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Petrale Sole Stock Assessment for 2003 and Recommendations for Management in 2004

Évaluation du stock de plie de Californie de 2003 et recommandations pour sa gestion en 2004

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Abstract

We summarise results of analysis of biological data, research survey data and fishery observer data for Petrale sole (*Eopsetta jordani*). Size composition summaries suggest that the proportion of smaller fish entering the fishery has increased over the 1998-2002 period. The estimated instantaneous total mortality rate from survey data in 2000 was only slightly larger than the best estimate of the natural mortality rate. We conclude that the current fishing mortality rate for Petrale sole stocks off the West Coast of Canada is at or below the sustainable level. We present time series of previously unsummarised results for petrale sole from three sets of trawl surveys from the west coast of Canada, all of which show a generally increasing trend of biomass indices since the mid- to late-1990s, although the trend from the NFMS triennial survey is probably not significant.

We present a series of general linear models for three areas of the coast: west coast Vancouver Island, Queen Charlotte Sound and Hecate Strait. The models presented explore the non-zero landings, the change in the proportion of zero landings and a model combining the two sets of indices over a period 1996/97 to 2002/03. The non-zero models for WCVI and Queen Charlotte Sound do not show much change over this period, except for an increase in the most recent one or two fishing years, while the Hecate Strait non-zero model shows an increasing trend beginning in 1998/99. The binomial models are not greatly different from the lognormal models from the same area over the seven years modelled and the combined models indicate an increasing trend in CPUE in all three areas for the most recent three to four fishing years.

A delay-difference model was developed which uses the biological parameters for growth and the length/weight functional relationship along with six sets of data representing respectively the mean annual weight of petrale sole, the time series of catch and CPUE, and three sets of trawl survey indices. A model which combines all the available data sets estimates a large standing stock, low fishing mortality rates and a stock status above B_{msy}. One year catch projections based on this model predict that the stock size will remain above F_{msy} with catch levels up to about 2000 t. The only model which is somewhat pessimistic is the model which omits the weight data. This model also estimates that the current stock status exceeds B_{msy}, but predicts that the stock would fall below this level at a catch in 2004/05 of 400 t and the F in 2004/05 would drop below F_{msy} at 650 t.

Résumé

Nous résumons les résultats de l'analyse de données biologiques, de données de relevés scientifiques et de données recueillies par des observateurs de pêche sur la plie de Californie (*Eopsetta jordani*). Les synthèses de la composition par taille suggèrent que la proportion de petits poissons dans le recrutement a augmenté durant la période 1998-2002. Le taux de mortalité instantané estimé à partir des données du relevé de 2000 n'était que légèrement supérieur à la meilleure estimation du taux de mortalité naturelle. Nous concluons que le taux actuel de mortalité par pêche des stocks de plie de Californie au large de la côte Ouest du Canada est à un niveau soutenable ou inférieur à celui-ci. Nous présentons des séries chronologiques de résultats (qui n'avaient pas été synthétisés auparavant) de trois relevés pluriannuels au chalut de la plie de Californie effectués le long de la côte Ouest du Canada. Ces séries indiquent toutes que les indices de biomasse ont généralement tendance à augmenter depuis le milieu ou la fin des années 1990, même si la tendance du relevé triennal du NFMS n'est sans doute pas significative.

Nous présentons une série de modèles linéaires généraux pour trois zones côtières, soit la côte ouest de l'île de Vancouver (COIV), le bassin Reine-Charlotte et le détroit d'Hécate. Il s'agit du modèle des débarquements non nuls, du modèle des changements dans la proportion des débarquements non nuls et d'un modèle qui combine les deux indices sur la période allant de 1996-1997 à 2002-2003. Le modèle des débarquements non nuls montre peu de changement durant cette période, tant pour la COIV que pour le bassin Reine-Charlotte, si ce n'est d'une augmentation pour la ou les deux dernières années de pêche, tandis qu'il indique une tendance à la hausse depuis 1998-1999 dans le détroit d'Hécate. Pour les sept années modélisées, le modèle binomial ne diffère pas beaucoup du modèle log-normal pour une même zone. Le modèle combiné montre une tendance à la hausse des CPUE dans chacune des trois zones depuis trois ou quatre ans.

Nous avons élaboré un modèle à différences retardées qui intègre les paramètres biologiques de croissance et la relation longueur-poids, ainsi que six jeux de données, soit les données de poids moyen annuel de la plie de Californie, les séries chronologiques des captures et des CPUE, et trois indices de relevé au chalut. Selon les estimations obtenues grâce à un modèle qui combine tous les jeux de données disponibles, la taille du stock est grande, les taux de mortalité par pêche sont faibles, et la biomasse est supérieure à B_{RMS}. Des projections de captures sur un an fondées sur ce modèle indiquent que la taille du stock restera supérieure à F_{RMS} pour des captures allant jusqu'à environ 2000 t. Le seul modèle qui donne des résultats un peu pessimistes est celui qui ne comprend pas les données de poids des poissons. Ce modèle donne aussi une estimation de la biomasse actuelle du stock supérieure à B_{RMS}, mais il prédit que la biomasse baisserait en dessous de cette valeur si les captures atteignaient 400 t en 2004-2005, et que F serait inférieur à F_{RMS} si les captures atteignaient 650 t en 2004-2005.

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1.0 INTRODUCTION

The groundfish resource in British Columbia (B.C.) increased in importance in the late 1970s with the implementation of Extended Jurisdiction in 1977 and subsequent expansion of the domestic fleet. Recommendations for quota management of groundfish species were not forthcoming until 1979 (Ketchen 1980). Since that time, detailed and interim assessments for various flatfish species have been conducted annually including recommendations for catch limitations. The last assessment of petrale sole (brill) was conducted in 1998 (Fargo 1999).

Between the late1940s and the late1950s, Canadian landings of petrale sole in the B.C. trawl fishery averaged 3000 t per year. U.S. trawlers that were allowed to fish in Canadian waters also landed substantial amounts. By the mid 1960s, landings had decreased and petrale sole abundance had declined substantially (Ketchen and Forrester 1966). In the 1970s, a catch-age analysis indicated that these stocks were at a low level of abundance compared to the 1940s and 1950s, but concluded that environmental factors were probably the main cause of the decline in abundance (Pedersen 1975). Stocks remained at low abundance in the 1980s and 1990s and annual landings were capped at 479 t in 1997. The cap eliminated all directed fishing on this species while permitting bycatch when pursuing other associated groundfish species. Recently fishermen have provided information that they have observed an increase in the bycatch rates of petrale sole which make it difficult for them to stay within the cap.

Petrale sole is an important component of the offshore ecosystem. This is particularly relevant as investigators shift their emphasis from single species to multi-species or ecosystem assessment. Previous studies indicate that this species is a top end predator whose diet overlaps with that of Arrowtooth flounder (adult and juvenile), dogfish, Pacific cod (adult and juvenile), Pacific halibut, sand sole and several rockfish species. The adults also show more dependence on herring as a food item than any other allied species. Petrale sole also consume cephalopods, euphausiids and shrimp (Pearsall and Fargo *in prep*.). Juvenile petrale sole are prey items for large pollock, Pacific cod and spiny dogfish.

In this document, we summarise biological information and present the results of an analysis of catch-effort, survey and biological data. We develop an assessment model to provide advice to managers on harvest levels for the 2004/05 fishing year.

2.0 BIOLOGY OF PETRALE SOLE

2.1 RANGE AND STOCK STRUCTURE

Petrale sole (*Eopsetta jordani*) range from northern Baja California to the eastern Bering Sea. It is an inner shelf-mesobenthal species from British Columbia to central California. The British Columbia population of this species is thought to be composed of two stocks (Ketchen and Forrester 1966, Pedersen 1975). The southern stock occupies both the Canadian and U.S. portions of Area 3C, while the northern stock occupies Areas 3D-5D. This paper treats British Columbia Petrale sole as a single stock because the current DFO policy is to manage this species as a coastwide stock.

Petrale sole can live as long as 30 years and spawn annually in the winter. Adults occupy depths of 80–550 metres off the west coast of Vancouver Island, in the entrance of Queen Charlotte Sound, in parts of Hecate Strait and off the west coast of the Queen Charlotte Islands. Males begin to spawn at three years of age, while females begin at four years. Petrale sole begin to recruit to the commercial fishery in their third year but recruitment is not knife-edged.

Castillo et al. (1995) demonstrated that offshore Ekman transport of eggs and larvae accounted for 55% and 65% of the variation in Petrale sole year-class strength in PMFC Areas 2B and 3A, respectively. They concluded, as have previous investigators, that density-independent survival variation at the early life stages is high compared to variation in spawning biomass. However, the prolonged low abundance of these stocks off British Columbia in the 1980s and 1990s was flagged as an area of concern by PSARC (Fargo 1995). As a result of this PSARC concern, a coastwide landings cap of 479 t was set in 1997 which has only permitted non-target landings since then.

Petrale sole adults move from shallow summer feeding grounds to deep-water spawning grounds in the winter although there seems to be little north-south movement by this species. Eggs and larvae are transported from offshore spawning areas to nearshore nursery areas by oceanic currents and wind (Ketchen and Forrester 1966). Petrale sole tend to move into deeper water with increased age and size. Ten separate breeding stocks have been identified along the Pacific coast of North America (Casillas et al 1998). However, stocks intermingle on summer feeding grounds. Of these, two occur off British Columbia, two off Washington, two off Oregon and four off California.

2.2 LIFE HISTORY

Petrale sole adults inhabit depths from 80 to 550 m and show tolerance for a wide range of bottom temperatures across their range (Perry et al. 1994). The species occupies the waters of the continental shelf and slope. Both adults and juveniles show an affinity for sand, sandy mud and occasionally muddy substrates. Juveniles feed primarily on mobile prey, such as cumaceans, carideans, and gammarid amphipods. Adults are piscavores. Their preferred prey is herring *(Clupea harengus)*, and they show a stronger preference for herring than most other fish predators (Pearsall and Fargo *in prep.*). Adults also consume juvenile pollock *(Theagra chalcogramma)* and shrimp (*Pandalus platyceros*, *Pandalus tridens , Pandalus jordani*) and epibenthos (Mysidacea) (Pearsall and Fargo *in prep.*).

Spawning occurs over the continental shelf and continental slope to as deep as 550 m. Eggs are pelagic and larvae are neritic and epipelagic. Eggs are found primarily in waters between 4-10°C and salinities of 25-30 ppt. Optimum conditions for egg incubation and larval growth were 6-7°C and a salinity range of 27.5-29.5 ppt (Ketchen and Forrester 1966, Castillo et al. 1995). Adults and juveniles are found in euhaline waters. Larvae are often found in the upper 50 m of the water column far offshore. Juveniles are generally found between 18-82 m and larger juveniles at 25-145 m. Off British Columbia, spawning adults, as well as eggs, larvae and juveniles, are found in highest densities in the waters around Vancouver Island. Adults may utilise summer feeding grounds in nearshore areas, and non-migrating adults may overwinter in near shore areas as well.

Petrale sole are oviparous, and fertilisation is external. Length at 50% maturity for males is 315 mm (4 years) and is 357 mm (5 years) for females. The petrale sole is a broadcast spawner. Spawning occurs over the continental shelf and continental slope to as deep as 550 m (Casillas et al. 1998). Off British Columbia the spawning period lasts from December–April, and peaks in January-February. Petrale sole spawn in the same general area year after year. Fecundity is determinate. A 42-cm female petrale sole produces about 400,000 eggs, while a 57-cm female will produce as many as 1,200,000 eggs.

3.0 COMMERCIAL FISHERY INFORMATION FOR PETRALE SOLE

3.1 COMMERCIAL TRAWL DATA

The Department of Fisheries and Oceans has maintained records of groundfish catch and effort data from 1954 to 1995 using a combination of voluntary skipper interviews, vessel logbooks, landings records (sales slips or validation records) and observations at the waterfront. These data are archived in a database called *GFCATCH* (Leaman and Hamer 1985), the history of which has recently been described by Rutherford (1999).

Skipper interviews and logbooks provided information on fishing areas and amount of effort; however, the catch for each species was estimated. Species composition was usually limited to the dominant species retained in the catch (Rutherford 1999). Skipper interview and logbook data were transcribed into a trip report by DFO staff. Sales slips or validation records provided accurate weights of species landed, but little information on fishing location or effort. If an offload was observed, information might be gathered that supplemented or superseded logbooks and landing records. For example, errors in species identification might be corrected. The "best" estimate of catch required synthesis of all data sources. Typically, the actual weights from landings were used to adjust the trip reports by prorating the landed weights using fishing location and catch information recorded at sea (Leaman and Hamer 1985).

3.1.1 Commercial trawl observer data 1996-2000: PacHarv database

A mandatory at-sea observer program was implemented for most Option A and some Option B trawl vessels in 1996. This includes about 90% of the trawl fleet in terms of reported catch. The observers provide information on catch locations, bridge log data and species composition (by weight). Observers also collect biological data for selected species according to a specified design. A relational database, *PacHarvest*, was developed by the slope rockfish assessment team using Microsoft Server 7.0 (Schnute et al. 2000). The database is located on the Windows NT server *PacStad* at the Pacific Biological Station, Nanaimo, B.C. Documentation and database shells for connecting to *PacHarvest* can be found on the DFO Intranet at http://pacstad/pacharvdb/Default.htm. Further details can be found on the website and in Schnute et al. (2000).

3.1.2 Dockside validation

Since 1996 every trawler unloading is monitored at the port of landing. The dockside validator estimates the species composition of the landing by weight. This information is used together with observer at-sea information to resolve the species composition (by weight) of the catch. Dockside validation data for trawl is contained in the database tables *B5_Validation_Headers* and *B6_Validation Species* in the *PacHarv* database described above.

3.1.3 Landing statistics

Landings for the southern stock of Petrale sole decreased slightly to 300 t in 1997 from 314 t in 1996 while landings for the northern stock decreased to 126 t in 1997 from 145 t in 1996, (Table 1). Landings for this species exhibit cyclic fluctuations with peaks occurring about once a decade. Fluctuations in landings have coincided with recruitment cycles for the species (Ketchen and Forrester 1966, Castillo et al. 1995). Landings for both stocks show a marked decline since the start of the fishery. Since 1985 regulatory measures have exacerbated this. A trip limit of 40,000 lb was in effect for the first quarter from 1985 to 1991. From 1991 to 1995 a trip limit of 10,000 lb was in effect during the first quarter of the year while in 1996 only incidental catches were permitted. A coastwide landings cap of 479 t was put in place in 1997 and has continued at this level to the present. Discards have only been estimated since the start of the mandatory at-sea observer program (Section 3.1.1). There appears to be relatively little discarding for this species, based on the available observer data (Table 2).

Table 1. Historical catches (t) of petrale sole by calendar year (up to the end of 1996) and by fishing year (1 April–31 March, from 1 April 1997) by DFO Major Area. Catches labelled 1997 are for January-March only. Catches are summarised from GFCatch (up to the end of 1995) and from PacHarvest (from February 1996 onwards) and are for bottom and mid-water trawl methods only.

Calendar year		DFO Major Area							
or Fishing year	4B	3C	3D	5A	5B	5C	5D	5E	Total
1954	4.94	306.47	57.48	17.80	18.92	0.74	5.10		411.45
1955	1.69	171.87	87.73	7.64	6.51	7.86	12.29		295.59
1956	5.91	198.37	16.53	20.65	19.91	29.86	4.25		295.47
1957	5.43	236.53	5.97	67.60	21.63	48.59	113.91		499.67
1958	11.63	187.12	14.62	24.06	46.44	20.40	115.21		419.48
1959	18.26	182.64	5.99	20.73	40.63	35.73	77.92		381.89
1960	15.65	193.73	12.93	49.18	65.99	55.90	59.89		453.27
1961	5.48	205.34	9.41	54.29	43.59	3.10	93.25		414.46
1962	7.82	147.75	24.95	75.18	79.19	11.20	151.57		497.66
1963	5.11	75.44	9.22	68.05	195.98	7.83	62.63		424.27
1964	4.23	171.13	43.06	110.91	83.08	37.03	106.58		556.02
1965	18.41	182.50	66.30	58.78	62.02	90.54	105.63		584.18
1966	1.63	113.30	57.68	77.81	83.24	191.46	82.60		607.73
1967	4.16	120.27	66.94	75.50	53.55	108.36	47.28		476.06
1968	0.49	113.45	35.87	62.69	19.74	110.72	32.29		375.24
1969	2.05	55.03	52.18	19.06	7.91	11.97	10.90		159.09
1970	1.62	143.32	31.17	10.27	0.92	6.67	15.55		209.53
1971	1.28	384.97	30.07	29.77	4.36	22.84	32.54		505.85
1972	0.64	477.43	12.44	26.38	32.26	11.28	22.81		583.25
1973	1.09	393.51	7.33	37.77	9.88	9.62	13.32		472.53
1974	3.55	581.92	5.26	49.02	30.40	4.27	9.36		683.79
1975	5.16	318.53	15.76	30.74	44.74	11.08	16.14		442.14
1976	3.91	202.55	13.79	47.51	38.41	9.72	21.39		337.28
1977	1.89	199.40	9.32	19.42	30.66	8.77	15.33	0.65	285.46
1978	5.57	107.63	10.00	20.33	34.17	5.69	7.31	35.13	225.83
1979	2.51	91.58	9.90	26.62	30.57	23.48	15.73	2.08	202.47
1980	2.09	115.26	31.25	19.13	21.23	18.31	14.44	0.82	222.51
1981	5.31	177.67	15.20	23.62	17.77	14.59	27.11	7.71	288.98
1982	4.80	232.28	29.84	40.39	20.25	7.54	8.88	22.50	366.48
1983	6.69	183.97	29.57	60.37	100.29	10.49	24.50	23.31	439.20
1984	7.57	214.48	76.85	39.80	38.99	11.71	12.04	15.50	416.95
1985	1.48	147.04	50.20	31.98	47.74	14.28	7.62	35.80	336.14
1986	3.19	197.24	24.23	89.94	30.50	15.13	9.78	45.67	415.68
1987	0.64	122.53	37.38	96.29	67.93	53.30	47.95	19.50	445.53
1988	3.47	183.35	275.72	66.06	100.63	92.32	41.24	30.40	793.19
1989	0.44	385.55	177.18	79.67	138.39	124.80	26.77	20.02	952.82
1990	0.36	478.24	250.12	45.08	104.77	101.57	34.55	51.77	1066.45
1991	0.42	407.94	137.16	19.86	120.94	72.25	12.50	24.11	795.17
1992	0.55	267.03	134.31	37.00	59.80	61.93	9.85	38.18	608.64
1993	6.34	247.66	106.75	25.07	80.88	50.35	14.63	49.57	581.25
1994	1.83	140.45	54.75	103.23	92.75	33.11	12.67	45.72	484.50
1995	0.33	158.61	82.63	183.37	153.86	33.89	8.06	51.63	672.37
1996	0.46	123.24	46.83	19.50	46.05	13.24	12.06	14.15	275.55
1997	0.14	140.48	25.10	4.83	5.09	0.26	1.39	8.42	185.71
97/98	0.97	147.71	59.64	23.01	48.37	12.49	11.87	20.55	324.61
98/99	1.67	183.98	50.76	23.95	45.75	9.02	9.53	30.78	355.45
99/00	0.96	141.91	40.52	15.47	100.87	30.20	13.03	34.68	377.62
00/01	0.83	182.09	52.33	16.80	84.42	27.07	22.27	69.17	454.98
01/02	0.25	147.35	108.54	18.85	149.50	19.71	14.92	14.66	473.78
02/03	0.00	168.57	78.71	38.62	110.01	33.40	19.84	9.01	458.16

Table 2. Summary of landed and discarded catch (t) by DFO major area and fishing year since the inception of the intensive observer programme in early 1996. The "unknown" major area category includes minor catches taken in Major Area 3B (US waters from the border to 47° 30') and SE Alaska.

Fishing year	Unknown	4B	3C	3D	5A	5B	5C	5D	5E	Total
Landed catch										
96/97	14.43	0.60	207.70	53.15	23.82	47.00	13.46	13.34	11.48	384.97
97/98	3.43	0.97	147.71	59.64	23.01	48.37	12.49	11.87	20.55	328.04
98/99	3.50	1.67	183.98	50.76	23.95	45.75	9.02	9.53	30.78	358.95
99/00	3.14	0.96	141.91	40.52	15.47	100.87	30.20	13.03	34.68	380.76
00/01	5.67	0.83	182.09	52.33	16.80	84.42	27.07	22.27	69.17	460.65
01/02	6.59	0.25	147.35	108.54	18.85	149.50	19.71	14.92	14.66	480.38
02/03	4.32	0.00	168.57	78.71	38.62	110.01	33.40	19.84	9.01	462.48
Discarded catch										
96/97	0.00	0.04	11.12	4.02	3.67	4.20	1.20	7.83	0.74	32.82
97/98	0.00	0.02	4.25	0.85	4.26	5.57	0.97	8.13	2.03	26.09
98/99	0.00	0.00	6.40	1.41	5.35	3.39	1.68	3.18	0.40	21.81
99/00	0.00	0.00	6.23	1.45	3.73	6.53	1.51	5.92	0.14	25.51
00/01	0.00	0.00	12.75	4.13	2.94	4.24	0.93	6.56	0.16	31.71
01/02	0.00	0.00	8.06	2.32	2.89	4.57	2.18	0.95	0.02	21.01
02/03	0.00	0.00	17.58	5.52	10.43	5.69	1.85	1.14	0.01	42.22

3.2 BIOLOGICAL DATA

Biological samples containing length, sex, maturity, and ageing information have been collected from the trawl fishery in British Columbia since the 1950s. However data in the database only cover the 1979–2002 period. Samples were pooled to estimate biological statistics on length, age, and maturity.

3.2.1 Research surveys

The species assemblage trawl survey in Hecate Strait (Fargo and Tyler 1991) has provided CPUE and length and age data from 1984–2003. The survey provides synoptic data that has allowed the mapping of fish assemblages in that region. In addition, this survey provides data on the abundance and distribution for groundfish species in the region. The fishing gear used on this survey has remained the same since its inception. The net is equipped with a small-mesh codend liner to ensure sampling of all size/age groups.

The survey employs a systematic depth stratified design to achieve broad spatial coverage. A grid of 10 X 10 nm blocks was superimposed on a chart of the region. Sampling stations within each block were allocated for each 20 m depth interval. The selection of a station within a stratum was made by the fishing master who searched each stratum for trawlable bottom. At the end of each tow, the species composition of the catch by weight is determined and length measurements were made for all species in the catch. Exceptions to this procedure occurred when the catch was >3000 lbs. whereupon a random subsample was taken for the collection of biological data.

4.0 REVIEW OF EXISTING TRAWL SURVEY INDICES

4.1 NMFS TRIENNIAL SURVEY

4.1.1 Methods

Tow-by-tow data from the triennial survey covering the entire Vancouver INPFC region were provided by Mark Wilkins (NFMS) for the seven survey years that ventured into Canadian waters (Table 3). All usable tows have an associated net width and distance travelled, allowing for the calculation of the area swept by the tow. Biomass indices and the associated analytical CVs for petrale sole were calculated for the total Vancouver INPFC region and for each of the Canadian and Vancouver sub-regions, using appropriate area estimates for each stratum (Table 3).

Tow data were provided by stratum and location of the tow, including by country fished based on tow start position (Figure 1; Table 3). The definition of the strata varied between years (Table 4) in terms of the stratum numbering and the amount of area fished in each year (Table 3). In general, the size of the total area fished was about twice as large in Canadian waters than in US waters (Table 4), although the number of tows used in US and Canadian waters tended to be about the same (Table 3). The analysis was confined to strata which covered depth ranges (between 55 and 366 m) that had been consistently surveyed throughout the seven surveys (Table 4). Note that no petrale sole have ever been caught in the deepest strata.

Table 3. Number of usable tows performed and area surveyed in the INPFC Vancouver region separated by the international border between Canada and the United States. Strata 37, 38 and 39 (Table 4) were dropped from this analysis as they were not consistently conducted over the survey period.

	Number tows			Area surveyed (km^2)		
Survey year	**Canadian waters**	**US waters**	**Total**	**Canadian waters**	**US waters**	**Total**
1980	59	26	85	7,399	4,738	12,137
1983	47	70	117	7,399	4,738	12,137
1989	67	55	122	9,413	4,699	14,112
1992	61	50	111	9,413	4,699	14,112
1995	64	35	99	9,762	4,976	14,738
1998	55	42	97	9,696	4,801	14,497
2001	36	37	73	9,608	4,976	14,584
Total	389	315	704	–	–	–

Table 4. Amount of relevant area (km^2) by survey year and by stratum in the INPFC Vancouver region shown divided into the amount of area available in the waters of each country. Cells highlighted in grey are strata which are located in the 366–500 m depth range which were not consistently surveyed throughout the period.

Stratum	Canadian waters & year				US waters & year			
Number	1980	1983	1989 & 1992	1995 & >	1980	1983	1989 & 1992	1995 & >
10					3,537	1,307		
11	6,572					2,230		
12		6,572						
17							1,033	1,033
18			159				2,123	2,123
19			8,224	8,224			363	363
27							125	125
28			88	88			787	787
29			942	942			270	270
30					443	66		
31	325					377		
32		325						
37								102
38				66				175
39				442				
50					758	127		
51	503					631		
52		503						
Total	7,400	7,400	9,413	9,762	4,738	4,738	4,701	4,978

The data were analysed using the following equations. The biomass in any year y was obtained by summing the product of the petrale sole CPUE and the area surveyed across the surveyed strata i:

$$B_y = \sum_{i=1}^{k_y} C_{y_i} A_{y_i} = \sum_{i=1}^{k_y} B_{y_i} \qquad \textbf{Eq. 1}$$

where C_{y_i} = mean CPUE density (kg/km^2) for petrale sole in year y in stratum i

A_{y_i} = area of stratum i (km^2) in year y

k_y = number of strata in year y

B_{y_i} = biomass of petrale sole in stratum i for year y

CPUE $\left(C_{y_i}\right)$ in stratum i for year y was calculated as a density in kg/km^2 by

$$C_{y_i} = \frac{\sum_{j=1}^{n_{y_i}} \left(W_{y_i j} \big/ D_{y_i j} w_{y_i j} \right)}{n_{y_i}} \qquad \textbf{Eq. 2}$$

where $W_{y_i j}$ = catch weight (kg) in year *y* in stratum *i* and tow *j*

$D_{y_i j}$ = distance travelled (km) in year *y* by tow *j* in stratum *i*

$w_{y_i j}$ = wingspread width (km) in year *y* for tow *j* in stratum *i*

n_{y_i} = number of tows in year *y* for stratum *i*

The variance of the survey biomass estimate V_{B_y} in year *y* is calculated in kg^2 as follows:

$$V_{B_y} = \sum_{i=1}^{k_y} \sigma_{y_i}^2 A_{y_i}^2 \big/ n_{y_i} = \sum_{i=1}^{k_y} V_{y_i} \qquad \textbf{Eq. 3}$$

where $\sigma_{y_i}^2$ = variance of CPUE (kg^2/km^4) for year *y* in stratum *i*

V_{y_i} = variance of petrale sole in stratum *i* for year *y*

It was assumed that the variance and CPUE within any stratum was equal, even for strata that were split by the presence of the US/Canada border. The total biomass $\left(B_{y_i}\right)$ within a stratum which straddled the border was split between the two countries $\left(B_{y_{i_c}}\right)$ by the ratio of the relative area within each country:

$$B_{y_{i_c}} = B_{y_i} \frac{A_{y_{i_c}}}{A_{y_i}} \qquad \textbf{Eq. 4}$$

where $A_{y_{i_c}}$ = area (km^2) within country *c* in year *y* and stratum *i*

The variance $V_{y_{i_c}}$ for that part of stratum *i* within country *c* was calculated as being in proportion to the ratio of the square of the area within each country *c* relative to the total area of stratum *i*. This assumption resulted in the CVs within each country stratum being the same as the CV in the entire stratum:

$$V_{y_{i_c}} = V_{y_i} \frac{A_{y_{i_c}}^2}{A_{y_i}^2} \qquad \textbf{Eq. 5}$$

The partial variance $V_{y_{i_c}}$ for country *c* was used in Eq. 3 instead of the total variance in the stratum V_{y_i} when calculating the variance for the total biomass in US or Canadian waters.

The CV for each year y was calculated as follows:

$$CV_s = \frac{\sqrt{V_{B_s}}}{B_s} \qquad \textbf{Eq. 6}$$

The biomass estimates (Eq. 1) and the associated standard errors were adjusted to a constant area covered using the ratios of area surveyed provided in Table 4. This was required so that the Canadian biomass estimates for 1980 and 1983 could be adjusted to account for the smaller area surveyed in those years compared to the succeeding surveys. The biomass estimates from Canadian waters were consequently multiplied by the ratio 1.27 (=9400/7400) to make them equivalent to the coverage of the surveys from 1989 onwards. Note that the slightly higher areas covered from 1995 onwards are due to the extension of the triennial survey into deeper waters. Tows in these strata were dropped from this analysis and consequently the total area surveyed did not change between 1992 and 1995.

Biomass estimates were bootstrapped for 5000 random draws with replacement to obtain bias corrected (Effron 1982) 95% confidence regions for each year and for three area categories (total Vancouver region, Canadian Vancouver only and US Vancouver only) based on the distribution of biomass estimates and using the above equations.

4.1.2 Results

Petrale sole have been caught consistently from tows north of 47° 30’ in each of the seven years that the triennial survey has surveyed Canadian waters (Figure 6; Figure 2). The northern extension of the survey has varied between years (Figure 2). This difference has been compensated for by using a constant survey area for all years. Coverage by depth has been consistent for all seven years of the survey (Figure 3).

The biomass estimates and the associated annual CVs obtained from the above methods show a generally increasing trend for the Total Vancouver INPFC region and for the Canadian Vancouver section of the region (Figure 4). The trend for the US-Vancouver sub-region shows a less pronounced increasing trend over the series. The petrale sole biomass estimates have reasonably precise CVs, generally below 20% for the total Vancouver region, although CVs tend to be somewhat higher for estimates solely from Canadian or US waters (Table 5). The bootstrap confidence regions overlap for all survey years which indicates that the observed increasing trend of the biomass indices is probably not significant.

Just over one-half (375 tows) of the total 704 tows in this data set caught petrale sole over the entire history of the survey. The proportion of tows which contain petrale sole has improved in a similar manner in each of the areas as the overall biomass estimates for petrale sole since the beginning of the triennial survey series (Figure 5).

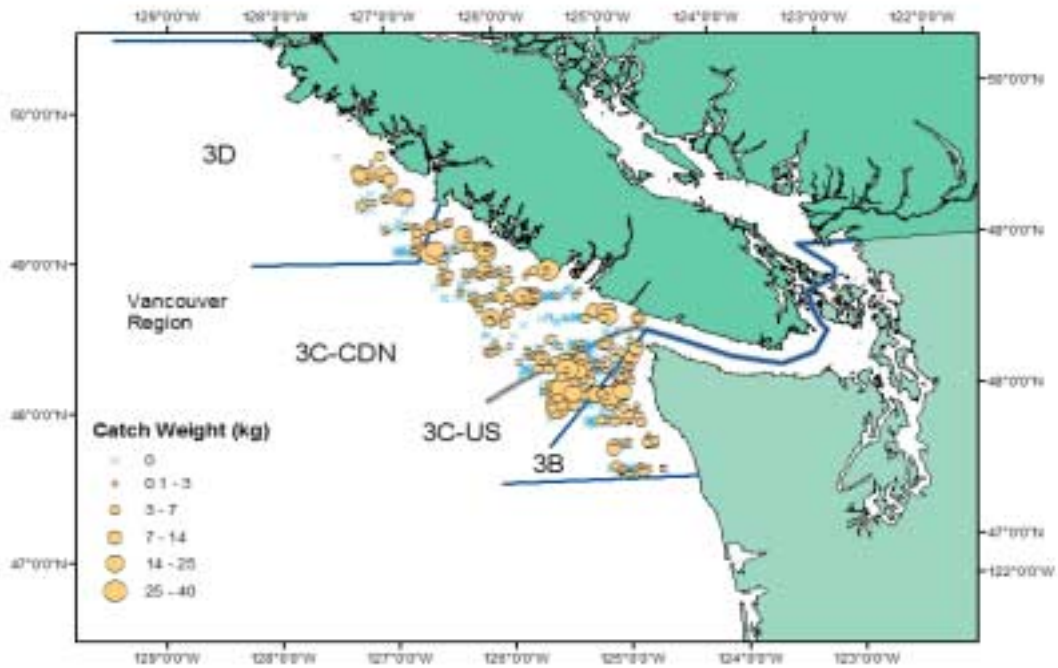

Figure 1. Map of the locations of all trawls in the Canadian and US waters of the Vancouver INPFC region covered over the seven years of the NFMS triennial survey. Indicated boundaries are the DFO major management regions, not the boundaries of the Vancouver INPFC region.

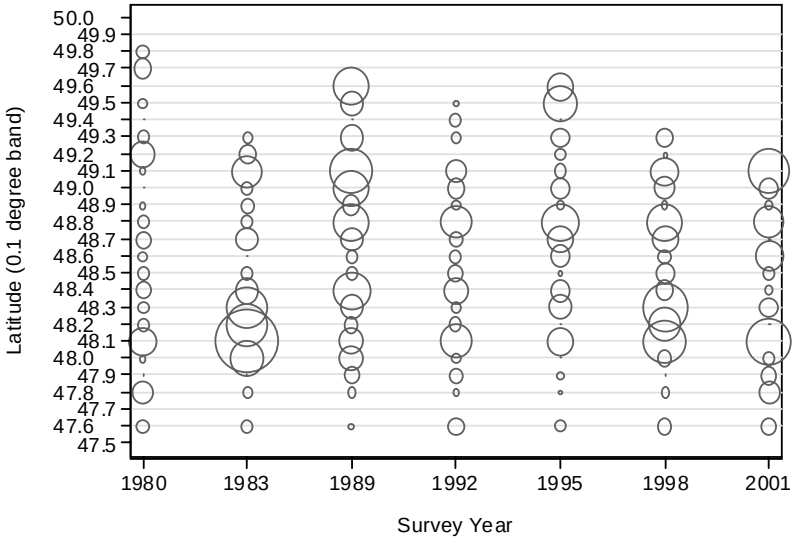

Figure 2. Distribution of petrale sole catch weights by survey year and 0.1 degree latitude band for all valid tows. Each latitude band is labelled with the upper limit of latitude. Maximum circle size=127 kg.

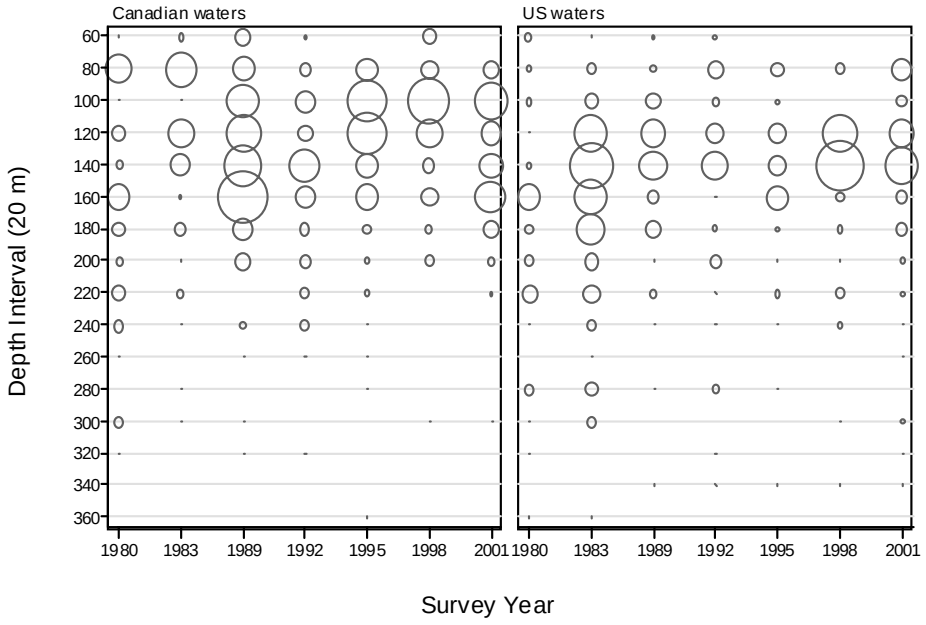

Figure 3. Distribution of petrale sole catch weights for each survey year by 20 m depth intervals for all tows in Canadian and US waters of the Vancouver INPFC area. Depth intervals are labelled with the upper limit of the interval. Maximum circle size, Canadian waters=87 kg; US waters=116 kg.

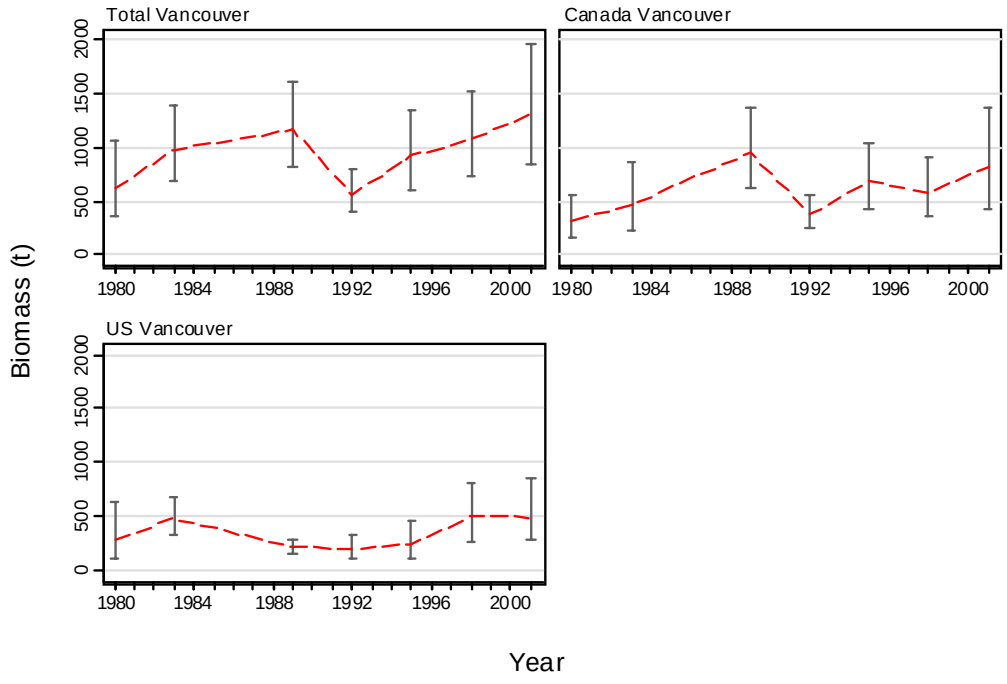

Figure 4. Three biomass estimates for the INPFC Vancouver region (total region, Canadian waters only and US waters only) with 95% bias corrected error bars estimated from 5000 bootstraps.

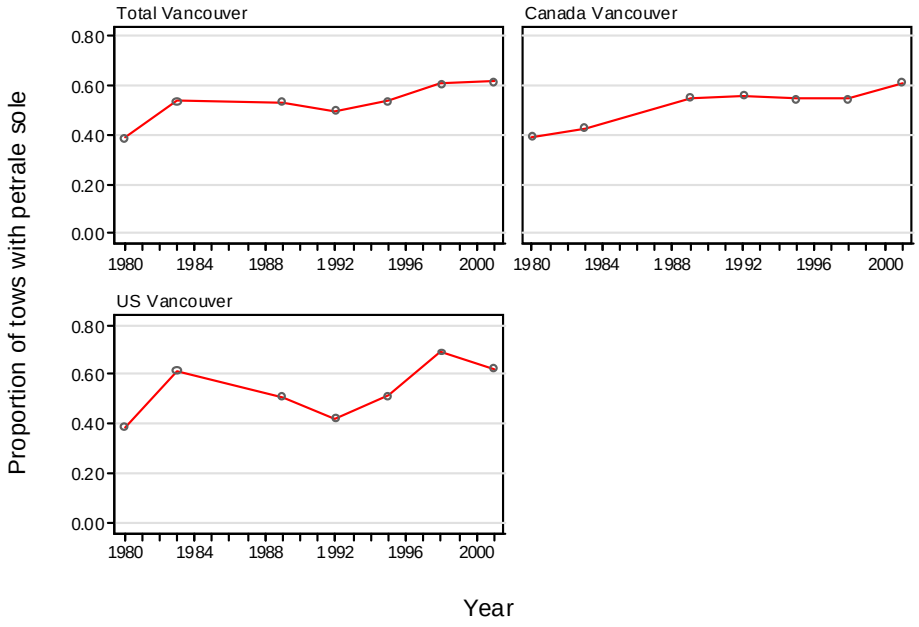

Figure 5. Proportion of tows with petrale sole by year for the Vancouver INPFC region (total region, Canadian waters only and US waters only).

Table 5. Biomass estimates for the Vancouver INPFC region (total region, Canadian waters only and US waters only) with 95% confidence regions based on the bootstrap distribution of biomass. Biomass estimates are calculated as in Eq. 1. The bootstrap estimates are based on 5000 random draws with replacement.

Estimate type	**Year**	**Biomass (Eq. 1)**	**Mean bootstrap biomass**	**Lower bound biomass**	**Upper bound biomass**	**CV bootstrap**	**CV Analytic (Eq. 6)**
Total Vancouver	1980	616.1	616.8	349.6	1064.8	0.285	0.288
	1983	981.0	981.3	689.7	1405.7	0.185	0.184
	1989	1167.7	1163.3	819.8	1617.3	0.175	0.176
	1992	562.3	552.2	406.7	795.2	0.173	0.170
	1995	923.3	914.9	614.4	1341.1	0.197	0.197
	1998	1079.7	1076.9	741.5	1526.0	0.187	0.188
	2001	1302.9	1297.1	836.3	1964.8	0.215	0.219
Canada Vancouver	1980	320.2	318.9	161.0	563.3	0.313	0.319
	1983	461.7	463.3	232.5	861.4	0.342	0.346
	1989	957.5	953.6	629.1	1376.7	0.201	0.202
	1992	372.0	367.9	253.7	556.5	0.203	0.201
	1995	688.5	683.5	428.2	1039.3	0.222	0.222
	1998	578.7	576.6	356.9	911.5	0.238	0.239
	2001	820.3	818.8	433.2	1363.4	0.286	0.288
US Vancouver	1980	276.6	278.3	100.8	625.5	0.455	0.468
	1983	478.3	477.4	313.4	673.1	0.191	0.190
	1989	210.2	209.7	151.1	282.0	0.157	0.157
	1992	190.3	184.3	112.0	322.9	0.273	0.266
	1995	234.7	231.4	111.2	446.7	0.363	0.373
	1998	501.1	500.3	261.3	817.8	0.285	0.284
	2001	482.6	478.3	272.3	853.9	0.296	0.300

4.2 WEST COAST VANCOUVER ISLAND (WCVI) SHRIMP TRAWL SURVEY

4.2.1 Methods

All data from the west coast Vancouver Island shrimp trawl survey, including all groundfish caught for every year in each tow, was made available (N. Olsen *pers. comm.*). This survey has been operated 28 times in most years off the west coast of Vancouver Island between 1973 to 2003. This survey is therefore the longest series that is available to monitor petrale sole. The recommendations for this survey documented by Starr et al. (2002) in their reanalysis of the data from the same survey for WCVI pacific cod have been adopted. These recommendations include:

a. stratifying the data into two areas, Areas 124 and 125 (Table 6; Table 7) with some minor modifications, because these are the areas that have been monitored the most consistently over the history of the survey. The modifications included dropping some tows which occurred in the most northerly part of Area 125 in the early to mid-1970s because these tows were not repeated in later surveys (Table 6). There are also a number of outlier tows which appear to be data errors which were also dropped;

b. moving a small number of tows from Area 124 to 123 as these tows were made in inshore waters and were clearly spatially more closely associated with Area 123;

c. following the suggestion of Starr et al. (2002) to use the mean catch rate for Area 124 as an estimate of the catch rate in Area 125 for 1989 and 1991 when Area 125 was not surveyed;

d. subdividing the two area strata into depth strata at the 160 m contour to account for differences in the depth coverage between years (Table 8). The shrimp trawl survey data were analysed using three stratification schemes: i) two area strata as performed by Starr et al. (2002), therefore not considering any effect of depth; ii) four area strata, thus accounting for depth by dividing Areas 124 and 125 each into two strata based on the 160 m contour (Table 7); and iii) two area strata by dropping the two deep strata and only using the two shallow in Areas 124 and 125. This last procedure is probably the most reliable as there seems to have been consistent coverage of the depth below the 160 m contour in all surveys (Table 8).

Table 6. List of tows available from the WCVI shrimp trawl survey by survey year and stratum. Only tows from strata 124 and 125 were used in the analysis.

	Area stratum			Dropped tows		Total
Year	**123**	**124**	**125**	**Number**	**Petrale sole (kg)**	**tows**
1973	0	56	19	7	13	82
1975	0	62	17	6	127	85
1976	0	69	18	2	9	89
1977	0	130	26	0	–	156
1978	6	134	36	5	3	181
1979	0	52	24	0	–	76
1980	0	59	26	0	–	85
1981	0	58	30	0	–	88
1982	0	56	25	0	–	81
1983	0	51	26	0	–	77
1985	1	59	22	0	–	82
1987	0	50	18	0	–	68
1988	0	69	10	0	–	79
1989	0	67	0	0	–	67
1990	0	72	10	0	–	82
1991	0	86	0	0	–	86
1992	0	77	6	0	–	83
1993	0	70	33	0	–	103
1994	3	67	30	0	–	100
1995	0	63	23	0	–	86
1996	28	60	12	0	–	100
1997	30	61	21	3	0	115
1998	28	44	22	1	0	95
1999	28	51	31	2	2	112
2000	31	43	30	1	5	105
2001	35	48	22	1	2	106
2002	33	50	26	1	10	110
2003	32	46	19	0	–	97
Total	255	1810	582	29	171	2676

Table 7. Area (km^2) of each stratum above and below the 160 m depth demarcation (Norm Olsen *pers. comm.*). Areas in "Total_2" column were used by Starr et al. (2002) to weight the same two strata.

Stratum	**<=160 m**	**>160 m**	**Total**	**Total_2**
124	2166	425	2591	1714
125	1493	572	2065	969

Table 8. Number of tows from the WCVI shrimp trawl survey by survey year separated into 20 m depth intervals from valid tows performed in strata 124 and 125.

	Depth Interval (20 m)											Deepest
Year	**60**	**80**	**100**	**120**	**140**	**160**	**180**	**200**	**220**	**240**	**Total**	**tow (m)**
1975			9	35	29	12					85	154
1976			13	41	28	7					89	146
1977			15	41	60	37	3				156	174
1978	2	4	7	51	67	48	2				181	176
1979			6	23	30	16	1				76	172
1980			8	23	34	16	3	1			85	187
1981			5	24	32	21	4	2			88	192
1982			7	20	31	18	4	1			81	192
1983			4	16	31	20	3	1	2		77	219
1985			7	24	26	22	3				82	168
1987			2	19	29	15	3				68	172
1988			6	26	30	15	2				79	176
1989			8	23	23	13					67	159
1990			6	25	33	16	2				82	175
1991			8	33	30	15					86	159
1992			9	28	25	20	1				83	162
1993			7	30	41	22	3				103	165
1994				31	43	24	2				100	166
1995			7	26	36	17					86	159
1996			17	33	29	20	1				100	164
1997		1	25	38	34	16				1	115	251
1998		1	17	29	30	16	1		1		95	217
1999	1	1	13	30	40	27					112	159
2000		2	16	20	37	29	1				105	170
2001		2	17	30	37	20					106	159
2002		1	22	28	38	20	1				110	161
2003		2	20	30	29	16					97	160

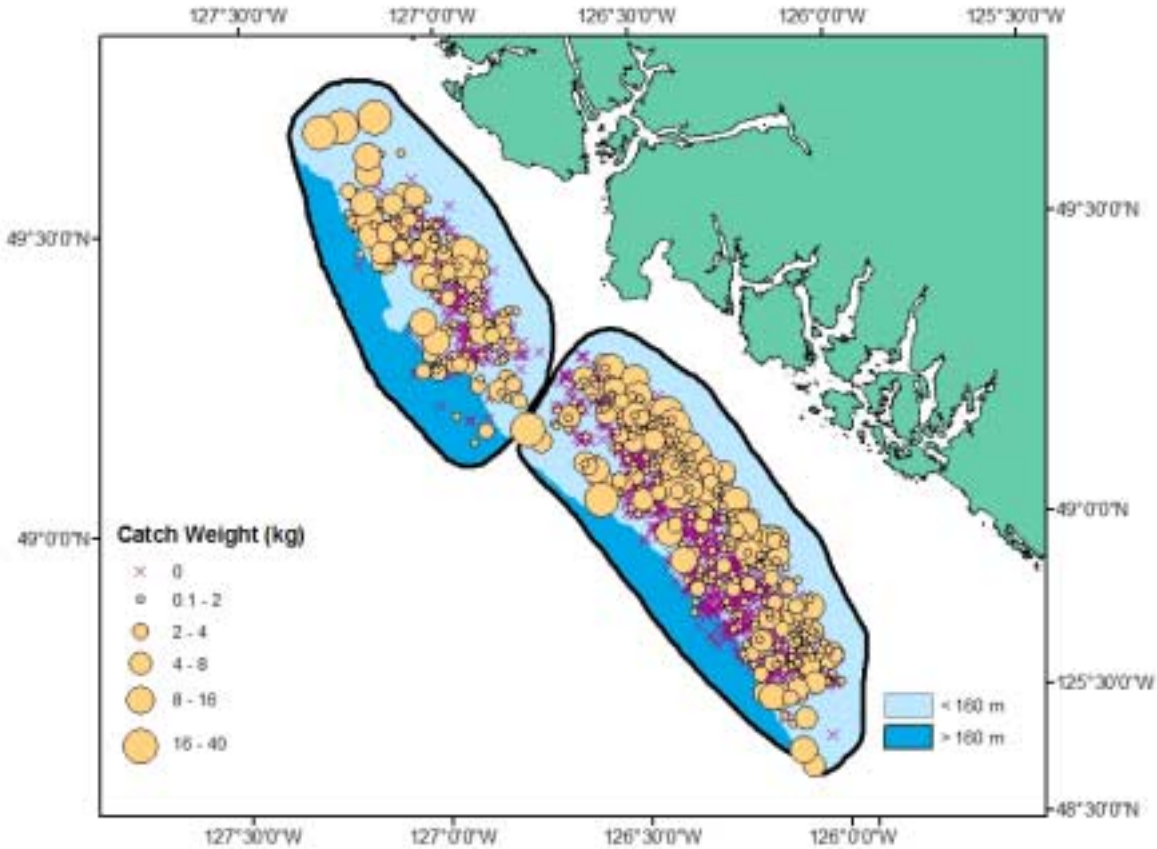

Figure 6. Map of the locations of all trawls in areas 124 and 125 that were associated with the WCVI shrimp trawl survey, showing the density of the tows which captured petrale sole. Areas 124 and 125 are the strata that have been surveyed the most consistently over the history of the survey and which are in locations most likely to catch petrale sole. Also indicated are the extent of the strata and the tows located above and below the 160 m depth contour.

The survey data were analysed for each year using equations Eq. 1, Eq. 2, Eq. 3 and Eq. 6, which assume that tow locations were selected randomly within a stratum relative to the biomass of petrale sole. This was not an assumption made by the original survey design and the area stratification definition in Figure 6 was not used when conducting the survey. The original survey design used latitudinal transects and selected the stations randomly along the transect and continued the transect until shrimp catches dropped off. Five thousand bootstrap replicates with replacement were made on the survey data to estimate bias corrected 95% confidence regions for each survey year (Effron 1982).

4.2.2 Results

Catches of petrale sole are widely distributed throughout the entire survey area (Figure 6). Petrale sole were generally only taken at depths less than 160 m (Figure 7). This indicates that depth considerations are not very important for this species. This is borne out by the comparison of biomass estimates based on different stratification assumptions, which shows that there is little sensitivity between the biomass series regardless of which stratification assumption was used (Figure 8).

Estimated biomass levels for petrale sole from the WCVI shrimp trawl survey appear to have been high in the mid-1970s, and then dropped to relatively constant levels that persisted until the late 1990s (Figure 9; Table 9). Biomass levels then recovered to levels equivalent to the levels of the early 1970s, but with considerable variation. Confidence bounds are wide and variable, with the estimated CVs for petrale sole from this survey ranging from around 0.16 to nearly 0.9, depending on the year (Table 9). The confidence regions of the lowest survey indices in the early 1990s do not overlap with the confidence regions of the recent high biomass indices, indicating that the overall level of petrale sole biomass has probably increased significantly since then.

As for other surveys taking petrale sole, the estimated biomass levels are related to the proportion of tows containing petrale sole, with high biomass levels having the highest incidence of petrale sole (Figure 10).

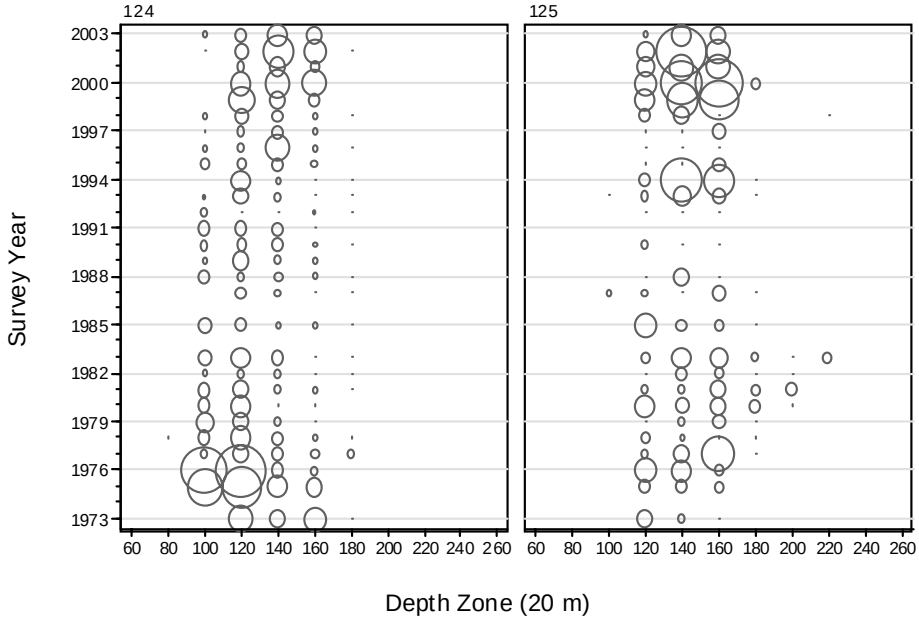

Figure 7. Distribution of catch weight of petrale sole by area stratum, survey year and 20 m depth zone. Depth zones are indicated by the endpoint of the depth interval. Maximum circle size: Area 124=145 kg; Area 125=50 kg.

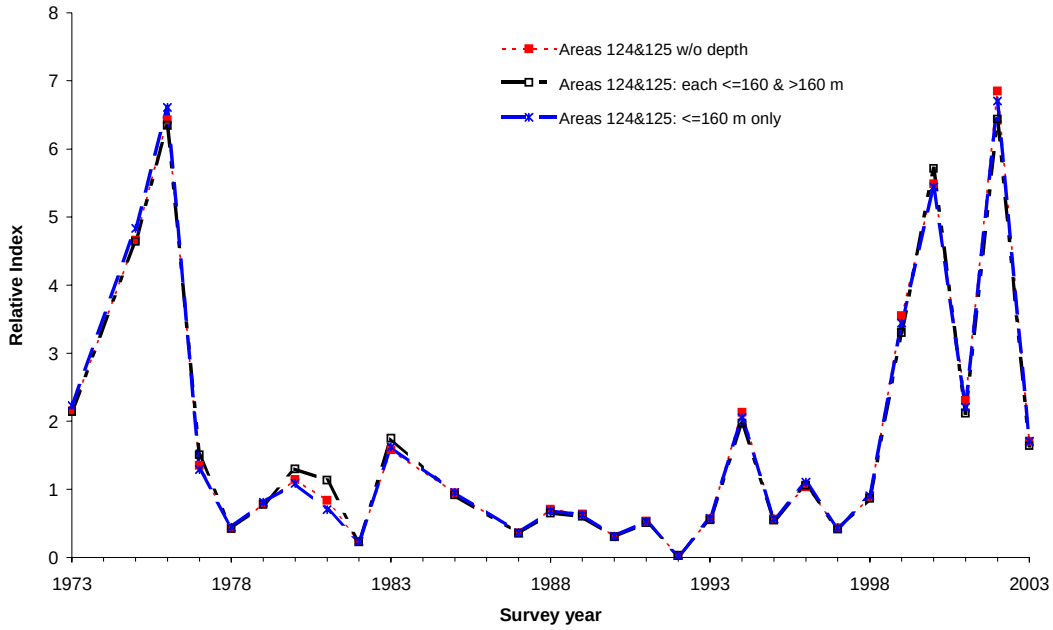

Figure 8. Comparison of three sets of relative biomass estimates for petrale sole: a) Areas 124 and 125 only without consideration of depth; b) four strata: Areas 124 and 125 each divided at the 160 m contour; c) Areas 124 and 125 constrained to tows at depths less than 160 m only. Each survey series has been standardised relative to its geometric mean.

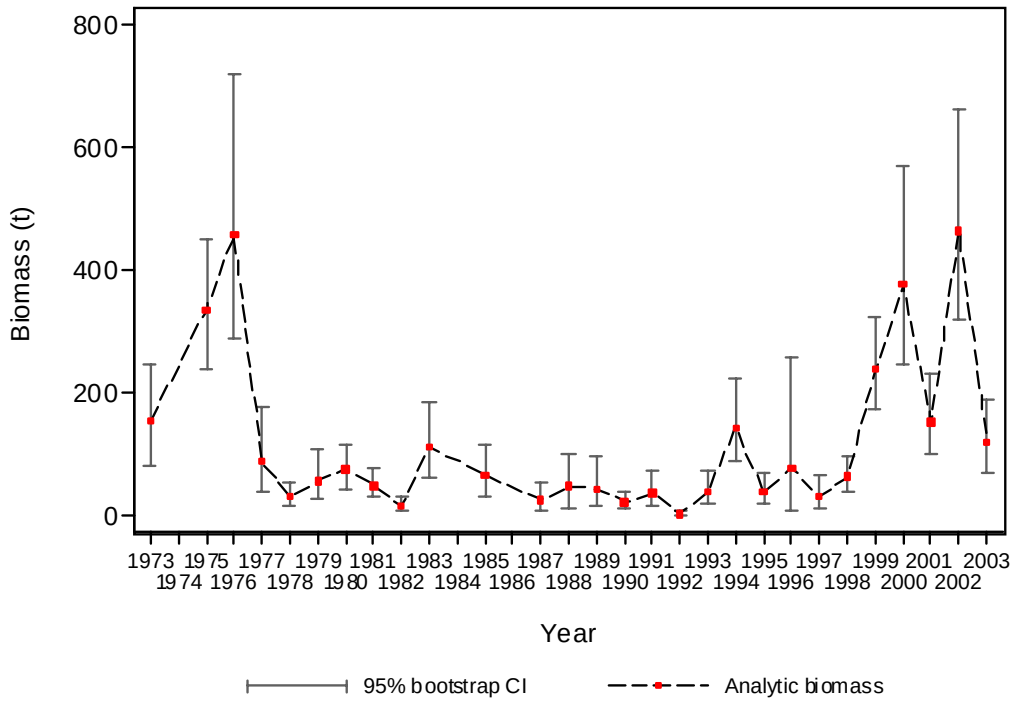

Figure 9. Plot of biomass estimates for petrale sole from the WCVI shrimp trawl survey for the period 1973 to 2003. Bias corrected 95% confidence intervals from 5000 bootstrap replicates are plotted.

Table 9. Biomass estimates for petrale sole from the WCVI shrimp trawl survey for the survey years 1973 to 2003. Biomass estimates are based on a post-stratification of this survey into two strata (confined to tows ≤160m; Figure 6) and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 5000 random draws with replacement. The analytic CV (Eq. 6) is based on the assumption of random tow selection within a stratum.

Survey Year	Biomass (t) (Eq. 1)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. 6)
1973	154.3	154.1	81.4	246.0	0.271	0.268
1975	333.9	332.7	238.4	448.4	0.159	0.161
1976	456.8	455.8	287.2	718.7	0.236	0.232
1977	89.2	88.7	39.7	174.7	0.377	0.381
1978	30.7	30.5	15.7	51.7	0.298	0.298
1979	56.1	56.4	25.0	106.6	0.358	0.364
1980	75.3	75.7	41.2	116.8	0.253	0.251
1981	48.7	48.7	28.7	74.8	0.237	0.238
1982	16.4	16.5	6.1	31.1	0.389	0.394
1983	112.1	113.0	61.7	184.9	0.278	0.276
1985	66.2	66.1	32.6	116.5	0.323	0.322
1987	25.3	25.3	7.6	53.5	0.443	0.452
1988	47.1	47.5	11.3	99.7	0.464	0.468
1989	43.4	42.8	13.4	97.4	0.478	0.446
1990	21.8	21.9	10.1	38.2	0.330	0.326
1991	36.6	36.8	14.5	71.5	0.379	0.391
1992	2.1	2.1	0.0	7.7	0.881	0.875
1993	39.5	39.7	19.3	73.8	0.341	0.340
1994	141.8	141.4	86.8	223.4	0.240	0.240
1995	39.1	38.9	19.0	70.1	0.328	0.326
1996	76.3	76.5	8.0	258.2	0.824	0.832
1997	29.8	29.9	10.7	64.0	0.443	0.453
1998	62.5	62.5	39.0	94.9	0.226	0.224
1999	237.7	238.3	171.3	321.5	0.159	0.163
2000	376.2	375.6	247.7	569.4	0.213	0.214
2001	152.5	151.9	99.9	230.9	0.214	0.214
2002	463.1	463.8	320.0	660.6	0.186	0.185
2003	117.9	117.7	69.8	189.4	0.256	0.260

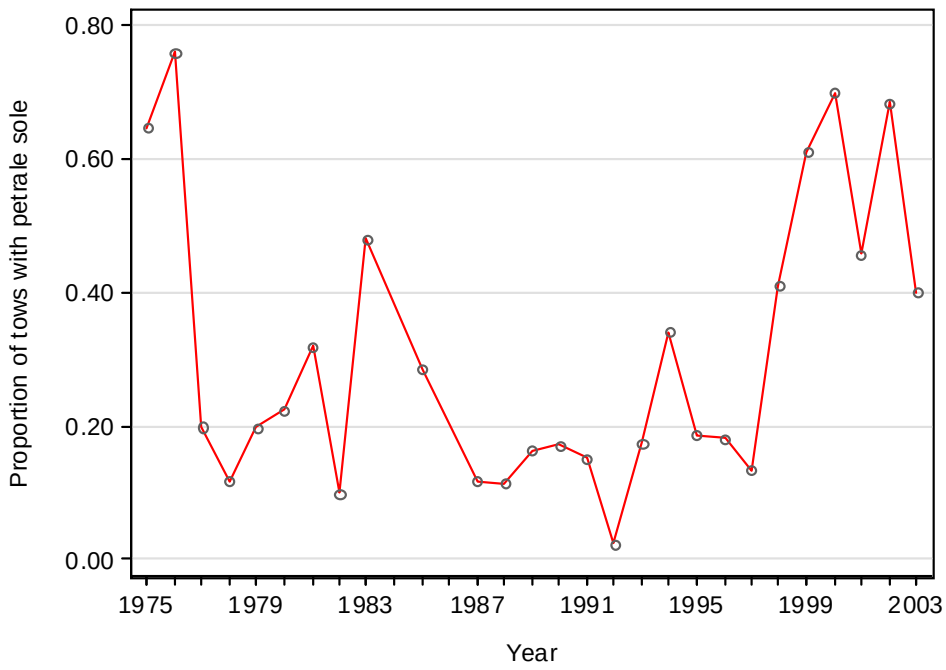

Figure 10. Proportion of tows by year which contain petrale sole for the WCVI shrimp trawl survey.

4.3 HECATE ST. ASSEMBLAGE SURVEY

4.3.1 Methods

Data from the Hecate Strait assemblage trawl survey for every year in each tow were made available (N. Olsen *pers. comm.*). The recommendations by Sinclair (1999) were used to analyse these data. These recommendations include:

a. distributing the tows into strata represented by 10 fathom depth intervals;

b. analysing the data in the range of 10 to 80 fathoms (to ensure comparability between surveys); and

c. applying a constant factor of 0.0486 km^2/h to convert the estimates of CPUE in kg/h to swept area estimates (see Eq. 7 below).

The distribution of tows by depth zone and survey year as presented by Sinclair (1999) could not be duplicated exactly, but the differences were relatively small (compare Table 10 in this document with Table 4 in Sinclair 1999). These differences may be due to different conversion assumptions as the depth data are provided in metres and the depth intervals are defined in fathoms. Alternatively, the original data may have been recorded in fathoms and there may be a loss in precision when converting from fathoms to metres and back to fathoms. Three definitions of depth based on the two depth fields provided (depth at the beginning of each set, depth at the end of each set, and mean depth for the set) are available in the dataset and each were tested to see if a better match could be obtained with the Sinclair results. All three definitions performed similarly but none provided an exact match. In the end, depth at the beginning of the

set was used as the standard as this distribution seemed to be the closest to that provided by Sinclair (1999).

Table 10. Number of tows by depth zone and year of the Hecate Strait assemblage survey. Also shown are the estimated sizes of each stratum for the survey in square kilometres.

Year	10-19 fm	20-29 fm	30-39 fm	40-49 fm	50-59 fm	60-69 fm	70-79 fm	Total
1984	19	19	23	25	23	23	14	146
1987	15	12	12	11	16	10	9	85
1989	17	12	12	15	12	9	13	90
1991	18	12	15	10	21	15	6	97
1993	16	20	11	15	10	15	7	94
1995	16	19	15	16	14	14	7	101
1996	25	24	21	10	11	10	4	105
1998	14	11	17	13	13	14	4	86
2000	19	22	19	14	15	11	6	106
2002	15	17	15	16	11	9	5	88
2003	15	16	17	18	16	10	5	97
Area (km^2)	2,657	1,651	908	828	912	792	612	8,360

The survey data were analysed using equations Eq.1, Eq. 3 and Eq. 6 which assume that tow locations were selected randomly within a stratum relative to the biomass of petrale sole. This was not an assumption made by the original survey design and the depth zone stratum definitions presented in Table 10 were not used when conducting the survey. A modification was made to Eq. 2 to calculate the CPUE density for petrale sole $\left(C_{y_i}\right)$ in stratum *i* for year *y* following the suggestion of Sinclair (1999) to convert kg/h to kg/km^2:

$$C_{y_i} = \frac{\sum_{j=1}^{n_{y_i}} \left(W_{y_i j} \big/ E_{y_i j} 0.0486 \right)}{n_{y_i}} \qquad \textbf{Eq. 7}$$

where $W_{y_i j}$ = catch weight (kg) for petrale sole in stratum *i* for year *y* and tow *j*

$E_{y_i j}$ = effort (h) by tow *j* in stratum *i* for year *y*

0.0486 = constant factor (km^2/h) applied to convert CPUE in kg/h to swept area (kg/km^2)

n_{y_i} = number of tows in stratum *i*

Five hundred bootstrap replicates with replacement were made on the survey data to estimate bias corrected 95% confidence regions for each survey species (Effron 1982).

4.3.2 Results

The distribution of petrale sole catches from this survey tend to be along the edge of the shelf (Figure 11). They are also taken at all survey depths, but seem to be highest in the 40-49 fathom depth stratum (Figure 12).

Estimated biomass levels for petrale sole from the Hecate Strait assemblage trawl survey increased from a point estimate of about 600 t in the first year of the survey to 1400 t in 1991, (Figure 13;Table 11). The biomass estimates decreased to quite low levels by the mid-1990s but

have since recovered to near the maximum level. Confidence bounds are variable, with the estimated CVs for petrale sole ranging from about 0.20 to over 0.80, depending on the year (Table 11). Note that the highest CV is associated with largest biomass estimate (Table 11). The confidence region of the lowest survey index in 1995 does not overlap with the confidence regions of the high biomass indices observed in 2002 and 2003, indicating that the overall level of petrale sole biomass has probably increased significantly between these surveys. The sequence of the proportion of tows which contain petrale sole resembles the biomass trajectory, with high levels in the early 1990s and 2000s and a low point in the mid-1990s (Figure 14).

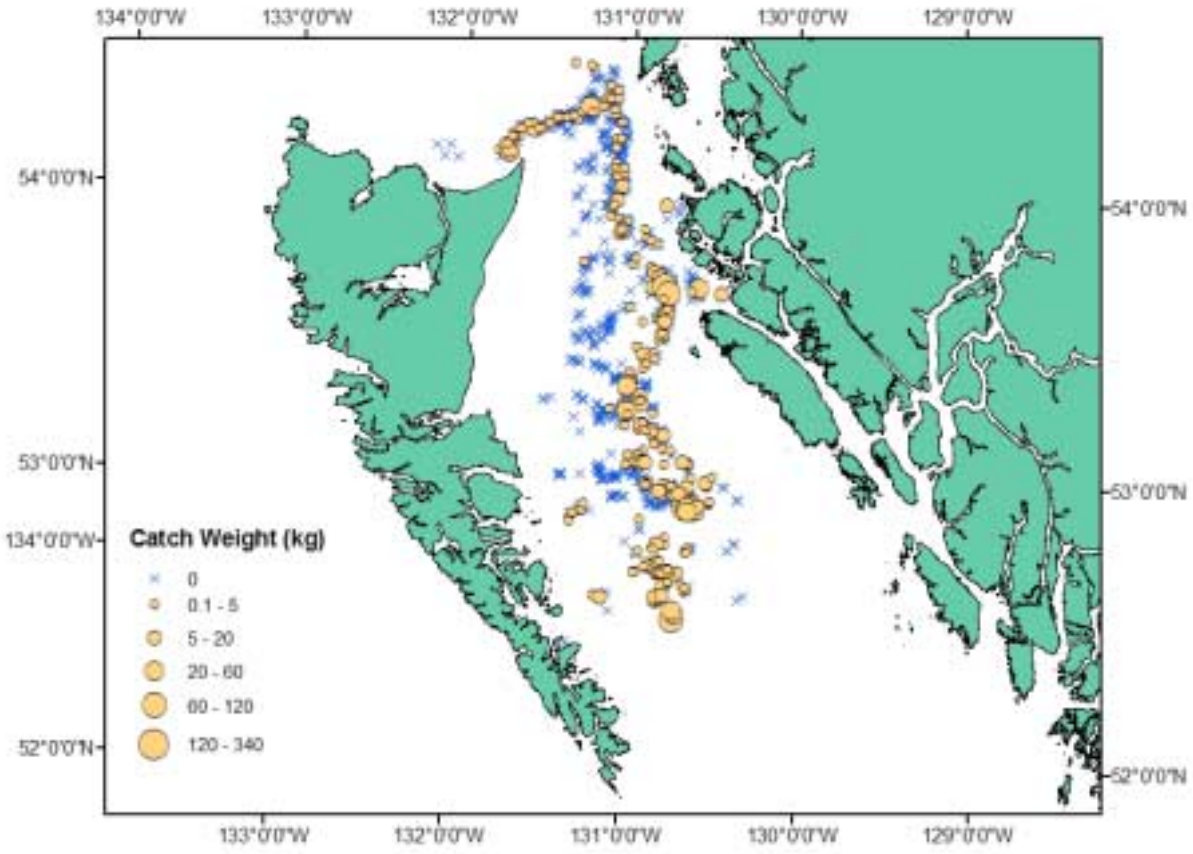

Figure 11. Plot of starting tow locations for all survey tows in the Hecate Strait assemblage trawl survey. Tows which took petrale sole are indicated by a variable circle which is proportional to the catch weight taken (in kg).

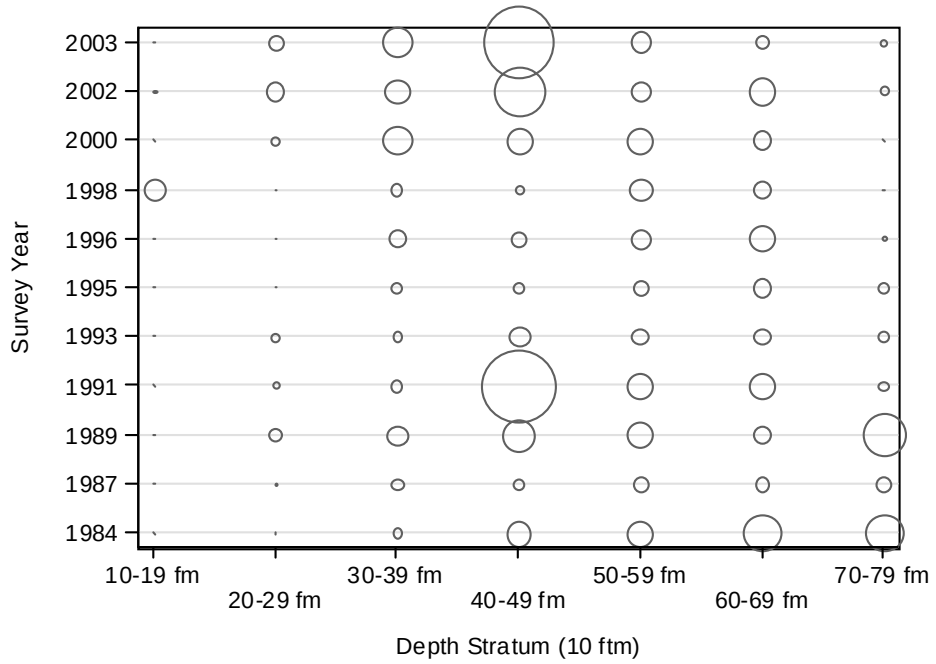

Figure 12. Distribution of catch weight of petrale sole by depth stratum and survey year. Maximum circle size: 340 kg.

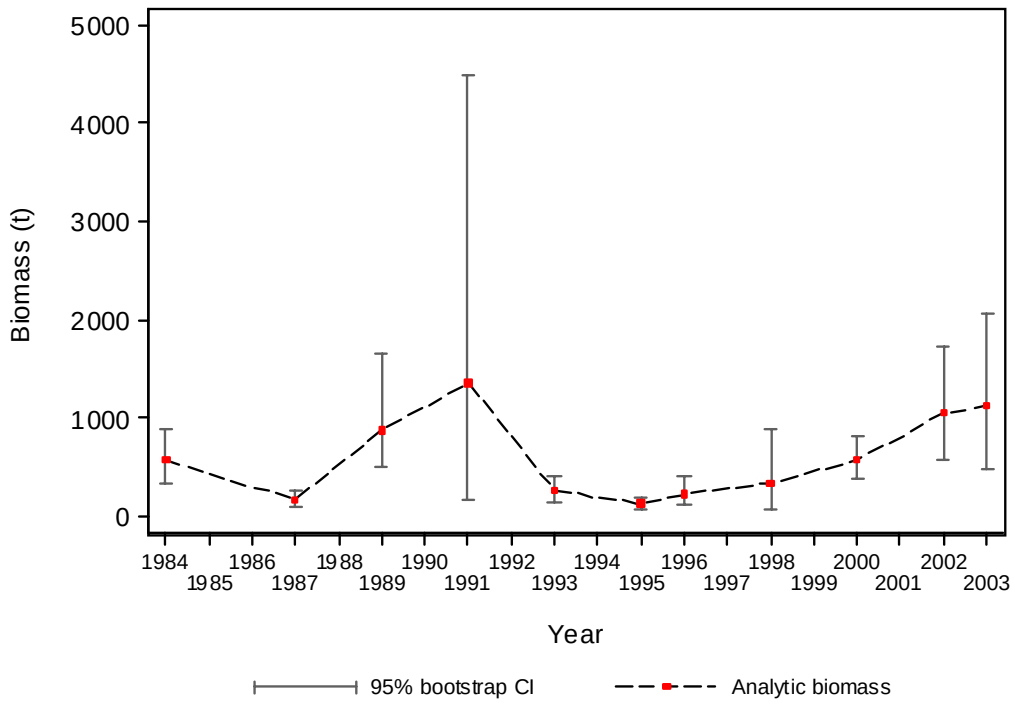

Figure 13. Plot of biomass estimates for petrale sole from the Hecate Strait assemblage trawl survey for the period 1984 to 2003. Bias corrected 95% confidence intervals from 5000 bootstrap replicates are plotted.

Table 11. Biomass estimates for petrale sole from the Hecate Strait assemblage trawl survey for the survey years 1984 to 2003. Biomass estimates are based on a post-stratification of this survey into 10-fathom depth zones (Table 10) and by assuming that the survey tows were randomly selected within these depth zones. Bootstrap bias corrected confidence intervals and CVs are based on 5000 random draws with replacement. The analytic CV (Eq. 6) is based on the assumption of random tow selection within a stratum.

Survey year	Biomass (t) (Eq. 1)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. 6)
1984	570.5	573.7	341.6	895.7	0.244	0.243
1987	170.9	170.9	98.1	253.3	0.231	0.231
1989	877.6	878.6	499.2	1649.4	0.326	0.325
1991	1357.2	1371.5	167.3	4496.5	0.830	0.832
1993	266.2	264.9	147.6	415.3	0.255	0.257
1995	124.6	125.6	66	198.3	0.270	0.273
1996	224.9	224	112.7	401.3	0.322	0.327
1998	337.7	339.1	77	887.9	0.613	0.617
2000	570.4	570.7	382.9	819.7	0.193	0.196
2002	1048.9	1049.1	580.8	1737.5	0.277	0.280
2003	1120.3	1122.1	470.4	2072.4	0.359	0.363

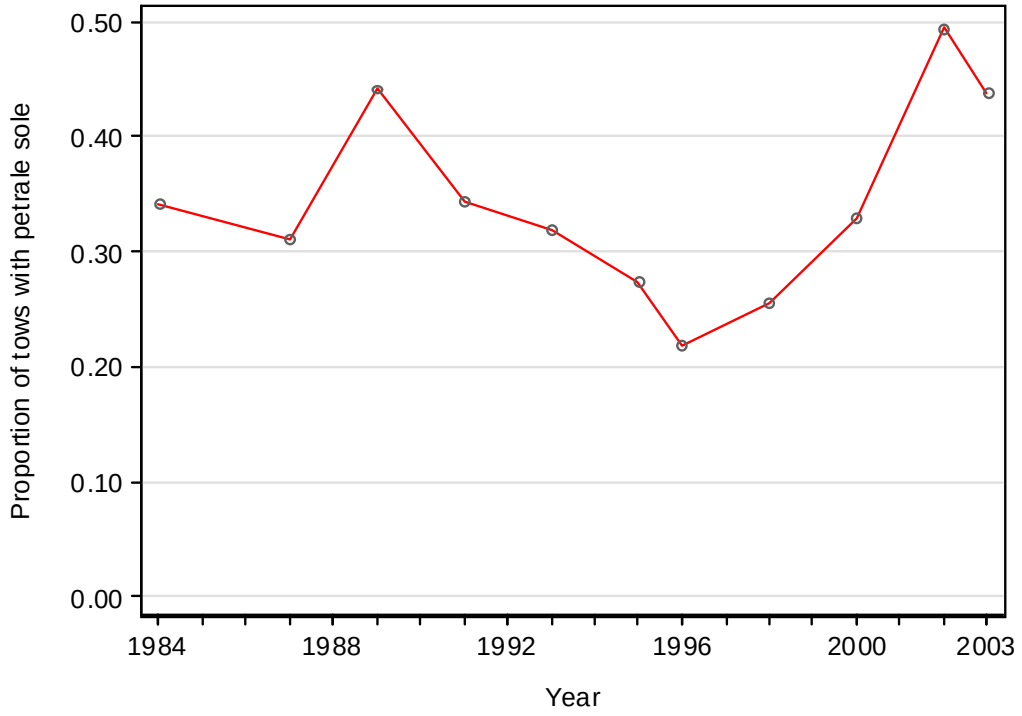

Figure 14. Proportion of tows by year which contain petrale sole for the Hecate Strait assemblage trawl survey.

4.4 QUEEN CHARLOTTE SOUND BOTTOM TRAWL SURVEY

The first of a proposed long terms series of surveys of Queen Charlotte Sound and southern Hecate Strait to estimate relative abundance for a range of demersal species was conducted in the summer of 2003. Petrale sole catches were observed in 67 of the 239 valid tows which provided a reasonably precise biomass estimate of about 300 t with a CV of 19% (Figure 15). The primary purpose of this survey is to provide relative abundance indices for most fish species vulnerable to bottom trawling. The results presented in Stanley et al. (2003) indicate that this survey should track the petrale sole population in Queen Charlotte Sound with reasonable precision, with the estimated relative error in this first year estimated at 0.19.

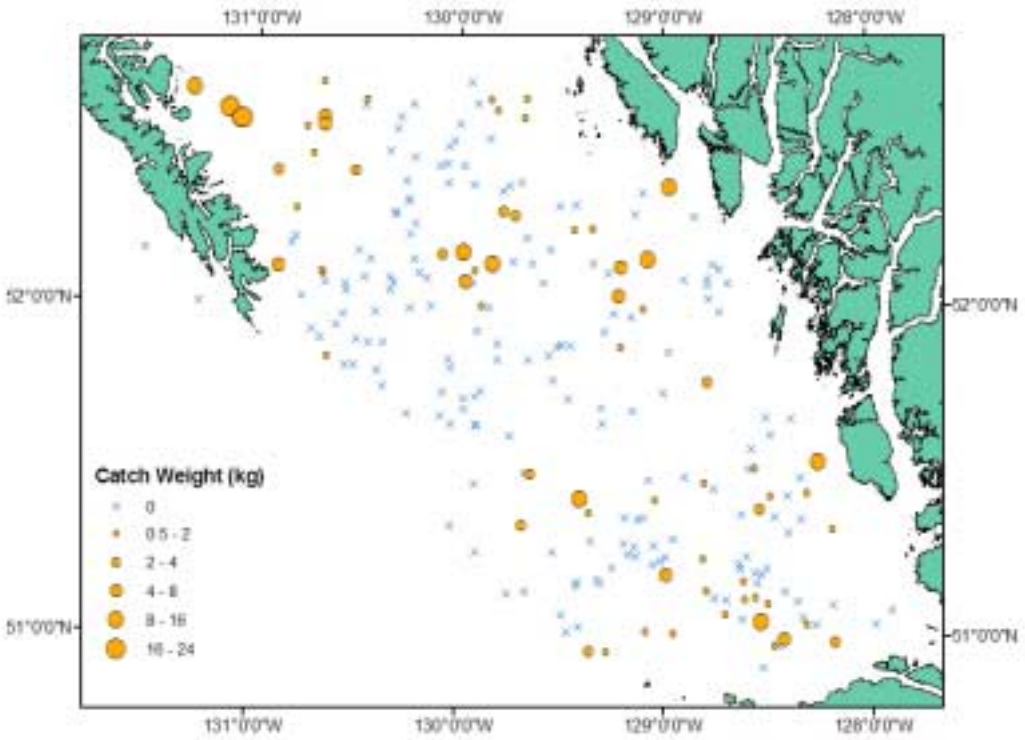

Figure 15. Density plot for the 2003 Queen Charlotte Sound survey showing locations of capture for petrale sole.

4.5 SUMMARY OF AVAILABLE TRAWL SURVEY DATA

The three available time series of biomass indices for petrale sole show reasonably consistent trends: low indices during the 1980s and early to mid-1990s followed by an increase in the late 1990s and early 2000s (Figure 16). The increasing trends are probably statistically significant for the WCVI shrimp and Hecate Strait surveys. All three surveys show an increasing proportion of the tows with petrale sole (Figure 5; Figure 10; Figure 14), an observation which is consistent with a general increase in abundance for this species. The shrimp trawl survey indicates that the biomass levels in the mid-1970s were as high as they are at present. This survey also shows a much greater relative difference in abundance between the periods, while the triennial survey shows the least difference, with the shrimp survey indicating that the current biomass levels are eight to ten times larger than the lowest abundances while the relative differences in the triennial survey are only twice the lowest abundances. It is not known which survey is the most reliable for this species.

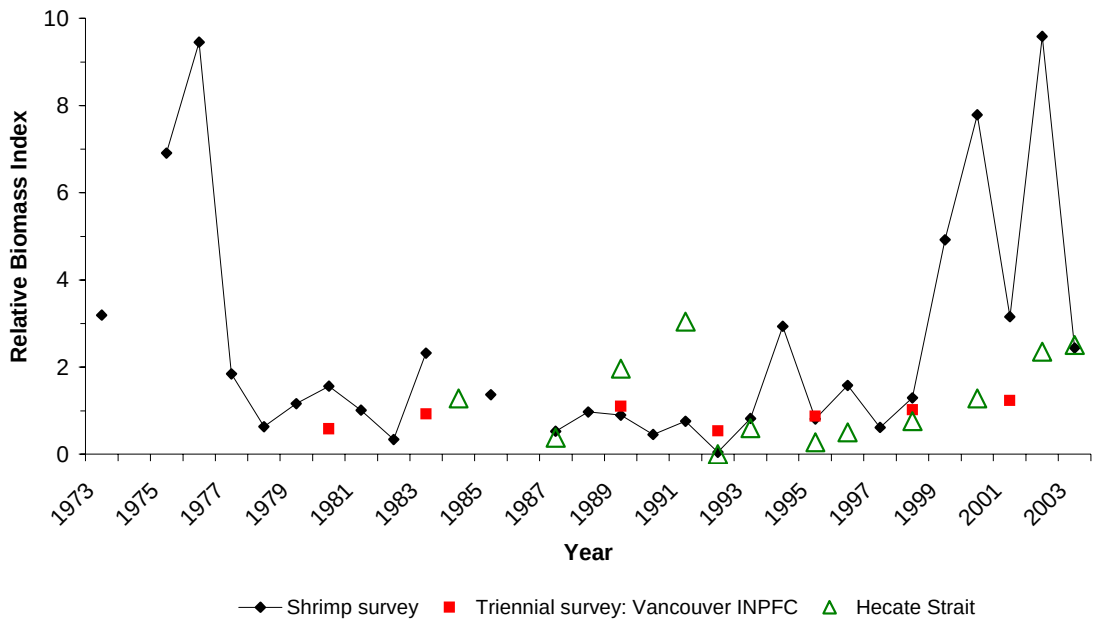

Figure 16. Comparison of the three available series of survey biomass indices for petrale sole. Each index has been standardised relative to the mean of the 1989, 1995 and 1998 survey years (the only three years that are shared by all three surveys).

5.0 BIOLOGICAL STATISTICS

Current estimates of life history parameters for petrale sole are presented in Table 12. These estimates are based on commercial and research samples without reference to sample type or to the underlying representation of the samples in the catch or in the survey biomass. Because the underlying sampling structure has not been taken into account, we have not attempted to include error estimates for these parameters.

5.1 LENGTH WEIGHT RELATIONSHIP

The allometric expression describing the length weight relationship is:

$$W_i = a\, L_i^b$$

where W_i is the weight (g) and L_i is the length (mm) of fish i, were determined from pooled samples for 1979 to 2002. Males rarely reach a size of 500 mm while females commonly reach that size (Figure 17). Weight at age is similar among the sexes until around 300 mm, the time of sexual maturation. Thereafter females surpass the males in weight at length.

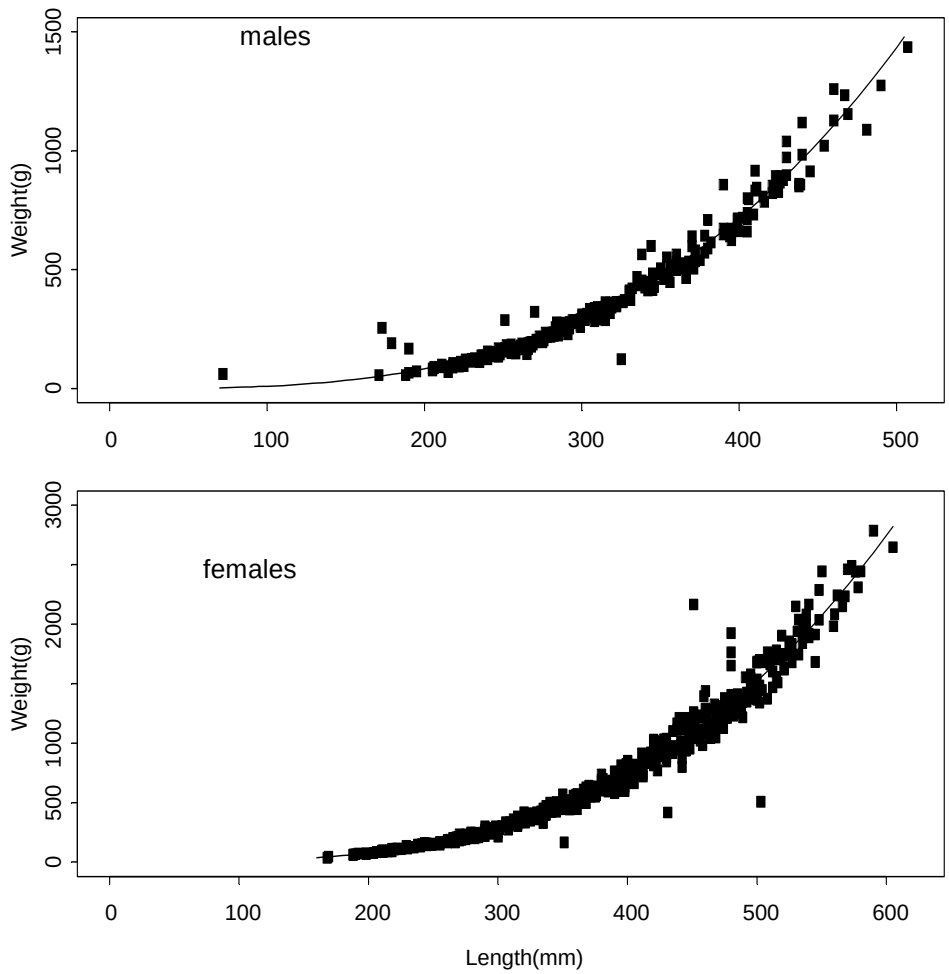

Figure 17. Length-weight relationships for Petrale sole males and females. The data are pooled from research and commercial samples collected between 1979 to 2002.

5.2 LENGTH-AGE RELATIONSHIPS

Von Bertalanffy growth curves (Figure 18) were fitted to data from pooled samples by sex using the equation below where l_t is length at age t, L_∞ is the ultimate length for the population, K is a growth coefficient and t_o is the time when length would theoretically be zero. Growth in length for petrale sole males slows markedly after about age seven while females continue to grow in length until about age twelve.

$$l_t = L_\infty \left[1 - e^{-K(t-t_0)} \right]$$

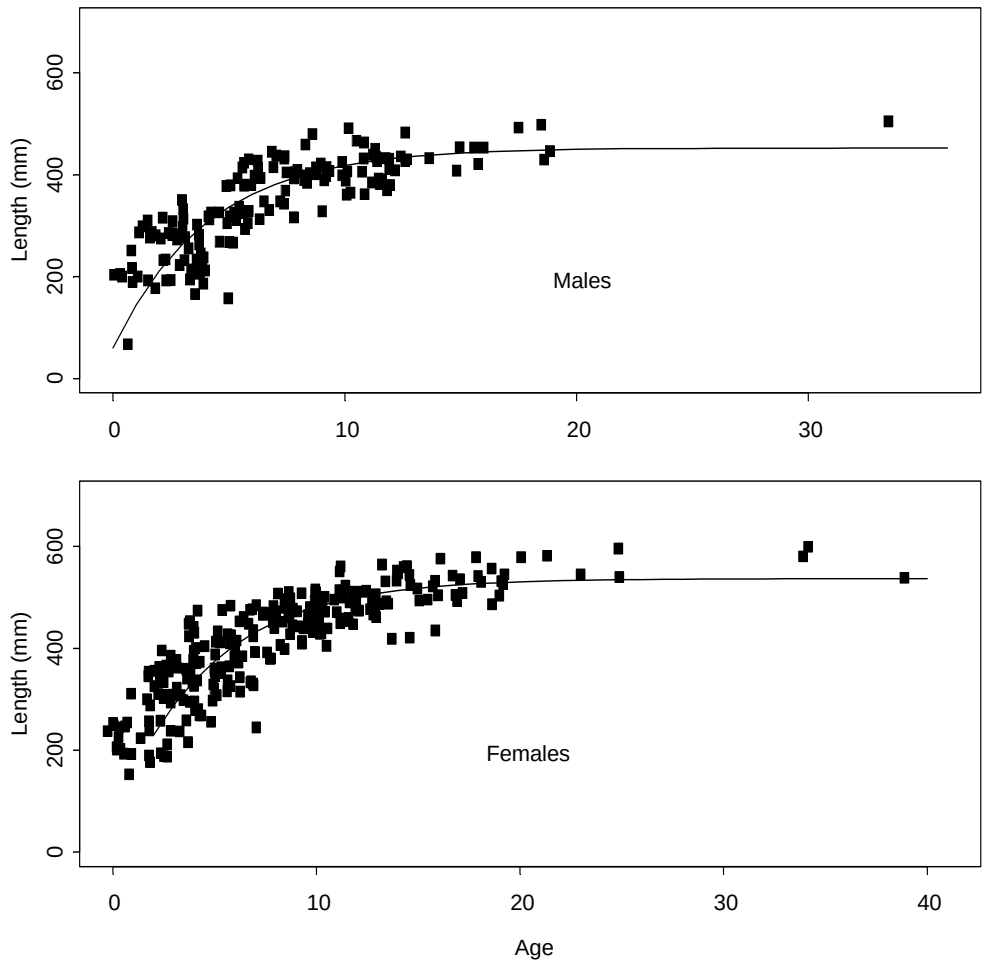

Figure 18. Length age relationships (jitter plot) for petrale sole males (upper panel) and females (lower panel). The data represent pooled commercial and research samples from 1979 to 2002.

5.3 MATURITY

We examined the relationship between length and maturity using data from pooled samples from research cruises and the commercial fishery. The samples were pooled to obtain adequate sample size. Stage of maturity was determined macroscopically and fish were partitioned into one of seven maturity stages (Workman et al. 1996), two immature and five mature. Fish at stages one and two were treated as immature and fish at stages 3-7 were treated as mature. Maturity ogives were fit to these data using a simple logistic regression (Ricker 1975), where the probability of a fish being mature at a given length L, P_L, is a function of the length, L, and the regression coefficients β_0 and β_1.

$$P_L = \frac{e^{\beta_0 + \beta_1 L}}{1 + e^{\beta_0 + \beta_1 L}}$$

Males begin to mature at a size of about 290 mm while females begin to mature at about 320 mm. The rate of maturity at length is different among the sexes as well with males maturing faster than females. $L_{100,}$ the length at which 100% of the fish are mature, is 380 mm for males and 420 mm for females (Figure 19).

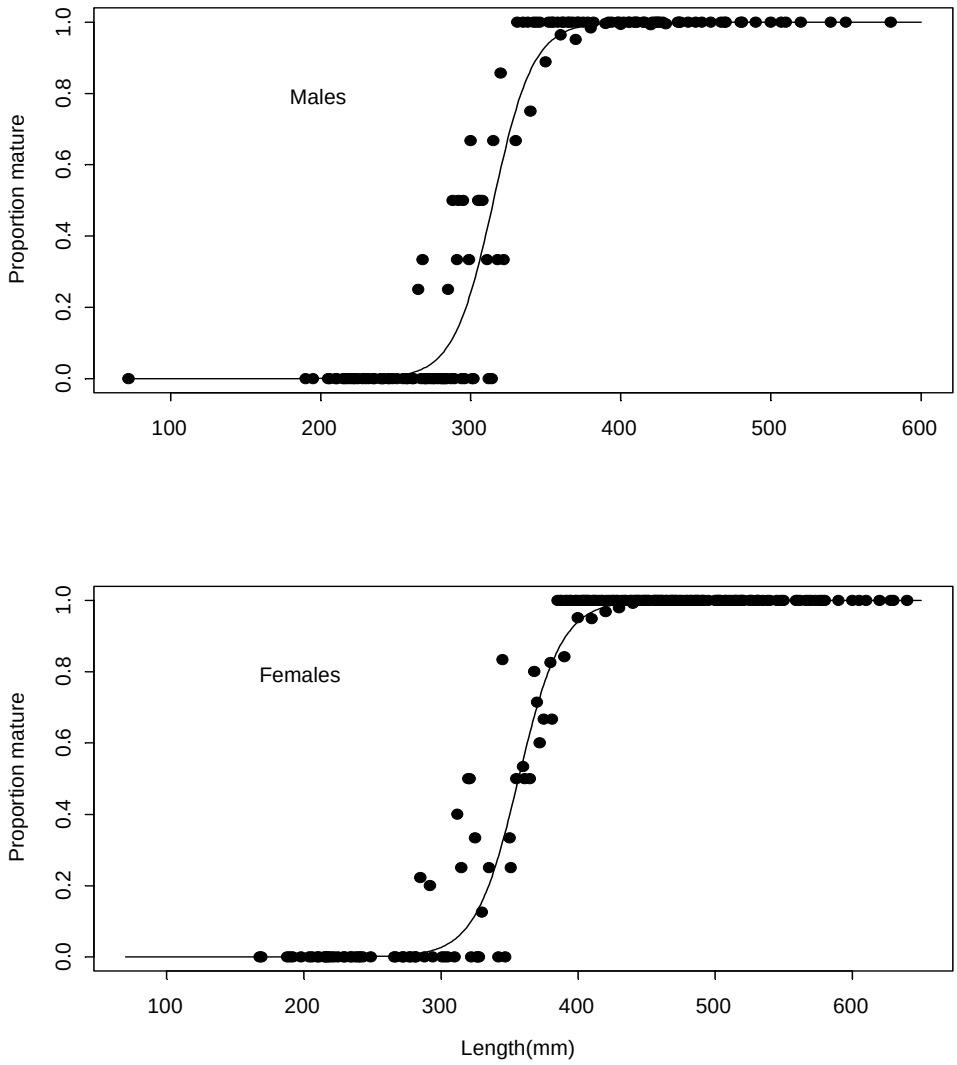

Figure 19. Maturity ogives for male and female Petrale sole. Data are pooled port samples from 1979-2003.

5.4 NATURAL MORTALITY

We estimated the instantaneous rate of natural mortality (M) using Hoenig's (1983) method which is based on species longevity (t_{max}):

$$\ln M = 1.44 - 0.984 \ln(t_{max})$$

Estimates of M were 0.22 and 0.15 for maximum age (t_{max}) of 20 and 30 years. A value of $M = 0.2$ has been used in the U.S. assessments of Petrale sole (Wilderbuer and Sample 2000) and we have used this value in this assessment as well.

5.5 SIZE AND AGE COMPOSITION

Size composition data for 1981-2002 are presented in Figure 20. Data for 1984, 1987, 1989, 1991, 1993, 1995, 1996, 1998, 2000 and 2002 are from research surveys while the balance of the data come from commercial samples. After 1996, samples from the commercial fishery were taken by observers from unsorted catch. Since 1998, there has been an increase in the proportion of juveniles. Although this has occurred occasionally in the past, a trend was never established. This may indicate an increased contribution from the mid-1990s year-classes over the last four years. Samples from the commercial fishery for 1999 and 2001 show the same characteristic.

Table 12. Estimates of biological parameters for Petrale sole caught in the trawl fishery or taken in trawl surveys off the west coast of Canada.

	Males	Females
K	0.243	0.214
$L\infty$	452 mm	537 mm
t_0	-0.587	-0.608
M	0.2	0.2
w_j	29.9 96.2 190.5 297.9 406.4 508.3 599.3 677.8 744.1 799.1 843.8 880.7 910.1 933.0 952.3 967.0 978.6 988.1 995.0 1001.2 1005.4	27.7 94.0 192.0 306.4 423.9 535.5 636.1 723.4 797.5 859.2 909.5 951.1 984.4 1010.3 1032.1 1048.8 1061.9 1072.7 1080.5 1087.6 1092.3
l_j	144.6 210.9 262.9 303.7 335.7 360.8 380.5 395.9 408.0 417.5 424.9 430.8 435.4 438.9 441.8 444.0 445.7 447.1	156.3 229.7 288.9 336.7 375.3 406.4 431.6 451.9 468.3 481.5 492.2 500.8 507.8 513.4 518.0 521.6 524.6 527.0
p_j	0.00 0.00 0.02 0.30 0.82 0.97 0.99 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00	0.00 0.00 0.01 0.22 0.77 0.96 0.99 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
a	0.000006005599	0.00000277445
b	3.10	3.24

where:

K, L_∞, , t_0 are coefficients estimated for the von Bertalanffy growth formulation
M is the instantaneous rate of natural mortality
w_j: mean weight at age j, where j=2 to 22
l_j: mean length at age j
p_j: mean proportion mature at age j
j indexes age groups 1-15
a,b are the length-weight coefficients

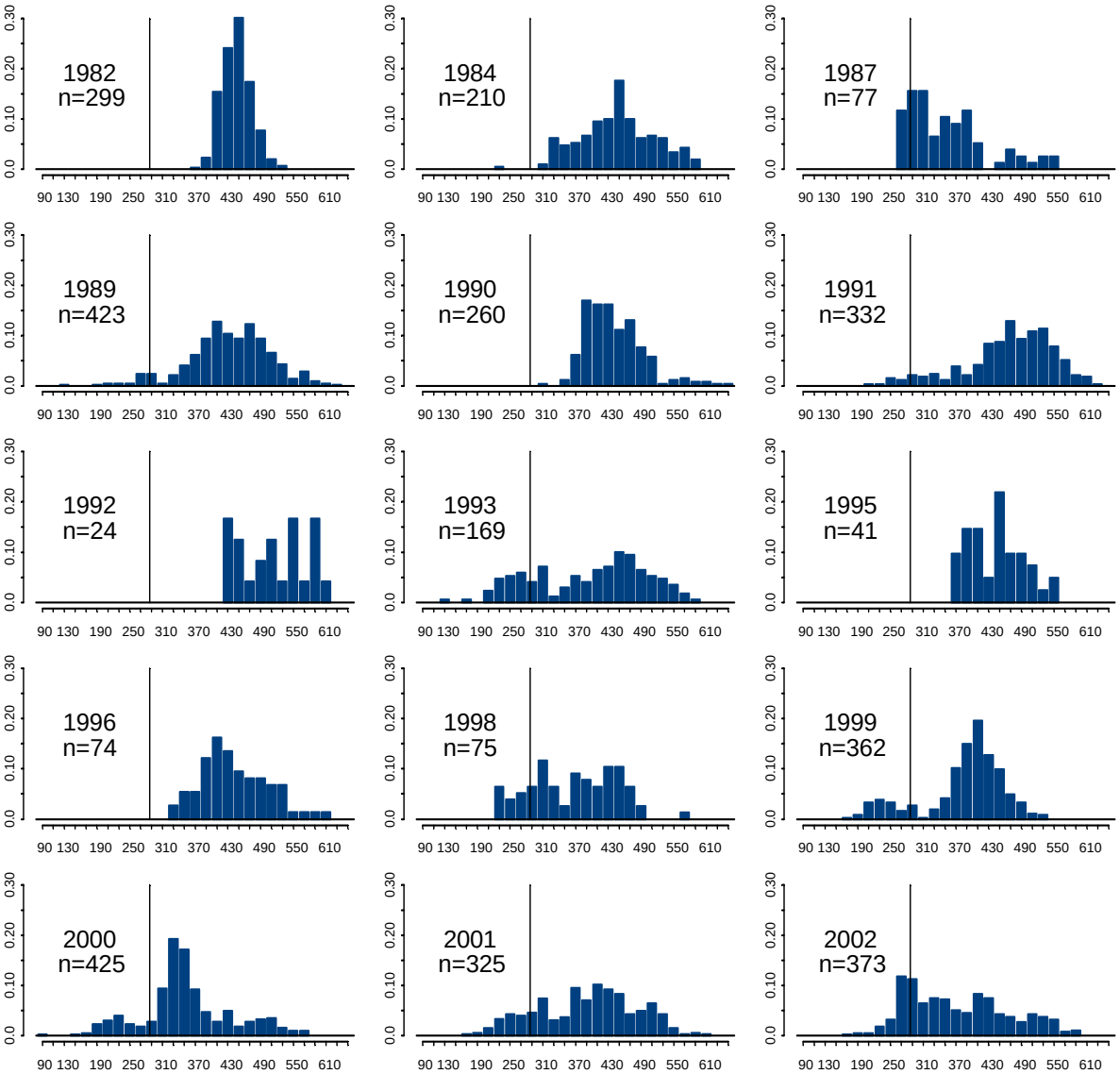

Figure 20. Size frequency composition (mm) for Petrale sole, 1981-2002. The vertical line in each plot corresponds to the length where fish first appear in the commercial fishery.

5.6 TOTAL MORTALITY

We estimated *Z*, the instantaneous total mortality rate from the age composition data for females for samples collected on the Hecate Strait assemblage survey in 2000 (Figure 21). These are the most recent data where there was an adequate sample size (n=124). We used the method of Ricker (1975), which employs log to the base 10 of numbers at age for fully recruited fish to restrict the y-axis to 2.0 on age (Figure 21). The sign of the slope from the regression is changed and multiplied by 2.3 to obtain an estimate of *Z* (Ricker 1975). The estimate of *Z* from this sample was 0.22, only slightly higher than the best estimate of *M* (0.20). This implies an estimate of *F* of 0.02 but there is considerable uncertainty in this estimate. This analysis can only be considered as indicative of an average level of total mortality over the previous ten years, given the range of ages in the sample. This analysis also assumes that recruitment has been stable and average, assumptions which are unlikely to be correct.

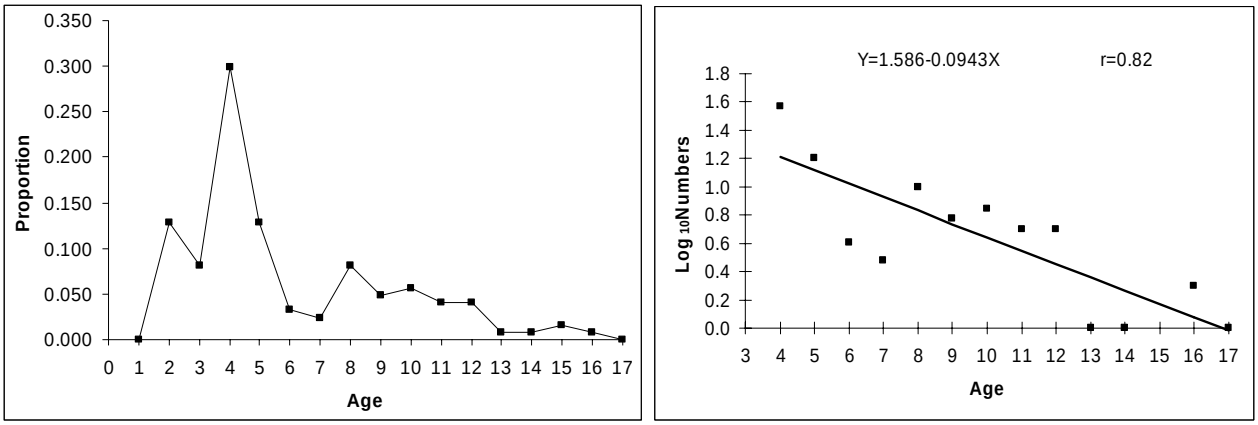

Figure 21. [left panel] Age composition of female petrale sole from the Hecate Strait survey, 2000; [right panel] Estimate of total mortality, *Z,* for female petrale sole from the Hecate Strait survey, 2000.

6.0 ANALYSIS OF CATCH/EFFORT DATA

6.1 ANALYTICAL PROCEDURE USED FOR CATCH/EFFORT DATA

A stepwise multiple linear regression (where data are modelled assuming lognormal variability) was used to estimate trends in CPUE derived from commercial catch and effort data. This approach is commonly used to analyse fisheries catch and effort data and are described generally in Hilborn and Walters (1992) and Quinn and Deriso (1999).

Quinn and Deriso (1999) describe a general linear model based on the lognormal distribution:

$$U = U_r \prod_i \prod_j P_{ij}^{X_{ij}} e^{\varepsilon} \qquad \textbf{Eq.8}$$

where U is the observed CPUE, U_r is the reference CPUE, P_{ij} is a factor i at level j, and X_{ij} is a categorical variable which takes a value of 1 when factor P_{ij} is true and 0 when it is false. ε is a normal random variable with mean=0 and standard deviation σ.

Taking the logarithm of Eq.8 gives the following general form for one explanatory factor:

$$\ln U = \ln U_r + \sum_i \sum_j X_{ij} \ln P_{ij} + \varepsilon$$

or **Eq.9**

$$Y = \beta_0 + \sum_k \beta_k X_k + \varepsilon$$

where the subscript k in the second form of Eq.9 combines subscripts i and j in the first form, β_0 is the intercept of ln(CPUE) and β_k is the logged coefficient of the categorical variable for the factor under consideration. The lognormal model described in the first form of Eq. 9 can only performed on positive CPUE records as the logarithm of zero is undefined. Models using the second form of Eq. 9 which assume a binomial distribution and which are fitted to a binary dependent variable (which is set to zero for those records where CPUE is zero and set to one for the positive catch records) can be used to predict the success or failure of catch.

The models described in Eq. 8 and Eq. 9 are over-parameterised and can take on an infinite number of solutions. The approach used to overcome this problem in this analysis is to fix one of the β_k coefficients and to estimate the remainder of the coefficients relative to the fixed coefficient. Practically this is done in the regression model by dropping one coefficient (usually the first) and estimating the model with k-1 coefficients. The dropped coefficient will be equal to zero (in log space).

Categorical variable coefficients obtained by dropping one factor will take on different values depending on which coefficients has been dropped. Following the suggestion of Francis (1999), these coefficients are transformed to "canonical" coefficient calculated relative to the geometric mean ($\overline{\beta}$)of the series:

$$\beta_k^0 = \beta_k / \overline{\beta} \qquad \textbf{Eq.10}$$

As the analysis is done in log space, this is equivalent to:

$$b_k^0 = \mathrm{e}^{(\hat{\beta}_k - \overline{\beta})} \qquad \textbf{Eq.11}$$

where $\hat{\beta}_k$ is the coefficient calculated for each value of the predictor variable and $\overline{\beta}$ is the mean of those coefficients, including the dropped coefficient. When this procedure is applied to the annual variable ('year' or 'fishing year' and which is often interpreted as an index of relative abundance), the resulting set of canonical indices is termed the "Standardised" CPUE index [Y_k^0] in this report.

The use of the canonical form allows the computation of standard errors for every coefficient, including the dropped coefficient (Appendix 2 in Fargo & Starr 2001). Ordinarily, the use of a fixed reference coefficient sets the standard error for that coefficient to zero and spreads the error associated with that coefficient to the other coefficients in the variable.

As described above, the second form of Eq. 9 can be used to predict the success or failure of catch based on the same suite of categorical independent variables. This is accomplished using a logit link function and assuming a binomial error distribution. Continuous independent variables can be approximated by assuming a polynomial form and estimating the polynomial coefficients. Any order of polynomial can be used, but a third order polynomial approximation seems to work well in most instances.

Eq. 9 can be extended to include as many factors as are thought to be reasonable, including interaction terms. A selection procedure has been developed (Vignaux 1994; Francis 2001) to determine the relative importance of these factors in the model and to establish a stopping rule which will include only the most important factors. This procedure involves a forward stepwise fitting algorithm which generates a regression model iteratively, starting with the simplest model (one dependent and one independent variable).

The following iterative stepwise procedure was used to fit the models, given a data set with candidate predictor variables:

1. Calculate the regression with each predictor variable against the natural log of CPUE (usually kg/h).

2. Generate the AIC (Akaike Information Criterion; Akaike 1974) for each regression based on the number of model degrees of freedom. Select the predictor variable that has the lowest AIC.

3. Repeat Steps 1 and 2, accumulating the number of selected predictor variables and increasing the model degrees of freedom, until the increase in residual deviance (=R^2) for the final iteration is less than 0.01.

The AIC is used for predictor selection to account for variables which may have equivalent explanatory power in terms of residual deviance but add fewer degrees of freedom to the model (Francis 2001).

The lognormal and binomial models described above can be combined into a single index using the following equation (Vignaux 1994):

$$C_i = \frac{L_i}{\left(1 - P_0\left[1 - {}^{1}\!/_{B_i}\right]\right)} \qquad \text{Eq.12}$$

where C_i = combined index for year i
L_i = lognormal index for year i
B_i = binomial index for year i
P_0 = proportion zero for base year 0

Calculating standard errors for the combined index C_i is not straightforward because the standard errors of the two sets of indices are likely be correlated as they come from the same dataset. Francis (2001) suggests that a bootstrap procedure is the appropriate way to estimate the variability of the combined index. This was accomplished by performing 100 resamples with replacement from the original dataset and calculating the combined index (C_i) for each sample using Eq. 12 to generate a distribution of C_i which is then used to estimate the precision of each annual index based on a 95% confidence region.

A simple ratio estimator of mean annual CPUE is calculated annually by:

$$R_j = \frac{\sum_{k=1}^{M_j} C_{jk}}{\sum_{k=1}^{M_j} E_{jk}} \qquad \textbf{Eq. 13}$$

where M_j is the number of records in the data set for year j, C_{jk} is the catch and E_{jk} is the effort associated with each record in the data set for year j. The series of annual indices calculated in this manner is termed the "Simple Ratio" CPUE index in this report and is the arithmetic mean of

CPUE weighted by effort. All CPUE series are compared by standardising the indices relative to the geometric mean of the index series.

6.2 DATA SOURCE, DATA PREPARATION AND VARIABLES USED

Data were derived from the *PacHarv* database held by the Department of Fisheries and Oceans (Schnute et al. 2000). The initial selection of data was made as follows:

a. Restricted from 1 April 1996 to 31 March 2003 (February 1996 is the beginning of the period after which the trawl fleet had 100% independent observer coverage; the beginning date was selected to allow for consistent reporting by DFO management or "fishing" year);

b. Only selected vessels which had fished in the analysed area for at least 5 trips in each of 5 years;

c. Bottom trawl gear only;

d. Success codes 0 and 1;

e. Depth range from 50 m to 500 m;

f. Hours fished >0 and <24 and not NULL;

g. No tows where the total catch (all species) is 0 or NULL.

Table 13. List of explanatory variables used in the lognormal and binomial models.

Variable	Type, number categories, and description
Year	Categorical: 7 fishing years from 1996/97 to 2002/03
Vessel	Categorical (number of categories dependent on vessel selection criteria for the area analysed)
DFO locality code	Categorical: the number of categories depends on area. All localities with less than 200 observations over the 12 fishing were lumped into a single "accumulated" area. DFO localities represent consistent reporting areas which have been defined in terms of local fishery practice.
Major species in tow	Categorical: 8 categories based on the predominant catch of the tow: 1) pacific cod, 2) dogfish, 3) all Sebastes species, 4) sablefish, 5) lingcod, 6) turbot, 7) all other sole species, 8) all remaining tows.
Depth zone X Month (interaction term)	Categorical: either 6 depth bands, beginning at 50 m and extending to 500 m at 75 m intervals [WCVI & Queen Charlotte Sound models] or 4 depth bands, beginning at 50 m and extending to 450 m at 100 m intervals [Hecate St. model] & 12 months from April to March (Note: one category for each of the main effects is dropped when creating the interaction term)
Hours fished	3rd order polynomial used in the binomial model only

Data were aggregated into three areas: west coast of Vancouver Island (DFO Major areas 3C & 3D), Queen Charlotte Sound (DFO Major areas 5A & 5B) and Hecate St (DFO Major areas 5C & 5D). Only landed data (Table 2) were used in this analysis as it was deemed that the discard information would be unreliable due to sampling difficulties. Also the relatively small amount of discard catches (Table 2) are not likely to be sufficiently large to materially affect the conclusions of the analysis.

Four explanatory categorical variables and one interaction term were offered to both the lognormal and binomial models (Table 13). Month and depth effects were offered to both models as a combined interaction term with the main effects for these factors omitted. The binomial model was offered a third order polynomial term describing the number of hours fished (Table 13). The dependent variable offered to the lognormal model was $\ln(catch/hour)$ using positive catches only. A binary success/failure variable was used for the binomial model where failure equalled zero and success equalled one with the model calculating the probability of successfully catching petrale sole.

6.3 WCVI MODELS

6.3.1 WCVI lognormal model

Thirty-two percent of the total deviance was explained by the five explanatory factors selected by the model (Table 14). The depthXmonth interaction term was the most important factor selected in the lognormal model for this area, followed by DFO locality and major species in tow. Model residuals show good conformity to the lognormal distributional assumption, with only minor deviations from normality in the lower tail of the distribution (Figure 22).

The year coefficients show a no trend followed by an upturn in the most recent year (Figure 23). The DFO localities showing the largest CPUE are credible, with the highest catch rates in SE Corner, SW Corner and Fingers (Table 15), which are all areas of good catch success for petrale sole catches. The explanatory variable describing the major species in the tow peaks for the sole species (Figure 23), with the remaining species categories all being near 1.0 except for turbot (which is also a sole species). The vessel coefficients range between 0.6 and 1.5 and are all reasonably well determined. The depthXmonth interaction coefficients show the best catch rates occurring in the winter months at the relatively deeper depths (275-425 m; Figure 24), which is consistent with the known winter spawning fishery. These coefficients also show a relatively steady and consistent fishery for all months at the shallowest depths, which may be directed at juvenile petrale sole (Figure 24).

Table 14. Final output table for WCVI lognormal model with LN(catch/h) as the dependent variable.

Variable order of acceptance	**1**	**2**	**3**	**4**	**5**	**6**
Year	0.006					
DepthXMonth	0.223	0.231				
DFO Locality	0.127	0.133	0.274			
Major species in tow	0.081	0.088	0.268	0.312		
Vessel	0.049	0.054	0.256	0.295	**0.331**	
DFO Major area	0.009	0.014	0.231	0.275	0.313	0.331
additional deviance explained	0.000	0.226	0.043	0.038	0.019	0.000

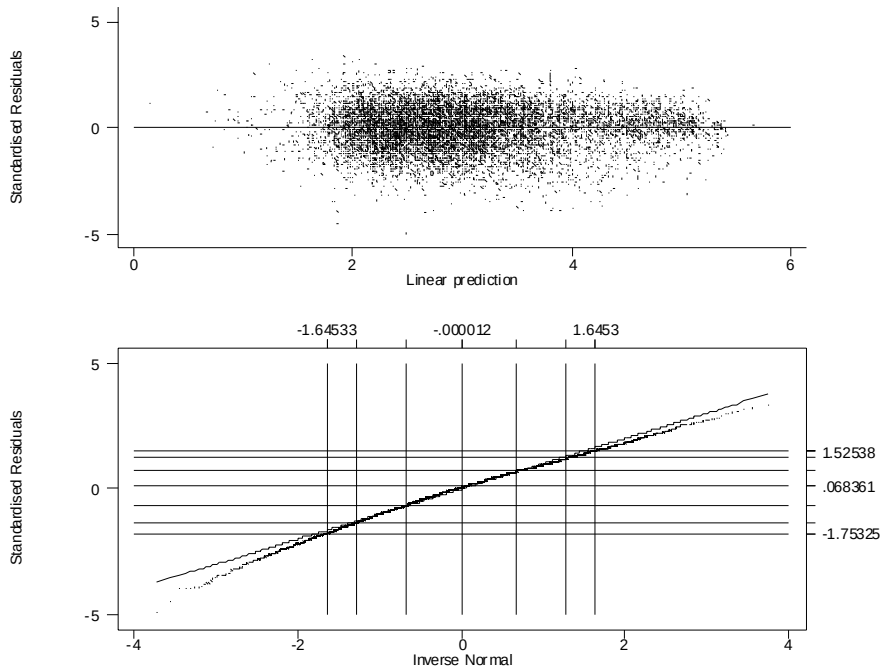

Figure 22. Standardised (Pearson) residuals for the WCVI lognormal model with LN(catch/h) as the dependent variable. Grid lines in the lower q-q plot specify the .05, .10, .25, .50, .75, .90, and .95 quantiles.

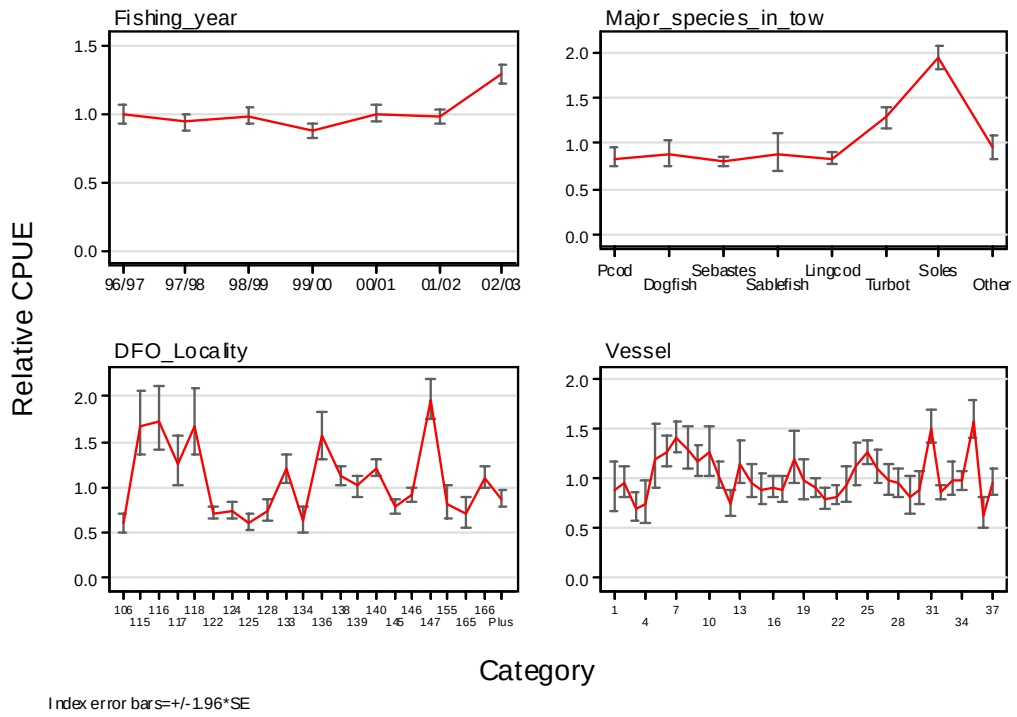

Figure 23. Plots for each categorical variable accepted into the lognormal model using all explanators for WCVI with LN(catch/h) as the dependent variable. The DFO localities are coded and the codes are named in Table 15. Each vessel is labelled with a non-identifying number. Each index has been divided by the geometric mean of the series.

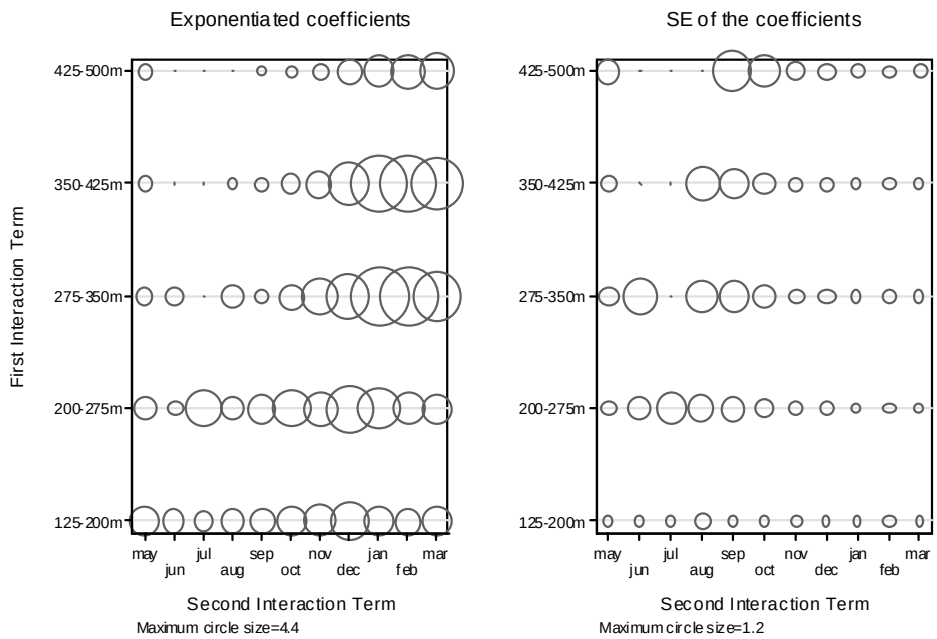

Figure 24. Plot of the exponentiated interaction coefficients and associated standard errors for the WCVI lognormal model with LN(catch/h) as the dependent variable. Cells with no observations are indicated with a '.'.

Table 15. Names, values, upper and lower bounds and standard errors for the locality codes presented in Figure 23 for the WCVI lognormal model with LN(catch/h) as the dependent variable. The "accumulated group" contains all localities with less than 200 observations over all fishing years.

Code	Name	Index	Upper bound	Lower bound	SE
106	SWIFTSURE	0.598	0.711	0.503	0.088
115	SW CORNER	1.660	2.055	1.340	0.109
116	SE CORNER	1.717	2.097	1.405	0.102
117	BIG BANK	1.249	1.553	1.005	0.111
118	FINGERS	1.673	2.070	1.353	0.109
122	DEEP BIG BANK/BARKLEY CANYON	0.718	0.786	0.657	0.046
124	UCLUELET/LOUDON CANYONS	0.734	0.837	0.644	0.067
125	NITINAT CANYON	0.603	0.700	0.520	0.076
128	BARKLEY HAKE	0.741	0.866	0.633	0.080
133	LENNARD I./TOFINO	1.193	1.360	1.046	0.067
134	SIDNEY INLET	0.619	0.771	0.497	0.112
136	CLAYOQUOT	1.550	1.835	1.310	0.086
138	FATHER CHARLES CANYON	1.129	1.238	1.029	0.047
139	CLAYOQUOT CANYON	1.006	1.133	0.893	0.061
140	SOUTH ESTEVAN	1.210	1.299	1.128	0.036
145	NORTH ESTEVAN	0.784	0.866	0.710	0.050
146	NOOTKA	0.910	0.995	0.833	0.045
147	ESPERANZA EAST	1.956	2.177	1.758	0.055
155	KYUQUOT SD (>100 FM)	0.820	1.028	0.655	0.115
165	WEST CAPE COOK	0.698	0.879	0.554	0.118
166	QUATSINO SOUND	1.095	1.213	0.988	0.053
Plus	ACCUMULATED GROUP	0.867	0.957	0.785	0.051

6.3.2 WCVI binomial model

Seventeen percent of the total deviance was explained by the five explanatory factors selected by the model (Table 16). As for the lognormal model, the depthXmonth interaction term was the most important factor selected for this area, followed by DFO locality, the effort polynomial and vessel. The "major species in tow" explanator was not accepted which differed from the lognormal model. Model residuals show a generally good fit to the binomial distributional assumption except for some departure from that assumption in the upper tail of the distribution (Figure 25).

The year coefficients show a slightly increasing trend which reflects an increasing probability of catch success (Figure 26). The DFO localities showing the greatest probability of success differ a bit from the lognormal model, with the addition of Clayoquot and Esperanza East as important areas for this model (Table 17). The vessel coefficients range between about 0.6 and 1.7 and seem reasonably well determined. The range between the highest and lowest coefficients is only slightly greater than for the lognormal model. The depthXmonth interaction coefficients are similar to those for the lognormal model, with the highest success rates occurring in the winter months at the relatively deeper depths (275-425 m; Figure 27), which is also consistent with the known winter spawning fishery. As for the lognormal model, these coefficients also show a relatively steady and consistent fishery for all months at the shallowest depths, which may be directed at juvenile petrale sole (Figure 27). The effort polynomial shows an increasing probability of success up to about 4 hours of towing, followed by a decreasing trend (Figure 28). This decrease is probably due to poor determination of the polynomial at higher levels of effort because 95% of the effort data in the model is for tows of 4 hours or less.

Table 16. Final output table for WCVI binomial model with binary success/failure as the dependent variable.

Variable order of acceptance	**1**	**2**	**3**	**4**	**5**	**6**
Year	0.004					
DepthXMonth	0.095	0.100				
DFO Locality	0.046	0.049	0.134			
Effort (3rd order polynomial)	0.026	0.031	0.124	0.153		
Vessel	0.025	0.027	0.118	0.149	**0.166**	
Major species in tow	0.024	0.029	0.113	0.144	0.160	0.173
DFO Major area	0.004	0.008	0.100	0.135	0.155	0.167
additional deviance explained	0.000	0.095	0.035	0.019	0.012	0.007

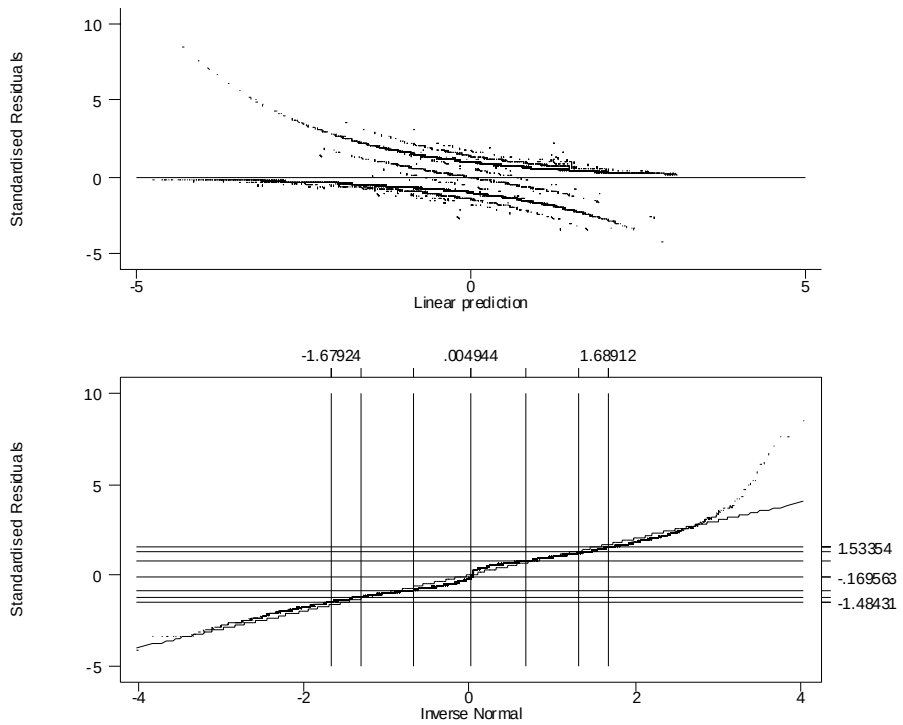

Figure 25. Standardised (Pearson) residuals for the WCVI binomial model with binary success/failure as the dependent variable. Grid lines in the lower q-q plot specify the .05, .10, .25, .50, .75, .90, and .95 quantiles.

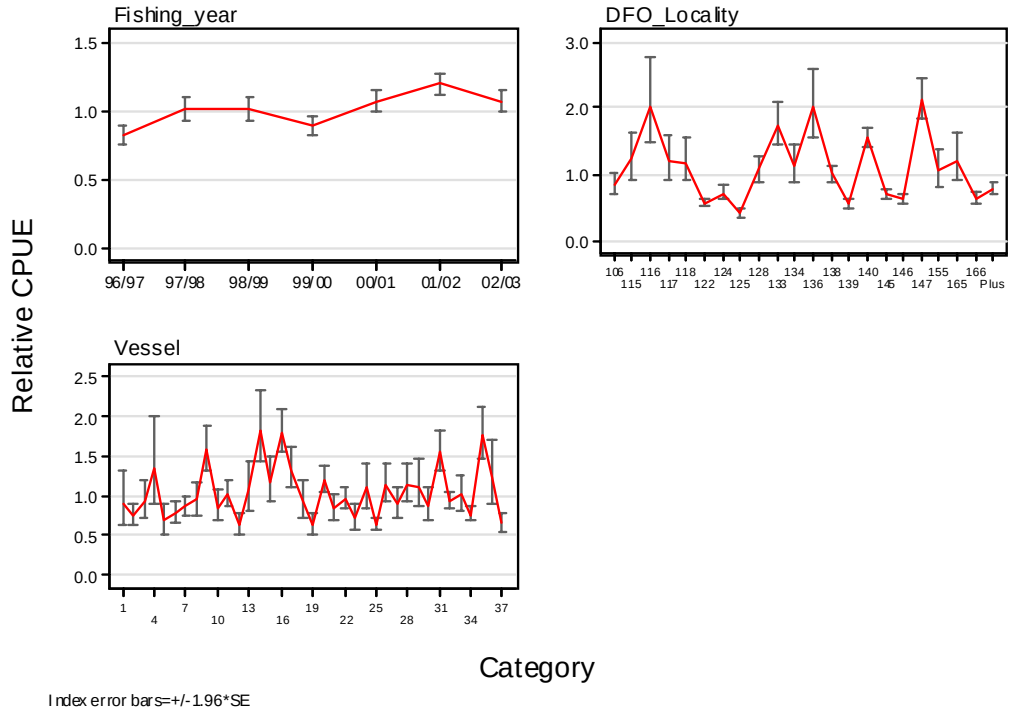

Figure 26. Plots for each categorical variable accepted into the WCVI binomial model with binary success/failure as the dependent variable. The DFO localities are coded and the codes are named in Table 17. Each vessel is labelled with a non-identifying number. Each index has been divided by the geometric mean of the series.

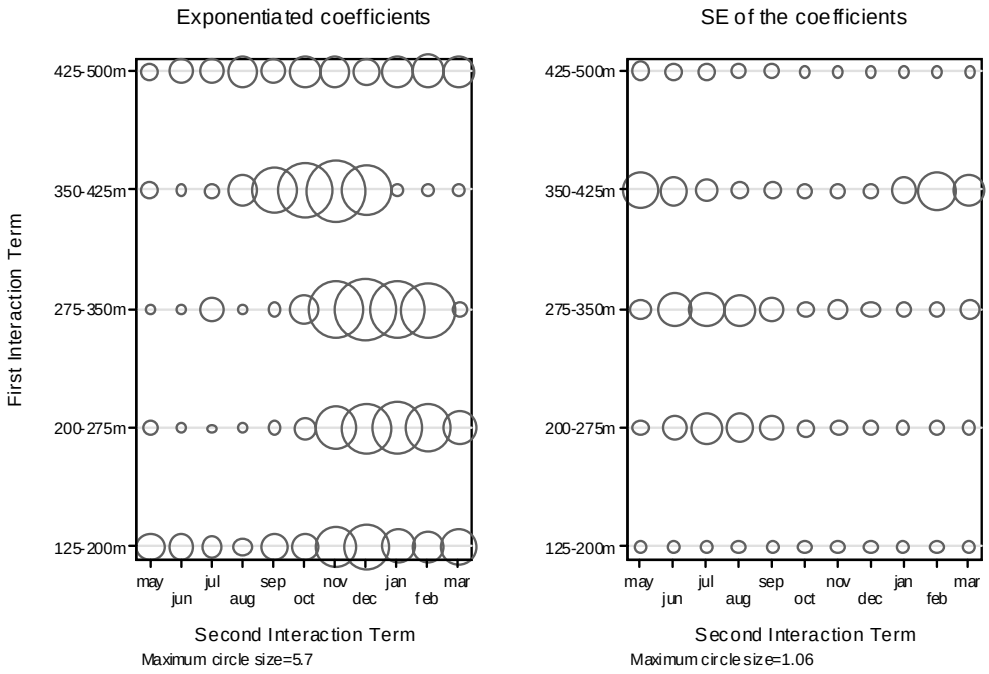

Figure 27. Plot of the interaction coefficients and associated standard errors for the WCVI binomial model with binary success/failure as the dependent variable. Cells with no observations are indicated with a '.'.

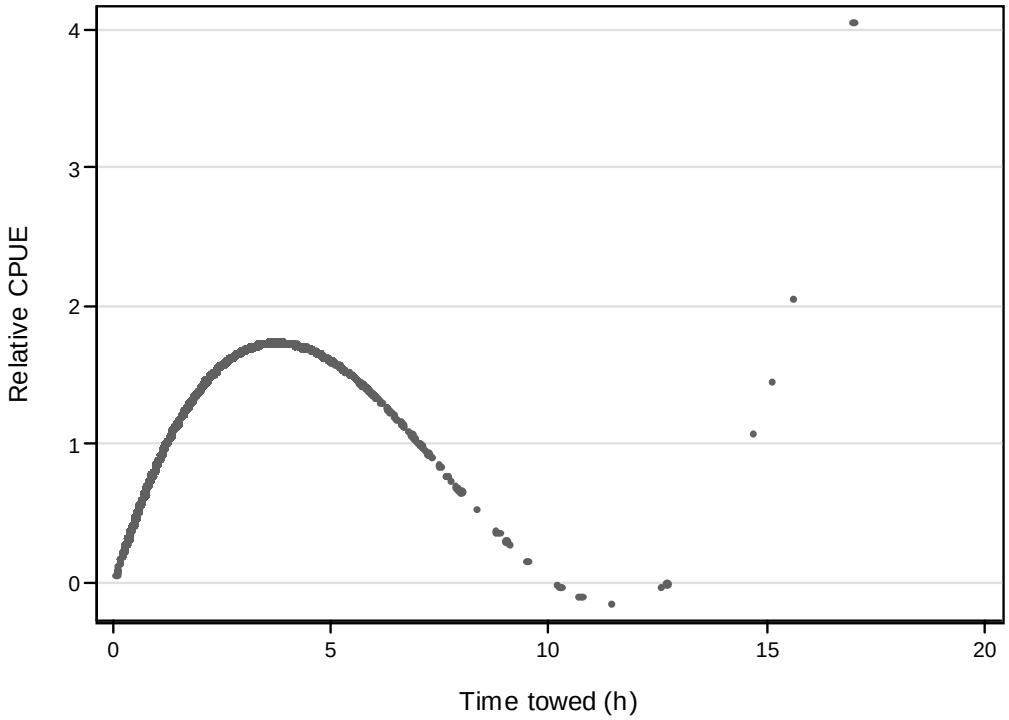

Figure 28. Plot of the predicted effort polynomial for the WCVI binomial model with binary success/failure as the dependent variable.

Table 17. Names, values, upper and lower bounds and standard errors for the locality codes presented in Figure 26 for the WCVI binomial model with binary success/failure as the dependent variable. The "accumulated group" contains all localities with less than 200 observations over all fishing years.

Code	Name	Index	Upper bound	Lower bound	SE
106	SWIFTSURE	0.838	1.023	0.687	0.101
115	SW CORNER	1.226	1.615	0.931	0.141
116	SE CORNER	2.026	2.754	1.491	0.157
117	BIG BANK	1.209	1.602	0.912	0.144
118	FINGERS	1.173	1.533	0.898	0.137
122	DEEP BIG BANK/BARKLEY CANYON	0.559	0.620	0.504	0.053
124	UCLUELET/LOUDON CANYONS	0.711	0.829	0.610	0.078
125	NITINAT CANYON	0.418	0.492	0.355	0.084
128	BARKLEY HAKE	1.073	1.290	0.893	0.094
133	LENNARD I./TOFINO	1.747	2.091	1.460	0.092
134	SIDNEY INLET	1.118	1.446	0.864	0.131
136	CLAYOQUOT	2.014	2.600	1.561	0.130
138	FATHER CHARLES CANYON	1.006	1.139	0.888	0.064
139	CLAYOQUOT CANYON	0.537	0.612	0.471	0.067
140	SOUTH ESTEVAN	1.557	1.714	1.415	0.049
145	NORTH ESTEVAN	0.684	0.773	0.606	0.062
146	NOOTKA	0.622	0.686	0.563	0.050
147	ESPERANZA EAST	2.120	2.444	1.839	0.073
155	KYUQUOT SD (>100 FM)	1.059	1.386	0.810	0.137
165	WEST CAPE COOK	1.211	1.627	0.901	0.151
166	QUATSINO SOUND	0.642	0.727	0.567	0.063
Plus	ACCUMULATED GROUP	0.774	0.868	0.689	0.059

6.3.3 WCVI combined model

The WCVI model which combines the two sets of indices (using Eq. 12) shows no trend in the annual indices up to 1999/2000, after which there is an increasing trend (Figure 29; Table 18). The proportion of zero tows is largely unchanged in this fishery (Figure 29; Table 18) and the lognormal model based on successful tows also shows no trend with an upturn in the most recent year (Figure 23).

Table 18. Indices for the WCVI model by fishing year: simple ratio estimator, binomial, log normal and combined model. Also shown are the proportion of tows with no petrale sole, the mean and CV of 100 bootstrap draws along with the lower and upper 95% bounds from the bootstrap distribution. All indices have been standardised relative to the geometric mean of the series.

Fishing year	Proportion zero tows	Simple ratio (Eq. 6)	Binomial model	Lognormal model	Combined model	Mean bootstrap estimate	Lower bound	Upper bound	Bootstrap CV
96/97	0.585	0.980	0.824	0.990	0.890	0.880	0.819	0.949	0.047
97/98	0.483	1.069	1.009	0.934	0.941	0.947	0.892	1.025	0.038
98/99	0.546	1.295	1.005	0.981	0.986	0.992	0.914	1.054	0.041
99/00	0.546	0.787	0.889	0.871	0.818	0.810	0.761	0.873	0.033
00/01	0.487	0.956	1.062	1.002	1.036	1.040	0.984	1.090	0.028
01/02	0.474	0.939	1.195	0.982	1.078	1.086	0.988	1.137	0.036
02/03	0.494	1.045	1.060	1.285	1.327	1.328	1.218	1.398	0.034

The lack of an increasing trend from the successful tows is consistent with a regulated fishery where there are strong incentives to avoid catching this species, given the low available TACs that have been imposed to allow for stock rebuilding. These incentives may tend to depress any signal of increased abundance from the successful catch tows because of avoidance behaviour which will bias the trend.

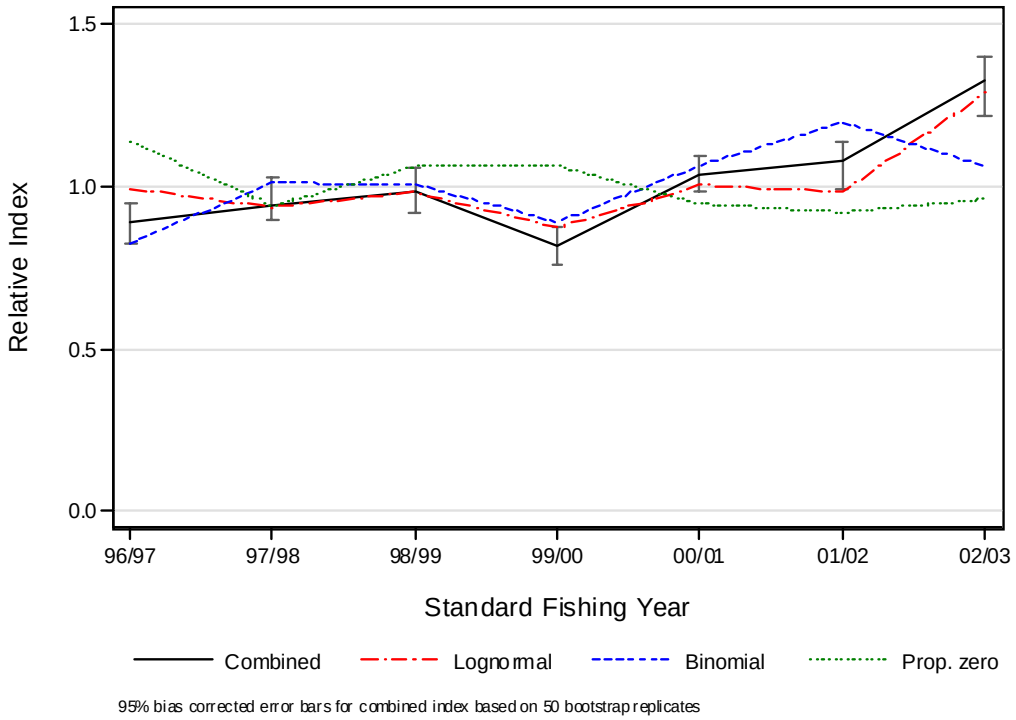

Figure 29. Plot of three indices for the WCVI GLM model. All indices, including the proportion of tows with no petrale sole, are plotted relative to the geometric mean of the series. Bootstrap error bars are provided for the combined index from 100 bootstrap simulations drawn with replacement from the original dataset.

6.4 QUEEN CHARLOTTE SOUND MODELS

6.4.1 Queen Charlotte Sound lognormal model

Twenty-seven percent of the total deviance was explained by the five explanatory factors selected by the model (Table 19). As for the two WCVI models, the depthXmonth interaction term was the second factor selected in the lognormal model for this area, followed by DFO locality and followed by vessel. Model residuals show excellent conformity to the lognormal distributional assumption, with almost no deviations from normality in either tail of the distribution (Figure 30).

The year coefficients show a declining trend from 1996/97 to 1999/2000, followed by an increasing trend to the end of the series (Figure 31). The DFO localities show some strong peaks in the areas around Cape St. James (Table 20). These are areas known for good success for petrale sole catches. The vessel coefficients range between about 0.3 and 1.8 and all but a few seem reasonably well determined. The explanatory variable describing the major species in the tow shows little contrast, with slightly higher coefficients for sablefish and the sole species

(Figure 31). The depthXmonth interaction coefficients show some high catch rates for the deepest depth strata at intermittent months throughout the year (350-500 m; Figure 32), but these coefficients have low precision which may reflect the relatively few available records and the lack of a consistent winter fishery on spawning petrale sole. As in the WCVI models, there is a relatively consistent fishery over all months at the shallowest depths (Figure 32).

Table 19. Final output table for Queen Charlotte Sound lognormal model with LN(catch/h) as the dependent variable.

Variable order of acceptance	**1**	**2**	**3**	**4**	**5**	**6**
Year	0.017					
DepthXMonth	0.130	0.146				
DFO Locality	0.121	0.135	0.208			
Vessel	0.073	0.088	0.196	0.241		
Major species in tow	0.064	0.076	0.167	0.235	**0.266**	
DFO Major area	0.037	0.050	0.160	0.208	0.241	0.267
additional deviance explained	0.000	0.129	0.062	0.033	0.025	0.000

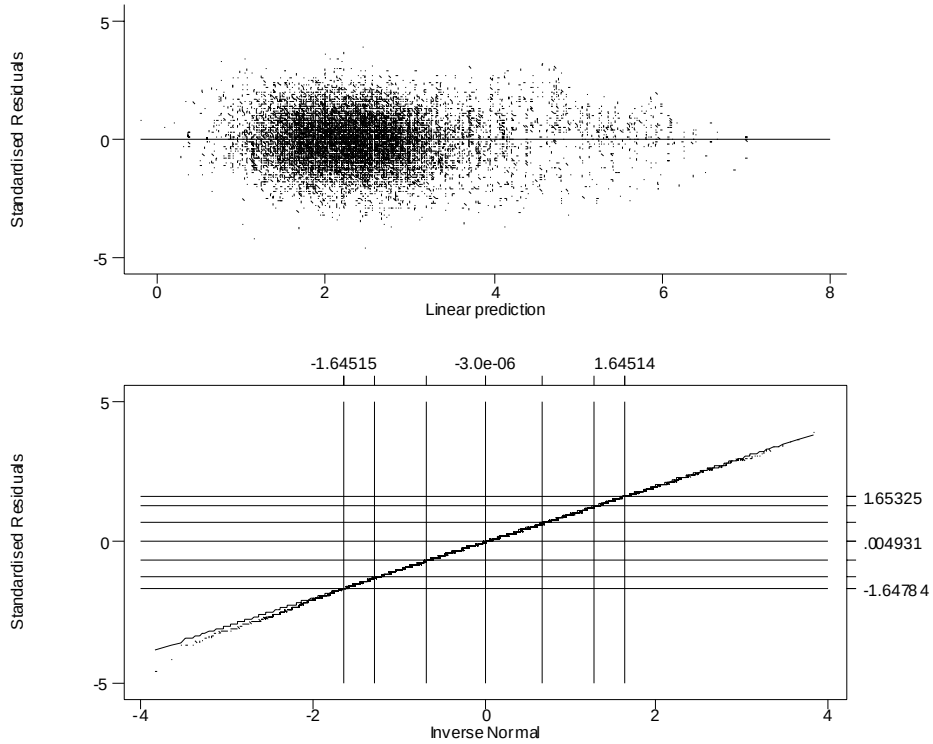

Figure 30. Standardised (Pearson) residuals for the Queen Charlotte Sound lognormal model with LN(catch/h) as the dependent variable. Grid lines in the lower q-q plot specify the .05, .10, .25, .50, .75, .90, and .95 quantiles.

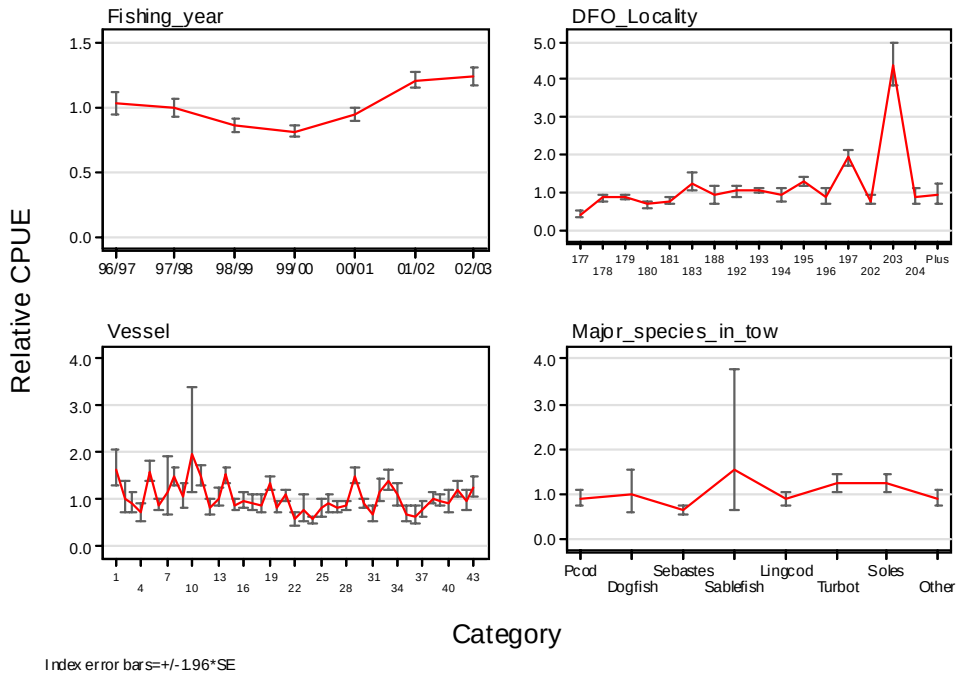

Figure 31. Plots for each categorical variable accepted into the lognormal model for Queen Charlotte Sound with LN(catch/h) as the dependent variable. The DFO localities are coded and the codes are named in Table 20. Each vessel is labelled with a non-identifying number. Each index has been divided by the geometric mean of the series.

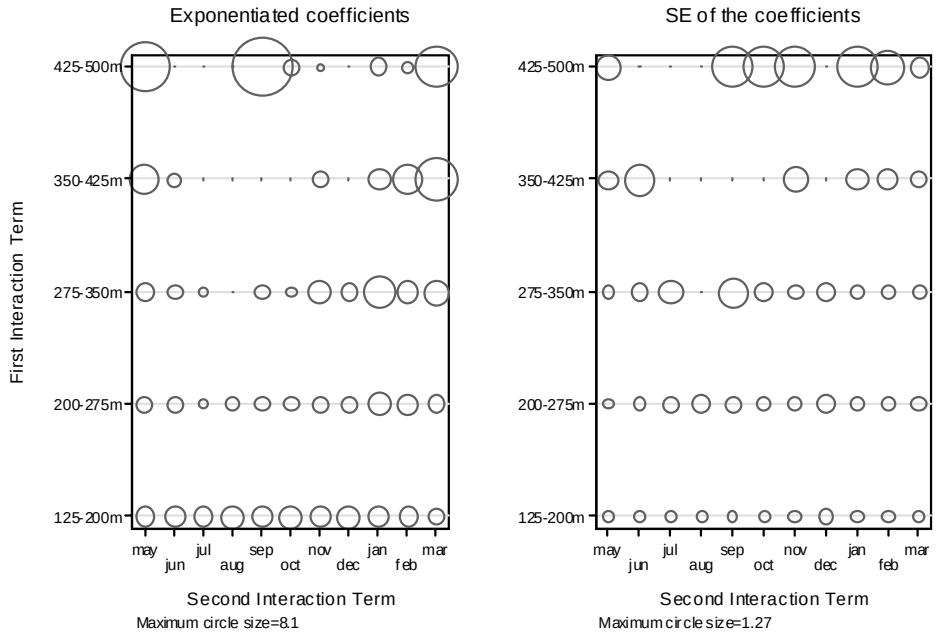

Figure 32. Plot of the exponentiated interaction coefficients and associated standard errors for the lognormal model for Queen Charlotte Sound with LN(catch/h) as the dependent variable. Cells with no observations are indicated with a '.'.

Table 20. Names, values, upper and lower bounds and standard errors for the locality codes presented in Figure 31 for the Queen Charlotte Sound lognormal model with LN(catch/h) as the dependent variable. The "accumulated group" contains all localities with less than 200 observations over all fishing years.

Code	Name	Index	Upper bound	Lower bound	SE
177	UNKNOWN	0.396	0.475	0.330	0.093
178	TRIANGLE	0.858	0.954	0.771	0.054
179	CAPE SCOTT SPIT	0.874	0.943	0.810	0.039
180	MEXICANA	0.658	0.756	0.573	0.071
181	TOPKNOT	0.777	0.892	0.677	0.070
183	SOUTH SCOTT ISLANDS	1.232	1.497	1.014	0.099
188	PISCES CANYON	0.910	1.189	0.697	0.136
192	NE GOOSE	1.013	1.166	0.879	0.072
193	SE GOOSE	1.056	1.132	0.985	0.036
194	NW GOOSE	0.928	1.132	0.760	0.102
195	SW GOOSE	1.287	1.391	1.190	0.040
196	MITCHELL'S GULLY	0.878	1.129	0.682	0.129
197	SE CAPE ST. JAMES	1.912	2.130	1.716	0.055
202	SW MIDDLE BANK	0.765	0.895	0.654	0.080
203	OUTSIDE CAPE ST. JAMES	4.388	4.977	3.869	0.064
204	WEST VIRGIN ROCKS	0.878	1.129	0.682	0.129
Plus	ACCUMULATED GROUP	0.932	1.225	0.710	0.139

6.4.2 Queen Charlotte Sound binomial model

Only eleven percent of the total deviance was explained by the four explanatory factors selected by this model (Table 21). As for the lognormal model for this area, the depthXmonth interaction term was the most important factor selected for this area, followed by DFO locality and the "major species in tow" variable. Neither the effort polynomial nor the vessel explanators were selected by this model. Model residuals show a slight departure from the binomial distributional assumption in the lower and upper tails of the distribution (Figure 33).

Table 21. Final output table for Queen Charlotte Sound binomial model with binary success/failure as the dependent variable.

Variable order of acceptance	1	2	3	4	5
Year	0.005				
DepthXMonth	0.064	0.068			
DFO Locality	0.038	0.042	0.096		
Major species in tow	0.033	0.038	0.081	**0.106**	
Effort (3rd order polynomial)	0.013	0.017	0.077	0.103	0.114
Vessel	0.016	0.021	0.077	0.103	0.114
DFO Major area	0.000	0.005	0.069	0.096	0.106
additional deviance explained	0.000	0.063	0.028	0.011	0.008

The year coefficients show a generally increasing trend which reflects an increasing probability of catch success (Figure 34). The DFO localities showing the greatest probability of success are similar to the lognormal model, with the highest success rates in the "Triangle", "SW Goose" and the two Cape St. James localities (Table 22). The "major species in tow" coefficients are highest for Pacific cod, sablefish and ling, although the sablefish coefficient is very poorly determined. The depthXmonth interaction coefficients shows a pattern that differs somewhat with the lognormal model, with good success rates occurring in every month in both the 425-500 m

and the 125-200 m strata (Figure 35). The patterns in the intermediate depth zones are more variable, with large coefficients in the summer months in the 350-425 m zone while the larger coefficients in the 200-275 m and 275-350 m zones occur in the late autumn and winter months. The precision is low on all the 350-425 m zone coefficients, indicating that there probably was not much fishing taking place in this depth zone.

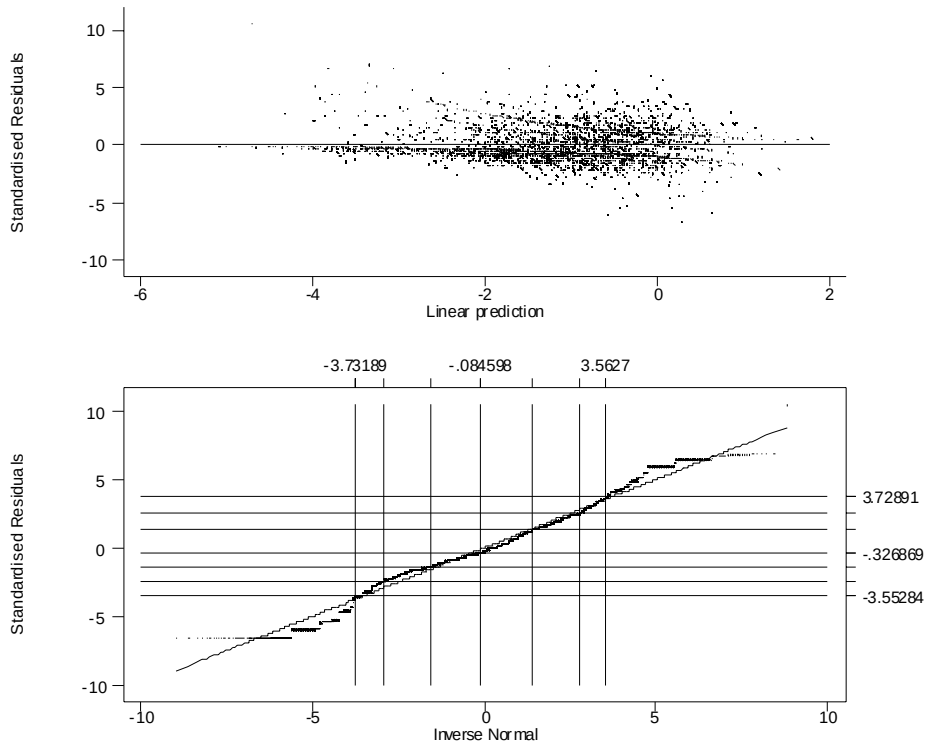

Figure 33. Standardised (Pearson) residuals for the Queen Charlotte Sound binomial model with binary success/failure as the dependent variable. Grid lines in the lower q-q plot specify the .05, .10, .25, .50, .75, .90, and .95 quantiles.

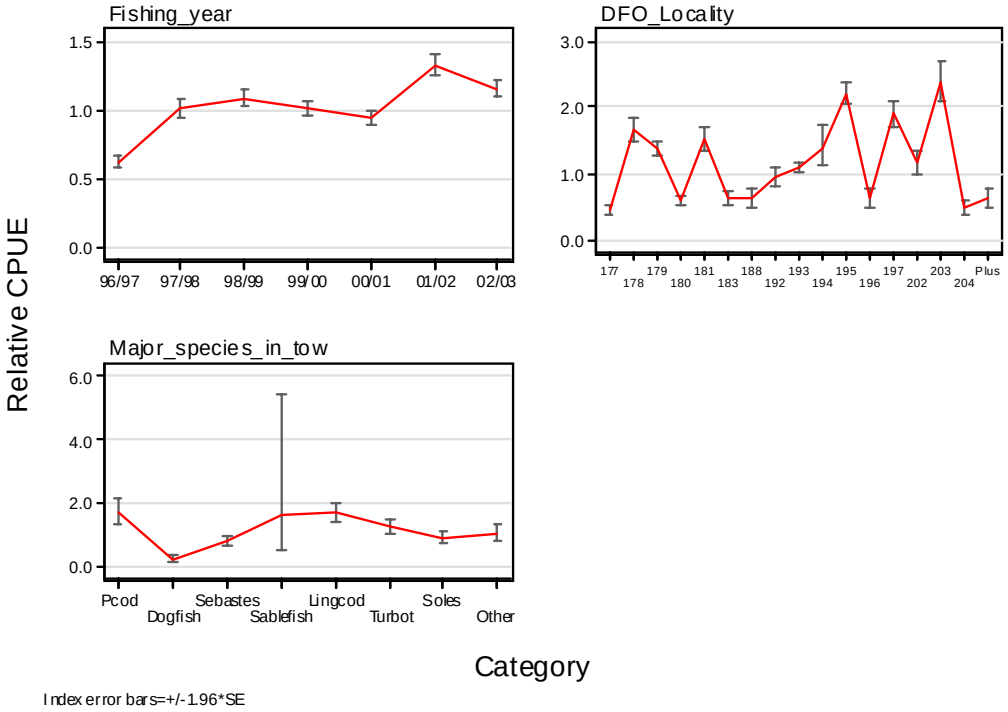

Figure 34. Plots for each categorical variable accepted in the Queen Charlotte Sound binomial model with binary success/failure as the dependent variable. The DFO localities are coded and the codes are named in Table 22. Each vessel is labelled with a non-identifying number. Each index has been divided by the geometric mean of the series.

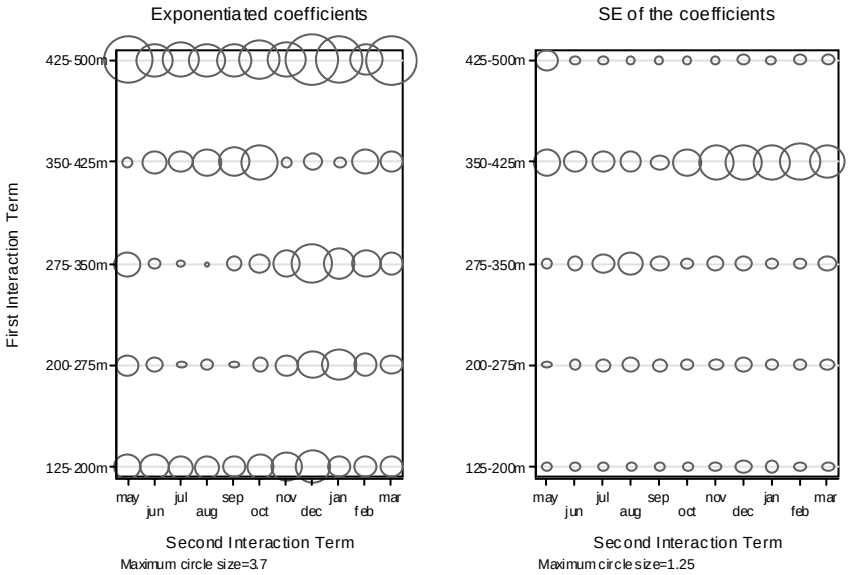

Figure 35. Plot of the exponentiated interaction coefficients and associated standard errors for the Queen Charlotte Sound binomial model with binary success/failure as the dependent variable. Cells with no observations are indicated with a '.'.

Table 22. Names, values, upper and lower bounds and standard errors for the locality codes presented in Figure 34 for the Queen Charlotte Strait binomial model with binary success/failure as the dependent variable. The "accumulated group" contains all localities with less than 200 observations over all fishing years.

Code	Name	Index	Upper bound	Lower bound	SE
177	UNKNOWN	0.447	0.526	0.380	0.083
178	TRIANGLE	1.656	1.834	1.495	0.052
179	CAPE SCOTT SPIT	1.361	1.465	1.265	0.038
180	MEXICANA	0.592	0.672	0.521	0.065
181	TOPKNOT	1.523	1.710	1.356	0.059
183	SOUTH SCOTT ISLANDS	0.616	0.731	0.518	0.088
188	PISCES CANYON	0.615	0.773	0.489	0.117
192	NE GOOSE	0.941	1.075	0.824	0.068
193	SE GOOSE	1.095	1.169	1.026	0.033
194	NW GOOSE	1.394	1.716	1.132	0.106
195	SW GOOSE	2.207	2.393	2.036	0.041
196	MITCHELL'S GULLY	0.617	0.767	0.497	0.111
197	SE CAPE ST. JAMES	1.900	2.106	1.714	0.053
202	SW MIDDLE BANK	1.150	1.322	1.000	0.071
203	OUTSIDE CAPE ST. JAMES	2.378	2.702	2.093	0.065
204	WEST VIRGIN ROCKS	0.471	0.584	0.380	0.109
Plus	ACCUMULATED GROUP	0.608	0.773	0.478	0.123

6.4.3 Queen Charlotte Sound combined model

The Queen Charlotte Sound model which combines the two sets of indices (using Eq. 12) shows a jump between the first two fishing years, followed by no trend for the next four years and an increase in the two most recent fishing years (Figure 36; Table 23).

Table 23. Indices for the Queen Charlotte Sound model by fishing year: simple ratio estimator, binomial, log normal and combined model. Also shown are the proportion of tows with no petrale sole, the mean and CV of 100 bootstrap draws along with the lower and upper 95% bounds from the bootstrap distribution. All indices have been standardised relative to the geometric mean of the series.

Fishing year	Proportion zero tows	Simple ratio (Eq. 6)	Binomial model	Lognormal model	Combined model	Mean bootstrap estimate	Lower bound	Upper bound	Bootstrap CV
96/97	0.763	0.604	0.624	1.024	0.735	0.742	0.671	0.824	0.052
97/98	0.698	0.860	1.017	0.998	1.014	1.011	0.954	1.131	0.039
98/99	0.673	0.732	1.082	0.859	0.909	0.906	0.853	1.005	0.044
99/00	0.668	0.980	1.010	0.811	0.820	0.822	0.745	0.867	0.034
00/01	0.697	1.052	0.944	0.942	0.911	0.911	0.850	0.987	0.040
01/02	0.637	1.950	1.325	1.207	1.451	1.450	1.326	1.540	0.037
02/03	0.659	1.309	1.153	1.236	1.363	1.364	1.266	1.440	0.032

This trend is generally mid-way between the lognormal and binomial series for the same area, with the increasing trend in the binomial series cancelling out the decreasing trends in the lognormal series. As for the WCVI model, there is no trend in the proportion of zero tows (Figure 36; Table 23). The binomial series or the combined series should probably be preferred as an indicator for this species in this fishery over the lognormal series as these latter two series attempt to incorporate signals from the tows which caught no brill.

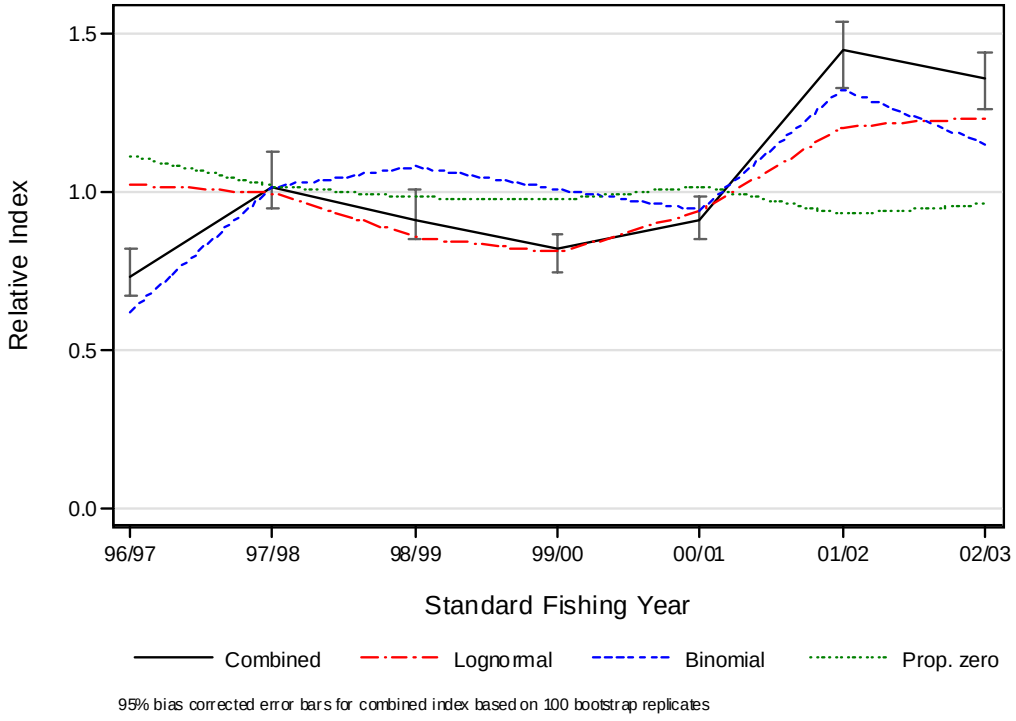

Figure 36. Plot of three indices for the Queen Charlotte Sound GLM model. All indices, including the proportion of tows with no petrale sole, are plotted relative to the geometric mean of the series. Bootstrap error bars are provided for the combined index from 100 bootstrap simulations drawn with replacement from the original dataset.

6.5 HECATE STRAIT MODELS

6.5.1 Hecate Strait lognormal model

Thirty percent of the total deviance was explained by the five explanatory factors selected by the model (Table 24). Unlike for the WCVI and Queen Charlotte Sound where the depthXmonth interaction term was the most important explanator, the depthXmonth interaction term was the penultimate factor selected in the lognormal model for this area. It is preceded by DFO locality and vessel and followed by the "major species in tow" explanator. The low explanatory power of this interaction factor compared to the other models may be a function of the relatively shallow depths which characterise the Hecate Strait fishery and the lack of contrast between different months of the year. Model residuals show good conformity to the lognormal distributional assumption, with little deviation from normality in either tail of the distribution (Figure 37).

The year coefficients show an increasing trend between 1998/99 and 2000/01 and have remained at the new higher level since that fishing year (Figure 38). The DFO localities show a very strong peak in the "South Bonilla" locality and high catch rates in the "North Moresby" and "East Horseshoe" localities (Table 25). These are areas known for good catch rates for petrale sole. The vessel coefficients range between about 0.6 and 1.9 and the larger coefficients are not as well determined as the lower coefficients. The range between the highest and lowest vessel

coefficients in this lognormal model is greater than for the lognormal models in the other two areas. The explanatory variable describing the major species in the tow peaks shows little contrast between the species categories, with only the coefficient for dogfish showing a high but very imprecise peak (Figure 38). The depthXmonth interaction coefficients show the highest catch rates for the middle depth stratum across the late autumn and winter months (250-350 m; Figure 39). As in the other two models, there is a steady and consistent catch rates for petrale sole over all months at the shallowest depth stratum (Figure 39).

Table 24. Final output table for Hecate St. lognormal model with LN(catch/h) as the dependent variable.

Variable order of acceptance	**1**	**2**	**3**	**4**	**5**	**6**
Year	0.039					
DFO Locality	0.181	0.214				
Vessel	0.090	0.109	0.258			
Depth Band X Month	0.078	0.115	0.247	0.289		
Major species in tow	0.042	0.076	0.223	0.269	**0.300**	
DFO Major area	0.019	0.056	0.215	0.261	0.293	0.305
additional deviance explained	0.000	0.175	0.044	0.031	0.011	0.005

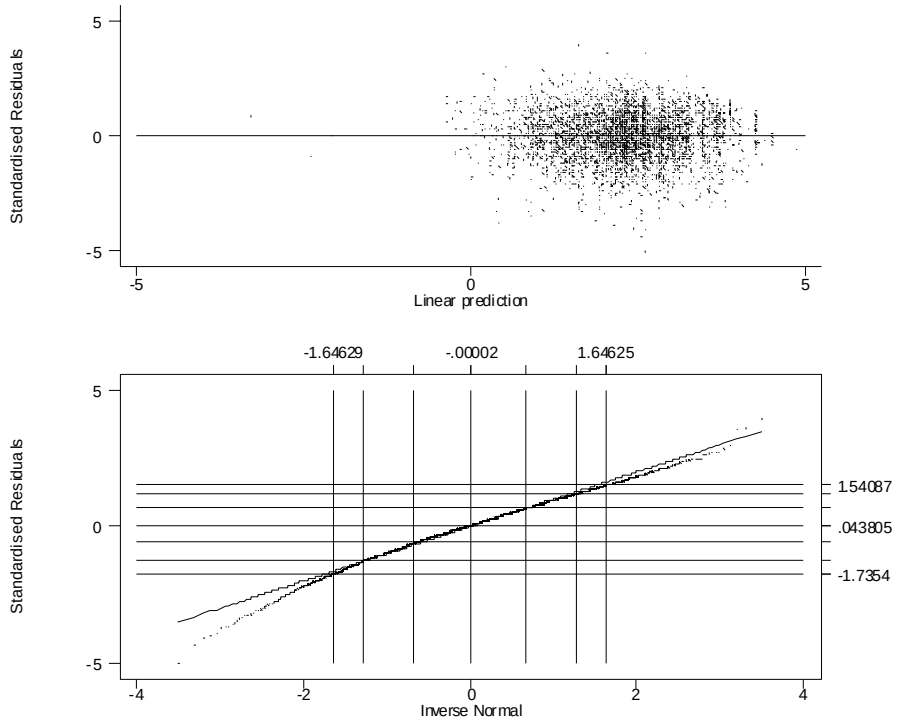

Figure 37. Standardised (Pearson) residuals for the Hecate St. lognormal model with LN(catch/h) as the dependent variable. Grid lines in the lower q-q plot specify the .05, .10, .25, .50, .75, .90, and .95 quantiles.

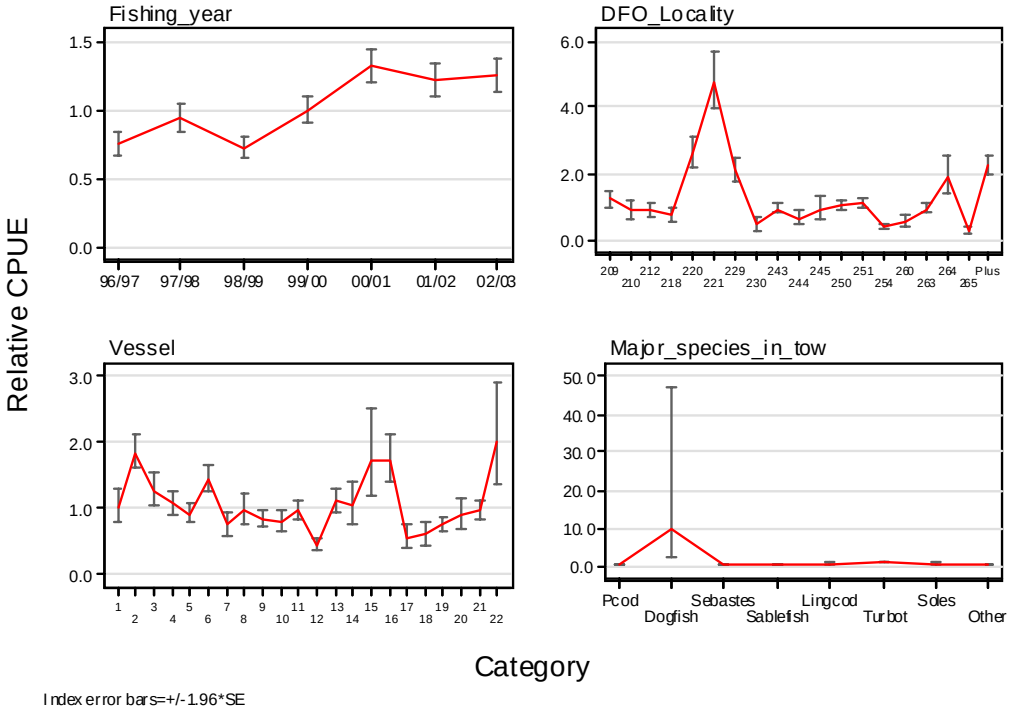

Figure 38. Plots for each categorical variable accepted into the lognormal model for Hecate Strait with LN(catch/h) as the dependent variable. The DFO localities are coded and the codes are named in Table 25. Each vessel is labelled with a non-identifying number. Each index has been divided by the geometric mean of the series.

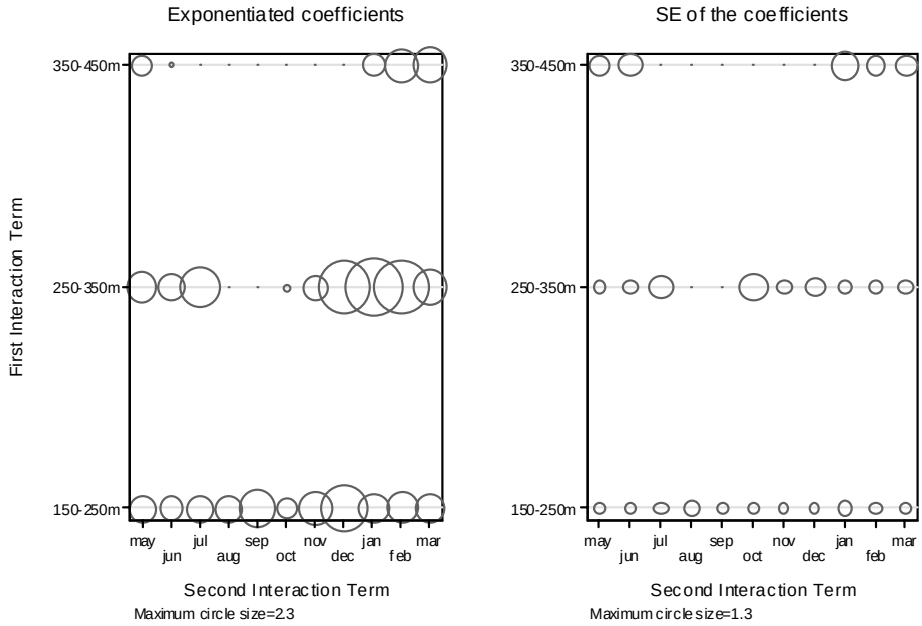

Figure 39. Plot of the exponentiated interaction coefficients and associated standard errors for the lognormal model for Hecate Strait with LN(catch/h) as the dependent variable. Cells with no observations are indicated with a '.'.

Table 25. Names, values, upper and lower bounds and standard errors for the locality codes presented in Figure 38 for the Hecate Strait lognormal model with LN(catch/h) as the dependent variable. The "accumulated group" contains all localities with less than 200 observations over all fishing years.

Code	Name	Index	Upper bound	Lower bound	SE
209	WEST HORSESHOE	1.210	1.485	0.987	0.104
210	OLE SPOT	0.870	1.182	0.639	0.157
212	SOUTH MORSEBY	0.893	1.112	0.716	0.112
218	NW MIDDLE BANK	0.741	0.972	0.564	0.139
220	NORTH MORESBY	2.588	3.069	2.182	0.087
221	SOUTH BONILLA	4.763	5.696	3.983	0.091
229	EAST HORSESHOE	2.090	2.454	1.779	0.082
230	UNKNOWN	0.438	0.714	0.269	0.249
243	MCINTYRE BAY	0.936	1.104	0.794	0.084
244	WEST MASSET	0.642	0.866	0.475	0.153
245	NE LANGARA	0.904	1.350	0.605	0.205
250	BUTTERWORTH	1.028	1.183	0.894	0.072
251	TWO PEAKS	1.109	1.244	0.990	0.058
254	DUNDAS	0.387	0.485	0.309	0.115
260	S OF BARREN ISLAND	0.523	0.737	0.371	0.175
263	WHITE ROCKS	0.932	1.080	0.803	0.076
264	BONILLA	1.912	2.574	1.420	0.152
265	SHELL GROUND	0.256	0.416	0.158	0.247
Plus	ACCUMULATED GROUP	2.224	2.555	1.936	0.071

6.5.2 Hecate Strait binomial model

Twelve percent of the total deviance was explained by the four explanatory factors selected by this model (Table 26). As in the lognormal model for this area, the depthXmonth interaction term was the penultimate factor selected, preceded by DFO locality followed by vessel. Neither the effort polynomial nor the "major species in tow" explanators were selected by this model. Model residuals show some departure from binomial distributional assumption in both the lower and upper 5% of the distribution (Figure 40).

Table 26. Final output table for Hecate St. binomial model with binary success/failure as the dependent variable.

Variable order of acceptance	1	2	3	4	5
Year	0.013				
DFO Locality	0.071	0.085			
Depth Band X Month	0.019	0.032	0.107		
Vessel	0.022	0.032	0.095	**0.116**	
DFO Major area	0.011	0.021	0.088	0.111	0.121
3rd order effort polynomial	0.000	0.013	0.085	0.107	0.116
Major species in tow	0.010	0.020	0.090	0.111	0.120
additional deviance explained	0.000	0.072	0.022	0.009	0.005

The year coefficients show a strong increasing trend from 1998/99, after having no trend in the first three years of the series (Figure 41). The localities with the highest catch rates are the same as in the lognormal model, including the order of importance (Table 27). The vessel coefficients range between about 0.5 and 1.5 and all seem reasonably well determined except the largest coefficient. The range between the highest and lowest vessel coefficients for the binomial model in this area is less than for the lognormal model. There is little pattern in the depthXmonth interaction coefficients, with high coefficients during the summer months at the deepest depth zone and few large coefficients in the winter months (Figure 42).

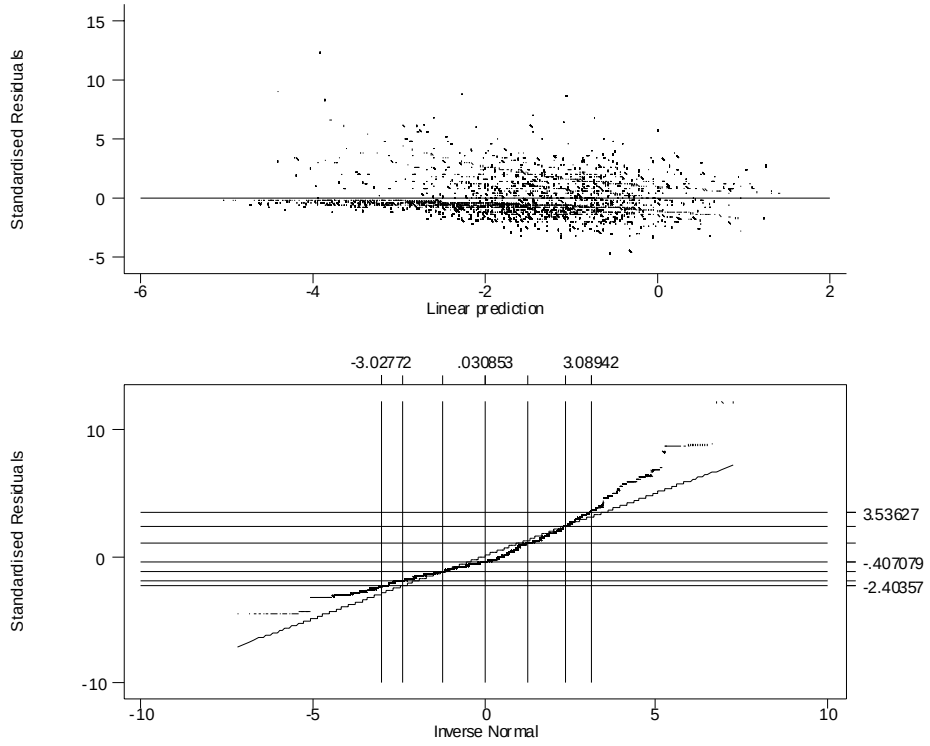

Figure 40. Standardised (Pearson) residuals for the Hecate St. binomial model with binary success/failure as the dependent variable. Grid lines in the lower q-q plot specify the .05, .10, .25, .50, .75, .90, and .95 quantiles.

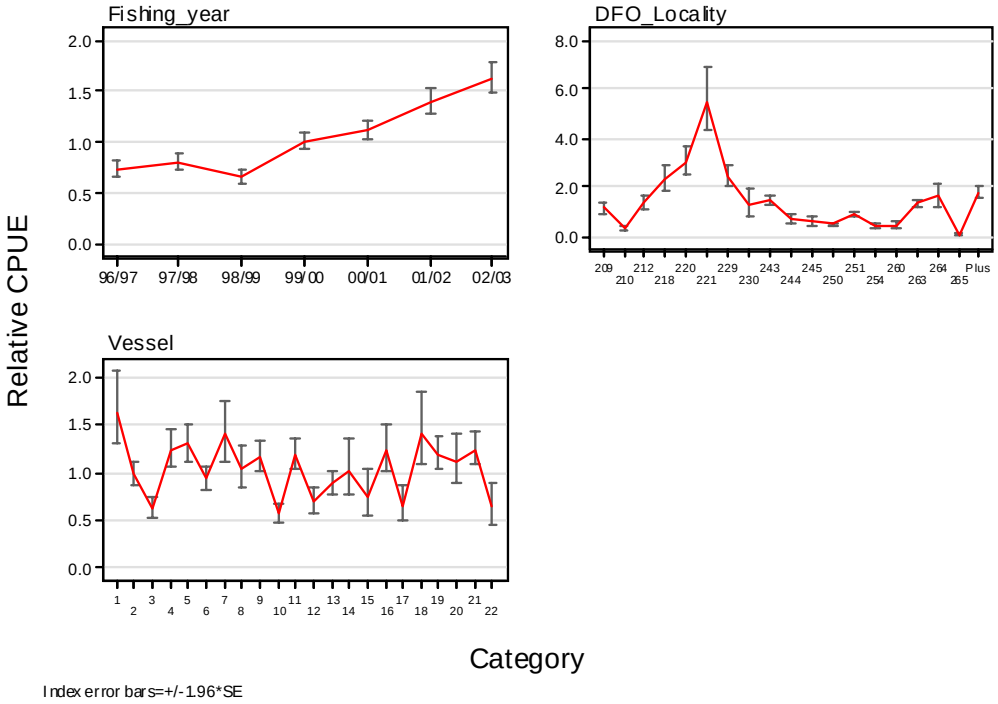

Figure 41. Plots for each categorical variable accepted in the Hecate Strait binomial model with binary success/failure as the dependent variable. The DFO localities are coded and presented in Table 27. Each vessel is labelled with a non-identifying number. Each index has been divided by the geometric mean of the series.

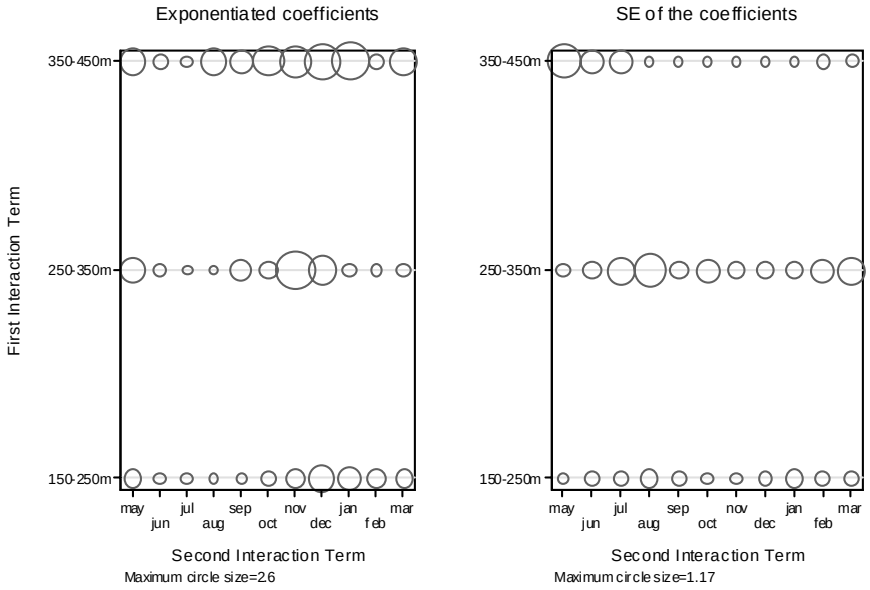

Figure 42. Plot of the exponentiated interaction coefficients and associated standard errors for the Hecate Strait binomial model with binary success/failure as the dependent variable. Cells with no observations are indicated with a '.'.

Table 27. Names, values, upper and lower bounds and standard errors for the locality codes presented in Figure 41 for the Hecate Strait binomial model with binary success/failure as the dependent variable. The "accumulated group" contains all localities with less than 200 observations over all fishing years.

Code	Name	Index	Upper bound	Lower bound	SE
209	WEST HORSESHOE	1.148	1.387	0.949	0.097
210	OLE SPOT	0.339	0.438	0.262	0.131
212	SOUTH MORSEBY	1.355	1.622	1.132	0.092
218	NW MIDDLE BANK	2.358	2.931	1.897	0.111
220	NORTH MORESBY	3.027	3.622	2.530	0.092
221	SOUTH BONILLA	5.515	6.919	4.395	0.116
229	EAST HORSESHOE	2.446	2.877	2.080	0.083
230	UNKNOWN	1.285	1.941	0.850	0.211
243	MCINTYRE BAY	1.465	1.707	1.257	0.078
244	WEST MASSET	0.722	0.943	0.553	0.136
245	NE LANGARA	0.612	0.853	0.439	0.169
250	BUTTERWORTH	0.503	0.565	0.447	0.059
251	TWO PEAKS	0.881	0.968	0.802	0.048
254	DUNDAS	0.434	0.521	0.362	0.093
260	S OF BARREN ISLAND	0.447	0.596	0.335	0.147
263	WHITE ROCKS	1.342	1.532	1.175	0.068
264	BONILLA	1.639	2.180	1.232	0.145
265	SHELL GROUND	0.071	0.105	0.049	0.195
Plus	ACCUMULATED GROUP	1.757	2.004	1.540	0.067

6.5.3 Hecate Strait combined model

The Hecate Strait combined model (Eq. 12) resembles the year indices for the binomial model in the same area, with a flat trend in the first three fishing years, followed by an increasing trend in the four most recent fishing years (Figure 43; Table 28). As in the other two models, there is no trend in the proportion of zero tows over this period (Figure 43; Table 28). The increasing trend in this index is mirrored over the same period in the biomass indices for petrale sole derived from the Hecate St. assemblage survey (Figure 13).

Table 28. Indices for the Hecate Strait model by fishing year: simple ratio estimator, binomial, log normal and combined model. Also shown are the proportion of tows with no petrale sole, the mean and CV of 100 bootstrap draws along with the lower and upper 95% bounds from the bootstrap distribution. All indices have been standardised relative to the geometric mean of the series.

Fishing year	Proportion zero tows	Simple ratio (Eq. 6)	Binomial model	Lognormal model	Combined model	Mean bootstrap estimate	Lower bound	Upper bound	Bootstrap CV
96/97	0.822	0.507	0.735	0.753	0.594	0.593	0.518	0.708	0.081
97/98	0.809	0.754	0.804	0.940	0.798	0.798	0.721	0.993	0.077
98/99	0.854	0.462	0.661	0.717	0.518	0.519	0.458	0.594	0.076
99/00	0.781	1.178	1.009	0.992	1.008	1.013	0.879	1.102	0.057
00/01	0.767	1.444	1.112	1.320	1.445	1.438	1.269	1.633	0.061
01/02	0.746	1.480	1.404	1.209	1.568	1.586	1.304	1.715	0.057
02/03	0.700	2.252	1.624	1.244	1.784	1.791	1.602	1.965	0.058

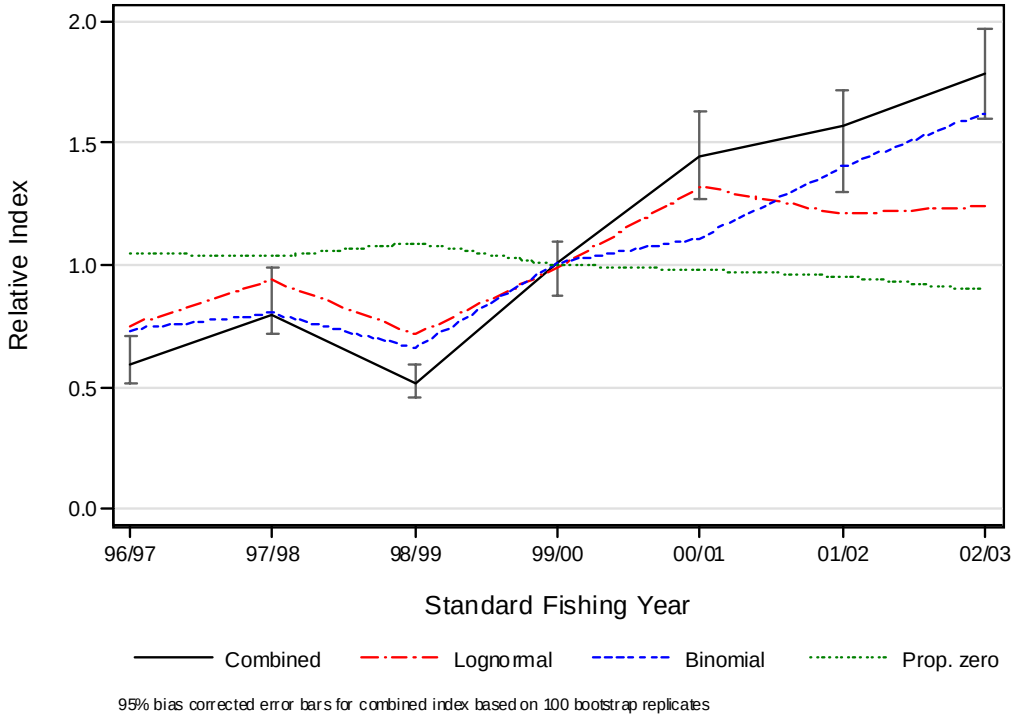

Figure 43. Plot of three indices for the Hecate Strait GLM model. All indices, including the proportion of tows with no petrale sole, are plotted relative to the geometric mean of the series. Bootstrap error bars are provided for the combined index from 100 bootstrap simulations drawn with replacement from the original dataset.

6.6 DISCUSSION: CATCH/EFFORT GLM MODELS FOR PETRALE SOLE

A comparison of the combined annual indices for each of the three models considered in this section shows good agreement over all three analyses (Figure 44). All three analyses show a period of no trend from 1996/97 to 1998/99, followed by an increasing trend in the last three to four years of the series. The upturn seems to have occurred soonest and is strongest in the Hecate Strait area and is later and less pronounced in the WCVI and Queen Charlotte Sound areas (Figure 44).

The three analyses show consistency in other ways as well. All show little trend in the proportion of zero catches over the seven fishing years. The explanatory power and conformity of the model to the distributional assumptions seem to be consistent among the three lognormal model. The explanatory power of the binomial models is similar but lower in the three binomial models. All three binomial models show some departure from the binomial distributional assumption at the upper tail of the residual distribution. All models select plausible areas for high catch rates or high probability of success. The distribution of the interaction coefficients are plausible given what is known about these fisheries.

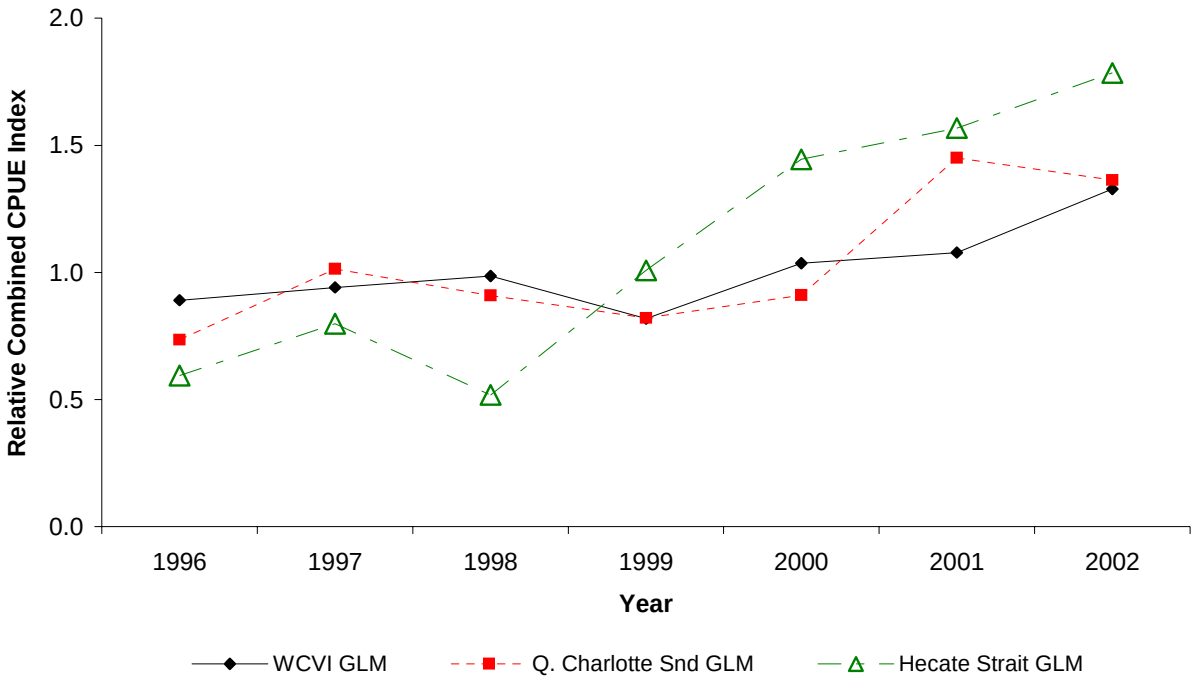

Figure 44. Comparison of the combined annual indices from the WCVI, Queen Charlotte Snd and Hecate St. GLM analyses. All indices have been standardised to the geometric mean of the entire series.

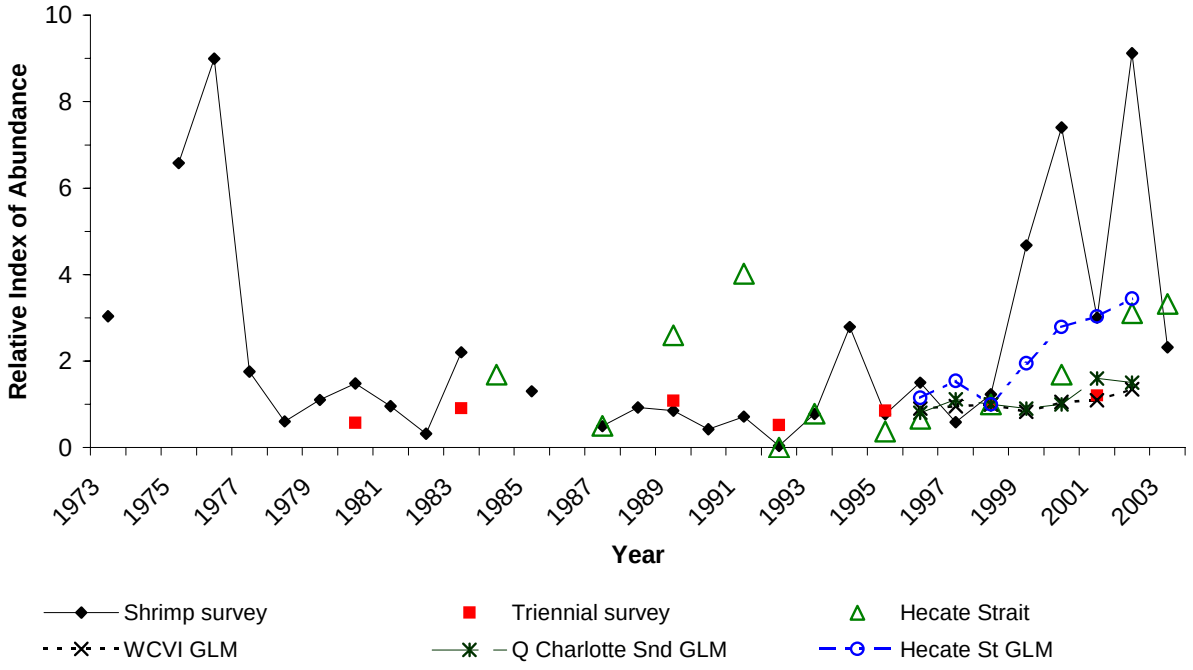

Figure 45. Comparison of the three sets of abundance indices for petrale sole based on time series of trawl survey indices with the three sets of annual combined abundance indices derived from the GLM analysis of DFO catch and effort data. All series are standardised relative to the value obtained for 1998/99.

All models show an increasing trend in the last three to four years. This is consistent with the results from the three available trawl surveys, all of which indicate an increase over the same recent period (Figure 45). It should be emphasised that these increasing trends in standardised CPUE are estimates of the response of the fishery to a range of factors, only one of which is the change in the abundance of petrale sole. It is notable that the increases estimated by the trawl surveys tend to be larger than those estimated from the CPUE analyses. This is consistent with the hypothesis that the fisheries have been constrained by management, particularly TAC caps, thus attenuating the response of the CPUE indices to any increases in abundance. It would be surprising if the fishery CPUE did not respond positively to a general trend of increasing abundance. However, other factors, such as a TAC or economic considerations, will also affect the CPUE and preclude its interpretation as a strict indicator of abundance change.

7.0 DELAY-DIFFERENCE ASSESSMENT MODEL FOR PETRALE SOLE

A delay-difference assessment model similar to the models used by Sinclair et al. (2001) and Starr et al. (2002) to assess Canadian west coast pacific cod was used to assess the petrale sole stock. This assessment treated the stock of petrale sole as a single stock, including all the major fishing areas on the Canadian west coast but excluding the west coast of the Queen Charlotte Islands. While this stock definition is large and may not be correct, this definition was used as a first approximation which allowed all the available data to be used and was also based on the fact that the total coastwide catches for this species are not large and there would probably be sample size issues when going to a more restricted stock definition.

The model dynamics and likelihoods are very similar to those presented in Sinclair et al. (2001) and Starr et al. (2002), with the exception that a Beverton-Holt stock-recruitment function was used instead of the Ricker recruitment function used in the previous analyses. Likelihood terms were added to this current model so that the three sets of survey data described in this paper could be used in the estimation: the NFMS triennial, the WCVI shrimp and the Hecate St. assemblage surveys (Appendix 2). The model was also fitted to a set of annual weight data derived from data for petrale sole contained in the DFO GFBio database. Similar to the previous pacific cod models, this model estimated the catch data using an effort series calculated from a CPUE index.

7.1 MODEL DATA

7.1.1 Biological inputs

Length-weight parameters are available for male and female petrale sole (Section 5.1). These were interpolated to provide an average length-weight relationship for combined males and females because the assessment model is a single sex model (Figure 46). Similarly, an interpolated average von-Bertalanffy growth model was estimated based on the sex-specific growth models, using fully recruited fish at age four and older (Figure 46). Finally, the von-Bertalanffy growth function was made into a Walford plot by converting the deterministic lengths at age into the equivalent weights using the length-weight parameters. The line was then fitted to estimate the slope and intercept parameters which are key inputs into the delay-difference model (Appendix 2).

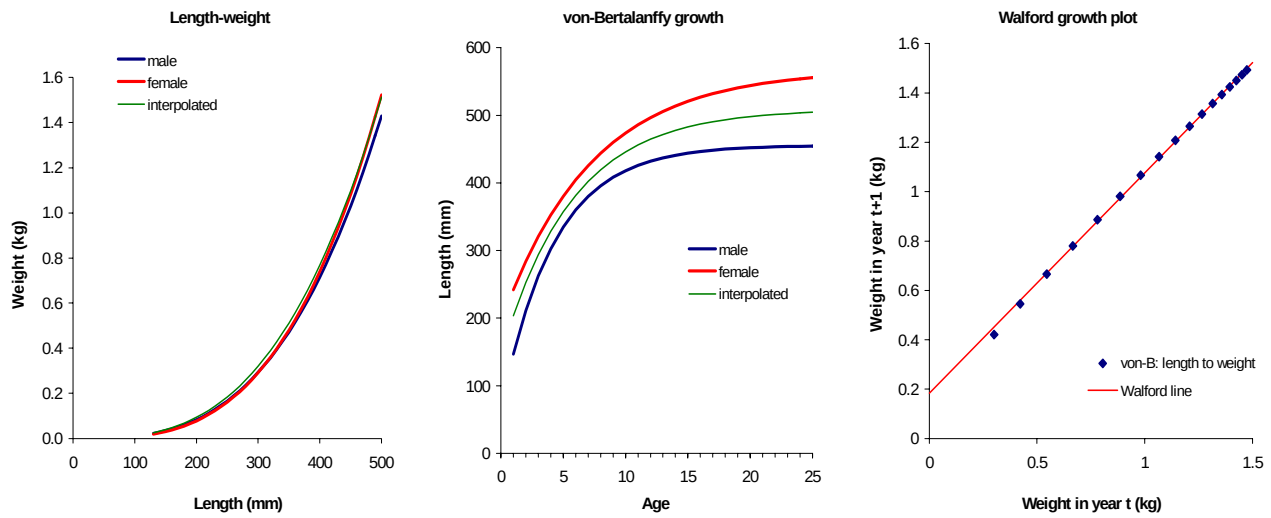

Figure 46. Plots of biological inputs to the petrale sole delay-difference model. Male and female functions were averaged to provide growth and length-weight relationships which would be appropriate inputs for a combined sex model. The Walford growth function was estimated by converting the deterministic lengths at age from the von-Bertalanffy growth function into weights and then fitting the linear parameters. Both growth functions are for fully recruited fish at age 4 and older.

7.1.2 Fishery data inputs

7.1.2.1 Fishery weight data

All available length data in the DFO GFBio database for petrale sole were extracted by year and sex without reference to the location of capture because virtually all the data come from the west coast (Table 29). A sex-weighted average for each fishing year was calculated using the sex ratio in the data. Lengths for fish of unknown sex were apportioned to each sex based on the sex ratio of known sex fish. One of the years (1984/85) had no fish lengths with known sex. A mean unweighted sex ratio for all the other years combined was used to estimate the sex ratio for 1984/85. Although these mean weights are not properly scaled to the fishery catch, there is a reasonable consistency across the years in the mean weight values. Also it is unlikely that the samples were collected sufficiently broadly that a better estimate would be obtained through stratifying the data.

Table 29. Summary of available length data for petrale sole by fishing year, arranged by sex or by major DFO area of capture. Also shown are the estimated mean weights by year used as inputs to the model. NA: no data.

Fishing	Mean	DFO Major Area							No.	No.	No.	Prop.	Total
year	weight (kg)	3C	3D	5A	5B	5C	5D	5E	male	female	unknwn	male	length
79/80	1.038	333	299						171	461		0.271	632
80/81	0.871	900	300						811	388	1	0.676	1,200
81/82	1.282			299		3	11	299	337	270	5	0.555	612
82/83	0.844	274							206	68		0.752	274
83/84	0.983	300			300				440	160		0.733	600
84/85	0.870					195	73				268	0.521	268
85/86	1.296	300							118	182		0.393	300
86/87	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
87/88	1.026	314			388	61	16		565	137	77	0.805	779
88/89	1.008	300							206	94		0.687	300
89/90	1.010	357			49	241	227	172	406	399	241	0.504	1,046
90/91	1.182	146	51		100			43	101	239		0.297	340
91/92	1.195	51				312	20		40	42	301	0.488	383
92/93	1.203	49				24			25	48		0.342	73
93/94	0.872	38			56	102	39	37	66	110	96	0.375	272
94/95	0.912	56			146				160	42		0.792	202
95/96	1.027							41	22	19		0.537	41
96/97	0.914	49				27		47	57	39	27	0.594	123
97/98	0.866	178	469		187			1	79	68	688	0.537	835
98/99	0.875	651	543			40	35	304	162	154	1,257	0.513	1,573
99/00	0.956	159		8	351			39	54	65	438	0.454	557
00/01	0.896	421	488		510	304	77	192	131	279	1,582	0.320	1,992
01/02	0.677	40	214		93	18	120		110	126	249	0.466	485
02/03	0.821	211			169	225	149		198	345	211	0.365	754
Total or Average	0.951	5,127	2,364	307	2,349	1,552	767	1,175	4,465	3,735	5,441	0.506	13,641

7.1.2.2 Fishery catch and effort data

All catches (Table 1) assigned to petrale sole from the DFO GFCatch and the PacHarvest databases were extracted by a 1 April to 31 March fishing year for the all the major west coast DFO reporting regions (Major areas 3C, 3D, 5A, 5B, 5C and 5D), with the exception of the west coast of the Queen Charlottes (Major area 5E). This extraction was done without reference to the qualification of the data as these catches were to be used as an absolute measure of the total mortalities for this species. The average level of discards (Table 2) was estimated to be 7% of the total landed catch for the period 1996 to 2003. Landed catches prior to 1996 were increased by this percentage to account for discarding prior to the initiation of the observer programme.

A second extract of the petrale sole data was then performed based on the following qualifications:

a. Major DFO areas 3C, 3D, 5A, 5B, 5C and 5D;

b. Bottom trawl gear only;

c. Success codes 0 and 1;

d. Depth range from 50 m to 500 m;

e. Hours fished >0 and <24 and not NULL;

f. No tows where the total catch (all species) is 0 or NULL.

This extract was used to calculate a simple CPUE vector by 1 April/31 March fishing year for petrale sole which was then applied to the total catches taken in the first extract to calculate a nominal level of fishing effort (Figure 47). A catch of 500 t was assumed for the current (2003/04) fishing year so that a beginning year biomass could be estimated for 2004/05. This is required so that one year projections can be made into 2004/05. This amount of catch is equivalent to level of removals (landed catch plus discards) taken in 2002/03, the most recent fishing year with complete data.

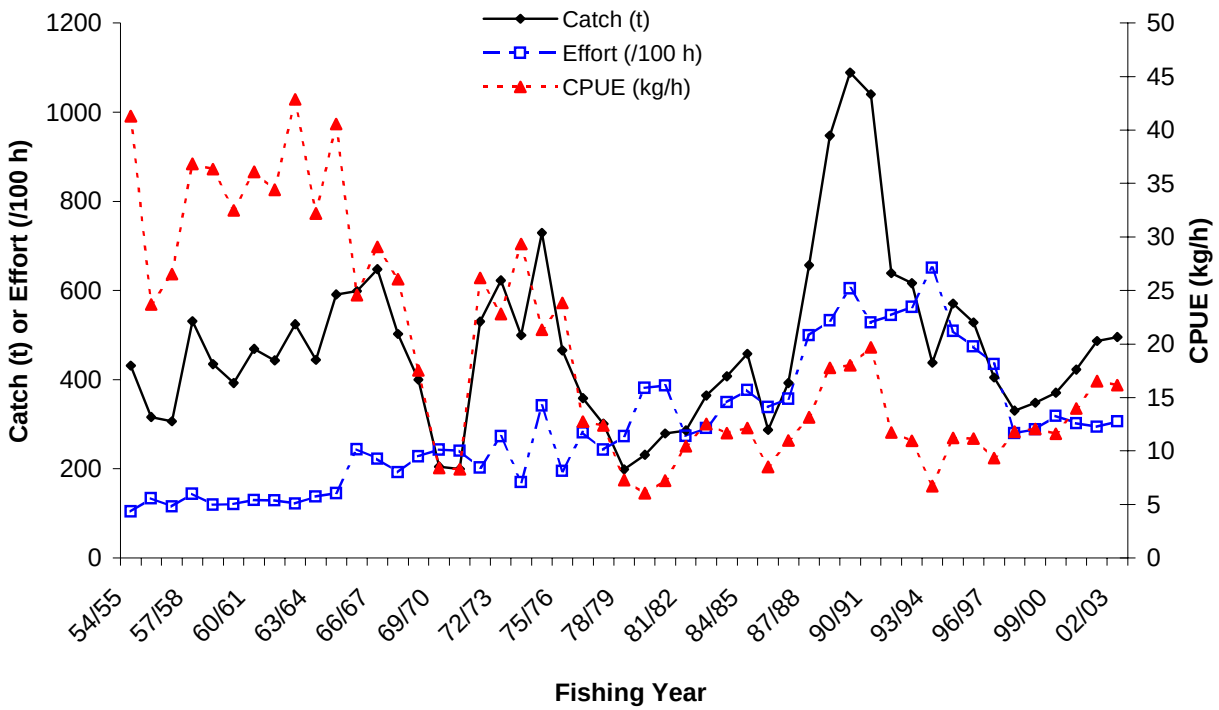

Figure 47. Plot of catch (t), effort (in 100's of hours) and CPUE (kg/h) used as inputs into the petrale sole assessment model. Catch was summed without qualification and effort was estimated from a qualified CPUE summary as described in the text.

7.1.2.3 Survey data

Each series of survey data (NFMS triennial survey: Table 5; WCVI shrimp survey: Table 9; Hecate St. survey: Table 11) was used as a data time series in the model. Both the biomass indices and the associated CVs were used as model inputs.

7.1.2.4 Data weighting

The relative weighting between the five available data sets data sets was made based on achieving a standard deviation equal to 1.0 for the standardised (Pearson) residuals associated with each data set. This criterion is based on the observation that the model distributional assumptions (in this case based on a lognormal error structure) for any set of data are satisfied when the standard deviation of the standardised residuals is equal to 1.0 (RICC Francis, *pers. comm.*; V. Haist, *pers. comm.*). A similar criterion is that the median of the absolute value of the standardised residuals should be about 0.6 if the residuals are normally distributed. Achieving a realistic weighting based on objective criteria is essential for a model which has a range data sources. This operation was done by iteratively running the model with trial CVs for each dataset and then adjusting each dataset by raising or lowering the CV until the desired outcome was achieved. The CVs for each of the survey data sets were increased by adding process error, as suggested by Francis et al. (2001). Appendix 2 describes this procedure.

7.2 MODEL RESULTS

Model parameter estimates are very similar for the "all data" run and the runs which successively dropped one of the three sets of survey data (Runs A, D, E & F; Table 30). Run C, which dropped the weight data, had to have the instantaneous natural mortality (*M*) fixed at a value of 0.2 because the model could not find a fit at a credible value for this parameter. This run estimates a substantially lower B_0 than for the other runs. Run B is the same as Run A, except that *M* was fixed at 0.2. This was done to see the effect of fixing this parameter on the run which included all the data. One effect is to lower the estimate of B_0 compared to Runs A, D, E and F, but not nearly to as low a level as for Run C (Table 30).

Table 30. Results for six model runs: A) all five data sets with most parameters estimated except for the stock-recruitment steepness (*h*) and the initial biomass ratio (γ); B) same as Run A except that *M* is fixed at 0.20; C) to F) successively drop the weight data or one of the three sets of survey data. *M* was fixed for Run C and q_c in Run B was constrained to be no lower than the q_c estimated for Run A. All other runs are comparable to Run A. All biomass levels are expressed as beginning year. Catches are by fishing year (*fyear*) as presented in Table 1. The standard deviations for the three surveys in this table are the average of the combined observation and process error CVs over all years of data. NC: none of the investigated catches caused B_{2005} to go below B_{MSY} or F_{2004} to go below F_{MSY}.

RUN	A All data	B All data/No weight /M M fixed	C fixed	D No triennial survey	E No shrimp survey	F No Hecate St survey
Parameters						
γ (B_1/B_0)	1.000	1.000	1.000	1.000	1.000	1.000
B_0 (unfished equilibrium biomass)	52242	44042	12602	49541	50922	52473
M (instantaneous natural mortality)	0.108	0.200	0.200	0.107	0.107	0.108
q_c (catchability for fit to catch data)	8.325E-07	8.325E-07	4.663E-06	8.924E-07	8.597E-07	8.222E-07
q_t (catchability for fit to triennial survey)	0.059	0.059	0.303	0.000	0.061	0.058
q_s (catchability for fit to shrimp survey)	0.005	0.004	0.024	0.005	0.000	0.004
q_h (catchability for fit to Hecate St. survey)	0.027	0.027	0.138	0.030	0.028	0.000
h (Beverton-Holt steepness)	0.750	0.750	0.750	0.750	0.750	0.750
Standard deviations						
Weight	0.11	0.13	0.00	0.12	0.11	0.11
Catch	0.35	0.33	0.25	0.35	0.35	0.35
Triennial survey	0.28	0.25	0.20	0.00	0.28	0.28
Shrimp trawl	1.04	1.04	1.04	1.04	0.00	1.04
Hecate St survey	0.73	0.73	0.73	0.73	0.73	0.00
ϕ_t	0.60	0.60	0.60	0.60	0.60	0.60
Likelihoods						
Weight	-17.558	8.022	0.000	-16.735	-17.310	-17.315
Catch	18.081	14.023	3.723	18.383	18.177	18.089
Triennial survey	0.457	0.054	-2.745	0.000	0.563	0.487
Shrimp trawl	38.889	38.734	38.518	39.052	0.000	39.017
Hecate St survey	11.651	11.748	11.164	11.730	11.781	0.000
ϕ_t	27.878	29.034	34.467	26.364	27.167	27.405
Total likelihood	79.398	101.615	85.127	78.794	40.378	67.683
Sum: observed catch	23,230	23,230	23,230	23,230	23,230	23,230
Sum: predicted catch	22,137	22,120	22,235	22,133	22,164	22,143

RUN	A All data	B All data/No weight /M M fixed	C fixed	D No triennial survey	E No shrimp survey	F No Hecate St survey
Derived Parameters						
F_{msy}	0.110	0.199	0.199	0.109	0.109	0.110
B_{msy}	16155	13747	3934	15383	15748	16294
F_{crash}	0.516	1.191	1.191	0.513	0.511	0.519
B_{2003}/B_{MSY}	127%	144%	101%	117%	121%	123%
$Catch_{2004}$: $B_{2005}/B_{2004}<1$	600	250	450	600	600	600
$Catch_{2004}$: $B_{2005}/B_{MSY}<1$	NC	NC	400	NC	NC	NC
$Catch_{2004}$: $F_{2004}/F_{MSY}<1$	2050	NC	650	1800	1900	2050
Residuals						
SD_weight data	1.0387	0.9385	0.0000	0.9884	1.0517	1.0508
SD_catch data	1.0102	0.9857	1.0532	1.0165	1.0122	1.0104
SD_triennial survey data	0.9975	1.0448	0.8335	0.0000	1.0153	1.0025
SD_shrimp trawl survey data	1.0018	0.9958	0.9874	1.0080	0.0000	1.0067
SD_Hecate St. trawl survey data	1.0096	1.0192	0.9602	1.0174	1.0223	0.0000
Median_absolute(weight resids)	0.5677	1.3429	0.0000	0.5375	0.4951	0.5138
Median_absolute(catch resids)	0.6365	0.5768	0.5000	0.6174	0.6447	0.6360
Median_absolute(triennial index resids)	0.7176	0.7600	0.6169	0.0000	0.7493	0.7145
Median_absolute(shrimp index resids)	0.5268	0.4628	0.5575	0.5230	0.0000	0.5435
Median_absolute(Hecate St. index resids)	0.9638	0.9583	0.7466	1.0128	1.0163	0.0000

The initial biomass ratio parameter (γ) was not estimated in any of the runs because it was felt that there is little information in the data to determine this parameter and preliminary fits indicated that it never moved very far from the initial value set at 1.0. The Beverton-Holt steepness parameter (h) also was not estimated because past experience has shown that fisheries data typically hold little information for determining stock-recruitment parameters. The fixed value selected for this parameter is an intermediate value that has been used for less productive stocks (e.g. NZ orange roughy; Francis 1992).

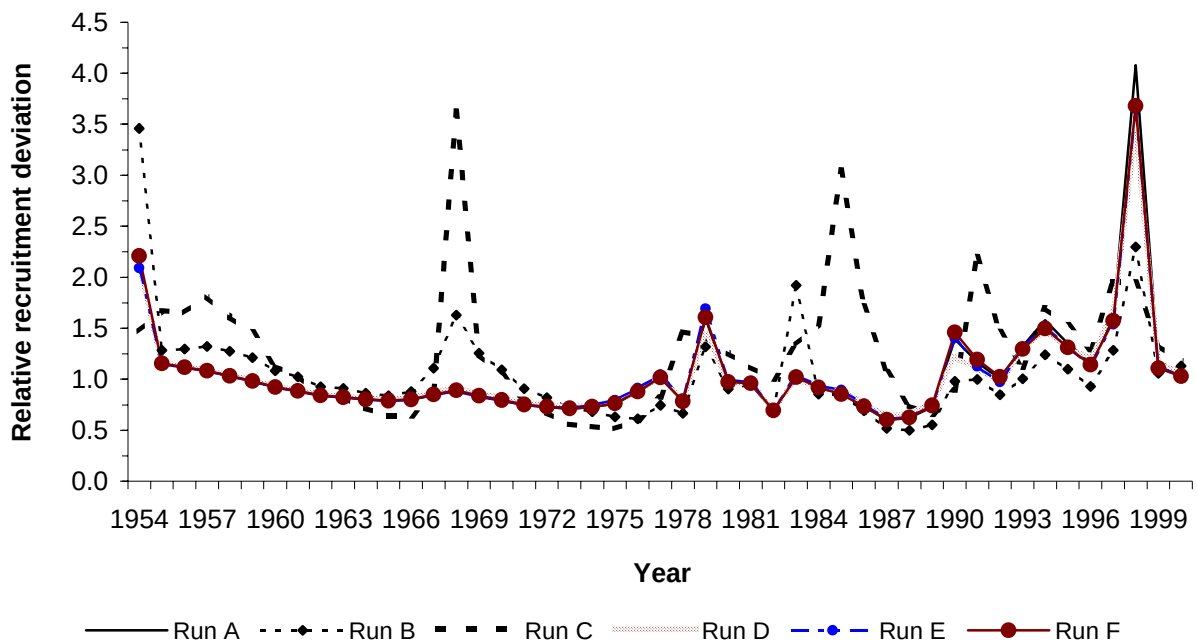

Figure 48. Comparison of the estimated recruitment deviations for the six model runs presented in Table 30.

A comparison of the estimated recruitment deviations shows very few differences among the four runs which estimated *M* (Runs A, D, E & F; Figure 48). The runs with fixed *M*=0.2 estimated some large recruitment anomalies in the mid-1960s, the mid-1980s and in the early 1990s which were not present in the other four runs (Figure 48). This could be because these runs have lower B_0 estimates and some extra biomass is required to cover increased catch levels in the following years. All six runs estimate a large recruitment deviation in 1998, although it is smaller for the two fixed M runs. The contrasting population trajectories for Runs A and C each show a declining biomass trend from the beginning of the simulation to early 1990s, after which both model runs show a gradually increasing biomass trend (Figure 49 and Figure 50)

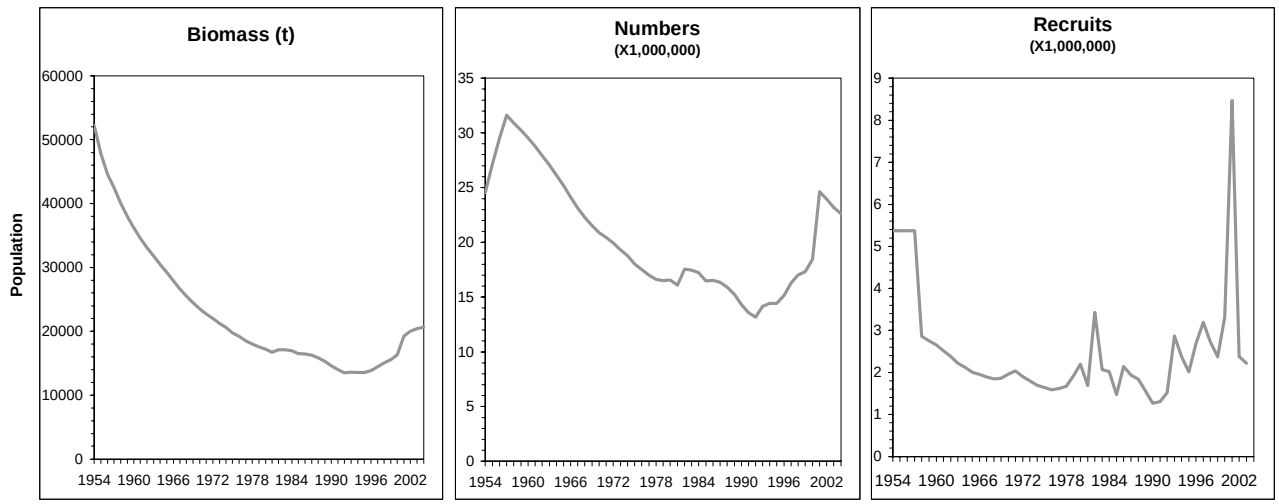

Figure 49. Population (total biomass, numbers, and number of recruits) trends for model Run A (Table 30).

The fits to the data are reasonable for both Run A (Figure 51) and Run C (Figure 52). Run C did not attempt to fit to the weight data and consequently had a very poor fit to these data (Figure 52). The contrast between these plots indicates that it is likely that the weight data are giving the primary signal for requiring a larger overall biomass level for this stock, because it is clear from Figure 52 that reasonable fits can be obtained to the other four data sets at lower B_0 estimates. Arguably the fit to the catch data appears to be better for Run C (Figure 52), although the total amount of catch explained by all six models is approximately the same (Table 30). The strong difference in the stock size estimates between Run A and Run C is evident in the trajectory of annual harvest rates for each assessment (Figure 53). It is notable that neither assessment indicates that the harvest rates have ever been very high, even for Run C which estimates much lower overall levels of biomass.

Model diagnostics are reasonable, with the standard deviations of the standardised residuals close to 1.0 for practically all the data sets in every run (Table 30). Most of the data sets also had median values for the absolute value of the standardised residuals between 0.5 and 0.7 (Table 30). These results indicate that the model fits generally conformed to the log-normal distributional assumptions and that it was possible to adopt a "natural" weighting between the various data sets while also obtaining reasonable fits to the data. Plots of the standardised residuals against the predicted values for each of the data sets in Run A (Figure 54) and in Run C (Figure 55) do not show any strong trends in the fits to the data across time or predicted value for either of the runs. One exception to this generalisation is that model underestimates the large

observed values at the beginning and end of the shrimp survey data set in both runs (Figure 51 and Figure 52). Quantile-normal plots which test the conformity of the standardised residuals to a normal distribution show reasonable fits to the normal distribution for all data sets in Run A (Figure 56) and Run C (Figure 57), with the possible exception of the catch data set which shows some departure from normality in the low tail in both runs.

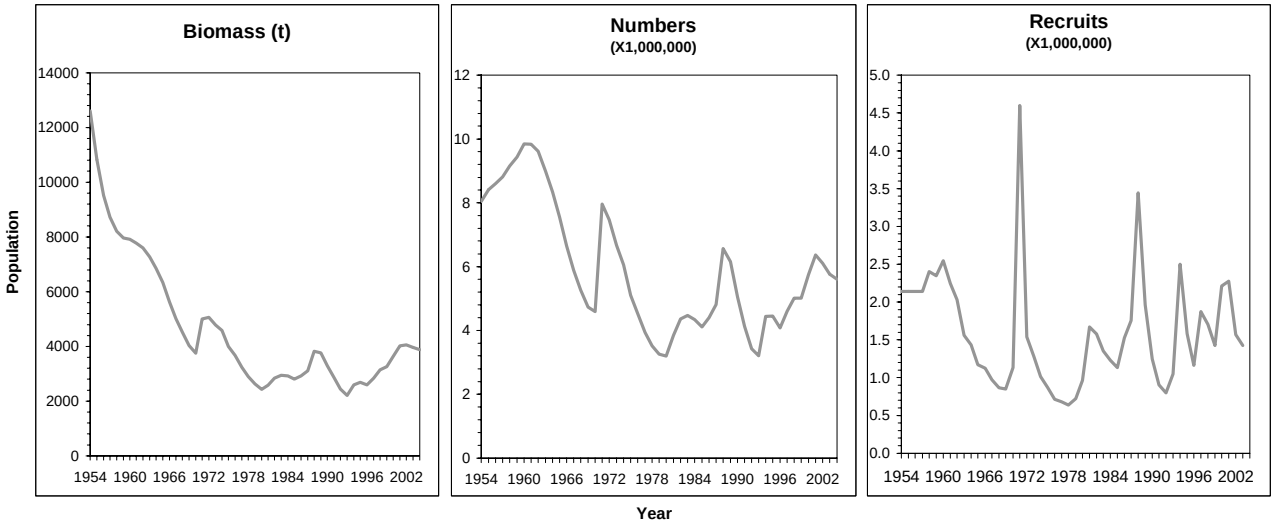

Figure 50. Population (total biomass, numbers, and number of recruits) trends for model Run C (Table 30).

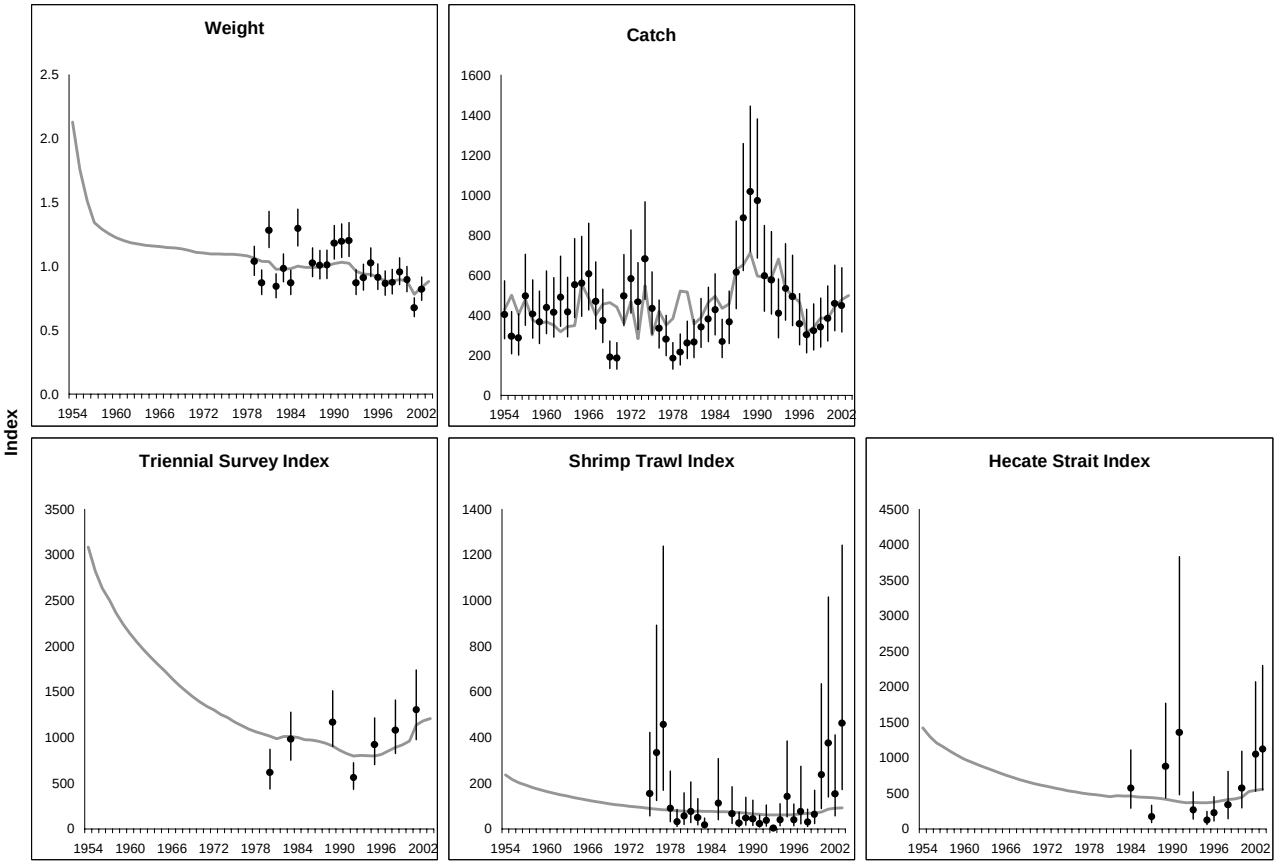

Figure 51. Model fits to the observed data for model Run A (Table 30).

Model predictions of reference points of management interest were made over a wide range of catch levels by estimating the F required to take each catch from the beginning year biomass for 2004/05. All runs made reasonably optimistic reference point predictions, with all six runs indicating that the current biomass levels are above B_{MSY} (Table 30). Five of the six runs indicate that all of the investigated catch levels (up to 2500 t) will allow the stock to remain above B_{MSY}. Four of these five runs indicate that F_{MSY} will only be exceeded at catches greater than 1800 t and the fifth (with a higher M) will not exceed F_{MSY} even at a catch of 2500 t. Therefore, Runs A, D, E and F are all quite optimistic, with catches up to about 600 t allowing the stock size to increase. Run B indicates the stock size is expected to decrease after catches exceed 250 t, but the stock is predicted to stay above B_{MSY} and F_{MSY}. The one exception to these optimistic predictions is the run which omits the weight data and has a fixed estimate for M=0.2. This run also estimates that the current stock size is slightly above B_{MSY}, but, unlike the other runs, this run predicts that the stock size will go below B_{MSY} at a catch level of 400 t and below F_{MSY} at a catch level of 650 t (Table 30).

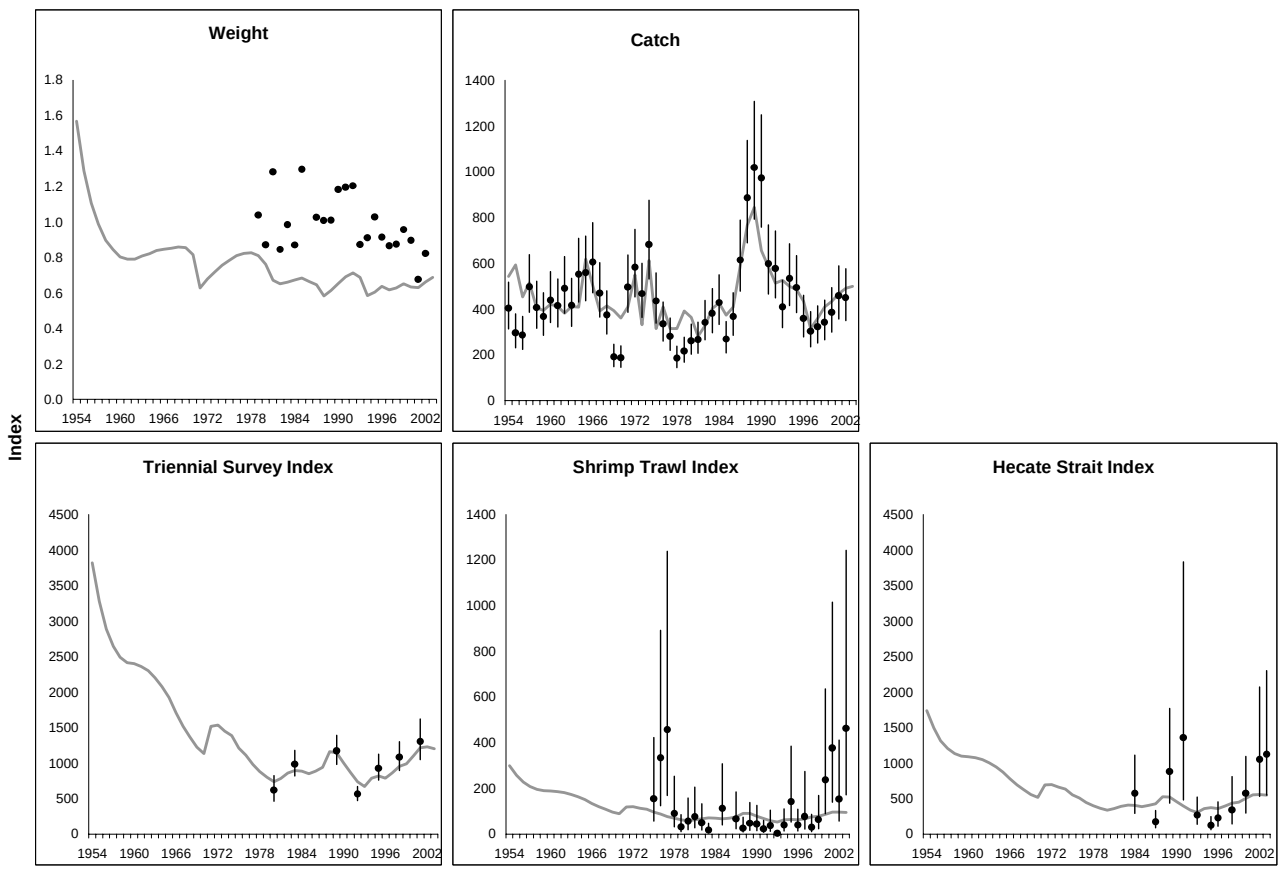

Figure 52. Model fits to the observed data for model Run C (Table 30).

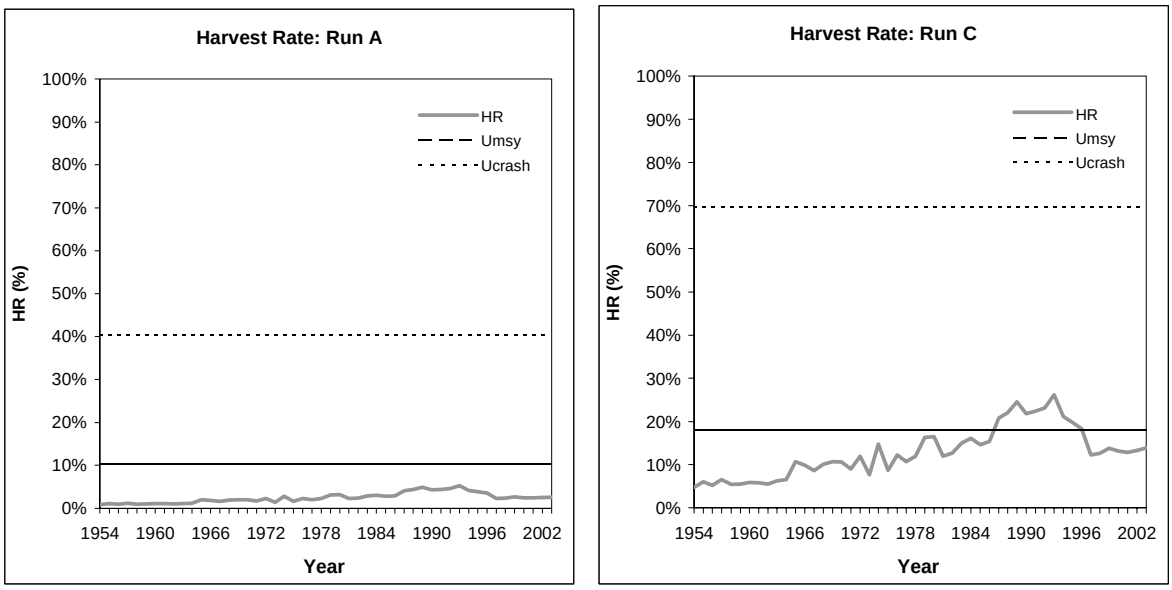

Figure 53. Comparison of annual harvest rates and management targets for Runs A and C (Table 30).

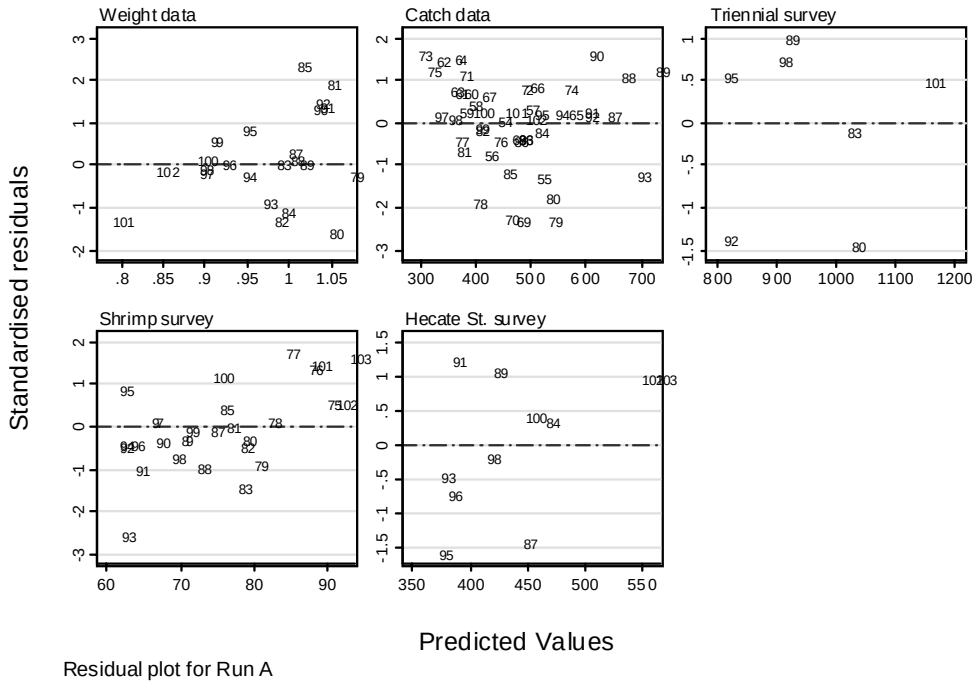

Figure 54. Plot of standardised residuals against predicted values for model Run A (Table 30). The last digits of the year associated with each data point are used as the plotting symbol.

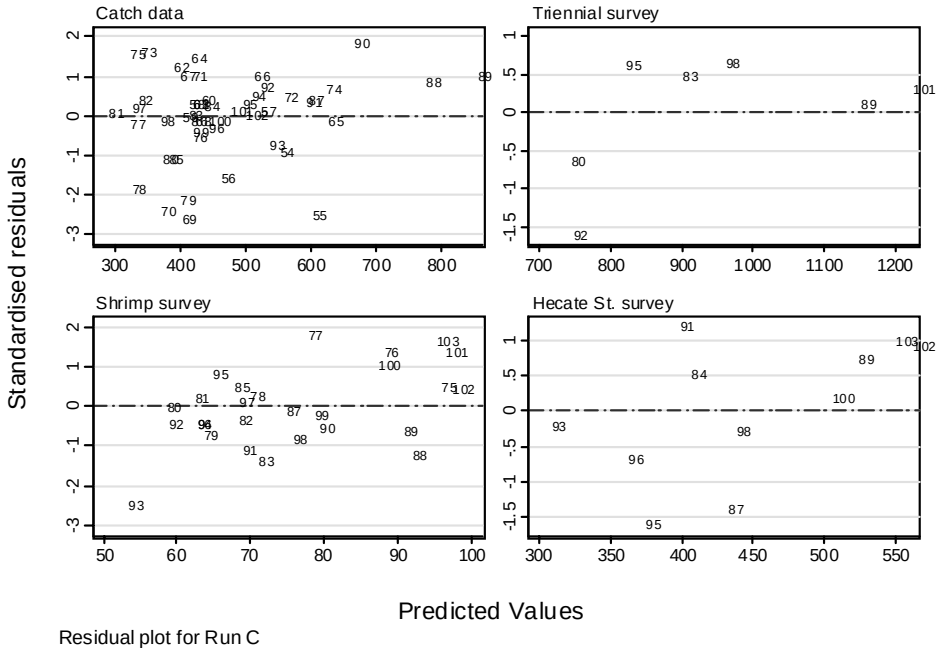

Figure 55. Plot of standardised residuals against predicted values for model Run C (Table 30). The last digits of the year associated with each data point are used as the plotting symbol.

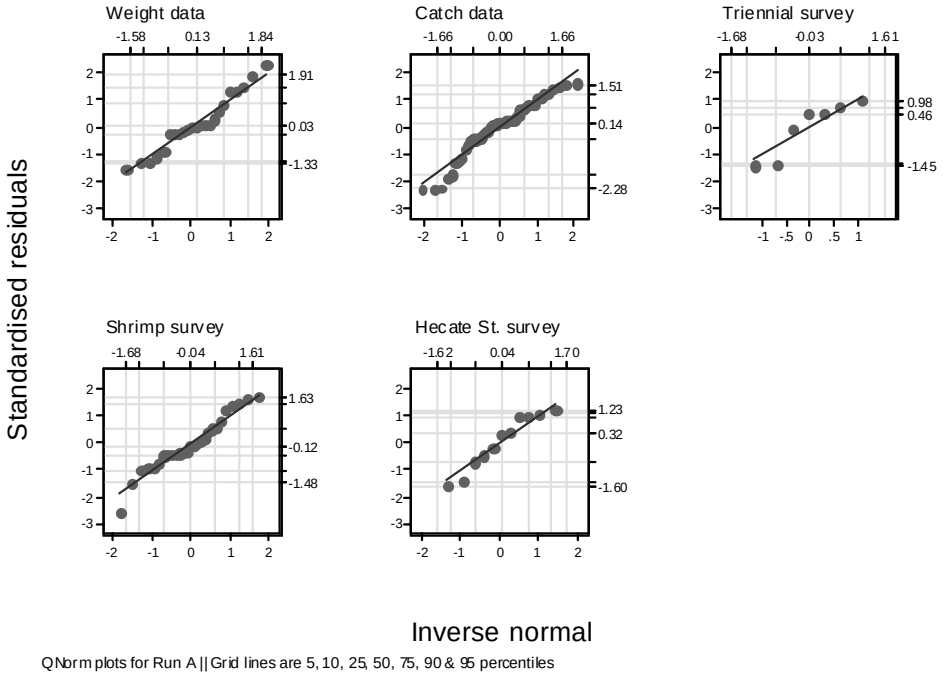

Figure 56. Quantile-normal plots of standardised residuals against a normal distribution for each data type in model Run A (Table 30).

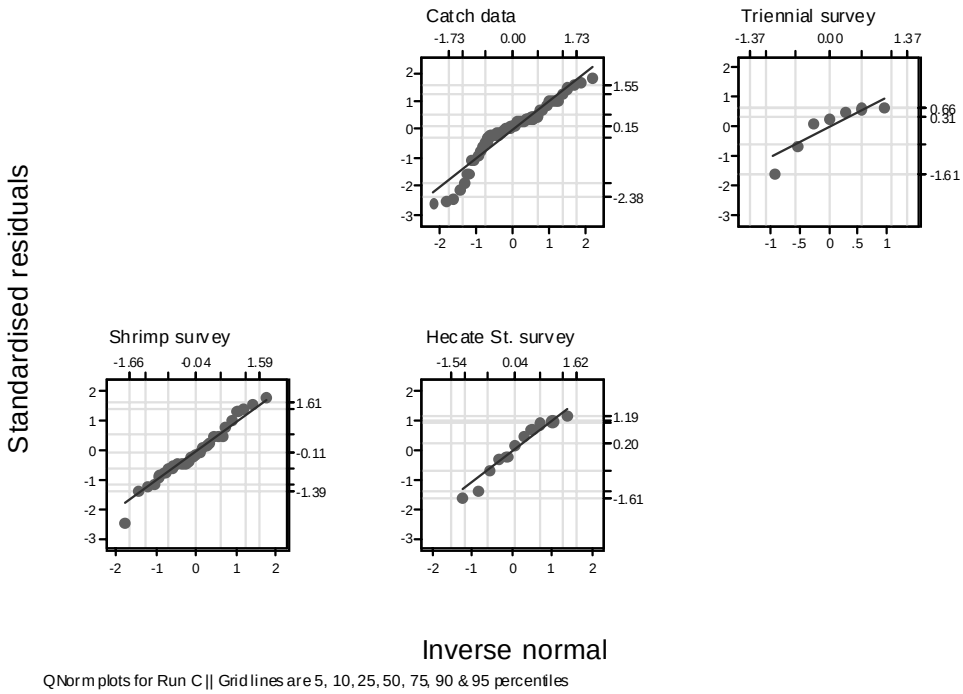

Figure 57. Quantile-normal plots of standardised residuals against a normal distribution for each data type in model Run C (Table 30).

None of these model runs are completely credible. All fit the data reasonably well, except for Runs B and C which do not fit the weight data. Run C probably has the most reasonable levels of estimated biomass, but the model wants to estimate a very high M for this run and it cannot fit the weight data. The weight data are problematic in that they probably were not taken representatively from the entire fishery. However, it is more likely that the mean weight of the catch was on the order of 0.8 to 1.0 kg rather than the much lower estimates around 0.6 kg which are estimated by Run C (Figure 52). One possibility is that the true age of recruitment to the fishery is older than the age 4 used in this model. However, there are insufficient age data available for this species to determine this issue. And when higher ages of knife-edge recruitment were tested in this model, model estimates of M increased, but the estimates of B_0 also stayed high, resulting in equally optimistic projections.

7.3 DISCUSSION

The model (Run A) which includes all five data sets in the estimation procedure is, in principle, preferable to the remaining models. However, this model estimates a large B_0 and consequently provides an assessment that the overall stock size is large and that there is little consequence to stock size from catches at present levels. This conclusion is not consistent with past experience for this species on the west coast of Canada (which was recently considered depleted) but is consistent with the estimate of Z presented in Section 5.6. However, even Model Run C, which excludes the weight data and fixes M at the accepted value of 0.2 and consequently estimates a much smaller overall level of stock size, indicates that the harvest rates resulting from the historical level of commercial removals have rarely exceeded the estimated value for F_{msy} for this stock (Figure 53).

In general, the projections from the models which use the weight data are probably over-optimistic, given the past history of this stock which was only recently considered in difficulty. However, it is clear from the analyses presented in this paper that all indicators pertaining to west coast petrale sole are increasing under current levels of removal (see Sections 4.0 and 6.0). These indicators, when transferred into a stock assessment model, understandably result in optimistic predictions.

The sixth model, which omits the weight data and consequently had to fix the M parameter to obtain credible estimates for the other parameters, is less optimistic in its projections. This model is also less credible in that it leaves out information available for this stock. However, this model also shows an increasing stock size and suggests that a modest increase in catch levels is likely reasonably safe.

The model diagnostics indicate that the residuals from the fits to the data are reasonable and that a "natural" weighting between the data sets based on balancing the respective data standard deviations can be achieved. This means that the model distributional assumptions are being met while selecting the relative weights for the data sets on an objective basis.

The delay-difference approach is not ideal for petrale sole because the model requires the assumption that recruitment to the fishery is knife-edged. We used age 4 for this assumption in this model, based on the information presented in Figure 20 which shows that petrale sole are reasonably well represented in the catch at length data which are approximately equivalent to age 4. We explored the sensitivity to this assumption by repeating Run A and Run C using knife edge recruitment at ages 5 and 7. Model performance did not improve, with each model run estimating even larger standing stock sizes than those reported in Table 30. More robust results are probably not obtainable without changing to a more complex model which incorporates a gradual selectivity function to estimate recruitment into the fishery.

As indicated in Starr et al. (2002), the modelling approach adopted in this paper could be improved by using Bayesian methodology to allow the estimation of the uncertainty associated with predictions of stock status at different catch levels. Another possible improvement would be the incorporation of the estimation of the growth rate parameters into the model likelihood.

Further extensions of the delay-difference approach could be investigated, such as applying some of the more complex models suggested by Schnute (1985). It is felt that the delay-difference approach suits situations where data are limited and when there are insufficient data to justify an age-structured approach, as is the case for this species.

8.0 SUMMARY COMMENTS REGARDING STOCK STATUS

These analyses suggest that the west coast Canada petrale sole population has increased in abundance in the most recent three or four years. They also suggest that current stock status for petrale sole is at or above the level of maximum yield. We make these conclusions for the following reasons:

- Results from two of the three available trawl surveys indicate that there has been an increase in biomass in the most recent three to five years. The third survey shows a non-significant increasing trend. The survey biomass estimates for petrale sole off the B.C. coast do not have optimal coverage for petrale sole and probably represent minimum biomass estimates.

- The regression models fitted to the commercial catch and effort data also show an increasing trend in the last three to four years.

- The estimate of total mortalities (Z) based on one recent (2000) sample from survey age composition information was only slightly larger than the best estimate for M (0.2).

- Model runs indicate that current biomass is at or above B_{msy}. This result should be interpreted with caution because many of the input biological parameters are poorly known and a full range of possible models have not been investigated.

- Model runs and the empirical Z analysis indicate that fishing mortality rates appear to be low. This result seems to be robust even for models which estimate relatively small overall levels of biomass.

- All the delay-difference model runs indicate that the current level of total removals of about 500 t (the total of the bycatch cap of 479 t set by DFO management and a small amount of discards) is well below what appears to be a safe level of harvest for the coming fishing year.

9.0 RECOMMENDATIONS FOR MANAGEMENT DIRECTIONS

It is likely that the resource could sustain some increase in the overall level of catch, possibly in locations where it is difficult to remain within the by-catch cap. Model results, while uncertain, indicate that the level of fishing mortality is probably low. We cannot recommend specific higher catch limits, given the uncertainty in the modelling and the potential for model mis-specification.

We recommend that, if catch levels for this species are increased, a full review of the available information for petrale sole, including further development of the delay-difference assessment model (or some other appropriate model) be presented to PSARC prior to the 2006/07 fishing year (that is, after two full years of the increased levels of catch).

10.0 ACKNOWLEDGEMENTS

We thank Mark Wilkins for providing the petrale sole survey data for the Vancouver INPFC Region from the NFMS Triennial Survey. We thank Jim Boutillier for making available the WCVI shrimp trawl survey data. We thank Norm Olsen for extracting the WCVI shrimp and the Hecate Strait assemblage trawl survey data and for providing the fine density plots of the four sets of survey data presented in Section 4.0. We would like to thank John Holmes for his helpful review of this paper.

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12.0 APPENDIX 1. REQUEST FOR WORKING PAPER

Date Submitted: October 2003

Individual or group requesting advice: Groundfish Management Unit

Proposed PSARC Presentation Date: January 2004

Subject of Paper: Petrale sole Stock Assessment and Recommendations for Management for 2004

Lead Authors: J.Fargo/P. Starr

Rationale for request:

Petrale sole (Brill) have been fished off the British Columbia coast since the late 1940's. Catches are highly valued by fishermen and there is a high demand for product in the marketplace.

Fishery managers set and have maintained the total allowable catch at 479 t for this stock since 1997. The last detailed assessment and scientific advice on this stock was completed in 1998.

The 1997 establishment of a TAC coupled with the implementation of the Individual Vessel Quota (IVQ) Management system for the west coast groundfish trawl fishery has virtually eliminated all directed fishing on this stock. Petrale sole are encountered as bycatch coast-wide by the fleet. Under the IVQ program rigid control of catch to holdings of non-directed IVQ'd species, such as Petrale sole, is one of the major factors considered by trawl fishing captains when planning/conducting fishing activities.

Repeatedly of the past seasons, fishermen are reporting that there is a significant increase in the overall coastwide abundance of Petrale sole. Despite deploying measures to avoid Petrale sole bycatch, the increase abundance is causing many in the fleet to forgo fishing opportunities for other species of groundfish.

An updated of the 1998 stock assessment for this species is sought.

Objectives of Working Paper:

This document will:

1. Review the available biological, research survey, and fishery and at-sea observer information on for Petrale sole to provide an update of current status of the biomass.
2. Suggest reassessment timing and possible advice on the development new/modified stock assessment approaches for this stock.

Question(s) to be addressed in the Working Paper:

1. What is the current biomass and stock size structure of Petrale sole and how does this relate to historical stock conditions.
2. What advice can Science provide to Fishery Managers on the potential levels of harvest and associated risks to the stock given the current status and level of harvest of Petrale sole in BC.

Stakeholders Affected:

Commercial trawl licence holders.

How Advice May Impact the Development of a Fishing Plan:

The advice will assist in a review of the current allowed harvest level for Petrale sole by the groundfish trawl fleet.

Timing Issues Related to When Advice is Necessary:

The advice is required for development of the 2004/2005 Integrated Fisheries Management Plan for Groundfish Trawl.

Approved:

Science Manager: _____;

Date:_____

Fisheries Manager: _____;

Date:_____

13.0 APPENDIX 2. DELAY DIFFERENCE MODEL

A delay-difference stock production model (Hilborn & Walters 1992, Quinn & Deriso 1999, Schnute 1985) was used to estimate stock parameters and reference points relevant to management. The model uses two age groups, recruits and spawners. A Beverton-Holt stock-recruitment function was used to link the two groups. Recruitment to the spawning population and the fishery was assumed to be knife edged at age 4. Growth was assumed to follow a constant von-Bertalanffy function and the length-weight relationship was assumed to be constant. Input parameters for growth were estimated as presented in Section 5.1 and were assumed to be known. The model is conditioned on fishing effort, estimated as the ratio of catch divided by catch per unit effort. The objective function includes terms for minimising the differences between the predicted and the observed catch, the predicted and the observed mean weight of the population, the predicted and observed biomass indices from the three surveys (NFMS triennial, WCVI shrimp, and Hecate St.) and minimising the recruitment deviations relative to the mean recruitment. The model used in this assessment differs from the model described by Sinclair et al. (2001) and by Starr et al. (2002) by the addition of two additional survey indices, switching to a Beverton-Holt stock-recruitment function, changing the formula for the mean weight at B_0 and some changes to the equilibrium equations. The following tables describe the model parameters, data, dynamics and likelihoods.

Estimated Parameters

Parameter	Description
B_0	unfished equilibrium population biomass
M	instantaneous natural mortality rate
γ	ratio B_1 / B_0, population size in year 1 relative to unfished population size (fixed at 1.0)
h	"steepness" of the Beverton-Holt stock-recruitment curve: where fraction defines the proportion of the maximum recruitment which is available when the spawning stock size is 20% B_0 (Francis 1992) [fixed at 0.75]
q_c	fishery catchability
q_t	NFMS triennial trawl survey catchability
q_s	WCVI shrimp trawl survey catchability
q_h	Hecate Strait trawl survey catchability
ϕ_t	recruitment anomalies in year t (there are 47 of these parameters)

Fixed parameters

Parameter	Value	Description
L_∞	508.8	Asymptotic length in von-Bertalanffy growth equation (mm) (ages 4+ only)
k	0.175	growth rate parameter in von-Bertalanffy growth equation (ages 4+ only)
t_0	-1.916	time at L_0 in von-Bertalanffy growth equation (ages 4+ only)
a	9.609E-09	slope of length – weight relationship (mm to kg)
b	3.037	Exponent of length – weight relationship
r	4	age of knife edge recruitment to fishery and spawning population
ρ	0.8932	slope of the Ford-Walford plot, age r to 19
α	0.1828	Intercept of Ford-Walford plot, age r to 19

Annual Input Data

Data series	Description
E_t	fishing effort (h) in year *t*
C_t	weight of catch in year *t*
w_t	mean weight of individuals in the population in year *t*
$T_{index,t}$	NFMS triennial survey index in year *t*
$T_{\sigma,t}$	Standard error for the NFMS triennial survey index in year *t*
$S_{index,t}$	WCVI shrimp trawl survey index in year *t*
$S_{\sigma,t}$	Standard error for the WCVI shrimp survey index in year *t*
$H_{index,t}$	Hecate Strait assemblage survey index in year *t*
$H_{\sigma,t}$	Standard error for the Hecate Strait assemblage survey index in year *t*

Derived parameters:

Equation	Description
$w_r = a\left(L_\infty\left(1-e^{-k(r-t_0)}\right)\right)^b$	weight at the age of recruitment
$S = e^{-M}$	natural survival rate
$\overline{w} = \dfrac{(1-S)w_r}{\left(1-(1-\rho)S+\rho S^2\right)}$	average body weight in the unfished population (Eq. 9.3.4 in Hilborn & Walters [1992] modified for Deriso delay-difference assumption where $w_{r-1} = 0$)
$N_0 = \dfrac{B_0}{\overline{w}}$	equilibrium population numbers at B_0
$R_0 = N_0(1-S)$	equilibrium recruitment at B_0
$alpha = \dfrac{B_0}{R_0}\left(1-\dfrac{(h-0.2)}{(0.8h)}\right)$	Beverton-Holt 'alpha' parameter expressed in terms of the steepness parameter (Francis 1992)
$beta = \dfrac{5h-1}{4hR_0}$	Beverton-Holt 'beta' parameter expressed in terms of the steepness parameter (Francis 1992)

Model Equations

Equation	Description
$F_t = q_c E_t$	instantaneous fishing mortality in year *t*
$N_t = N_{t-1}e^{(-M-F_{t-1})} + R_{t-r+1}$	population numbers in year *t*
$B_t = \left(\alpha N_{t-1} + \rho B_{t-1}\right)e^{(-M-F_{t-1})} + w_r R_{t-r+1}$	population biomass in year *t*
$\hat{w}_t = \dfrac{B_t}{N_t}$	predicted mean weight of individuals in the population in year *t*
$R_t = \dfrac{B_{t-r}}{\left(alpha + beta\, B_{t-r}\right)}e^{\phi_{t-r}}$	recruitment in year *t*
$\hat{C}_t = \dfrac{B_t\left(1-e^{(-M-F_t)}\right)F_t}{M+F_t}$	predicted catch in year *t*
$\hat{T}_{index,t} = q_t B_t$	predicted NFMS triennial survey biomass index in year *t*

Equation	Description
$\hat{S}_{index,t} = q_s B_t$	predicted WCVI shrimp survey biomass index in year *t*
$\hat{H}_{index,t} = q_h B_t$	predicted Hecate St. survey biomass index in year *t*
$C_t = \dfrac{B_t\left(1-e^{(-M-F_t)}\right)F_t}{M+F_t}$	solve F_t for in years 2004/05
$U_t = 1-\exp^{(-q_c E_t)}$	Exploitation rate in year *t*

Objective Function:
There were up to six terms for the objective function that were minimised, depending on the number of data sets included in the model. These six terms are described in the equations below:

$$\left(n\ln\sigma_\phi + \frac{1}{2\sigma_\phi^2}\sum(\phi^2)\right) + \left(n\ln\sigma_c + \frac{1}{2\sigma_c^2}\sum(\ln C_t - \ln\hat{C}_t)^2\right)$$
$$+\left(n\ln\sigma_w + \frac{1}{2\sigma_w^2}\sum(\ln w_t - \ln\hat{w}_t)^2\right) + \left(n\ln\sigma_\tau + \sum\frac{(\ln T_{index,t} - \ln\hat{T}_{index,t})^2}{2\sigma_{\tau,t}^2}\right)$$
$$+\left(n\ln\sigma_\varsigma + \sum\frac{(\ln S_{index,t} - \ln\hat{S}_{index,t})^2}{2\sigma_{\varsigma,t}^2}\right) + \left(n\ln\sigma_\gamma + \sum\frac{(\ln H_{index,t} - \ln\hat{H}_{index,t})^2}{2\sigma_{\gamma,t}^2}\right)$$

The residual standard deviations used for weighting the components of the objective function were set to the values in the table below. The standard errors for the various data components were arrived at by iteratively reweighting each data set until the standard deviation of the standardised (Pearson) residuals from the model fit for that data set was near 1.0 (as predicted if the data fit the lognormal distributional assumptions). Process error was added to the estimated survey standard errors using $\sigma_{survey,t} = \sqrt{X_{\sigma,t}^2 + \sigma_{survey,2}^2}$ (where $X_{\sigma,t}^2$ is the observed standard error for one of the three surveys included in the model and $\sigma_{survey,2}^2$ is the additional process error added to each index to bring the standard deviation of the survey residuals to the 1.0 target, Francis et al. 2001).

Residual standard deviations (NA=not applicable)

Observation error	Process error	Description
$\sigma_w = 0.11$	NA	Standard deviations for mean weight (Run A: Table 30)
$\sigma_c = 0.35$	NA	Standard deviations for catch (Run A: Table 30)
$T_{\sigma,t}$	$\sigma_{\tau,2} = 0.19$	Standard deviations for NFMS triennial survey (Run A: Table 30)
$S_{\sigma,t}$	$\sigma_{\varsigma,2} = 0.97$	Standard deviations for WCVI shrimp survey (Run A: Table 30)
$H_{\sigma,t}$	$\sigma_{\gamma,2} = 0.62$	Standard deviations for Hecate St. survey (Run A: Table 30)
$\sigma_\phi = 0.6$	NA	Standard deviations for recruitment deviations (all runs: Table 30)

Equilibrium Predictions

Equation	**Description**
$S_e = e^{-M-F_e}$	survival rate with fishing at equilibrium
$\mathrm{K} = \dfrac{w_r}{\left(1-(1-\rho)S_e + \rho S_e^{\,2}\right)}$	growth-survival constant (Eq. 9.3.2 in Hilborn & Walters [1992] modified for Deriso delay-difference assumption where $w_{r-1} = 0$)
$B_e = \dfrac{1/\mathrm{K} - alpha}{beta}$	population biomass at equilibrium (derived from Eq. 9.2.11 in Hilborn & Walters [1992])
$Y_e = \dfrac{B_e\left(1-e^{(-M-F_e)}\right)F_e}{M+F_e}$	yield at equilibrium