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Turbot Stock Assessment for 2001 and Recommendations for Management in 2002

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Abstract

We summarise results of analysis of biological data, research survey data and observer data for turbot (*Atheresthes stomias*). Results from the analysis of observer data indicate that the variability in the CPUE index from the commercial fishery is mainly due to area and seasonal effects (and in some cases depth) and that these variables can change among years. The analysis of the discard data indicates that this fishery appears to be passive with little evidence of targeting behaviour. The turbot CPUE index from research surveys conducted between 1984 and 2000 shows no trend but does show cyclic fluctuation over that period. Size and age composition data show no distinct trends over time. The instantaneous total mortality rate estimates for 1980, 1998 and 2000 did not differ despite a twenty year exploitation history. We conclude that the current fishing mortality rate for turbot stocks off the West Coast of Canada is at or below the sustainable level.

Résumé

Nous résumons les résultats de l'analyse de données biologiques, de données de relevés de recherche et de données d'observateurs pour la plie à grande bouche (*Atheresthes stomias*). Les résultats de l'analyse des données d'observateurs révèlent que la variabilité de l'indice CPUE issu de la pêche commerciale est principalement imputable aux effets du secteur et de la saison de pêche (et dans certains cas de la profondeur) et que ces variables peuvent changer d'une année à l'autre. L'analyse des données sur les rejets indique que cette pêche semble être opportuniste, ne manifestant qu'une faible tendance à être ciblée. L'indice CPUE de plie à grande bouche issu des relevés de recherche menés entre 1984 et 2000 ne révèle aucune tendance mais fluctue toutefois de façon cyclique pendant cette période. Les données sur la composition par taille et par âge ne montrent aucune tendance distincte au fil du temps. Les estimations du taux instantané de mortalité totale pour 1980, 1998 et 2000 ne sont pas différentes en dépit d'un dossier de pêche de 20 ans. Nous concluons que le taux actuel de mortalité par pêche imposé aux stocks de plie à grande bouche de la côte ouest du Canada se situe au ou sous le niveau durable

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. This prompted the first assessments of groundfish in 1977 (Westrheim 1977). Recommendations for quota management of groundfish species were not forthcoming until 1979 (Ketchen 1980). Since that time, detailed and interim assessments have been conducted annually including recommendations for catch limitations. The last detailed assessment of turbot (also known as arrowtooth flounder) was conducted in 1987 (Fargo 1988).

Turbot is an important component of the trawl fishery. Over the past 45 years most of the turbot catch has been discarded at sea. The species is soft-fleshed and proteolysis occurs in the muscle tissue of turbot soon after death producing a mush flesh. Although alternative processing methods have been developed for the species there is no large market for these fillets.

Although turbot are of limited economic importance, they are an important ecological component of the offshore ecosystem as well as the ecosystem in Hecate Strait. This is particularly relevant as investigators shift their emphasis from single species to multi-species or ecosystem assessment. Previous studies indicate that the major food item in the diet of the adults is fish although they also consume cephalopods, euphausiids and shrimp. Juvenile turbot are prey items for large pollock, and Pacific cod.

In this document, we summarise biological information and present the results of an analysis of catch-effort, survey and biological data. We use these analyses to provide advice to managers on harvest levels for the 2002/2003 fishing year.

2.0 Background

2.1 Range and stock structure

Turbot (*Atheresthes stomias*) ranges from Baja California to the eastern Bering Sea and is most abundant at the northern part of its range. Off B.C., turbot show a preference for a narrow range of bottom temperature of 7-8 ^{o}C. The species shows a preference for coarse sand substrate as well (Perry et al. 1994). The species occupies the waters of the continental shelf until about age 4 when juveniles join the adult portion of the population occupying the continental slope. Limited research has been carried out on the species' life history. Little is known about the stock structure of this species on the Pacific coast.

2.2 Niche

Turbot inhabit depths from 50 to 900 m and show little preference for bottom temperature over their range. Adults show little affinity for a particular sediment type, while juveniles prefer sand or mud substrate. Juveniles feed primarily on mobile prey, such as cumaceans, carideans, and gammarid amphipods. Adults are piscavores and cannabalistic. Their preferred prey is herring *(Clupea harengus)*, juvenile pollock *(Theagra chalcogramma)* and Pacific sandlance (*Ammodytes hexapterus*) (Fargo et al. 1981). Diet variation results as much from food availability as it does from prey preference.

2.3 Growth/Lifespan

Turbot exhibit sexual dimorphism. As juveniles (< 380mm), males and females grow at the same rate. However, after sexual maturity, females grow faster than males, and attain a larger maximum size (Figures 1 and 2). The maximum size observed for males in biological samples over the last 20 years is 750 mm. The maximum size for females over the same period is 840 mm. The maximum weights of males and females determined from biological samples are 1676 g and 3102 g, respectively. The growth in weight is also similar among the sexes until maturation (age 5). Thereafter the weight gain by females is significantly higher than for males.

Age at 50% maturity for males is 4 years and for females is 5 years (Figure 3). Recruitment to the exploitable population begins at age 5 but recruitment is not knife-edged. The maximum age recorded for this species in B.C. is 25 years, although most of the exploited population is less than 15 years of age.

2.4 Reproduction

Turbot are batch spawners and peak spawning occurs at depths deeper than 350 m in the fall and winter months (Rickey 1995). The mature population off Washington migrates seasonally from depths of about 183 m in summer to depths exceeding 475 m in winter (Rickey 1995). There is some evidence to suggest that the time of first spawning and the time of peak spawning vary interannually (Rickey 1995). The species produces pelagic eggs that drift with the ocean currents. There is some evidence of an extended larval period of several months however (Rickey 1995). Fecundity of the species is not known (DiCosimo 1998).

Larvae remain in the upper 100m of the water column for about 4 weeks. Young of the year one and two year olds occupy shallower depths than the adults, while three and four year olds are generally found in deeper water with the adults. Turbot occupy separate spawning (winter) and feeding (summer) areas. They undergo a seasonal bathymetric movement from shallower water to deeper depths in the fall and winter.

3.0 Data Sources

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, the history of which has recently been described in detail 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 (Rutherford 1999).

3.2 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 some 90% of the trawl fleet. The observers provide information on catch locations, bridge log data and species composition (by weight). Observers also collect biological data for selected species. A relational database, *PacHarvest*, was developed by the slope rockfish assessment team using Microsoft Server 7.0 (Schnute et al. 1999). 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. (1999).

A detailed explanation of catch and effort data used in the general linear modelling section of this document is provided in Appendix 1, including a description of the data selection and grooming procedures.

3.3 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* of the *PacHarv* database described above.

3.4 Landing statistics

Annual landing statistics for turbot are presented by PFMC statistical area in Table 1. The landings exhibit cyclic fluctuations between the mid 1950s and the mid 1980s. Between the late 1980s and 2001 landings have increased to triple the previous high.

Table 1. Turbot landings and discards by Major Statistical Area and calendar year, 1954-2001.

	Major Area									
Year	4B	3C	3D	5A	5B	5C	5D	5E	Total	Discard
54	104	96	-	274	10	-	49	-	533	
55	68	304	26	747	-	-	177	-	1322	
56	81	741	55	730	10	-	507	-	2124	
57	19	132	-	236	-	2	139	-	528	
58	55	119	-	35	1	12	103	-	325	
59	80	156	0	178	1	-	292	-	707	
60	92	96	5	318	38	8	369	-	926	
61	48	335	1	1089	2	4	638	-	2117	
62	78	185	23	452	25	1	591	-	1355	
63	101	48	-	385	9	-	77	-	620	
64	133	29	4	457	9	4	195	-	831	
65	137	104	5	278	7	1	145	-	677	
66	248	51	1	133	1	-	252	-	686	
67	86	65	0	1049	22	-	417	-	1639	
68	138	31	1	301	-	85	386	-	942	
69	114	41	22	1156	48	19	508	-	1908	
70	51	-	-	42	9	2	212	-	316	
71	11	4	-	-	2	0	20	-	37	
72	3	1	-	27	-	-	202	-	233	
73	14	19	-	37	-	16	342	-	428	
74	4	17	-	9	62	17	224	-	333	
75	18	83	2	147	58	6	457	-	771	
76	1	121	1	40	86	43	760	-	1052	
77	1	275	5	150	98	24	843	26	1422	
78	30	203	4	385	262	77	1294	27	2282	
79	5	40	23	138	52	182	1265	7	1712	
80	12	85	5	121	170	80	821	4	1298	
81	18	69	15	151	132	64	398	6	853	
82	9	66	-	137	143	11	139	-	505	
83	8	31	-	52	75	9	92	2	269	
84	4	23	-	20	49	11	199	8	314	
85	0	73	11	35	23	2	435	12	591	
86	-	131	6	190	11	6	367	14	725	
87	-	37	9	276	100	26	641	15	1104	
88	3	31	30	116	45	3	120	19	367	
89	-	38	34	144	348	4	30	11	609	
90	-	325	379	527	521	12	781	16	2561	
91	2	218	639	318	881	23	152	27	2260	
92	3	560	989	761	1045	62	149	24	3593	
93	3	410	1828	388	1023	16	336	47	4051	
94	2	825	1425	280	1020	40	300	81	3973	
95	0	315	1267	447	583	24	326	46	3008	
96	0	458	2529	368	799	56	343	6	4558	3271
97	0	581	914	434	624	30	277	25	2885	2453
98	0	632	1778	444	623	3	325	7	3812	3284
99	0	506	878	463	860	31	777	19	3555	3818
00	0	662	1082	377	1644	10	466	14	4255	3561
01	0	2165	2100	55	1277	4	797	65	6464	1124

3.5 Biological data

Biological samples containing length, sex, maturity, and ageing information have been collected from the trawl fishery in British Columbia continuously since the mid-1940s. Samples collected on turbot, however, were too few in number to warrant analysis and we used biological data collected from research cruises for the analysis in this assessment.

Biological samples for turbot were most numerous during research cruises conducted in Hecate Strait including the previously mentioned Hecate Strait survey and turbot biomass survey. In the early years of the Hecate Strait survey attention was devoted to sampling every species in the catch to provide data for multispecies stock assessment work. This permitted the collection of size composition data only. Since 1998, however, biological samples for important commercial species have included information on length, sex, stage of maturity and ageing structures.

3.6 Research surveys

Two surveys in Hecate Strait provide some information on turbot. In 1980 a turbot biomass survey was conducted in Hecate Strait (Fargo et al. 1981). Biological information collected on that survey included age, length, sex and maturity data. In 1984 a multispecies trawl survey was initiated in Hecate Strait (Fargo and Tyler 1990). This work was carried out as part of the Hecate Strait Project (Fargo 1986, Fargo 1989) with an objective to develop an ecological basis for mixed species stock assessment. The survey provides synoptic data that allowed the mapping of fish assemblages available to bottom trawls in that region. Although the Hecate Strait Project work halted in 1993, the multispecies survey was continued (Hand et al. 1994, Workman et al. 1996, Wilson et al. 1991). The survey now provides data on the abundance and distribution for groundfish species in the region. The survey data has also been used to document the spatial and temporal changes in species composition in Hecate Strait. The fishing gear used on the survey, a Yankee 36 bottom trawl, 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 Biological Statistics

Current estimates for life history parameters for turbot are presented in Table 2. These estimates are based on port samples 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.

4.1 Length weight relationship

The expression describing the length weight relationship is:

$$\ln W_i = a + b \ln L_i \quad , (1 \le i \le n)$$

where W_i is the weight (kg) and L_i is the length (mm) of fish *i*, were determined from pooled samples for 1980 to 2000. Males rarely reach a size of 600 mm while females commonly reach that size (Figure 1). Weight at age is similar among the sexes until around 300 mm, the time of sexual maturation. Thereafter the females surpass the males in weight at length.

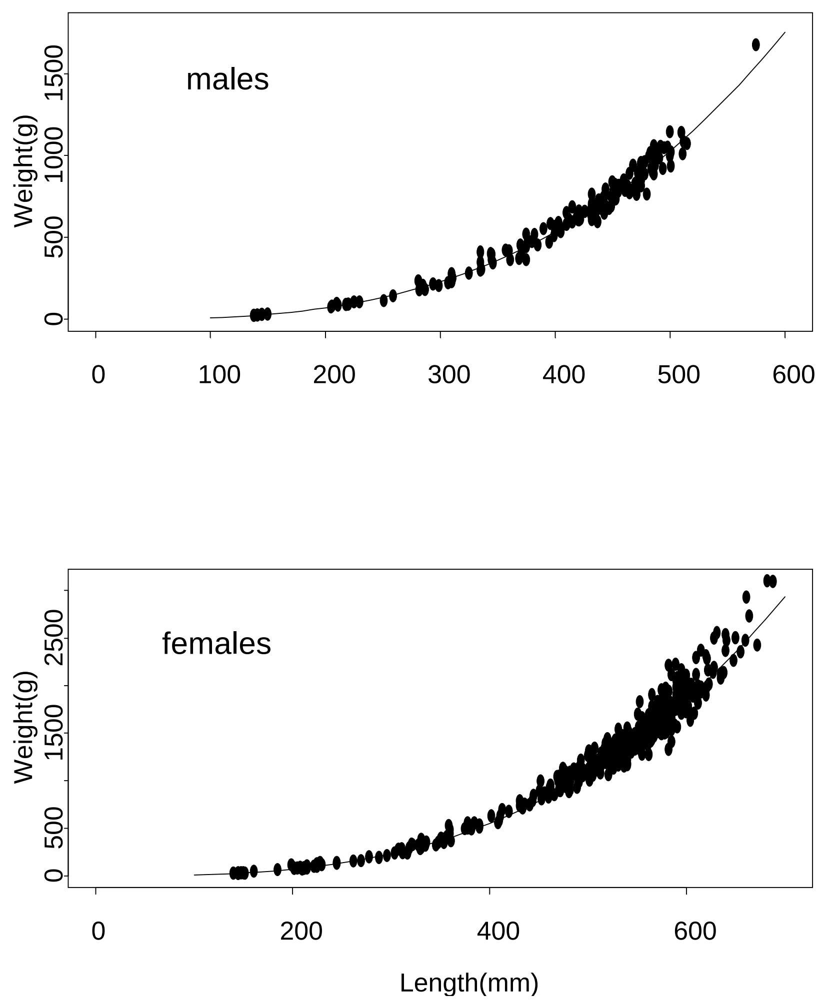


Figure 1. Length-weight relationships for turbot males and females. The data are pooled from survey samples collected from 1980 to 2000.

4.2 Length-age relationships

Von Bertalanffy growth curves (Figure 2) were fit to data for both sexes 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 turbot males slows markedly after about age seven while females continue to gain significant growth in length until slowing at about age twelve.

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

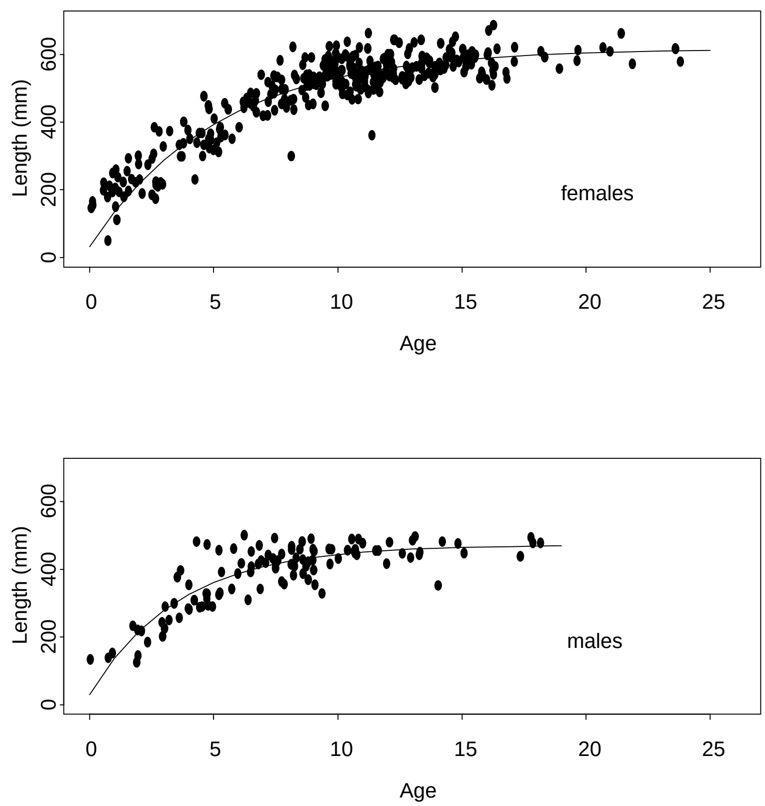


Figure 2. Length age relationships (jitter plot) for turbot females (upper panel) and males (lower panel). The data represent pooled survey samples from 1945 to 1999.

4.3 Maturity

We estimated length at maturity for the catch-age model using data obtained from samples from research cruises and the commercial fishery. 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. Length-maturity data were obtained from pooling the data to acquire an adequate sample size. Maturity ogives were fit to these data using a simple logistic regression (Hosmer and Lemeshowe 1989), 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 mature at a size of about 310 mm compared to females at about 380 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 430 mm for males and 550 mm for females (Figure 3).

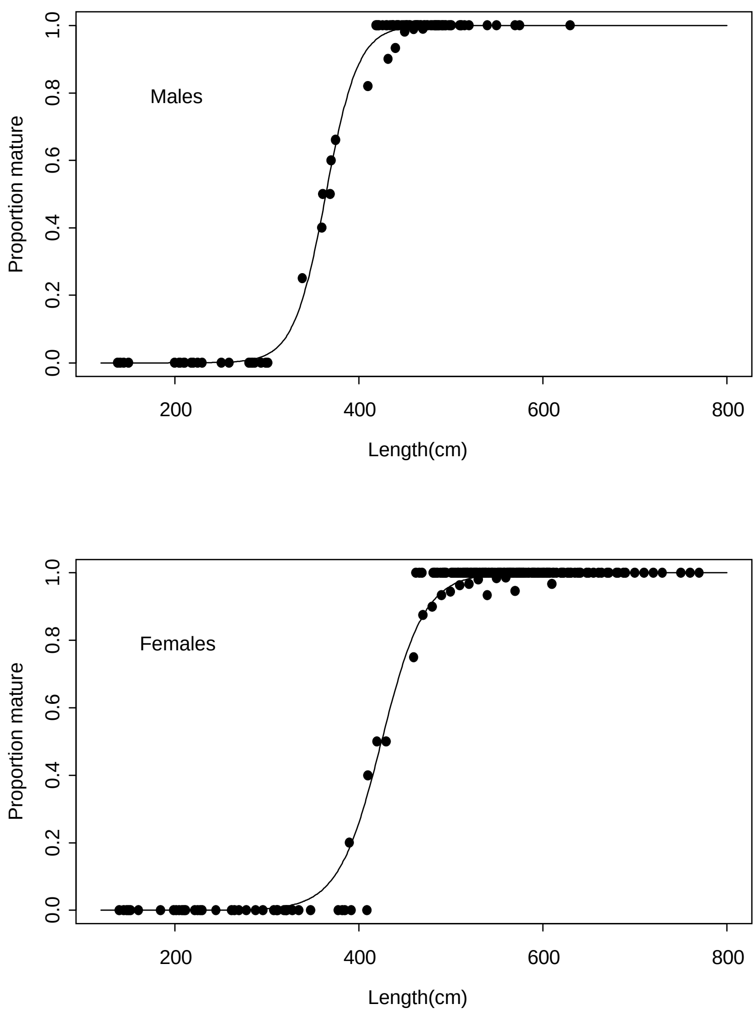


Figure 3. Maturity ogives for male and female turbot. Data are pooled from research survey samples from 1980-2000.

4.4 Natural mortality

Pauly (1980) described a multiple regression relationship between *M* and life history characteristics and temperature regime of 175 fish stocks. He found that *M* varied linearly with species asymptotic length L_∞, the growth coefficient *K*, and mean annual ocean temperature *T*

$$\log M = 0.065 - 0.287 \log L_\infty + 0.604 \log K + 0.513 \log T$$

Estimates of *M* from Pauly's method were 0.38 and 0.28 for males and females, respectively. This is well above the value of 0.2 used for Gulf of Alaska and Washington State assessments (Wilderbuer and Sample 2000). However, many of species that Pauly examined were warm water species and this may have biased his results. We propose to use *M*=0.2 for both sexes of this species as this value is consistent with the estimate that would be obtained using the relationship described by Hoenig (1983) below and the approximate maximum age, t_{max}, observed for this species in B.C. waters of between 20 (M=0.22) and 24 (M=0.19).

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

4.5 Size and Age composition

Size composition summaries from the 1980 turbot biomass survey are presented in Figure 4. The sample in 1980 was collected during the turbot biomass survey while the samples from 1984 to 2000 were collected during the Hecate Strait multispecies survey. Interannual variation in the proportion of juveniles (<380 mm) and adults (≥380 mm) is apparent. The proportion of juveniles was noticeably smaller for the 1980 samples than for the others. The overall size composition has remained fairly consistent since 1984. This may indicate an increase in recruitment due to 1998 and 1999 year-classes. There is no indication from these data that the size range has been truncated over time. We compared the age composition from 1980 with that from 2000 to see if juvenation had occurred (Figure 5). The proportions of younger and older fish were actually higher in the 2000 sample than in the 1980 sample. The sample sizes from samples taken from the commercial fishery samples are so small that no interpretation of them is made.

Table 2. Estimates of biological parameters for turbot caught in the trawl fishery or taken in trawl surveys off the west coast of Canada.

	Males	Females
K	0.278	0.192
L∞	471 mm	617 mm
t_0	-0.234	-0.278
M	0.2	0.2
w_j	22.7 89.0 186.0 290.8 395.6 485.1 566.3 629.5 678.7 720.7 754.6 779.4 799.7 815.1 825.5	21.1 90.7 207.2 356.8 524.2 695.9 863.1 1020.0 1162.7 1289.6 1401.5 1497.9 1581.1 1651.9 1712.5
l_j	136.6 217.7 279.2 325.7 361.0 387.7 408.0 423.3 434.9 443.7 450.4 455.5 459.3 462.2 464.4	134.4 218.8 288.4 345.9 393.4 432.5 464.8 491.5 513.5 531.6 546.6 558.9 569.1 577.5 584.5

p_j	0.00 0.00 0.00 0.03 0.21 0.58 0.85 0.95 0.98 0.99 0.99 1.00 1.00 1.00 1.00	0.00 0.00 0.01 0.10 0.45 0.79 0.92 0.97 0.98 0.99 0.99 0.99 1.00 1.00 1.00
a	0.0000127	0.00000914
b	2.93	2.99

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*
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

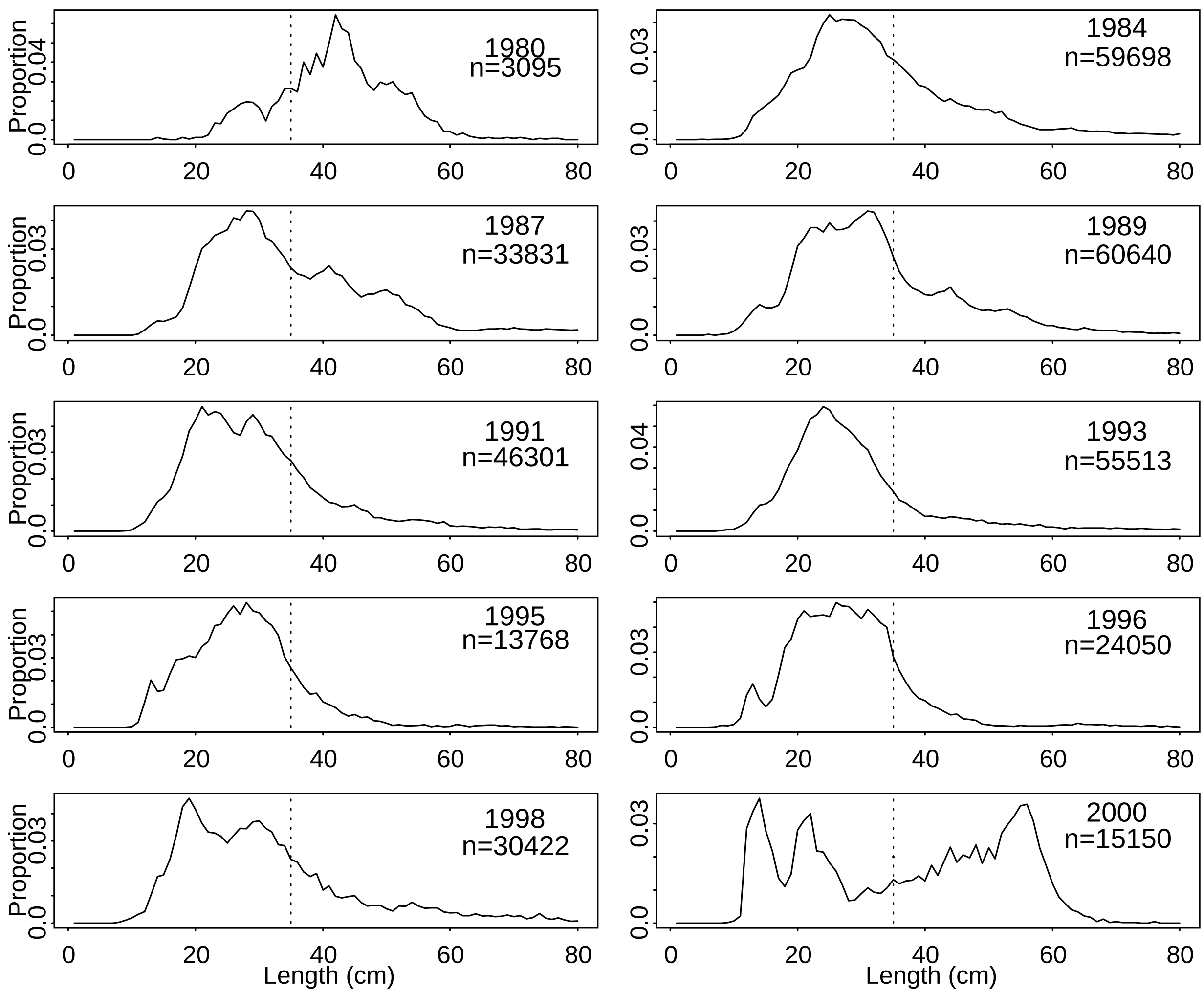


Figure 4. Size composition (cm) for turbot in Hecate Strait, 1980-2000.

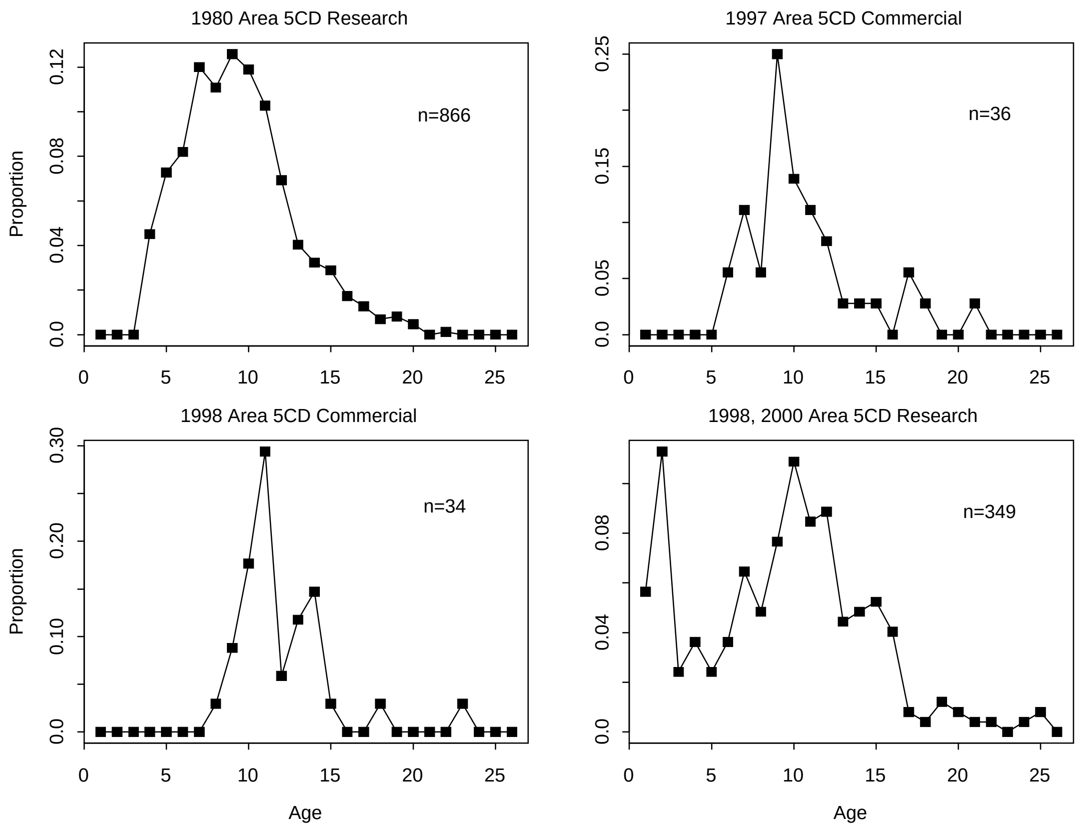


Figure 5. Age composition of female turbot from research and commercial samples 1980,1997,1998 and 2000.

4.6 Total mortality

We estimated *Z*, the instantaneous total mortality rate from the age composition data for females for samples collected on the turbot biomass survey in 1980, samples collected on the 1998 and 2000 multispecies survey and from all research and port samples collected from 1997 – 2001. We used the method of Ricker (1975) where he used log to the base 10 of numbers at age to restrict the y-axis to 2.0. The facilitates the comparison of samples for different years. This calculation also requires the assumption that recruitment variation is low, which we believe is justified for this species (Rickey 1995**,** Wilderbuer and Sample (2000)). We used the regression relationship between the log of the numbers for fully recruited ages on age (Figure 6). To obtain estimates of *Z* the sign of the slope from the regression was changed and then it was multipied by 2.3 (Ricker 1975). The estimates of Z were all between 0.35 and 0.37. This implies a range of 0.15 to 0.17 for *F* assuming that *M* is 0.2 (the estimate that is used in U.S. stock assessments). Moreover, there was no significant difference in the slopes from the regressions for any of the time periods (analysis of covariance, $p<0.0001$).

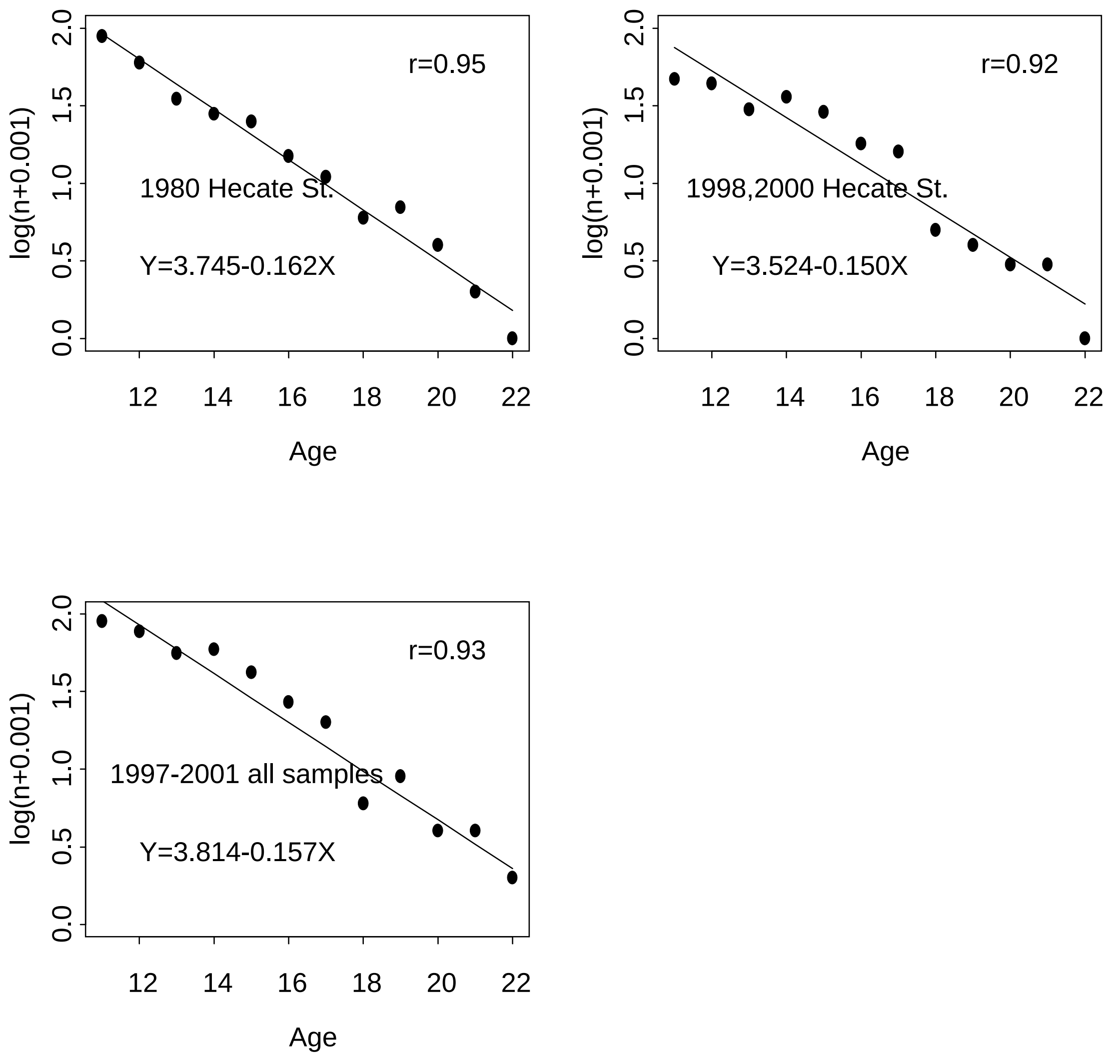


Figure 6. Estimates of total mortality, *Z,* for female turbot from research and commercial samples, 1980-2001.

5.0 Analysis of Observer data

5.1 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 abundance from CPUE data derived from the commercial catch and effort database (see Appendix 1 [Section 10.0] for how these data were generated). This approach is commonly used to analyse fisheries catch and effort data and are described in Hilborn and Walters (1992) and Quinn and Deriso (1999).

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

$$U = U_r \prod_i \prod_j P_{ij}^{X_{ij}} e^{\varepsilon} \qquad \textbf{Eq.1}$$

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.1 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.2**

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

where the subscript k in the second form of Eq.2 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 model described in Eq. 1and Eq. 2 is overparameterised and can take on an infinite number of solutions. The approach used to overcome this problem in this analysis was 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 ($\bar{\beta}$)of the series:

$$\beta_k^0 = {}^{\beta_k}\!/_{\bar{\beta}} \qquad \textbf{Eq.3}$$

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

$$b_k^0 = \mathrm{e}^{(\hat{\beta}_k - \bar{\beta})} \qquad \textbf{Eq.4}$$

where $\hat{\beta}_k$ is the coefficient calculated for each value of the predictor variable and $\bar{\beta}$ is the mean of those coefficients, including the dropped coefficient. When this procedure is applied to the annual abundance variable ('year' or 'fishing year'), 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 [Section 11.0]). 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.

Eq. 2 can be extended to include as many factors as are thought to be reasonable, including interaction terms. A selection procedure has been developed (Vignaux 1993, 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 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 (kg/hr).
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).

A direct comparison of a number of alternative estimates of annual CPUE is made by standardising all available indices relative to the geometric mean of the index series. The simplest estimate of mean annual CPUE is:

$$R_j = \frac{\sum_{k=1}^{M_j} C_{jk}}{\sum_{k=1}^{M_j} E_{jk}} \qquad \textbf{Eq. 5}$$

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 abundance indices calculated in this manner is termed the "Arithmetic" CPUE index in this report and is the arithmetic mean of CPUE weighted by effort. This index can also be scaled relative to its geometric mean ($\overline{R}$) in the same manner as the canonical standardised index (Eq. 3):

$$R_j^0 = {R_j}\big/{\overline{R}} \qquad \textbf{Eq.6}$$

Another simple index of annual abundance based on CPUE is:

$$U_j = \mathrm{e}^{\left[\frac{\sum_{k=1}^{M_j} \ln\left(\frac{C_{jk}}{E_{jk}}\right)}{M_j}\right]} \qquad \textbf{Eq. 7}$$

where U_j is the annual geometric mean of the CPUE observations. The resulting series of indices is termed the "Unstandardised" CPUE index in this report as it is equivalent to a GLM where the only predictor variable is the year (= abundance) term. This index can also be scaled relative to its geometric mean ($\bar{U}$) in the same manner as the canonical standardised index (Eq. 3):

$$U_j^0 = {}^{U_j}\!\!\diagup_{\bar{U}} \qquad \textbf{Eq.8}$$

5.2 Catch regions

A preliminary examination of the turbot catch and effort data was made to see if there was a basis on which to separate turbot catch into regions which were consistent with turbot abundance patterns. Accordingly, simple turbot CPUE was calculated for 5 km^2 grids (using Eq. 3) over the entire period of available data (January 1994 to March 2001) to determine areas of high and low turbot CPUE and whether these patterns could be used to establish sensible catch regions (Figure 7; Figure 8). This was done using both the landed and discard turbot catches as it was expected that reasonable patterns should be consistent with both forms of catch.

Table 3. Proposed definitions for turbot catch regions based on the existing DFO "major", "minor" and "locality" names (Rutherford 1999). The names of the major and minor areas are taken from Appendix E, Figure 6 in Rutherford (1999).

Proposed turbot catch region name	Major area	Minor area	Locality
West & North Charlottes	part of 5D & all of 5E	2AW, IW, IE	see Table 4
Upper Hecate Strait	part of 5D	part of 1E, 4, 5U, 2AE & part of 5L	see Table 4
Moresby Gully	5C & part of 5B & 5E	2BW, 2BE, 5L, 6 & part of 8	see Table 4
Mitchell Gully	part of 5B	part of 8	see Table 4
Goose Island Gully	part of 5A & 5B	parts of 8 & 11	see Table 4
upper west coast Vancouver Island	part of 3D & part of 5A	27 & part of 11	see Table 4
lower west coast Vancouver Island	all of 3C & part of 3D	21,23:26	all
Georgia Strait undefined for turbot	4B	all	all

The regions of high catch rates separated by areas of low catch rates described in the previous paragraph can be approximated using the existing area and "locality" definitions which are presently available in the DFO catch and effort databases (Rutherford 1999). As these definitions have remained reasonably constant over the history of DFO catch reporting, they can be applied over the entire period. The proposed area definitions for turbot catch regions in terms of the DFO major and minor areas and the smaller localities are presented in Table 3 and Table 4.

Figure 7 and Figure 8 demonstrate that there are areas where turbot catch rates (both landed and discard) are low between regions of high catch rates. These form natural boundaries which can be used to define turbot catch regions. One such break occurs just off Brooks Peninsula on the west coast of Vancouver Island. Another break lies in a diagonal from Cape Scott to Triangle Island at the top end of Vancouver Island. The three "gullies" which characterise Queen Charlotte Sound are clearly defined in Figure 7, particularly the division between Mitchell and Moresby gullies. There is an area of high CPUE in the upper regions of Hecate Strait and another off Langara Island, with a clear break occurring in mid-Dixon Entrance (Figure 7). These patterns are clearer when the landed catches are used because the discard catch rates tend to be more ubiquitous and spread out. However, the general pattern described here is consistent for both forms of turbot catch (compare Figure 8 with Figure 7)

Table 4. Locality definitions (Rutherford 1999) used to establish the proposed turbot catch regions defined in Table 3. As the localities are not numbered uniquely, they must be identified in the context of each minor area. The names of the minor areas are taken from Appendix E, Figure 6 in Rutherford (1999). Locality numbers are those shown in Appendix E, Figures 7 to 10 in Rutherford (1999). Commas separate unique localities; a colon (':') indicates that all localities are taken inclusively in the range indicated. Locality '0' is "unknown".

Minor Area Name	**West & North Charlottes**	**Upper Hecate Strait**	**Moresby**	**Mitchell**	**Goose Island**	**Upper Vancouver Island**
1E	3, 5	1,2,4				
2BW			1:5			
2BE			1:10			
5L		2	1,3:10			
6			1:4			
8			6,11:12	3:5,14:15	0:2,7:10,13	
9					1:2	
11					0:3,5,7,12	4,6,10:11

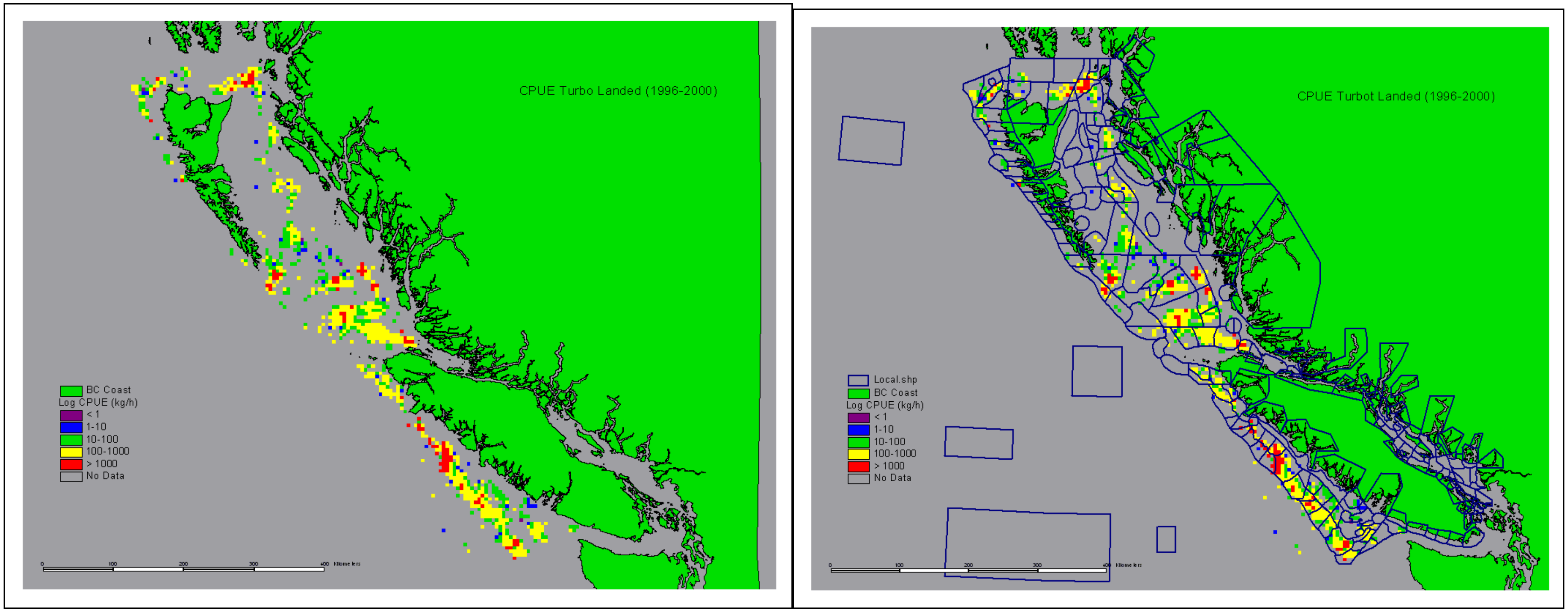


Figure 7. Left panel: distribution map of turbot CPUE for retained catch only (calculated for 5 km^2 grids using Eq. 3 and based on total catch and effort from January 1994 to March 2001). Right panel: same distribution map as in left panel but with DFO "locality" boundaries (see Rutherford 1999 for definitions and names) superimposed, along with proposed boundaries for turbot catch regions based on the locality boundaries and the combined CPUE patterns from the catch and discard data.

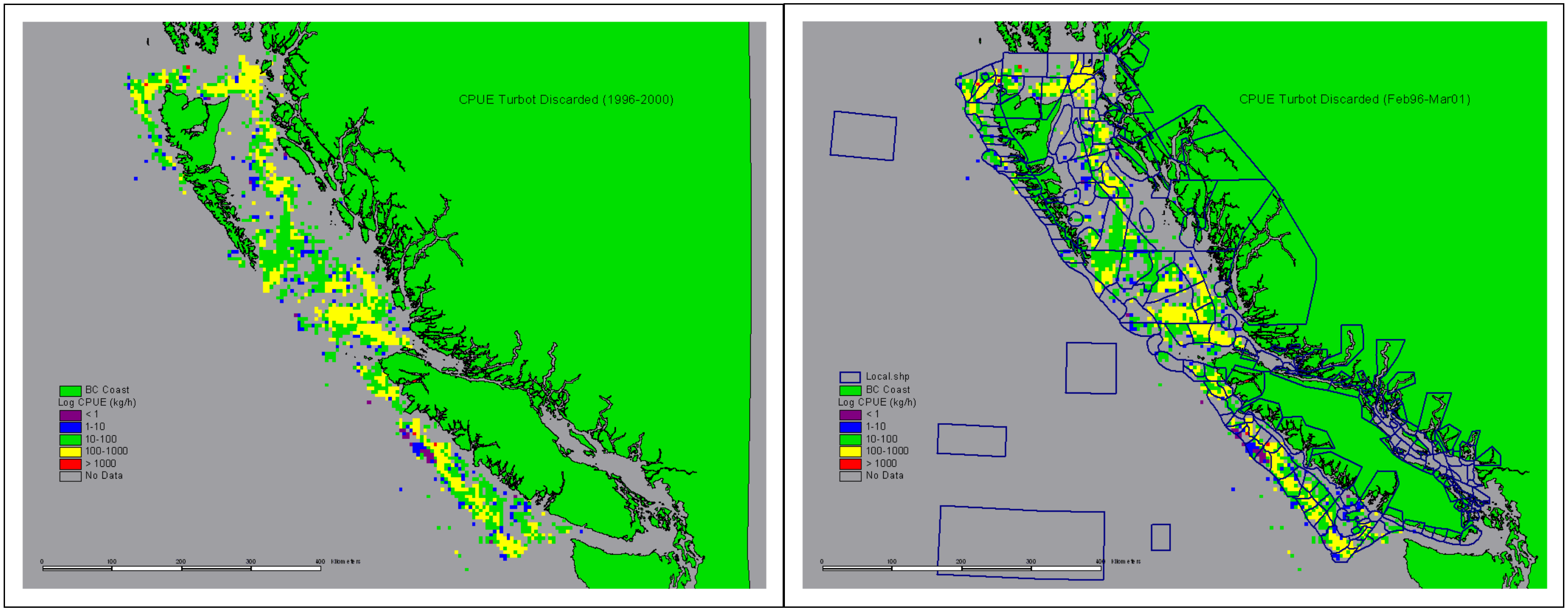


Figure 8. Left panel: distribution map of turbot CPUE for discarded catch only (calculated for 5 km^2 grids using Eq. 3 and based on total discards and effort from February 1996 to March 2001). Right panel: same distribution map as in left panel but with DFO "locality" boundaries (see Rutherford 1999 for definitions and names) superimposed, along with proposed boundaries for turbot catch regions based on the locality boundaries and the combined CPUE patterns from the catch and discard data.

5.3 Distribution of annual landing and discard catches

The dataset used to estimate catch rates from the observer data can also be used to summarise the retained and discard catches based on the catch regions described in Section 5.2 (Table 5). This table indicates that the total coastwide catches of turbot have ranged between 7,000 and 8,500 metric tonnes between 1996/97 and 2000/01, except for 1997/98 when both the retained and discard catches dropped considerably. The coastwide split between retained and discard catches has averaged approximately 45% discarded, ranging between 41% and 51% with no apparent trend over time (Table 5). Catches and discards of turbot have also been summarised by standard fishing year (1 April-31 March) for the major DFO catch reporting regions (Table 6).

When the catches and discards are examined separately by catch region, the distribution between retained and discarded catch varies considerably between regions and between fishing years. The most striking differences are the high level of retained catch in the lower west coast of Vancouver Island (about 75% of the catch is retained) and the high rates of discard in upper west coast Vancouver Island, upper Hecate Strait and the Queen Charlotte Islands. Catches in Queen Charlotte Sound have been evenly split between retained and discarded catches. In Mitchell Gully there is a trend towards increasing levels of discard over time while there is a decreasing trend for discards in Moresby Gully. The other areas are reasonably consistent between the fishing years. Retained catches are highest in the lower west coast of Vancouver Island while discard catches are highest in upper Hecate Strait (Table 5).

Table 5. Total retained and discard catches (t) and their distribution by standard fishing year (1 April – 31 March) for the total B.C. Coast and for the seven catch regions defined in Table 3. Discard estimates prior to the 1996/97 fishing year should be regarded as incomplete as they are not based on observer estimates.

Fishing Year	Catch Type			% of Total		Catch Type			% of Total	
	Retained	Discard	Total	% Ret	% Disc	Retained	Discard	Total	% Ret	% Disc
	Total B.C.					**Lower WCVI**				
1991/92	2,206	711	2,918	76%	24%	857	128	985	87%	13%
1992/93	3,592	709	4,297	84%	16%	1,548	249	1,796	86%	14%
1993/94	3,943	1,095	5,035	78%	22%	2,026	312	2,338	87%	13%
1994/95	3,933	773	4,705	84%	16%	2,148	133	2,281	94%	6%
1995/96	3,642	715	4,357	84%	16%	1,895	225	2,119	89%	11%
1996/97	5,001	3,476	8,477	59%	41%	3,115	803	3,919	79%	20%
1997/98	2,722	2,522	5,244	52%	48%	1,645	583	2,228	74%	26%
1998/99	3,938	3,217	7,156	55%	45%	2,188	523	2,711	81%	19%
1999/00	3,900	4,031	7,932	49%	51%	1,309	764	2,074	63%	37%
2000/01	4,726	3,440	8,168	58%	42%	2,218	578	2,796	79%	21%
	Upper WCVI					**Goose Island Gully**				
1991/92	95	49	143	66%	34%	341	155	497	69%	31%
1992/93	222	94	315	70%	30%	708	119	827	86%	14%
1993/94	200	42	241	83%	17%	487	136	622	78%	22%
1994/95	156	112	267	58%	42%	454	91	545	83%	17%
1995/96	121	37	158	77%	23%	850	132	982	87%	13%
1996/97	19	149	168	11%	89%	507	486	993	51%	49%
1997/98	51	87	138	37%	63%	599	671	1,270	47%	53%

Fishing Year	Catch Type			% of Total		Catch Type			% of Total	
	Retained	Discard	Total	% Ret	% Disc	Retained	Discard	Total	% Ret	% Disc
1998/99	151	186	337	45%	55%	710	887	1,597	44%	56%
1999/00	33	134	167	20%	80%	681	932	1,613	42%	58%
2000/01	54	128	182	30%	70%	987	795	1,782	55%	45%
	Mitchell Gully					**Moresby Gully**				
1991/92	130	29	159	82%	18%	597	27	625	96%	4%
1992/93	430	26	455	95%	6%	478	16	494	97%	3%
1993/94	527	41	568	93%	7%	315	43	358	88%	12%
1994/95	483	20	503	96%	4%	316	28	343	92%	8%
1995/96	211	98	309	68%	32%	162	34	196	83%	17%
1996/97	304	219	522	58%	42%	685	575	1,260	54%	46%
1997/98	80	99	179	45%	55%	60	263	323	19%	81%
1998/99	158	130	288	55%	45%	387	425	813	48%	52%
1999/00	78	186	264	30%	70%	1,011	584	1,595	63%	37%
2000/01	30	187	218	14%	86%	898	199	1,098	82%	18%
	Upper Hecate Strait					**North & West Charlottes**				
1991/92	148	222	370	40%	60%	38	101	139	27%	73%
1992/93	154	119	273	56%	44%	52	86	137	38%	63%
1993/94	335	293	627	53%	47%	53	228	281	19%	81%
1994/95	303	123	426	71%	29%	73	266	340	21%	78%
1995/96	373	110	484	77%	23%	30	79	109	28%	72%
1996/97	344	989	1,333	26%	74%	27	255	282	10%	90%
1997/98	277	672	949	29%	71%	10	147	157	6%	94%
1998/99	327	914	1,241	26%	74%	17	152	169	10%	90%
1999/00	768	1,283	2,051	37%	63%	20	148	168	12%	88%
2000/01	470	1,426	1,896	25%	75%	69	127	196	35%	65%

Table 6. Total retained and discard catches (t) and their distribution by standard fishing year (1 April – 31 March) for the major DFO catch regions (defined in Appendix E. Fig. 6 in Rutherford 1999). Discard estimates prior to the 1996/97 fishing year should be regarded as incomplete as they are not based on observer estimates.

Fishing Year	Catch Type			% of Total		Catch Type			% of Total	
	Retained	Discard	Total	% Ret	% Disc	Retained	Discard	Total	% Ret	% Disc
	Total B.C.					**3C**				
1991/92	2,206	711	2,918	76%	24%	273	68	341	80%	20%
1992/93	3,592	709	4,297	84%	16%	557	150	707	79%	21%
1993/94	3,943	1,095	5,035	78%	22%	398	73	470	85%	16%
1994/95	3,933	773	4,705	84%	16%	814	55	869	94%	6%
1995/96	3,642	715	4,357	84%	16%	374	137	511	73%	27%
1996/97	5,001	3,476	8,477	59%	41%	644	435	1,079	60%	40%
1997/98	2,722	2,522	5,244	52%	48%	740	412	1,152	64%	36%
1998/99	3,938	3,217	7,156	55%	45%	433	379	812	53%	47%
1999/00	3,900	4,031	7,932	49%	51%	495	501	996	50%	50%
2000/01	4,726	3,440	8,168	58%	42%	1,096	438	1,534	71%	29%
	3D					**5A**				
1991/92	646	83	728	89%	11%	320	118	438	73%	27%
1992/93	1,040	125	1,165	89%	11%	761	127	888	86%	14%
1993/94	1,806	261	2,067	87%	13%	401	120	521	77%	23%
1994/95	1,413	141	1,555	91%	9%	305	120	425	72%	28%

Fishing Year	Catch Type			% of Total		Catch Type			% of Total	
	Retained	Discard	Total	% Ret	% Disc	Retained	Discard	Total	% Ret	% Disc
1995/96	1,590	116	1,706	93%	7%	499	102	601	83%	17%
1996/97	2,487	426	2,913	85%	15%	369	330	698	53%	47%
1997/98	936	222	1,158	81%	19%	435	352	787	55%	45%
1998/99	1,814	202	2,016	90%	10%	444	662	1,106	40%	60%
1999/00	830	342	1,172	71%	29%	464	505	969	48%	52%
2000/01	1,158	216	1,374	84%	16%	378	393	771	49%	51%
	5B					**5C**				
1991/92	759	99	857	89%	12%	23	22	45	51%	49%
1992/93	949	87	1,036	92%	8%	78	15	93	84%	16%
1993/94	933	82	1,015	92%	8%	16	39	55	29%	71%
1994/95	984	61	1,045	94%	6%	42	7	49	86%	14%
1995/96	749	147	896	84%	16%	27	32	59	46%	54%
1996/97	1,075	816	1,891	57%	43%	55	234	289	19%	81%
1997/98	294	599	893	33%	67%	30	133	164	18%	81%
1998/99	891	767	1,659	54%	46%	14	150	164	9%	91%
1999/00	1,304	978	2,282	57%	43%	20	293	313	6%	94%
2000/01	1,549	740	2,289	68%	32%	10	214	224	4%	96%
	5D					**5E**				
1991/92	148	222	370	40%	60%	38	101	139	27%	73%
1992/93	154	118	272	57%	43%	52	86	137	38%	63%
1993/94	335	295	631	53%	47%	52	224	276	19%	81%
1994/95	301	123	424	71%	29%	73	266	339	22%	78%
1995/96	373	113	487	77%	23%	30	69	98	31%	70%
1996/97	344	1,001	1,345	26%	74%	27	235	262	10%	90%
1997/98	278	696	974	29%	71%	9	109	118	8%	92%
1998/99	332	935	1,267	26%	74%	12	124	135	9%	92%
1999/00	769	1,283	2,052	37%	63%	18	130	148	12%	88%
2000/01	468	1,320	1,788	26%	74%	68	119	187	36%	64%

5.4 Selection of GLM models

After some preliminary exploratory analysis, four models were investigated for trends in catch rates (Table 7). These model choices were dictated by the amount of data available after the grooming process described in Appendix 1. In particular, it was decided to combine the analysis of the retained and discard catch of turbot for Queen Charlotte Sound and for Hecate Strait because there were insufficient data available to do the retained catch analysis separately for these areas. The discard catch analysis was conducted for the same combination of areas for comparability with the retained catch analysis.

Table 7. Models investigated using general linear modelling for turbot and the time periods included in the modelling.

Area	Retained catch	Discarded catch
West coast Vancouver Island	April 1994 – March 2001	April 1996 – March 2001
Queen Charlotte Sound (“gullies”) Hecate Strait	Combined QCS & HS analysis: April 1994 – March 2001	Combined QCS & HS analysis: April 1996 – March 2001

The analysis on retained catch was limited to the period 1 April, 1994 to 31 March, 2001 as records of the latitude and longitude of each tow were not maintained until early in 1994. These data were crucial in this analysis as the spatial explanatory variable was usually the most important variable offered in every model investigated. The analysis on discarded catch was limited to the period 1 April, 1996 to 31 March, 2001 as reliable estimates of discarded catch were not available until observer coverage was instituted on nearly 100% of the deepwater trawl fleet.

We decided to limit the analysis to those tows which recorded a catch of turbot, either retained or discarded, depending on the model being investigated. Records without retained turbot catch were dropped because it is known that the decision to land turbot is based on economic factors, with the marginal value of this species dependent on the holding capacity of the vessel and the demand for the species by the processor. Therefore, a zero catch of retained turbot is rarely an indication of a lack of abundance and should not be treated in this way. It is more difficult to maintain a similar argument for discarded turbot catch, but it is likely that vessels which are not fishing for turbot will not always be fishing in a location or depth where turbot are likely to be caught. Distinguishing between records that should have caught turbot and did not as compared to records which were not in areas where turbot would be expected to be part of the bycatch would be a very difficult task. As well, it is possible that small amounts of discarded turbot will not always be enumerated by the observer. Future analyses may attempt this type of analysis.

5.5 Variables for GLM models

A large number of preliminary analyses were investigated but which will not be reported. These analyses showed that the most important variables offered to the model usually were variables which defined the area of catch. As indicated in Table 8, there were a number of such variables. When all available variables were offered to the model, the procedure outlined in Section 5.1 selected an area variable first in three of the four analyses and often selected more than one area variable before the model selection procedure ceased. When more than one area variable was selected into the model, the model fit was better (as defined in terms of the deviance explained); however, the plots of the area coefficients and their standard errors showed that many of the coefficients were poorly estimated (with very large error bars) and the correct interpretation of multiple area predictor variables is not clear. Therefore, for all the models reported in this document, only the area variable with the best explanatory power (as determined in a preliminary fit) was presented during the final fitting procedure, thus eliminating all other area variables. Furthermore, the model estimates of the abundance coefficients (year coefficients) were not very sensitive to which area variable was used or how many were included in the model.

Table 8. Area categorical variables used in the turbot general linear modelling.

Variable	**Description**
5km	constant 5 km^2 grid blocks
10km	constant 10 km^2 grid blocks
25km	constant 25 km^2 grid blocks
40km	constant 40 km^2 grid blocks
lat	0.1° latitude strips (WCVI models only)
minor	DFO minor statistical areas

All models forced the abundance index, defined as a standard fishing year (1 April to 31 March), as the first predictor variable. This was done because in most cases the year variable was not sufficiently important in terms of explanatory power to be introduced into the model and there is little point in pursuing these analyses for stock assessment purposes without creating an abundance index.

Each of the analyses presented in this paper has been supported by a presentation of auxiliary information on the distribution of the underlying data by standard fishing year and the distribution of log(CPUE) for the selected predictor variables (Appendix 3).

5.6 Main effects model: analysis of retained catch

5.6.1 West coast Vancouver Island

The analysis of retained catch for the west coast of Vancouver Island introduced four explanatory variables in addition to fishing year and explained approximately 0.36 of the residual deviance (Table 9). The plot of the abundance indices indicated that the 1996/97 to 1998/99 fishing years had the highest CPUE in the series, with considerably lower CPUE in 1994/95 and 1995/96 and an apparent small drop in the two most recent years (Figure 9). The two unstandardised sets of abundance indices follow the same broad trend but appear to be more variable than the standardised indices. Examination of the supporting data (Section 12.1) shows that there were fewer tows available in the first two years (Appendix Table 3) but that the distributions of data in those years for the selected predictor variables were similar to those seen in subsequent years (Appendix Figure 2).

Table 9. Regression results for GLM model applied to west coast Vancouver Island retained catch of turbot. Total deviance explained was 0.36 and the first four variables were accepted in the model (indicated by *****). Fishing year was forced as the first variable in model to provide an index of relative abundance. Table values are the proportion of the total residual deviance explained by each predictor variable at the specified iteration.

	Iteration				
Variable	**1**	**2**	**3**	**4**	**5**
Fishing year*	0.0375				
25 km^2 area grid*	0.1962	0.2209			
Vessel*	0.1251	0.1500	0.2929		
Month*	0.1408	0.1739	0.2831	0.3610	
Depth	0.0470	0.0778	0.2290	0.3000	0.3674
Increase in proportion deviance explained	0.0000	0.1835	0.0719	0.0681	0.0065

The plots of the coefficients for the 25 km^2 area variable show consistently high catch rates for areas 3 and 10 (Figure 10), which probably correspond to the areas of high retained catch rates shown in Figure 7. The monthly coefficients are uniformly high from May to October (Figure 10). Several vessels show high catch rates relative to the other vessels, indicating that these vessels may specialise in targeting on this species (Figure 10).

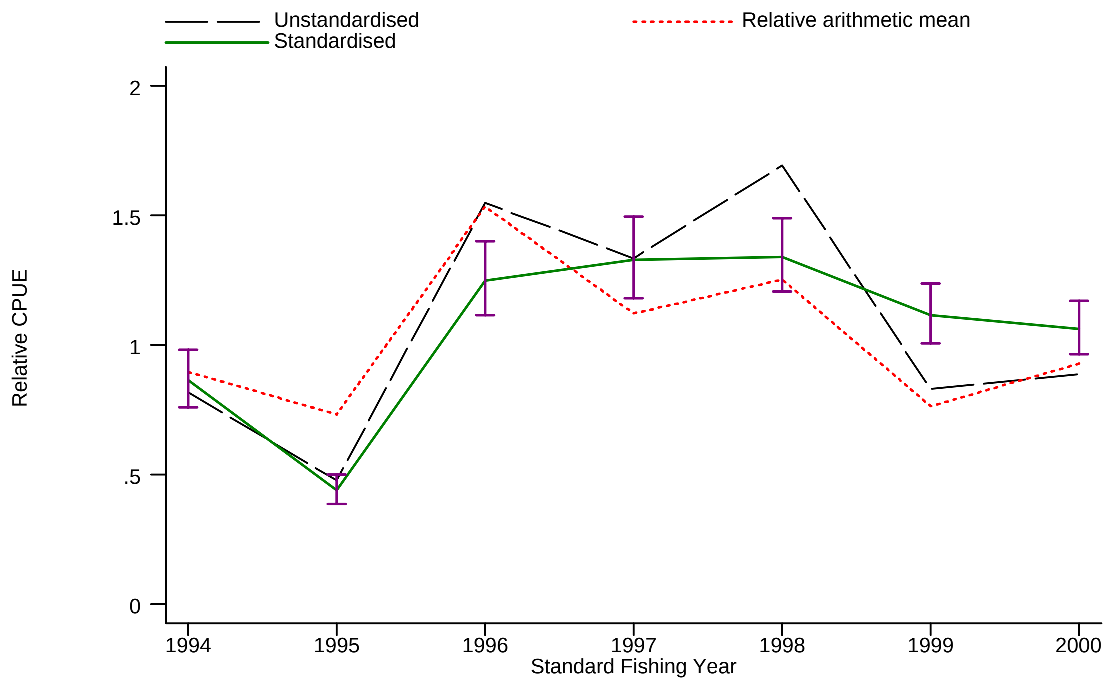


Figure 9. Plot of fishing year abundance estimates for WCVI retained catch regression model (only 25 km^2 area predictor variable offered) with each annual index normalised relative to the geometric mean of the indices in each set. Plotted lines: standardised index from the GLM (Eq. 3); unstandardised geometric mean of CPUE (Eq. 8); annual index of the arithmetic mean CPUE (Eq. 6).

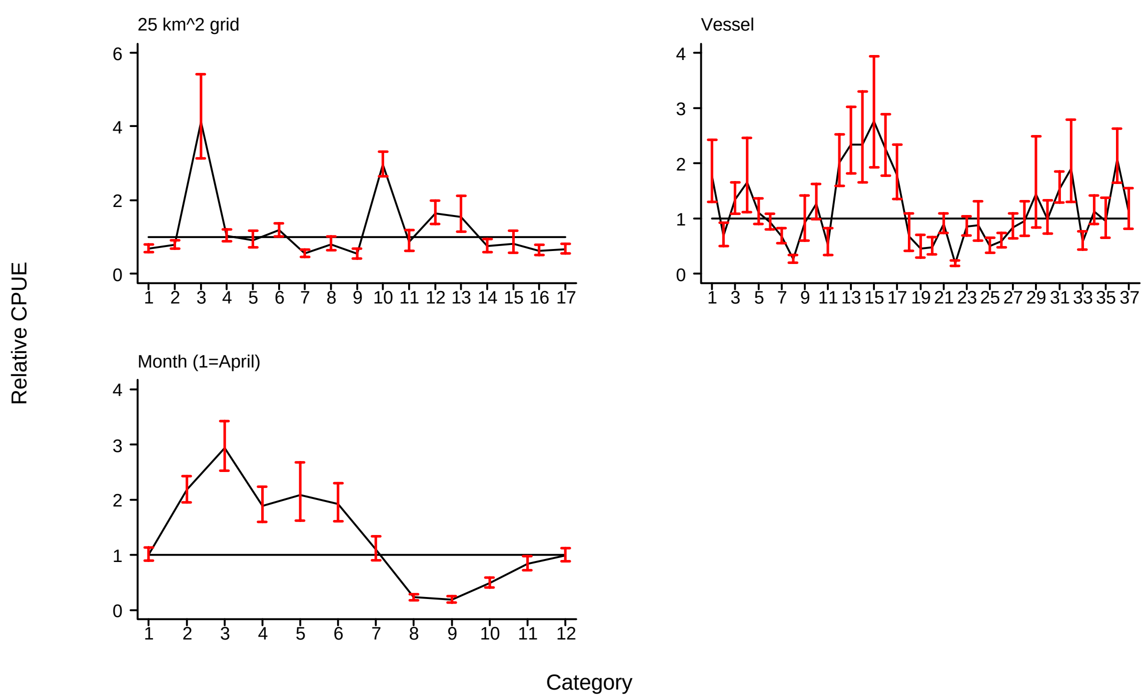


Figure 10. Canonical (Eq. 3) categorical variable coefficients for the WCVI retained catch regression model (only 25 km^2 area predictor variable offered) plotted as relative CPUE.

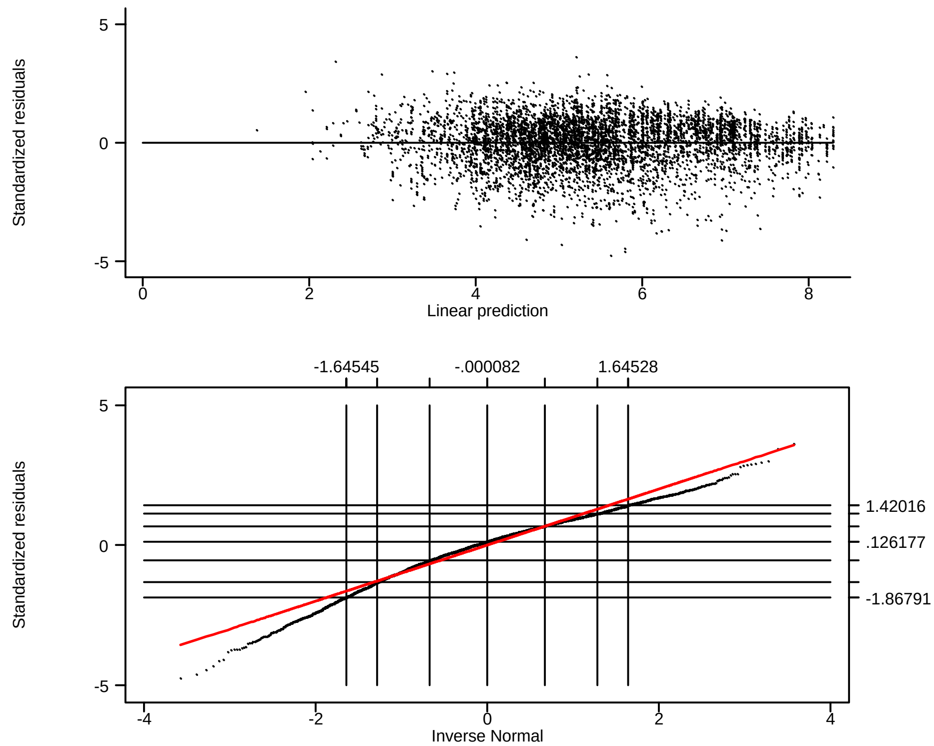


Figure 11. Standardised residuals for the WCVI retained catch regression model (only 25 km^2 area predictor variable offered).

The residual diagnostics for this model show deviations from the normal assumption at both ends of the distribution. The model shows a tendency to underestimate the observations at both the lower and upper tails and a slight bulge of overestimation in the centre of the distribution (Figure 11).

5.6.2 Combined Queen Charlotte Sound/Hecate Strait

The analysis of retained catch for the combined dataset for Queen Charlotte Sound and Hecate introduced only three explanatory variables in addition to fishing year and explained approximately 0.40 of the residual deviance (Table 10). Fishing year as an explanatory variable was stronger in this model than for any of the other models investigated, with fishing year entering into the model in third position when this model was fitted without forcing. The 10 km^2 grid area predictor variable was the best explanatory variable, providing 0.23 of the residual deviance in the first iteration.

The trend in the abundance indices is similar to that seen in the WCVI retained catch indices, with the 1996/97 fishing year showing the highest CPUE in the series and with considerably lower CPUE in 1994/95 and 1995/96. This series shows a tendency to decline towards the most recent years (Figure 9), but the current levels are higher than those experienced in 1994/95 or 1995/96 (Figure 12). The two unstandardised sets of abundance indices show a trend of increasing catch rates, indicating that the standardisation procedure has possibly captured some changes in fishing practices which have led to higher unstandardised catch rates but which are attributable to factors in the other explanatory variables.

Table 10. Regression results for GLM model applied to combined QCS&HS retained catch of turbot. Total deviance explained was 0.40 and the first four variables were accepted in the model (indicated by *****). Fishing year was forced as the first variable in model to provide an index of relative abundance. Table values are the proportion of the total residual deviance explained by each predictor variable at the specified iteration.

	Iteration				
Variable	**1**	**2**	**3**	**4**	**5**
Fishing year*	0.0869				
10 km^2*	0.2291	0.2887			
Vessel*	0.2043	0.2503	0.3812		
Month*	0.0267	0.1089	0.3022	0.3974	
Depth	0.0569	0.1376	0.2991	0.3888	0.4025
Increase in proportion deviance explained	0.0000	0.2018	0.0924	0.0162	0.0051

The plot of the coefficients for the 10 km^2 area variable shows high catch rates for areas 18 to 20 and 22 to 24 (Figure 13). These probably correspond to the areas of high catches rates shown in Figure 7. The monthly coefficients are similar to those estimated for the WCVI retained catch (compare Figure 13 with Figure 10), being uniformly high from May to October. As seen in the WCVI retained catch analysis, a few vessels (here about 4 to 6 vessels) show relatively high catch rates, possibly being indicative of specialisation in this species by these vessels.

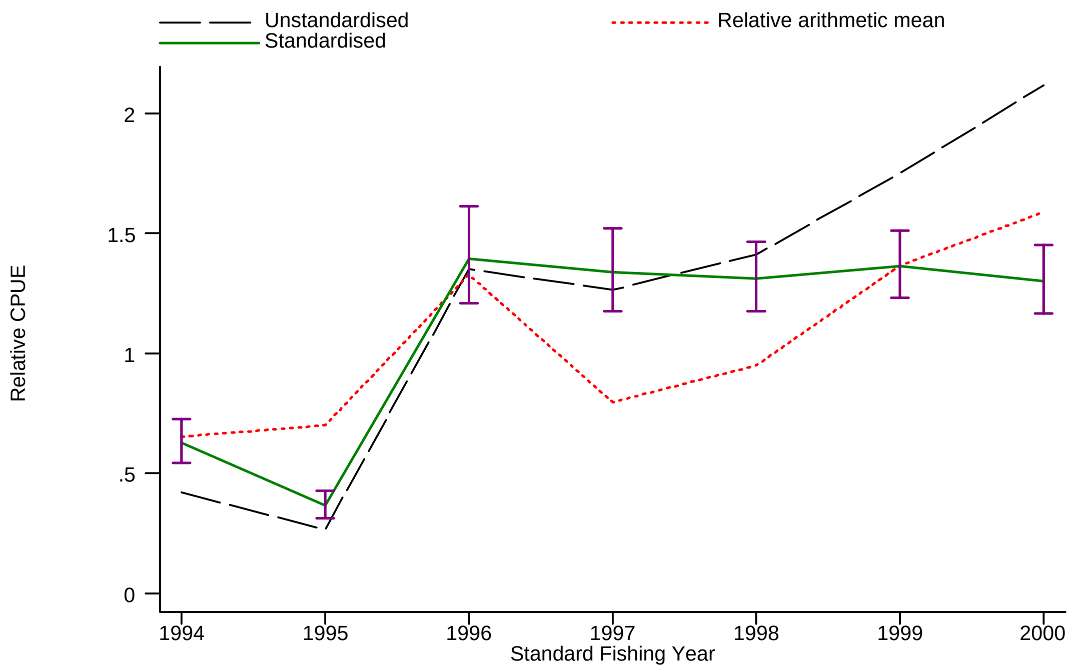


Figure 12. Plot of fishing year abundance estimates for the combined QCS and Hecate St. retained catch regression model (only 10 km^2 area predictor variable) with each annual index normalised relative to the geometric mean of the indices in each set. Plotted lines: standardised index from the GLM (Eq. 3); unstandardised geometric mean of CPUE (Eq. 8); annual index of the arithmetic mean CPUE (Eq. 6).

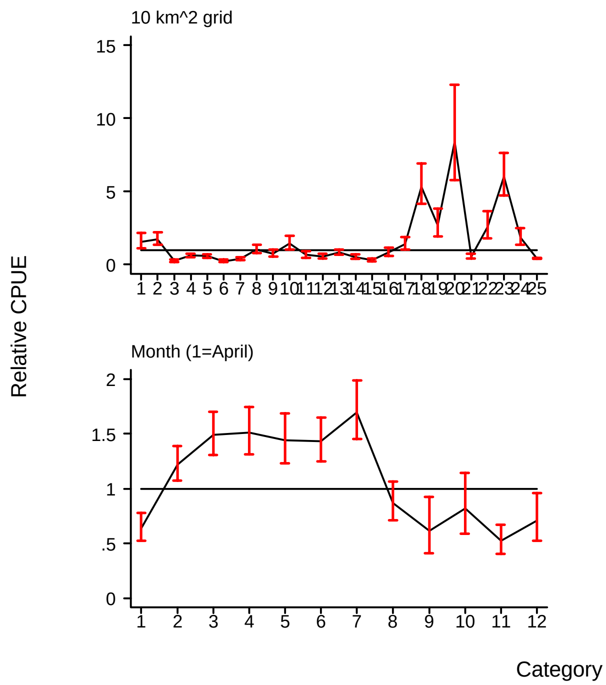


Figure 13. Canonical (Eq. 3) categorical variable coefficients for the combined QCS and Hecate St. retained catch regression model (only 10 km^2 area predictor variable offered) plotted as relative CPUE.

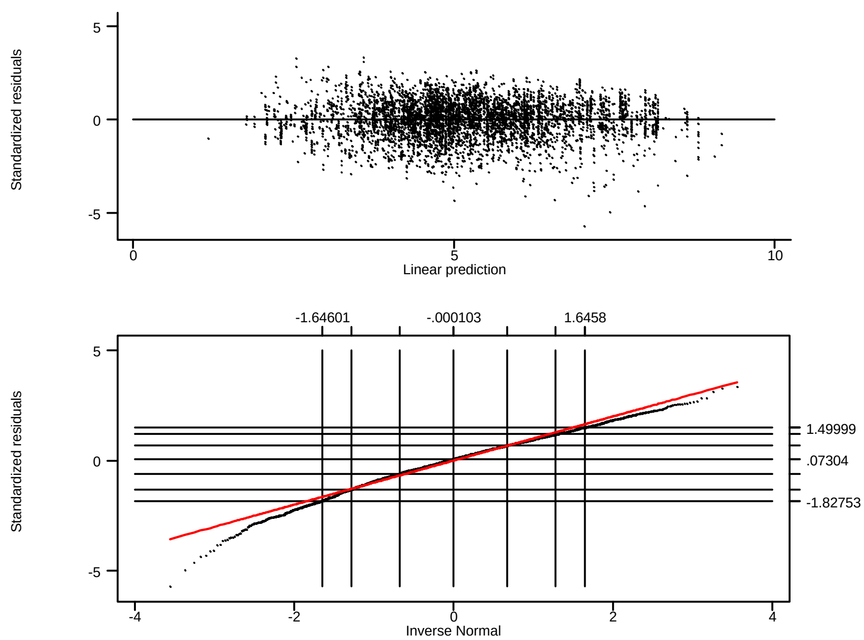


Figure 14. Standardised residuals for the combined QCS and Hecate St. retained catch regression model (only 10 km^2 area predictor variable offered).

The residual diagnostics for this model seem better than for the WCVI retained catch model, with deviations from the normal assumption at both ends of the distribution being smaller and without the bulge in the centre of the distribution (Figure 14).

5.7 Main effects model: analysis of discards

5.7.1 West coast Vancouver Island

The analysis of discarded catch for the west coast of Vancouver Island introduced five explanatory variables in addition to fishing year and explained approximately 0.17 of the residual deviance (Table 11). The predictor variable for area (in this case the 0.1° latitude band variable) was much less important than for the equivalent retained catch analysis, as evidenced by its late entry into the analysis (it entered in the last significant position). The plot of the abundance indices shows almost no contrast in abundance over the five years of data (Figure 15) and only a small amount of deviance is explained by this predictor variable (0.0019; Table 11). The two unstandardised sets of abundance indices follow the same trend as the standardised index and the underlying data show very little contrast (Appendix Figure 6).

Table 11. Regression results for GLM model applied to west coast Vancouver Island discarded catch of turbot. Total deviance explained was 0.17 and the first five variables were accepted in the model (indicated by *). Fishing year was forced as the first variable in model to provide an index of relative abundance. Table values are the proportion of the total residual deviance explained by each predictor variable at the specified iteration.

	Iteration				
Variable	**1**	**2**	**3**	**4**	**5**
Fishing year*	0.0019				
Vessel*	0.0501	0.0527			
Month*	0.0394	0.0401	0.0991		
Depth*	0.0362	0.0385	0.0856	0.1534	
0.1° Latitude band*	0.0342	0.0358	0.0841	0.1371	0.1725
Increase in proportion deviance explained	0.0000	0.0508	0.0463	0.0543	0.0190

The plot of the coefficients for month shows the same trends as do the two retained catch analysis (Figure 16). The plot of the coefficients for depth band shows above average catch rates from the 250-300 m band to the 450-500 m band (Figure 16). The plot of the 0.1° latitude band area variable coefficients shows high catch rates for bands 13 to 15 (Figure 16) which correspond to latitude bands 49.4°-49.5°, 49.6°-49.7° and 50.3°-50.4° which correspond to the regions of high discard rates shown near mid-Vancouver Island (Figure 8). While some vessels have relatively higher catch rates than others, the contrast between the highest and lowest vessels is less for the discard fishery than for the equivalent retained turbot catch fishery (compare Figure 10 and Figure 16).

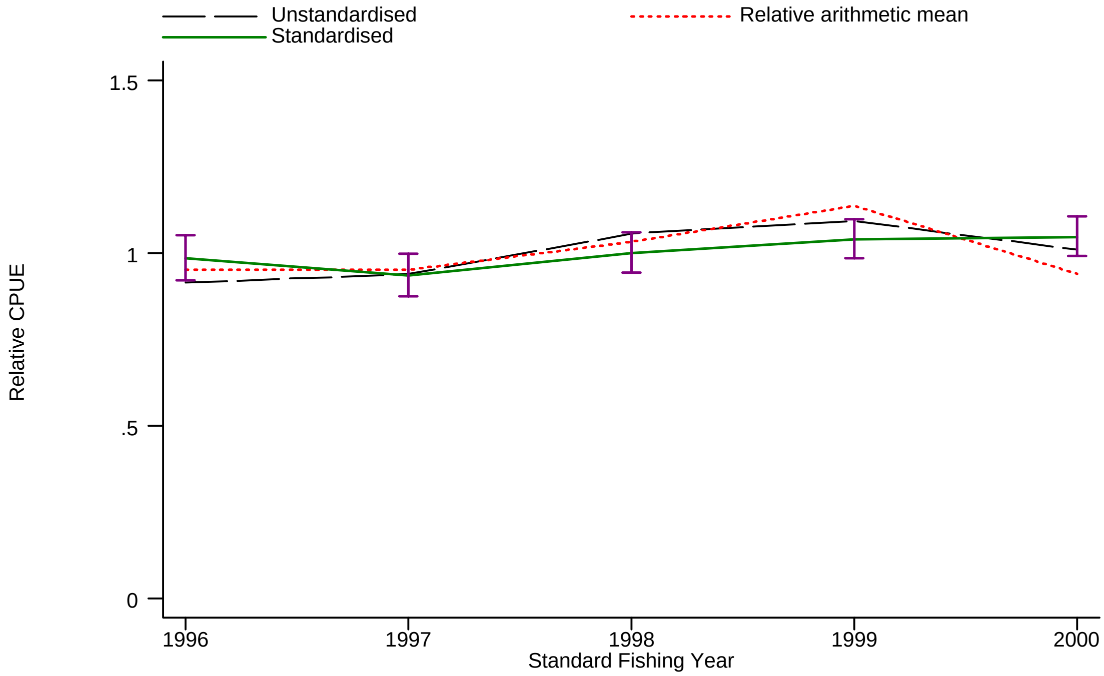


Figure 15. Plot of fishing year abundance estimates for WCVI discarded catch regression model (only 0.1° latitude band predictor variable offered) with each annual index normalised relative to the geometric mean of the indices in each set. Plotted lines: standardised index from the GLM (Eq. 3); unstandardised geometric mean of CPUE (Eq. 8); annual index of the arithmetic mean CPUE (Eq. 6).

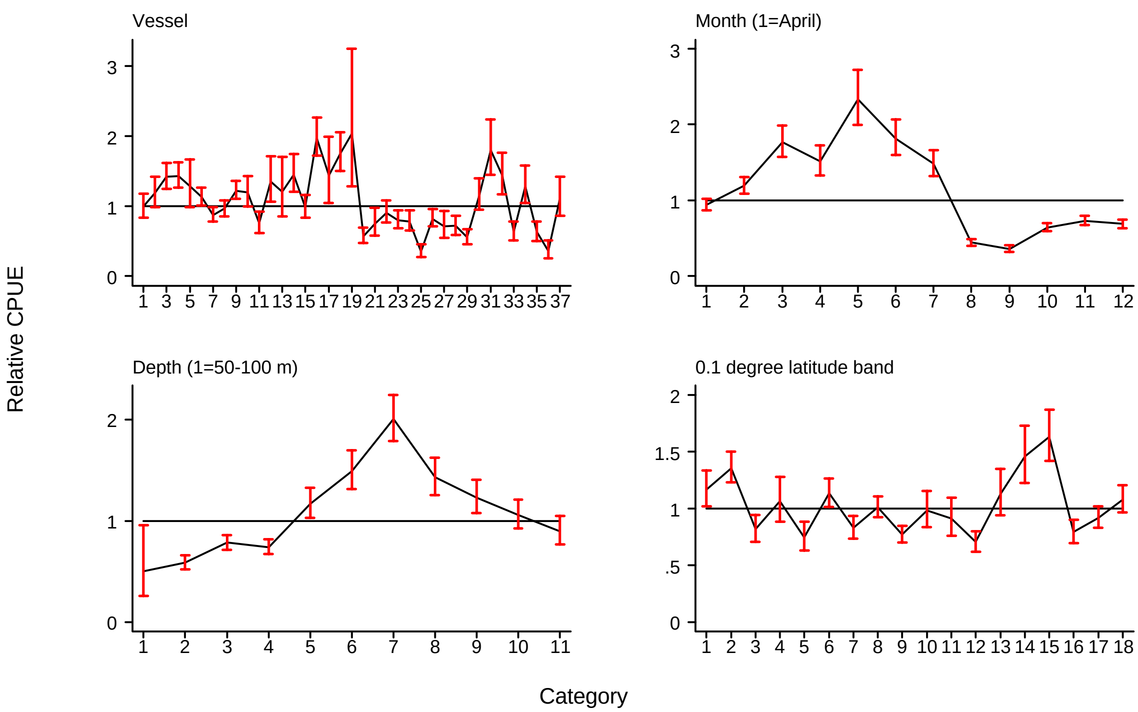


Figure 16. Canonical (Eq. 3) categorical variable coefficients for the WCVI discarded catch regression model (only 0.1° latitude predictor variable offered) plotted as relative CPUE.

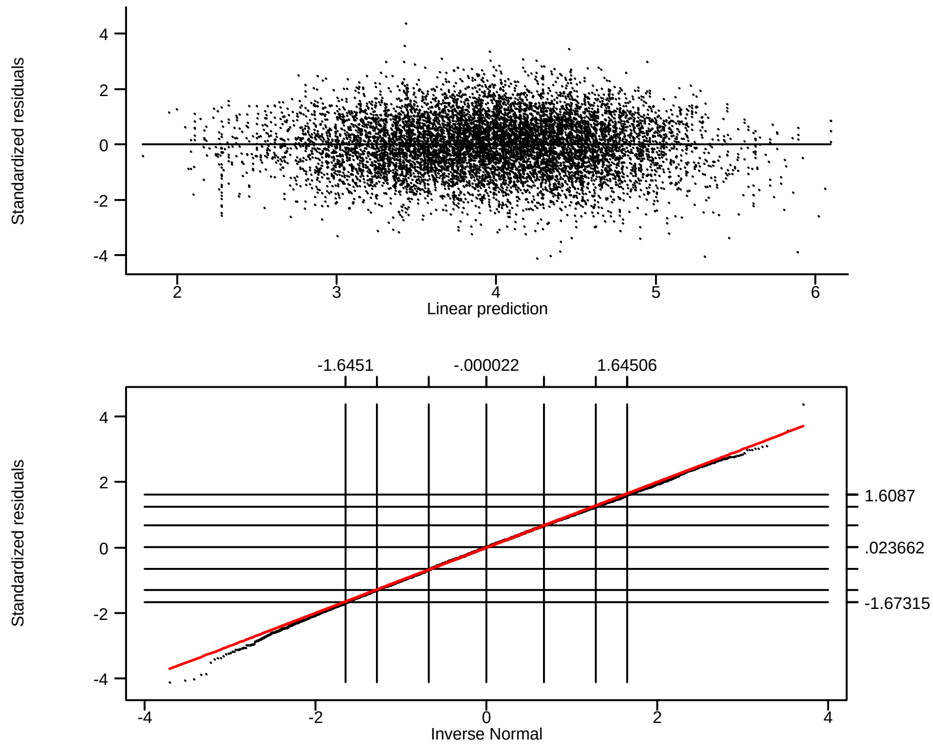


Figure 17. Standardised residuals for the WCVI discarded catch regression model (only 0.1° latitude area predictor variable offered).

The residual diagnostics for this model are very good, with almost no deviations from the normal assumption at either end of the distribution (Figure 17).

5.7.2 Combined Queen Charlotte Sound/Hecate Strait

The analysis of discarded catch for the combined dataset for Queen Charlotte Sound and Hecate introduced four explanatory variables in addition to fishing year and explained approximately 0.24 of the residual deviance (Table 12). As with the WCVI discard catch analysis, fishing year was a very poor predictor of ln(CPUE), accounting for only 0.0034 of the residual deviation in the first model iteration. Unlike the WCVI discard analysis, the area predictor variable (the 40 km^2 grid variable) was the strongest explanatory variable, entering the model first and accounting for 0.10 of the residual deviance.

The plot of the abundance indices is similar to those for the WCVI discarded catch, with almost no contrast in the indices over the five year period (Figure 18). The unstandardised and arithmetic indices also show little contrast. The plots of the coefficients for month and 50 m depth band are similar to the same plots for the other discard analysis (compare Figure 19 with Figure 16), with the highest catch rates occurring from May to October and in the 250-300 m to the 450-500 m depth bands. This pattern is also evident in the plots of the auxiliary supporting data provided in Appendix Figure 8. The 40 km^2 grid area variable shows very high catch rates for areas 15 to 17 (Figure 19).

Table 12. Regression results for GLM model applied to combined QCS&HS discarded catch of turbot. Total deviance explained was 0.24 and the first five variables were accepted in the model (indicated by *). Fishing year was forced as the first variable in model to provide an index of relative abundance and depth was truncated at 1/99% of the distribution. Table values are the proportion of the total residual deviance explained by each predictor variable at the specified iteration.

	Iteration				
Variable	**1**	**2**	**3**	**4**	**5**
Fishing year*	0.0034				
40 km^2 grid*	0.0968	0.0996			
Month*	0.0705	0.0719	0.1784		
Vessel*	0.0417	0.0434	0.1298	0.2139	
Depth Band*	0.0291	0.0324	0.1204	0.2093	0.2422
Increase in proportion deviance explained	0.0000	0.0962	0.0789	0.0354	0.0283

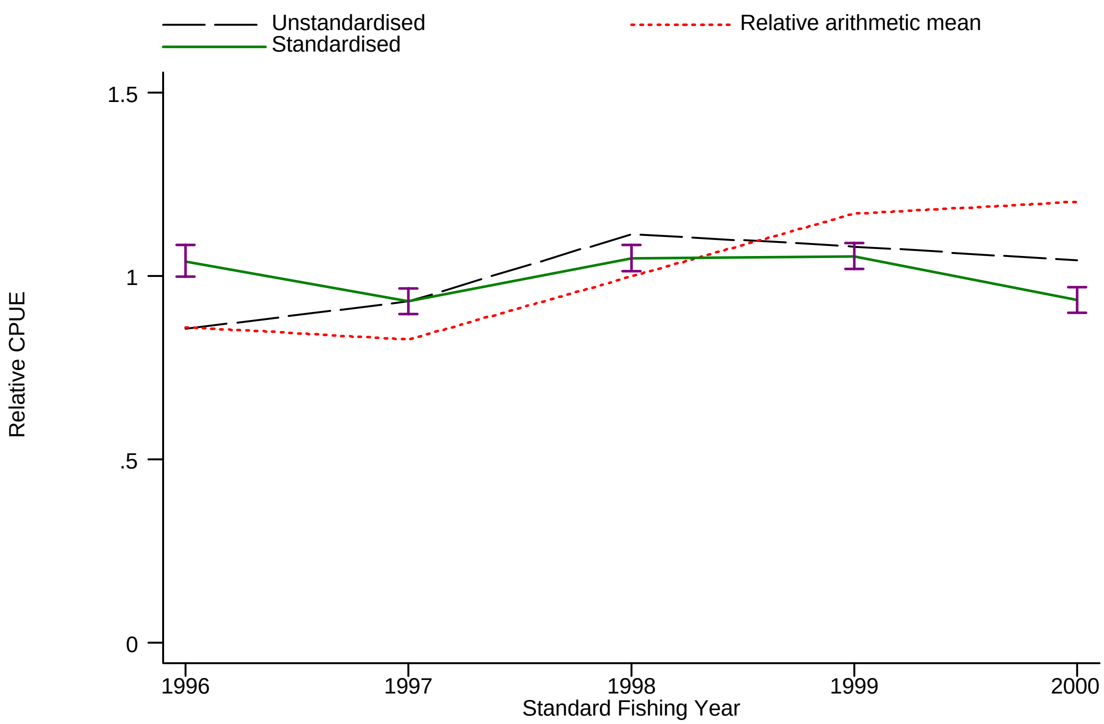


Figure 18. Plot of fishing year abundance estimates for the combined QCS and Hecate St. discard catch regression model (only 40 km^2 area predictor variable offered and depth truncated at 1/99%) with each annual index normalised relative to the geometric mean of the indices in each set. Plotted lines: standardised index from the GLM (Eq. 3); unstandardised geometric mean of CPUE (Eq. 8); annual index of the arithmetic mean CPUE (Eq. 6).

As for the west coast of Vancouver Island discard analysis, the residual diagnostics for this model are very good, with almost no deviations from the normal assumption at either end of the distribution (Figure 20).

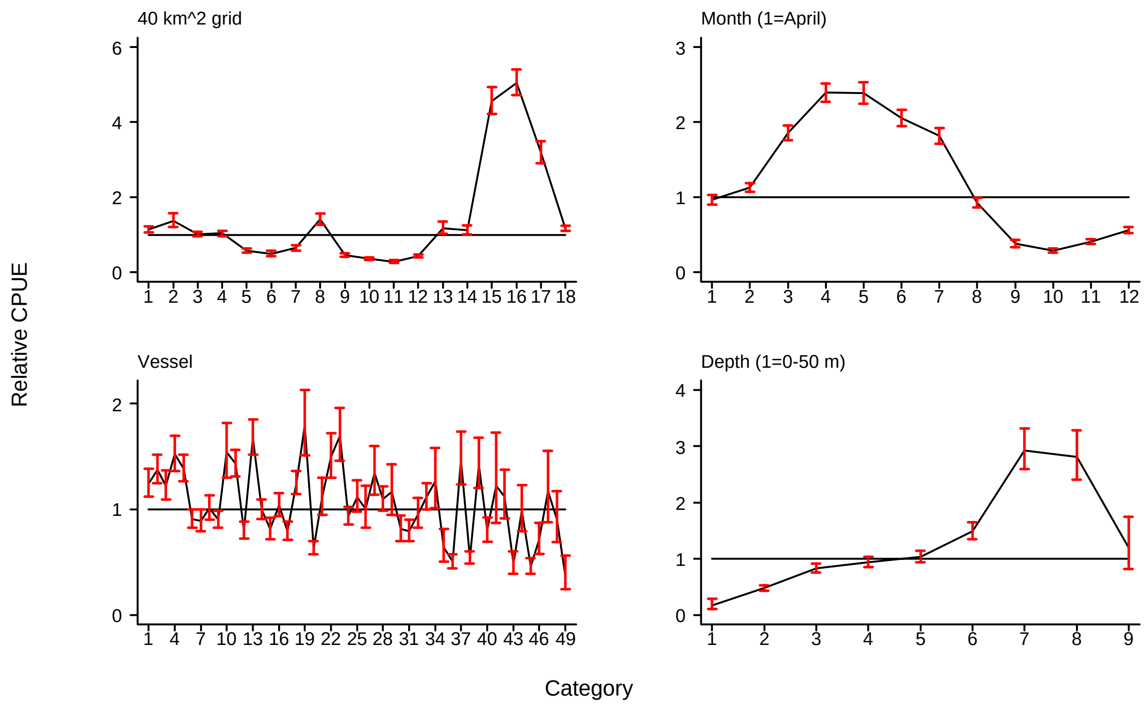


Figure 19. Canonical (Eq. 3) categorical variable coefficients for the combined QCS and Hecate St. discard catch regression model (only 40 km^2 area predictor variable offered and depth truncated at 1/99%) plotted as relative CPUE.

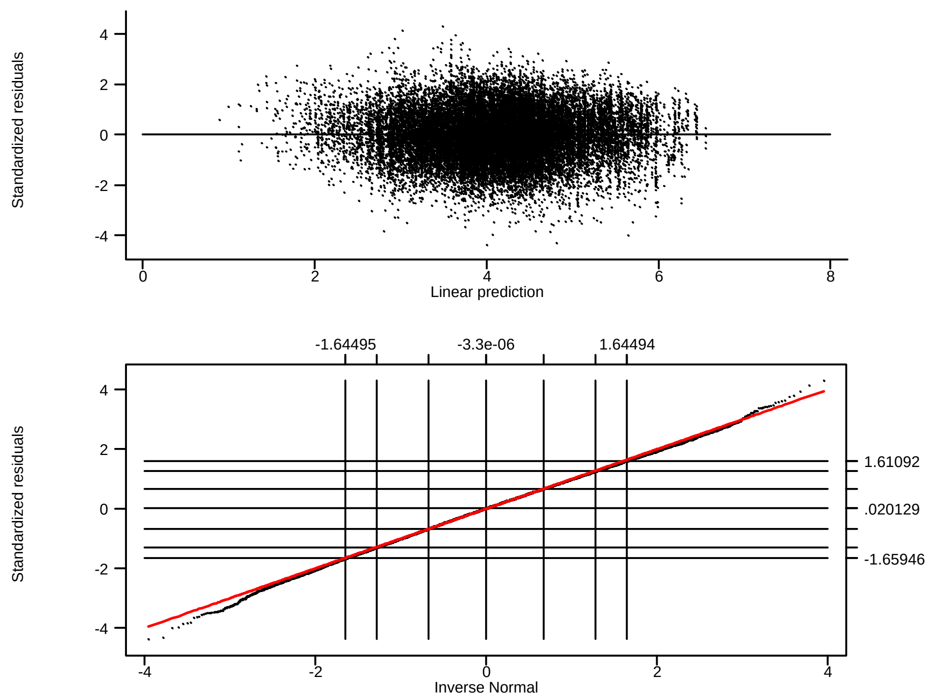


Figure 20. Standardised residuals for the combined QCS and Hecate St. discard catch regression model (only 40 km^2 area predictor variable offered and depth truncated at 1/99%).

5.8 Main effects model: summary of results

All four of the main effects models introduced similar predictor variables into the final regression (Table 13). Both retained catch models accepted the same four variables in the same order. Both retained catch models also did not include depth as an explanatory variable. The only difference between these models was that the WCVI model used a larger area grid explanator (25 km^2) than the QCS&HS model (10 km^2). Both models also accounted for approximately the same proportion of the total deviance (0.36 and 0.40). The discard catch models accepted the same five explanator variables but in a different order, with the area explanator variable being considerably more important for the QCS&HS model than for the WCVI model (Table 13). Both discard catch models used the depth categorical variable, but this variable entered the model late in the stepwise selection process. The discard catch models accounted for much less of the total deviance (0.17 and 0.24) than did the retained catch models (Table 13).

Table 13. Summary of the four main effects models performed on two catch types over two areas of the B.C. coast: order of acceptance of key predictor variables and the proportion of the total deviance explained. “NA” indicates that the variable was not accepted into the model.

Variable	WCVI Retained	QCS&HS Retained	WCVI Discard	QCS&HS Discard
Fishing year	1	1	1	1
Area variable	2	2	5	2
Vessel	3	3	2	4
Month	4	4	3	3
Depth	NA	NA	4	5
Proportion of deviance explained	0.36	0.40	0.17	0.24

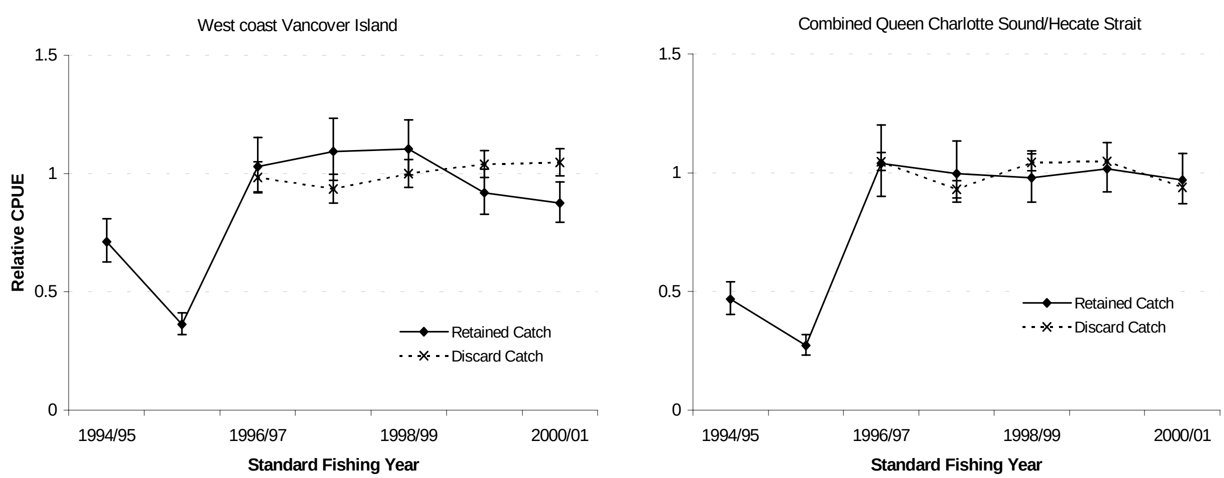


Figure 21. Overlay of the canonical (Eq. 3) coefficients for fishing year for the retained and discard catch models from each of the two area modelled: [left panel] west coast Vancouver Island; [right panel] combined Queen Charlotte Sound/Hecate Strait. The coefficients and the error bars from the two retained catch models have been standardised relative to the geometric mean for the 1996/97 to 2000/01 fishing years for comparability to the discard catch models.

The abundance trends estimated by the four main effects model are surprisingly similar for the overlapping fishing years (Figure 21). The two WCVI models show some divergence in abundance trends in the two most recent fishing years while the QCS&HS models estimate the same relative coefficients for all five years of overlap. It can also be seen from Figure 21 that the coefficient error bars estimated by all four models substantially overlap, indicating that the data provide consistent abundance trends for each of the areas when using either the retained or discarded turbot catch data.

5.9 Interaction effects model

An analysis of the interaction effects for all the selected model predictor parameters (with the exception of vessel interactions) was performed for each of the four models described in the previous section. The omission of vessel interactions was forced due to limitations in the available software which precluded performing the full analysis on the large number of variables generated when using all selected first order predictor variables and the consequent second order interaction combinations based on the selected predictor variables. The interaction analysis was done by creating categorical variables which described the interactions between each pair of selected predictor variables, providing a total of three to six combinations of variable interactions, depending on the analysis. Each paired interaction term was then offered to the model after the main effects model predictor variables were used. The selection criteria provided in Section 5.1 were used as the basis for deciding which interaction pairs would be considered "significant" as traditional tests of model significance are almost always true, given the relatively large number of observations in these models.

Each of the four models selected three or four of the interaction terms using the Section 5.1 criteria, with all models showing considerable improvement in fit relative to the main effects model. These models probably have far too many variables, resulting in unusual coefficient estimates in some instances and large standard errors for the more poorly determined coefficients. However, these analyses indicate that there are complex interactions in these models which affect the interpretation of the trends that are seen in the simpler main effects models.

5.9.1 Interaction effects model: west coast Vancouver Island retained catch

The first interaction term entering this model is an areaXmonth interaction, which is not surprising given the strong seasonal nature of most fisheries and the necessity of fishing in exposed areas only during the more clement seasons (Table 14). Interaction terms involving fishing year follow, first with month and then with the 25 km^2 area grid. There is a good improvement in the amount of deviance explained by this model, increasing from 0.36 to 0.52 (Table 14). There are changes to some of the categorical coefficients compared to the estimates from the main effects model, with substantial changes in the coefficient patterns for fishing year and month while the coefficient pattern for vessel is almost completely unchanged (compare Figure 22 with Figure 10). Model fits do not appear to be improved in the interaction model compared to the main effects model (Figure 23 and Figure 11). Pairwise plots of the fishing year coefficients for every combination of the 25 km^2 grids show major differences in the fishing year coefficient patterns between some of the grids (eg. grids 3 and 8 or grids 7 and 14 or grids 11 and

14; Figure 24). There are also many cases of similar trends between areas (eg. 2 and 4 or 4 and 8; Figure 24) and instances of similar trends in all years except for the first or last year (eg. 2 and 8 or 13 and 17; Figure 24). While these differences in fishing year coefficient trends are apparent to the eye, the model selection process selected this interaction term last, with an improvement in deviance of about 0.03 (Table 14).

Table 14. Regression results for interaction effects GLM model applied to west coast Vancouver Island retained catch of turbot. Total deviance explained was 0.52, an improvement of 0.15 over the main effects model. All three of the interaction terms offered to the model were accepted (indicated by a *****). These three interaction terms represent all the available interactions from the main effects model after excluding the vessel interactions. Table values are the proportion of the total residual deviance explained by each interaction variable at the specified iteration after fitting all the main effects terms indicated in Table 9.

	Iteration		
Interaction Variable	**1**	**2**	**3**
25 km^{2}Xmonth*	0.4586		
Fishing yearXMonth*	0.4066	0.4930	
Fishing yearX25 km^2*	0.4154	0.4927	0.5218
Increase in proportion deviance explained	0.0976	0.0344	0.0288

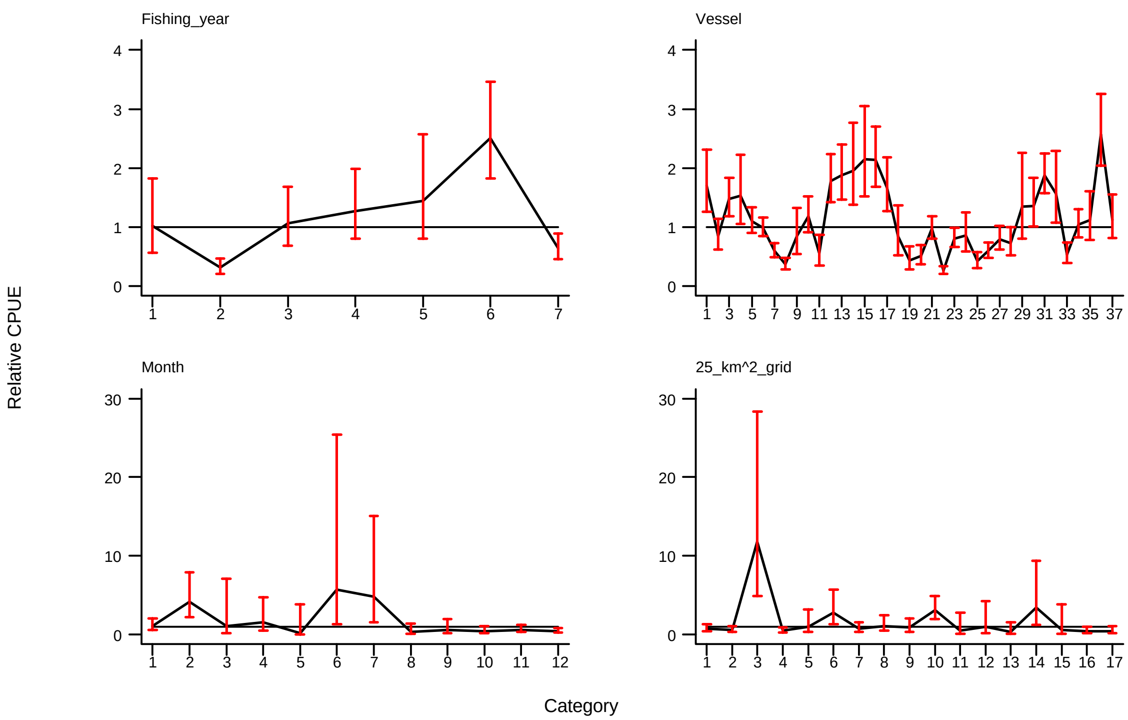


Figure 22. Main effects coefficients and 2*standard error confidence bounds for the WCVI retained catch interaction effects model (Table 14)..

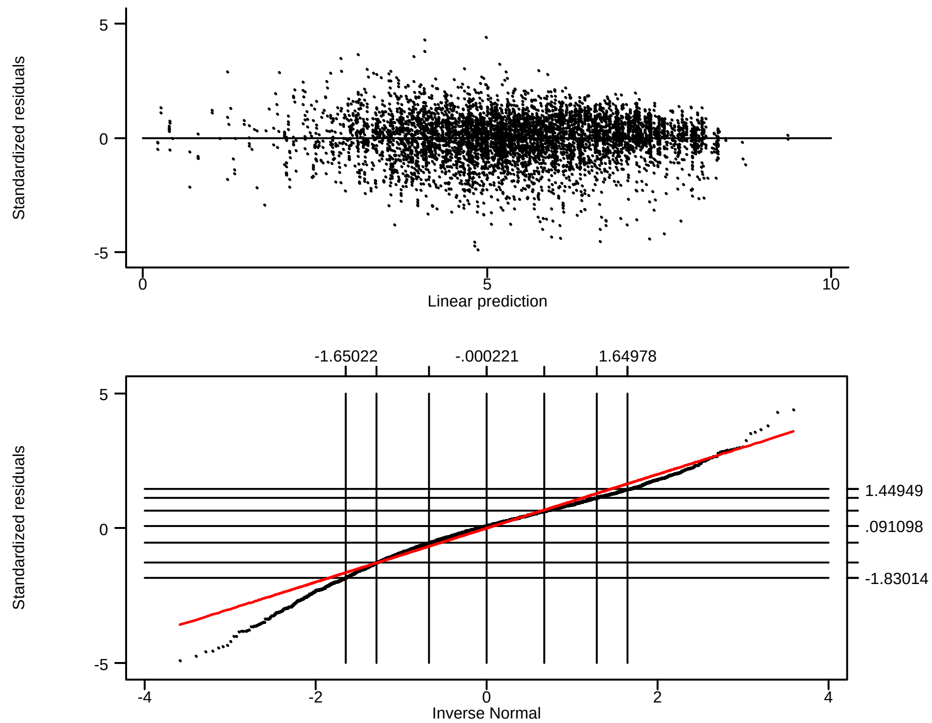


Figure 23. Standardised residuals for the WCVI retained catch interaction effects regression model (only 25 km^2 area predictor variable offered).

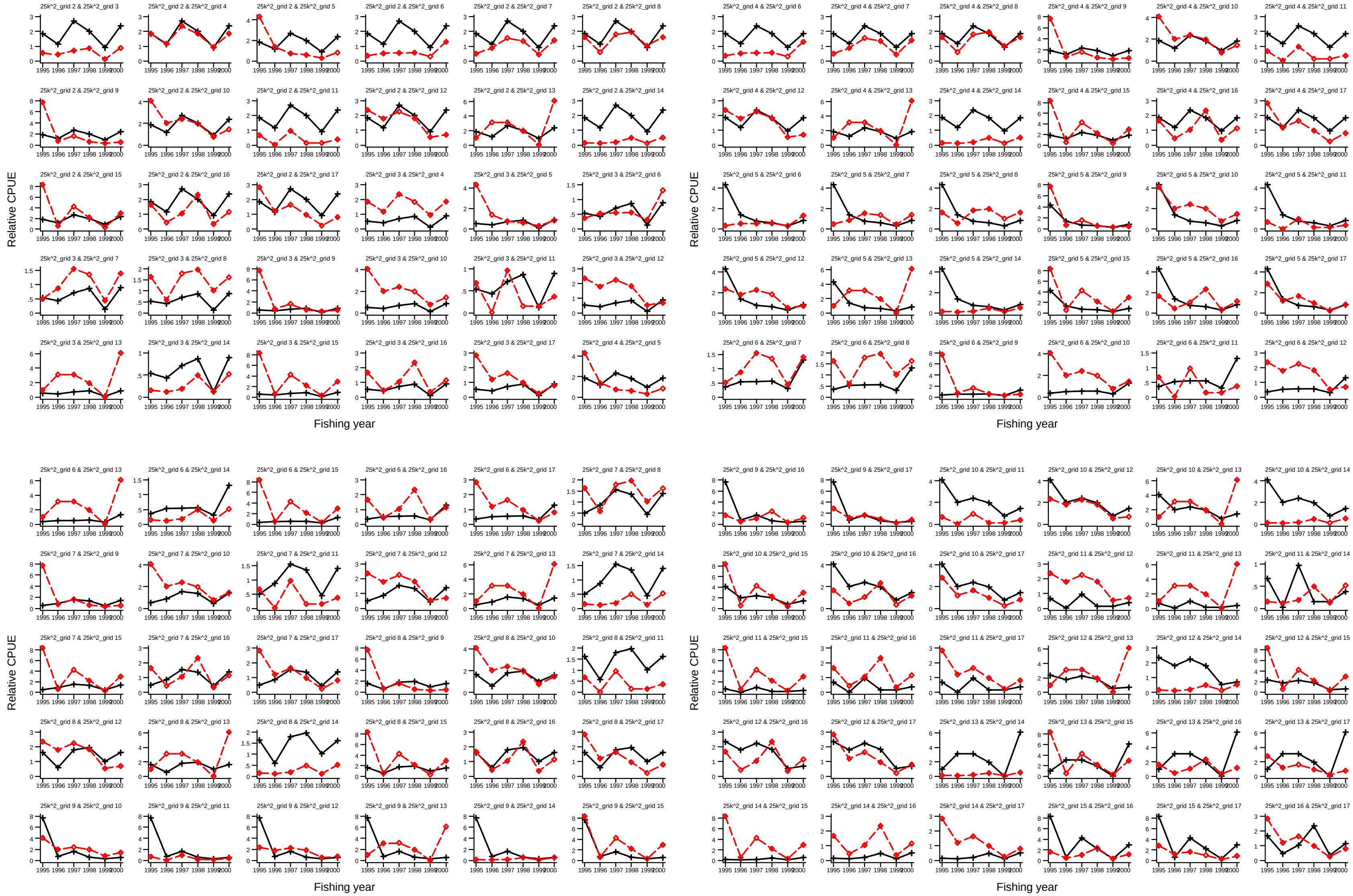


Figure 24. Fishing year coefficients for every combination of paired 25 km^2 grid for the WCVI retained catch interaction model described in Table 14.

5.9.2 Interaction effects model: Queen Charlotte Sound & Hecate Strait retained catch

The order of acceptance of the interaction terms for this model is the same as for the west coast Vancouver Island retained catch model: areaXmonth, followed by fishing yearXmonth and fishing yearXarea (Table 15). This is a striking similarity given the different nature of the fisheries, possibly being evidence for stock or biological affinity. As with the other retained catch model, there is a good improvement in the amount of deviance explained by this model, increasing from 0.40 to 0.58 (Table 15). The categorical coefficients are considerably changed compared to the estimates from the main effects model, particularly to the coefficient patterns for fishing year, month and 10 km^2 area grid (Figure 25 and Figure 13) As with the other retained catch model, the coefficient pattern for vessel is almost completely unchanged (compare Figure 25 with Figure 13) Model fits are similar between the interaction model and the main effects model (Figure 26and Figure 14). There are a great many pairwise plots of the fishing year coefficients for every combination of the 10 km^2 grids (276 for 24 categories) which show similar major differences between some of the grids in the fishing year coefficient patterns as were seen for the west coast Vancouver Island retained catch interaction model (eg. grids 7 and 19 or grids 2 and 22;Figure 27). There are some cases of similar trends between areas (eg. 6 and 7 or 2 and 7) and many instances of similar trends in all years except for the first or last year (eg. 2 and 5 or 8 and 24). As with the other retained catch model, the model selection process selected this interaction term last, with an improvement in deviance of around 0.03 (Table 15).

Table 15. Regression results for interaction effects GLM model applied to the combined Queen Charlotte Sound/Hecate St. retained catch of turbot. Total deviance explained was 0.58, an improvement of 0.18 over the main effects model. All three of the interaction terms offered to the model were accepted (indicated by a *****). These three interaction terms represent all the available interactions from the main effects model after excluding the vessel interactions. Table values are the proportion of the total residual deviance explained by each interaction variable at the specified iteration after fitting all the main effects terms indicated in Table 10.

	Iteration		
Variable	**1**	**2**	**3**
10 km^2Xmonth*	0.5142		
Fishing yearXMonth*	0.4408	0.5440	
Fishing yearX10 km^2*	0.4503	0.5503	0.5788
Increase in proportion deviance explained	0.1168	0.0298	0.0348

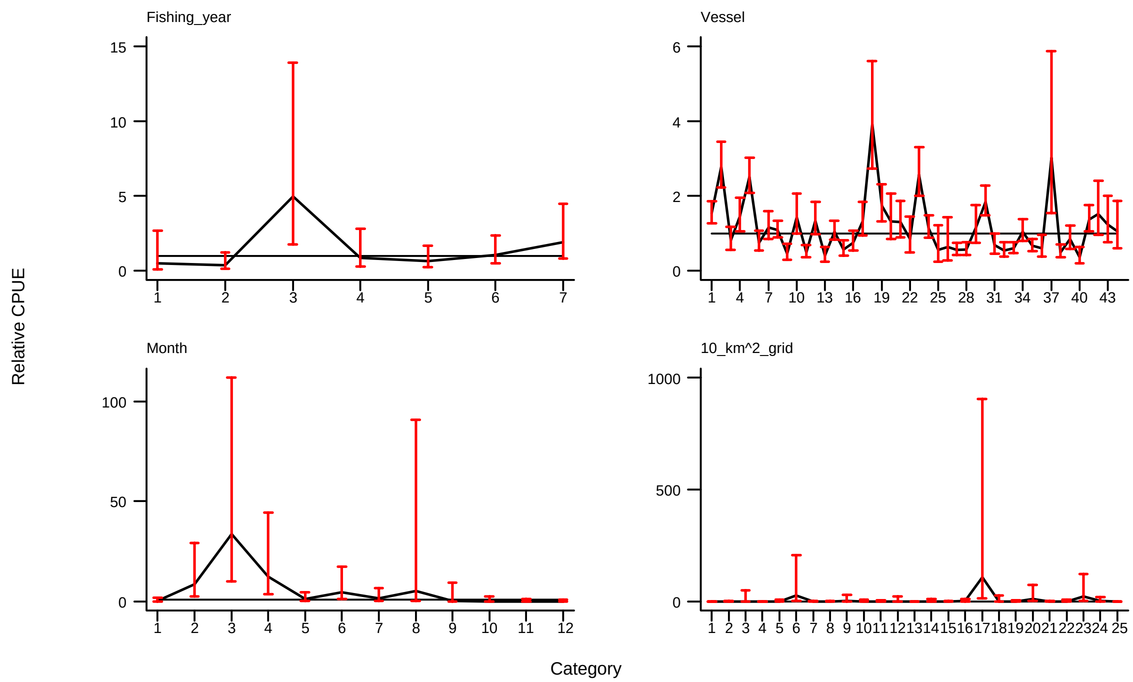


Figure 25. Main effects coefficients and 2*standard error confidence bounds for the combined QCS/HS retained catch interaction effects model (Table 15)..

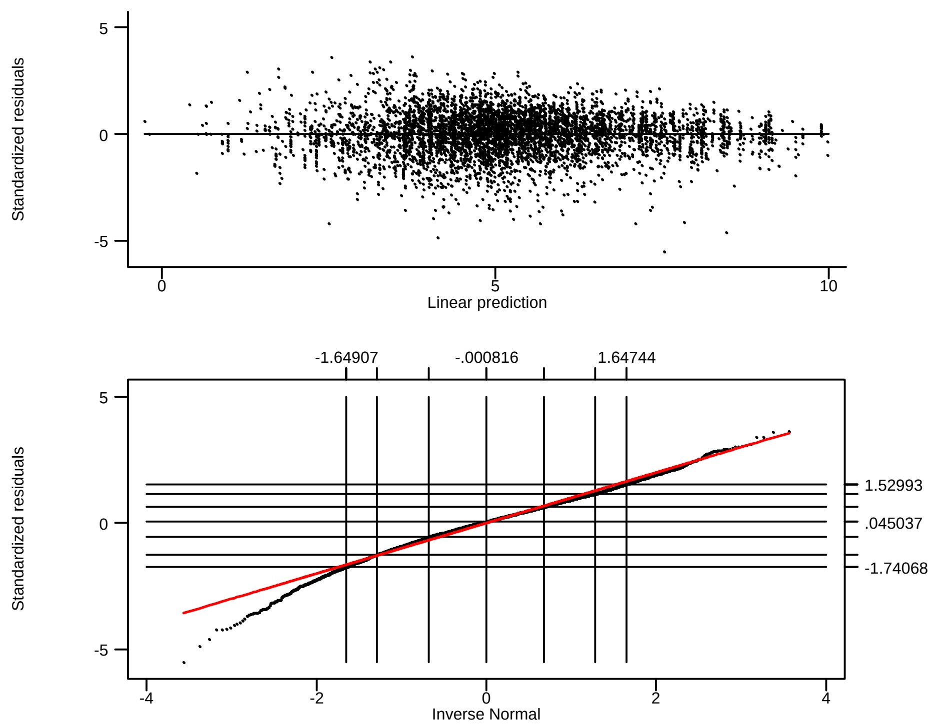
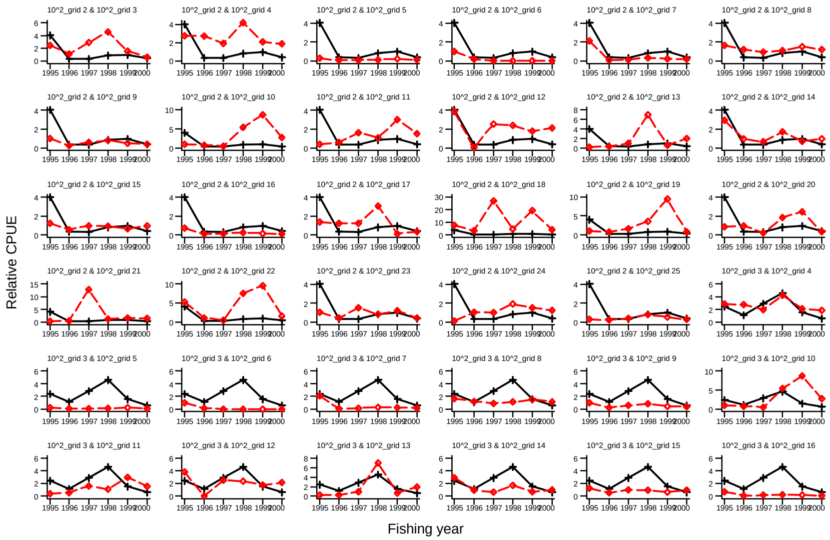
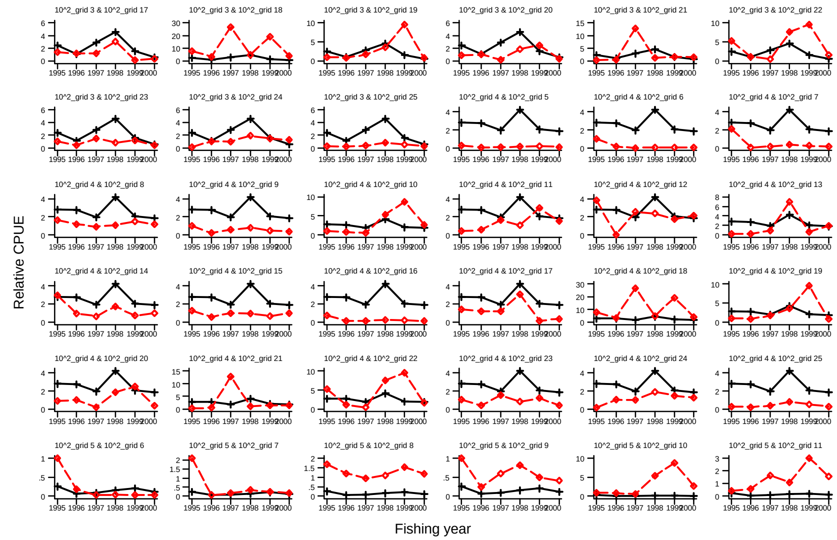
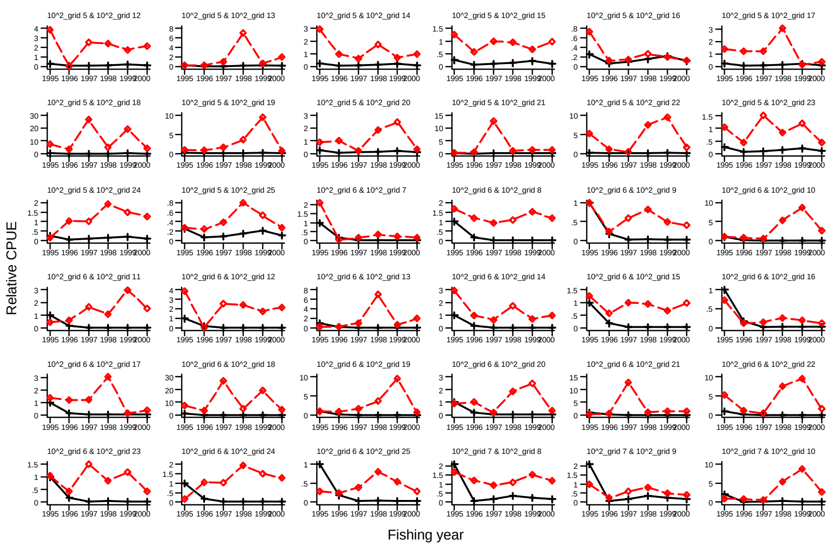
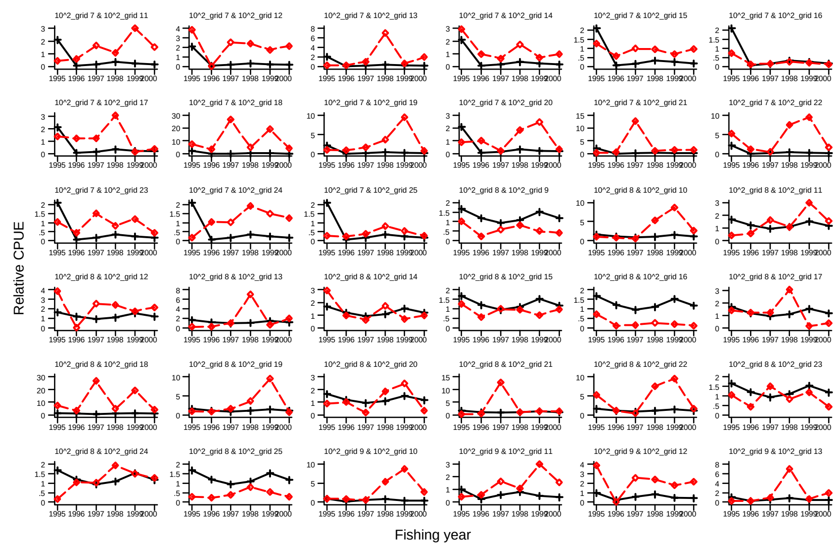


Figure 26. Standardised residuals for the combined QCS/HS retained catch interaction effects regression model (only 10 km^2 area predictor area variable offered).


Relative CPUE
Fishing year


Relative CPUE
Fishing year


Relative CPUE
Fishing year


Relative CPUE
Fishing year

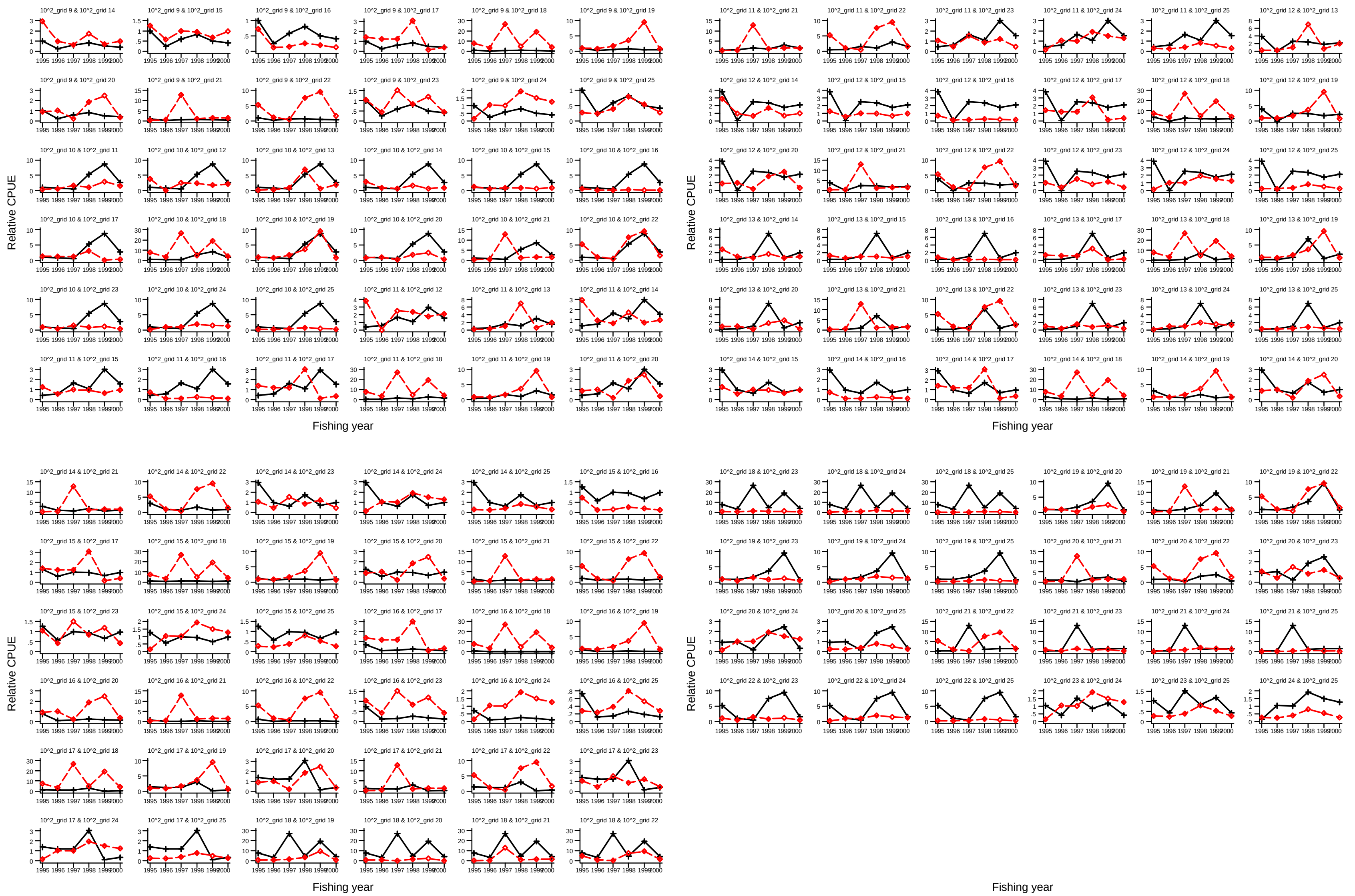


Figure 27. Fishing year coefficients for every combination of paired 10 km^2 area grid for the combined QCS&HS retained catch interaction model described in Table 15.

5.9.3 Interaction effects model: west coast Vancouver Island discard catch

There are three additional interaction terms included in the two discard catch models compared to the retained catch models because the two main effects models based the discard catch included a depth effect while the retained catch models did not. However, only three of these six interaction terms were included in the model based on the criteria provided in Section 5.1 (Table 16). There were no fishing yearXarea interactions included and the only interaction term including fishing year was with month (Table 16). The improvement in the amount of deviance explained by this model is proportionately large, increasing by 0.14 from 0.17 to 0.31 (Table 16). The categorical coefficients for the main effects appear to be changed less than for the retained catch models (eg. fishing year, vessel and latitude band; compare Figure 28 and Figure 16), possibly because of the larger amount of data available compared to the retained catch models. However, there are wide confidence bounds for some of the coefficient estimates and the coefficient patterns for the month and depth effects have changed. As for the main effects model, the residual diagnostics are very good and indicate a good fit to the model assumptions concerning data distribution (Figure 29). Pairwise plots of the fishing year coefficients for every combination of month show similar fishing year coefficient patterns for many of the month pairs (eg. months 2 and 3 or months 8 and 10; Figure 30). Some months show different patterns (eg. 5 and 9 or 3 and 7; Figure 30) and many months diverge in the first or last year (eg. 3 and 12 or 4 and ; Figure 30). The model selection process selected this interaction term second, with an improvement in deviance of 0.02 (Table 16).

Table 16. Regression results for interaction effects GLM model applied to the west coast Vancouver Island discard catch of turbot. Total deviance explained was 0.31, an improvement of 0.14 over the main effects model. Only three of the six interaction terms offered to the model were accepted (indicated by a *****). The six interaction terms represent all the available interactions from the main effects model after excluding vessel interactions. Table values are the proportion of the total residual deviance explained by each interaction variable at the specified iteration after fitting all the main effects terms indicated in Table 11.

	Iteration			
Variable	**1**	**2**	**3**	**4**
MonthXDepth band*	0.2533			
Fishing yearXMonth*	0.1915	0.2726		
Latitude bandXMonth*	0.2298	0.2857	0.3062	
Fishing yearXDepth band	0.1861	0.2641	0.2802	0.3137
Fishing yearXLatitude band	0.1893	0.2683	0.284	0.3169
Latitude bandXDepth band	0.2031	0.2792	0.2981	0.3281
Increase in proportion deviance explained	0.0808	0.0194	0.0336	0.0075

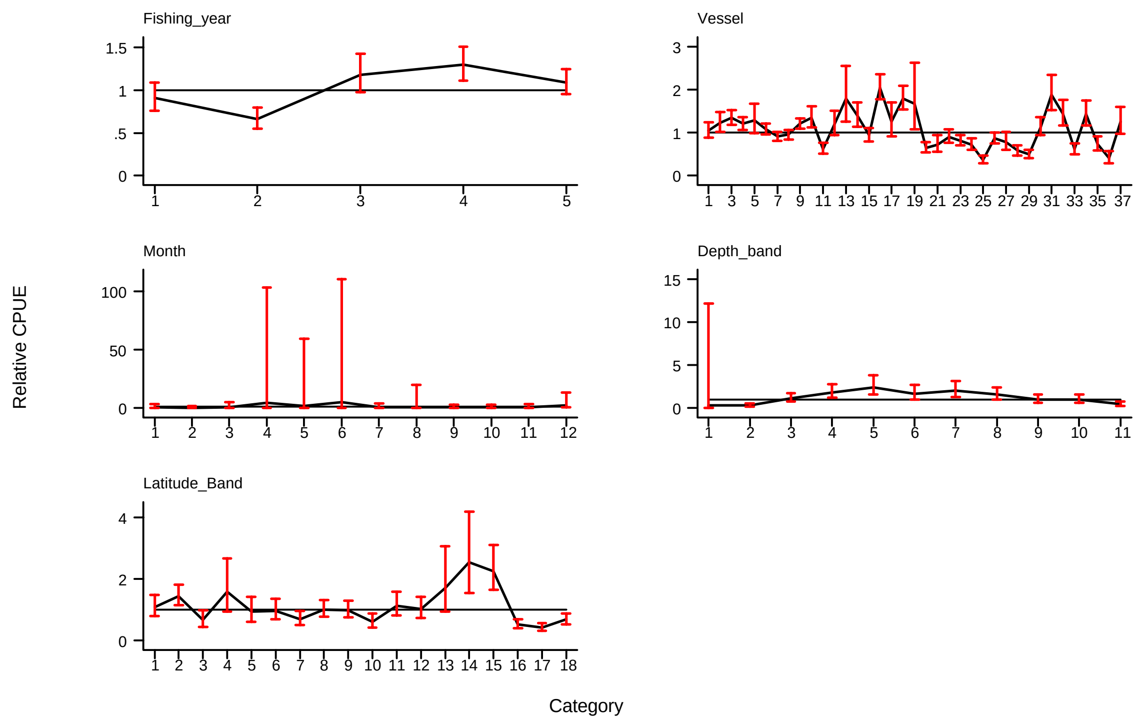


Figure 28. Main effects coefficients and 2*standard error confidence bounds for the west coast Vancouver Island discard catch interaction effects model (Table 16)..

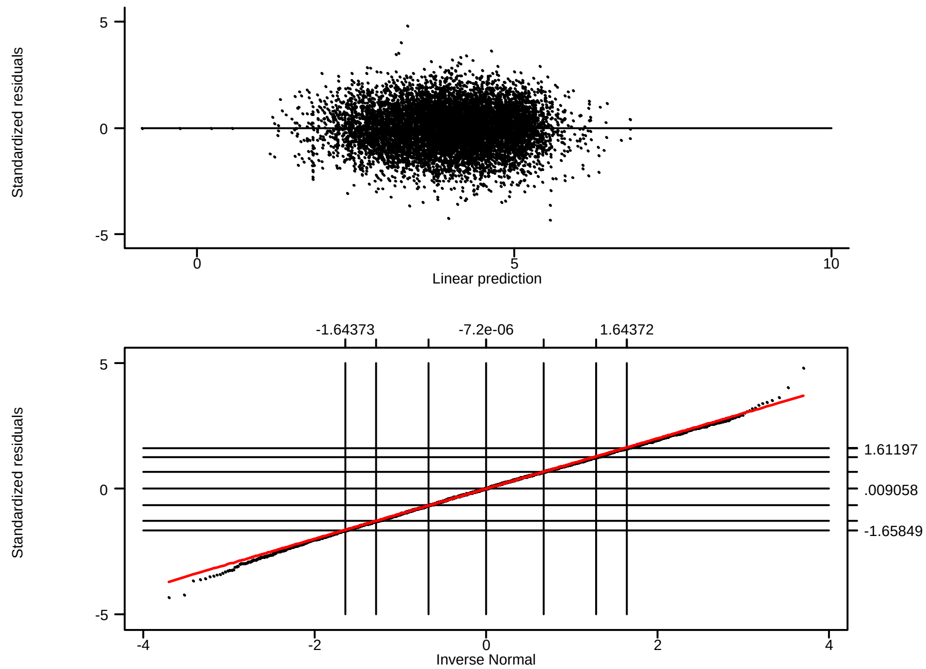


Figure 29. Standardised residuals for the west coast Vancouver Island retained catch interaction effects regression model (only 0.1° latitude band predictor area variable offered).

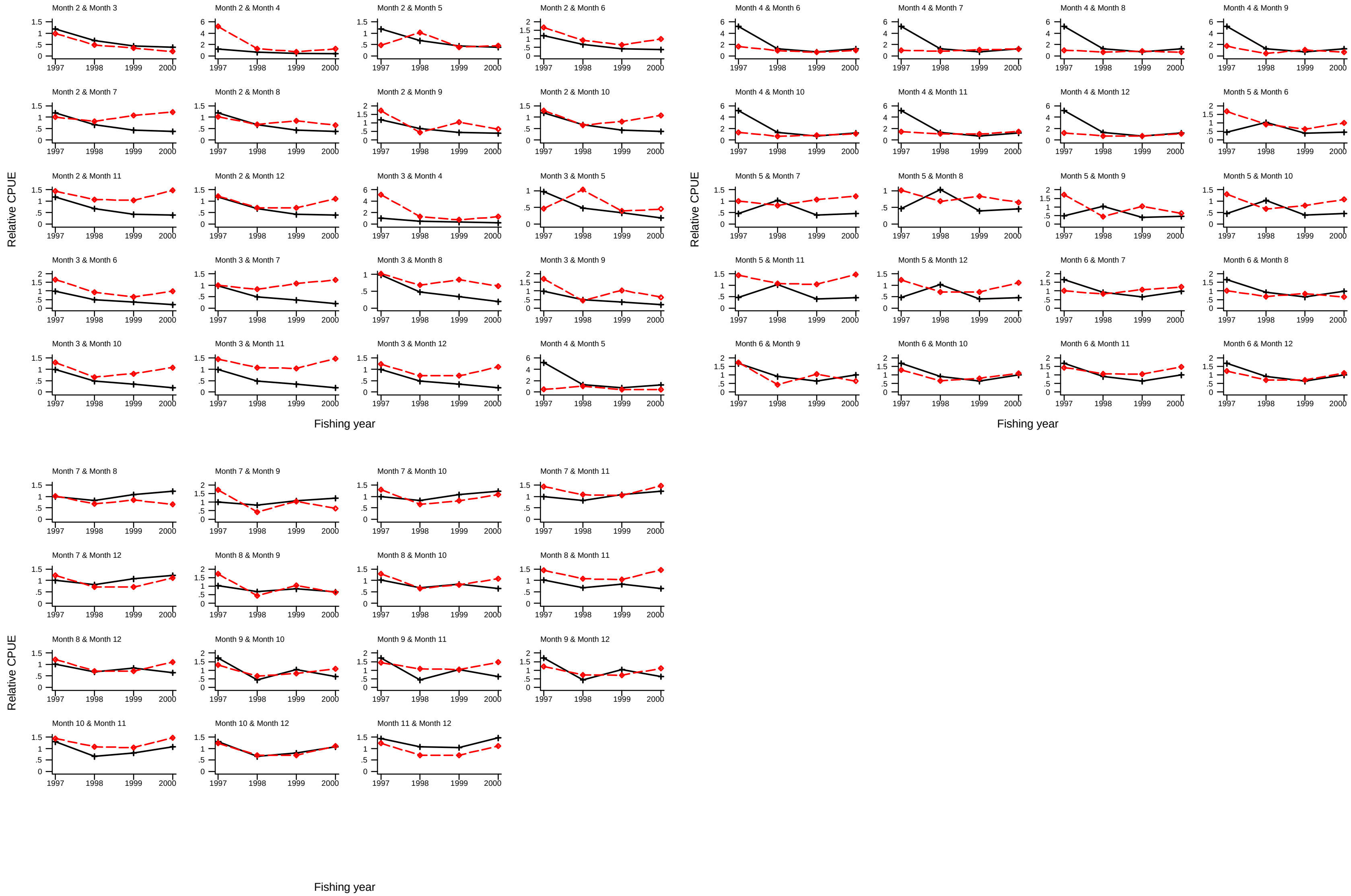


Figure 30. Fishing year coefficients for every combination of paired month (1= April) for the WCVI discard catch interaction model described in Table 16.

5.9.4 Interaction effects model: Queen Charlotte Sound & Hecate Strait discard catch

Four of the six offered interaction terms were included in the QCS/HS discard model based on the criteria provided in Section 5.1 (Table 17). Fishing yearX40 km^2 area grid interaction was selected third, with an improvement in deviance explained of less than 0.015 (Table 17). The improvement in the amount of deviance explained in this model is equivalent to that seen in the west coast Vancouver Island discard catch model, increasing by 0.13 from 0.24 to 0.37 (Table 17). The categorical coefficients for the main effects are quite different for the month effect compared to main effects model (Figure 31 and Figure 19) and the standard errors for the depth band and area grid coefficients are very poorly determined (Figure 31). The residual diagnostics are very good and indicate a good fit to the model assumptions concerning the data distribution (Figure 32). Pairwise plots of the fishing year coefficients for every combination of 40 km^2 area grid show similar fishing year coefficient patterns for many of the area grid pairs (eg. grids 3 and 8 or grids 15 and 16; Figure 33). Only a few grid pairs show different patterns (eg. 9 and 16 or 4 and 11; Figure 33) and few grid pairs diverge in the first or last year.

Table 17. Regression results for interaction effects GLM model applied to the combined Queen Charlotte Sound/Hecate Strait discard catch of turbot. Total deviance explained was 0.37, an improvement of 0.13 over the main effects model. Only four of the six interaction terms offered to the model were accepted (indicated by a *****). The six interaction terms represent all the available interactions from the main effects model after excluding the vessel interactions. Table values are the proportion of the total residual deviance explained by each interaction variable at the specified iteration after having fitted all the main effects terms indicated in Table 12.

	Iteration				
Variable	**1**	**2**	**3**	**4**	**5**
40 km^2 gridXMonth*	0.3265				
40 km^2 gridXDepth band*	0.264	0.3473			
Fishing yearX40 km^2 grid*	0.2624	0.3405	0.361		
MonthXDepth band*	0.3076	0.3418	0.3595	0.3729	
Fishing yearXDepth band	0.2505	0.3335	0.354	0.3668	0.3786
Fishing yearXDepth band	0.2509	0.3319	0.352	0.363	0.375
Increase in proportion deviance explained	0.0843	0.0208	0.0137	0.0119	0.0057

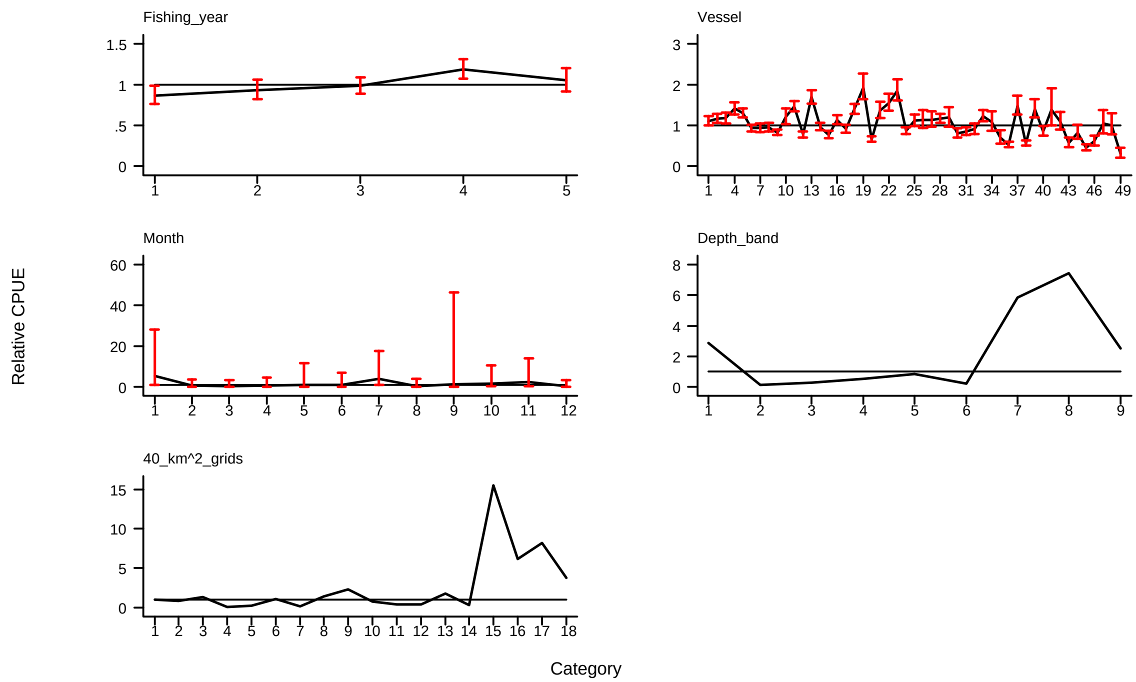


Figure 31. Main effects coefficients and 2*standard error confidence bounds for the combined QCS/HS discard catch interaction effects model (Table 17). Error bars are not shown for the 'depth band' and 40 km2 area grid coefficients as the estimated standard errors were too large to calculate in normal space.

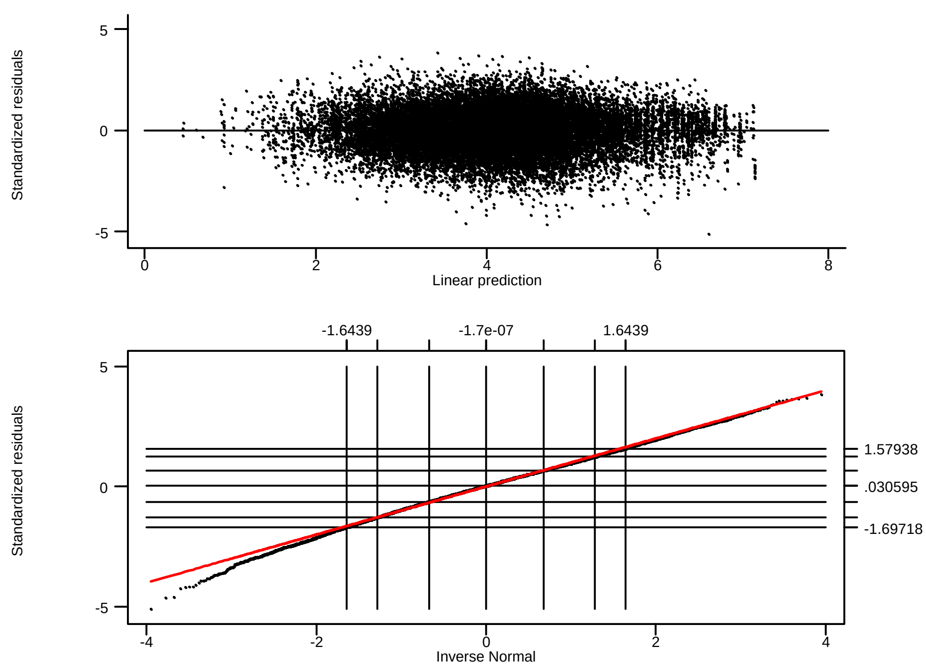


Figure 32. Standardised residuals for the combined QCS/HS discard catch interaction effects regression model (only 40 km^2 area grid predictor variable offered).

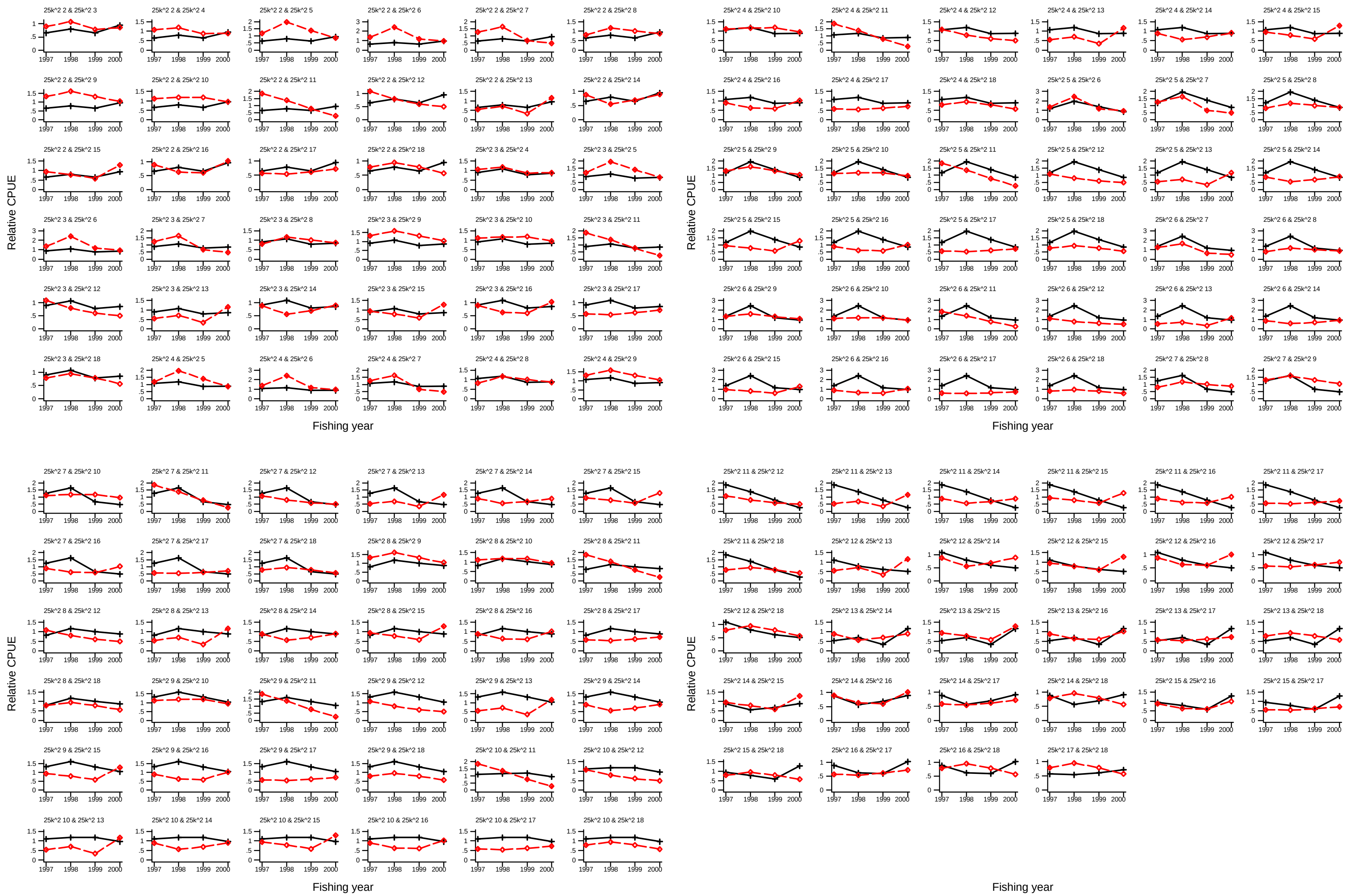


Figure 33. Fishing year coefficients for every combination of paired 40 km^2 area grid for the combined QCS&HS discard catch interaction model described in Table 17.

5.9.5 Summary: GLM interaction analysis

The apparent importance of interaction effects in these four models is troubling but understandable. It is not surprising that coefficients for one categorical variable will change by differing amounts across the range of another categorical variable. What is not clear is how much this will affect the estimates of key main effect variables such as the abundance variable (eg. fishing year). One difficulty in gauging changes in these estimates is the deterioration of the quality of the estimates as indicated by the wide (or non-existent) standard errors that are estimated for some of the coefficients in these interaction models (eg. Figure 31). The credibility of these models is suspect given the poor determination of the coefficients and the likely overparameterisation of the models. It is reasonable to suppose that our understanding of interaction effects will improve as more analyses are performed and the amount of data available increases.

5.9.6 GLM conclusions

The consistency in the relative biomass estimates between these four reasonably independent analyses is striking (Figure 21). This is in spite of the low explanatory power associated with these coefficients from these models, amounting to less than 4% in most of the analyses except for the QCS&HS model (=9%; Table 9, Table 10, Table 11and Table 12) and the lack of contrast between years. Plots of the underlying distributions of LN(CPUE) by fishing year also show the lack of contrast in this variable in the most recent five fishing years. The lack of signal in the abundance trend from these fisheries may indicate that the effect of fishing has been low on the vulnerable biomass, either because the biomass level is large relative to the exploitation rate or that recruitment and mortalities are reasonably balanced.

6.0 Biomass estimation using spatial data from research surveys

6.1 Research surveys

The distributional characteristics of turbot make it a good candidate for abundance indexing using area-swept survey methods. Biomass estimates for turbot from research surveys were available for Washington, west coast Vancouver Island, Hecate Strait, Aleutian Islands and the eastern Bering Sea (Table 18). The estimates for Washington and the west coast of Vancouver Island were produced using data from the U.S. west coast triennial trawl survey (Mark Wilkins pers. comm.). The 1980 estimate for Hecate Strait is from the turbot biomass survey conducted by Fargo et al. (1981). The estimates for Hecate Strait in 1984, 87, 89, 91, 93, 95, 96, 98, and 2000 were calculated using data from the Hecate Strait multispecies trawl survey using the same derivation detailed in Fargo et al. (1990). They represent the biomass of the entire population. The biomass estimates for the eastern Bering Sea and Aleutian Islands were presented in the 2000 stock assessment for these regions by Wilderbuer and Sample (2000). These estimates represent the exploitable population.

6.2 Biomass estimates

The abundance of turbot increased with latitude. The lowest densities were observed off Washington state and the highest densities were found in the Bering Sea where considerably more prime habitat is available than in the other areas. Biomass estimates for the west coast of Vancouver Island ranged from 16,417 t in 1992 to 75,424 t. in 1995. However the 1992 survey did not cover 3 of the 5 depth strata that received survey coverage in the other years. The estimates for Washington Start and the west coast of Vancouver Island show no overall tend. Biomass estimates for Hecate Strait ranged from 24,362 t in 1993 to 72,011 t in 1989. Adults comprise about 90% of the biomass by weight. Biomass in Hecate Strait increased between 1980 and 1991 then declined from 1991 to 1998 and increased in 2000 to a level comparable to 1991.

Table 18. Turbot biomass estimates for Washington, west coast of Vancouver Island, Hecate Strait, Aleutian islands and the eastern Bering Sea, 1977-2000.

Year	Biomass survey[1]	Multispecies Trawl survey[1]							Triennial Survey[1]	Triennial Survey	U.S.-Japan[2]	U.S.-Japan
	Area											
	Hecate Strait	Hecate Strait							Washington	WCVI	E.Bering Sea	Aleutian Islands
		20-29f	30-39f	40-49f	50-59f	60-69f	70-79f	Total				
1977									15960			
1978												
1979											71700	
1980	32600								13784			40400
1981											84400	
1982											92100	
1983									20420			45100
1984		106	1364	2737	15734	9785	395	30120				
1985											234300	
1986									8913			125700
1987		46	822	2874	17519	18421	302	39985				
1988											337100	
1989		824	19947	15689	18327	16552	670	72011	22588	77318		
1990												
1991		44	16181	14690	19220	19402	184	69721			357200	37294
1992									4408	16417	414000	
1993		285	3964	4739	4322	10716	335	24362			543600	
1994											570600	107019
1995		296	3302	11449	11686	22192	113	49038	12889	75427	480800	
1996		654	4069	10688	4746	23672	127	43956			556400	
1997											478600	111557
1998		346	1099	20947	14877	12274	291	49833	29066	53419	344900	
1999											243800	
2000		219	21252	18006	11416	10710	575	62178			340400	93515

[1] Total biomass
[2] Exploitable biomass

6.3 Relative CPUE

A summary of the annual CPUE index for turbot from the Hecate Strait multispecies survey is presented in Figure 34. There is no overall trend but the index fluctuates from a relatively low level in 1984 to a high level maximum in 1989 followed by a decline to 1993 and an increase to 2000. The biomass level in 2000 is comparable to that in the early 1990s. A summary of the CPUE index by 10 fathom depth interval is presented in Figure 35. Most of these plots show the 1989 peak that was seen in the overall CPUE index (Figure 34). However, there is more variation in these indices. This is due partly to the smaller sample size but also to the species preference for depth (Perry et. al. 1994).

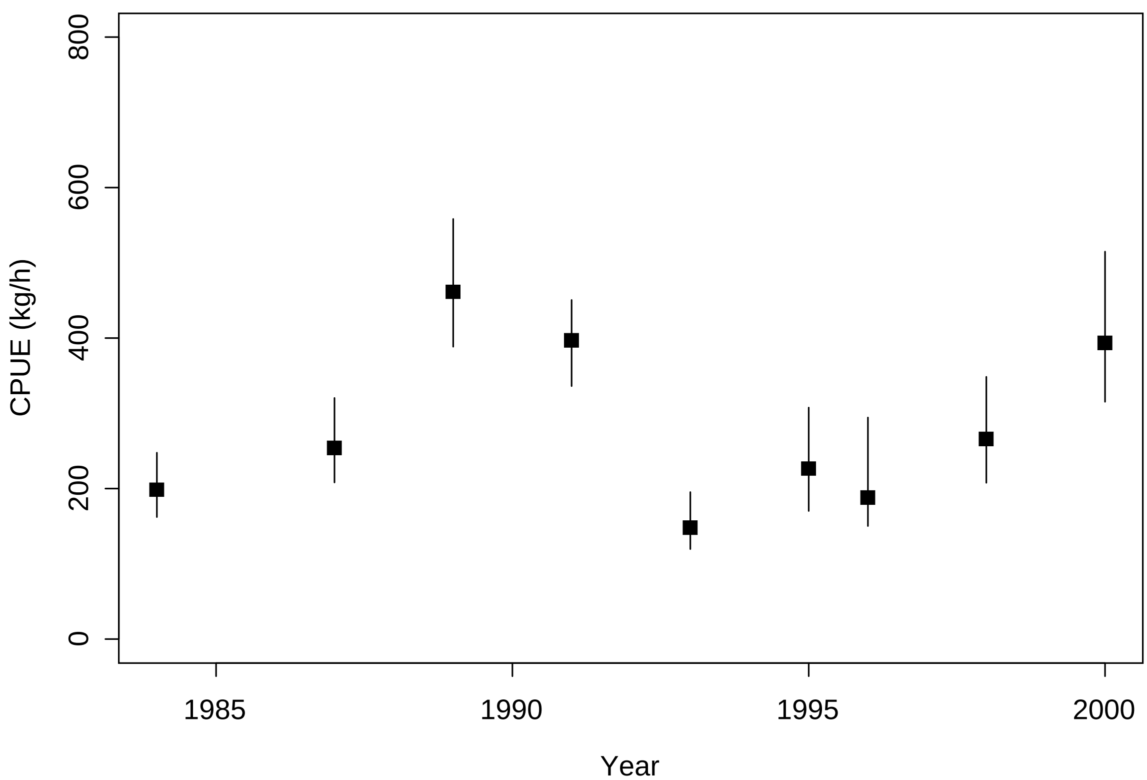


Figure 34. Mean CPUE and 90% confidence interval for turbot from the Hecate Strait multispecies survey, 1984-2000.

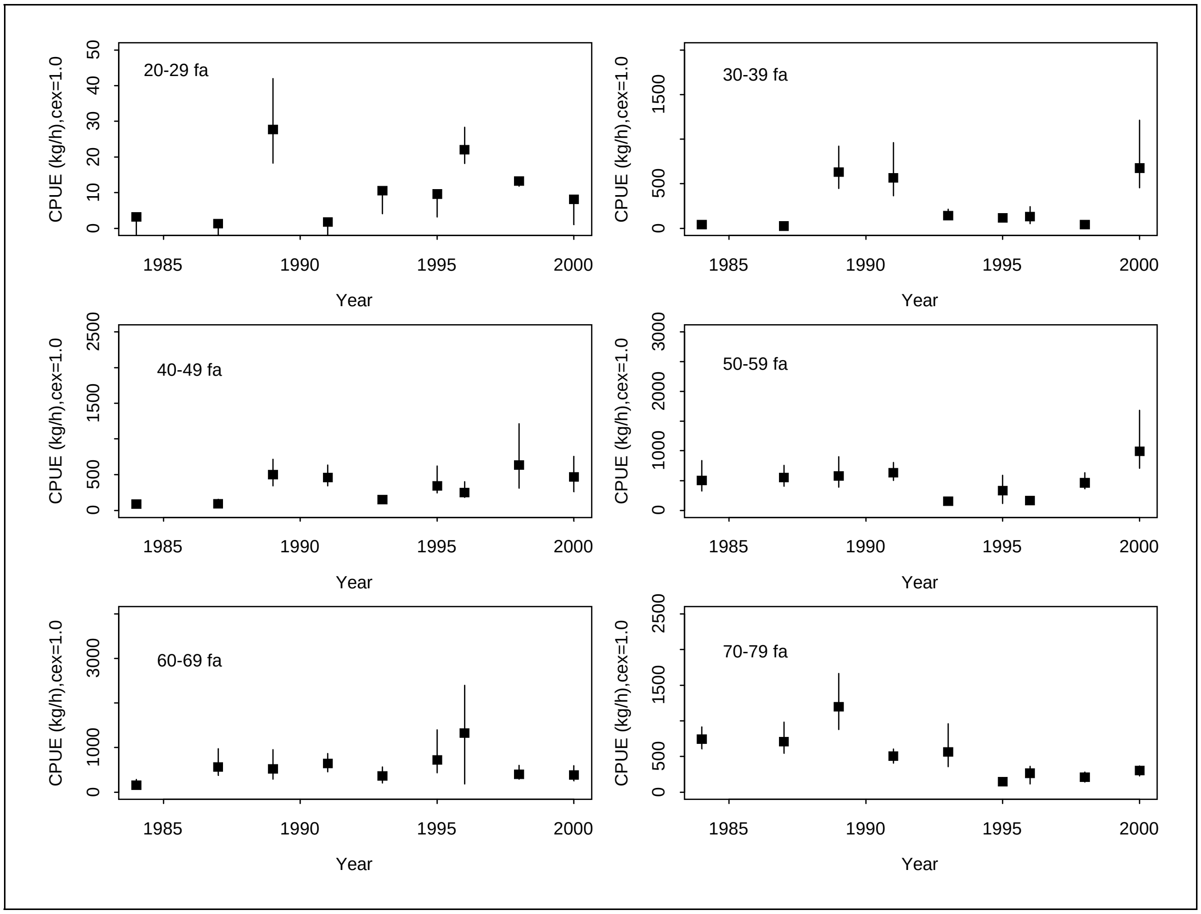


Figure 35. Mean CPUE and 90% confidence interval for turbot by 10 fathom depth interval from the Hecate Strait multispecies surveys, 1984 – 2000.

7.0 Recommendations and Yield Options

These analyses suggest that turbot populations in all areas examined are being fished at or below sustainable levels. We conclude this for the following reasons:

- There was no detectable change in *Z* in Hecate Strait between 1980 and 2000, implying that exploitation rates in the area covered by the Hecate Strait trawl survey have not substantially changed the age distribution of the turbot population over that period. The age compositions shown in Figure 5 show no truncation of the older age classes.
- The biomass survey index for Hecate Strait shows no long term trend despite having the longest exploitation history of any area(Figure 34).
- Assuming that catch rates are a measure of population abundance, the catch rates derived from GLM models for the west coast of Vancouver Island show no trends for retained catch (Figure 9) or discard catch (Figure 12) from 1996/97 to 2000/01. Similarly, catch rates from the Queen Charlotte Sound/Hecate Strait show no trends for retained catch (Figure 15) or discard catch (Figure 18) from 1996/97 to 2000/01.

- There is little evidence that targeting by the fleet is causing the high proportion of discards in the turbot fishery (Figure 16 and Figure 19). Only a few vessels appear to specialise in landing this species (Figure 10 and Figure 13).
- Estimates of *F* were below the best estimate for *M* (=0.2; Section 4.4).

At the present time turbot are largely taken as bycatch in other target fisheries. This is due to a lack of markets for this species. However, over the past 2-3 years there has been a lot of interest in this species and targeting has been undertaken by a few vessels as landings opportunities arise. The analysis of the Canadian observer data indicates that most of the variation CPUE over time is due to differences in areas, time of year fished and, depth fished.

Currently off B.C., there are biomass estimates for the west coast of Vancouver Island from US Triennial Survey and for Hecate Strait from the long-term multispecies survey. However, both of these surveys fail to cover the entire known range of turbot in BC, either in terms of the depth range or area. In addition, there is a substantial population in Queen Charlotte Sound but no biomass survey.

The stock structure of turbot is poorly understood. It is thought that the population of turbot off the west coast of Vancouver Island is separate from the population in Hecate Strait because of geographic barriers between the two areas. It is not known if the population in Queen Charlotte Sound is contiguous with the population in Hecate Strait, with that off the west coast of Vancouver Island or whether it is a separate stock

Given the current information, the current level of catch is probably the minimum sustainable because fishing mortality is below the instantaneous natural mortality rate. The analyses presented in this paper indicate that current levels of removals, which include discards have been sustainable over the last 20 years in Hecate Strait) and over the last 12 years for the west coast of Vancouver Island. Evidence from the discard analysis indicates that this aspect of the fishery appears to be passive with no indication of targeting behaviour. However, managers should work with the industry to reduce the level discards in this fishery where possible.

Although it is likely that the resource could sustain increased catches in some areas, it is not possible to recommend specific higher catch limits at this time. We recommend that, if catch levels for this species are increased, a monitoring program should also put in place along with agreed responses to changes in the "performance indicators" which are generated by the monitoring program. There are many examples of similar management procedures which are operational in various fisheries on a world-wide basis. This would ensure the safe development of the fishery for this species.

8.0 Acknowledgements

We appreciate the assistance of Kate Rutherford with the GFBio database and the fish ageing unit for providing all the age determinations. Rowan Haigh produced the maps used in Figure 7 and Figure 8.

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10.0 Appendix 1: GLM data preparation

10.1 Catch and effort data

All catch and effort data were obtained from summary tables generated from the PacHarvest and GFCatch databases held by the DFO at the Pacific Biological Station in September 2001. See Schnute et al. (2000) for a description of the PacHarvest database, including the available data fields. A description of the GFCatch database is available in Rutherford (1999).

The two datasets were amalgamated for performing the analyses on the retained catch of turbot. However, only two years could be added as records of latitudes and longitudes for the individual tows were not maintained until January 1994. The addition of these data from the GFCatch database considerably aided the analysis of the retained turbot catch as there were relatively few records in this model.

Only the PacHarvest data were used for the analysis of discarded catch because it was not until mid-February 1996 that observers were present on most vessels which caught this species. There are no reliable estimates of discarded catch prior to February 1996.

10.2 GLM Data preparation and grooming

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

- Tow start date after 31 March 1994 for retained catch and 31 March 1996 for discarded catch
- Bottom trawl type
- Areas outside the Strait of Georgia (i.e. <> Major Area =4B)
- Fishing success code <=1 (code 0= unknown; code 1= useable)
- Valid major, minor and locality area codes
- Valid depth value
- Tows from vessels which had been in the fishery for at least four years (for discarded catch analysis) and five years (for retained catch analysis)
- Tows with valid latitude and longitude co-ordinates
- Tows with valid estimates of time set

The locations of the selected tows have been translated into UTM (Universal Transverse Mercator) co-ordinates based on the latitude and longitude for each tow in the database. The UTM grid system and its application is described in detail in Schnute *et al.* (2000). This system was used to generate constant sized grid boxes of 5 km^2, 10 km^2, 25 km^2 and 40 km^2 which each offered as predictor variables in the generalised linear analysis.

Continuous variables (time of day set, number of species in tow and number of tows by vessel in data set) were entered into the model as third order polynomials. However, exploratory analysis showed that these variables had little explanatory power in any of the models and were dropped from the final analyses. As well, plots of the data showed that the time of day set variable was incomplete prior to 1996/97, making this variable unsuitable for the retained catch models. The number of species reported in a tow also seems suspiciously low in 1994/95 and 1995/96, rendering this variable unsuitable for the retained catch models.

Depth was entered into the model as a categorical variable in 50 m depth bands. Initial analysis also showed that depth had little explanatory power in these models and the depth distributions were truncated in all models at the 5 and 95%-tiles to only include depth bands with sufficient number of observations. The only exception to this was the discard catch model for the combined Queen Charlotte Sound and Hecate Strait where the depth distribution was truncated to the 1 and 99%-tiles as this model has the greatest number of tows. Depth as a continuous variable was also investigated in some of the regression models. However, the fit of the data to depth when offered as a 3rd order polynomial was generally not as good as for the categorical variable.

Fields or derived fields that were kept in the data set are described in Appendix Table 1. All variables in the final models were entered as categorical variables.

Appendix Table 1. Fields in the data set used to analyse turbot catch and effort data

Field	**Description**
CPUE	Kg/hour
Depth	Converted into 50m bands
Discarded catch	Kg
Effort	Tow time in hours
Latitude	In decimal degrees based on the mid-point of the tow
Locality	DFO locality area description (Rutherford 1999)
Longitude	In decimal degrees based on the mid-point of the tow
Minor Area	DFO minor area description (Rutherford 1999)
Month	From April 1994 to March 2001
Nspp	Number of species in tow
Pcatch	Proportion turbot catch to total catch
Pdiscard	Proportion of turbot discard to total discard
Retained catch	Kg
Standardised fishing year	01 April – 31 March
Time	Time of day when tow set
Tows	Total number tows by vessel in fishery
UTME	Universal Transverse Mercator Easting (Schnute et al 2000)
UTMN	Universal Transverse Mercator Northing (Schnute et al 2000)
Vessel	Coded

11.0 Appendix 2: Calculating Standard Errors for CPUE

BY CHRIS FRANCIS, 7 JUNE 2001

This note describes how to calculate standard errors (*s.e.*s) for standardised CPUE indices following the suggestion of Francis (1999). These *s.e.*s relate to what Francis (1999) called the *canonical form* for CPUE indices (in which there is no reference year).

These *s.e.*s have two advantages over those calculated by the method that has been used by most people at NIWA. First, an *s.e.* is calculated for every year (i.e., we don't have an *s.e.* of 0 for the reference year). Second, the *s.e.*s are not inflated by the uncertainty associated with the reference year (see fig. 2 of Francis 1999, which shows that the *s.e.*s can vary a lot with the choice of reference year, and that they are always much smaller when there is no reference year).

In the procedure described here, I am assuming that you have carried out a CPUE standardisation in the conventional way (i.e., with a reference year) and are able to obtain, from whatever software you are using, the estimated covariance matrix for your year coefficients. By the year coefficients, I mean the vector of regression coefficients associated with each year. If there are n years in your data set this vector will have length n-1 (because the reference year is excluded). Note that these year coefficients are in log space; to get year effects (in natural space) you need to exponentiate the year coefficients. Suppose that the reference year you have chosen is the rth of your n years (very often $r = 1$) and that **V** is the estimated covariance matrix for the year coefficients (so **V** is an (n-1) x (n-1) matrix).

You need to construct an n x (n-1) matrix **Q,** whose ijth element is given by

$$Q_{ij} = \begin{cases} (n-1)/n & \text{if } i < r \text{ and } i = j \\ (n-1)/n & \text{if } i > r \text{ and } i = j+1 \\ -1/n & \text{otherwise} \end{cases}$$

If you are working in S or Splus, you can create **Q** using the following two commands

```
Q<–matrix(-1/n,n,n-1)
Q[-r,]<–Q[-r,]+diag(rep(1,n-1))
```

Now calculate matrix $\mathbf{V}^0 = (\mathbf{Q} * \mathbf{V}) * \mathbf{Q}'$, where * represents matrix multiplication and **Q'** is the matrix transpose of **Q**. In S or Splus, V0<–(Q %*% V) %*% t(Q).

$\mathbf{V}^0$ is the covariance matrix that you want. That is, the *s.e.* for the ith year coefficient is $\sqrt{V_{ii}^0}$. (Note that $\mathbf{V}^0$ is an n x n matrix so this provide *s.e.*s for all n years, including the reference year).

12.0 Appendix 3: Data Summaries Supporting the GLM Analysis

The following tables and graphs summarise the data available in each dataset used for the GLM models presented in Sections 5.6 and 5.7. Each model is supported by the following data summaries consisting of two tables and five graphs:

- 1st table: distribution of vessels, tows, catch, and effort by number years that the vessels have been in the fishery;
- 2nd table: distribution of tows by standard fishing year and DFO minor statistical area;
- 1st graph: box plots of the distribution of data for key variables by standard fishing year;
- 2nd graph: box plots of the distribution of LN(CPUE) for key predictor variables used in the models.

Note that, for both graphs and the 2nd table, the data have been restricted to vessels which had been in the fishery for at least five years (retained catch models) or for four years (discard catch models) and that records at the extremes of the depth distributions have been dropped.

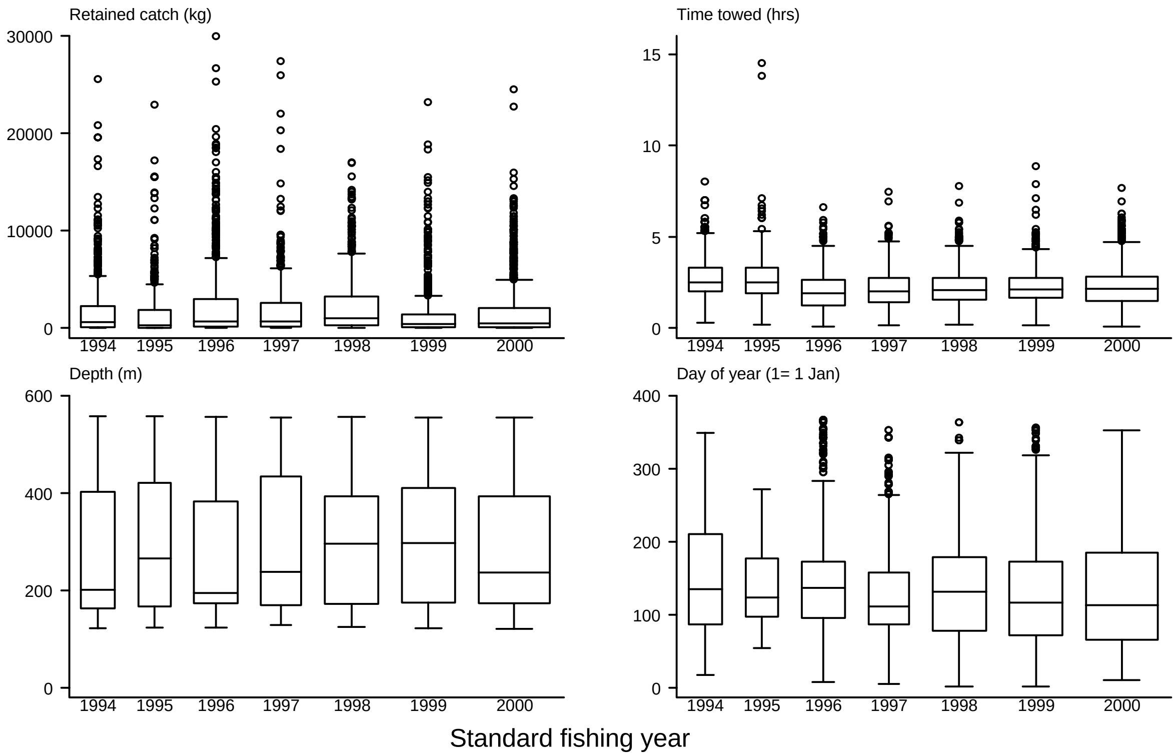
12.1 West coast Vancouver Island retained catch analysis summary statistics

Appendix Table 2. Number of vessels in the WCVI retained catch dataset grouped by the number of years the vessel was in the fishery along with the associated number of tows, total catch in kg and total effort in hours. These latter three totals are also expressed as a descending cumulative total in percent, indicating the cumulative amount of data present in the dataset beginning at that number of years.

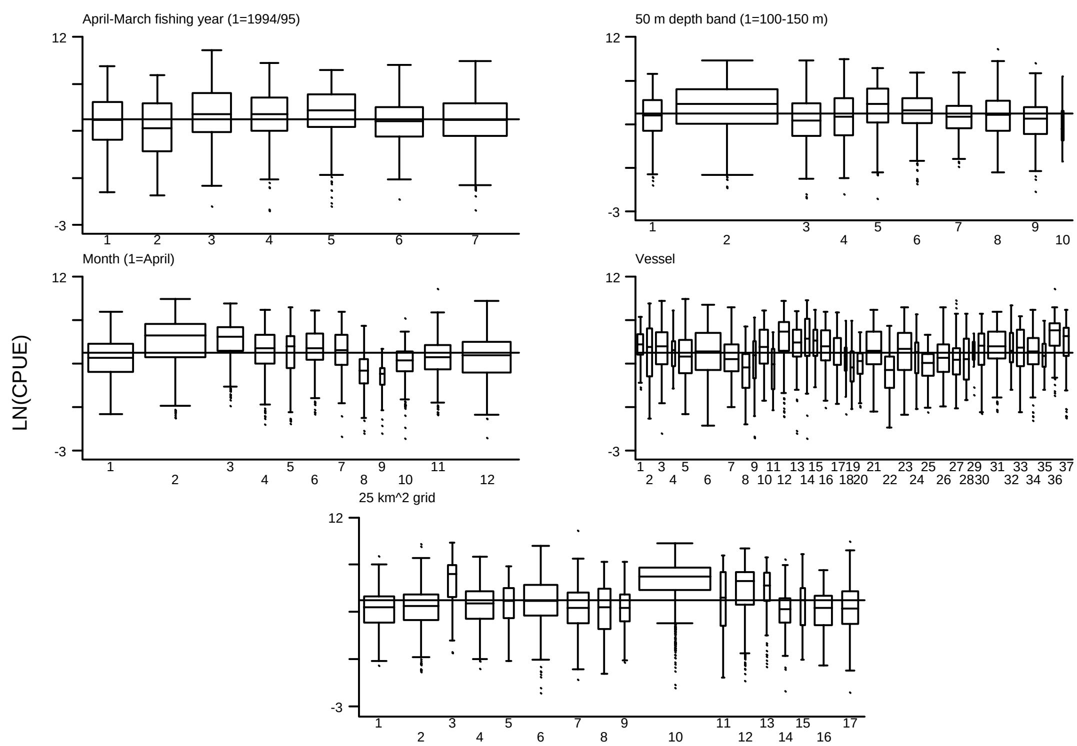
Years in fishery	Number vessels	Total tows	Total Catch (kg)	Total effort (hrs)	Descending cumulative tows (%)	Descending cumulative catch (%)	Descending cumulative effort (%)
1	19	164	160,385	473	100	100	100
2	20	645	932,938	1,561	98	99	98
3	10	601	563,382	1,393	90	92	89
4	6	489	1,147,583	1,222	83	88	82
5	11	1165	2,247,239	2,717	76	79	76
6	10	1634	2,955,348	3,718	62	63	61
7	16	3381	5,579,353	7,900	42	41	42

Appendix Table 3. Number of tows in the WCVI retained catch dataset by standard fishing year and DFO minor statistical area (arranged from south to north) in the dataset. Note that the tows from minor area 11 only extend to Cape Scott. The dataset has been limited to vessels which have been in the fishery for at least five years and tows outside of 5/95% of the depth distribution have been dropped.

Fishing	DFO Minor Statistical Area							
Year	21	23	24	25	26	27	11	Total
1994/95	0	195	69	248	12	27	24	575
1995/96	7	135	124	239	10	38	12	565
1996/97	4	175	185	319	29	30	6	748
1997/98	2	196	193	194	35	39	40	699
1998/99	9	182	175	376	26	60	87	915
1999/2000	6	308	213	274	7	68	41	917
2000/01	5	314	388	365	13	88	62	1,235
Total	33	1,505	1,347	2,015	132	350	272	5,654



Appendix Figure 1. Distribution of data for catch (kg), time set (hours), depth (m) and day of year of tow used in the WCVI retained catch model by standard fishing year. Depth is truncated at 5 and 95% of the depth distribution and the data set confined to vessels which have been the fishery for at least five years.



Appendix Figure 2. Distribution of LN(CPUE) [kg/hr] for five categorical predictor variables used in the WCVI retained catch model. The width of the boxes is proportional to the number of tows in each category and the mean of LN(CPUE) is plotted as a horizontal line in all graphs.

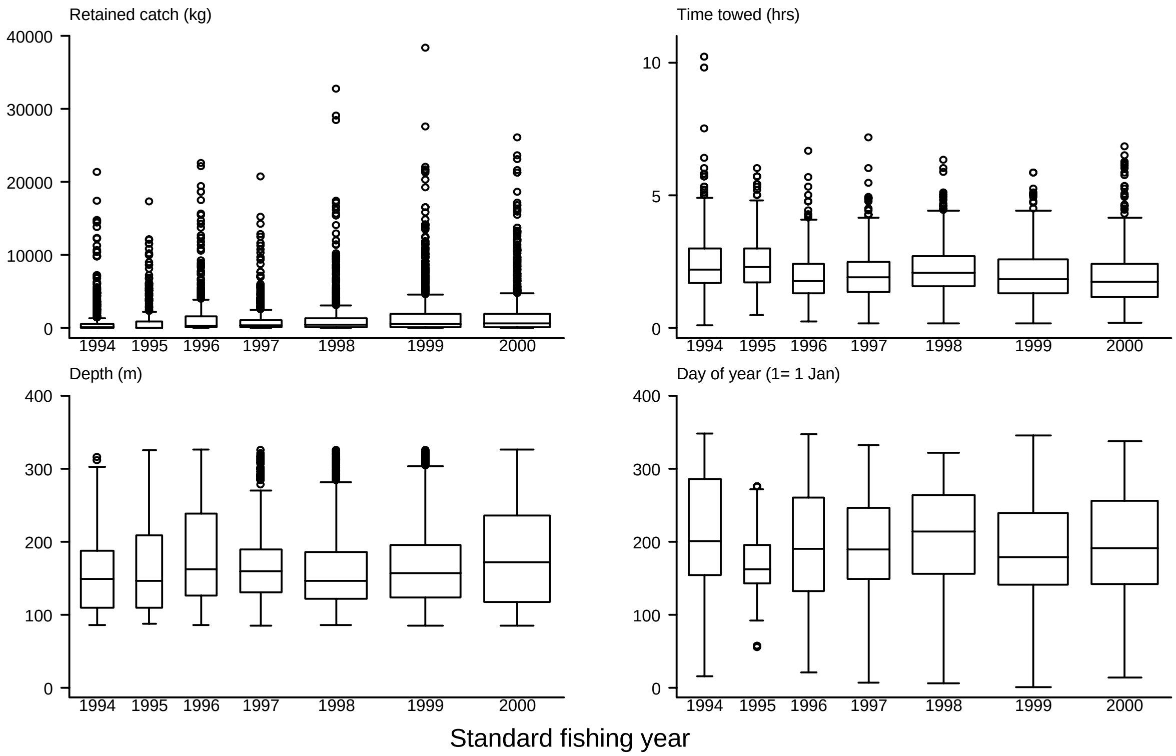
12.2 Combined Queen Charlotte Sound/Hecate St retained catch analysis summary statistics

Appendix Table 4. Number of vessels in the QCS & HS retained catch dataset grouped by the number of years the vessel was in the fishery along with the associated number of tows, total catch in kg and total effort in hours. These latter three totals are also expressed as a descending cumulative total in percent, indicating the cumulative amount of data present in the dataset beginning at that number of years.

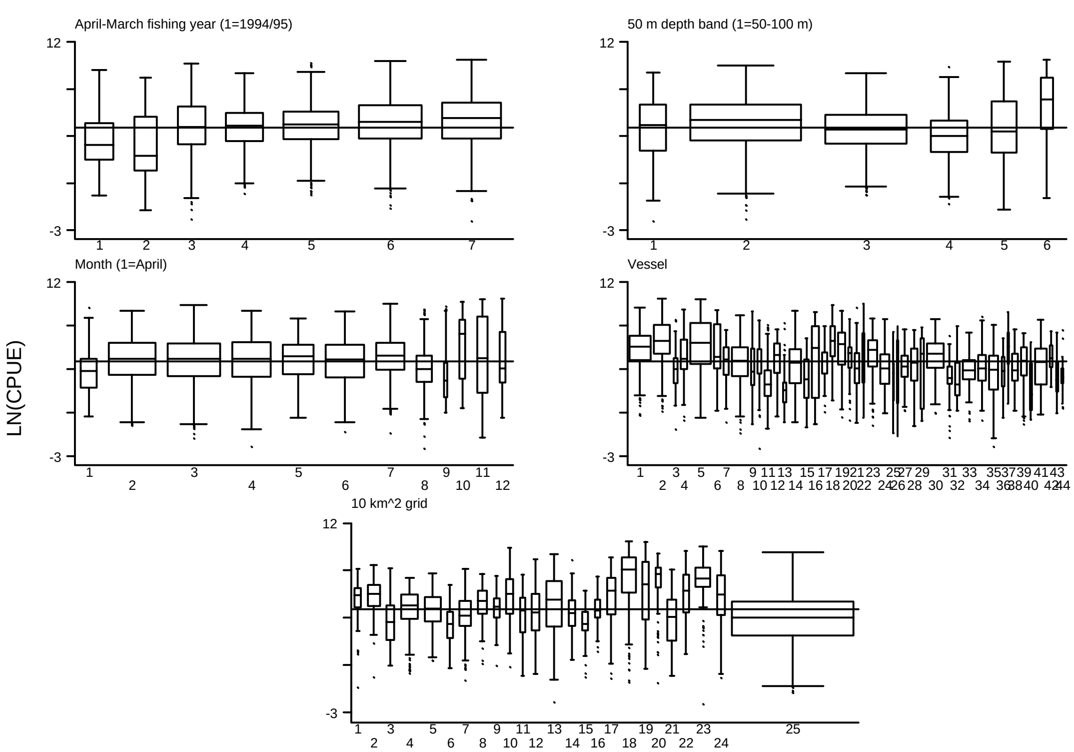
Years in fishery	Number vessels	Total tows	Total Catch (kg)	Total effort (hrs)	Descending cumulative tows (%)	Descending cumulative catch (%)	Descending cumulative effort (%)
1	16	70	7,812	153	100	100	100
2	17	483	195,426	1,061	99	100	99
3	15	756	375,777	1,636	93	98	93
4	13	919	1,445,195	2,049	84	95	83
5	18	1596	1,476,905	3,291	72	82	71
6	11	1272	1,828,150	2,628	53	68	52
7	15	2971	5,650,248	6,219	37	51	37

Appendix Table 5. Number of tows in the QCS & HS retained catch dataset by standard fishing year and DFO minor statistical area (arranged from north to south) in the dataset. Note that the tows from minor area 11 only extend from Cape Scott. The dataset has been limited to vessels which have been in the fishery for at least five years and tows outside of 5/95% of the depth distribution have been dropped.

Fishing	DFO Minor Statistical Area										
Year	2AE	2BE	1E	4	5	6	7	8	9	11	Total
1994/95	1	9	64	107	33	19	1	220	0	67	521
1995/96	0	29	7	117	6	10	3	166	0	77	415
1996/97	0	32	2	68	3	16	3	221	1	154	500
1997/98	0	7	9	44	17	23	2	248	0	318	668
1998/99	0	26	22	102	16	0	0	372	0	456	994
1999/2000	0	8	29	176	3	9	1	459	0	445	1,130
2000/01	1	15	6	176	16	7	2	562	0	281	1,066
Total	2	126	139	790	94	84	12	2,248	1	1,798	5,294



Appendix Figure 3. Distribution of data for catch (kg), time set (hours), depth (m) and day of year for tow used in the QCS&HS retained catch model by fishing year. Depth is truncated at 5 and 95% of the depth distribution and the data set confined to vessels which have been the fishery for at least five years.



Appendix Figure 4. Distribution of LN(CPUE) [kg/hr] for five categorical predictor variables used in the QCS&HS retained catch model. The width of the boxes is proportional to the number of tows in each category and the mean of LN(CPUE) is plotted as a horizontal line in all graphs.

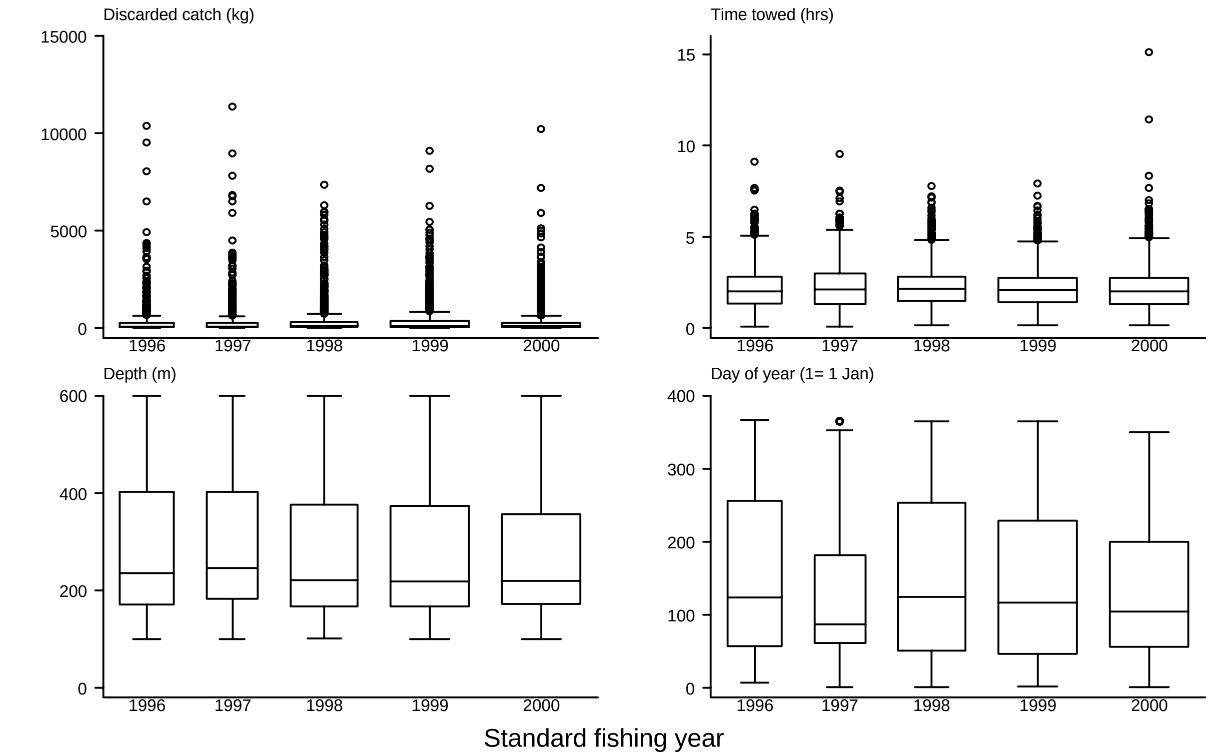
12.3 West coast Vancouver Island discard catch analysis summary statistics

Appendix Table 6. Number of vessels in the WCVI discard catch dataset grouped by the number of years the vessel was in the fishery along with the associated number of tows, total catch in kg and total effort in hours. These latter three totals are also expressed as a descending cumulative total in percent, indicating the cumulative amount of data present in the dataset beginning at that number of years.

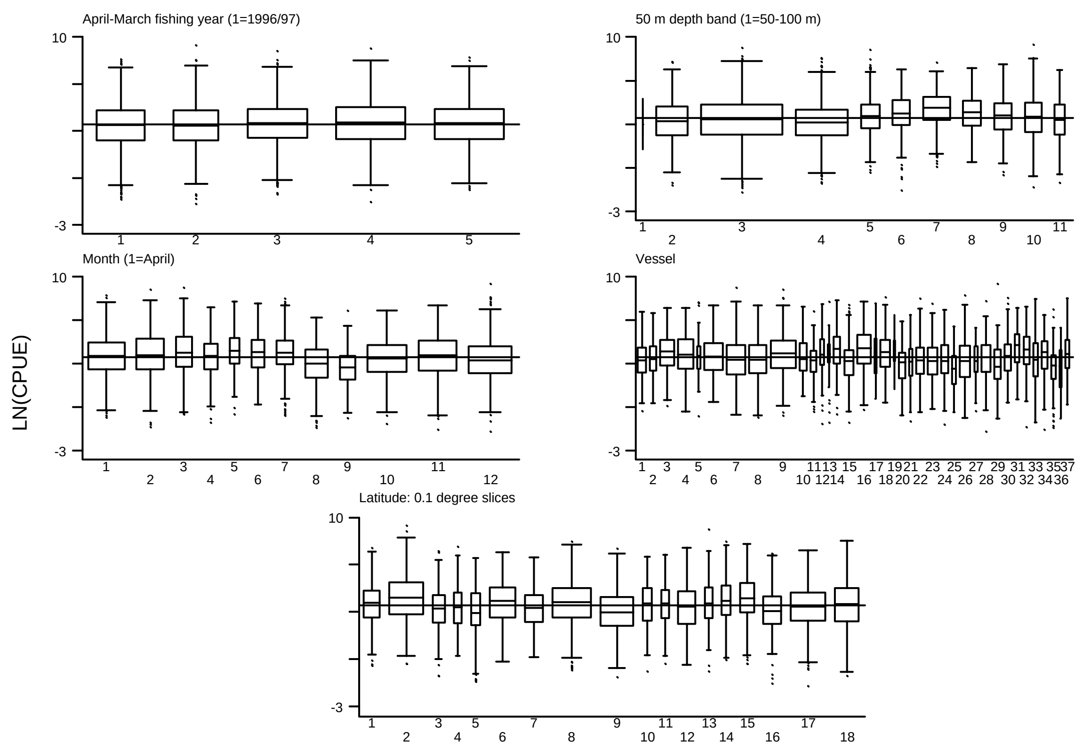
Years in fishery	Number vessels	Total tows	Total Catch (kg)	Total effort (hrs)	Descending cumulative tows (%)	Descending cumulative catch (%)	Descending cumulative effort (%)
1	28	909	250,518	2,082	100	100	100
2	12	689	220,810	1,708	93	93	93
3	10	808	201,771	1,764	88	88	87
4	5	837	193,209	1,915	81	82	82
5	32	9709	2,955,346	22,627	75	77	75

Appendix Table 7. Number of tows in the WCVI discard catch dataset by standard fishing year and DFO minor statistical area (arranged from south to north) in the dataset. Note that the tows from minor area 11 only extend to Cape Scott. The dataset has been limited to vessels which have been in the fishery for at least four years and tows outside of 5/95% of the depth distribution have been dropped.

Fishing Year	DFO Minor Statistical Area							Total
	21	23	24	25	26	27	11	
1996/97	7	355	486	363	86	133	134	1,564
1997/98	6	327	517	232	54	170	164	1,470
1998/99	50	441	641	325	52	176	261	1,946
1999/2000	34	611	604	431	66	241	285	2,272
2000/01	15	512	685	435	65	254	303	2,269
Total	112	2,246	2,933	1,786	323	974	1,147	9,521



Appendix Figure 5. . Distribution of data for catch (kg), time set (hours), depth (m) and day of year for tow used in the WCVI discard catch model by fishing year. Depth is truncated at 5 and 95% of the depth distribution and the data set confined to vessels which have been the fishery for at least four years.



Appendix Figure 6. Distribution of LN(CPUE) [kg/hr] for five categorical predictor variables used in the WCVI discard catch model. The width of the boxes is proportional to the number of tows in each category and the mean of LN(CPUE) is plotted as a horizontal line in all graphs.

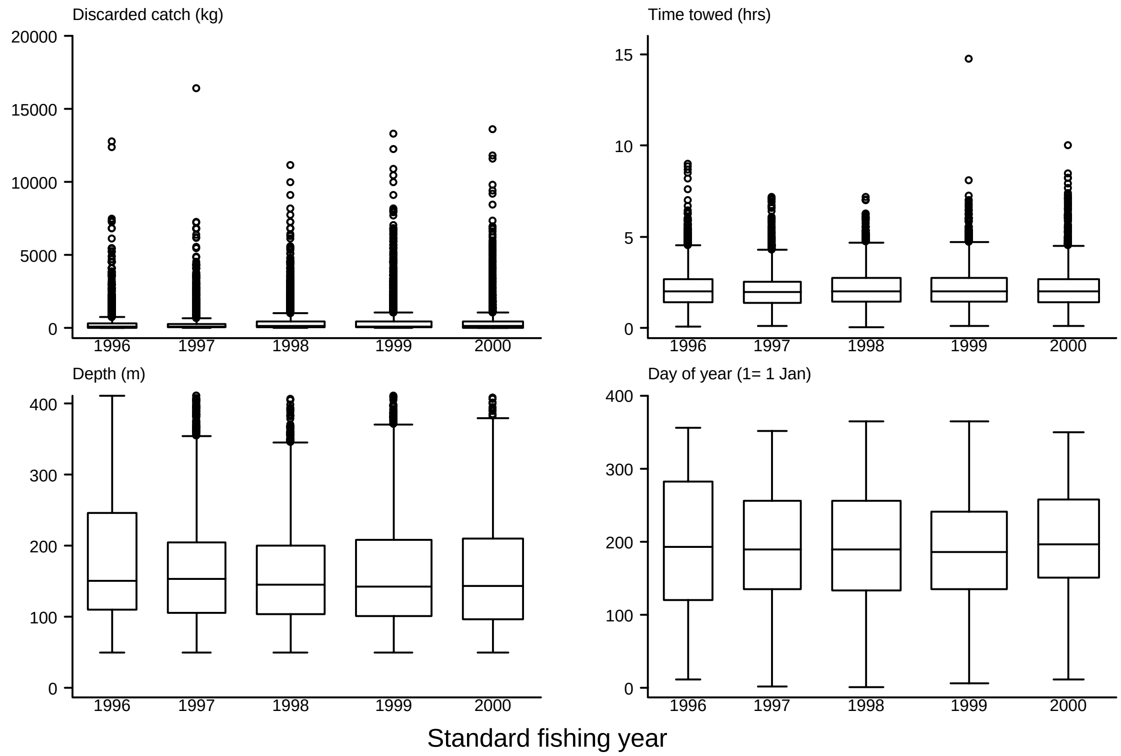
12.4 Combined Queen Charlotte Sound/Hecate St discard catch analysis summary statistics

Appendix Table 8. Number of vessels in the QCS & HS discard catch dataset grouped by the number of years the vessel was in the fishery along with the associated number of tows, total catch in kg and total effort in hours. These latter three totals are also expressed as a descending cumulative total in percent, indicating the cumulative amount of data present in the dataset beginning at that number of years.

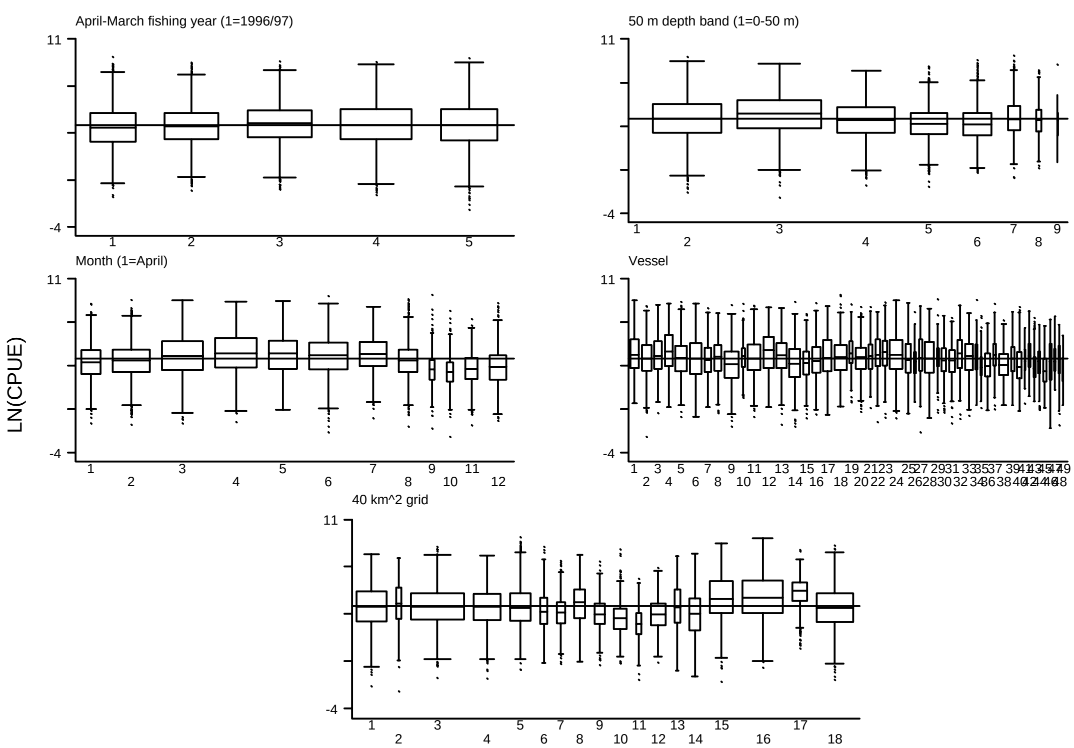
Years in fishery	Number vessels	Total tows	Total Catch (kg)	Total effort (hrs)	Descending cumulative tows (%)	Descending cumulative catch (%)	Descending cumulative effort (%)
1	25	1795	350,061	3,717	100	100	100
2	14	1798	570,630	4,176	94	97	95
3	10	2072	719,481	4,446	89	92	88
4	7	2206	584,889	4,694	82	86	82
5	42	23881	9,409,150	50,906	75	81	75

Appendix Table 9. Number of tows in the QCS & HS discard catch dataset by standard fishing year and DFO minor statistical area (arranged from north to south) in the dataset. Note that the tows from minor area 11 only extend from Cape Scott. The dataset has been limited to vessels which have been in the fishery for at least five years and tows outside of 5/95% of the depth distribution have been dropped.

Fishing	DFO Minor Statistical Area										
Year	2AE	2BE	1E	4	5	6	7	8	9	11	Total
1996/97	14	368	142	965	230	173	33	1,404	1	680	4,010
1997/98	17	248	104	898	282	228	18	1,968	4	975	4,742
1998/99	17	325	138	1,367	259	179	26	1,906	1	1,392	5,610
1999/2000	7	521	134	1,412	166	304	31	2,554	1	1,094	6,224
2000/01	9	326	122	1,172	144	162	24	2,217		816	4,992
Total	64	1,788	640	5,814	1,081	1,046	132	10,049	7	4,957	25,578



Appendix Figure 7. Distribution of data for catch (kg), time set (hours), depth (m) and day of year for tow used in the QCS & HS discard catch model by fishing year. Depth is truncated at 1 and 99% of the depth distribution and the data set confined to vessels which have been the fishery for at least four years.



Appendix Figure 8. Distribution of LN(CPUE) [kg/hr] for five categorical predictor variables used in the QCS&HS discard catch model. The width of the boxes is proportional to the number of tows in each category and the mean of LN(CPUE) is plotted as a horizontal line in all graphs.