A-1 \qquad \text{Eq 6}$$

The plus group for the initial year is given by

$$N_{A,1}^s = 0.5 N_{1,1} \, \mathrm{e}^{-M(A-1)} \frac{\prod_{i=1}^{i=A-1} (1 - s_{i,1}^{s,g} u_0^s)}{1 - \mathrm{e}^{-M} (1 - s_{A,1}^{s,g} u_0^s)} \qquad \text{Eq 7}$$

Uncertainty in the initial abundance at age vector is incorporated by using log-normal errors as stated above

$$N_{a,1}^s = N_{a,1} \, \mathrm{e}^{({}_I\varepsilon_a - \frac{{}_I\sigma^2}{2})} \quad \textit{where} \quad {}_I\varepsilon_a \sim N(0, {}_I\sigma^2); \quad \text{for} \quad a = 1, \cdots A-1 \qquad \text{Eq 8}$$

The plus group has an independent error component ${}_P\varepsilon_A$ (with its own variance), where *P* stands for plus group and *I* for initial.

9.4 STOCK-RECRUITMENT

Recruitment follows a Beverton-Holt stock-recruitment relationship with log-normal error structure of the form

$$N_{1,t+1}^s = \lambda \frac{S_t}{\alpha + \beta \, S_t} e^{\left({}_R\varepsilon_t - {}_R\sigma^2/2\right)} \qquad \text{Eq 9}$$

where ${}_r\varepsilon_t$ is the recruitment residual for year *t* (${}_R\varepsilon_t \sim N(0,{}_R\sigma^2)$), and S_t is spawning biomass in year *t* . The latter is computed as

$$S_t = \sum_a w_a^f \Phi_a N_{a,t}^f \qquad \text{Eq 10}$$

where Φ_a (maturity ogive) is the fraction of females that have reached maturity by age *a* and w_a^f is female weight at age.

Recruitment at equilibrium in the absence of fishing equals

$$R_0 = \frac{SpR - \alpha}{\beta\, SpR} \qquad \text{where} \qquad SpR = \lambda \sum_a w_a^f \Phi_a\, e^{(-M(a-1))} \qquad \text{Eq 11}$$

is the spawning biomass per recruit (a function of the surviving proportion, weight at age and maturity ogive). The model was parameterised with a steepness parameter , *z*, the proportion of the virgin recruitment that is realised at a spawning biomass level of 20% of the virgin spawning biomass (Francis, 1992b).

Thus both parameters can be formulated as a function of $z,\ R_0 \ \mathit{and}\ SpR$,

$$\alpha = S_0 \frac{1-z}{4z\, R_0} \qquad \text{Eq 12}$$

$$\beta = \frac{5z-1}{4zR_0} \qquad \text{Eq 13}$$

$$S_0 = 0.5\, R_0\, SpR \qquad \text{Eq 14}$$

9.5 GROWTH

Fish grow according to a von Bertalanffy model with mean size at age given by

$$L_a^S = L_1^S + \left[L_n^S - L_1^S\right] \frac{1-(\rho^S)^{a-1}}{1-(\rho^S)^{n_{ages}-1}} \qquad \text{Eq 15}$$

which corresponds to the parameterisation proposed by Schnute and Fournier (1980):

$$L_{a_1} = L_\infty (1 - e^{-k(a_1 - t_0)})$$

$$L_{a_n} = L_\infty (1 - e^{-k(a_n - t_0)}) \qquad \text{Eq 16}$$

$$\rho \quad = e^{-k}$$

We assume that the distribution of size at age is log-normal with standard deviation sd_a^s, which is a linear function of mean size at age

$$sd_a^S = {}_{L_1}\sigma^S + \left[\frac{{}_{L_n}\sigma^S - {}_{L_1}\sigma^S}{L_n^S - L_1^S}\right](L_a^S - L_1^S) \qquad \text{Eq 17}$$

This is basically a linear interpolation between the standard deviation of the mean length at the first (L_1^S) and last (L_n^S) age. The distribution of log(*L)* at age *a* (length-age relationship) for sex (*s)* is symbolised by $\varphi\left(\log(L) \mid \mu_a^s\, \sigma^{2}{}_a^s\right)$, and has mean μ_a^s and variance $\sigma^{2}{}_a^s$ respectively equal to

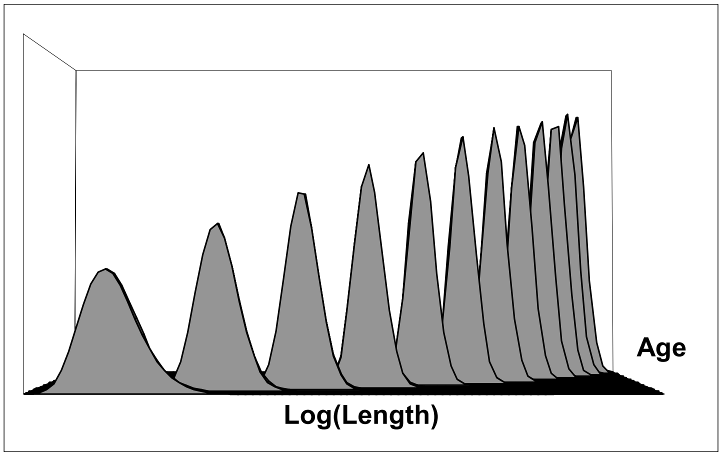
$$\mu_a^s = \log\left(L_a^s\right) - \frac{\sigma^{2}{}_a^s}{2}$$

$$\sigma^{2}{}_a^s = \left(\frac{sd_a^S}{L_a^s}\right)^2 \qquad \text{Eq 18}$$

The length proportions at age *a* can be approximated as

$$f_{l|a}^s = \frac{\varphi\left(\log L_l \mid \mu_a^s, \sigma^{2}{}_a^s\right)\Delta_l}{\sum_{l=1}^{n_L} \varphi\left(\log L_l \mid \mu_a^s, \sigma^{2}{}_a^s\right)\Delta_l} \qquad \text{Eq 19}$$

where Δ_l is the width of the interval in log scale. This relation can be visualised in the following graph:



The length proportions at age relationship is used in many sections of the model, depending on the amount of available data. It is used to compute the predicted size compositions, to convert a length based selectivity into a selectivity at age and to compute the mean weight at age when the selectivity function of the survey is a function of length.

9.6 WEIGHT AT AGE RELATIONSHIP

Weight-at-age is a vital piece of information in the assessment, because it is involved in the vulnerable biomass calculations. It can be directly incorporated into the model as observed data (design based estimations) or by using a model based approach (parameters of the weight-length power function).

By default the program uses the observed data. The rest of the temporal weight-at-age information arises from the following calculations:

a) If selectivity is a function of age, mean weight at age is predicted from the above given equation

$$w_a^s = b_i^S \, (L_a^S)^{b_{ii}^S} \, e^{\left(\frac{b_{ii}^S \, sd2_a^S \left(b_{ii}^S - 1\right)}{2}\right)} \qquad \text{Eq 20}$$

where the exponential is a correction for the variance of the log-normal distribution of size at age. If the survey selectivity is age based, than the weight at age for the commercial fleet is the same as the one for the surveys.

However, selectivity can be modelled as a function of fish size (only for survey) in which case the mean weight at age for the surveys is affected by selectivity at size and the length-age relationship according to

$$w_{a,t}^{s,g} = \frac{\sum_l b_i^S \, (L_l)^{b_{ii}^S} \, s_{l,t}^{s,g} \, f_{l|a}^s}{\sum_l s_{l,t}^{s,g} \, f_{l|a}^s} \qquad \text{Eq 21}$$

9.7 SELECTIVITY

Selectivity is a process that can be modelled as age or size-based. This model supports an age-based selectivity for the fishing fleet and a size or age-based selectivity for the surveys. In this model the only sex specific variation in the selectivity function arises from the difference between ages of full recruitment.

9.7.1 NOTATION:

w_a^s : mean weight at age, sex *s*.

L_a^S : mean length at age, sex *s*.

L_l : length in interval *l*.

$s^{s,g}_{l,t}$: selectivity at length, time t, sex s and survey gear g.
S_{full}^{s,g_i} : age of full selectivity by sex and gear.
φ : distribution of Log(L) at age.

9.7.2 SELECTIVITY AS A FUNCTION OF AGE

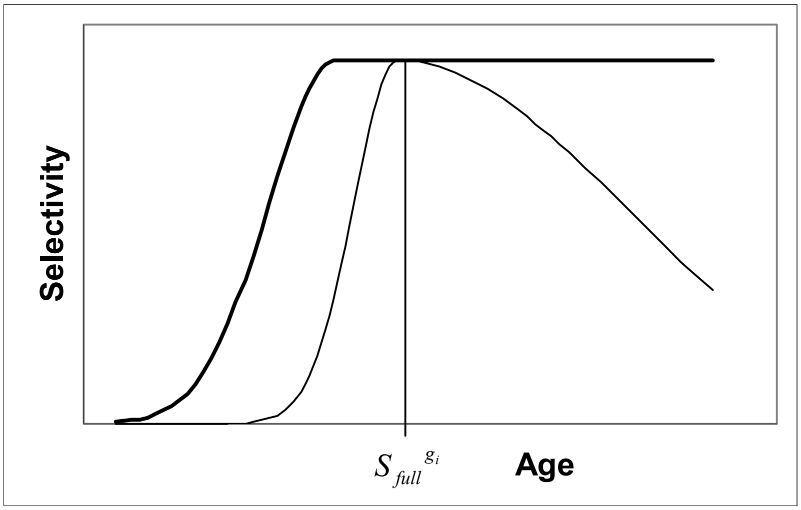
The selectivity function implemented in the model is a double half-Gaussian function of age.

$$\boldsymbol{s^{s,g}_{a,t}} = \begin{cases} \exp\left\{ \dfrac{-\left(a - S_{full}^{s,g}\right)^2}{{}_L v^g} \right\} & \textbf{for} \quad a \le S_{full}^{s,g} \\ \exp\left\{ \dfrac{-\left(a - S_{full}^{s,g}\right)^2}{{}_R v^g} \right\} & \textbf{for} \quad a > S_{full}^{s,g} \end{cases} \tag{Eq 22}$$

$$S_{full}^{s,g} = (S_{full}^{g} + (1 - j)\Delta_{S_{full}}{}^{g}) \tag{Eq 23}$$

where j is a dummy variable with value 1 for females and 0 for males and $\Delta_{S_{full}}{}^{g_i}$ is the sex specific difference in age of full recruitment for each gear.

The next graph show some of the shapes that this three-parameter model can adopt. The thick line represents a situation with very high right hand variance. The thin line shows a declining right-hand limb, caused by a smaller variance of the right hand side of the selectivity function.



Survey selectivities are assumed to be constant over time, while commercial selectivities are allowed to change over time according to a random walk model in the following way

$$S_{full_{t+1}}^{S,g} = S_{full_t}^{S,g} + {}_{S_{full}}\varepsilon^g_t \qquad \textit{where} \;\; {}_{S_{full}}\varepsilon^g_t \sim N(0\,,\; {}_{S_{full}}\sigma^2) \tag{Eq 24}$$

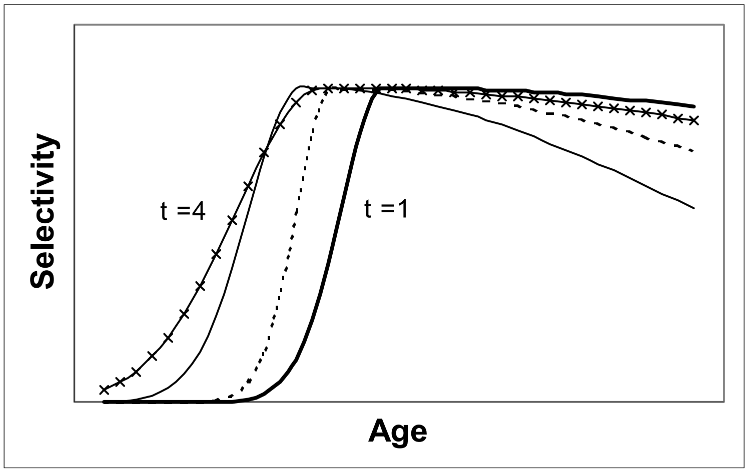
This means additive errors for the age of full recruitment and multiplicative for the variances

$$ {}_j v^{g}_{t+1} = {}_j v^{g}_{t+1}\, e^{{}_{jv}\varepsilon^{g}_{t}} \qquad {}_{jv}\varepsilon^{g}_{t} \sim N(0, {}_{Lv}\sigma^{2}) \tag{Eq 25} $$

where *j* is the right or left side variance.

Trends in selectivity have been associated with changes in spatial allocation of fishing effort and the variation considered in this approach is independent of sex.

The Figure below shows a declining pattern in the right side of the selectivity curve over time. It also shows a decrease in age of full selectivity between the first and last time periods.



9.7.3 SELECTIVITY AS A FUNCTION OF SIZE

A double-Gaussian function of size, with time invariant parameters, is used. The selectivity at age is computed by integrating the selectivity at size over the size proportions at age. Thus

$$ s^{s,g}_{a,t} = \int_{-\infty}^{\infty} s^{s,g}_{t}(L)\,\varphi\left(\log L \mid \mu^{s}_{a}, \sigma^{2s}_{a}\right) \mathrm{d}\log L \tag{Eq 26} $$

The integral above can be approximated by discretising the size distribution into n_L size classes, denoted as *l*, as

$$ s^{s,g}_{a,t} = \sum_{l=1}^{n_L} s^{s,g}_{l,t}\, f^{s}_{l|a} \tag{Eq 27} $$

where $s^{s,g}_{l,t}$ is the size-selectivity function evaluated at L_l, the length at the mid point of interval *l* . For converting the size based selectivity into a selectivity at age we weight the selectivity at size by the size proportion at the respective age. If we do not rescale the “new” selectivities at age, it is very likely that no age is fully selected. This would not affect the estimation procedure but is going to be reflected in the catchability coefficient.

9.8 DATA

9.8.1 PREDICTED ABUNDANCE INDICES

Commercial CPUE and survey indices, here denoted as I_t^g , are assumed to be directly proportional to the vulnerable biomass in the middle of the year

$$I_t^g = q_t^g \, e^{-0.5M} \left(\sum_s \sum_a s_{a,t}^{s,g} \, N_{a,t}^s \, w_{a,t}^g \right) e^{{}_{I^g}\varepsilon_t} \qquad \text{Eq 28}$$

where ${}_{I^g}\varepsilon_t \sim N(0, {}_{I^g}\sigma^2)$ and q_t^g is the gear-specific catchability. The temporal index for the catchability coefficient is incorporated only for the commercial CPUE (the catchability coefficient of the surveys are not allowed to have temporal variation).

A random walk model is used to model the temporal changes, thus

$$\ln\left(q_{t+1}^g\right) = \ln\left(q_t^g\right) + {}_q\varepsilon_t^{CPUE_i} \qquad \text{Eq 29}$$

where ${}_q\varepsilon_t^{CPUE_i} \sim N(0, {}_{q^g}\sigma^2)$. The parameter ${}_{q^g}\sigma^2$ is used to control the amount of year-to-year variation allowed in q_t^g . The formulation is identical to that used for selectivity parameters and we end up estimating residuals for every year and gear where we have CPUE data.

9.8.2 PREDICTED AGE AND SIZE COMPOSITION

The predicted age composition (in proportions) of the catch at time t by *sex* and *gear*, is represented by the following equation

$$P_{a,t}^{s,g} = e^{-0.5M} \frac{s_{i,t}^{s,g} N_{i,t}^s}{\sum_s \sum_i s_{i,t}^{s,g} N_{i,t}^s} M_{A\,x\,A}^{pool} \quad \Omega^S \qquad \text{Eq 30}$$

where Ω^S represents an upper diagonal matrix of age misclassification ("Fixed parameter" section # 14) and $M_{A\,x\,A}^{pool}$ pools the age frequencies for ages $a \geq A_{\text{pool}}$ into a plus group.

If no information on age misclassification is available, an identity matrix is used.

Similarly, size-compositions are predicted as

$$P_{l,t}^{s,g} = e^{-0.5M} \frac{s_{l,t}^{s,g} \sum_a f_{l|a}^s N_{a,t}^s}{\sum_s \sum_l s_{l,t}^{s,g} \sum_a f_{l|a}^s N_{a,t}^s} \qquad \text{Eq 31}$$

when selectivity is a function of fish size, or as

$$P_{l,t}^{s,g} = e^{-0.5M} \frac{\sum_a s_{a,t}^{s,g} f_{l|a}^{s} N_{a,t}^{s}}{\sum_s \sum_a s_{a,t}^{s,g} \sum_l f_{l|a}^{s} N_{a,t}^{s}} \qquad \text{Eq 32}$$

when selectivity is a function of mean length at age.

9.9 OBJECTIVE FUNCTION

Different sources of information contribute to the overall objective function. This can be summarised as follows:

- Survey index:
    - *by Index*
- CPUE :
    - *by commercial fishing gear index.*
- Catch-at-length:
    - *Survey*:
        - individuals whose sex is undetermined
        - sex.
        - gear
    - *Commercial fishery:*
        - sex.
        - gear
- Catch-at-age:
    - *Survey:*
        - sex.
        - gear
    - *Commercial fishery:*
        - sex.
        - gear

The objective function includes likelihood components for the different data types, and penalties on the variability of the stochastic parameters as specified by their Bayesian *prior* distributions.

9.9.1 ROBUSTIFIED NORMAL LIKELIHOOD FOR PROPORTIONS:

We use the robust likelihood formulation proposed by Fournier et al (1990) for the age-sex and size-sex catch compositions. The observed frequency data are incorporated to the likelihood function as proportions at age and sex, $\tilde{P}_{a,t}^{s,g}$, or at length, $\tilde{P}_{l,t}^{s,g}$. The robustified normal model has been selected instead of the more traditional multinomial error model because there is then no need to specify the effective number of fish sampled.

$$\begin{aligned}\ln L^g_{\text{age}} &= -0.5\sum_{i=1}^{Nage}\sum_{s}\sum_{a=1}^{A}\ln\left[\left(P^{s,g}_{a,t_i}(1-P^{s,g}_{a,t_i})+0.1/A\right)\right] \\ &+\sum_{i=1}^{Nage}\sum_{s}\sum_{a=1}^{A}\ln\left[\exp\left\{\frac{-(\widetilde{P}^{s,g}_{a,t_i}-P^{s,g}_{a,t_i})^2}{2(\widetilde{P}^{s,g}_{a,t_i}(1-\widetilde{P}^{s,g}_{a,t_i})+0.1/A)\tau^g}\right\}+0.01\right]\end{aligned} \qquad \text{Eq 33}$$

where A and τ^g are respectively the number of age or length classes and the inverse of the assumed sample sizes. N_{age} is the number of age composition samples available, which correspond to years $t_1,\cdots,t_{N_{\text{age}}}$. A similar formulation is used for the size-sex compositions.

9.9.2 ABUNDANCE INDICES:

Different likelihood functions can be used for the commercial and survey abundance indices, namely normal, log-normal, robust normal and robust log-normal.

The robust log-normal likelihood function has the following representation:

$$\ln L^g_I = \sum_t \ln\left[\exp\left(-0.5\frac{{}_{I^g}\varepsilon^2_t}{{}_{I^g}\sigma^2_t}\right)+0.01\right] \qquad \text{Eq 34}$$

9.9.3 TOTAL LIKELIHOOD:

The total log-likelihood corresponds to the sum of the individual log-likelihood components

$$\ln L = \sum_g \ln L^g_I + \sum_g \ln L^g_{\text{age}} + \sum_g \ln L^g_{\text{length}} \qquad \text{Eq 35}$$

9.9.4 PENALTIES:

Several penalties might be affecting the overall objective function, depending on different model assumptions. In general the penalties correspond to prior assumptions made about some of the stochastic processes involved, namely, recruitment variability,

$$PSS_r = 0.5\sum_t \frac{{}_r\varepsilon^2_t}{{}_r\sigma^2} \qquad \text{Eq 36}$$

time-series trends in catchability by gear,

$$PSS_q = 0.5\sum_t \frac{{}_q\varepsilon^2_t}{{}_q\sigma^2} \qquad \text{Eq 37}$$

and time-series trends in the parameters of the age-selectivity functions for the different commercial fisheries ,

$$PSS^g_{S\text{full}}=0.5\sum_t \frac{{}_{\text{full}}\varepsilon_t^2}{\sigma^2_{S\text{full}}}, \qquad PSS^g_{{}_Lv}=0.5\sum_t \frac{{}_Lv^g\,\varepsilon_t^2}{\sigma^2_{{}_Lv^g}} \quad \text{and} \quad PSS^g_{{}_Rv}=0.5\sum_t \frac{{}_Rv^g\,\varepsilon_t^2}{\sigma^2_{{}_Rv^g}} \qquad \text{Eq 38}$$

Hence the overall penalty would be the sum of the individual components

$$\text{penalties}=PSS_r+PSS_q+\sum_g PSS^g_{S\text{full}}+\sum_g PSS^g_{{}_Lv}+\sum_g PSS^g_{{}_Rv} \qquad \text{Eq 39}$$

9.9.5 GLOBAL OBJECTIVE FUNCTION:

Parameter estimates are obtained by minimising the overall objective function

$$f=-\ln L+\text{penalties} \qquad \text{Eq 40}$$

9.10 REFERENCES

Francis, R.I.C.C. 1992. Use of risk analysis to assess fisheries management strategies: a case study using orange roughy (*Hoplostethus antlanticus*) on the Chatham Rise, New Zealand. Can. J. Fish. Aquat. Sci. 49:922-930.

Fournier, D. A., Sibert, J. R., Majkowski, J., and Hampton, J. 1990. MULTIFAN a likelihood-based method for estimating growth parameters and age-composition from multiple length frequency data sets illustrated using data for southern bluefin tuna (*Thunnus maccoyii*). Can. J. Fish. Aquat. Sci. 47: 301–317.

Schnute, J.T. and D. A. Fournier. 1980. A new approach to length frequency analysis: growth structure. Can. J. Fish. Aquat. Sci. 37: 1337-1351.

10. APPENDIX 2: DATA PREPARATION NOTES

10.1 BIOLOGICAL SAMPLING DATA

10.1.1 COMMERCIAL LENGTH FREQUENCY SAMPLING

10.1.1.1 Data source

Length frequency data for longspine thornyheads from the commercial fishery were obtained from the GFBio database held by the Department of Fisheries and Oceans (DFO) at the Pacific Biological Station on 05 October 2000. The current description of this database, including available data fields, is available on the DFO website: **http://pacgfbio/** This website is accessible only within the DFO internal network.

10.1.1.2 Data preparation and grooming

These data required considerable preparation in order to link them to data available in the PacHarvest database (Section 10.2.1). because there is no explicit link between the two databases (this problem is presently being addressed). Trips were identified between the two data sets in most cases by vessel name and trip starting and ending dates. However, in 16 cases (of 125), this information was insufficient to achieve a match and manual matching was used to identify the most likely trip in the PacHarvest database in these cases. In one instance, there appeared to be a duplicate trip where the same vessel was sampled on the same date but given separate trip and sample identifications. This sample was dropped from the analysis.

Samples by tow were linked explicitly between the two databases through a field kept in the GFBio database. This linkage allowed a successful match for 356 of 376 possible samples. Nineteen of the remaining 20 samples could not be matched because they pointed to tows that did not report longspine thornyheads in the catch. Eighteen of these tows were assigned to the nearest reasonable match using the catch, depth and location information available from the sample data. One sample could not be matched and was dropped. The final mismatch belonged to the apparent duplicate trip.

Comparison of the size of sampled catch on the GFBio record with the catch totals available in the PacHarvest database allowed for the categorisation of the sample data into three classifications: total catch, retained catch or discarded catch. Unfortunately, there was no consistency in the type of sample taken by the samplers. In most cases, the entire catch of the tow appeared to have been sampled; but there were also many instances where either only the retained catch or the discarded catch had been sampled (Table 17). Twenty-five tows had two identified samples (Table 17). Fifteen of these were instances where the retained and discarded catch had been sampled separately. In the other 10 instances, a duplicate sample of the total or retained catch had been taken, the total and retained catch had been sampled, or the total catch and the discarded catch had been sampled. These samples were treated as follows when linked to the PacHarvest database:

- Single samples of the total or retained catch were linked to the appropriate catch fields
- Single samples of the discarded catch were dropped
- Tows in which both the retained and discarded catch were sampled were linked to the appropriate catch fields and then combined

- Tows where the same catch type was sampled twice were lumped
- Tows in which both the total catch and another catch type were sampled used the total catch sample and dropped the second sample

Table 17. Number of samples and length measurements classified by the number of samples taken per tow and by the sample type category for all useable samples taken prior to 1 April 2000. Sample catch type was determined by comparing the size of the sampled catch on the sampling record to the available catch totals in the PacHarvest database

	Number of Samples/Tow					
	1 Sample/Tow		2 Samples/Tow		Total	
Sample Type	**Samples**	**Lengths**	**Samples**	**Lengths**	**Samples**	**Lengths**
Total Catch	163	23821	11	1354	174	25175
Retained Catch	97	15823	21	3783	118	19606
Discarded Catch	64	10684	18	2830	82	13514
Total	324	50328	50	7967	374	58295

Examination of the statistics associated with each of the sample type categories (Table 18) shows that the overall mean and median values vary as would be expected, with the mean and median for the “discarded catch” category being much smaller than for either the “retained” or “total catch” categories and with the mean and median of the “total catch” category slightly smaller than for the “retained catch” category. However, a detailed examination of the data for the “discarded catch” category showed that about 10% of these samples had mean lengths that were larger than the discard limit specified by regulation (190 mm). An additional 12 samples which had been placed into the “total catch” category had mean lengths that were well below 190 mm and two of these had a maximum size in the sample which did not exceed 190 mm. It was therefore arbitrarily decided to use a 180 mm cut-off by defining samples with mean lengths less than this cut-off as “discard” catch samples and samples with mean lengths greater than this cut-off as “total catch” samples. Longspines with lengths greater than 450 mm were considered to be misidentified and dropped from the analysis (only 12 measurements were in this category).

Table 18. Minimum, median, mean, standard deviation and maximum statistics for length (weighted by the number of fish measured) by sample catch type. Catch type was determined as specified for Table 17

	Length of Longspine Thornyheads (mm)				
Sample Type	**Minimum**	**Median**	**Mean**	**Standard Deviation**	**Maximum**
Total Catch	40	230	226	31	390
Retained Catch	60	240	233	32	680
Discarded Catch	30	160	164	30	620

10.1.1.3 Analysis options explored

Two options for analysing the length frequency data were explored, based on the sample type as determined from the comparison of the sampled catch with the declared PacHarvest catches (see Table 17 for a description of this procedure). The first option was to use the samples classified as “total catch” as the basis for the estimate of the total distribution of fish landed on deck on the assumption that these are unbiased samples taken from the entire catch. Unfortunately, the number and coverage of these samples was relatively poor, even when 11 additional samples that had sampled different parts of the same tow were added (Table 19). The second option (termed the “retained catch” option) used all samples which were classified as “total catch” or as “retained catch” by truncating both sample types to fish ≥ 190 mm and assuming that these represent the size distribution of the retained catch. Approximately 100 additional samples were added to the analysis by making this assumption (Table 17 and Table 20).

Table 19. Number of samples by sample catch type for each standardised fishing year under the "total catch" option.

Fishing	Total Catch		Retained Catch		Discarded Catch		Total	
Year	Samples	Lengths	Samples	Lengths	Samples	Lengths	Samples	Lengths
1996	15	1490	0	0	0	0	15	1490
1997	14	1742	0	0	0	0	14	1742
1998	41	6371	7	1650	7	1158	55	9179
1999	102	15770	4	509	4	408	110	16687
Total	172	25373	11	2159	11	1566	194	29098

Table 20. Number of samples by sample catch type for each standardised fishing year under the "retained catch" option.

Fishing	Total Catch		Retained Catch		Total	
Year	Samples	Lengths	Samples	Lengths	Samples	Lengths
1996	15	1351	0	0	15	1351
1997	14	1515	2	192	16	1707
1998	41	6524	69	10938	110	17462
1999	102	14630	39	5634	141	20264
Total	172	24020	110	16764	282	40784

10.1.2 US SURVEY DATA

Length frequency data were obtained from standardised research surveys conducted by the NMFS along the U.S. Pacific west coast ranging from approximately 34°30'N in California to the US-Canada border (Lauth 1997b, Lauth 1999, Lauth 2000; data provided by Mark Wilkins – NOAA, Alaska Fisheries Centre). Two surveys are potentially important for longspine thornyheads: one, termed the "triennial survey" is a systematic survey directed at groundfish in the depth range 55 to 500 m. This survey has been conducted every three years since 1977, with the most recent in 1998 (Shaw et al. 2000). This survey, although the depth range of this survey is inadequate for assessing longspine thornyheads, it extends up to Estevan Point [49° 15'N] off the west coast of Vancouver Island. The other survey (termed the "slope" survey) is done more frequently and extends to much deeper depths (1300 m – Lauth et al. 2000). However, this survey stops at the US-Canada border at ~ 48°N.

Data were provided as estimated numbers-at-length in 1 cm intervals for the three most recent "slope" surveys (1996, 1997, 1999). These were converted to biomass-at-length using the length-weight relationship developed in Section 11.3 to determine the variations in length distributions between sex and depth categories. These distributions were also compared to the length frequency distributions obtained from the commercial fishery. Comparisons were done using the population estimates from the most northerly of the available strata (Columbia River to the Canadian border) to be most comparable with those observed off the west coast of Vancouver Island. The "slope" surveys were chosen for this comparison as population estimates from the "triennial" survey do not go sufficiently deep to be representative of this species.

10.2 CATCH AND EFFORT DATA

10.2.1 DATA SOURCE

All catch and effort data were obtained from a summary table (B7_SRFTable) generated from the PacHarvest database held by the DFO at the Pacific Biological Station on 05 October 2000. See Schnute et al. (1999) for a description of this database, including the available data fields.

10.2.2 DATA PREPARATION AND GROOMING

Records satisfying the following conditions were kept for the analysis in this report:

- Tow start date after 31 March 1996
- Bottom trawl type
- Areas outside the Strait of Georgia (i.e. <> SRF_Area=SG)
- Fishing success code <=1 (code 0= unknown; code 1= useable)
- Valid SRF_Area code
- Valid depth value

Fields or derived fields that were kept in the data set are described in Table 21 and Table 22.

Table 21. Fields kept in the data set used to analyse longspine thornyhead catch and effort data

Field	Description
Vessel	Coded
Month	From April 1996 to July 2000
Standardised fishing year	01 April – 31 March
Latitude	In 0.1° bands
SRF Area	Slope Rockfish Management Area (see Table 22 for code descriptors)
Depth	In 100m bands
Effort	Tow time in hours
Catch	kg
Retained catch	kg
Discarded catch	kg
CPUE	Kg/hour
Pcatch	Proportion longspine catch to total catch

Table 22. Codes and descriptors for the slope rockfish management areas (SRF_Area) used in this document (Figure 1)

Code	Description
3C	Southern Vancouver Island
3D	Northern Vancouver Island
5AB-GI	Queen Charlotte Strait: Goose Island Gully
5AB-MI	Queen Charlotte Strait: Mitchell Gully
5ES	West Coast Queen Charlotte Islands-South
5EN	West Coast Queen Charlotte Islands-North

10.2.3 DEFINITION OF ZERO CATCHES

There were over 4000 tows in B7_SRFTable (out of ~ 100,000 over the 4+ year period) that recorded no catch of any species. When these tows were examined in detail, they often had fishing “success codes” in the database that indicated the tow had failed in some manner (mostly gear malfunction or “water haul”). Therefore, all tows with a “success” code > 1 were dropped (code 0 = “unknown”; code 1 = “successful”). This dropped ~ 5,000 tows, some of which reported catch and left ~ 1,300 tows that had no catch at all.

Many tows only record catch for a few species. For the purposes of this analysis, in addition to the zero catches defined above, any tow > 600 m that did not record longspines was also designated as a zero tow, on the assumption that a tow on the bottom at these depths should have caught longspines. The number of tows that met these criteria were small and appeared to be less frequent in the more recent fishing years (Table 23).

Table 23. Total number of tows and tows with zero catches for longspines used in this analysis by standardised (1 April-31 March) fishing year

```
-------------+-------------------------------------------------------
Standardised |                      SRF_Area
fishing year |     3C      3D  5AB_GI  5CD_MR     5EN     5ES   Total
-------------+-------------------------------------------------------
Zero tows at depth 600 m or greater
        1996 |    158      65      13               1       6     243
        1997 |    117      13       1       5               1     137
        1998 |     49       3                                      52
        1999 |     57       2       1       3       2       3      68
             |
       Total |    381      83      15       8       3      10     500
-------------+-------------------------------------------------------
All tows at depth 600 m or greater
        1996 |   2173     492      18       4       1      11    2699
        1997 |   1328     253      74       5               2    1662
        1998 |   1596     228      22                      29    1875
        1999 |   1102     811       5       3       6      68    1995
             |
       Total |   6199    1784     119      12       7     110    8231
-------------+-------------------------------------------------------
```

10.2.4 ADDITIONAL GROOMING DONE FOR THE GLM ANALYSIS

Further grooming of the longspine catch and effort data was done prior to the GLM (general linear model) analysis:

- The range of depths considered was narrowed to 700 m to 1200 m (this excluded only 6% of the available catch)
- All tows started after 31 Mar 2000 were dropped
- All tows north of latitude 50° were dropped
- Catch and effort data from the 12 vessels that caught the most longspines over the 4 year period were used. This fishery is highly specialised and there are only a few major players on the coast. These 12 vessels accounted for ~80% of the total catch.

- Zero catches (as defined in Section 10.2.3) were replaced with a catch of 2.7 kg/hr (=e^1) as the analysis was performed on log-transformed data (the log of zero is undefined). This catch rate is about one tenth of the mean catch rate in the data and should not bias the results.

The final data set consisted of 5,600 records of which 82 recorded a catch of zero.

The CPUE statistic chosen was catch per hour towed as there appeared to be a strong linear relationship between catch and time towed and there was no suggestion in the data that net saturation was occurring (Figure 32). There were no extreme values of CPUE in the final data set after the above selection and grooming (the highest value of CPUE was 351 kg/hr).

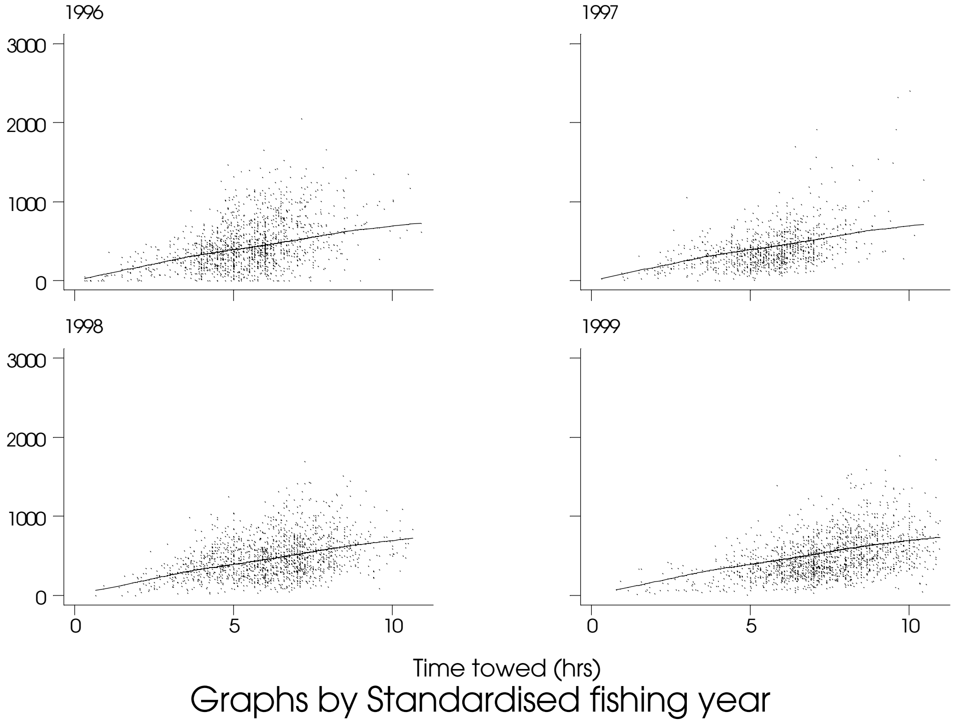


Figure 32. Plot of catch vs. effort by tow for the data set used for the GLM analysis by standardised fishing year (truncated at effort=11 hr). Lowess smoothed lines (spand=80%) also shown.

11. APPENDIX 3: ANALYSIS OF LENGTH-WEIGHT DATA

11.1 THEORY

The standard model used in fisheries is a two-parameter "allometric" model that assumes weight is a power function of length (Quinn & Deriso 1999):

$$\boldsymbol{W_i = aL_i^b} \qquad \text{Eq 41}$$

The main issue with respect to this equation is the error term. It can be either additive (this model is solved using non-linear minimisation):

$$\boldsymbol{W_i = aL_i^b + \varepsilon_i} \qquad \text{Eq 42}$$

or multiplicative (this model is transformed into log space and solved using linear least squares):

$$\boldsymbol{W_i = aL_i^b\ e^{\varepsilon_i}} \qquad \text{Eq 43}$$

The choice between the two models is whether (i) the variability is relatively constant as length increases (additive model) or (ii) the variability is increasing with increasing length (multiplicative model).

11.2 DATA SOURCES

11.2.1 2000 TANNER CRAB SURVEY

A set of 255 observation pairs (one pair has no data) were obtained from six samples on a WE Ricker Tanner crab trip in SRF_Area 5AB between 26 August 2000 and 30 August 2000. Length and weights for males and females were very similar (Table 24). There were a number of mostly small fish which were not sexed which constituted an "unknown" sex category.

Table 24. Summary statistics by sex for the longspine data from the 2000 WE Ricker Tanner crab survey. One obvious outlier (length=485 mm and weight=66 g) has been removed

```
----------+---------------------------------------
     sex2 | mean(length)  mean(weight)     N(length)
----------+---------------------------------------
  unknown |        134.3          42.7            35
     male |        237.2         170.6           105
   female |        230.5         155.9           113
          |
    Total |        220.0         146.3           253
----------+---------------------------------------
```

11.2.2 US SURVEY DATA

A second data set was obtained from three United States National Marine Fisheries Service (NMFS) trawl surveys which cover the Pacific west coast from about 34°30'N to the US-Canada border (upper continental slope surveys: 1995 [Lauth 1997a], 1997 [Lauth 1999] and 1999 [Lauth 2000] – data provided by Mark Wilkins, NOAA, Alaska Fisheries Science Centre). The exact locations from where these data were collected were not provided, although the tow numbers are available in the data. All length-weight pairs were associated with a 200 fathom depth stratum. As with the Tanner crab survey data, there were a large number of small longspines of unknown sex (Table 25).

Table 25. Summary statistics by sex and survey for the longspine data from three US upper continental slope surveys (1995, 1997 and 1999 – data from Mark Wilkins, NOAA Seattle)

```
-------------+---------------------------------------
Survey year  |
and SEX      | mean(length)  mean(weight)     N(length)
-------------+---------------------------------------
1995         |
     unknown |        113.6          17.6           132
        male |        221.2         147.4           217
      female |        221.3         149.5           239
       Total |        197.1         119.1           588
-------------+---------------------------------------
1997         |
     unknown |        115.4          21.1           256
        male |        217.8         145.3           606
      female |        220.9         150.5           587
       Total |        201.0         125.5          1449
-------------+---------------------------------------
1999         |
     unknown |        114.6          17.0           296
        male |        219.3         138.7           596
      female |        219.3         140.3           618
       Total |        198.8         115.5          1510
-------------+---------------------------------------
Total        |
     unknown |        114.7          18.7           684
        male |        219.0         142.9          1419
      female |        220.3         146.0          1444
       Total |        199.4         120.2          3547
-------------+---------------------------------------
```

11.3 RESULTS

11.3.1 TANNER CRAB SURVEY DATA

The data fit either of the models (Eq. 2 and Eq. 3) equally well and the residuals indicate that the additive model is likely to be more appropriate (Figure 33 and Table 26).

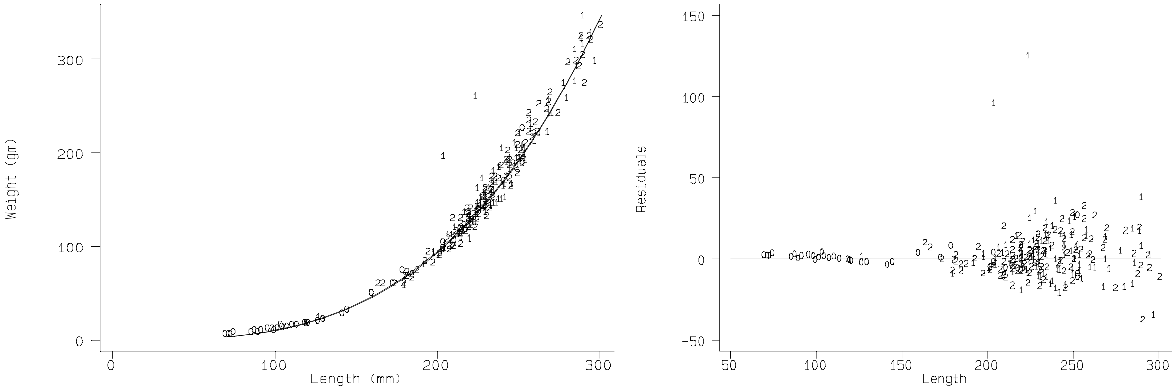


Figure 33. Length-weight relationship and residuals for longspine thornyheads measured during the 2000 Tanner crab survey off the west coast of Vancouver Island. Plotting symbols are 0=unknown sex; 1=male; 2=female; 3=unknown sex. Fitted lines using non-linear estimation and log-transformation are plotted but not visible due to superimposition. Residual plot is for the non-linear estimation model only. One outlier has been removed from the data set (length=485 mm and weight=66 g).

Table 26. Parameter estimates for the fit to the longspine thornyhead length-weight data for all options considered. Two fitting procedures were used (non-linear least squares and a linear log-transformation). The constant parameters in the log-transformed case have been converted to normal space for comparison. Parameter estimates with and without the obvious outlier in the Canadian Tanner crab data have been provided where applicable (N/A: not applicable)

	Non-linear Estimation		**Log-transformation Estimation**	
	Including outlier	**Drop outlier**	**Including outlier**	**Drop outlier**
Canadian Tanner Crab Survey				
a	.0264097	4.75e-06	7.729e-06	3.938e-06
b	1.596256	3.172804	3.077253	3.205288
US "Slope" Survey				
a	4.63e-06	N/A	5.244e-06	N/A
b	3.170226	N/A	3.1439948	N/A
Combined Data				
a	.0000351	4.85e-06	5.282e-06	5.116e-06
b	2.805339	3.162594	3.142987	3.149218

11.3.2 US LENGTH-WEIGHT DATA

The data fit either of the models (Eq. 2 and Eq. 3) equally well and the residuals indicate the multiplicative model is likely more appropriate (Figure 34 and Table 26). As there seemed to be little difference between the two data sets (compare the parameter estimates in Table 26), the data were combined into a single set. The resulting parameter estimates in Table 26 are very similar to the estimates when the data are included separately.

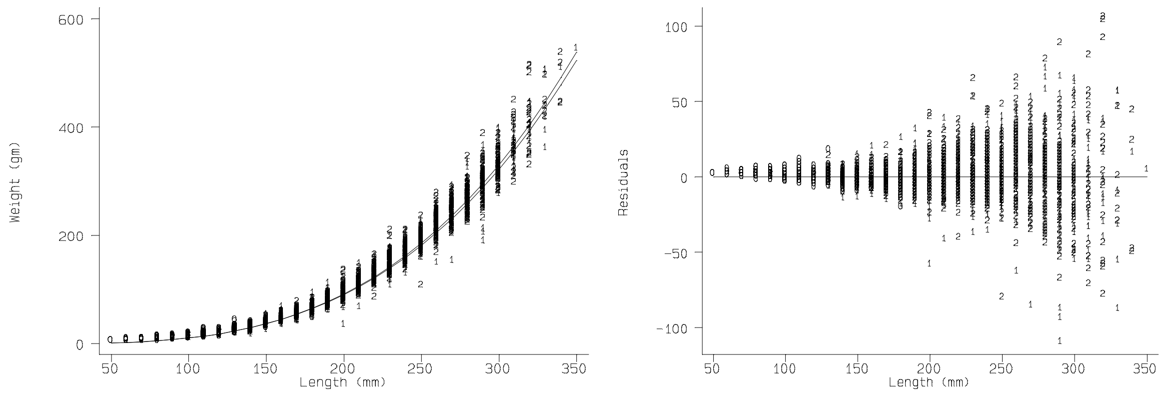


Figure 34. Length-weight relationship and residuals for longspine thornyheads measured from 3 continental slope surveys off the west coast of the United States. Plotting symbols are 0=unknown sex; 1=male; 2=female. Fitted lines using non-linear estimation and log-transformation are shown (but nearly superimposed). Residual plot is for the non-linear estimation model only.

11.3.3 ANALYSIS OF RESIDUALS TO THE COMBINED MODEL

11.3.3.1 Residuals by sex category

When the residuals from the model fitted to all the data are plotted separately by sex category (Figure 35), the fit to the data appear to be similar and well distributed in each sex category. There is no evidence of separate length-weight relationships by sex. An F-test of the residuals by sex category shows that the means of the residuals are equivalent in each sex category (Table 27).

Table 27. Test of the mean of the residuals from the additive model by sex category (unknown, male, female) for all data combined (all US plus Canadian Tanner crab data). The test is non-significant

```
                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      397.503927      2   198.751963      0.89     0.4093
 Within groups      844671.939   3797   222.457714
------------------------------------------------------------------------
    Total           845069.443   3799   222.445234

Bartlett's test for equal variances:  chi2(2) = 1378.9813  Prob>chi2 = 0.000
```

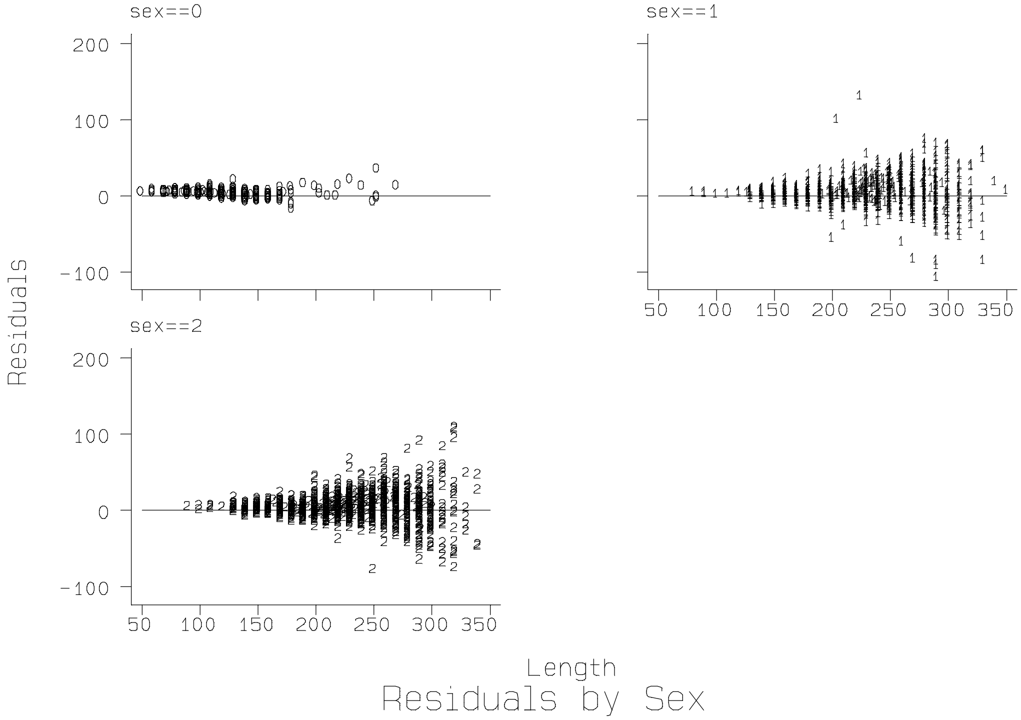


Figure 35. Residuals to the non-linear estimation model fitted to all data by sex category for longspine thornyheads measured from combined US and Canadian Tanner crab surveys. Data plotted by sex category (0=unknown sex; 1=male; 2=female).

11.3.3.2 Residuals by depth category

When the residuals from the fit of the US survey data to the non-linear model are plotted separately by depth category (Figure 36), there appears to be a slight overestimate of weight at length. This bias is similar in all three depth categories. The F-test of the residuals by depth category indicates a significant difference in the mean residuals between depth categories (Table 28).

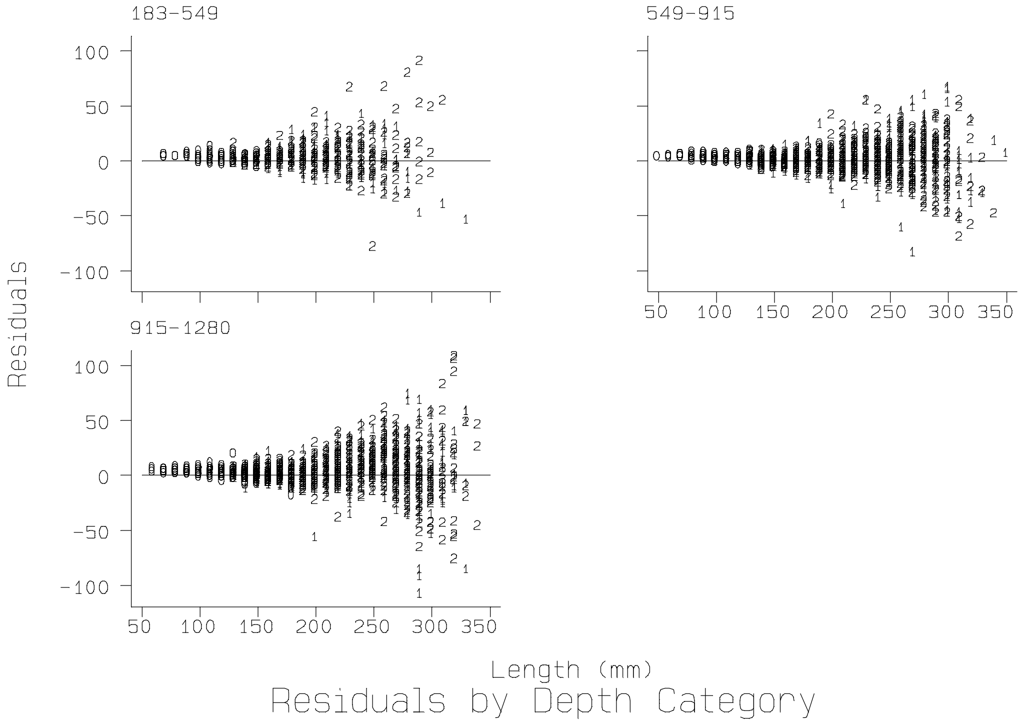


Figure 36. LN residuals from the model fitted to all the data (Equations 3 & 4) from 3 continental slope surveys off the west coast of the United States plotted by 3 depth strata. Plotting symbols are 0=unknown sex; 1=male; 2=female.

Table 28. Test of the mean of the residuals from the additive model by depth category (183-549 m, 549-915 m, 915-1280 m) for US data only. The test is significant

```
                          Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      5473.5687       2   2736.78435     12.49     0.0000
 Within groups     776405.097    3544    219.07593
------------------------------------------------------------------------
    Total          781878.666    3546   220.495958

Bartlett's test for equal variances:  chi2(2) =  54.9445  Prob>chi2 = 0.000
```

11.3.3.3 Residuals by US survey category

When the residuals from the fit of the US survey data to the non-linear model are plotted separately by US survey year (Figure 37), there also seems to be a slight overestimate of weight at length in the first two surveys. The F-test of the residuals by US survey year indicates a significant difference in the mean residuals between years (Table 29).

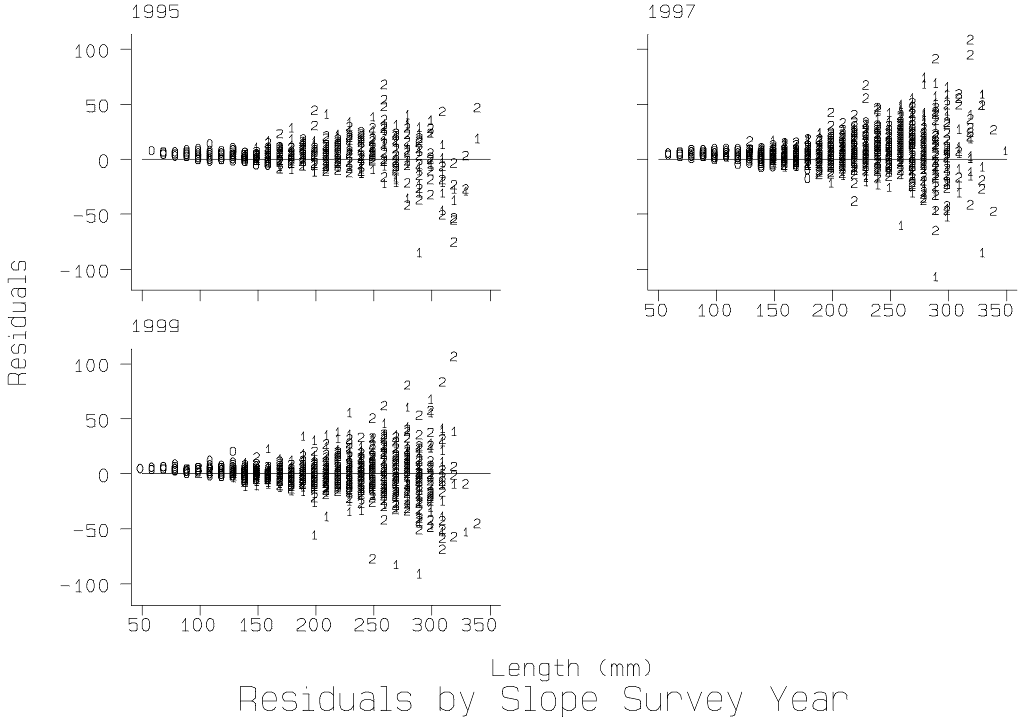


Figure 37. LN residuals from the model fitted to all the data (Equations 3 & 4) from 3 continental slope surveys off the west coast of the United States plotted by biannual cruise. Plotting symbols are 0=unknown sex; 1=male; 2=female.

Table 29. Test of the mean of the residuals from the additive model by cruise year (1995, 1997, 1999) for US data only. The test is significant

```
                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      30364.6531      2   15182.3265     71.60     0.0000
 Within groups      751514.013   3544   212.052487
------------------------------------------------------------------------
    Total           781878.666   3546   220.495958

Bartlett's test for equal variances:  chi2(2) =  14.9870  Prob>chi2 = 0.001
```