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A review of yellowmouth rockfish *Sebastes reedi* along the Pacific coast of Canada: biology, distribution, and abundance trends

Examen du sébaste à bouche jaune Le *Sebastes reedi* le long de la côte du Pacifique du Canada : biologie, distribution et tendances relatives de l'abondance

Rowan Haigh[1] and Paul Starr[2]

[1]Fisheries and Oceans Canada
Marine Ecosystems and Aquaculture Division
Pacific Biological Station, 3190 Hammond Bay Road, Nanaimo BC, V9T 6N7

[2]Canadian Groundfish Research and Conservation Society
1406 Rose Ann Drive, Nanaimo BC, V9T 4K8

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Abstract

We summarize the available information on yellowmouth rockfish *Sebastes reedi*. Specifically, this paper reviews the current data on the biology, distribution, and abundance trends, primarily for citation by COSEWIC stock status reports. This species has a mean weight of 1.467 kg/fish, representing the samples from the observed commercial fishery. Growth relationships shows no strong difference between the sexes. Allometric analyses yield curvature parameter estimates β all > 3, suggesting non-isometric growth. Length-age analyses also show little difference between males and females, although the models consistently predict slightly higher L_∞ values for females. Natural mortality *M* is estimated to be 0.047, based on an exponential decay model and a maximum observed age of 99. The total mortality *Z* estimate from catch-curve analysis of the 2003 data is 0.063 (95% confidence interval = 0.044-0.083). Maturity ogives yield ages at 50% maturity *k* of 10.1 y for males and 10.6 y for females. Assuming *k* = 10.5 y and *M* = 0.047, the generation time is 31.8 y. Depth-of-capture frequency in commercial trawl tows suggests that most of the population occurs between 130 m and 357 m. Using this bathymetry interval, the estimated potential habitat is 48,368 km^2. The estimated area of occupancy based on trawl tow observations covers 33,092 km^2 using a DFO grid (0.1° longitude × 0.075° latitude) or 11,332 km^2 using a COSEWIC grid (2 km^2 × 2 km^2). Within its preferred depth range, yellowmouth rockfish is caught with numerous other species including Pacific ocean perch *Sebastes alutus*, arrowtooth flounder *Atheresthes stomias*, redstripe rockfish *S. proriger*, silvergray rockfish *S. brevispinis*, and yellowtail rockfish *S. flavidus*. Total removal of yellowmouth rockfish from BC coastal waters by Canadian and US commercial fleets since 1930 equals at least 60,000 t. The long-term surveys are generally not useful for tracking abundance of this species due to low index precision. Two of these surveys (Hecate Strait assemblage and WCVI shrimp) are too shallow and rarely catch yellowmouth rockfish. The current series of synoptic groundfish surveys being conducted on the BC coast may provide indicators of population trends in future, but the available biomass indices are not precise (relative error = 30–50%), which may reduce the capacity of these surveys to track abundance changes for yellowmouth rockfish. The survey imprecision is likely associated with a substantial mid-water presence for this species. The commercial trawl CPUE indices coastwide show a decline of 2.5% per year from 1996 to 2006. It is not known if the trend in CPUE indices represents a change in abundance of this species or in fishing practices associated with the introduction of IVQ management.

Résumé

Le présent texte résume les renseignements disponibles sur le sébaste à bouche jaune (*Sebastes reedi*). De manière plus précise, ce document examine les données actuelles de la biologie, de la distribution et des tendances relatives de l'abondance afin de servir de référence pour les Rapports sur l'état des stocks du Comité sur la situation des espèces en péril au Canada (COSEPAC). Les poissons de cette espèce pèsent en moyenne 1,467 kg, selon les échantillons de la pêche commerciale observée. Les rapports de croissance ne démontrent pas une grosse différence entre les sexes. Selon le paramètre de la courbe de rendement des analyses allométriques, tous les $\beta > 3$, suggérant une croissance non isométrique. Les analyses de longueur selon l'âge ont également démontré qu'il existe une petite différence entre les mâles et les femelles, bien que les modèles dénotent de manière uniforme des valeurs de L_∞ un peu plus élevées pour les femelles. La mortalité naturelle M est évaluée à 0,047, selon un modèle de décroissance exponentielle et d'un âge maximum observé de 99 ans. La mortalité totale Z évaluée selon les données de l'analyse de la courbe des prises en 2003 est de 0,063 (l'intervalle de confiance de 95 p. 100 = 0,044 à 0,083). Les courbes des fréquences cumulées de maturité évaluent l'âge à 50 p. 100 de la maturité k à 10,1 ans pour les mâles et à 10,6 ans pour les femelles. Si on part de l'hypothèse que k = 10,5 ans et M = 0,047, la durée de génération sera de 31,8 ans. Selon la fréquence de profondeur des prises lors des coups de filet des chaluts commerciaux, la majorité de la population se situe entre 130 m et 357 m. Selon l'intervalle bathymétrique, la zone d'habitat est évaluée à 48 368 km^2. La zone d'occupation évaluée selon des observations lors des coups de filet des chaluts couvre 33 092 km^2 en se servant de la grille (0,1° de longitude × 0,075° de latitude) du ministère des Pêches et Océans, et 11 332 km^2 en se servant de la grille (2 km^2 × 2 km^2) du COSEPAC. Lorsque le sébaste à bouche jaune est pêché alors qu'il se tient dans la tranche d'eau qu'il préfère, ce dernier est capturé avec plusieurs autres espèces telles que le sébaste à longue mâchoire (*Sebastes alutus*), la plie à grande bouche (*Atheresthes stomias*), le sébaste à raie rouge (*Sebastes proriger*), le sébaste argenté (*Sebastes brevispinis*) et le sébaste à queue jaune (*Sebastes flavidus*). Le nombre de sébastes à bouche jaune retirés des eaux côtières de la Colombie-Britannique par les flottes commerciales canadiennes et américaines depuis 1930 s'élève à plus de 60 000 t. En général, les relevés à long terme ne sont pas utiles pour le repérage de l'abondance de cette espèce, car l'index n'est pas très précis. Les données de deux relevés (sur l'assemblage du détroit d'Hécate et la crevette de la côte Ouest de l'Île de Vancouver) sont trop superficielles et comprennent rarement les données sur la prise de sébaste à bouche jaune. La série de relevés synoptiques sur les poissons de fond qui est faite actuellement le long de la côte de la Colombie-Britannique pourrait nous fournir des indications sur les tendances de la population, mais les indices de biomasses disponibles ne sont pas précis (erreur relative = 30 à 50 %), ce qui peut réduire la capacité de ces relevés à repérer les changements d'abondance du sébaste à bouche jaune. Il est très probable que le manque de précision des relevés soit lié à la présence pélagique importante de cette espèce. Les indices de captures par unité d'effort (CPUE) le long de la côte par des chaluts commerciaux démontrent une baisse de 2,5 p. 100 par année entre 1996 et 2006. On ne sait pas si la tendance des indices de CPUE concernant le changement de l'abondance de cette espèce ou des pratiques de pêche est liée à l'introduction de la gestion de quota individuel de bateau (QIB).

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1. Introduction

We summarise the available information on a data-limited species, yellowmouth rockfish *Sebastes reedi* (Westrheim & Tsuyuki 1967), along the British Columbia (BC) coast. Specifically, this paper reviews the current data on the biology, distribution, and abundance trends. The species gets its scientific name from a the Canadian Department of Fisheries and Oceans research vessel G.B. Reed (Westrheim and Tsuyuki 1967), which in turn was named after the late Professor G. B. Reed (Queen's University) who also acted as a chairman of the Fisheries Research Board of Canada during 1947-55 (Johnstone 1977). Its common name stems from yellow-black blotches in the mouth (Westrheim and Tsuyuki 1967). The body sports a mixture of colours – red, orange, yellow – and features a thin pink-red strip along the lateral line and dusky saddles along the back (Love et al. 2002). Genetically, this species has close ties to darkblotched rockfish.

Figure 1. Yellowmouth rockfish *Sebastes reedi*
Source: http://pacpbsgfiis/gfimages/photos/020811_04W.jpg. Photo: Terri Bonnet

Taxonomic hierarchy* for *Sebastes reedi* (Westrheim and Tsuyuki, 1967)
Taxonomic Serial No. (TSN) 166737:

Kingdom	Animalia	animals
Phylum	Chordata	chordates
Subphylum	Vertebrata	vertebrates
Superclass	Osteichthyes	bony fish
Class	Actinopterygii	ray-finned fish, spiny rayed fish
Subclass	Neopterygii	neopterygians
Infraclass	Teleostei	
Superorder	Acanthopterygii	
Order	Scorpaeniformes	scorpion fish, sculpins
Suborder	Scorpaenoidei	
Family	Scorpaenidae	scorpionfish
Genus	Sebastes Cuvier, 1829	rockfish, rockcod
Species	*Sebastes reedi* (Westrheim and Tsuyuki, 1967)	yellowmouth rockfish

*Source: http://www.itis.gov/servlet/SingleRpt/SingleRpt

According to Love et al. (2002), yellowmouth rockfish commonly range from southeast Alaska to Oregon but have been identified further afield – Gulf of Alaska to the north, San Francisco to the south. Along the BC coast, Westrheim and Tsuyuki (1967) noted a decrease in modal size from south to north, although this observation might have been confounded with increasing depth. The reported depth of habitation for yellowmouth rockfish ranges from 100 to 431 m, with a preferred range of 180-275 m. Adults occur frequently in midwater above high-relief rocks. They can live as long as 86 years.

In BC waters, larval release occurs from February to June. Males achieve 50% maturity at 37 cm, females at 38 cm. Lengths reach a maximum at approximately 54 cm (Hart 1973).

2. Biology

2.1. Biometrics

Biometric data (length, weight, maturity, age, etc.) on fish species collected by Fisheries and Oceans Canada (DFO) personnel and affiliates are stored in DFO's Oracle database called `GFBio`, and mirrored in an SQL database called `GFBioSQL` on the groundfish server `PACPBSGFDB`. We use data from the latter in the analyses that follow.

2.1.1. Length-weight

The mean weight $\hat{w}$ of yellowmouth rockfish caught by the observed commercial trawl fishery is 1.467 kg ($\hat{\sigma}$ = 0.328 kg, n = 1678). This value can be used when expressing commercial catches, expressed in tonnes of biomass, as numbers of fish.

Length to weight relationships can be derived by fitting a simple exponential model (A.1) through the data. A summary of these fits to DFO data by trip type and sex appears in Table 1. The parameter estimates α and β describe the condition factor (y-intercept) and curvature (rate of change in weight with respect to length), respectively. All estimated β exceed 3, suggesting non-isometric growth.

Table 1. Summary of length-weight data. Allometric relationship for curve-fitting: $W = \alpha L^{\beta}$, where W =weight (kg) and L =length(cm). Columns: n =number of fish specimens, log(α) = y-intercept; SE_{α} = standard error of estimated α; β = curvature parameter; SE_{β} = standard error of estimated β; $\overline{W}$ = mean weight (kg); $SD_{\overline{W}}$ = standard deviation of $\overline{W}$; W_{min} =minimum observed weight (kg); W_{max} = maximum observed weight (kg).

	n	log(α)	$SE_{\log(\alpha)}$	β	SE_{β}	W	SD_W	W_{min}	W_{max}
Males									
Non Obs Comm	408	-11.551	0.183	3.134	0.048	1.413	0.301	0.433	2.225
Research	870	-12.167	0.045	3.293	0.012	1.142	0.607	0.006	2.350
Charter	1,261	-12.064	0.043	3.269	0.012	1.214	0.443	0.023	2.632
Obs Comm	922	-11.291	0.136	3.071	0.036	1.451	0.307	0.517	2.345
Res+Chart	2,131	-12.149	0.030	3.290	0.008	1.185	0.517	0.006	2.632
Commercial	1,330	-11.376	0.111	3.092	0.029	1.439	0.306	0.433	2.345
Females									
Non Obs Comm	394	-11.124	0.170	3.019	0.045	1.495	0.327	0.558	2.578
Research	914	-11.860	0.049	3.196	0.013	1.275	0.566	0.008	2.501
Charter	1,157	-11.451	0.079	3.103	0.021	1.264	0.453	0.046	2.522
Obs Comm	756	-11.123	0.127	3.024	0.034	1.486	0.352	0.459	2.600
Res + Chart	2,071	-11.748	0.043	3.175	0.012	1.269	0.506	0.008	2.522
Commercial	1,150	-11.096	0.103	3.015	0.027	1.489	0.343	0.459	2.600
Males+Females									
Non Obs Comm	802	-11.303	0.124	3.067	0.033	1.454	0.317	0.433	2.578
Research	1,784	-12.018	0.033	3.245	0.009	1.211	0.590	0.006	2.501
Charter	2,418	-11.783	0.044	3.193	0.012	1.238	0.448	0.023	2.632
Obs Comm	1,678	-11.184	0.093	3.041	0.025	1.467	0.328	0.459	2.600
Res + Chart	4,202	-11.969	0.026	3.238	0.007	1.226	0.513	0.006	2.632
Commercial	2,480	-11.205	0.076	3.045	0.020	1.462	0.325	0.433	2.600

2.1.2. Length frequencies

Relative frequencies of sampled yellowmouth rockfish lengths by trip type (non-observed domestic commercial, research, charter, and observed domestic commercial) and calendar year appear in the histogram matrices below (Figure 2 to Figure 4). Only matrix cells containing more than 40 sampled fish are displayed. Mean lengths generally lie between 40 and 45 cm. In 2004-2007, the charter trips appeared to sample juveniles, which reduced the mean length.

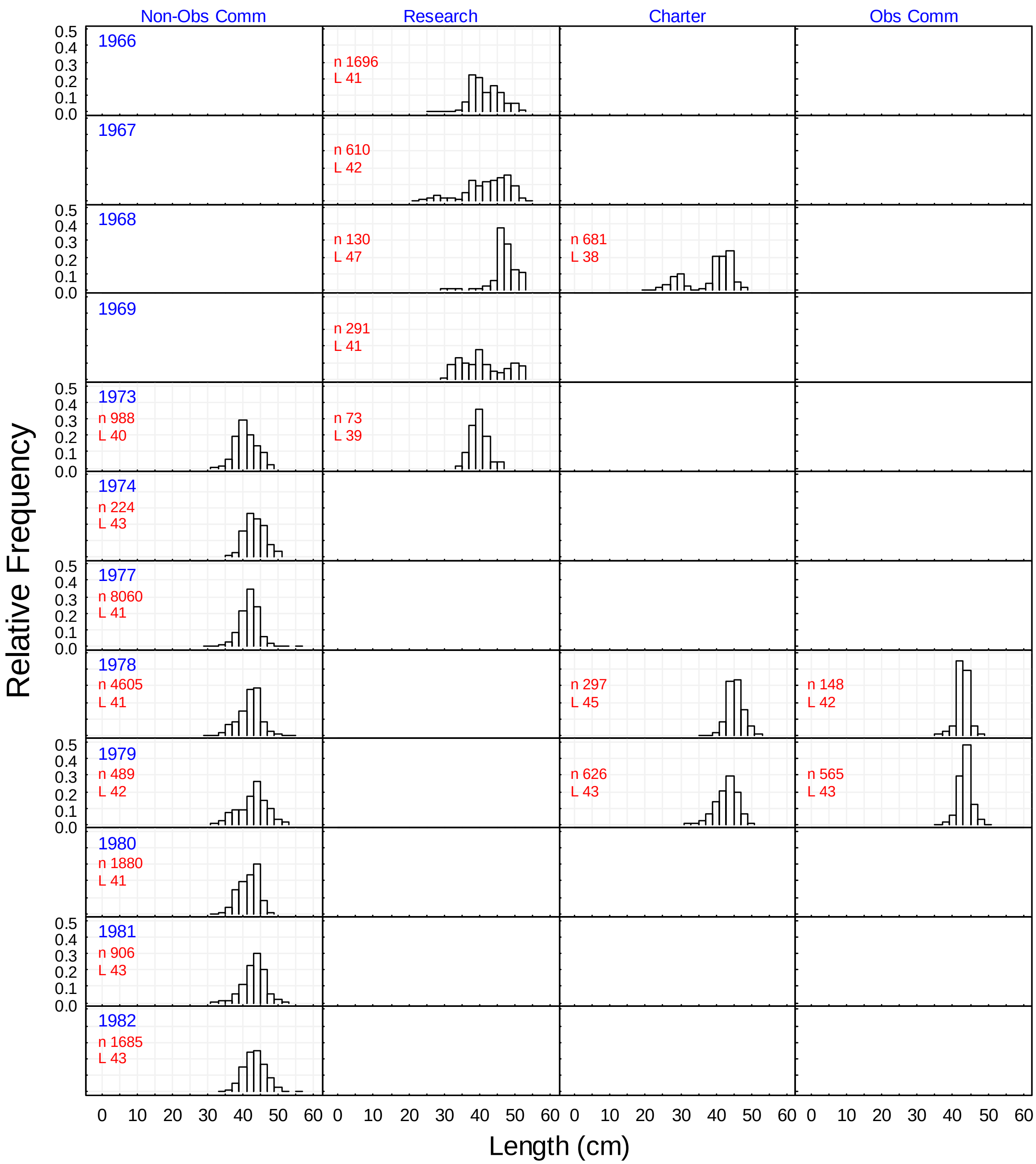

Figure 2. Relative frequency of yellowmouth rockfish lengths (cm) by calendar year (1966 to 1982) and trip type. Lengths are binned using 2-cm intervals. n = number of fish, L = mean length (cm).

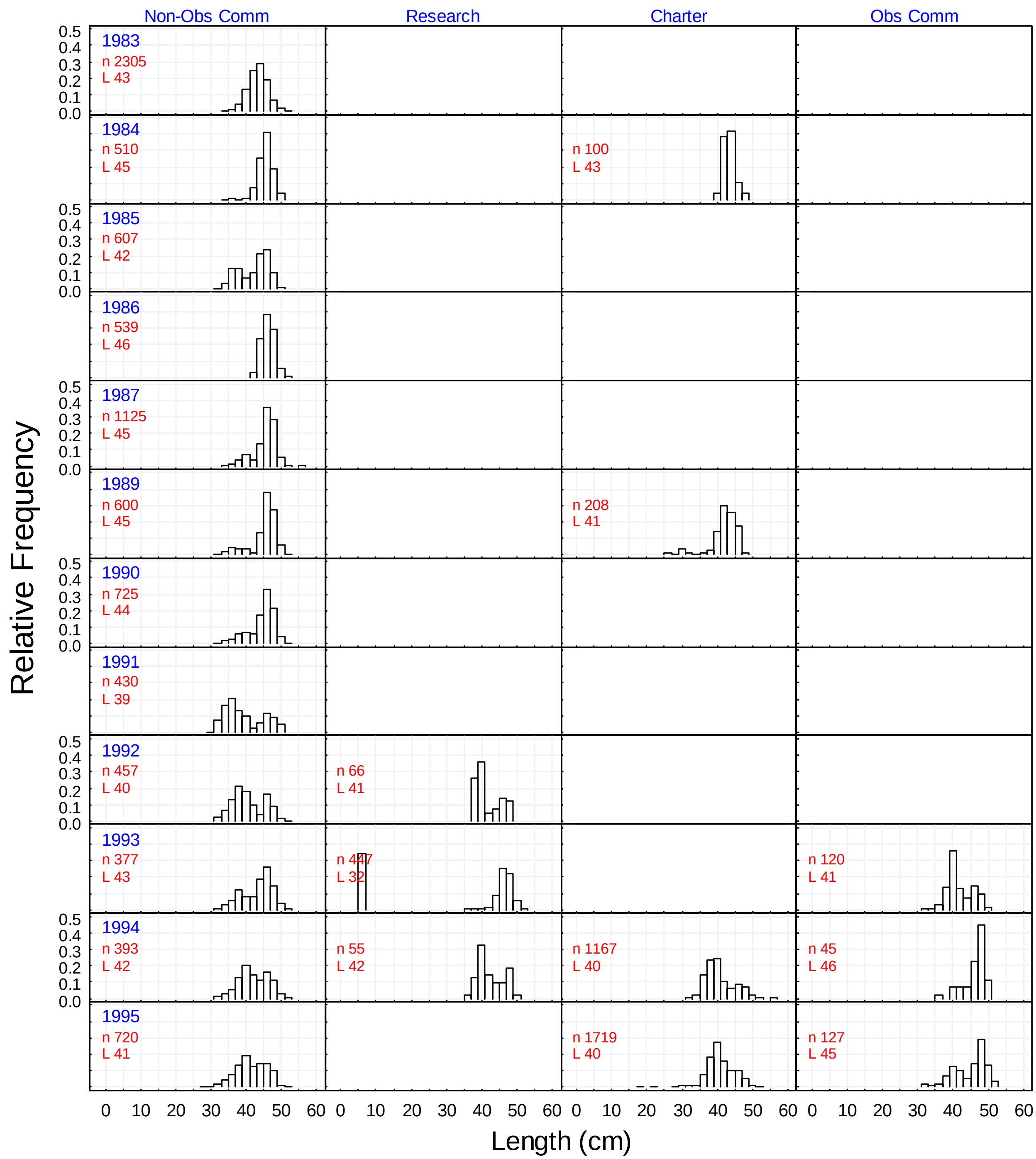

Figure 3. Relative frequency of yellowmouth rockfish lengths (cm) by calendar year (1983 to 1995) and trip type. Lengths are binned using 2-cm intervals. n = number of fish, L = mean length (cm).

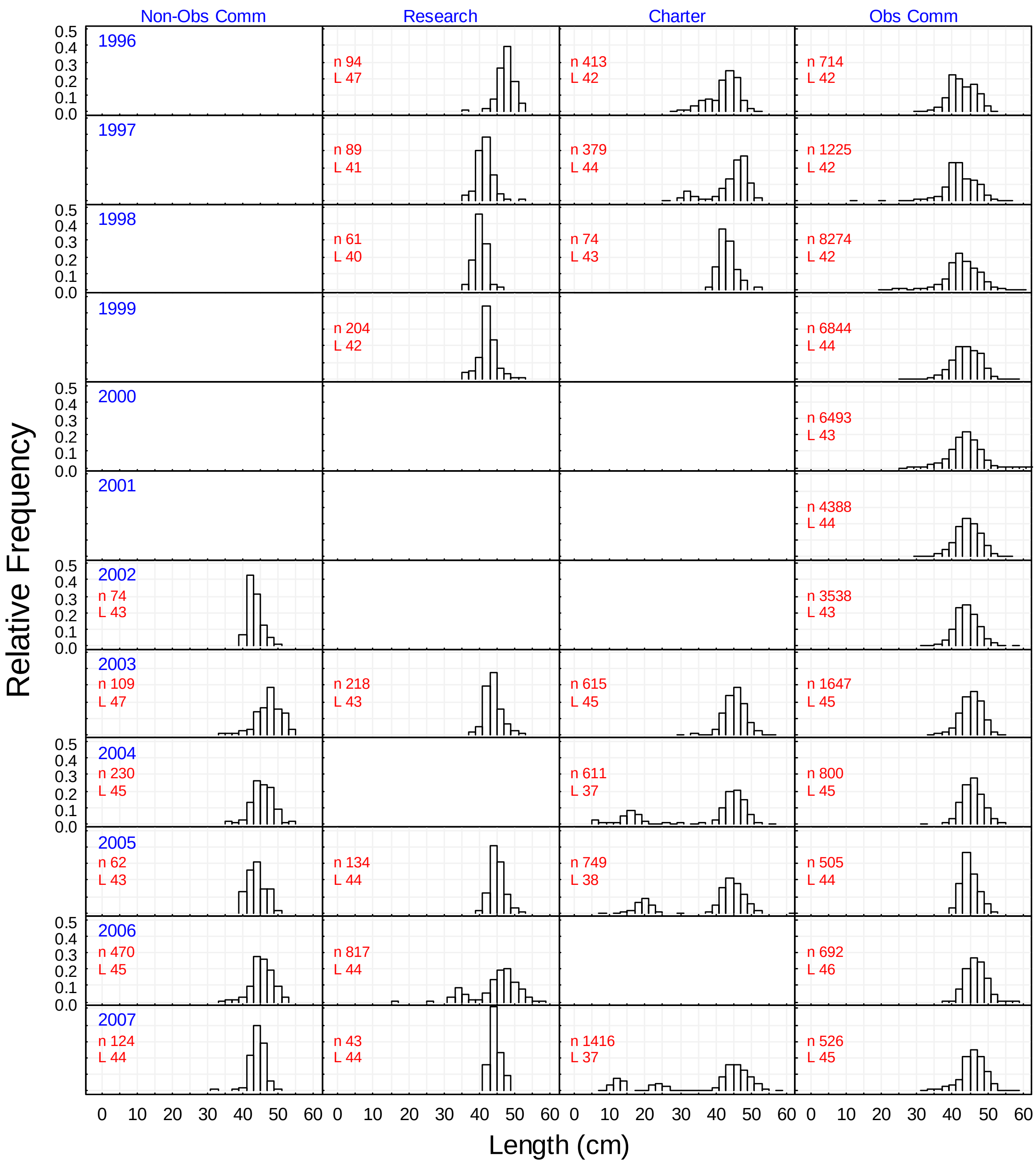

Figure 4. Relative frequency of yellowmouth rockfish lengths (cm) by calendar year (1996 to 2007) and trip type. Lengths are binned using 2-cm intervals. n = number of fish, L = mean length (cm).

2.2. Growth

2.2.1. Length-age

Length-age relationships can be derived either through the von Bertalanffy model (A.2) or through Schnute's growth model that employs an alternate parameterization (Schnute 1981). Here we simply provide a number of von Bertalanffy fits to DFO length-age data. The selection criteria are:

- species identified as yellowmouth rockfish (code = 440);
- specimens identified as either male or female (codes = 1 and 2, respectively);
- specimens collected in BC waters (Pacific Marine Fisheries Commission (PMFC) areas 3C, 3D, 5A, 5B, 5C, 5D, 5E);
- otoliths broken and burnt;
- lengths ≥ 21 cm and ≤ 60 cm (to remove a few outliers);
- ages > 0 y and ≤ 90 y (to remove a few outliers).

The above qualification yielded 6,860 yellowmouth rockfish specimens (maximum age = 86 y) with the following distributions:

- by sex – males (3492), females (3368);
- by area – 3C (50), 3D (481), 5A (2792), 5B (1949), 5C (166), 5E (1422);
- by gear – bottom trawl (6625), midwater trawl (235);
- by year – 1978 (95), 1979 (597), 1990 (492), 1991 (245), 1992 (296), 1993 (434), 1994 (363), 1995 (748), 1996 (496), 1997 (312), 1998 (441), 1999 (483), 2000 (397), 2001 (528), 2002 (524), 2003 (409);
- by trip type – non-observed commercial (2016), research (94), charter (1278), observed commercial (3472).

The von Bertalanffy fits (A.2.3) through length-age data by trip type (Figure 5) show similar values for L_∞ with no obvious difference between the sexes. A great deal of variation exists in length for any particular age, and the reported fit remains an approximation. Sampling by various agencies can introduce bias. For instance, specimens selected from the commercial fishery will under-represent young age classes depending on the degree to which the gear (e.g., net mesh size) does not capture small fish. This lack of data points at younger ages greatly affects the estimate of the growth parameter K, which in turn influences the perception of natural mortality M (Quinn and Deriso 1999). Most of the estimates t_0 are negative which biases K downwards (i.e., underestimates K).

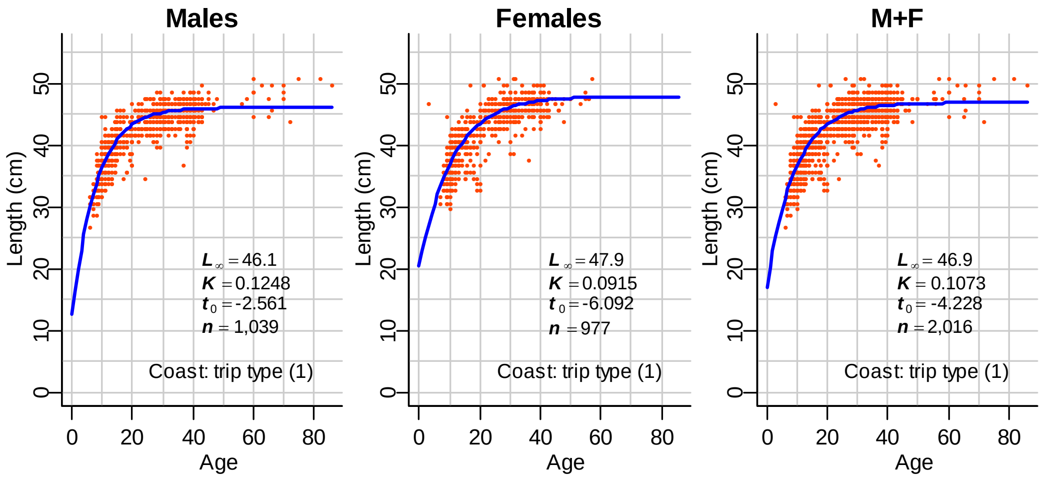

Figure 5. Length-at-age relationships for specimens collected on non-observed domestic commercial trips (trip type = 1) using the von Bertalanffy growth equation (see Appendix A.2). M+F = male and female specimens combined; *n* = number of specimens.

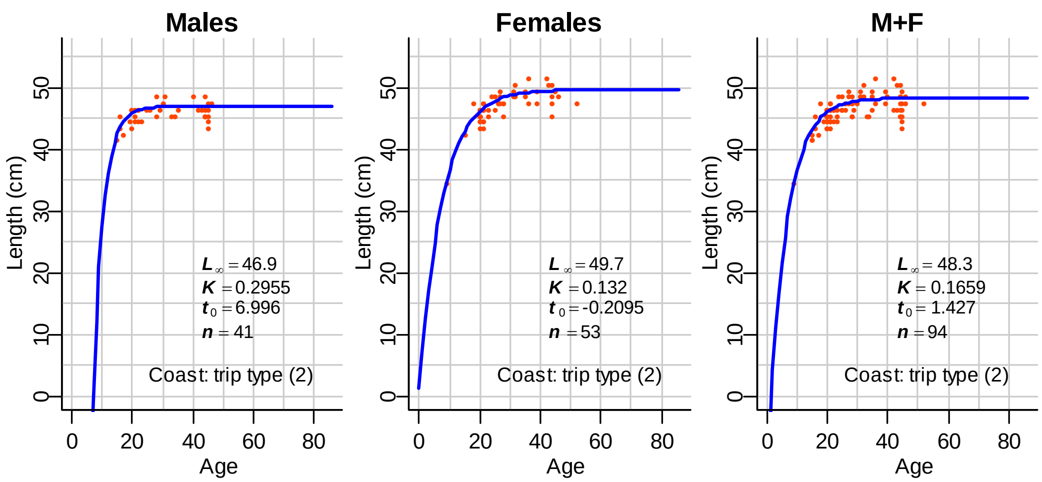

Figure 5 cont'd. Length-at-age relationships for specimens collected on research surveys (trip type = 2).

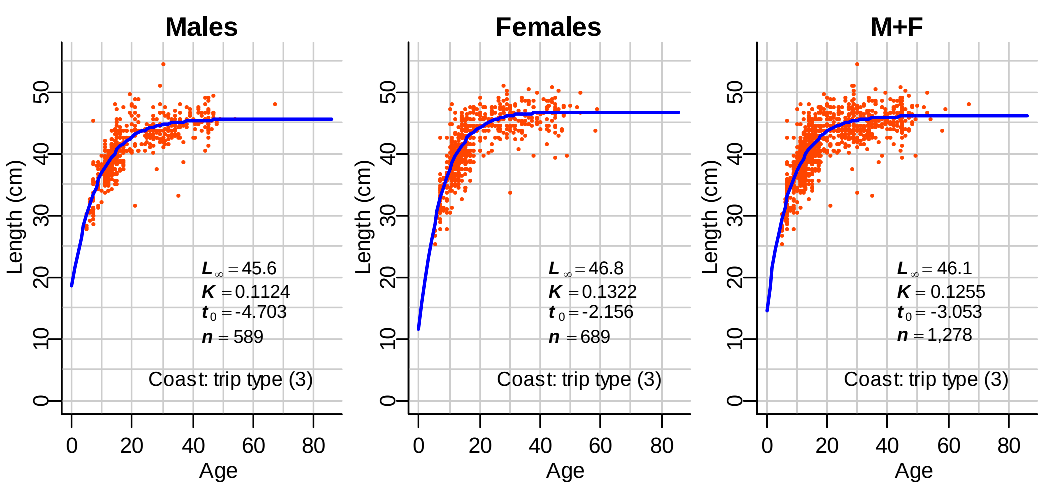

Figure 5 cont'd. Length-at-age relationships for specimens collected on charter surveys (trip type = 3).

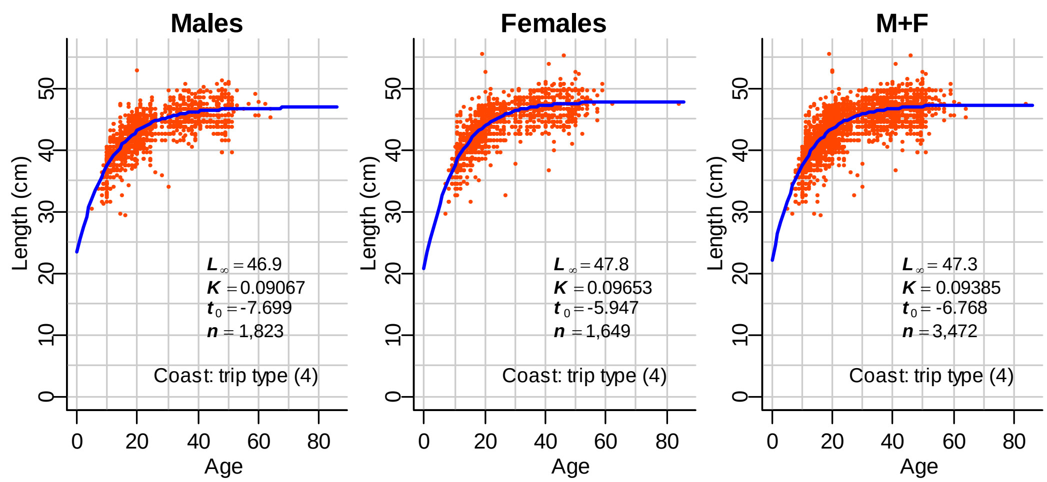

Figure 5 cont'd. Length-at-age relationships for specimens collected on observed domestic commercial trips (trip type = 4).

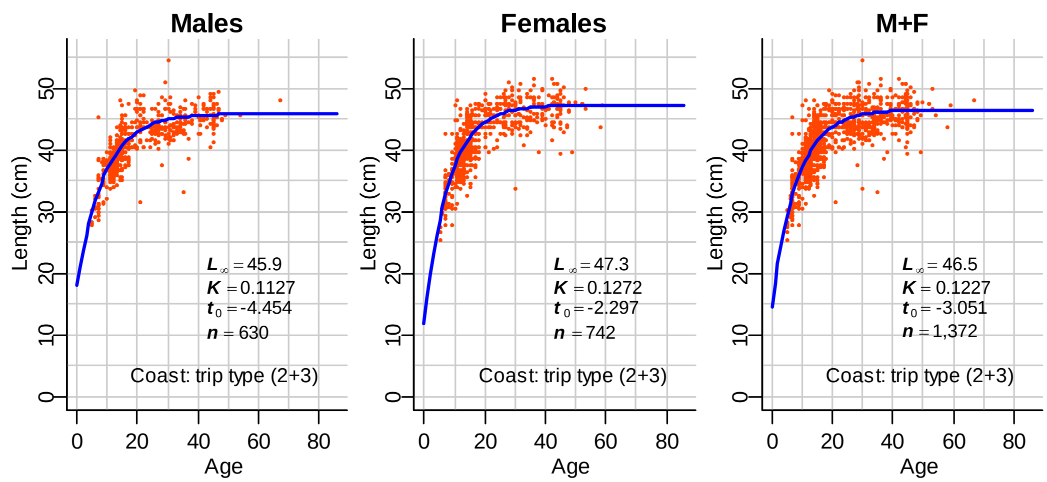

Figure 5 cont'd. Length-at-age relationships for specimens collected on research and charter surveys combined.

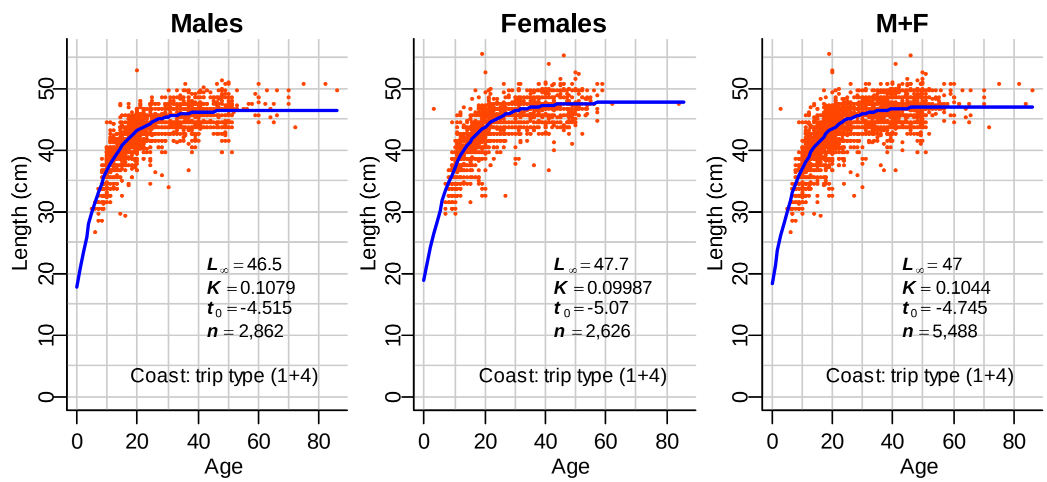

Figure 5 cont'd. Length-at-age relationships for specimens collected on all domestic commercial trips.

2.3. Mortality, maturity, and generation time

2.3.1. Mortality

Natural mortality remains unknown, but past authors (e.g., Schnute et al. 1999) assumed M=0.05. Quinn and Deriso (1999) present a simple formula, based on Hoenig's (1983) finding that natural mortality is inversely proportional to longevity, which assumes the proportion of a population reaching the maximum observed age t_m is 0.01. Their rearrangement of the exponential law of population decline

$$M = \frac{-\log(0.01)}{t_m} = \frac{4.605}{99} = 0.047$$

yields M = 0.047 for yellowmouth rockfish, using the maximum observed age of 99 (Figure 6).

Proportions-at-age data (Figure 7 to Figure 10) point to a strong recruitment year in 1982. We applied the catch-curve analysis of Schnute and Haigh (2007) to the 1990 and 2003 age data (all measured using break-and-burn) above to estimate average mortality Z during these periods. The modal estimates from an R statistical package non-linear algorithm (`nlm`) yield Z-values for 1990 and 2003 of 0.090 and 0.067, respectively (Figure 11 to Figure 12). However, the mean estimates (with 95% confidence intervals) from a Bayes posterior sample (using the R-package `BRugs`, which employs Gibbs sampling) are 0.071 (0.044-0.100) and 0.063 (0.014-0.083), respectively. The differences in mean Z between 1990 and 2003 are not statistically different from each other. At this value of M, fishing mortality F appears to be relatively low (0.016-0.024). However, values of Z derived through catch-curve analysis are highly smeared and do not adequately represent the impact of current fishing mortality.

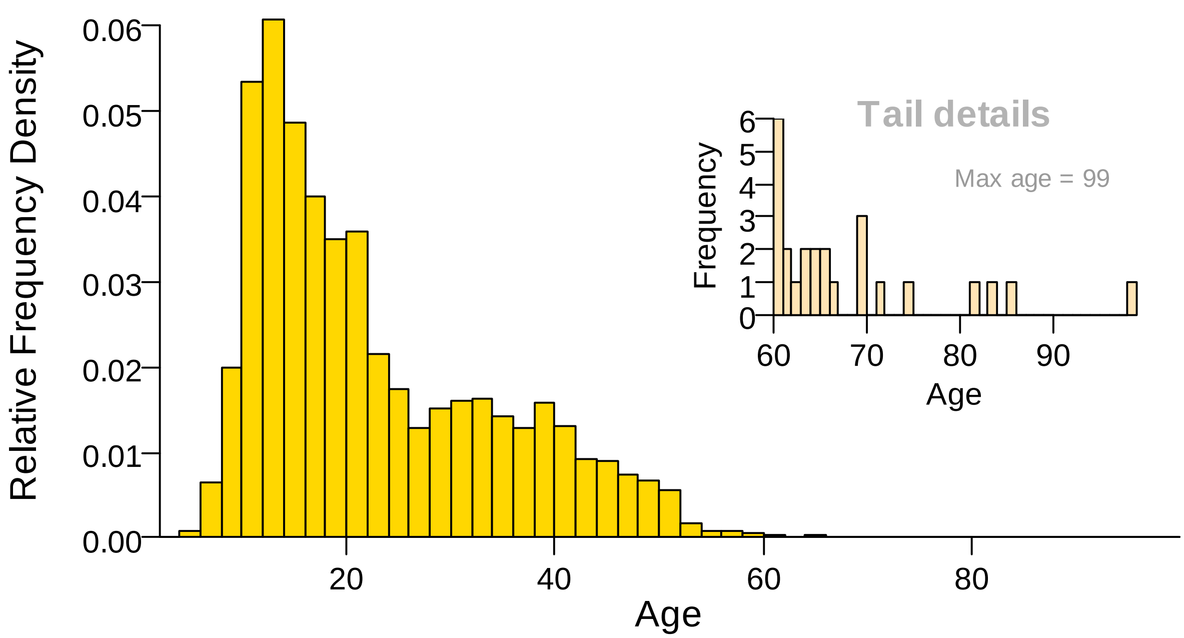

Figure 6. Relative frequency distribution of 6,901 yellowmouth rockfish ages. Inset zooms in on the tail of the distribution. Maximum age recorded in BC is 99.

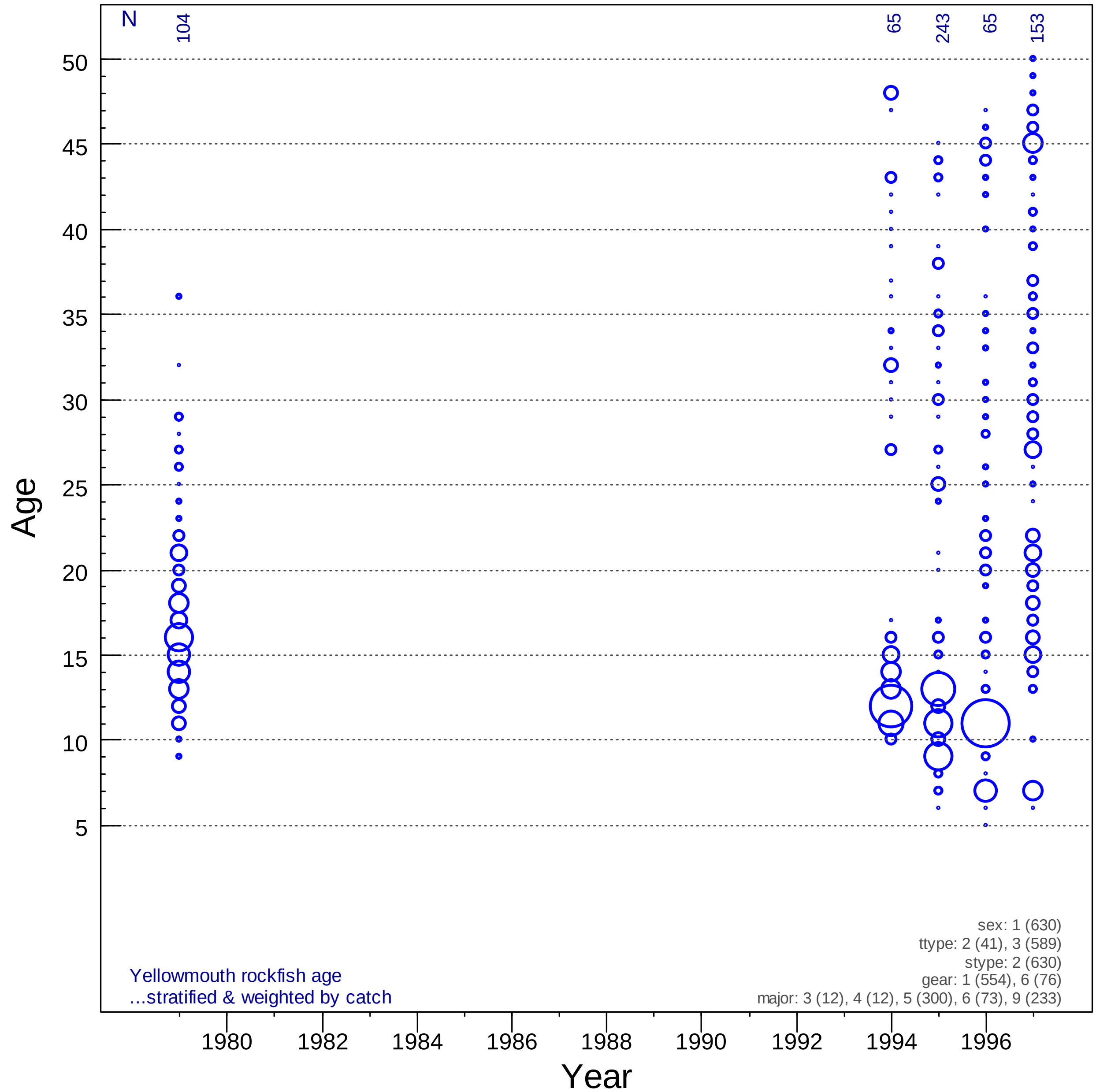

Figure 7. Bubble plot of observed age proportions for male (sex = 1) yellowmouth rockfish samples collected by research surveys (trip type 2) or charter vessels (trip type 3). Proportions are stratified and weighted by catch. Age 50 acts as a plus-class. Table at bottom right indicates the distribution of specimens used in the figure, where stype = sample type (0 = unknown, 2 = random), gear (1 = bottom trawl, 6 = midwater trawl), major = PMFC area (3 = 3C, 4 = 3D, 5 = 5A, 6 = 5B, 9 = 5E).

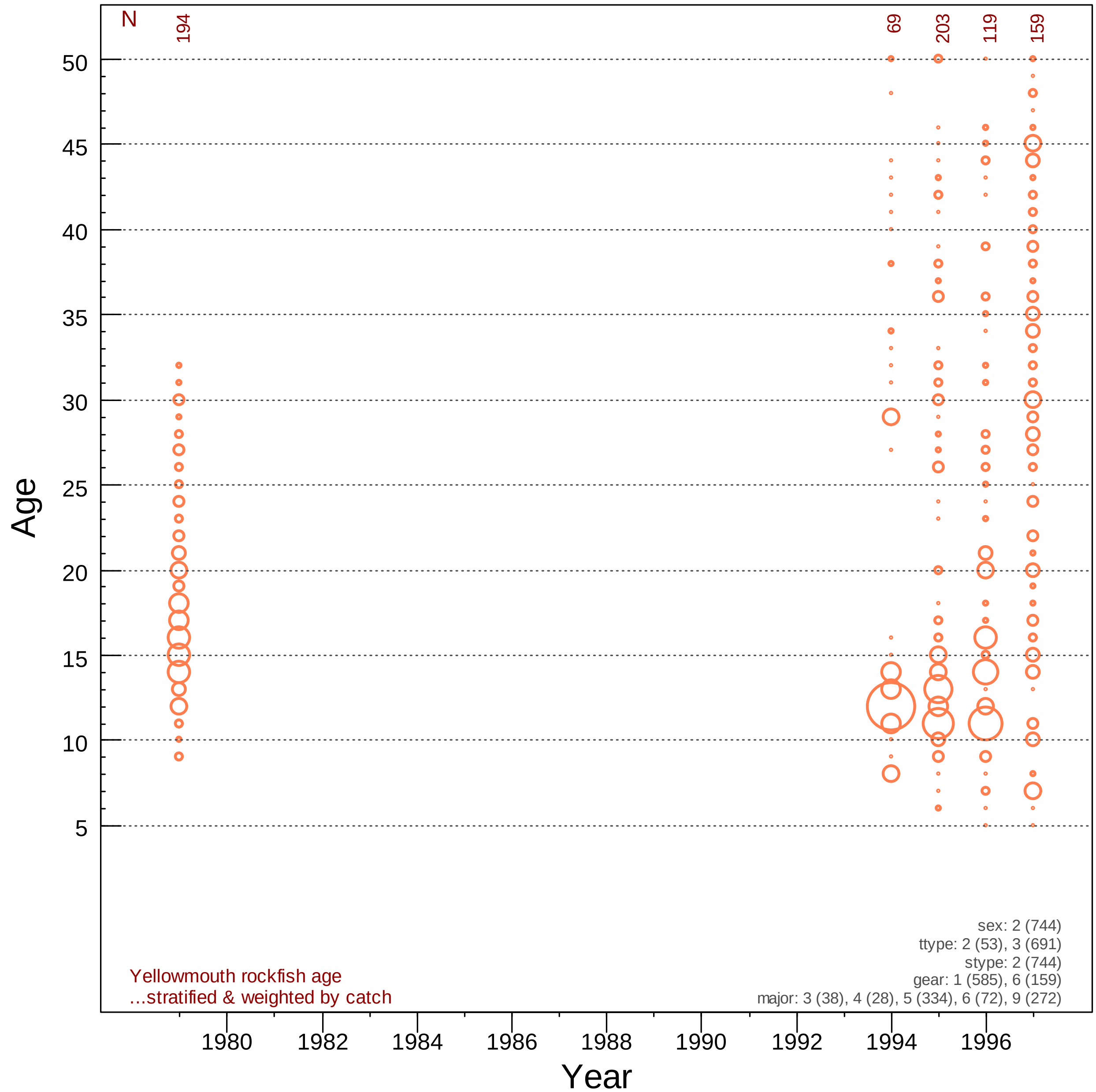

Figure 8. Bubble plot of observed age proportions for female (sex = 2) yellowmouth rockfish samples collected by research surveys (trip type 2) or charter vessels (trip type 3). Proportions are stratified and weighted by catch. Age 50 acts as a plus-class. Table at bottom right indicates the distribution of specimens used in the figure, where stype = sample type (0 = unknown, 2 = random), gear (1 = bottom trawl, 6 = midwater trawl), major = PMFC area (3 = 3C, 4 = 3D, 5 = 5A, 6 = 5B, 9 = 5E).

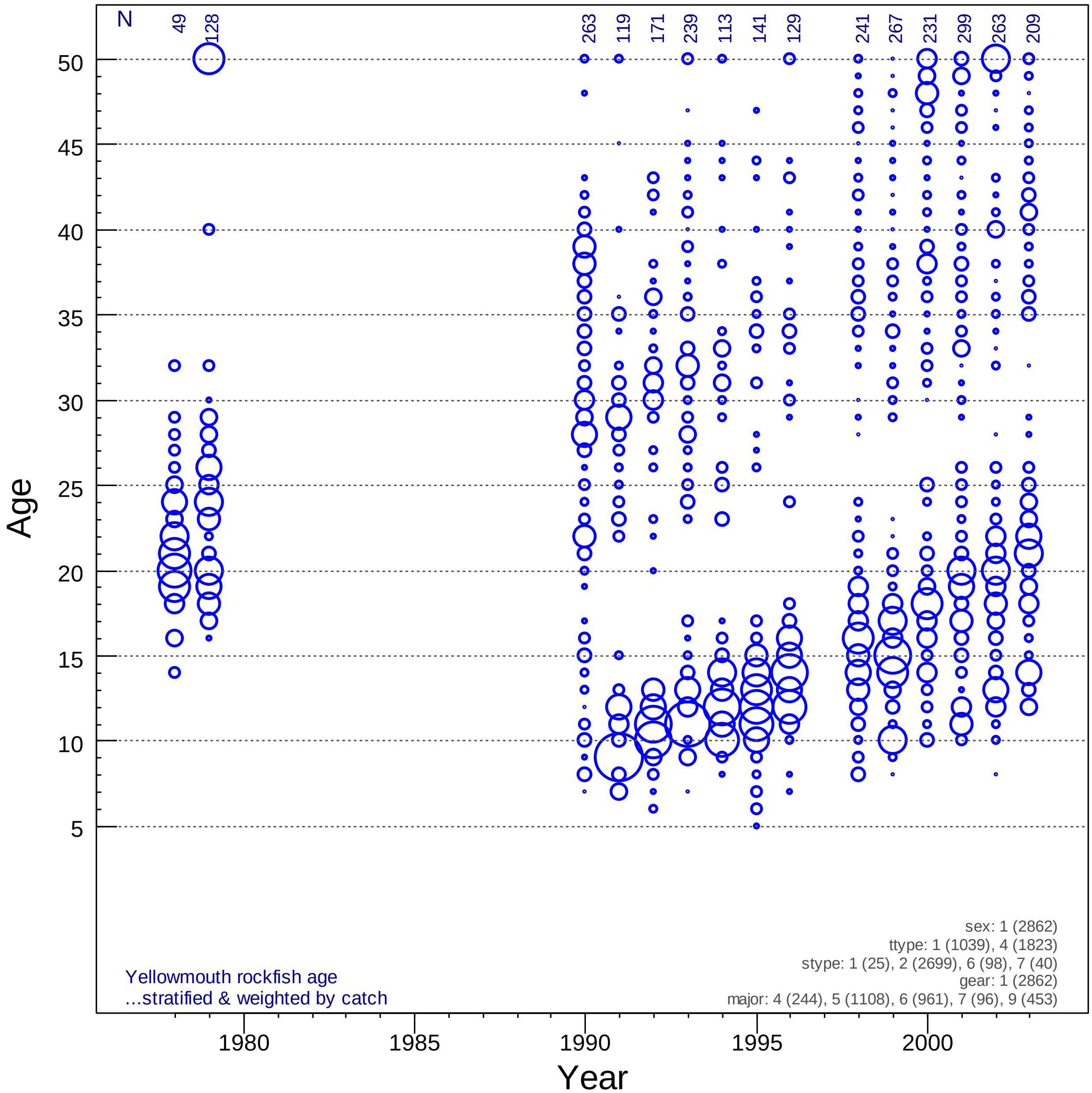

Figure 9. Bubble plot of observed age proportions for male (sex = 1) yellowmouth rockfish samples collected by non-observed commercial trips (trip type 1) or observed commercial trips (trip type 4). Proportions are stratified and weighted by catch. Age 50 acts as a plus-class. Table at bottom right indicates the distribution of specimens used in the figure, where stype = sample type (0 = unknown, 2 = random, 6 = random from randomly assigned set,7 = random from set after randomly assigned set), gear (1 = bottom trawl), major = PMFC area (4 = 3D, 5 = 5A, 6 = 5B, 7 = 5C, 9 = 5E).

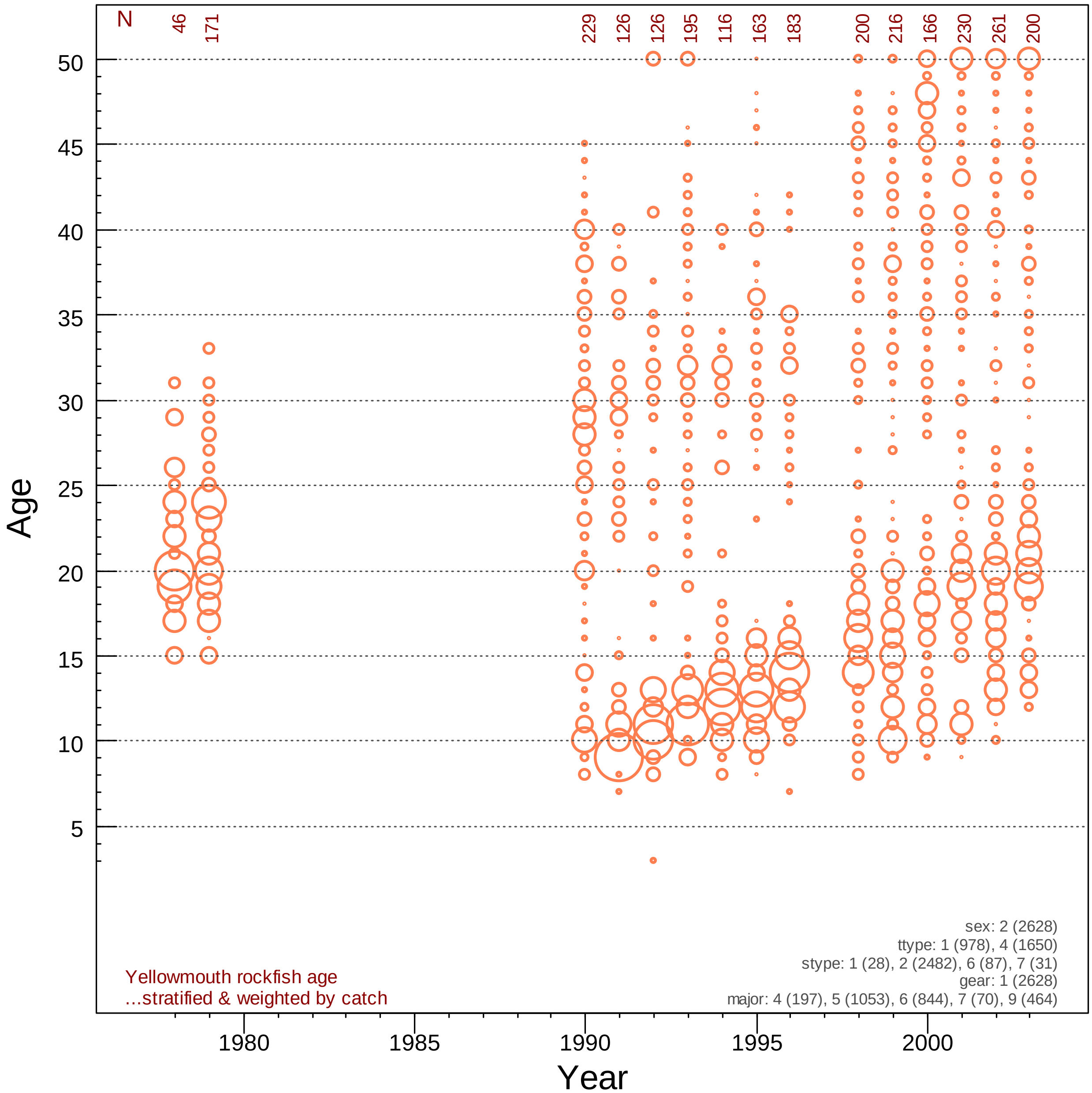

Figure 10. Bubble plot of observed age proportions for female (sex = 2) yellowmouth rockfish samples collected by non-observed commercial trips (trip type 1) or observed commercial trips (trip type 4). Proportions are stratified and weighted by catch. Age 50 acts as a plus-class. Table at bottom right indicates the distribution of specimens used in the figure, where stype = sample type (0 = unknown, 2 = random, 6 = random from randomly assigned set,7 = random from set after randomly assigned set), gear (1 = bottom trawl), major = PMFC area (4 = 3D, 5 = 5A, 6 = 5B, 7 = 5C, 9 = 5E).

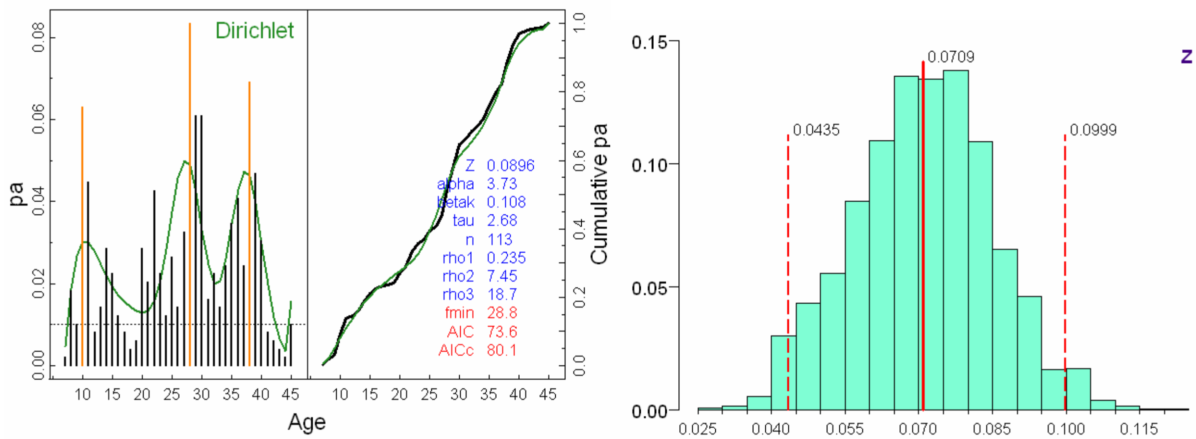

Figure 11. **Left**: Age proportions (vertical bars) for 1990 and the Schnute-Haigh catch curve model fit using the Dirichlet distribution. Recruitment anomalies highlighted in orange at ages 10, 28, and 38. **Middle**: Curves showing cumulative proportions: observed (black) and estimated (green). Inset table shows modal estimates of model parameters (blue) and model goodness-of-fit values (red). **Right**: Bayes posterior sample (*n*=2000) of *Z*. Solid vertical line indicates the mean *Z*-value, dashed vertical lines indicate the 2.5% and 97.5% quantiles.

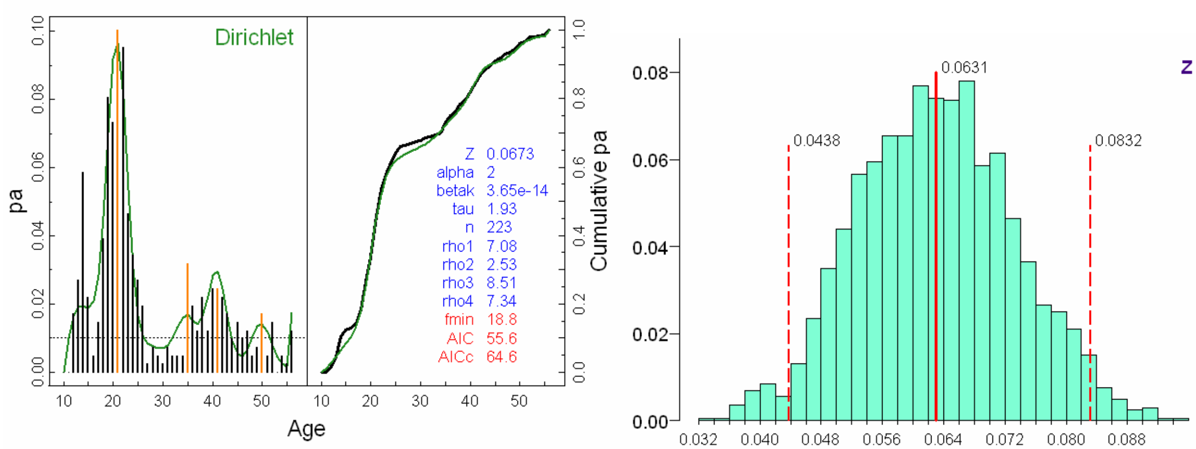

Figure 12. **Left**: Age proportions (vertical bars) for 2003 and the Schnute-Haigh catch curve model fit using the Dirichlet distribution. Recruitment anomalies highlighted in orange at ages 21, 35, 41, and 50. **Middle**: Curves showing cumulative proportions: observed (black) and estimated (green). Inset table shows modal estimates of model parameters (blue) and model goodness-of-fit values (red). **Right**: Bayes posterior sample (*n*=2000) of *Z*. Solid vertical line indicates the mean *Z*-value, dashed vertical lines indicate the 2.5% and 97.5% quantiles.

2.3.2. Maturity

A frequency chart of all available maturity data (1967-2007) for yellowmouth rockfish (Figure 13) suggests that females mature from September to October, are fertilized in February, and bear young in April and May. Westrheim (1975) noted that parturition for *S. reedi* peaks in May in BC. Fertility in males appears to peak in September, although this could reflect a lack of observations for this category in other months. Data for the other categories; however, confirm the timing of maximum fertility (Figure 13).

Ideally, lengths- and ages-at-maturity are calculated at times of peak development stages (males – inseminations season, females – parturition season; Westrheim 1975). On the other hand, to see changes in maturity, we use data from time periods that span the transition from immature to mature fish. In the case of *S reedi*, this period appears to cover a full calendar year, though the timing is different for the two sexes(Figure 13). We define maturity to be stage 3 and up, and use only break-and-burn ages to construct a maturity ogive (Figure 14). To smooth the maturity data, the ages are binned in 2 year age groups. For each group, the proportion of mature individuals is calculated (Table 2) and The ages of 50% maturity k (10.1 y for males, 10.6 y for females) are interpolated from the curves. Maturity ogives of length (not presented here) yield lengths at 50% maturity of 37 cm for males and 39 cm for females, values similar to those reported in the literature (37 cm and 38 cm, respectively, Westrheim 1975).

Assuming a natural mortality rate $M = 0.047$ and using $k = 10.5$ y, the generation time calculation (A.3.2) yields 31.8 y.

Table 2. Proportions of mature yellowmouth rockfish by age group. Maturity is defined by codes 3-7. p = proportion mature fish, n = number of fish specimens, a = mean age of specimens in group, σ = standard deviation of the mean age.

Age	**All**				**Males**				**Females**			
Group	p	n	a	σ	p	n	a	σ	p	n	a	σ
5-6	0.000	20	5.7	0.49	0.000	13	5.7	0.48	0.000	7	5.6	0.53
7-8	0.092	119	7.4	0.49	0.167	54	7.4	0.49	0.031	65	7.4	0.49
9-10	0.368	435	9.5	0.50	0.400	205	9.5	0.50	0.339	230	9.5	0.50
11-12	0.670	740	11.5	0.50	0.701	371	11.4	0.50	0.640	369	11.5	0.50
13-14	0.821	642	13.4	0.50	0.832	309	13.4	0.49	0.811	333	13.5	0.50
15-16	0.888	385	15.5	0.50	0.884	199	15.5	0.50	0.892	186	15.5	0.50
17-18	0.875	304	17.5	0.50	0.889	162	17.5	0.50	0.859	142	17.5	0.50
19-20	0.862	312	19.6	0.49	0.826	132	19.5	0.50	0.889	180	19.6	0.48
21-22	0.891	239	21.5	0.50	0.861	122	21.5	0.50	0.923	117	21.4	0.50
23-24	0.905	189	23.5	0.50	0.859	92	23.6	0.49	0.948	97	23.5	0.50
25-26	0.897	145	25.5	0.50	0.811	74	25.5	0.50	0.986	71	25.5	0.50
27-28	0.907	151	27.6	0.50	0.857	77	27.5	0.50	0.959	74	27.6	0.49
29-30	0.921	203	29.5	0.50	0.882	102	29.5	0.50	0.960	101	29.5	0.50
31-32	0.949	198	31.6	0.49	0.920	100	31.6	0.49	0.980	98	31.6	0.49
33-34	0.920	138	33.5	0.50	0.910	78	33.5	0.50	0.933	60	33.5	0.50
35-36	0.951	185	35.5	0.50	0.934	106	35.5	0.50	0.975	79	35.5	0.50
37-38	0.919	149	37.7	0.47	0.879	91	37.7	0.48	0.983	58	37.7	0.46
39-40	0.922	141	39.5	0.50	0.873	79	39.5	0.50	0.984	62	39.6	0.50
41-42	0.938	96	41.5	0.50	0.894	47	41.5	0.51	0.980	49	41.5	0.50
43-44	0.920	87	43.5	0.50	0.880	50	43.5	0.50	0.973	37	43.5	0.51
45-46	0.938	96	45.4	0.49	0.867	45	45.4	0.50	1.000	51	45.4	0.48
47-48	0.972	71	47.5	0.50	0.947	38	47.5	0.51	1.000	33	47.5	0.51
49-50	0.944	54	49.6	0.50	0.971	35	49.6	0.50	0.895	19	49.5	0.51

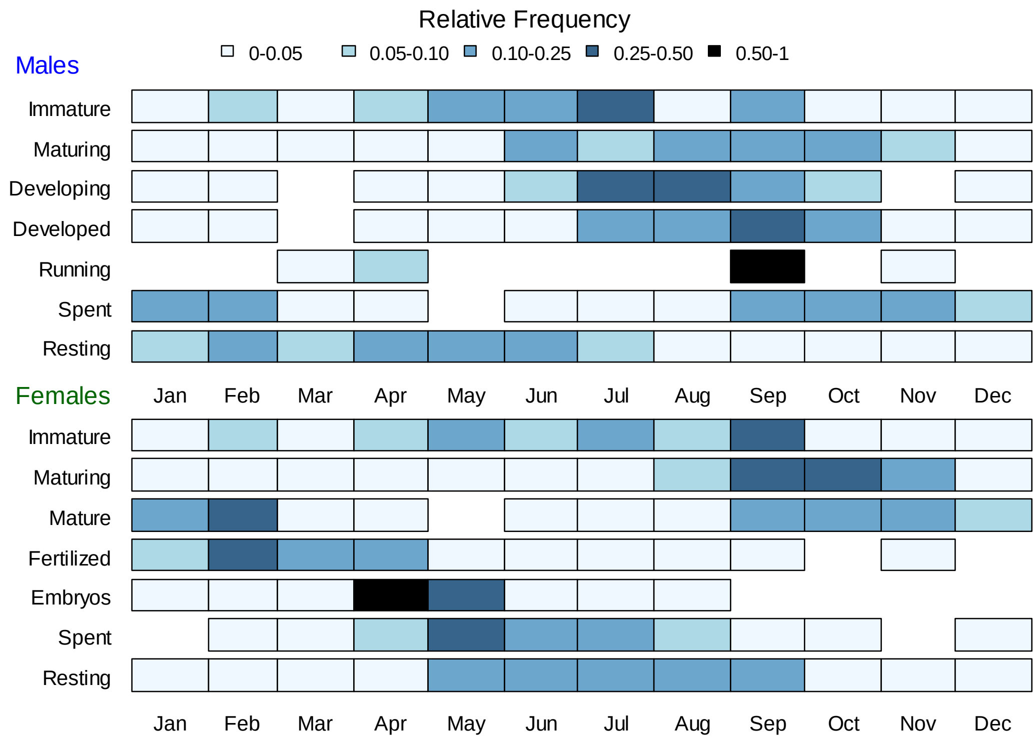

Figure 13. Relative frequency of maturity codes (data stored in DFO's GFBioSQL database) for yellowmouth rockfish . Frequencies are expressed by month for each maturity category.

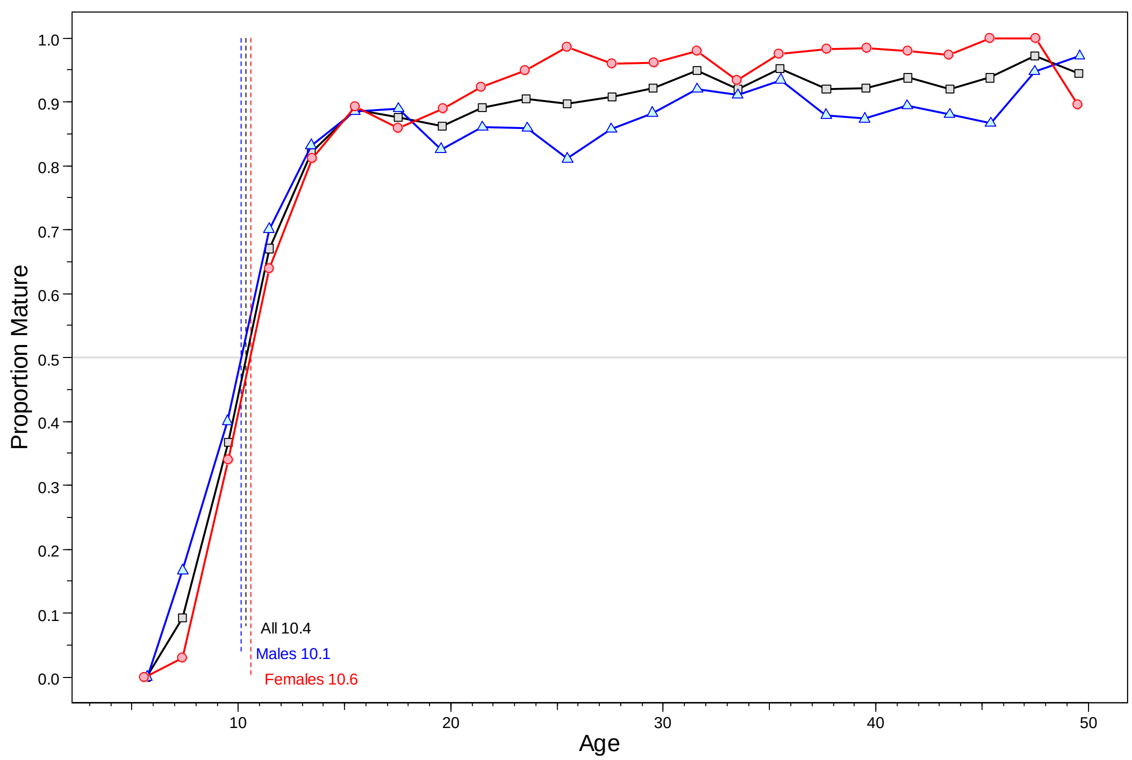

Figure 14. Maturity ogives for yellowmouth rockfish using ages grouped at 2-year age intervals. The age of each group is expressed as the mean of the observed ages in each group. Vertical dashed lines indicate ages at 50% maturity for males, females, and all available specimens, including those without a sex determination.

3. Distribution

Distribution data (geo-referenced catch and effort, depth, etc.) on fish species collected by onboard observers in the groundfish trawl fleet and verified by dockside monitors are stored in DFO's SQL database called `PacHarvest` on the groundfish server `PACPBSGFDB`. The `PacHarvest` database is commonly referred to as the "observer trawl database". We use these data in the analyses that follow.

3.1. Depth preference

The depths of all fishing events (1996-2007) that captured yellowmouth rockfish were extracted from the observer trawl database. The 2.5% and 97.5% quantiles of these observations – 130 m and 357 m (Figure 15) – act as a proxy for the preferred depth range of yellowmouth rockfish. The relative cumulative catch by depth is superimposed on the histogram to show that the depth of median cumulative yelloweye catch (219 m) corresponds with the distribution of tows that capture yelloweye rockfish. For reference, the total trawl effort appears as a shaded histogram in the background. The areas under both histograms each sum to one. Yellowmouth rockfish appear confined in a very tight depth range.

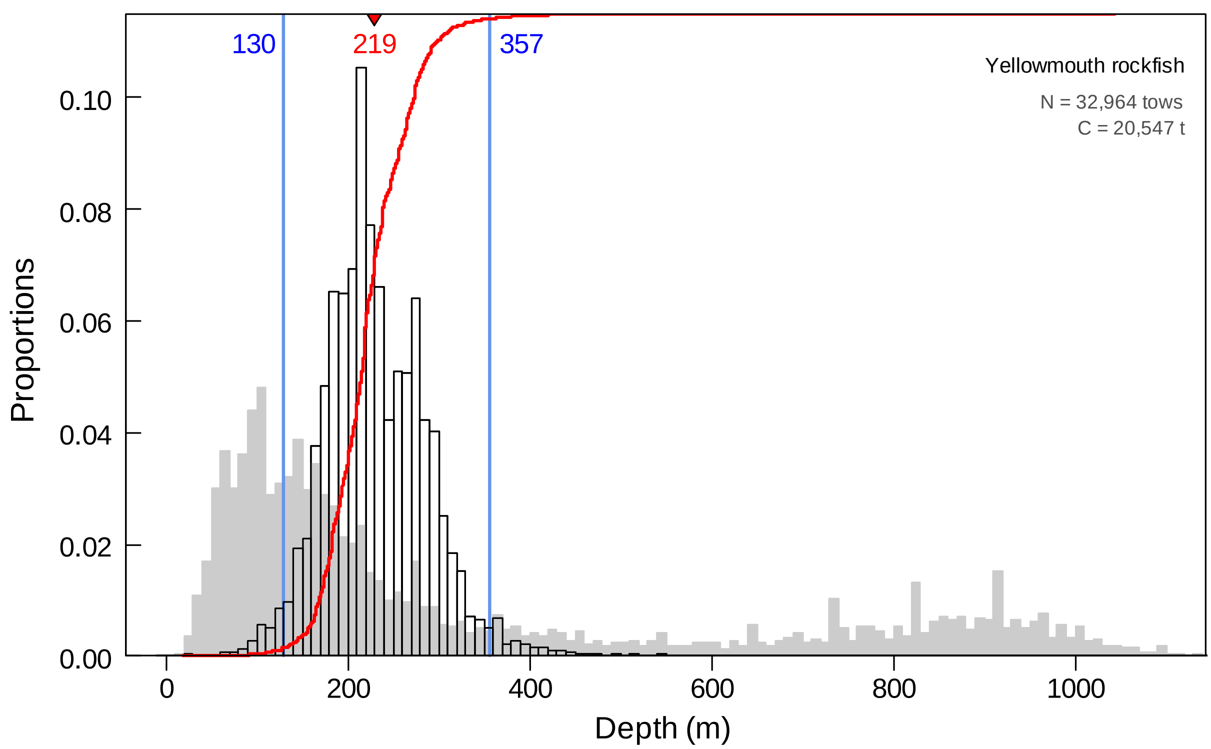

Figure 15. Depth frequency of tows that capture yellowmouth rockfish from commercial trawl logs (1996-2007). The vertical solid lines denote the 2.5% and 97.5% quantiles. The shaded histogram in the background reports the relative trawl effort on all species. The cumulative catch of yellowmouth rockfish, superimposed on the histogram in relative space (0 to 1), provides confirmation that the bulk of yellowmouth catch comes from these depths. The depth of median cumulative catch is indicated by an inverted red triangle at top. 'N' reports the total number of tows; 'C' reports the total catch (t).

3.2. Habitat Requirements

Taking into account the empirically derived depth range (Figure 15), we can identify potential habitat for yellowmouth rockfish as the bottom bathymetry that lies between 130 and 357 m (Figure 16). A mechanical survey of this sort obviously picks up regions where yellowmouth rockfish would not occur (e.g., Masset Inlet on Graham Island) as well as missing those where they have been recorded (e.g., depths outside the 95% quantile range); however, the highlighted bathymetry (48,368 km²) serves as a proxy for its potential habitat.

No comprehensive maps detailing bottom topography off the BC coast have been published yet. Maps of surficial geology exist for the Queen Charlotte basin (Barrie et al. 1991, Sinclair et al. 2005). Adapted from Sinclair et al. (2005), Figure 17 shows how the surficial geology of the Queen Charlotte basin and Hecate Strait overlap the potential habitat of yellowmouth rockfish. Fishing events capturing this species, *weighted by catch* and standardised to a 1 km² grid (Sinclair 2007), intercept the surficial geology with a percentage frequency in Table 3. Westrheim and Tsuyuki (1967) found three substantial aggregations (off La Pérouse Bank, west of Triangle Island, and west of Rennell Sound) all over very rough bottom. The table above appears to support their observations in that this species occurs most frequently over hard bottoms (sand, gravel, and bedrock) rather than mud ones, at least in the Queen Charlotte basin.

Table 3. Percentage frequency of yellowmouth catch in Queen Charlotte basin surficial geology categories.

Surficial geology category	**% Frequency**
Outwash Sand & Gravel	30.4
Sand & Gravel / Bedrock	21.6
Bedrock	18.3
Glaciomarine Mud	11.0
Holocene Sand & Gravel	9.9
Holocene Mud	5.6
Till	1.7
Sand & Gravel / Glaciomarine Mud	1.5
Sand & Gravel	0.1

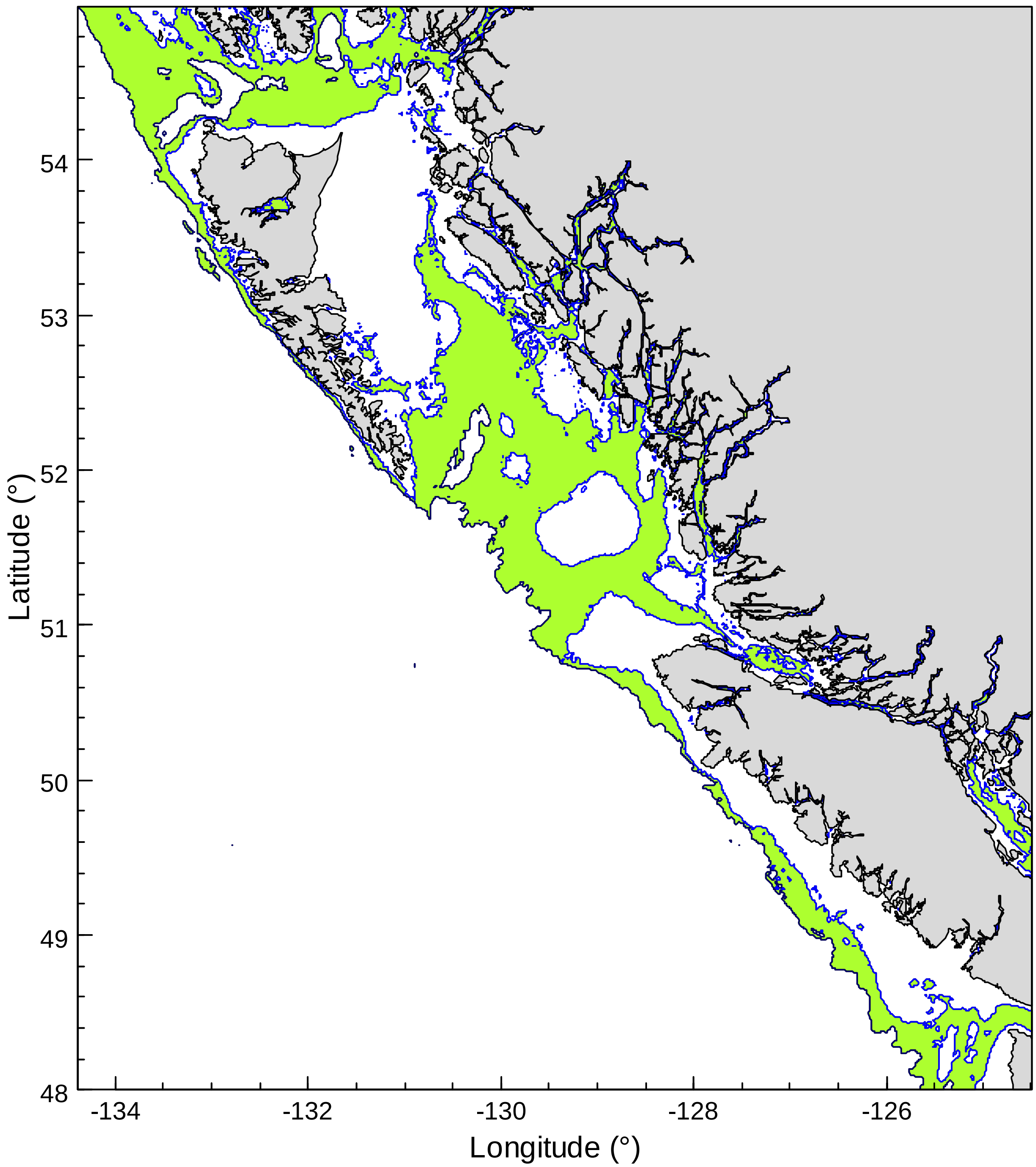

Figure 16. Highlighted bathymetry (green) between 130 and 357 m serves as a proxy for yellowmouth rockfish habitat along the BC coast.

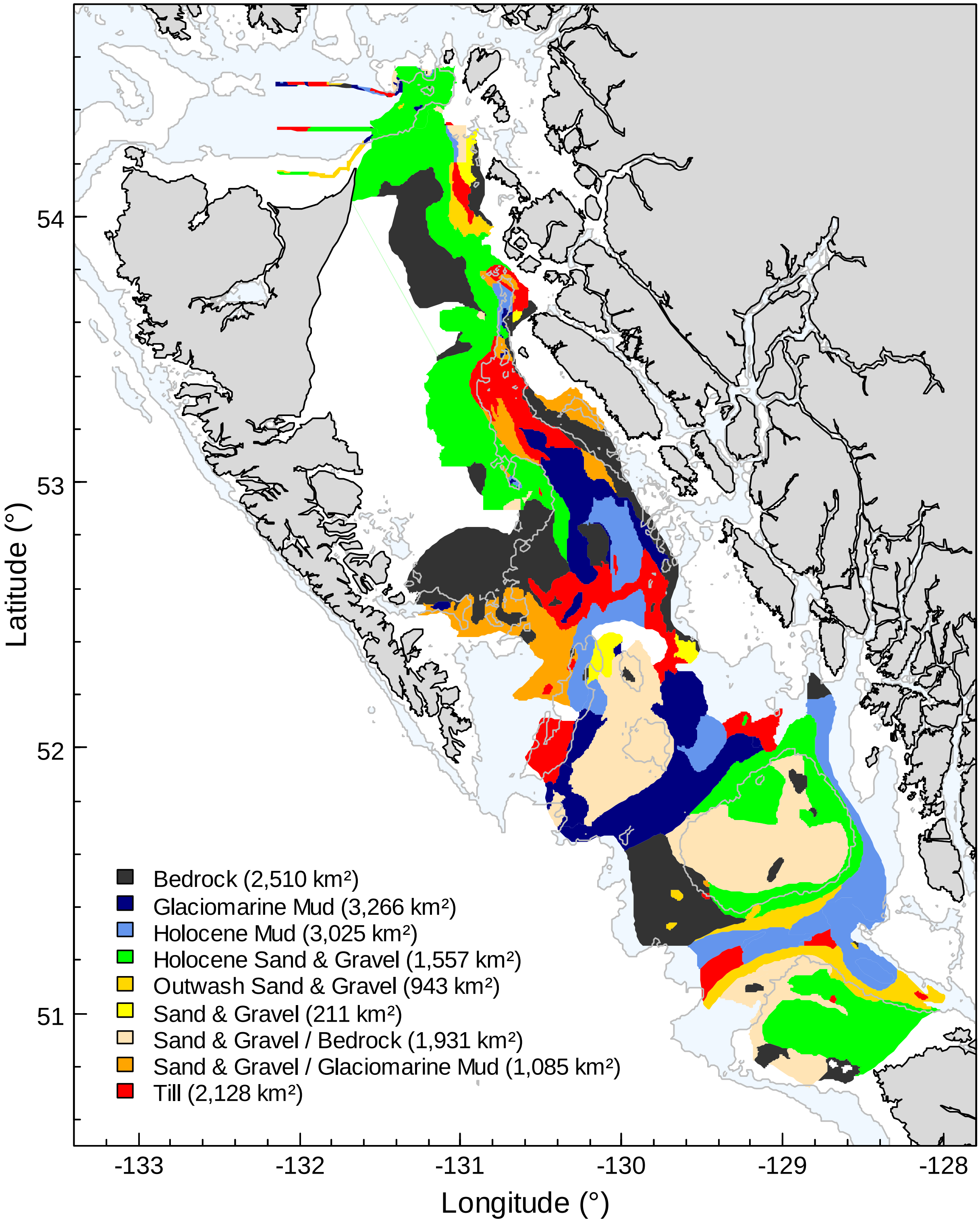

Figure 17. Surficial geology of the Queen Charlotte basin and Hecate Strait. The bathymetry contour (130-357 m) of Figure 16 lies beneath the highlighted geology. The legend shows geology categories and the area (km²) intersecting the bathymetry interval.

3.3. Density proportional to CPUE

Observer trawl data were selected using the following qualifications:

- species identified as yellowmouth rockfish (code = 440);
- gear type = bottom trawl (code=1);
- successful hauls (code=0:1);
- valid spatial coordinates.

Data from DFO's `PacHarvHL` database were not used as only 236 hook and line fishing events recorded catching yellowmouth rockfish.

After qualification, CPUE was calculated as the simple ratio $U_i = C_i / E_i$ (kg/h) for each tow/set i. The U_i were located within a grid using cells of dimension 0.10° longitude × 0.075° latitude. Sinclair (2007) explores the biases of perceived impacted area depending on the grid cell size chosen by an analyst. One of our cells in mid Queen Charlotte Sound (with origin 130°W, 51.5°N) would cover approximately 59 km², which equals 7.7 km squared. A typical elliptical trawl tow might encircle (but not necessarily impact) a similar area. In each grid cell, the mean CPUE was calculated:

$$\bar{U}_c = \frac{1}{n_c} \sum_{j=1}^{n_c} U_j \qquad (1)$$

where c = cell index;
n_c = number of tows in cell c.

Only those grid cells with positive mean CPUE (calculation includes zero-catch tows) for yellowmouth rockfish are displayed. Additionally, cells where positive mean CPUE results from fewer than 3 different vessels have been excluded due to privacy concerns.

The dataset from the trawl fishery gives the most comprehensive density distribution of yellowmouth rockfish along the BC coast (Figure 18). The highest densities seen by trawlers occur in the gullies of Queen Charlotte Sound, off NW Vancouver Island, and offshore from Rennell Sound. The inclusion of grid cells containing fewer than three vessels yields an estimated occupied area of 33,092 km². A similar gridding exercise in Universal Transverse Mercator (UTM) coordinate space using 2 km by 2 km cells (without vessel exclusion) yields an area of occupancy equal to 11,332 km². Appendix B reports the differences in occupied area estimates using a DFO grid *vs.* a COSEWIC grid and presents spatial density maps for each fishing year. Annual area coverage appears less than that for the cumulative 11 years of observations.

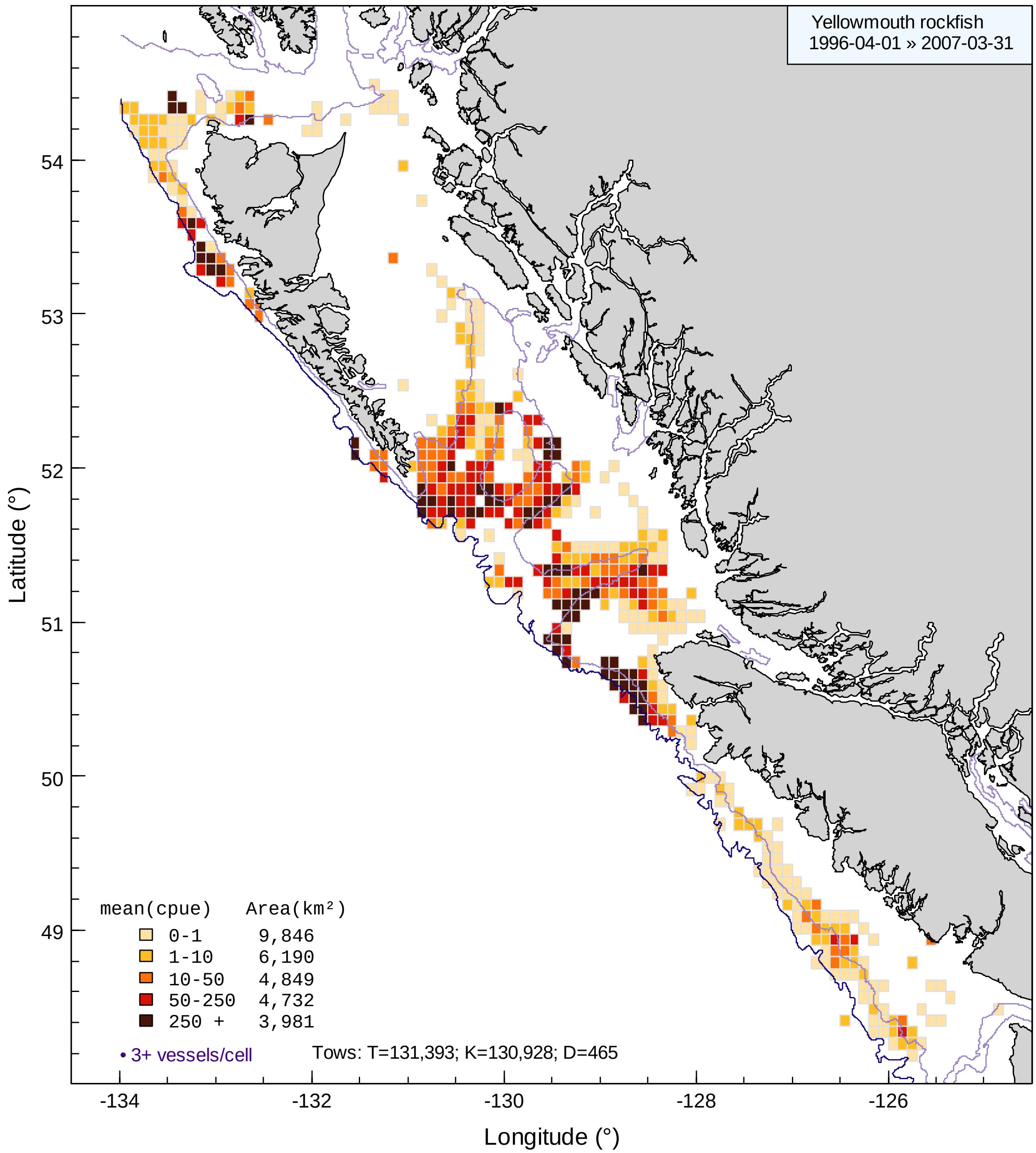

Figure 18. Mean CPUE (kg/h) of yellowmouth rockfish caught by the trawl fishery in 0.1° × 0.075° grid cells along the BC coast. Isobaths displayed are 200 m and 1000 m.

3.4. Concurrence of species in trawl tows

Within the depth range 130-357 m (Section 3.1), we calculate the total catch weight (landings + discards) for each species caught in commercial trawl tows that contained at least one yellowmouth rockfish. We then convert these weights to proportions of the total catch weight of all species caught, and rank them in descending order. The top 20 species are displayed as a horizontal bar chart (Figure 19). The depth at which yellowmouth rockfish occurs most frequently is dominated by Pacific ocean perch *Sebastes alutus* with a substantial presence of arrowtooth flounder *Atheresthes stomias*, redstripe rockfish *S. proriger*. , silvergray rockfish *S. brevispinis*, and yellowtail rockfish *S. flavidus*.

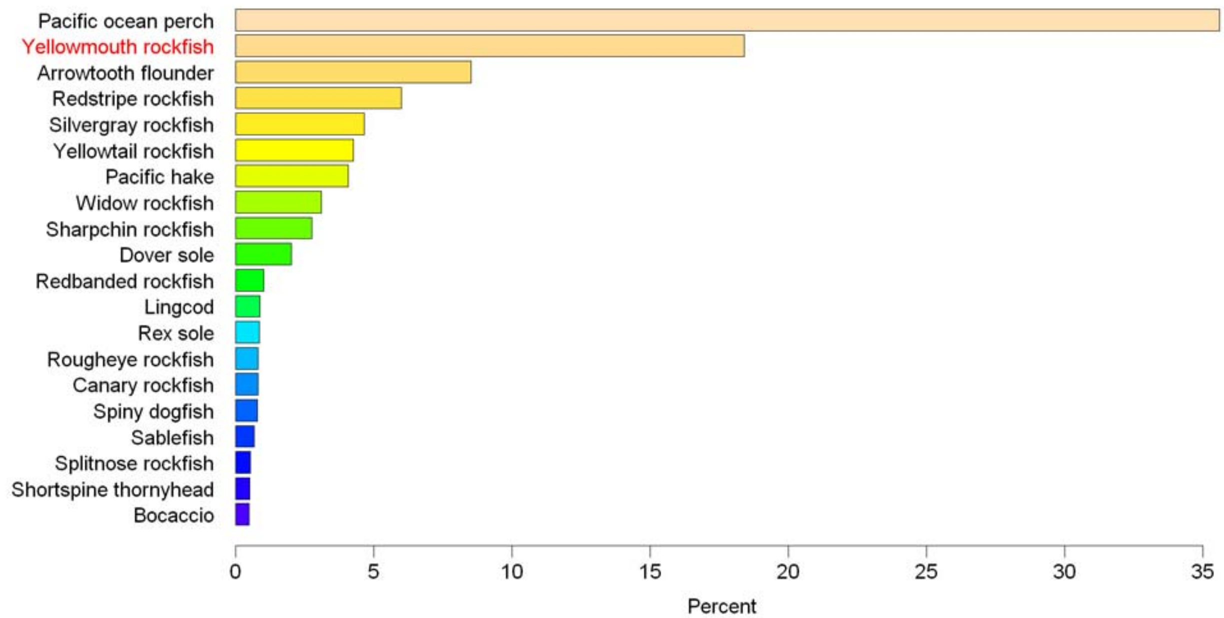

Figure 19. Concurrence of species in trawl tows (1996-2007) capturing yellowmouth rockfish at depths 129-360 m. Abundance is expressed as a percent of total catch weight.

3.5. Groundfish communities

The groundfish assemblage comprises a diverse group of species, including 30+ rockfish (*Sebastes* spp.). While observer trawl observations record fishing effort that reflects targetting and avoidance behaviour, the species caught by the commercial fleet reflect groundfish assemblages fairly well. Geo-referenced catch proportion data (1996-2007; 167,233 records) for 79 fish species from all commercial trawl records (Option A: bottom and mid-water trawls primarily outside PMFC area 4B, 100% observer coverage; Option B: bottom trawls in PMFC area 4B only, partial observer coverage) are summarized into eight groups using a technique outlined in Kaufman and Rousseeuw (1990, chapter 3) called “clustering large applications”. This algorithm exists as a function called `clara` in the package `cluster` available on the R statistical platform. Essentially, `clara` sub-samples the large data set, identifying the best *k* medoids using a dissimilarity metric. In the end, all records are assigned to one of the *k* clusters. Further routines in the R-package `PBSmapping` locate fishing events in grid cells and display the results.

Eight groundfish clusters characterized by the top three contributors to each medoid appear in Figure 20. Generally, these groupings emphasize available biomass. The gullies of Queen Charlotte Sound host large populations of Pacific ocean perch (POP), which remains the trawl industry's chief economic species. Also on the shelf but in shallower waters, yellowmouth and redstripe rockfish co-occur with POP. In Hecate Strait, flatfish like rock sole and arrowtooth flounder are common. In the deeper slope regions the thornyheads and sablefish prevail. Yellowmouth catch appears to be heaviest (red medoid) off NW Vancouver Island and in the three gullies of QCS (particularly Goose Island) and in a hotspots off Rennell Sound.

Off the WCVI (Figure 21), communities appear more uniform than those further north, with large stretches dominated by the thornyhead-sablefish complex in deep water and the hake-dogfish-pollock complex off Barkley Sound. The red medoid indicates extensive stretches of yellowmouth catch in shallow waters north of Barkley Sound.

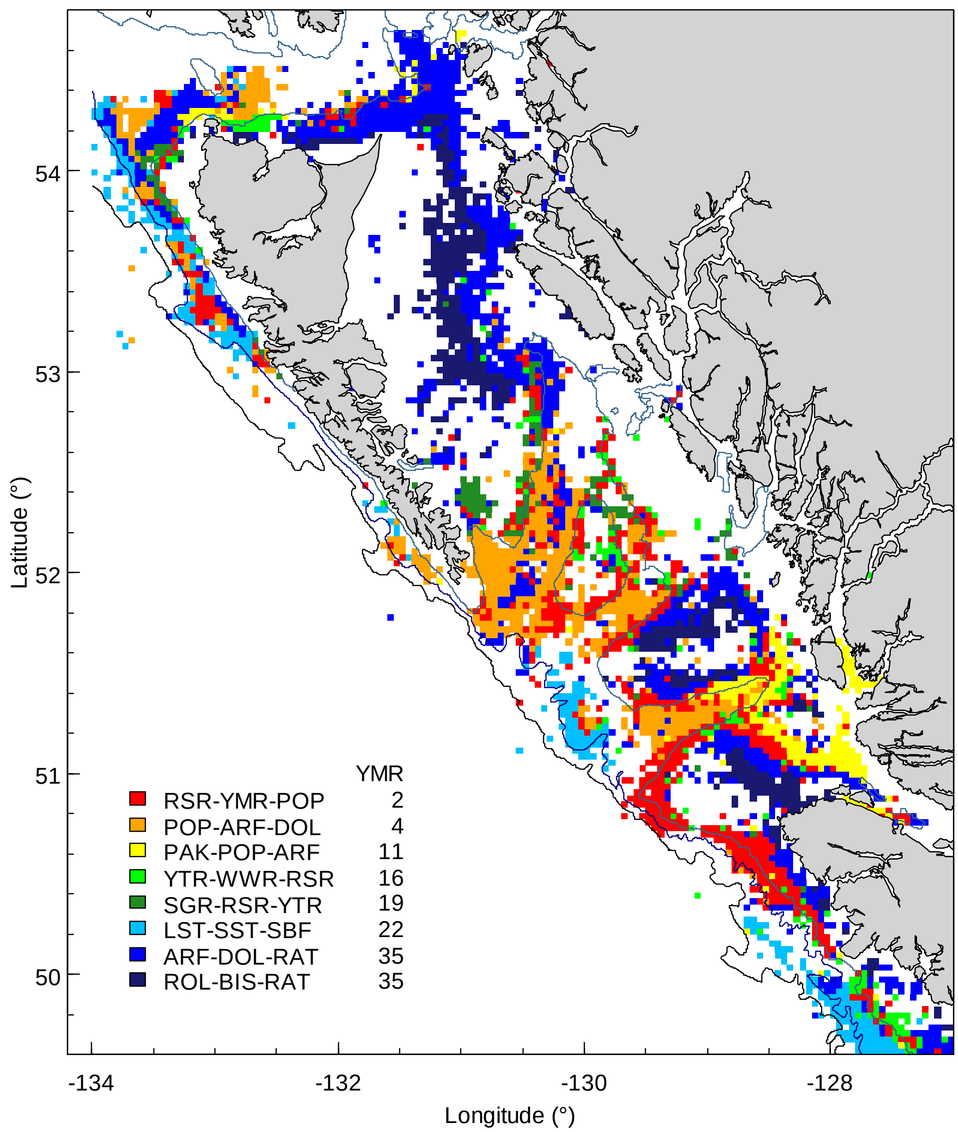

Figure 20. Groundfish groups identified by `clara` (clustering large applications) in R's package `cluster` and summarized using `PBSmapping`'s spatial functions for the north and central coast of BC. Isobaths trace the 200, 1000, and 1800 m depth contours. The legend identifies eight clusters by the top three species comprising the medoids; the clusters are ordered by the contribution of yellowmouth rockfish (**YMR**) to each medoid. Species codes:

ARF arrowtooth flounder *Atheresthes stomias*, **ROL** rock sole *Lepidopsetta bilineatus*,

BIS big skate *Raja binoculata*,
DOL Dover sole *Microstomus pacificus*,
LST longspine thornyhead *Sebastolobus altivelis*,
PAC Pacific cod *Gadus macrocephalus*,
PAK Pacific hake *Merluccius productus*,
POP Pacific ocean perch *Sebastes alutus*,
RAT spotted ratfish *Hydrolagus colliei*,
RSR redstripe rockfish *Sebastes proriger*,
SBF sablefish *Anoplopoma fimbria*,
SGR silvergray rockfish *Sebastes brevispinis*,
SST shortspine thornyhead *Sebastolobus alascanus*,
WWR widow rockfish *Sebastes entomelas*,
YMR yellowmouth rockfish *Sebastes reedi*,
YTR yellowtail rockfish *Sebastes flavidus*.

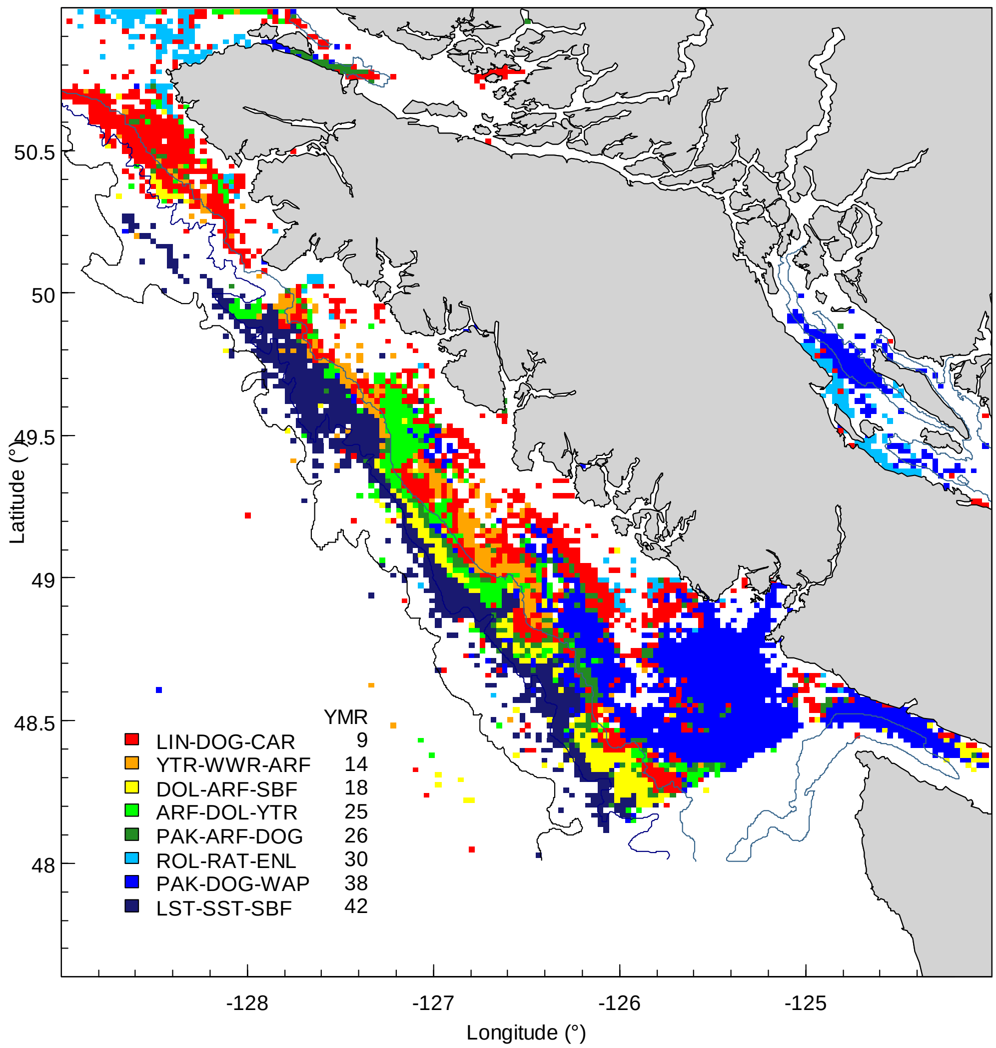

Figure 21. Groundfish groups identified by `clara` (clustering large applications) in R's package `cluster` and summarized using `PBSmapping`'s spatial functions for the west coast of Vancouver Island. Isobaths trace the 200, 1000, and 1800 m depth contours. The legend identifies eight clusters by the top three species comprising the medoids; the clusters are ordered by the contribution of yellowmouth rockfish (**YMR**) to each medoid. Species codes:

ARF arrowtooth flounder *Atheresthes stomias*,
CAR canary rockfish *Sebastes pinniger*,
DOG spiny dogfish *Squalus acanthias*,
DOL Dover sole *Microstomus pacificus*,
ENL English sole *Parophrys vetulus*,
LIN lingcod *Ophiodon elongatus*,
LST longspine thornyhead *Sebastolobus altivelis*,
PAK Pacific hake *Merluccius productus*.
RAT spotted ratfish *Hydrolagus colliei*,
ROL rock sole *Lepidopsetta bilineatus*,
SBF sablefish *Anoplopoma fimbria*,
SST shortspine thornyhead *Sebastolobus alascanus*,
WAP walleye pollock *Theragra chalcogramma*,
WWR widow rockfish *Sebastes entomelas*,
YTR yellowtail rockfish *Sebastes flavidus*,

4. Population Trends

4.1. Management history

A trawl fishery for slope rockfish has existed in BC since the 1940s. However, historical Canadian trawl catches were relatively minor. Between 1965–76, rockfish along the BC coast were targeted primarily by Soviet and Japanese vessels. Exact removals by foreign fisheries are unknown due to a lack of species composition and locality information, especially for Soviet vessels. Ketchen (1980) estimated the Soviet rockfish catch in BC to be between 28,802–63,491 tonnes in 1966, the year of the largest fishery.

No quotas were in effect for slope rockfish prior to 1977. For most subsequent years, rockfish management has involved a combination of species/area quotas, area/time closures, and trip limits on the major species (Richards 1994). Quotas were first introduced in 1979 for Pacific ocean perch *Sebastes alutus* and yellowmouth rockfish (Table 4).

Table 4. Rockfish species composition of the 1988-1992 domestic trawl catch off British Columbia (mean ± SE) and the year that domestic catch quotas were first introduced for each major species. Reproduced from Table 1 in Richards (1994).

Species	Common name	Trawl catch (t)	Year of first quota
Sebastes alutus	Pacific ocean perch	5,440 ± 538	1979
S. flavidus	Yellowtail rockfish	4,759 ± 133	1979
S. entomelas	Widow rockfish	3,075 ± 522	1993
S. brevispinis	Silvergray rockfish	2,329 ± 381	1982
S. proriger	Redstripe rockfish	2,012 ± 268	1993
S. pinniger	Canary rockfish	1,609 ± 97	1979
S. reedi	Yellowmouth rockfish	1,448 ± 86	1979
S. aleutianus	Rougheye rockfish	1,176 ± 120	1982
S. paucispinis	Bocaccio	1,023 ± 87	
Other nonquota species		1,430 ± 156	
Total rockfish		24,300 ± 906	

In the 1980s, two experimental programs were initiated to assess adaptive management of Pacific ocean perch (POP) stocks (Leaman and Stanley 1993). The first focused on the SW Vancouver Island POP stock (PMFC area 3C) by overharvesting it for five years (1980-84) followed by a return to sustainable harvests in 1985. Surveys in 1979 and 1985 showed a decline in relative abundance of yellowmouth rockfish of 17.1% during the overharvest period compared with a decline in POP relative abundance of 55.8%. The survey catch of yellowmouth declined from 2,077 kg to 668 kg while the survey CPUE declined from 22.1 kg/h to 6.68 kg/h (-69.7%).

The second experiment focused on the Langara Spit POP stock (NW Queen Charlotte Islands, PMFC area 5E) with a proposal to allow unlimited harvesting for a specified period (3-5 y) followed by an equivalent period of no harvest. However, pressure from industry and political compromises kept the fishing in place for 9 years (1984-92), reaching a peak POP catch of almost 5000 t in 1986, before the area was closed in 1993 (Leaman 1998). Surveys conducted in 1979 and 1983 showed abundance declines for yellowmouth rockfish (the relative biomass indices appear to be greatly biased, Table 5 in Leaman and Stanley 1993). The Langara Spit area was re-opened to fishing in 1997.

Until recently, most rockfish assessments suffered from the lack of reliable time series on fishery catch. The port monitoring program initiated in 1994 and the at-sea observer program initiated in October 1995 have led to major improvements in data quality. We have no information on historical levels of dumping, discarding, or misreporting prior to the at-sea-observer program. The trawl fishery underwent a major change in 1997 through the introduction of individual vessel quotas (IVQs). In addition, the schedule of management was changed from a calendar year basis to a fishing year that begins in April and ends the following March. Management details appear in Table 5 and total allowable catches (TACs) or quotas for yellowmouth rockfish appear in Table 6.

Table 5. Management initiatives that have affected the groundfish fleet and commercial harvest periods (fishing years) for various groundfish sectors.

Year	Management Programs Initiated (•) and Commercial Harvest Periods (♠)
1976	• Limited vessel entry for trawl fleet
1979	• Limited vessel entry for halibut fleet
1980	• Start experimental overharvesting of SW Vancouver Island POP stock
1981	• Limited vessel entry for sablefish fleet ♠ From 1981 to 1989, sablefish fishery was managed by opening on a specified date and closing when DFO estimated that the TAC was taken.
1984	• End experimental overharvesting of SW Vancouver Is. POP stock • Start experimental unlimited harvesting of Langara Spit POP stock
1990	• IVQ systems for halibut and sablefish
1991	• DMP for halibut fleet • Limited vessel entry for H&L fleet inside
1992	• Limited vessel entry for H&L fleet outside • End experimental unlimited harvesting of Langara Spit POP stock
1993	• POP fishery closed in PMFC area 5EN (Langara Spit)
1994	• DMP for trawl fleet
1995	♠ Bottom trawl fishing year: 1/1/95 to 9/29/95 ♠ Midwater trawl fishing year: 10/11/95 to 12/31/95 • Catch limit (monthly) on rockfish aggregate for H&L
1996	♠ Trawl fishing year: 2/16/96 to 12/31/96 • 100% onboard observer program for offshore trawl fleet • DMP for H&L fleet
1997Q1	♠ Interim period 1/1/97 to 3/31/97 before implementation of IVQ for offshore trawl.
1997	♠ Trawl fishing year: 4/1/97 to 3/31/98 • IVQ system for trawl TAC species • Catch limit (15,000 lbs per trip) on combined non-TAC rockfish for trawl fleet
1998	♠ Trawl fishing year: 4/1/98 to 3/31/99 ♠ H&L fishing year: 4/1/98 to 3/31/99 ♠ Halibut fishing year: 3/15/98 to 11/15/98
1999	♠ Trawl fishing year: 4/1/99 to 3/31/00 ♠ H&L fishing year: 4/1/99 to 3/31/00 ♠ Halibut fishing year: 3/15/99 to 11/15/99 ♠ Sablefish fishing year 1/1/99 to 7/31/00
2000	♠ Trawl fishing year: 4/1/00 to 3/31/01 ♠ H&L fishing year: 4/1/00 to 3/31/01 ♠ Halibut fishing year: 3/15/00 to 11/15/00 ♠ Sablefish fishing year 8/1/00 to 7/31/01 • Catch limit (20,000 lbs per trip) on rockfish aggregate for halibut option D fleet. • Formal allocation of rockfish species between halibut and H&L sectors.
2001	♠ Trawl fishing year: 4/1/01 to 3/31/02

Year	Management Programs Initiated (•) and Commercial Harvest Periods (♠)
	♠ H&L fishing year: 4/1/01 to 3/31/02 ♠ Halibut fishing year: 3/15/01 to 11/15/01 ♠ Sablefish fishing year 8/1/01 to 7/31/02
2002	♠ Trawl fishing year: 4/1/02 to 3/31/03 ♠ H&L fishing year: 4/1/02 to 3/31/03 ♠ Halibut fishing year: 3/18/02 to 11/18/02 ♠ Sablefish fishing year 8/1/02 to 7/31/03 • Five new longspine thornyhead management regions established with the Flamingo area (51º56′ N to 53º05′ N) closed to all directed longspine thornyhead fishing. • Inshore rockfish conservation strategy established. • Area closures to preserve four unique sponge reefs.
2003	♠ Trawl fishing year: 4/1/03 to 3/31/04 ♠ H&L fishing year: 4/1/03 to 3/31/04 ♠ Halibut fishing year: 3/1/03 to 11/15/03 ♠ Sablefish fishing year 8/1/03 to 7/31/04
2004	♠ Trawl fishing year: 4/1/04 to 3/31/05 ♠ H&L fishing year: 4/1/04 to 3/31/05 ♠ Halibut fishing year: 2/29/04 to 11/15/04 ♠ Sablefish fishing year 8/1/04 to 7/31/05
2005	♠ Trawl fishing year: 4/1/05 to 3/31/06 ♠ H&L fishing year: 4/1/05 to 3/31/06 ♠ Halibut fishing year: 2/27/05 to 11/15/05 ♠ Sablefish fishing year 8/1/05 to 7/31/06
2006	♠ Trawl fishing year: 4/1/06 to 3/31/07 ♠ H&L fishing year: 4/1/06 to 3/31/07 ♠ Halibut fishing year: 3/5/06 to 11/15/06 ♠ Sablefish fishing year 8/1/06 to 7/31/07 • Introduced IFMP for most groundfish fisheries • 100% at-sea electronic monitoring for H&L • Mandatory retention of rockfish for H&L
2007	♠ Trawl fishing year: 4/1/07 to 3/31/08 ♠ H&L fishing year: 4/1/07 to 3/31/08 ♠ Halibut fishing year: 3/10/07 to 11/15/08 ♠ Sablefish fishing year 8/1/07 to 2/20/09
2008	♠ Trawl fishing year: 4/1/08 to 2/20/09 ♠ H&L fishing year: 4/1/08 to 2/20/09 ♠ Halibut fishing year: 3/8/08 to 2/20/09
2009	♠ Commencing Feb 21, 2009 all groundfish fisheries will share a common season start and end date.
DMP	Dockside Monitoring Program: program conducted by a company (designated by DFO) that verifies the species composition and landed weight of all fish landed from a commercial fishing vessel.
H&L	ZN Hook & Line fisheries (handline, longline, trollers).
IFMP	Integrated Fisheries Management Plan: a comprehensive management plan for all groundfish fisheries (except halibut) that replaces the individual plans that were produced prior to 2007.
IVQ	Individual Vessel Quota: transferable right (with value) to catch a certain species.
TAC	Total Allowable Catch: the amount of catch that may be taken from a stock.

Table 6. History of total allowable catches (TACs) for yellowmouth rockfish by fishing year, management area (PMFC combinations) and sector. Generally, BC yellowmouth TACs have been allocated amongst the sectors in the percentages: trawl 96.77, ZN H&L 2.49, halibut 0.74. Notes: Area 5E was managed on the basis of the slope rockfish aggregate (Pacific ocean perch, yellowmouth rockfish, and rougheye rockfish) between 1983–1988. In 1986, coastwide aggregate quotas were assigned to the slope aggregate. In 1989–93 species quotas were assigned on a coastwide basis and area-specific quotas reflect the contribution in the coastwide quota. Coastwide aggregate quotas were again assigned in 1994–96. Quotas listed for years in which aggregates were assigned include other species in addition to yellowmouth rockfish. The quota for 1996 is included in the Pacific ocean perch quota (Schnute et al. 1999).

Year	3C	3D/ 5AB	5CD	5E	Coast wide	Year	3C	3D 5AB	5CD	5E	Coast wide
Trawl						**ZN H&L**					
1979		50		750		1998					36
1980		250		800		1999					36
1981				800		2000					28
1982		250		700		2001					61
1983		250		agg		2002					61
1984		250	300	agg		2003					61
1985		350	250	agg		2004					61
1986			250	agg		2005					61
1987		350	250	agg		2006	4	21	13	25	62
1988		375	250	agg		2007	4	21	13	25	62
1989		500	350	600	1,450	2008	4	20	13	24	60
1990		500	330	550	1,380	**Halibut**					
1991		500	330	550	1,380	2000					8
1992		500	330	550	1,380	2001					18
1993		500	330	550	1,380	2002					18
1994					1,593	2003					18
1995					1,465	2004					18
1996						2005					18
1997	100	1,866	360		2,430	2006	1	6	4	7	19
1998	221	1,145	691	328	2,385	2007	1	6	4	7	19
1999	223	1,156	697	331	2,408	2008	1	6	4	7	18
2000	223	1,156	697	331	2,408						
2001	219	1,135	685	325	2,365						
2002	219	1,135	685	325	2,365						
2003	219	1,135	685	325	2,365						
2004	219	1,135	685	325	2,365						
2005	219	1,135	685	325	2,365						
2006	219	1,135	685	325	2,364						
2007	219	1,135	685	325	2,364						
2008	219	1,135	685	325	2,364						

4.2. Biomass removals

Generally, we equate biomass removals to total catch (landed catch + discarded catch). Where the term “catch” appears without qualification, assume total catch. The term “landings” refers only to the catch offloaded at some port without any accounting for catch discarded at sea.

Records of yellowmouth rockfish landings extend back only to 1971 as this was not a quota species until 1979. Prior to this period landings of rockfish excluding Pacific ocean perch were most often grouped into “other rockfish”. Following the ideas of Stanley et al. (2007), we attempt a reconstruction of historical removals for the Canadian and US fleets only. The proportion of yellowmouth rockfish (YMR) to other rockfish (ORF) in the trawl fishery from 1996 to 2006 has remained remarkably constant, at least on a coast wide basis where the ratio stabilizes at 0.09 (Figure 22). This may be an artifact of current management quotas but the ratio does indicate a high level of importance this species commands in the BC trawl fishery. A similar treatment comparing YMR to total rockfish (TRF, including POP) also yields stable ratios (Figure 23) and might be used in future to reconstruct removals by the large Soviet and Japanese fleets. For instance, Ketchen's 1966 estimate of Soviet recorded rockfish catch along the BC coast (28,802-63,491 t) and a mean ratio YMR/TRF = 0.047 (below) suggests a yellowmouth catch of 1,354-2,984 t in 1966 alone. Finally, proportion analysis shows low levels of discarding (Figure 24). Table 7 presents the mean values of the three ratios by PMFC area and coastwide (CST) of the annual mean values for 1996-2006 (mean of the blue triangle values in Figure 22 to Figure 24).

Table 7. Ratios of yellowmouth catch (expressed as the mean of mean annual ratios of catch from the trawl fishery over the period 1996-2006) by PMFC area. **YMR** = total catch (landings + discards) of yellowmouth rockfish, **ORF** = total catch of all rockfish other than Pacific ocean perch, **TRF** = total catch of all rockfish, **YMRd** = discarded catch of yellowmouth rockfish.

Ratio	3C	3D	5A	5B	5C	5D	5E	CST
YMR/ORF	0.01460	0.02739	0.15891	0.16809	0.04243	0.00143	0.11691	0.08553
YMR/TRF	0.01068	0.02136	0.11818	0.06637	0.02113	0.00076	0.07031	0.04694
YMRd/YMR	0.02506	0.02050	0.00932	0.01337	0.01886	0.12208	0.00861	0.01322

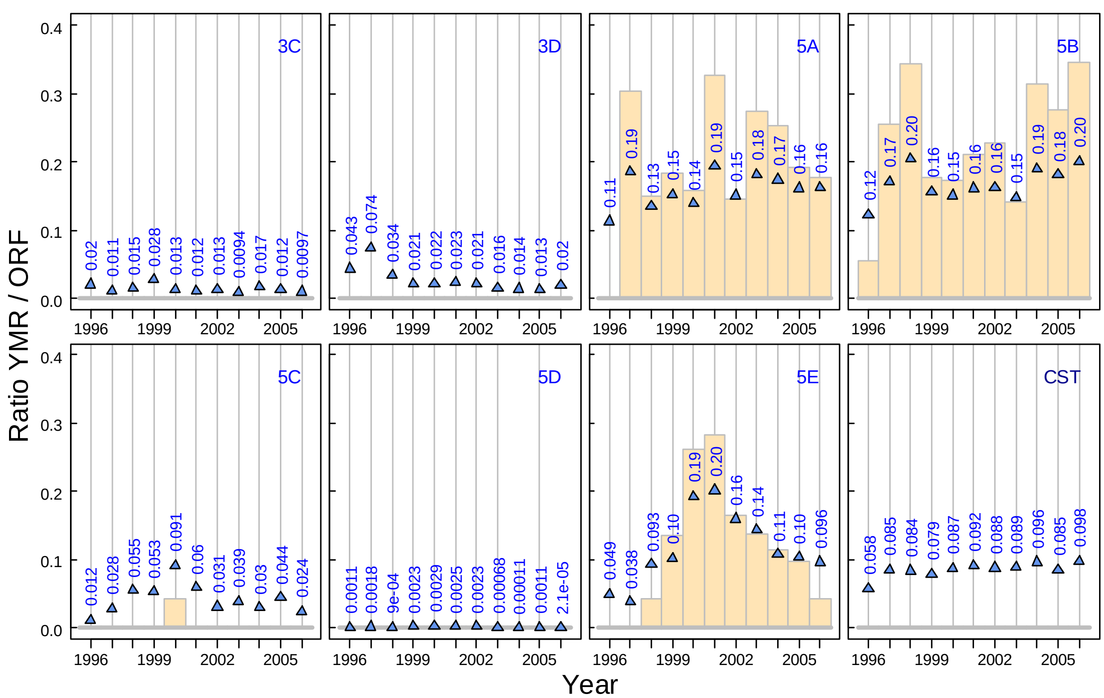

Figure 22. Distribution of proportions of yellowmouth rockfish catch to the catch of all rockfish other than Pacific ocean perch in the trawl fishery by fishing year (Apr to Mar). Horizontal grey bars within the boxplots indicate median ratios. Blue triangles indicate mean ratios (also presented as numbers). Panels summarize ratios by Pacific Marine Fisheries Commission (PMFC) areas; the final panel summarizes ratios on a coastwide basis.

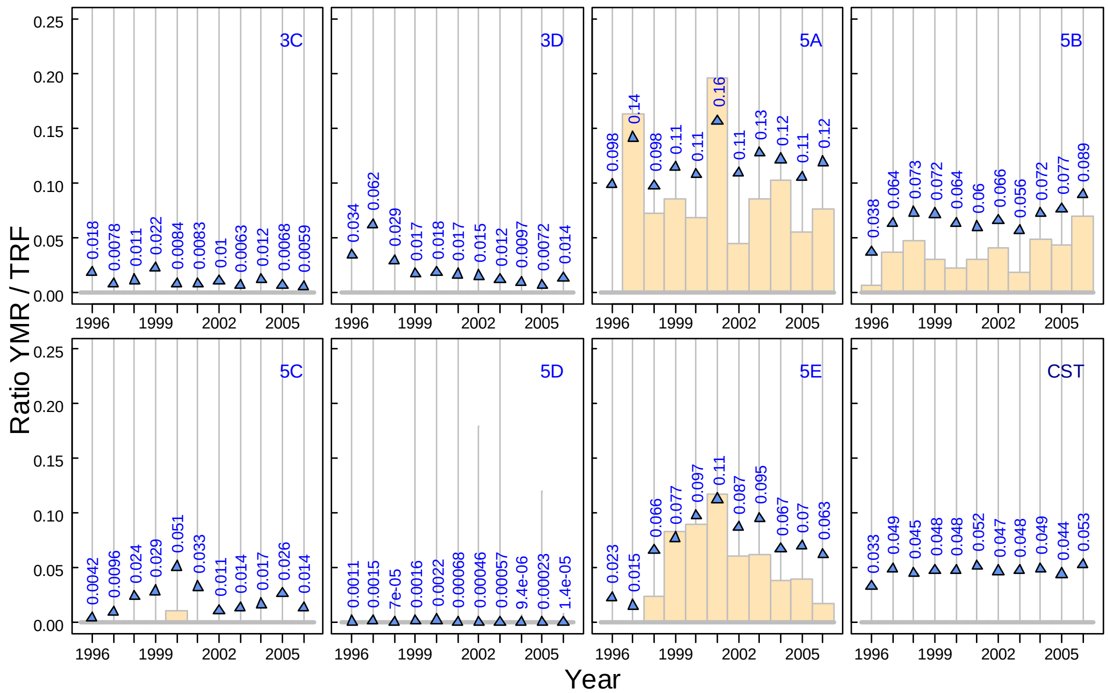

Figure 23. Distribution of proportions of yellowmouth rockfish catch to the catch of all rockfish, including Pacific ocean perch in the trawl fishery by fishing year (Apr to Mar). Horizontal grey bars within the boxplots indicate median ratios. Blue triangles indicate mean ratios (also presented as numbers). Panels summarize ratios by Pacific Marine Fisheries Commission (PMFC) areas; the final panel summarizes ratios on a coastwide basis.

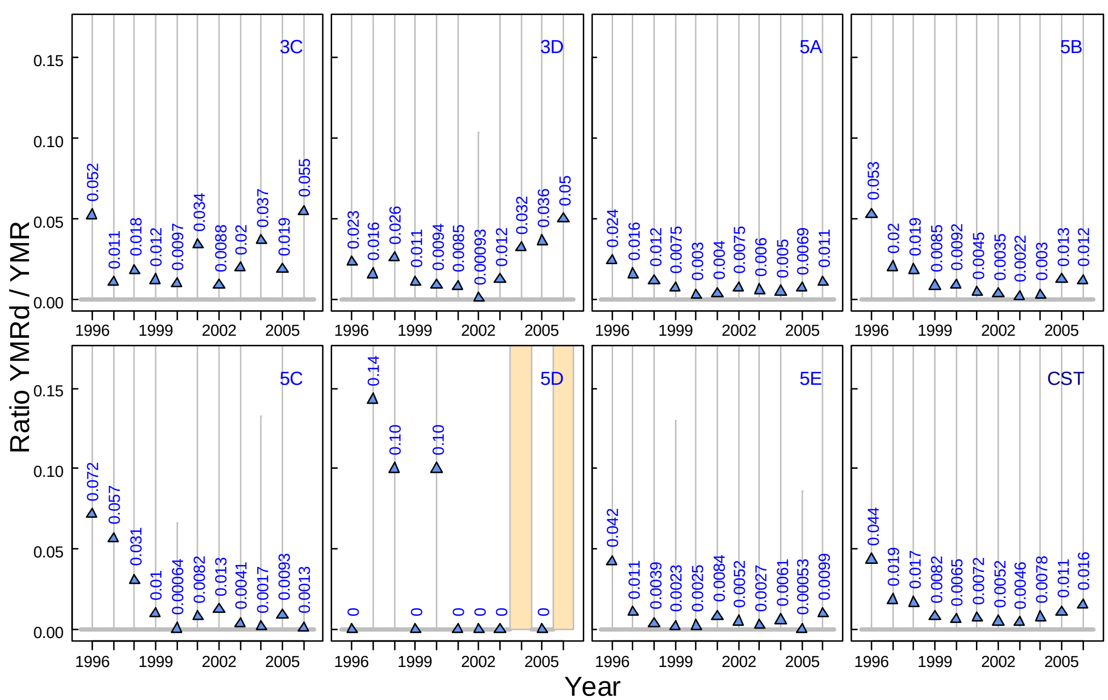

Figure 24. Distribution of proportions of discarded catch to total catch for yellowmouth rockfish in the trawl fishery by fishing year (Apr to Mar). Horizontal grey bars within the boxplots indicate median ratios (primarily 0). Blue triangles indicate mean ratios (also presented as numbers). Panels summarize ratios by Pacific Marine Fisheries Commission (PMFC) areas; the final panel summarizes ratios on a coastwide basis.

As outlined in Stanley et al. (2007), the earliest recorded catches of yellowmouth rockfish on the BC coast were taken by US trawl vessels. Ian Stewart (National Marine Fisheries Service, Seattle WA) cited in Stanley et al. (2007) provided total ORF 1930-1949 landings from Washington-based vessels, 71.5% of which came from BC waters, with an estimated allocation to Pacific Marine Fisheries Commission (PMFC) areas: 3C = 0.220, 3D = 0.163, 5A = 0.209, 5B = 0.87, 5C = 0.003, 5D = 0.018, 5E = 0 (Table 8). Ketchen (1976) summarizes the US and Canadian trawl kept catch by PMFC area from 1950 to 1975 (Table 9). Using the ratios YMR/ORF derived above and the discard rates YMRd/YMR, we calculate estimates of yellowmouth catch for the years 1930-1975 by US vessels (Table 10) and 1945-1976 for Canadian vessels (Table 11). Our assumption that observed YMR/ORF and YMRd/YMR from a modern IVQ fishery can be applied to earlier fisheries remains unrealistic; however, we use them for lack of a better alternative at present. As Ketchen's data summary ended in 1975 and the `GFCatch` SQL database, containing landed catch records prior to 1996 (Rutherford 1999), appears to offer credible yellowmouth landings starting in 1977, we base our yellowmouth catch for 1976 on the ORF landings in `GFCatch`. Additionally, a table of landings before 1954 in `GFCatch` allows us to calculate Canadian ORF catch for 1945-49.

Removals of yellowmouth rockfish give an indication of the biomass that was available in the shelf communities along the BC coast. Aside from the historical dominance of the US removals up until the mid 1970s, modern removals are dominated by the Canadian commercial trawl catch (Table 12, Figure 25), which peaked in 1986 at 2,491 t and has averaged 1,842 t annually during the years 1997-2007. Trawl catches of this species are highest in PMFC areas 5AB (lower Queen Charlotte Sound) and 5E (off the NW coast of the Queen Charlotte Islands). Very little of the coastwide removals results from hook and line fisheries (ZN: Table 13, Schedule II). The bycatch of YMR by the halibut longline fishery (L-license) has even less impact than the hook and line fisheries (Table 14). The total coastwide catch since 1930 is at least 60,000 t (Table 15) or approximately 41 million fish using the conversion 1.467 kg/fish (Section 2.1.1). As the yellowmouth rockfish population in BC offers substantial commercial opportunity, its inclusion as a quota species in 1979 saw the mean annual catches by decade increase abruptly (Figure 25). The current standing stock is not known.

Catches of yellowmouth rockfish in Alaskan waters (Table 16) and along the US Pacific coast are not high. Estimated biomass in the Gulf of Alaska remain uncertain (e.g., 1999 estimate = 5,570 t with 95% confidence interval 0-17,517 t, Heifetz et al. 2000). BC waters appear to host the population centre for this species along the Pacific coast of North America.

Table 8. Total landings (t) of rockfish other than Pacific ocean perch (ORF) in Washington State WA (Stewart in Stanley et al. 2007) and the estimated removal of ORF from BC waters in the WA landings using the ratio 0.7148 BC/WA. The BC removals are then allocated to Pacific Marine Fisheries Commission (PMFC) areas using proportions estimated by Stanley et al. (2007) and shown in the header.

Year	WA landings ORF (t)	BC ORF (t) in WA landings	3C 0.220	3D 0.163	5A 0.209	5B 0.387	5C 0.003	5D 0.018	5E *p*=0	Coast Σ PMFC Catch (t)
1930	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
1931	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
1932	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
1933	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
1934	4	2.9	0.6	0.5	0.6	1.1	0.0	0.1	0	3
1935	29	20.7	4.6	3.4	4.3	8.0	0.1	0.4	0	21
1936	37	26.4	5.8	4.3	5.5	10.2	0.1	0.5	0	26
1937	33	23.6	5.2	3.8	4.9	9.1	0.1	0.4	0	24
1938	49	35.0	7.7	5.7	7.3	13.6	0.1	0.6	0	35
1939	51	36.5	8.0	5.9	7.6	14.1	0.1	0.7	0	36
1940	113	80.8	17.8	13.2	16.9	31.3	0.2	1.5	0	81
1941	42	30.0	6.6	4.9	6.3	11.6	0.1	0.5	0	30
1942	821	586.9	129.1	95.7	122.7	227.1	1.8	10.6	0	587
1943	2,652	1,895.6	417.0	309.0	396.2	733.6	5.7	34.1	0	1,896
1944	1,102	787.7	173.3	128.4	164.6	304.8	2.4	14.2	0	788
1945	11,552	8,257.4	1,816.6	1,346.0	1,725.8	3,195.6	24.8	148.6	0	8,257
1946	5,824	4,163.0	915.9	678.6	870.1	1,611.1	12.5	74.9	0	4,163
1947	3,042	2,174.4	478.4	354.4	454.5	841.5	6.5	39.1	0	2,174
1948	4,940	3,531.1	776.8	575.6	738.0	1,366.5	10.6	63.6	0	3,531
1949	6,008	4,294.5	944.8	700.0	897.6	1,662.0	12.9	77.3	0	4,295

Table 9. Total catch (lbs) of rockfish other than Pacific ocean perch (ORF) in BC waters by US and Canadian trawl vessels. The data comprise a subset of catch tables appearing in Ketchen (1976).

	3C		3D		5A		5B		5C		5D	
Year	**CDN**	**USA**	**CDN**	**USA**	**CDN**	**USA**	**CDN**	**USA**	**CDN**	**USA**	**CDN**	**USA**
1950	31	1,919	7	1,654	15	2,246	26	2,736	0	35	91	214
1951	48	1,867	10	1,056	10	1,266	76	3,774	2	13	80	98
1952	124	1,439	4	1,174	28	1,439	200	2,987	1	15	97	112
1953	35	739	0	536	2	713	20	1,011	0	10	7	66
1954	118	769	10	614	6	568	116	1,065	0	19	13	74
1955	65	695	13	821	8	1,417	135	788	0	7	17	115
1956	27	630	2	892	0	1,485	84	696	6	18	9	31
1957	22	843	0	956	40	626	91	708	1	8	9	33
1958	13	635	2	652	50	918	94	429	12	0	9	63
1959	29	2,331	0	782	169	1,037	326	300	5	0	39	85
1960	16	2,350	4	821	28	459	48	535	1	3	21	55
1961	36	2,392	6	1,530	29	902	86	573	0	1	44	21
1962	36	2,943	31	2,428	56	1,394	401	1,459	0	0	106	52
1963	25	1,308	1	1,862	58	1,237	168	1,785	0	27	27	10
1964	26	1,237	13	755	358	975	207	1,077	3	17	53	34
1965	20	1,453	72	1,065	225	1,291	210	1,437	10	56	25	40
1966	46	1,405	24	1,772	119	3,174	168	1,846	8	3	45	0
1967	32	653	18	1,393	299	1,810	63	2,315	1	7	47	16
1968	29	1,088	108	1,690	340	3,001	120	2,572	17	0	22	0
1969	78	1,354	198	2,557	454	5,617	111	4,637	23	0	71	0
1970	134	1,354	173	3,010	397	3,458	284	3,433	26	0	417	0
1971	233	1,246	131	1,850	427	3,176	407	3,328	21	0	434	0
1972	91	783	47	1,775	869	3,352	1,407	3,782	7	0	886	0
1973	106	610	79	1,762	1,390	4,573	488	4,756	40	0	525	0
1974	156	193	77	2,077	475	2,492	580	2,775	41	0	640	0
1975	85	639	44	1,382	361	1,090	1,048	1,924	76	0	479	0

Table 10. Estimated catch (t) of yellowmouth rockfish (YMR) in BC waters (PMFC areas) by US trawl vessels from 1930 to 1975. Calculation:
[ORF catches (converted to tonnes where appropriate) appearing in Table 8 and Table 9] ×
[observed proportions *p* YMR/ORF by PMFC area (first proportions in header)] ×
[1 + observed discard rate *d* by PMFC area (second proportion in header)].

Year	3C *p*=0.0146 *d*=0.0251	3D 0.0274 0.0205	5A 0.1589 0.0093	5B 0.1681 0.0134	5C 0.0424 0.0189	5D 0.0014 0.1221	5E 0.1169 0.0086	Coast Σ PMFC Catch (t)
1930	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1931	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1932	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1933	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
1934	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0
1935	0.1	0.1	0.7	1.4	0.0	0.0	0.0	2
1936	0.1	0.1	0.9	1.7	0.0	0.0	0.0	3
1937	0.1	0.1	0.8	1.6	0.0	0.0	0.0	3
1938	0.1	0.2	1.2	2.3	0.0	0.0	0.0	4
1939	0.1	0.2	1.2	2.4	0.0	0.0	0.0	4
1940	0.3	0.4	2.7	5.3	0.0	0.0	0.0	9
1941	0.1	0.1	1.0	2.0	0.0	0.0	0.0	3
1942	1.9	2.7	19.7	38.7	0.1	0.0	0.0	63
1943	6.2	8.6	63.5	125.0	0.2	0.1	0.0	204
1944	2.6	3.6	26.4	51.9	0.1	0.0	0.0	85
1945	27.2	37.6	276.8	544.3	1.1	0.2	0.0	887
1946	13.7	19.0	139.5	274.4	0.5	0.1	0.0	447
1947	7.2	9.9	72.9	143.3	0.3	0.1	0.0	234
1948	11.6	16.1	118.4	232.8	0.5	0.1	0.0	379
1949	14.1	19.6	144.0	283.1	0.6	0.1	0.0	461
1950	13.0	21.0	163.4	211.4	0.7	0.2	0.0	410
1951	12.7	13.4	92.1	291.6	0.3	0.1	0.0	410
1952	9.8	14.9	104.7	230.8	0.3	0.1	0.0	361
1953	5.0	6.8	51.9	78.1	0.2	0.0	0.0	142
1954	5.2	7.8	41.3	82.3	0.4	0.1	0.0	137
1955	4.7	10.4	103.1	60.9	0.1	0.1	0.0	179
1956	4.3	11.3	108.0	53.8	0.4	0.0	0.0	178
1957	5.7	12.1	45.5	54.7	0.2	0.0	0.0	118
1958	4.3	8.3	66.8	33.1	0.0	0.0	0.0	113
1959	15.8	9.9	75.4	23.2	0.0	0.1	0.0	124
1960	15.9	10.4	33.4	41.3	0.1	0.0	0.0	101
1961	16.2	19.4	65.6	44.3	0.0	0.0	0.0	146
1962	20.0	30.8	101.4	112.7	0.0	0.0	0.0	265
1963	8.9	23.6	90.0	137.9	0.5	0.0	0.0	261
1964	8.4	9.6	70.9	83.2	0.3	0.0	0.0	172
1965	9.9	13.5	93.9	111.0	1.1	0.0	0.0	229
1966	9.5	22.5	230.9	142.6	0.1	0.0	0.0	406
1967	4.4	17.7	131.7	178.9	0.1	0.0	0.0	333
1968	7.4	21.4	218.3	198.7	0.0	0.0	0.0	446
1969	9.2	32.4	408.6	358.3	0.0	0.0	0.0	809
1970	9.2	38.2	251.6	265.3	0.0	0.0	0.0	564
1971	8.5	23.5	231.1	257.1	0.0	0.0	0.0	520
1972	5.3	22.5	243.9	292.2	0.0	0.0	0.0	564
1973	4.1	22.3	332.7	367.5	0.0	0.0	0.0	727
1974	1.3	26.3	181.3	214.4	0.0	0.0	0.0	423
1975	4.3	17.5	79.3	148.7	0.0	0.0	0.0	250

Table 11. Estimated catch (t) of yellowmouth rockfish (YMR) in BC waters (PMFC areas) by Canadian trawl vessels from 1945 to 1976. Note: Canadian ORF catches for 1945-49 and 1976 come from `GFCatch` (not presented). Calculation:
[ORF catches (converted to tonnes where appropriate) appearing in Table 8 and Table 9] ×
[observed proportions *p* YMR/ORF by PMFC area (first proportions in header)] ×
[1 + observed discard rate *d* by PMFC area (second proportion in header)].

Year	**3C** ***p*=0.0146** ***d*=0.0251**	**3D** **0.0274** **0.0205**	**5A** **0.1589** **0.0093**	**5B** **0.1681** **0.0134**	**5C** **0.0424** **0.0189**	**5D** **0.0014** **0.1221**	**5E** **0.1169** **0.0086**	**Coast** **Σ PMFC** **Catch (t)**
1945	2.4	9.6	1.7	0.3	0.2	0.0	0.0	14
1946	0.5	2.7	8.8	4.2	0.0	0.0	0.0	16
1947	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0
1948	0.2	0.0	0.3	0.4	0.0	0.0	0.0	1
1949	0.1	0.1	0.2	1.0	0.0	0.0	0.0	1
1950	0.2	0.1	1.1	2.0	0.0	0.1	0.0	3
1951	0.3	0.1	0.7	5.9	0.0	0.1	0.0	7
1952	0.8	0.1	2.0	15.5	0.0	0.1	0.0	18
1953	0.2	0.0	0.1	1.5	0.0	0.0	0.0	2
1954	0.8	0.1	0.4	9.0	0.0	0.0	0.0	10
1955	0.4	0.2	0.6	10.4	0.0	0.0	0.0	12
1956	0.2	0.0	0.0	6.5	0.1	0.0	0.0	7
1957	0.1	0.0	2.9	7.0	0.0	0.0	0.0	10
1958	0.1	0.0	3.6	7.3	0.2	0.0	0.0	11
1959	0.2	0.0	12.3	25.2	0.1	0.0	0.0	38
1960	0.1	0.1	2.0	3.7	0.0	0.0	0.0	6
1961	0.2	0.1	2.1	6.6	0.0	0.0	0.0	9
1962	0.2	0.4	4.1	31.0	0.0	0.1	0.0	36
1963	0.2	0.0	4.2	13.0	0.0	0.0	0.0	17
1964	0.2	0.2	26.0	16.0	0.1	0.0	0.0	42
1965	0.1	0.9	16.4	16.2	0.2	0.0	0.0	34
1966	0.3	0.3	8.7	13.0	0.2	0.0	0.0	22
1967	0.2	0.2	21.8	4.9	0.0	0.0	0.0	27
1968	0.2	1.4	24.7	9.3	0.3	0.0	0.0	36
1969	0.5	2.5	33.0	8.6	0.5	0.1	0.0	45
1970	0.9	2.2	28.9	21.9	0.5	0.3	0.0	55
1971	1.6	1.7	31.1	31.4	0.4	0.3	0.0	66
1972	0.6	0.6	63.2	108.7	0.1	0.6	0.0	174
1973	0.7	1.0	101.1	37.7	0.8	0.4	0.0	142
1974	1.1	1.0	34.6	44.8	0.8	0.5	0.0	83
1975	0.6	0.6	26.3	81.0	1.5	0.3	0.0	110
1976	2.0	4.8	53.2	126.5	2.1	0.6	0.0	189

Table 12. Annual (management fishing year) catch (landed + discarded; tonnes) of yellowmouth rockfish by the trawl fishery in PMFC areas along the BC coast (3CD ≈ west coast Vancouver Island, 4B ≈ Strait of Georgia, 5AB ≈ Queen Charlotte Sound, 5CD ≈ Hecate Strait, 5E ≈ west coast Queen Charlotte Islands, UNK =Unknown, CST = coastwide). Entries marked '---' indicate no recorded catch. Data from 1971 to 1995 are stored in `GFCatch` database; data from 1996 on reside in `PacHarvest`.

Year	3C	3D	4B	5A	5B	5C	5D	5E	UNK	CST
1971	---	---	---	5	---	---	---	---	---	5
1972	---	---	---	---	---	---	---	---	---	---
1973	---	---	---	177	---	---	---	---	---	177
1974	---	---	---	79	---	---	---	---	---	79
1975	0	---	---	1	---	---	---	---	---	2
1976	---	---	---	12	---	---	---	---	---	12
1977	---	---	---	333	3	---	4	1,257	---	1,596
1978	0	---	---	11	98	---	---	1,105	---	1,214
1979	2	0	---	6	25	---	---	405	---	438
1980	---	---	---	25	23	---	---	500	---	548
1981	0	0	---	---	46	69	---	925	---	1,039
1982	6	1	1	179	322	169	---	482	---	1,160
1983	33	40	---	411	342	58	---	640	0	1,524
1984	6	120	---	28	591	64	---	514	---	1,324
1985	4	412	---	128	371	37	0	676	---	1,628
1986	1	982	---	227	91	10	---	1,179	---	2,491
1987	7	703	---	439	82	67	0	559	---	1,857
1988	7	169	---	364	359	17	1	407	---	1,322
1989	43	315	---	599	245	24	---	386	---	1,611
1990	40	280	---	437	382	50	0	478	---	1,666
1991	37	217	---	490	339	20	1	121	---	1,225
1992	60	273	---	526	443	47	3	124	---	1,475
1993	48	301	---	383	247	19	2	157	---	1,157
1994	70	383	0	578	140	15	0	44	---	1,231
1995	65	275	---	672	290	16	1	72	---	1,391
1996[O]	112	242	0	487	418	26	0	116	---	1,402
97[I]	7	148	---	380	39	3	0	18	---	594
1997	24	326	---	882	642	20	7	38	---	1,939
1998	55	163	---	722	612	70	0	173	---	1,795
1999	66	97	---	802	758	66	1	220	---	2,008
2000	23	92	---	554	603	88	0	442	---	1,803
2001	42	82	---	809	521	43	1	432	---	1,930
2002	54	83	---	702	706	20	1	376	---	1,941
2003	22	30	0	820	617	31	0	340	---	1,860
2004	53	28	---	846	781	30	0	179	---	1,917
2005	24	22	---	596	971	40	2	161	---	1,816
2006	18	35	---	541	837	13	0	169	---	1,613
2007	21	44	0	370	992	8	12	233	---	1,680
Total	950	5,862	1	14,622	12,935	1,137	35	12,930	0	48,471

[I] Interim period (Jan-Mar) before implementation of IVQ in 1997 for offshore trawl. Fishing years prior to this period are calendar years; fishing years after this period run from April to March.
[O] Observer program started in 1996

Table 13. Annual (management fishing year) catch (landed + discarded; tonnes) of yellowmouth rockfish by the ZN hook and line fishery in PMFC areas along the BC coast (3CD ≈ west coast of Vancouver Island, 4B ≈ Strait of Georgia, 5AB ≈ Queen Charlotte Sound, 5CD ≈ Hecate Strait, 5E ≈ west coast of the Queen Charlotte Islands, UNK =Unknown, CST = coastwide). Entries marked '---' indicate no recorded catch. Data are stored in the `PacHarvHL` database. Catches from 1989 to 1994 are taken from fisher-log records; catches from 1995 on come from either validated dockside records or fisherlogs, whichever is highest.

Year	3C	3D	4B	5A	5B	5C	5D	5E	UNK	CST
1989	---	---	---	0.3	---	---	---	---	---	0
1990	0.5	2.2	0.1	0.3	0.5	0.7	0.5	6.9	---	12
1991	0.2	0.2	0.3	1.8	0.5	3.8	1.9	4.2	---	13
1992	0.0	---	---	1.0	5.6	0.0	0.4	5.5	---	13
1993	1.4	0.8	0.9	0.4	---	---	---	6.5	---	10
1994	---	0.0	---	9.6	0.1	---	---	1.7	---	12
1995	---	0.1	---	9.9	1.2	0.0	---	6.8	5.7	24
1996	0.0	0.7	---	7.8	---	0.0	0.2	3.0	0.6	12
97 [I]	---	---	---	---	---	---	---	0.0	---	0
1997	---	0.2	---	1.9	0.1	0.0	---	1.3	3.2	7
1998	0.0	0.0	0.0	4.0	0.0	0.0	---	4.5	0.4	9
1999	0.1	0.2	---	4.5	0.0	0.0	0.0	3.4	0.4	9
2000	---	0.1	0.0	4.2	2.3	0.0	0.0	1.9	0.1	9
2001	0.0	0.0	---	6.5	1.8	0.0	0.0	1.7	0.1	10
2002	---	0.1	---	14.9	3.2	0.2	0.0	3.7	2.8	25
2003	---	0.1	---	6.3	7.0	---	---	0.2	0.7	14
2004	---	0.1	---	7.8	3.7	---	---	0.1	---	12
2005	---	0.1	0.0	12.8	1.9	---	---	0.0	---	15
2006	---	---	---	---	---	---	---	0.0	---	0
2007	---	0.0	0.0	0.2	0.1	---	---	0.0	---	0
Total	2	5	1	94	28	5	3	52	14	204

[I] Interim period (Jan-Mar) before implementation of IVQ in 1997 for offshore trawl. Fishing years prior to this period are calendar years; fishing years after this period run from April to March.

Table 14. Annual (management fishing year) bycatch (tonnes) of yellowmouth rockfish by the halibut fishery in PMFC areas along the BC coast. Catches are rounded to the nearest tonne; entries marked '---' indicate no recorded catch. Data are stored in the PacHarvHL database. Catches from 1995 on come from either validated dockside records or fisherlogs, whichever is highest.

Year	3C	3D	4B	5A	5B	5C	5D	5E	UNK	CST
1995	---	---	0.0	0.0	0.0	0.0	---	0.0	2.1	2
1996	---	0.1	0.0	0.1	0.4	1.0	2.0	0.0	2.7	6
97 [I]	---	---	---	---	---	---	---	---	0.3	0
1997	---	0.1	0.1	0.6	0.6	0.0	---	0.0	0.9	2
1998	0.0	0.2	0.2	0.5	0.9	0.3	0.0	0.0	---	2
1999	0.0	0.4	0.1	0.3	1.4	0.1	0.0	0.1	---	2
2000	---	1.6	---	---	0.6	---	---	1.1	0.0	3
2001	---	2.1	---	---	0.9	---	---	1.3	0.0	4
2002	---	3.5	---	---	1.2	---	---	2.7	0.0	7
2003	---	5.0	---	---	2.0	---	---	1.0	0.0	8
2004	---	4.7	---	---	1.9	---	---	2.7	0.0	9
2005	---	2.5	---	---	1.1	---	---	1.3	0.0	5
2006	0.1	0.2	---	8.3	5.0	0.0	0.0	0.1	---	14
2007	0.1	0.1	---	6.3	4.1	0.0	0.0	0.2	---	11
Total	0	21	0	16	20	2	2	11	6	78

[I] Interim period (Jan-Mar) before implementation of IVQ in 1997 for offshore trawl. Fishing years prior to this period are calendar years; fishing years after this period run from April to March.

Regional areas used in the halibut fishery are assigned to the following Pacific Marine Fisheries Commission (PMFC) areas:: 5E = QC (Queen Charlotte Islands), 5D = NC (north coast) and PR (Prince Rupert), 5B = CC (central coast), 3D = WC (west coast Vancouver Island), 4D = SG (Strait of Georgia). DFO's Pacific Fishery Management areas (PFMA) are assigned to PMFC areas by locating PFMA centroids in PMFC polygons.

Table 15. Annual (management fishing year) catch (kept + discarded; tonnes) of yellowmouth rockfish coastwide by various BC fisheries. Catches are rounded to the nearest tonne; entries marked '---' indicate no recorded catch. Canadian trawl data from 1945 to 1995 are stored in the `GFCatch` database; data from 1996 on reside in `PacHarvest`. Hook and line data from the ZN, Schedule II, and halibut fisheries reside in `PacHarvHL`. Trip limit information can be found in various fisheries management plans at: http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/MPlans.htm?lang=en

Year	CA Trawl	US Trawl	Zn HL	Shed II	Halibut	Total HL	Total
1930	---	---	---	---	---	---	---
1931	---	---	---	---	---	---	---
1932	---	---	---	---	---	---	---
1933	---	---	---	---	---	---	---
1934	---	0	---	---	---	---	0
1935	---	2	---	---	---	---	2
1936	---	3	---	---	---	---	3
1937	---	3	---	---	---	---	3
1938	---	4	---	---	---	---	4
1939	---	4	---	---	---	---	4
1940	---	9	---	---	---	---	9
1941	---	3	---	---	---	---	3
1942	---	63	---	---	---	---	63
1943	---	204	---	---	---	---	204
1944	---	85	---	---	---	---	85
1945	14	887	---	---	---	---	901
1946	16	447	---	---	---	---	463
1947	0	234	---	---	---	---	234
1948	1	379	---	---	---	---	380
1949	1	461	---	---	---	---	463
1950	3	410	---	---	---	---	413
1951	7	410	---	---	---	---	417
1952	18	361	---	---	---	---	379
1953	2	142	---	---	---	---	144
1954	10	137	---	---	---	---	147
1955	12	179	---	---	---	---	191
1956	7	178	---	---	---	---	185
1957	10	118	---	---	---	---	128
1958	11	113	---	---	---	---	124
1959	38	124	---	---	---	---	162
1960	6	101	---	---	---	---	107
1961	9	146	---	---	---	---	155
1962	36	265	---	---	---	---	301
1963	17	261	---	---	---	---	278
1964	42	172	---	---	---	---	215
1965	34	229	---	---	---	---	263
1966	22	406	---	---	---	---	428
1967	27	333	---	---	---	---	360
1968	36	446	---	---	---	---	482
1969	45	809	---	---	---	---	854
1970	55	564	---	---	---	---	619
1971	66	520	---	---	---	---	587
1972	174	564	---	---	---	---	738
1973	142	727	---	---	---	---	868
1974	83	423	---	---	---	---	506
1975	110	250	---	---	---	---	360
1976[L]	189	---	---	---	---	---	189
1977	1,596	---	---	---	---	---	1,596

Year	CA Trawl	US Trawl	Zn HL	Shed II	Halibut	Total HL	Total
1978	1,214	---	---	---	---	---	1,214
1979[L]	438	---	---	---	---	---	438
1980	548	---	---	---	---	---	548
1981	1,039	---	---	---	---	---	1,039
1982	1,160	---	---	---	---	---	1,160
1983	1,524	---	---	---	---	---	1,524
1984	1,324	---	---	---	---	---	1,324
1985	1,628	---	---	---	---	---	1,628
1986	2,491	---	---	---	---	---	2,491
1987	1,857	---	---	---	---	---	1,857
1988	1,322	---	---	---	---	---	1,322
1989	1,611	---	0	---	---	0	1,611
1990	1,666	---	12	---	---	12	1,678
1991[D]	1,225	---	13	---	---	13	1,238
1992[L]	1,475	---	13	---	---	13	1,487
1993	1,157	---	10	---	---	10	1,167
1994[D]	1,231	---	12	---	---	12	1,243
1995[T]	1,391	---	24	---	2	26	1,417
1996[D,O]	1,402	---	12	---	6	19	1,421
1997[Q,T]	1,939	---	7	---	2	9	1,948
1998	1,795	---	9	---	2	11	1,806
1999	2,008	---	9	---	2	11	2,020
2000[T]	1,803	---	9	---	3	12	1,815
2001	1,930	---	10	---	4	15	1,945
2002	1,941	---	25	---	7	32	1,973
2003	1,860	---	14	0	8	22	1,883
2004	1,917	---	12	0	9	21	1,938
2005	1,816	---	15	---	5	20	1,835
2006	1,613	---	---	---	---	---	1,613
2007	1,680	---	0	---	11	11	1,691
Total	48,848	11,175	204	0	77	282	60,305

[D] Dockside monitoring program (DMP) started: 1991 – halibut; 1994 – trawl; 1996 – ZN H&L
[O] Observer program started: 1996 – trawl
[L] Limited vessel entry: 1976 – trawl; 1979 – halibut; 1992 ZN H&L
[Q] Individual vessel quota (IVQ) system started for TAC species: 1997 – trawl
[T] Trip limits implemented: 1995 – ZN monthly limit on rockfish aggregate; 1997 – trawl trip limit of 15,000 lbs for combined non-TAC rockfish; 2000 – halibut option D with annual limit of 20,000 lbs of rockfish aggregate.

Table 16. Estimates of catch (t) and biomass (t) for yellowmouth rockfish in the Gulf of Alaska (Heifetz et al. 2000). C = estimated catch, B = estimated biomass from triennial trawl surveys in Gulf of Alaska (NPMFC).

Year	footnote	C	Year	B
1992		102	1984	516
1993	a	498	1987	241
1994	b	40	1990	1,900
1995	b	15	1993	3,460
1996	b	6	1996	923
1997	b	63	1999	5,570
1998	b,c	1		
1999	c	2		

a = northern rockfish removed from subgroup "other slope rockfish"; apparent expansion in fishery for other species.
b = lower TACs; c = trawl closure in eastern Gulf of Alaska

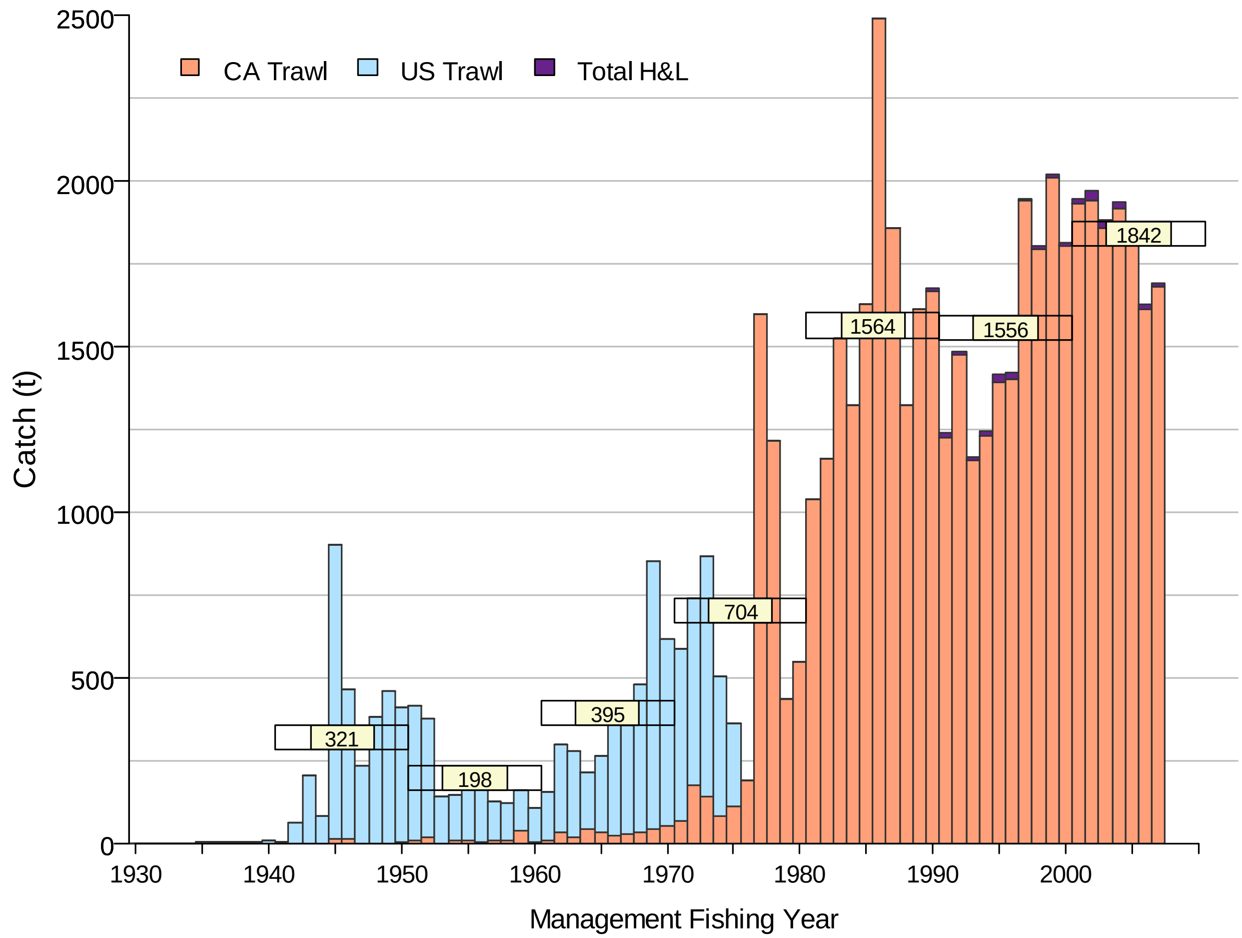

Figure 25. Catch history of yellowmouth rockfish by US and Canadian fleets along the BC coast. Mean annual catches by decade are displayed in horizontal boxes.

4.3. BC synoptic bottom trawl surveys

4.3.1. QCS synoptic bottom trawl survey

The Queen Charlotte Sound (QCS) synoptic bottom trawl survey was initiated in 2003 (Stanley et al. 2004) and was conducted annually for the initial three years. Thereafter, the design calls for biannual repetition. The survey area covers the region north of Vancouver Island to southern Hecate Strait at depths 50-500 m. It is comprehensive in nature, targetting all groundfish species using random tow allocations per stratum that optimize index CVs for representative species.

Survey results for 2003-2007 appear in `GFBio` as `SURVEY_ID` = (1, 2, 3, 121) and as `TRIP_ID` = (49750, 55600, 59120, 63726), respectively.

Strata population parameters (p, μ, ρ) for yellowmouth rockfish in the QCS synoptic survey appear in Table 17, as do the moment estimates of biomass, variance, and CV (described in Appendix A.6). While estimated biomass and variance can also be calculated using formulae in Cochran (1977), we provide strata population parameters to facilitate population simulation (sampling from a binomial-gamma distribution, Schnute and Haigh 2003), should the reader wish to do so. The population parameters and moment estimates agree with observations from the trawl industry in that yellowmouth rockfish appear more abundant at mid-depth strata (125-330 m).

At present, the time series available only comprised four index years, which is too short to detect trends for this species. The bootstrapped biomass index shows no clear trend (Figure 26). The precision of this abundance index is considered "adequate" to "poor" (sampling CVs: $0.3 < \mathrm{CV} \le 0.6$; Stanley et al. 2004). Over time, this survey will provide the most useful population indicator for yellowmouth rockfish in QCS.

The biomass estimates from this survey (Table 18) assume a catchability quotient $q = 1$; however, catchability for this species remains unknown and probably lies well below unity. Catches of yellowmouth rockfish in 2003 and 2004 in PMFC 5AB were 163 t and 194 t. The indices for these years appear to reflect the fishing impacts. If future biomass removals continue to affect the index in a sensible manner, stock assessment scientists should be able to estimate q, and subsequently absolute biomass.

Table 17. Population parameters and moment estimates for yellowmouth rockfish in each strata *h* of the QCS synoptic trawl survey: *p* = proportion of zero-catch tows, μ = mean density of non-zero tows (t/km^2), ρ = CV of non-zero tows, $\nu = 1/\rho^2$, *A* = area (km^2), *n* = number of tows, n^+ = number of tows catching yellowmouth rockfish, *B* = expected biomass (t), *V* = expected variance (t^2), CV = expected coefficient of variation.

year	h	p	μ	ρ	ν	A	n	n^+	B	V	CV
2003	18	1.000	---	---	---	5,093	29	---	0.0	---	---
2003	19	0.839	0.302	2.167	0.213	5,582	56	9	270.8	45,084	0.784
2003	20	0.517	0.693	1.863	0.288	2,931	29	14	981.0	274,243	0.534
2003	21	0.833	0.029	0.408	6.000	496	6	1	2.4	6	1.000
2003	22	1.000	---	---	---	2,024	5	---	0.0	---	---
2003	23	0.974	0.013	0.160	39.000	4,332	39	1	1.4	2	1.000
2003	24	0.769	0.493	1.802	0.308	3,976	52	12	452.3	68,480	0.579
2003	25	0.947	0.016	0.229	19.000	1,220	19	1	1.0	1	1.000
2004	18	1.000	---	---	---	5,093	42	---	0.0	---	---
2004	19	0.771	1.472	2.264	0.195	5,582	48	11	1,883.3	1,902,017	0.732
2004	20	0.387	0.379	1.957	0.261	2,931	31	19	681.7	103,089	0.471
2004	21	0.875	0.023	0.354	8.000	496	8	1	1.4	2	1.000
2004	22	0.750	0.036	1.902	0.276	2,024	20	5	18.3	293	0.935
2004	23	0.842	0.013	2.079	0.231	4,332	38	6	9.1	71	0.928
2004	24	0.846	2.354	2.210	0.205	3,976	39	6	1,440.1	1,980,718	0.977
2004	25	1.000	---	---	---	1,220	7	---	0.0	---	---
2005	18	0.966	0.001	0.186	29.000	5,093	29	1	0.1	0	1.000
2005	19	0.850	0.178	1.529	0.428	5,582	60	9	149.1	7,879	0.595
2005	20	0.483	0.533	1.869	0.286	2,931	29	15	808.3	173,202	0.515
2005	21	0.750	0.021	0.137	52.945	496	8	2	2.6	3	0.620
2005	22	0.750	0.008	0.900	1.235	2,024	8	2	4.3	14	0.883
2005	23	0.756	0.108	2.508	0.159	4,332	45	11	114.8	8,436	0.800
2005	24	0.919	0.228	1.692	0.349	3,976	37	3	73.4	6,792	1.123
2005	25	0.875	3.720	0.354	8.000	1,220	8	1	567.3	321,834	1.000
2007	18	1.000	---	---	---	5,093	33	---	0.0	---	---

year	h	p	μ	ρ	ν	A	n	n^+	B	V	CV
2007	19	0.790	0.417	1.763	0.322	5,582	62	13	488.2	71,502	0.548
2007	20	0.333	0.360	1.792	0.311	2,931	24	16	702.7	109,386	0.471
2007	21	0.714	0.393	1.372	0.531	496	7	2	55.7	4,021	1.139
2007	22	0.632	0.009	1.971	0.257	2,024	19	7	6.5	27	0.803
2007	23	0.579	0.014	2.905	0.119	4,332	57	24	25.2	239	0.613
2007	24	0.750	0.324	2.104	0.226	3,976	48	12	321.8	44,676	0.657
2007	25	1.000	---	---	---	1,220	7	---	0.0	---	---

Strata *h*: 18=S(50-125m), 19=S(125-200m), 20=S(200-330m), 21=S(330-500m)
22=N(50-125m), 23=N(125-200m), 24=N(200-330m), 25=N(330-500m)

Table 18. Relative yellowmouth biomass index (t) and confidence limits from 1000 bootstrapped biomass estimates. n = number of tows, n^+ = number of tows catching yellowmouth rockfish, $\mathrm{E}[B]$ = expected biomass (t), $\bar{B}$ = mean bootstrapped biomass (BB), $B_{0.05}$ = 5% quantile of BB, $B_{0.95}$ = 95% quantile of BB, CV = coefficient of variation.

Year	n	n+	$\mathrm{E}[B]$	$\bar{B}$	$B_{0.05}$	$B_{0.95}$	CV
2003	236	38	1,814	1,800	761	3,399	0.364
2004	234	48	4,256	4,251	1,165	9,493	0.477
2005	224	44	1,770	1,782	667	3,673	0.430
2007	257	75	1,656	1,625	838	2,788	0.302

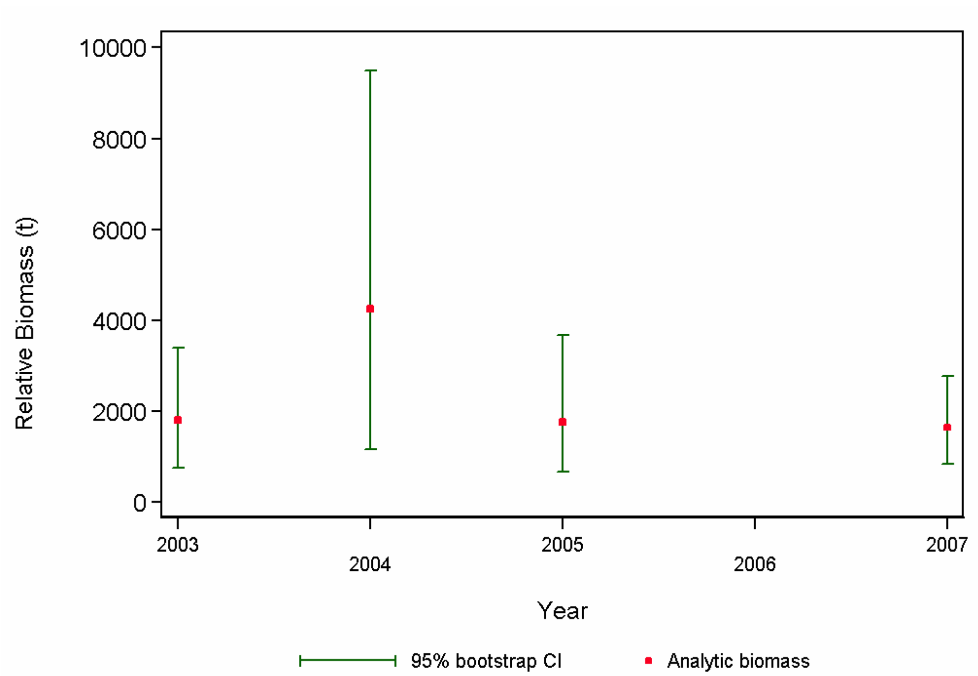

Figure 26. Relative index for yellowmouth rockfish in Queen Charlotte Sound from the QCS bottom trawl survey. Vertical bars indicate 90% confidence intervals from 1,000 bootstrapped biomass index estimates.

4.3.2. WCVI synoptic bottom trawl survey

The WCVI synoptic survey started in 2004 and uses the same depth strata as those in the QCS synoptic survey (Section 4.3).

Survey results for 2004 and 2006 appear in `GFBio` as `SURVEY_ID` = (16, 70) and as `TRIP_ID` = (54080, 61986), respectively.

Strata population parameters (p, μ, ρ) for yellowmouth rockfish in the WCVI synoptic survey appear in Table 19, as do the moment estimates of biomass, variance, and CV (described in Appendix A.6). Considering the p-values and CVs below, the third strata appears to track yellowmouth rockfish in this region.

The two index points appear in Figure 27 and Table 20.

Table 19. Population parameters and moment estimates for yellowmouth rockfish in each strata h of the WCVI synoptic trawl survey: p = proportion of zero-catch tows, μ = mean density of non-zero tows (t/km^2), ρ = CV of non-zero tows, $\nu = 1/\rho^2$, A = area (km^2), n = number of tows, n^+ = number of tows catching yellowmouth rockfish, B = expected biomass (t), V = expected variance (t^2), CV = expected coefficient of variation.

year	h	p	μ	ρ	ν	A	n	n^+	B	V	CV
2004	65	1.000	---	---	---	7,012	38	---	0.0	---	---
2004	66	1.000	---	---	---	4,313	37	---	0.0	---	---
2004	67	0.857	0.252	0.660	2.294	804	14	2	29.0	543	0.804
2004	68	1.000	---	---	---	789	8	---	0.0	---	---
2006	65	0.982	0.420	0.132	57.000	7,012	57	1	51.6	2,664	1.000
2006	66	1.000	---	---	---	4,313	69	---	0.0	---	---
2006	67	0.667	0.383	0.686	2.123	804	21	7	102.6	1,712	0.403
2006	68	0.947	0.025	0.229	19.000	789	19	1	1.1	1	1.000

Strata h: 65=50-125m, 66=125-200m, 67=200-330m, 68=330-500m

Table 20. Relative yellowmouth biomass index (t) and confidence limits from 1000 bootstrapped biomass estimates. n = number of tows, n^+ = number of tows catching yellowmouth rockfish, $\mathrm{E}[B]$ = expected biomass (t), $\bar{B}$ = mean bootstrapped biomass (BB), $B_{0.05}$ = 5% quantile of BB, $B_{0.95}$ = 95% quantile of BB, CV = coefficient of variation.

Year	n	n+	$\mathrm{E}[B]$	$\bar{B}$	$B_{0.05}$	$B_{0.95}$	CV
2004	98	2	29.3	28.9	0.0	82.0	0.736
2006	166	9	159.0	161.8	46.8	317.3	0.435

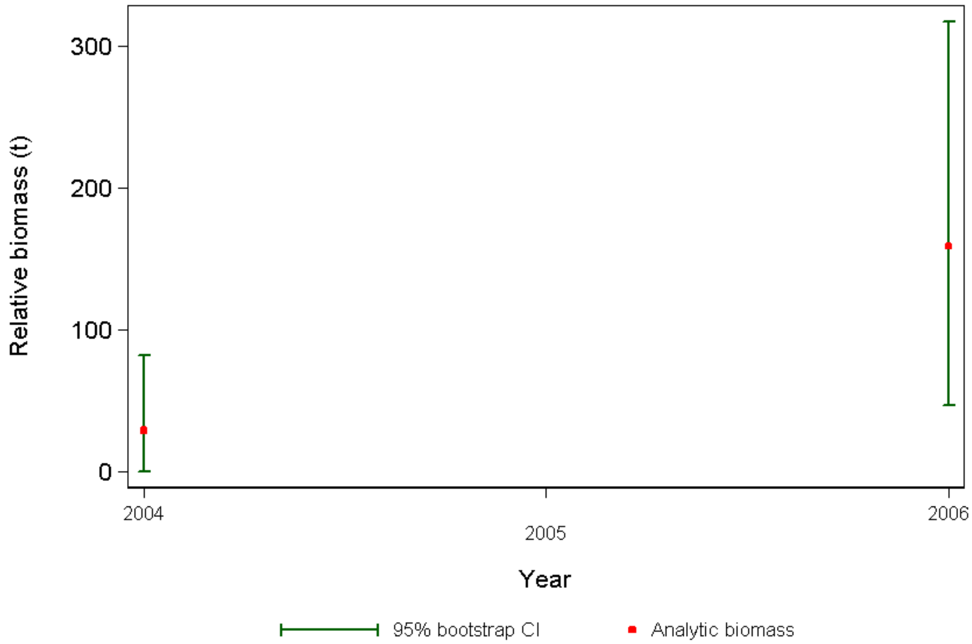

Figure 27. Relative index for yellowmouth rockfish on the west coast of Vancouver Island from the WCVI synoptic bottom trawl survey. Vertical bars indicate 90% confidence intervals from 1,000 bootstrapped biomass index estimates.

4.3.3. WQCI synoptic bottom trawl survey

The WQCI synoptic survey started in 2006 and uses depth strata that cover a wide range of depths from 180 m to 1,300 m.

Survey results for 2006 appear in `GFBio` as `SURVEY_ID` = (79) and as `TRIP_ID` = (62066).

Strata population parameters (p, μ, ρ) for yellowmouth rockfish in the WQCI synoptic survey appear in Table 21, as do the moment estimates of biomass, variance, and CV (described in Appendix A.6). Judging by the p-values and the strata CVs, the shallowest strata will likely prove most useful for tracking yellowmouth rockfish.

Table 21. Population parameters and moment estimates for yellowmouth rockfish in each strata *h* of the WQCI synoptic trawl survey: p = proportion of zero-catch tows, μ = mean density of non-zero tows (t/km^2), ρ = CV of non-zero tows, $\nu = 1/\rho^2$, A = area (km^2), n = number of tows, n^+ = number of tows catching yellowmouth rockfish, B = expected biomass (t), V = expected variance (t^2), CV = expected coefficient of variation.

year	h	p	μ	ρ	ν	A	n	n^+	B	V	CV
2006	126	0.614	0.269	1.940	0.266	1,326	57	22	137.9	3,783	0.446
2006	127	0.923	0.301	1.373	0.531	1,090	26	2	25.3	896	1.185
2006	128	1.000	---	---	---	927	15	---	0.0	---	---
2006	129	1.000	---	---	---	2,228	12	---	0.0	---	---

Strata *h*: 126=180-330m, 127=330-500m, 128=500-800m, 129=800-1300m

4.4. GB Reed historical Queen Charlotte Sound surveys

4.4.1. Data selection

Tow-by-tow data from a series of GB Reed historical trawl survey (details in Stanley *et al*. 2007, Appendix F) were available for 9 years spanning the period from 1965 to 1984. However, the first two surveys, in 1965 and 1966, were quite wide ranging, with the 1965 survey extending from near San Francisco to halfway up the Alaskan panhandle. The 1966 survey was only slightly less ambitious, ranging from the southern US-Canada border in Juan de Fuca Strait into the Alaskan panhandle. It was decided that the implicit design of these two surveys was likely to have been exploratory and that these surveys would not be comparable to the seven subsequent surveys which were much narrower in scope. The 1967 surveys had tows on the west coast of Vancouver Island, the Queen Charlotte Islands and SE Alaska, but both of these surveys had a considerable number of tows in the Goose Island Gully grounds. The 1971 survey was entirely confined to the Goose Island Gully while the following four surveys covered both Goose Island and Mitchell Gullies in Queen Charlotte Sound. Given the differences in area covered between surveys, it was decided to use only the tows from the Goose Island Gully grounds for the 1967 to 1984 surveys to ensure comparability. These grounds were defined as all tows lying between 50.9°N and 51.6°N latitude (Figure 28).

Table 22. Number of tows, minimum, mean and maximum depths by depth interval, based on the recorded depth at the beginning of each tow over all 9 historical GB Reed surveys (1965 to 1984).

Depth interval	Mean depth (m)	Min depth (m)	Max depth (m)	N depth
66-146 m	122	66	146	12
147-183 m	167	148	183	88
184-219 m	201	185	219	163
220-256 m	235	220	256	106
257-428 m	300	260	428	128
All tows	226	66	428	497

Table 23. Catch weight (kg) of yellowmouth rockfish for each of the 9 historical GB Reed surveys (1965 to 1984) by depth interval, based on the recorded depth at the beginning of each tow.

Survey	Depth Interval					All
year	66-146 m	147-183 m	184-219 m	220-256 m	257-428 m	tows
1965	0	0	0	0	0	0
1966	0	2,729	12,157	1,068	0	15,954
1967	0	40	531	9	6	587
1969		41	480	193	3	718
1971		0	1,731	19	24	1,774
1973		0	302	3	288	593
1976		3	541	33	185	762
1977	0	1	45	4	4	54
1984		2	199	31	1	233
Total	0	2,817	15,988	1,359	511	20,675

The original depth stratification of these surveys was in 20 fathom intervals, with the important strata for yellowmouth rockfish ranging from 80 fathoms (146 m) to 140 fathoms (256 m). The most shallow tows recorded for this survey were 66 and 67 m and there were only

12 tows (from a total of 497 tows) less than 146 m over the 9 surveys. About one-quarter of all tows (128 tows) were deeper than 256 m (Table 22).

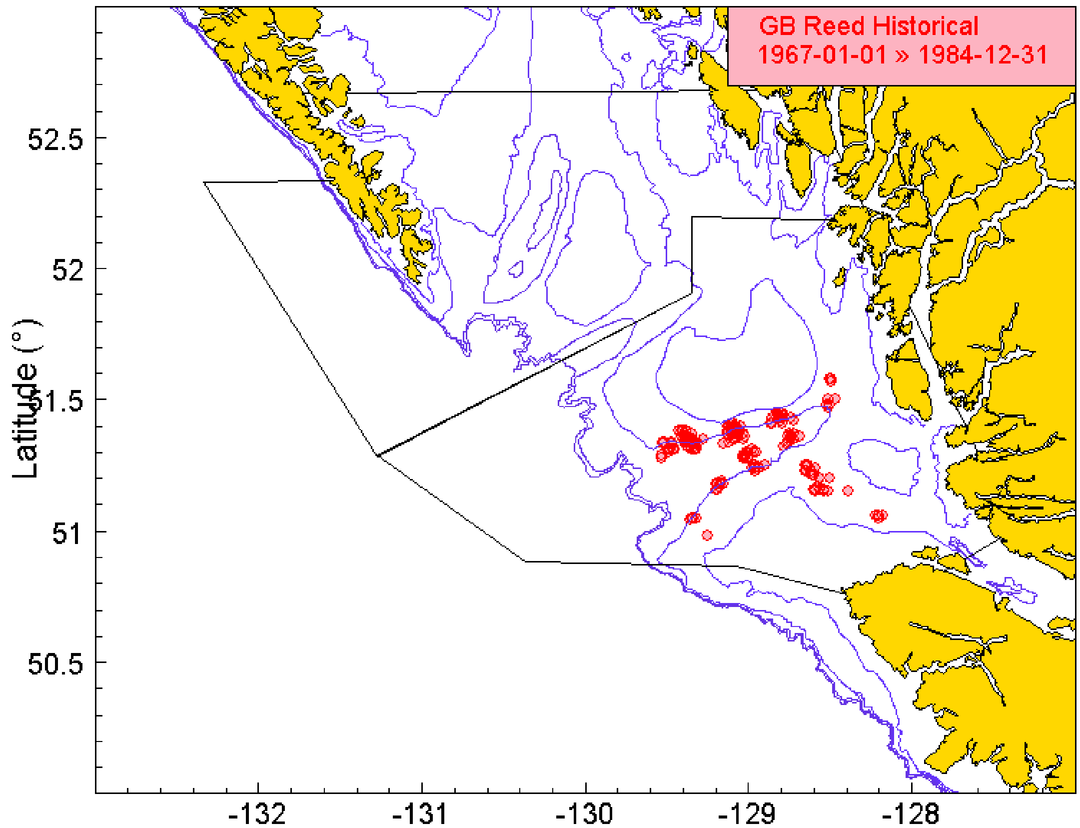

Figure 28. The full range of selected tows for the historical GB Reed surveys, showing the 100, 200, 300 and 400 m isobaths. The deep edge of the survey area is 549 m (300 fathoms) and the shallow cut-off is 37 m (20 fathoms). Only the tows lying between 146 m and 428 m were used in the analysis and the stratum boundaries for the current Q. Charlotte Sound synoptic survey are also shown.

Table 24. Number of tows available for biomass estimation from the 7 historical GB Reed surveys (1967 to 1984) in Goose Island Gully by depth interval.

Survey year	147-183 m	184-219 m	220-256 m	257-428 m	Total
1967	6	11	5	10	32
1969	9	11	6	6	32
1971	4	15	8	9	36
1973	7	11	7	8	33
1976	7	13	8	5	33
1977	12	14	14	6	46
1984	11	15	10	6	42
Total	56	90	58	50	254

No yellowmouth rockfish were caught in 1965 whereas close to 16 t were removed in the 1966 survey, primarily from the (184–219 m) stratum (Table 23). The shallow stratum was excluded from this analysis, as were the 1965 and 1966 surveys. A total of 254 tows in Goose Island Gully were included in the analysis of these seven historical surveys (Table 24).

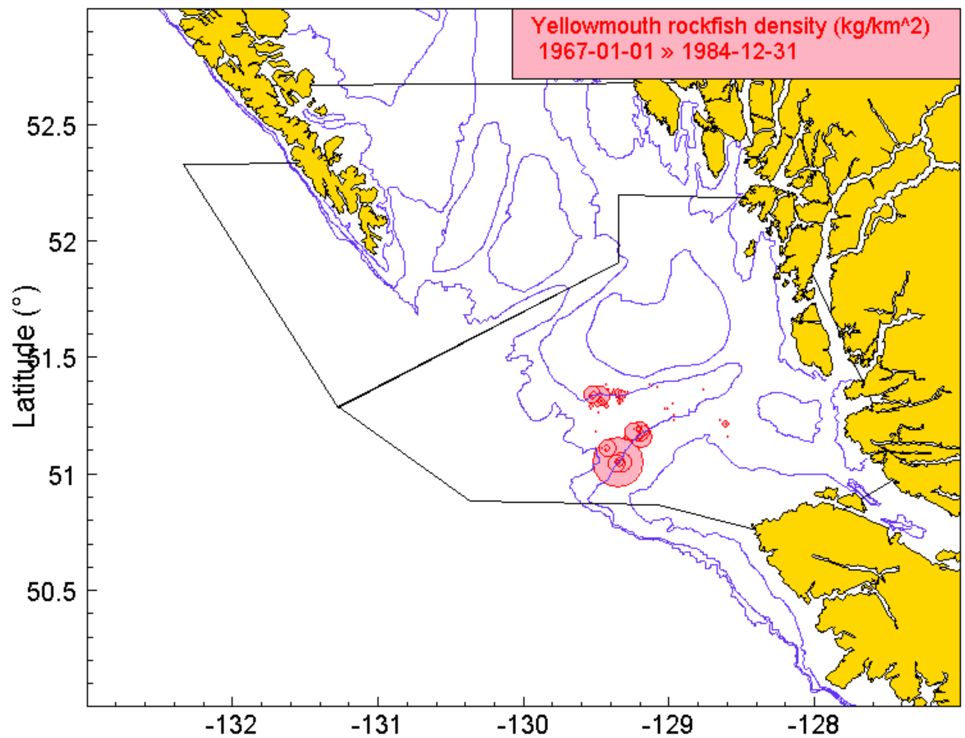

Figure 29. Map of the locations of all trawls from the historical GB Reed trawl survey (1967–1984) which caught yellowmouth rockfish. Only tows in Goose Island Gully which were used in the biomass index calculation are shown. Circles are proportional to catch density (largest circle=8.11 kg/km^2). Also shown are the 100, 200 and 300 m isobaths.

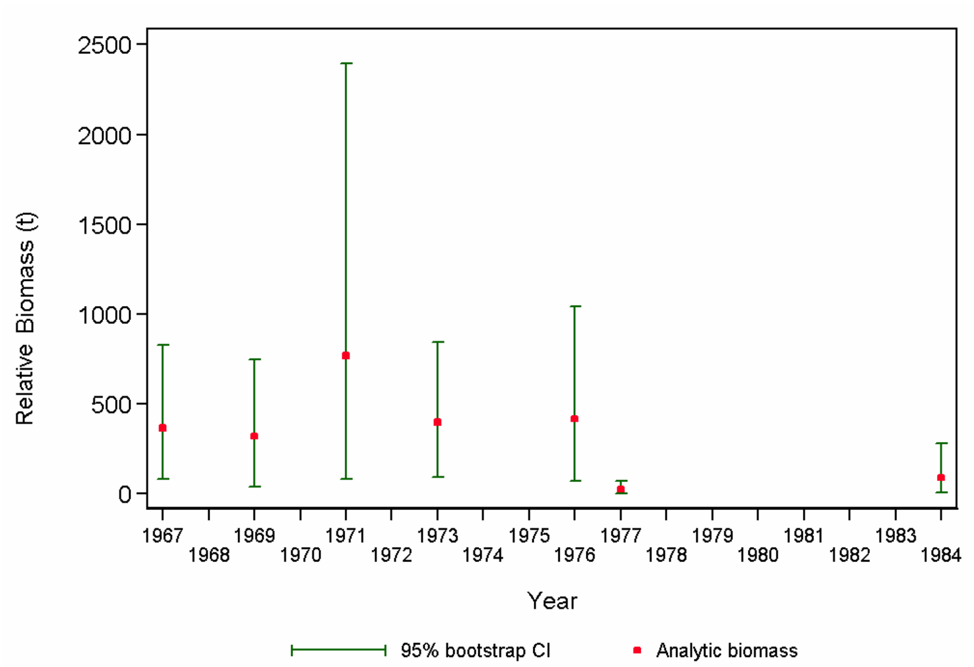

Figure 30. Relative biomass estimates for yellowmouth rockfish from the historical Goose Island Gully GB Reed trawl surveys for the period 1967 to 1984. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

4.4.2. Results

A map showing the locations where yellowmouth rockfish were caught in Goose Island Gully indicates that this species was primarily caught along the 200 m depth contour at the entrance to the gully (Figure 29). Estimated biomass levels in the Goose Island Gully for yellowmouth rockfish from the historical GB Reed trawl surveys were relatively constant with wide error bars in the first 5 years of this survey, but dropped considerably in the last two surveys (Figure 30; Table 25). All surveys have high levels of relative error levels with only one survey having a CV less than 50% and two of surveys (1971 and 1984) with CVs near to or greater than 80%. The precision of these survey indices is low and it is likely that survey methodology will be unable to track abundance shifts in this species. The proportion of tows which contained yellowmouth rockfish has been variable over the seven surveys, ranging from 25% in the 1967 survey to over 50% in the 1971 survey, then dropping to below 20% in the last two surveys.

Table 25. Relative biomass estimates for yellowmouth rockfish from the historical Goose Island Gully GB Reed trawl surveys for the years 1967 to 1984. Biomass estimates are based four depth strata (Table 24) and by assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. The analytic CV (A.5.6) is based on the assumption of random tow selection within a stratum.

Survey Year	Relative biomass (t)	Mean bootstrap biomass (t)	Lower 95% bound biomass (t)	Upper 95% bound biomass (t)	Bootstrap CV	Analytic CV
1967	366.5	357.5	82.9	830.0	0.501	0.509
1969	321.8	325.5	38.1	749.2	0.581	0.570
1971	770.2	799.3	81.7	2393.3	0.795	0.836
1973	398.9	404.6	95.2	845.7	0.468	0.492
1976	418.9	418.4	73.6	1045.4	0.569	0.569
1977	26.3	26.0	4.3	72.7	0.658	0.645
1984	89.8	86.2	5.9	280.5	0.802	0.799

4.5. WCVI shrimp trawl survey

Although this survey supplies a principle index series for bocaccio and canary rockfish, it appears to be incapable of monitoring yellowmouth rockfish. The survey was designed to assess shrimp and only incidentally catches rockfish species. There have only been two observations of yellowmouth rockfish (in 1988 and 1995) taken in a valid survey tow over the thirty one surveys which are available for yellowmouth rockfish biomass estimation. Therefore, we do not report this species from this survey.

4.6. QCS shrimp trawl survey

4.6.1. Data selection

This survey, described by Boutillier and Olsen (2000), covers the lower half of Queen Charlotte Sound extending westward from Calvert Island and Rivers Inlet into the Goose Island Gully (Figure 31). There is also a stratum providing coverage between Calvert Island and the mainland. Five vessels took part in the first year that the survey was conducted (1998) and the timing in that year was slightly later than in subsequent years (Table 26). It was decided to discard this survey year, given the exploratory nature of the first survey year and that five different vessels collected the data. Subsequent to that year, the survey has been conducted routinely by the *WE Ricker* (except in 2005 when the *Frosti* was used) in April or May and all years are reported. The survey is divided into three aerial strata: stratum 109 lying to the west of the outside islands and extending into Goose Island Gully; stratum 110 lying to the south of Calvert Island and stratum 111 lying between Calvert Island and the mainland (Figure 31). Stratum 111 has been discarded as its location is not considered good habitat for rockfish species and no yellowmouth rockfish has ever been taken in that stratum. The majority of tows occur in the larger of the two remaining strata (109) while only a few are placed in Stratum 110 (Table 27). Only tows with usability codes of 1 (usable), 2 (fail, but all data usable), and 6 (gear torn, but all data usable) were included in the biomass estimate. Over 600 usable tows have been conducted by this survey over the nine available survey years (Table 27).

Table 26. Number of sets made by each vessel involved in the Queen Charlotte Sound shrimp trawl by month and survey year. All Queen Charlotte Sound sets are included, not just sets used in the analysis.

	Month				
Vessel and Year	**Apr**	**May**	**Jun**	**Jul**	**Total**
Frosti					
2005		55			55
Ocean Dancer					
1998				18	18
Pacific Rancher					
1998				18	18
Parr Four					
1998				17	17
W. E. Ricker					
1999			133		133
2000		87			87
2001		75			75
2002	76				76
2003	65				65
2004	71				71
2006	72				72
2007	70				70
Westerly Gail					
1998				21	21
Western Clipper					
1998				18	18

A doorspread density value (A.5.4) was generated for each tow based on the catch of Yellowmouth rockfish, an arbitrary doorspread (25 m) for the tow and the distance travelled. The distance travelled was determined at the time of the tow, based on the bottom contact time (J. Boutillier, *pers. comm.*). The two missing values for this field were filled in by multiplying the vessel speed and the tow time. All tows were used regardless of depth because this survey, unlike the west coast Vancouver Island shrimp survey, has consistently sampled depths up to about 220 m (Figure 32), so there was no need to truncate the tows at depth to ensure comparability across survey years.

Table 27. Stratum designations, area covered, and number of useable tows, for the Queen Charlotte Sound shrimp survey from 1999 to 2007.

	Stratum		
Survey year	**109**	**110**	**Total**
1999	72	10	82
2000	76	8	84
2001	65	7	72
2002	65	7	72
2003	57	6	63
2004	59	6	65
2005	41	6	47
2006	61	6	67
2007	60	5	65
Total	556	61	617
Area (km^2)	2,142	159	2,301

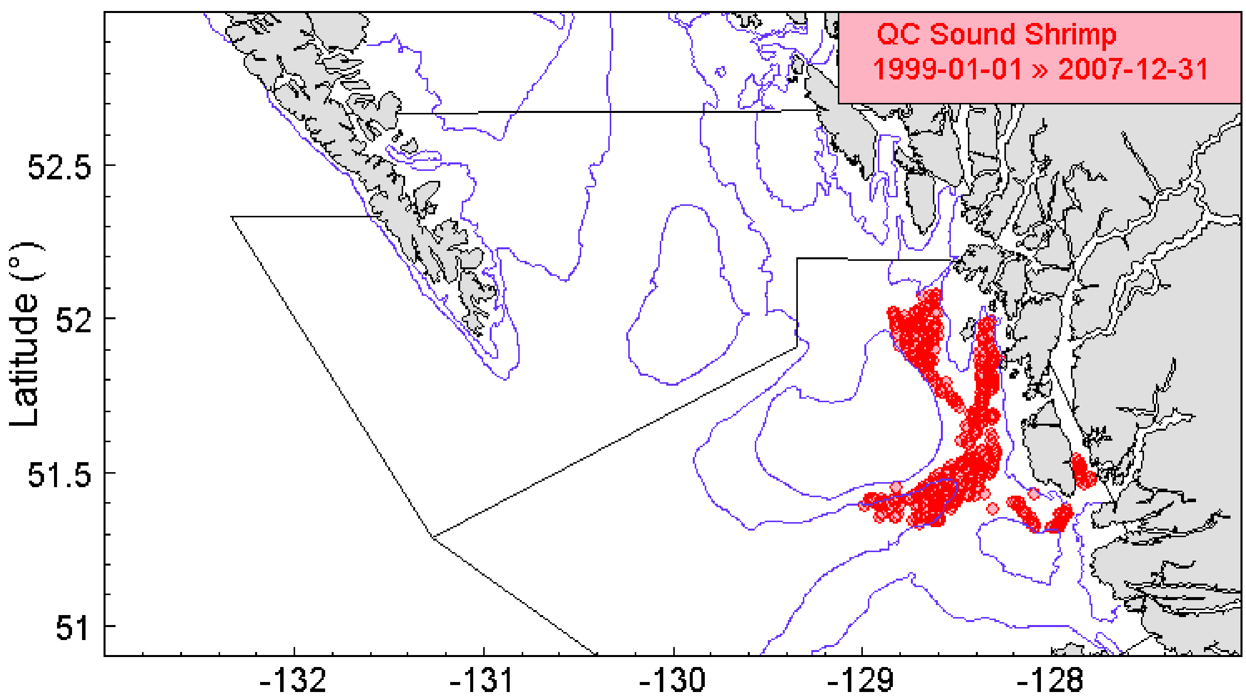

Figure 31. Map showing the locations of valid tows (Stratum numbers 109, 110, 111) conducted by the Queen Charlotte Sound shrimp survey over the period 1999 to 2007. The tows on the inside of Calvert Island represent Stratum 111 which was not used in the analysis of this survey for yellowmouth rockfish.

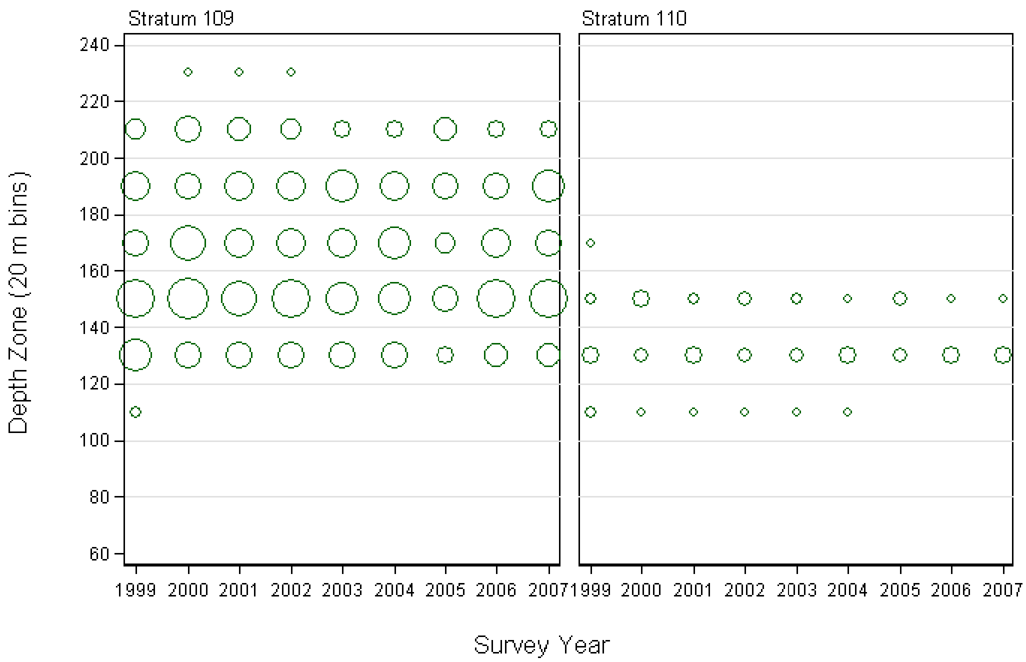

Figure 32. Distribution of tows by stratum, survey year and 20 m depth zone. Depth zones are indicated by the centre of the depth interval, weighted by the number of tows. Maximum circle size: Stratum 109=26 tows (150 m bin); Stratum 110=5 tows (130 m bin). Depth is the mean of the start and end depths for the tow.

4.6.2. Results

Catches of yellowmouth rockfish tend to be distributed along the upper section of Goose Island Gully and there are no observations of this species along shelf edge of the outside islands (unlike for several other rockfish species) (Figure 33). Yellowmouth rockfish were mainly taken at depths from 170 to 210 m and none were taken in Stratum 110 at any depth (Figure 34).

Estimated relative biomass levels for yellowmouth rockfish from the QC Sound shrimp trawl survey are relatively small and highly variable, with no trend (Figure 35; Table 28). The associated CVs are all very high, ranging between 37% and 91% (Table 28). The proportion of tows which took yellowmouth rockfish is also variable between surveys, ranging from below 5% to above 20% in Stratum 109. The high level of variation demonstrated by this species in this survey indicates that it is probably not a strong candidate for long-term monitoring of this species.

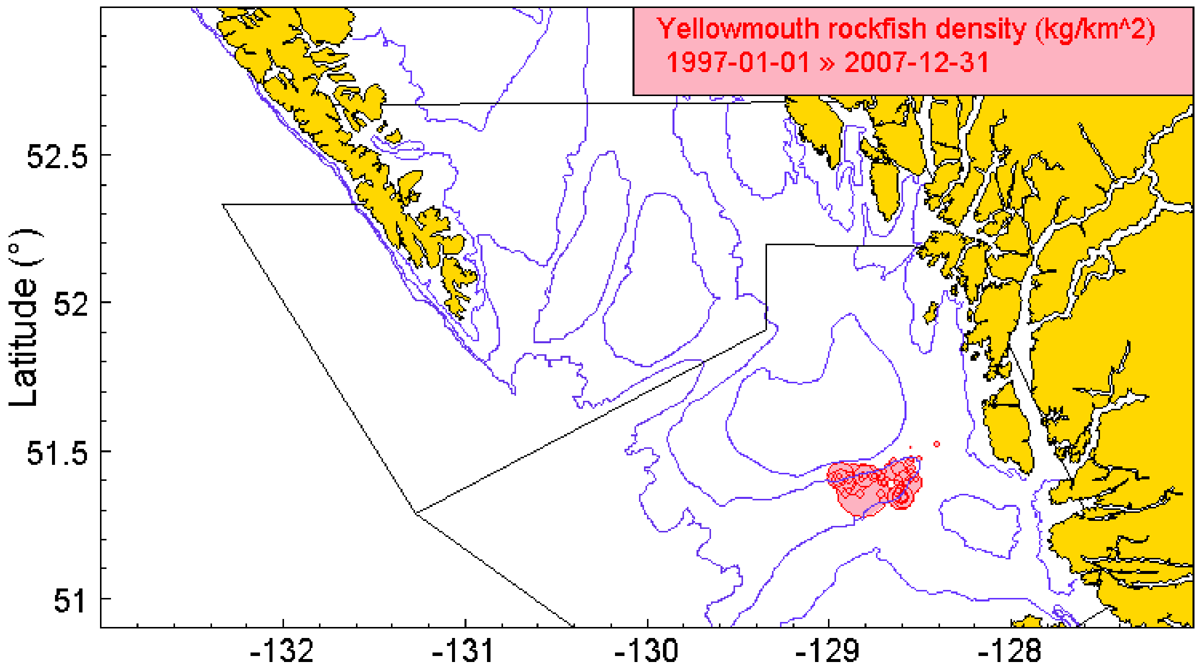

Figure 33. Map of the locations of all trawls from the Queen Charlotte Sound shrimp trawl survey (1999–2007) which caught Yellowmouth rockfish. Circles are proportional to catch density (largest circle=2.47 kg/km^2). Also shown are the 100, 200 and 300 m isobaths and the area stratum boundaries for the Queen Charlotte Sound synoptic survey.

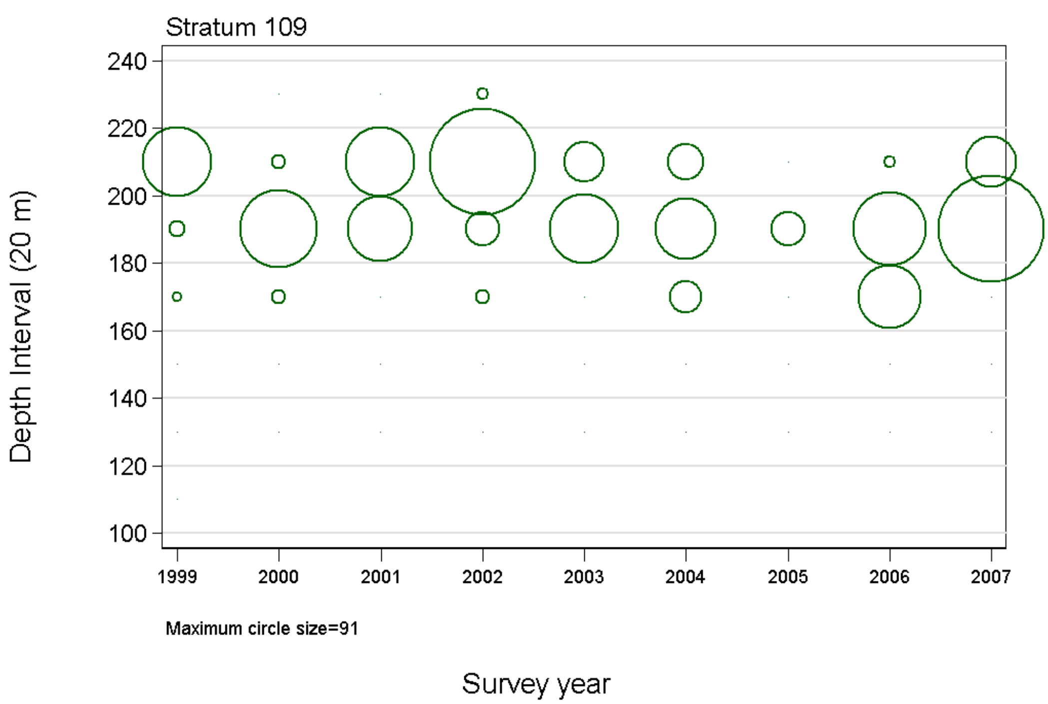

Figure 34. Distribution of catch weight of yellowmouth rockfish (YMR) by stratum (Table 27), survey year and 20 m depth zone. Depth zones are indicated by the centre of the depth interval. Maximum circle size: Stratum 109=91 kg (190 m bin). Minimum depth observed for YMR: 175 m; maximum depth observed for YMR: 221 m. Depth is determined by the depth at the start of the tow.

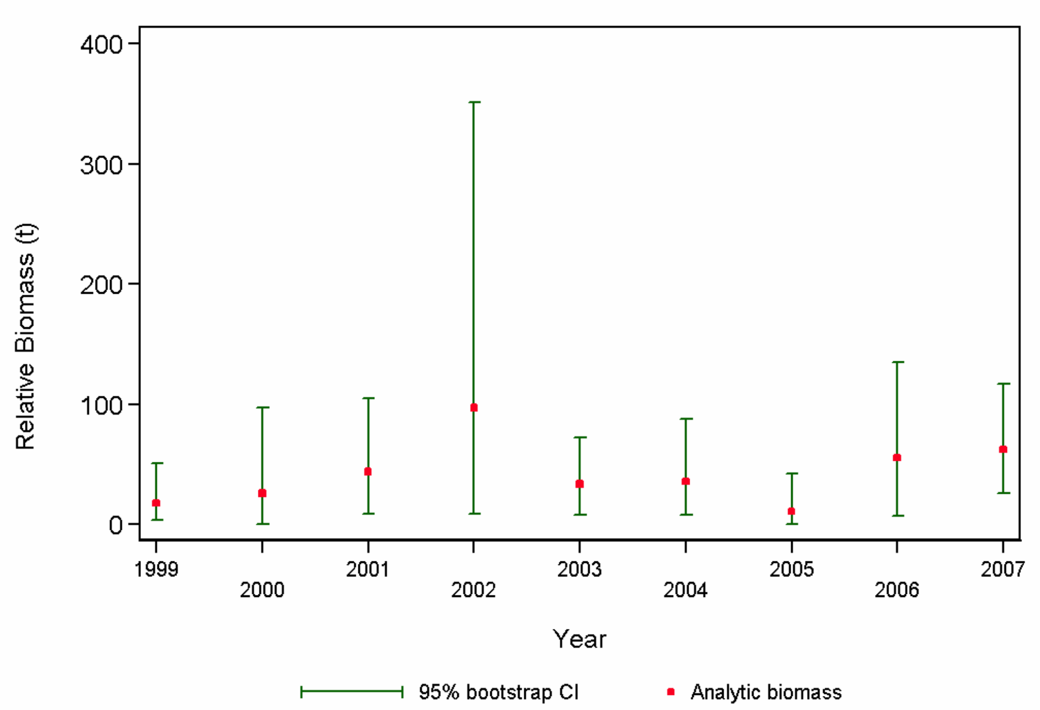

Figure 35. Relative biomass estimates for yellowmouth rockfish from the QC Sound shrimp trawl survey for 1999 to 2007. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

Table 28. Relative biomass estimates for yellowmouth rockfish from the QC Sound shrimp trawl survey for the survey years 1999 to 2007. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement. The analytic CV (A.5.6) is based on the assumption of random tow selection within a stratum.

Survey Year	Relative biomass (t)	Mean bootstrap biomass (t)	Lower 95% bound biomass (t)	Upper 95% bound biomass (t)	Bootstrap CV	Analytic CV
1999	17.8	17.9	3.9	51.0	0.604	0.609
2000	26.3	26.3	0.0	97.8	0.911	0.937
2001	44.3	44.4	8.9	105.4	0.526	0.538
2002	97.3	96.5	9.3	351.2	0.871	0.835
2003	34.0	34.5	8.5	72.7	0.459	0.456
2004	36.0	35.1	7.8	87.7	0.567	0.584
2005	11.2	11.0	0.0	42.5	0.884	0.887
2006	55.8	56.7	7.0	135.1	0.533	0.539
2007	62.9	63.9	26.3	116.9	0.366	0.371

4.7. NMFS US west coast bottom trawl survey

4.7.1. Introduction and data

Tow-by-tow data from the triennial survey covering the Vancouver INPFC (International North Pacific Fisheries Commission) region were provided by Mark Wilkins of the US National Marine Fisheries Service (NMFS) for the seven years that surveyed Canadian waters (Figure 36; Table 29). These tows were assigned to strata by the NMFS, but the size and definition of these strata have changed over the life of the survey (Table 30). The NMFS also provided information as to which country's waters each tow was located. This information was plotted and checked against the accepted US/Canada marine boundary: all tows appeared to be appropriately located with respect to country, based on the tow start position (Figure 37). The NMFS designations were accepted for tows located near the marine border.

Table 29. Number of tows by stratum and by survey year for the NMFS triennial survey. Strata which are coloured grey have been excluded from the analysis due to incomplete coverage across the seven survey years or to locations outside of the Vancouver INPFC area (Table 30).

Stratum	**1980**		**1983**		**1989**		**1992**		**1995**		**1998**		**2001**	
No.	Can	US	Can	US	Can	US	Can	US	Can	US	Can	US	Can	US
10		17		7										
11	48			39										
12			38											
17N						8		9		8		8		8
17S						27		27		25		26		25
18N					1		1							
18S						32		23		12		20		14
19N					58		53		55		48		33	
19S						4		6		3		3		3
27N						2		1		2		2		2
27S						5		2		3		4		5
28N					1		1		2		1			
28S						6		9		7		6		7
29N					7		6		7		6		3	
29S						3		2		3		3		3
30		4		2										
31	7			11										
32			5											
37N										1		1		1
37S										2		1		1
38N									1					
38S										2				3
39									6		4		2	
50		5		1										
51	4			10										
52			4											
Total	**59**	**26**	**47**	**70**	**67**	**87**	**61**	**79**	**71**	**68**	**59**	**74**	**38**	**72**

All usable tows have an associated net width and distance travelled, allowing for the calculation of the area swept by the tow. Relative biomass indices and the associated analytical CVs for yellowmouth rockfish were calculated for the total Vancouver INPFC region and for each of the Canadian and Vancouver sub-regions using appropriate area estimates for each stratum and year (Table 30). Strata that were not surveyed consistently in all seven years of the survey were dropped from the analysis (Table 29; Table 30), allowing the remaining data to provide a comparable set of data for each year from 1989 onwards (Table 31).

Table 30. Stratum definitions by year used in the NMFS triennial survey to separate out the survey results by country and by INPFC area. Stratum definitions in grey are those strata which have been excluded from the final analysis due to incomplete coverage across the seven survey years or to locations outside of the Vancouver INPFC area.

Year	Stratum No.	Area (km^2)	Start	End	Country	INPFC area	Depth range
1980	10	3537	47°30	US-Can Border	US	Vancouver	55-183 m
1980	11	6572	US-Can Border	49°15	Canada	Vancouver	55-183 m
1980	30	443	47°30	US-Can Border	US	Vancouver	184-219 m
1980	31	325	US-Can Border	49°15	Canada	Vancouver	184-219 m
1980	50	758	47°30	US-Can Border	US	Vancouver	220-366 m
1980	51	503	US-Can Border	49°15	Canada	Vancouver	220-366 m
1983	10	1307	47°30	47°55	US	Vancouver	55-183 m
1983	11	2230	47°55	US-Can Border	US	Vancouver	55-183 m
1983	12	6572	US-Can Border	49°15	Canada	Vancouver	55-183 m
1983	30	66	47°30	47°55	US	Vancouver	184-219 m
1983	31	377	47°55	US-Can Border	US	Vancouver	184-219 m
1983	32	325	US-Can Border	49°15	Canada	Vancouver	184-219 m
1983	50	127	47°30	47°55	US	Vancouver	220-366 m
1983	51	631	47°55	US-Can Border	US	Vancouver	220-366 m
1983	52	503	US-Can Border	49 °15	Canada	Vancouver	220-366 m
1989&after	17N	1033	47°30	47°50	US	Vancouver	55-183 m
1989&after	17S	3378	46°30	47°30	US	Columbia	55-183 m
1989&after	18N	159	47°50	48°20	Canada	Vancouver	55-183 m
1989&after	18S	2123	47°50	48°20	US	Vancouver	55-183 m
1989&after	19N	8224	48°20	49°40	Canada	Vancouver	55-183 m
1989&after	19S	363	48°20	49°40	US	Vancouver	55-183 m
1989&after	27N	125	47°30	47°50	US	Vancouver	184-366 m
1989&after	27S	412	46°30	47°30	US	Columbia	184-366 m
1989&after	28N	88	47°50	48°20	Canada	Vancouver	184-366 m
1989&after	28S	787	47°50	48°20	US	Vancouver	184-366 m
1989&after	29N	942	48°20	49°40	Canada	Vancouver	184-366 m
1989&after	29S	270	48°20	49°40	US	Vancouver	184-366 m
1995&after	37N	102	47°30	47°50	US	Vancouver	367-500 m
1995&after	37S	218	46°30	47°30	US	Columbia	367-500 m
1995&after	38N	66	47°50	48°20	Canada	Vancouver	367-500 m
1995&after	38S	175	47°50	48°20	US	Vancouver	367-500 m

Table 31. Number of usable tows performed and area surveyed in the INPFC Vancouver region separated by the international border between Canada and the United States. Strata 18N, 28N, 37, 38 and 39 were dropped from this analysis as they were not consistently conducted over the survey period. All strata occurring in the Columbia River INPFC region (17S and 27S) were also dropped.

Survey year	Number tows			Area surveyed (km^2)		
	Canadian waters	US waters	Total	Canadian waters	US waters	Total
1980	59	26	85	7,399	4,738	12,137
1983	47	70	117	7,399	4,738	12,137
1989	65	55	120	9,166	4,699	13,865
1992	59	50	109	9,166	4,699	13,865
1995	62	35	97	9,166	4,699	13,865
1998	54	42	96	9,166	4,699	13,865
2001	36	37	73	9,166	4,699	13,865
Total	382	315	697	–	–	–

The strata definitions used in the 1980 and 1983 surveys were considerably different than those used in subsequent surveys, particularly in Canadian waters (Table 31). Therefore, the 1980 and 1983 indices were scaled up by the ratio (1.24=9169 km^2/7399 km^2) of the total stratum areas relative to the 1989 and later surveys so that the coverage from the first two surveys would be comparable to the surveys conducted from 1989 onwards. The tow density was much higher in the US waters although the overall number of tows was approximately the same for each country (Table 31). This is because the size of the total area fished was about twice as large in Canadian waters than in US waters (Table 31).

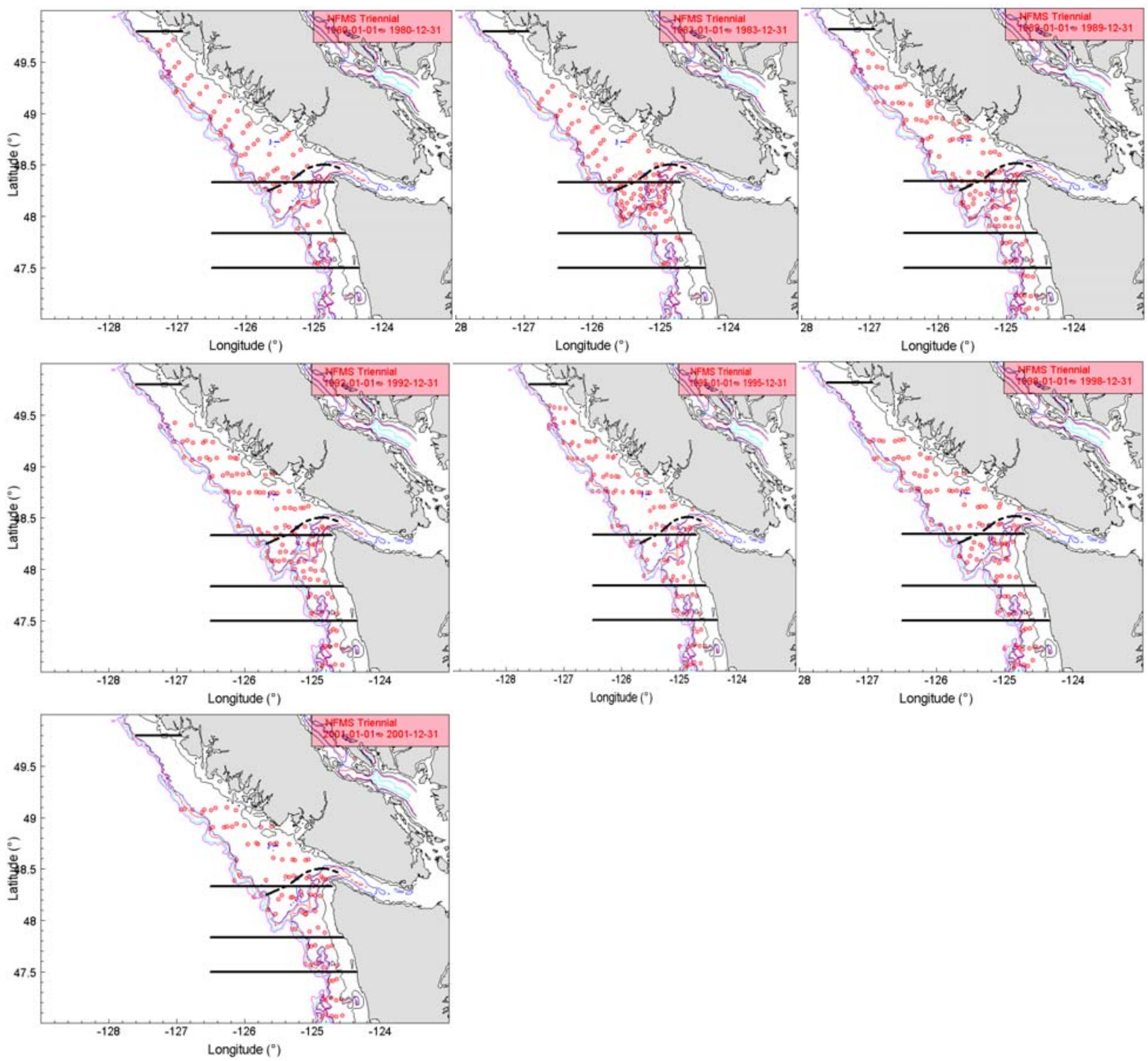

Figure 36. Plot of tow locations in the Vancouver INPFC region for each of the seven triennial surveys that surveyed Canadian waters. The approximate position of the US/Canada marine boundary is shown (dashed line). The horizontal lines are the stratum boundaries: 47°30′, 47°50′, 48°20′ and 49°50′. Tows south of the 47°30′ line were not included in the analysis. Isobaths are the stratum depth boundaries at 55, 183, 220, 366, and 500 m.

The data were analysed using the swept-area biomass formulae in Appendix A.5. We assumed that the variance and CPUE within any stratum was equal, even for strata that were split by the presence of the US/Canada border. The total biomass B_{yi} within a stratum which straddled the border was split between the two countries by the ratio of the relative area within each country:

$$B_{yic} = B_{yi} \frac{A_{yic}}{A_{yi}} \qquad (2)$$

where A_{yic} = area (km^2) within country c for year y in stratum i.

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

$$V_{yic} = V_{yi} \frac{A_{yic}^2}{A_{yi}^2} \qquad (3)$$

The partial variance V_{yic} for country c was used in (A.5.5) instead of the total variance in the stratum V_{yi} when calculating the variance for the total biomass in US or Canadian waters.

The biomass estimates (A.5.4) and the associated standard errors were adjusted to a constant area covered using the ratios of area surveyed provided in Table 31. This was required to adjust the Canadian biomass estimates for 1980 and 1983 to account for the smaller area surveyed in those years compared to the succeeding surveys. The biomass estimates from Canadian waters were consequently multiplied by the ratio 1.24 (=9166/7399) to make them equivalent to the coverage of the surveys from 1989 onwards.

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

4.7.2. Results

The largest catch of yellowmouth rockfish occurred in Canadian waters in 1983, along with several other large catches in that year (Figure 37). Catches were much smaller in all other years and barely register on the plots following the 1989 survey compared to the large catches in 1983 (Figure 37). The northern extension of the survey and stratum definition has varied between years (Figure 36), and this difference has been compensated for by using a constant survey area for all years. Coverage by depth has been consistent for all seven years of the survey, with yellowmouth rockfish being most abundant between about 100 to 300 m (Figure 38).

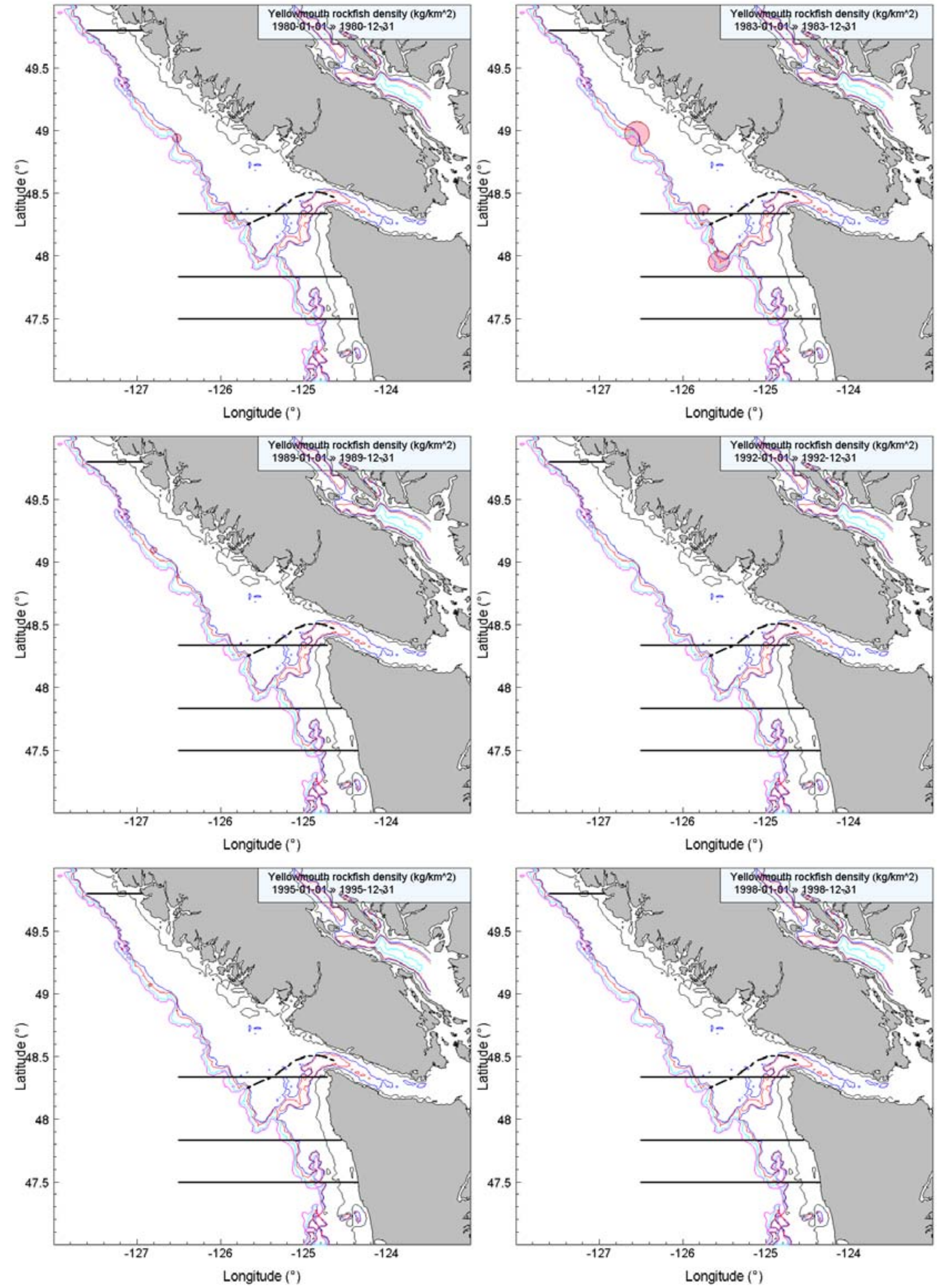

Figure 37. Plot of valid tows, weighted by the density of yellowmouth rockfish, in the Vancouver INPFC region for the seven triennial surveys that surveyed Canadian waters. Catches in each year are scaled to the weight of the largest density of yellowmouth rockfish (17,131 kg/km^2 in 2001). The approximate position of the US/Canada marine boundary is shown (dashed line). The solid horizontal lines are the stratum boundaries: 47°30’, 47°50’, 48°20’ and 49°50’.

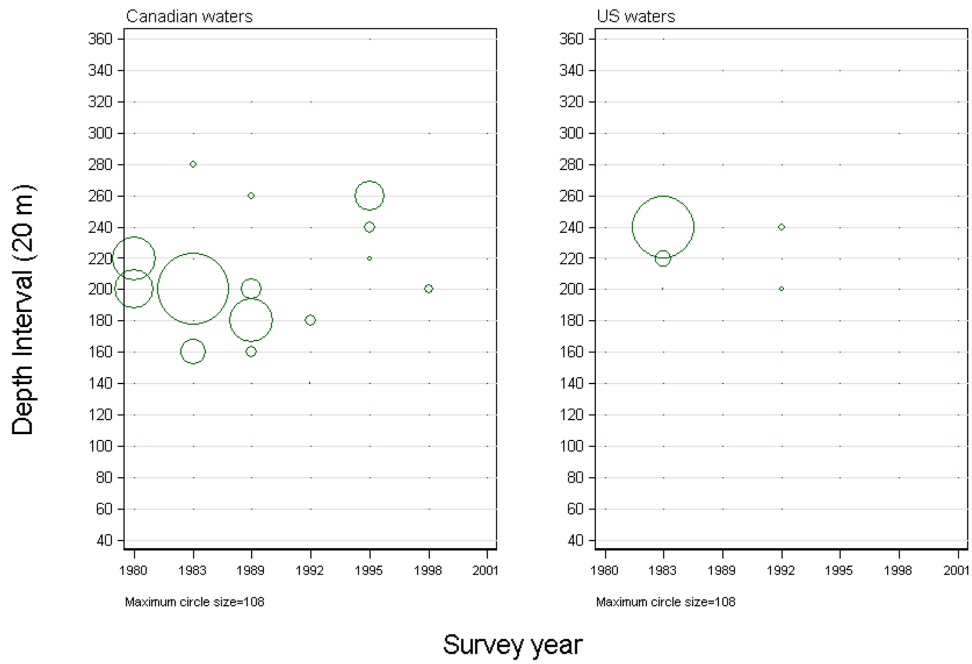

Figure 38. Distribution of yellowmouth rockfish catch weights for each survey year summarised into 20 m depth intervals for all valid tows (Table 30) in Canadian and US waters of the Vancouver INPFC area. Depth intervals are labelled with the mid-point of the interval.

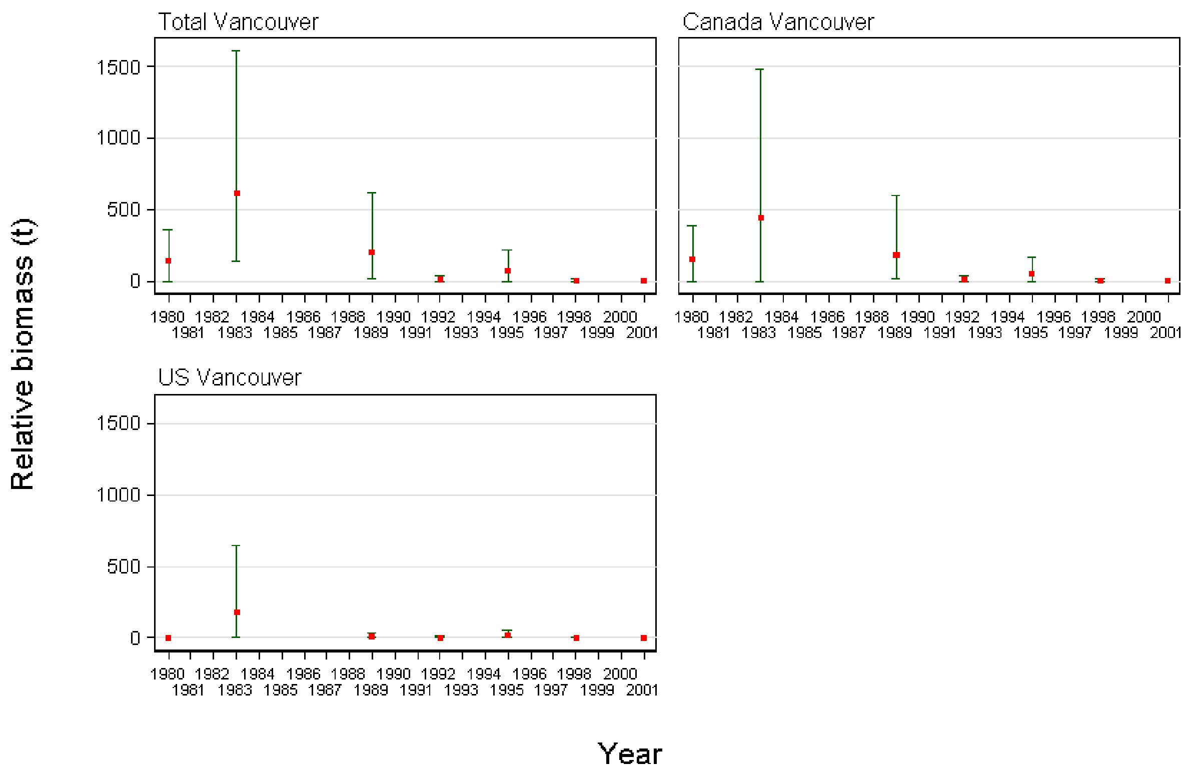

Figure 39. Relative biomass estimates for yellowmouth rockfish in the INPFC Vancouver region (total region, Canadian waters only, and US waters only) with 95% bias corrected error bars estimated from 5000 bootstraps.

Table 32. Relative biomass estimates for yellowmouth rockfish in the Vancouver INPFC region (total region, Canadian waters only and US waters only) with 95% confidence regions based on the bootstrap distribution of biomass. Biomass estimates are calculated as in (A.5.4). The bootstrap estimates are based on 5000 random draws with replacement.

Estimate type	Survey Year	Relative biomass (t)	Mean bootstrap biomass	Lower bound biomass	Upper bound biomass	Bootstrap CV	Analytic CV
Total Vancouver	1980	139	141	0	361	0.609	0.661
	1983	613	627	138	1,608	0.575	0.585
	1989	202	203	16	622	0.735	0.753
	1992	15	14	2	43	0.713	0.726
	1995	72	69	1	222	0.778	0.791
	1998	6	6	0	20	0.925	1.000
	2001	0	0	NA	NA	NA	NA
Canada Vancouver	1980	151	153	0	391	0.609	0.661
	1983	442	461	0	1,478	0.746	0.739
	1989	187	189	18	594	0.752	0.771
	1992	11	10	0	41	0.898	0.917
	1995	56	55	1	172	0.780	0.791
	1998	4	5	0	17	0.931	1.000
	2001	0	0	NA	NA	NA	NA
US Vancouver	1980	0	0	NA	NA	NA	NA
	1983	180	177	3	650	0.943	0.946
	1989	14	14	1	36	0.624	0.616
	1992	4	4	0	10	0.606	0.631
	1995	16	15	0	51	0.825	0.791
	1998	1	1	0	5	0.972	1.000
	2001	0	0	NA	NA	NA	NA

The relative biomass estimates from this survey for yellowmouth, although highly variable, were generally higher in the first three surveys in the 1980s than the following four surveys in the 1990s and 2001 (Figure 39; Table 32). Yellowmouth also appeared to be more abundant in Canadian waters over the US waters. The CVs for this species were very large, with the lowest CV just below 0.6 and tending towards 1.0 in several years (Table 32). Therefore it is difficult to conclude much from this series, other than there may have been a non-significant drop in abundance between the 1980s and the 1990s. Note that the bootstrap estimates of CV do not include any uncertainty with respect to the ratio expansion required to make the 1980 and 1983 survey estimates comparable to the 1989 and later surveys. Therefore, it is likely that the true uncertainty for this series is even greater than estimated.

Only 23 of the 697 tows in this data set caught yellowmouth rockfish over the seven years of this survey. The highest proportion of tows with yellowmouth was 0.092 in 1989 in Canadian waters and 0.060 in US waters in 1983. Yellowmouth were absent in US waters in 5 of 7 surveys and yellowmouth were completely absent in all strata north of 47° latitude in the 2001 survey.

4.8. GLM analysis of commercial trawl CPUE

Appendix C contains details of a GLM analysis on commercial trawl CPUE for the period April 1996 through March 2007 (fishing years running Apr-Mar). The beginning date of this analysis corresponds to the start of the At-Sea Observer Program (ASOP), and ignores the prior catch history that relied on fisher logs and sales slips. Catch rate data prior to 1996 are not comparable over time, owing largely to the significant and varying degrees of mis-reporting. Furthermore, trip limits varied over time; thus the direction of the biases would vary from one year to the next, or over groups of years. The inability of the catch reporting system to adequately quantify discards and the resulting difficulty to manage quotas was the primary reason that DFO imposed 100% observer coverage on the trawl fishery in 1996. Consequently, attempts to reconstruct past catch and effort histories on yellowmouth rockfish would probably not render reliable or useful commercial CPUE analyses.

A summary of the yellowmouth rockfish CPUE trend for the BC coast (Figure 40) shows an annual decline of 2.5% per year. This decline in commercial CPUE may or may not be related to abundance. During the period Feb 1996 to Mar 1997, the fishery experienced a trimester adjustment phase where vessels chose two out of three trimesters to maximize catch within the bounds of quotas and catch limits. This adjustment period was used to rationalize initial individual vessel quotas (IVQs) by species and area. Thereafter, IVQs have been transferable using a market-based trading system.

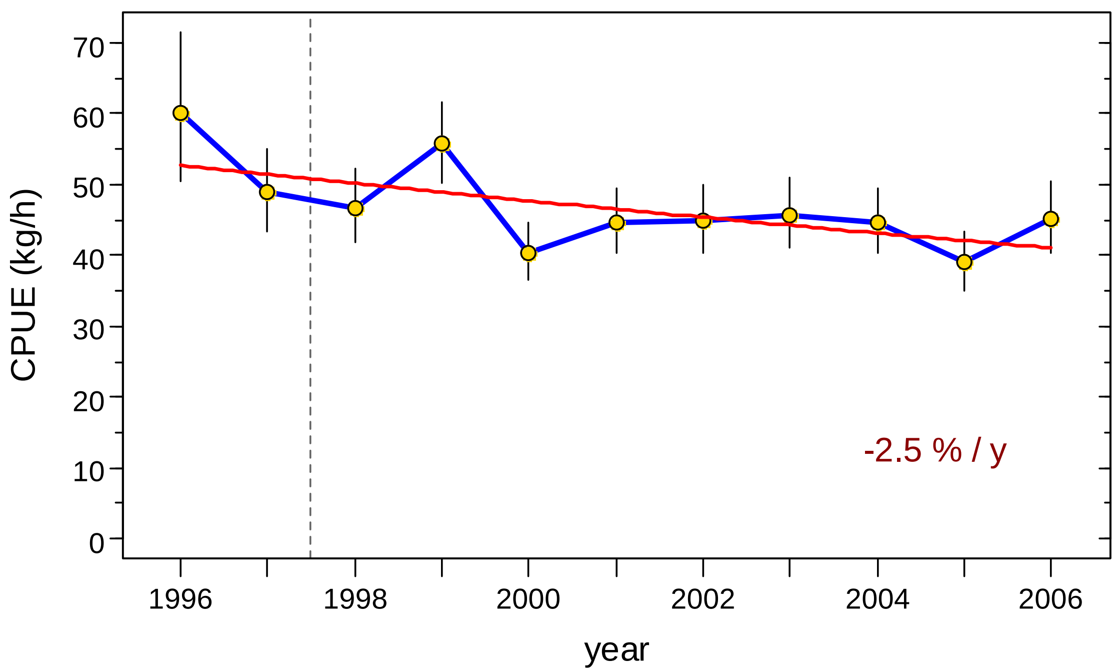

Figure 40. Annual index trend in yellowmouth rockfish commercial trawl CPUE data (1996-2006) using a GLM analysis with five factors: year, month, depth, latitude, and vessel (see Appendix C for details). The error bars show 95% confidence intervals. The vertical dashed line indicates period of adjustment (see text).

As yellowmouth rockfish abundance varies, fishers in an IVQ fishery are likely to alternate between targeting and avoiding this species depending on changes in local abundance and other factors, such as market requirements or quota availability. However, given large-scale changes in abundance, the CPUE signal should reflect a population change, particularly if the stock is declining (target catches will not be achieved). Therefore, the analyses presented in Appendix C are presented as a check for evidence of large-order depletion.

Caveat: Using commercial CPUE indices as relative abundance indices should be treated with caution as they are derived from fishery-dependent data and subject to among-year effects that may originate from sources other than fish abundance.

5. Summary

This document provides a summary of DFO's data and knowledge regarding yellowmouth rockfish *Sebastes reedi* in BC waters. The summary is geared specifically to provide information for a COSEWIC pre-screening document that can be cited by COSEWIC stock status reports. It is not intended to advise fisheries managers on harvest policy, but could serve as a base for future stock assessments.

This species appears to have a biomass mode in BC when compared to populations of *S. reedi* to the north (Alaska) and south (Washington/Oregon). Our synoptic surveys may provide indicators of population trends in future, but the available biomass indices are associated with high levels of relative error (30–50%), which will reduce the capacity of these surveys to track abundance changes for this species. These high levels of relative error are likely associated with the significant mid-water presence for this species that would not necessarily be captured by bottom trawl surveys (Brian Mose, Canadian Groundfish Research and Conservation Society, pers. comm.). We summarize the following conclusions from the information presented in this report.

- The distribution of this species is widespread through the Canadian west coast exclusive economic zone with highest densities off NW Vancouver Island, in Queen Charlotte Sound, and off the west coast of Queen Charlotte Islands.
- There is a reasonable amount of ageing information, principally beginning in 1990; however these samples primarily come from commercial trips and will contain biases associated with catchability. These data show that there was a year of high recruitment in 1982.
- The majority of biomass removals (landings + discards) of this species can be attributed to the offshore trawl fleet, with average annual catches of 1862 t/year over the period 1997-2007.
- None of the historical long-term survey time series appears to offer much guidance on the trend for this species. Either the survey design is not optimal (QCS and WCVI shrimp trawl surveys) or the variability of catch is too high (GB Reed, US NMFS surveys).
- The more recent QCS, WCVI, and WQCI synoptic surveys show some promise. In particular, the QCS survey CVs lie within the range (0.3-0.5). The WCVI survey appears to have similar precision.
- GLM analysis of commercial trawl fishing catch and effort data collected since 1996 shows an annual CPUE decline of 2.5%/year from 1996 to 2006. It is not known if this decline represents a decline in abundance or reflects fishing practices associated with targetting and avoiding multiple species within an IVQ system.

6. Acknowledgements

We thank our colleagues in groundfish for providing feedback on the analyses. We also recognize the dedication and effort of the many people who have worked on biological surveys and observer groundfish trawl trips over the years. We thank the Canadian Groundfish Research and Conservation Society for its ongoing support.

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Appendix A. Analytical Methods

Following are analytical methods typically used in DFO's COSEWIC pre-screening documents. Not all methods may be employed in this document. Ultimately, data availability for each species determines their usage.

A.1. Length-weight growth model

Length-weight relationships typically follow allometric growth (Quinn and Deriso 1999, p. 130), and models assume multiplicative error when the variability in growth increases as a function of length. Suppose that a set of data $\{L_i, W_i\}$ for fish $i = 1, \ldots, n$ exists. Then the typical growth model is

$$W_i = \alpha L_i^{\beta} e^{\sigma \varepsilon_i}, \tag{A.1.1}$$

where W_i = weight of fish i;
L_i = length of fish i;
α = scaling factor;
β = exponential factor;
σ = standard deviation of lognormal error;
ε_i = standard normal random variable i.

The logarithmic form

$$\ln W_i = \ln \alpha + \beta \ln L_i + \sigma \varepsilon_i \tag{A.1.2}$$

yields the negative log likelihood:

$$\ell(\alpha, \beta, \sigma) = n \log \sigma + \frac{1}{2\sigma^2} \sum_{i=1}^{n} \left(\ln W_i - \ln \alpha - \beta \ln L_i \right)^2 . \tag{A.1.3}$$

A.2. Length-age growth model

Growth rates of fish tend to slow down as they get older (Quinn and Deriso 1999, p. 135), hence a length-age growth model yields a concave curve approaching an upper asymptote. Typically, growth curves follow an S-shape with a leading convex curve; however, the region of growth at young ages usually lacks data so that models do not represent juvenile growth well. The von Bertalanffy equation (A.2.1) adequately describes the concave section of a growth curve. Suppose that a set of data $\{L_i, t_i\}$ for fish $i = 1, \ldots, n$ exists. Then the growth model with multiplicative error is

$$L_i = L_\infty \left[1 - e^{-K(t_i - t_0)} \right] e^{\sigma \varepsilon_i}, \tag{A.2.1}$$

where L_i = length of fish i;

t_i	=	age of the fish i;
L_∞	=	horizontal asymptote describing the theoretical maximum length;
K	=	parameter that governs the speed with which the curve reaches L_∞;
t_0	=	theoretical age when the fish is length 0;
σ	=	standard deviation of lognormal error;
ε_i	=	standard normal random variable i.

The logarithmic form is

$$\ln L_i = \ln L_\infty + \ln\left[1 - e^{-K(t_i - t_0)}\right] + \sigma\varepsilon_i\,, \tag{A.2.2}$$

and the negative log likelihood is

$$\ell\left(L_\infty, K, t_0, \sigma\right) = n\log\sigma + \frac{1}{2\sigma^2}\sum_{i=1}^{n}\left[\ln L_i - \ln L_\infty - \ln\left(1 - e^{-K(t_i - t_0)}\right)\right]^2 \,. \tag{A.2.3}$$

A.3. Generation Time

Generation time t_g, assumed to be the average age of adults (males and females) in the population, takes the form:

$$t_g = k + \frac{1}{e^M - 1}\,, \tag{A.3.1}$$

where	k	=	age at 50% maturity;
	M	=	instantaneous rate of natural mortality.

COSEWIC uses a rough approximation to generation time:

$$t_g = k + \frac{1}{M}\,, \tag{A.3.2}$$

which approaches (A.3.2) as $M \to 0$.

A.4. Catch-curve analysis

The catch-curve model used in this paper is that of Schnute and Haigh (2007). Essentially, the model has three age-dependent components – survival S_a, selectivity β_a, and recruitment R_a.

$$S_a = e^{-K(a-k)};\quad a = k,\ldots,B \tag{A.4.1}$$

$$\beta_a(\beta_k,\alpha)=\begin{cases} 1-(1-\beta_k)\left(\dfrac{b_0-a}{b_0-k}\right)^{\alpha}; & a=k,\ldots,b_0-1 \\ 1; & a=b_0,\ldots,B \end{cases} \quad \text{(A.4.2)}$$

$$R_a(\rho_1,\ldots,\rho_m,\tau)=1+\pm\sum_{h=1}^{m}\rho_h \exp\left[-\frac{1}{2}\left(\frac{a-b_h}{\tau}\right)^2\right];\ \ a=k,\ldots,B \quad \text{(A.4.3)}$$

$$p_a(\Theta)=\frac{S_a\beta_a R_a}{\sum_{a=k}^{B} S_a\beta_a R_a};\ \ a=k,\ldots,B \quad \text{(A.4.4)}$$

$$p_A(\Theta)=\sum_{a=A}^{B} p_a(\Theta) \quad \text{(A.4.5)}$$

Calculations depend on a fixed design vector

$$\Phi=(k,A,B;b_0;m,b_1,\ldots,b_m), \quad \text{(A.4.6)}$$

where k = youngest age of interest;
A = maximum age considered (plus class);
B = maximum age used internally by the model $(B \gg A)$;
b_0 = age of full selectivity with $\beta_a = 1$ for ages $a \ge b_0$;
m = number of recruitment anomalies;
b_h = age with anomalous recruitment $(h=1,\ldots,m)$; $k \le b_1 < \ldots < b_m < A$.

The predicted proportions $p_a(\Theta)$ vary with the parameter vector

$$\Theta=(Z;\alpha,\beta_k;\tau,\rho_1,\ldots\rho_m), \quad \text{(A.4.7)}$$

where Z = total mortality $Z=F+M$;
α = selectivity parameter $(\alpha>0)$;
β_k = selectivity on youngest age $a=k$ $(0<\beta_k<1)$;
τ = standard deviation for recruitment anomalies;
ρ_h = recruitment anomaly parameter at age b_h $(h=1,\ldots,m)$.

A.5. Swept-area biomass calculations

Catch and effort data for strata i in year y yield catch per unit effort (CPUE) values U_{yi}. Given a set of data $\{C_{yij},E_{yij}\}$ for tows $j=1,\ldots,n_{yi}$,

$$U_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{E_{yij}}, \tag{A.5.1}$$

where C_{yij} = catch (kg) in tow j, stratum i, year y;
E_{yij} = effort (h) in tow j, stratum i, year y;
n_{yi} = number of tows in stratum i, year y.

CPUE values U_{yi} convert to CPUE densities δ_{yi} (kg/km^2) using:

$$\delta_{yi} = \frac{1}{vw} U_{yi}, \tag{A.5.2}$$

where v = average vessel speed (km/h);
w = average net width (m).

Alternatively, if vessel information exists for every tow, CPUE density can be expressed

$$\delta_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{D_{yij} w_{yij}}, \tag{A.5.3}$$

where C_{yij} = catch weight (kg) for tow j, stratum i, year y;
D_{yij} = distance travelled (km) for tow j, stratum i, year y;
w_{yij} = net opening (km) for tow j, stratum i, year y;
n_{yi} = number of tows in stratum i, year y.

The annual biomass estimate is then the sum of the product of CPUE densities and bottom areas across m strata:

$$B_y = \sum_{i=1}^{m} \delta_{yi} A_i = \sum_{i=1}^{m} B_{yi}, \tag{A.5.4}$$

where δ_{yi} = mean CPUE density (kg/km^2) for stratum i, year y;
A_i = area (km^2) of stratum i;
B_{yi} = biomass (kg) for stratum i, year y;
m = number of strata.

The variance of the survey biomass estimate V_y (kg^2) follows:

$$V_y = \sum_{i=1}^{m} \frac{\sigma_{yi}^2 A_i^2}{n_{yi}} = \sum_{i=1}^{m} V_{yi}, \tag{A.5.5}$$

where σ_{yi}^2 = variance of CPUE density (kg^2/km^4) for stratum i, year y;
V_{yi} = variance of the biomass estimate (kg^2) for stratum i, year y.

The CV of the annual biomass estimates is

$$CV_y = \frac{\sqrt{V_y}}{B_y}. \quad \text{(A.5.6)}$$

A.6. Binomial-gamma population simulation

Schnute and Haigh (2003) describe a simulation model based on the compound binomial-gamma distribution. The analysis uses swept-area biomass density measurements from stratified tows. The basic idea is that every species in every survey stratum can have its own population distribution, described simply by three parameters (p, μ, ρ). Given these parameters, one can simulate a sampled population from the binomial-gamma distribution. This exercise yields the following estimates from strata $h = 1, \ldots, m$:

$$\mathrm{E}\left[\hat{B}_h\right] = (1 - p_h)\,\mu_h A_h, \quad \text{(A.6.1)}$$

$$\mathrm{V}\left[\hat{B}_h\right] = \frac{1}{n_h}\left(\rho_h^2 + p_h\right)(1 - p_h)\,\mu_h^2 A_h^2, \quad \text{(A.6.2)}$$

$$\mathrm{CV}\left[\hat{B}_h\right] = \sqrt{\frac{\rho_h^2 + p_h}{n_h(1 - p_h)}}. \quad \text{(A.6.3)}$$

where p_h = proportion of zero-catch tows in stratum h;
μ_h = mean biomass density $\left(\mathrm{t/km^2}\right)$ of non-zero tows in stratum h;
ρ_h = coefficient of variation of μ_h;
A_h = area (km^2) of stratum h;
n_h = number of tows in stratum h.

A.7. General linear models (GLM) for CPUE data

Quinn and Deriso (1999, p. 19) describe a general linear model based on the lognormal distribution:

$$U_{ijk} = U_0 \prod_i \prod_j P_{ij}^{X_{ij}} e^{\varepsilon_{ijk}}, \quad \text{(A.7.1)}$$

where U_{ijk} = the observed CPUE for tow k at the j^{th} level of factor i;
U_0 = the reference CPUE;
P_{ij} = coefficient for factor i at level j;

X_{ij} = 1 when the j^{th} level of the factor i contains data, and 0 when it does not;

ε_{ijk} = random deviate for observation k with mean=0 and standard deviation σ.

Taking the logarithm of (A.7.1) yields an additive linear regression model with p factors and $n_{i=1,\dots,p}$ levels:

$$\ln U_{ijk} = \ln U_0 + \sum_{i=1}^{p}\sum_{j=1}^{n_i-1} X_{ij}\ln P_{ij} + \varepsilon_{ijk} \quad \text{or} \quad Y_{ijk} = \beta_0 + \sum_{i=1}^{p}\sum_{j=1}^{n_i-1}\beta_{ij}X_{ij} + \varepsilon_{ijk}. \qquad \text{(A.7.2)}$$

where Y_{ijk} = $\ln U_{ijk}$;

β_0 = the model intercept $\ln U_0$;

β_{ij} = the logged coefficient P_{ij} of factor i at level j.

As the model described by (A.7.1) and (A.7.2) is over-parameterised, constraints must be imposed to allow estimation of model parameters. A common solution sets one coefficient for each factor to zero, usually the first, where the remaining $n_i - 1$ coefficients of each factor i represent incremental effects relative to the reference level.

The estimated factor coefficients are not unique: coefficients obtained by fixing a factor level will differ with the choice of reference level. However, the relative differences among the estimated coefficients will not be affected by the choice of constraint. Following the suggestion of Francis (1999), coefficients for factor i were transformed to "canonical" coefficients over all levels j calculated relative to their geometric mean $\bar{\beta} = \sqrt[n]{\prod_{j=1}^{n}\beta_j}$ (including the level where $\beta_j = 0$), so that

$$\beta'_j = \frac{\beta_j}{\bar{\beta}}. \qquad \text{(A.7.3)}$$

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

$$b'_j = \mathrm{e}^{\left(\beta_j - \bar{\beta}\right)}. \qquad \text{(A.7.4)}$$

The use of the canonical form allows the computation of standard errors for every coefficient, including the fixed coefficient (Francis 1999). 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.

A range of factors P_{ij} are available in the data which may be used to account for variability in the observed CPUE. These include factors such as the date of capture (usually year and month), the capturing vessel, and the depth and location of capture. The year of capture is usually given special significance in these analyses: variations between years in this factor are interpreted as relative changes in the annual abundance of the fish species which is the subject of the analysis. The resulting series of 'year' or 'fishing year' canonical coefficients is termed the "Standardised" annual CPUE index Y'_j in this report.

A selection procedure (Vignaux 1993, Vignaux 1994, Francis 2001) was applied to determine the relative importance of these factors in the model. The procedure involves a forward stepwise fitting algorithm which generates regression models iteratively, starting with the simplest model (one dependent and one independent variable) and building in complexity subject to a stopping rule designed to include only the most important factors.

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

- Calculate the regression with each predictive factor (variable) against the natural log of CPUE (kg/h).
- Generate the Akaike Information Criterion (AIC) (Akaike 1974) for each regression based on the number of model degrees of freedom. Select the predictor variable that has the lowest AIC. The AIC is used for model selection to account for variables which may have equivalent explanatory power in terms of residual deviance but require fewer degrees of freedom for the model (Francis 2001).
- 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 (as measured by R^2) for the final iteration is less than 0.01. The selection of 0.01 as the threshold is arbitrary but adding factors which explain small amounts of the total variance has little effect on the year coefficients and other coefficients of interest.

Other annual indices can be generated from the catch and effort data used for the linear modelling described above. The simplest estimate of mean annual CPUE is given by:

$$^{+}U_j = \sum_{k=1}^{M_j} C_{jk} \bigg/ \sum_{k=1}^{M_j} E_{jk} \qquad \text{(A.7.5)}$$

where C_{jk} denotes that catch and E_{jk} denotes the effort for each record k in year j. The series of annual estimates is termed the "Arithmetic" CPUE index in this report.

Another annual index is specified by

$$^{*}U_j = \exp\left[\frac{1}{M_j}\sum_{k=1}^{M_j} \ln\frac{C_{jk}}{E_{jk}}\right] \qquad \text{(A.7.6)}$$

where $^{*}U_j$ is the annual geometric mean of the CPUE observations. The resulting annual index is termed the "Unstandardised" CPUE index in this report. Annual estimates obtained using (A.7.6) are equivalent to the results obtained from a linear model where year is the only predictive factor.

Like the scaling described for the standardised index, the series specified by (A.7.5) and (A.7.6) can be scaled relative to their geometric means. This is done to provide comparability with the standardised indices. Given n years in each series, the geometric means of the arithmetic and unstandardised series are given by $\overline{{}^{+}U} = \sqrt[n]{\prod_{j=1}^{n} {}^{+}U_j}$ and $\overline{{}^{*}U} = \sqrt[n]{\prod_{j=1}^{n} {}^{*}U_j}$, respectively. Thus, each series can be scaled to the corresponding geometric mean as:

$$ {}^{+}U'_j = {}^{+}U_j \big/ \overline{{}^{+}U} \tag{A.7.7} $$

and

$$ {}^{*}U'_j = {}^{*}U_j \big/ \overline{{}^{*}U} \,. \tag{A.7.8} $$

The procedures described by (A.7.1), (A.7.2), and (A.7.6) are necessarily confined to the positive catch observations in the data set as ln(0) is undefined. Observations with zero catch can be handled in a number of ways:

- Zero-catch records are frequently dropped from further consideration, usually because they are not accurately recorded. This is particularly true for catch records which are maintained by fishermen who frequently discount small amounts of catch as being inconsequential.
- A small increment can be added to the zero catch records so that ln(0) can be calculated. This is not a satisfactory solution because model parameter estimates are sensitive to the value selected for the increment.
- A linear regression model based on a binomial distribution and using the presence/absence of the fish species as the dependent variable can be estimated using the same data set. Explanatory factors are estimated in the model in the manner described in (A.7.1) and (A.7.2). Such a model will provide another series of standardised coefficients of relative annual changes that is analogous to the series estimated from the lognormal regression. This approach has been followed for the data set based on observer records (`PacHarvest` after 1996) where it is felt that zero catch records are likely to have greater reliability (see below).
- A combined model which integrates the two series of relative annual changes estimated by the lognormal and binomial models can be estimated using the Δ-distribution which allows zero and positive observations (Vignaux 1994). This approach was not followed in this analysis.

A.8. Standardized Models in R

In R, we implement the additive lognormal model

$$ \log y_{ijklmn} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \lambda_m + \sigma\varepsilon_{ijklmn} \tag{A.8.1} $$

with the command `lm` that creates a list object of class “lm”. This command supports a variety of constraints on the factor coefficients, including

$$\sum_i \alpha_i = \sum_j \beta_j = \sum_k \gamma_k = \sum_l \delta_l = \sum_m \lambda_m = 0\,. \tag{A.8.2}$$

The estimated quantities are called “contrasts”. To implement (A.8.2), we use the “sum” contrast. For a factor with *n* levels and coefficients $a_i\,(i = 1,\ldots n)$, this treats the first $n-1$ coefficients as unknowns, and computes the final coefficient as

$$a_n = -\sum_{i=1}^{n-1} a_i \tag{A.8.3}$$

From (A.8.3), it follows that

$$\mathrm{V}[a_n] = \sum_{i=1}^{n-1}\sum_{j=1}^{n-1} \mathrm{Cov}[a_i, a_j] = \sum_{i=1}^{n-1}\sum_{j=1}^{n-1} \sqrt{\mathrm{V}[a_i]\mathrm{V}[a_j]}\,\mathrm{Cor}[a_i, a_j]\,, \tag{A.8.4}$$

where V[], Cov[], and Cor[] denote the variance, covariance, and correlation, respectively, and the square root of the variance corresponds to the standard deviation. A more detailed treatment of standardized CPUE analysis appears in Schnute et al. (2004).

From the output object produced by `lm`, a user can extract parameter coefficients, their standard deviations, and correlation matrix. The following simple code also uses (A.8.3)-(A.8.4) to estimate the final coefficient and its standard error to create a complete coefficient vector `fcoef` and a corresponding standard error vector `fserr`. The code assumes an initial data frame, herein called `dat`, with response variable “lnU” and factors “year”, “month”, “depth”, “latitude”, and “vessel”. The code below produces a coefficient vector for “year” only.

```
# Set the contrast option to “sum”
# -------------------------------
csum   <- c("contr.sum", "contr.sum")
names(csum) <- c("factor", "ordered")
options(contrasts = csum)

# Convert independent fields in ‘dat’ to factors
# ----------------------------------------------
facs <- c(“year”,“month”,“depth”,“latitude”,“vessel”)
fdat <- dat
for (i in facs)  fdat[,i] <- as.factor(fdat[,i])

# Run the linear model to estimate log CPUE
# -----------------------------------------
lmres  <- lm(lnU ~ year + month + depth + latitude + vessel, data=fdat)

# Get parameter coefficients, their standard errors, and correlation matrix
# -------------------------------------------------------------------------
coeffs <- lmres$coefficients
lmsum  <- summary(lmres,correlation=TRUE)
stderr <- lmsum$coeff[,"Std. Error"]
correl <- lmsum$correlation

# Extract coefficients and calculate missing last coefficient
# -----------------------------------------------------------
fact   <- “year”
z      <- is.element(substring(names(coeffs),1,nchar(fact)),fact)
```

```
rawcf  <- coeffs[z]
fcont  <- contr.sum(length(rawcf)+1)
fcoef  <- fcont %*% rawcf
fcoef  <- as.vector(fcoef)

# Extract standard errors and calculate missing last standard error
# -----------------------------------------------------------------
fserr  <- stderr[z]
fcorr  <- correl[z,z]
errZ   <- sqrt(fserr %*% fcorr %*% fserr)
fserr  <- c(fserr,errZ)
```

The estimated coefficients can be converted to annual indices and effects on CPUE through back-transformation from $\log_2$ scale to normal scale. The annual indices become $2^{\alpha+\mu}$ and factor effects are simply 2^{β}, etc. A linear regression through the log-transformed annual indices yields the annual logarithmic growth rate *b*, the annual relative growth rate $r = 2^b - 1$, and the accumulated relative change $R_I = 2^{b(I-1)} - 1$ during a time series of *I* observations.

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Appendix B. Spatial analysis

This appendix presents spatial CPUE patterns by fishing year (April to March). The grid cells displayed are 0.1° longitude by 0.075° latitude. The area covered by each grid cell will vary with latitude; however, one of our cells in mid Queen Charlotte Sound (with origin 130°W, 51.5°N) would cover approximately 59 km², which equals 7.7 km squared.

Sinclair (2007) explores the biases of perceived impacted area depending on the grid cell size chosen by an analyst. Table B1 shows the difference in estimates of occupied area when using a DFO grid *vs*. a COSEWIC grid. The reader should keep in mind that a trawl tow can traverse tens of kilometres but is only represented by one or two points (usually start position of the tow, sometimes end position).

Table B1. Estimates of occupied area (km²) for yellowmouth rockfish using two different grids – DFO geographic grid cell = 0.1° longitude × 0.075° latitude ≈ 7.7 km²; COSEWIC UTM grid cell = 2 km × 2 km = 4 km².

Fishing Year	DFO	COSEWIC
1996	16,673	3,796
1997	15,226	3,712
1998	15,863	3,696
1999	16,043	3,784
2000	16,195	3,836
2001	14,405	3,436
2002	15,029	3,440
2003	12,452	2,788
2004	13,611	3,112
2005	13,390	2,960
2006	12,675	3,088
1996-2006	33,092	11,332

In the figures that follow, any grid cell with positive mean CPUE resulting from the activity of fewer than 3 vessels has been excluded due to privacy issues. The occupied areas in Table B1 are computed without this privacy restriction (i.e., all cells with positive mean CPUE are used for the calculation).

References

Sinclair, A. 2007. Trends in groundfish bottom trawl fishing activity in BC. Canadian Science Advisory Secretariat, Research Document 2007/006. 22 + iv pp.

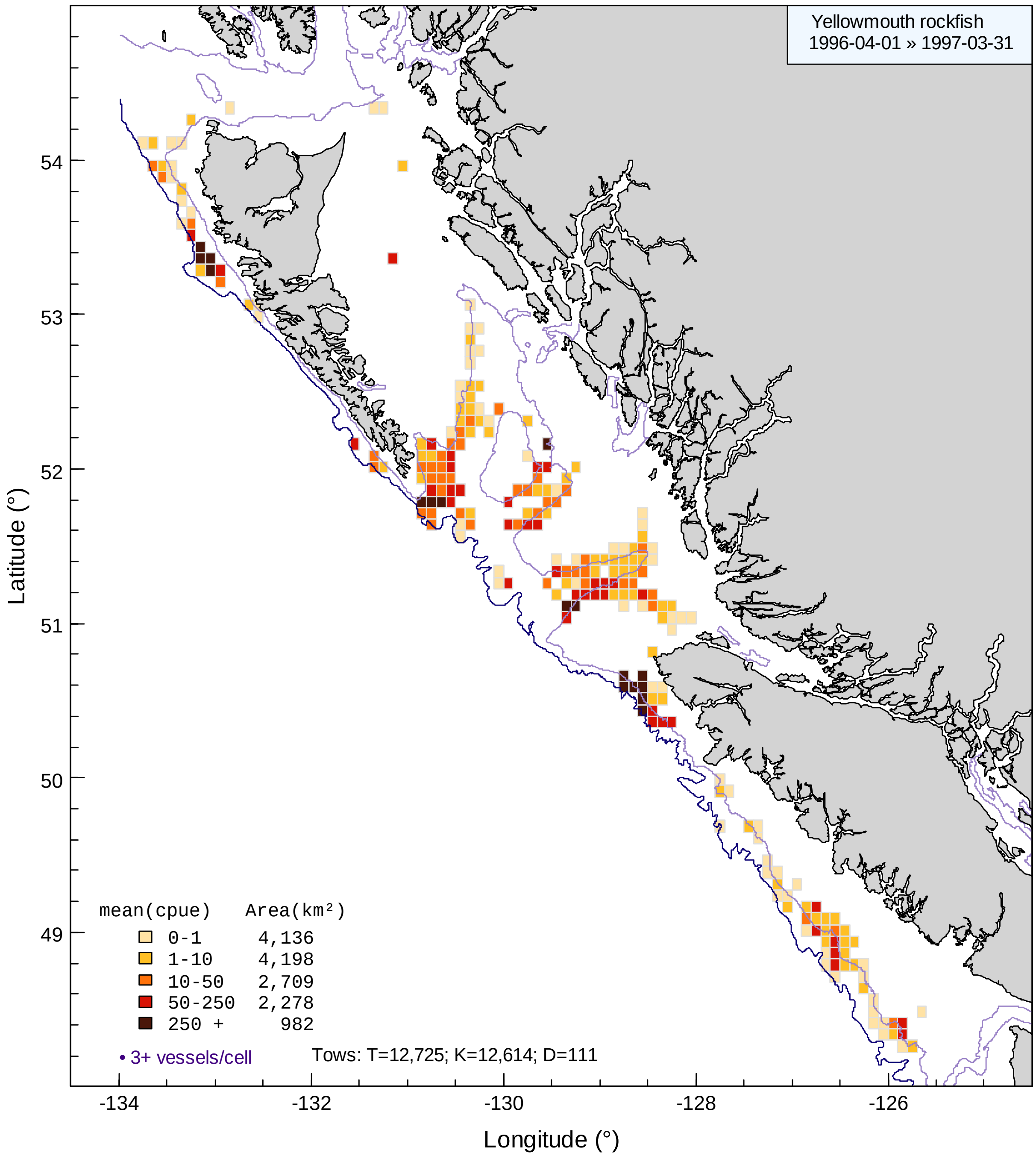

Figure B1. Mean CPUE (kg/h) of yellowmouth rockfish caught by the BC trawl fishery from 4/1/96 to 3/31/97. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

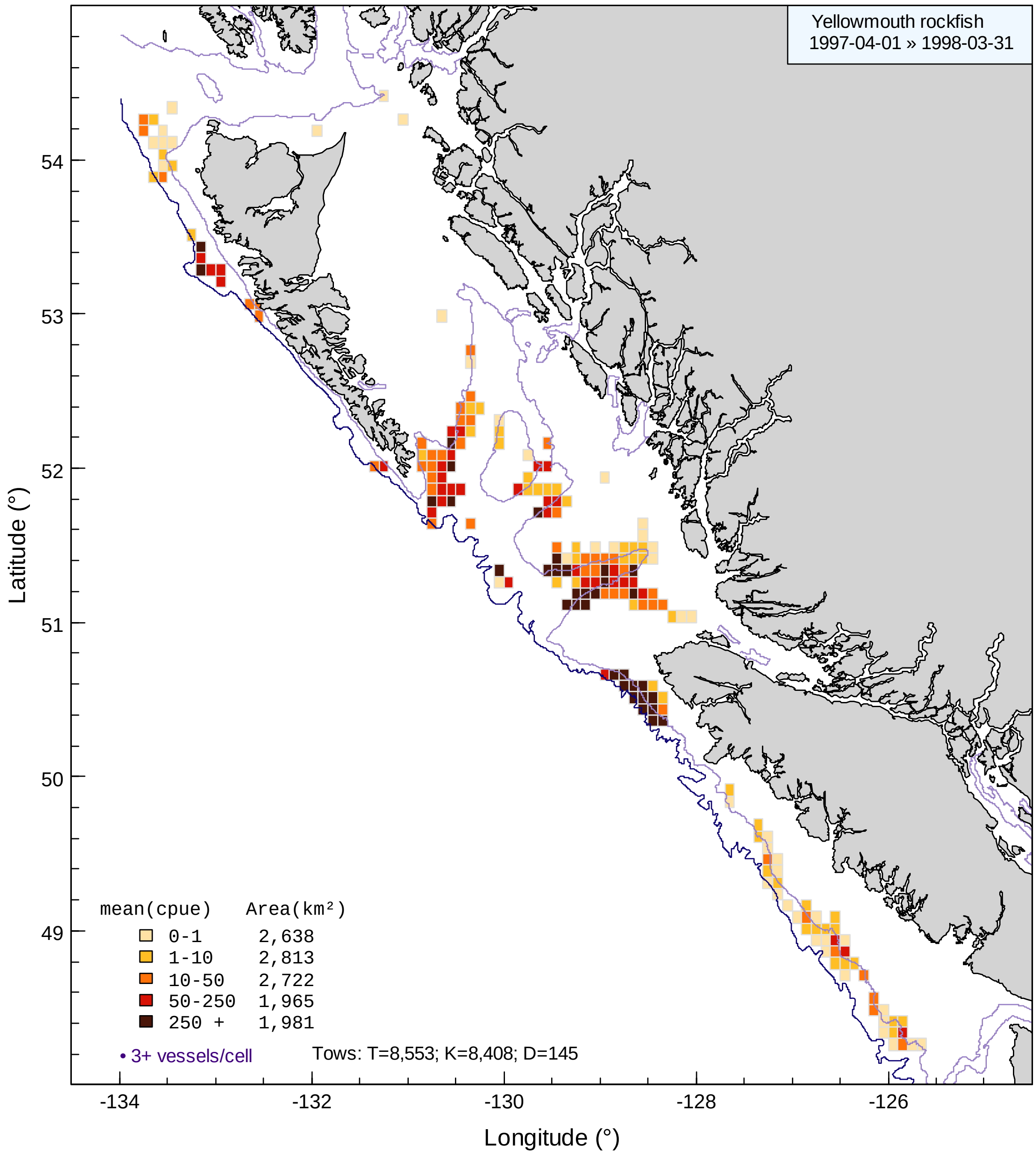

Figure B2. Mean CPUE (kg/h) of yellowmouth rockfish caught by the BC trawl fishery from 4/1/97 to 3/31/98. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

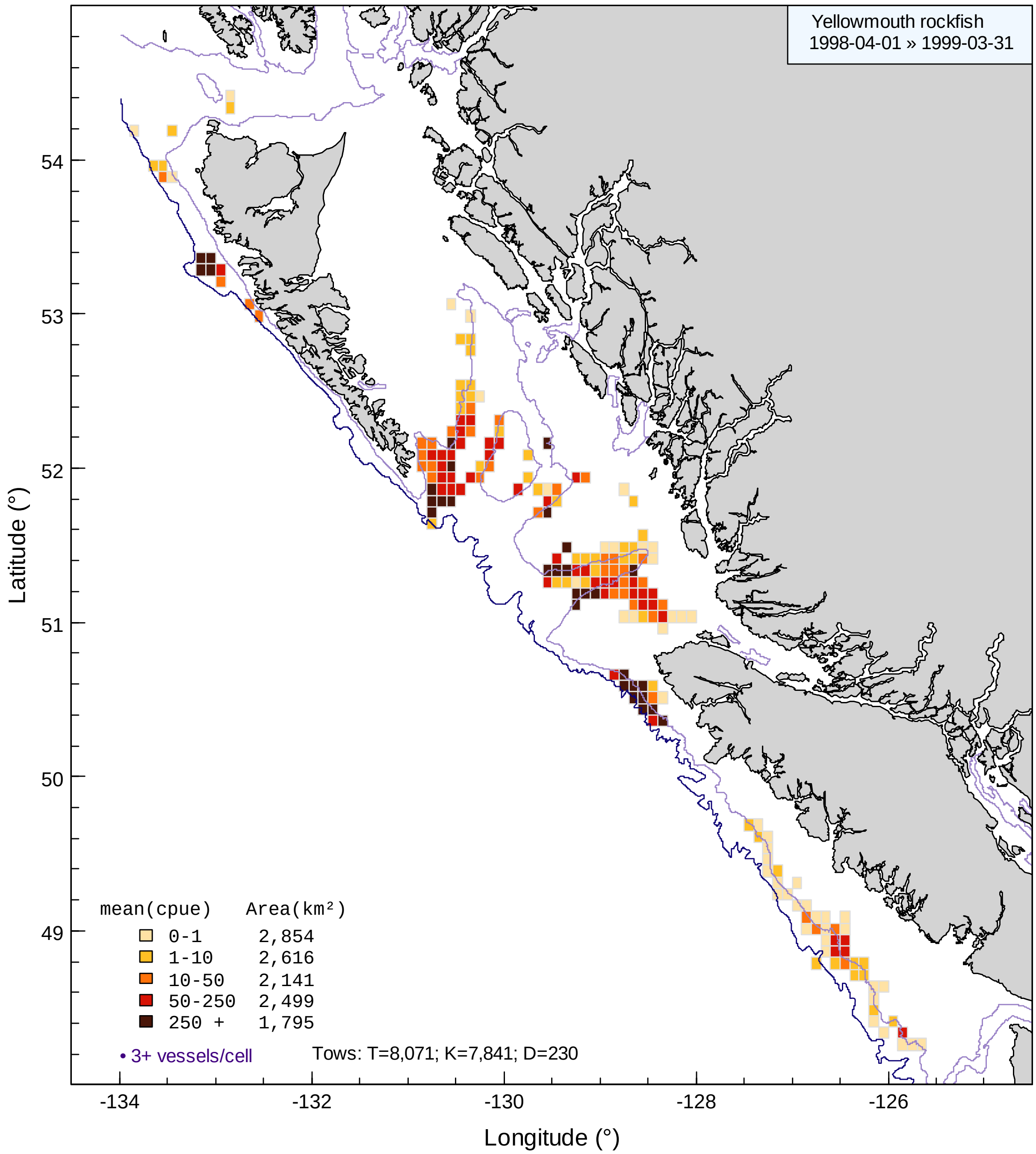

Figure B3. Mean CPUE (kg/h) of yellowmouth rockfish caught by the BC trawl fishery from 4/1/98 to 3/31/99. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

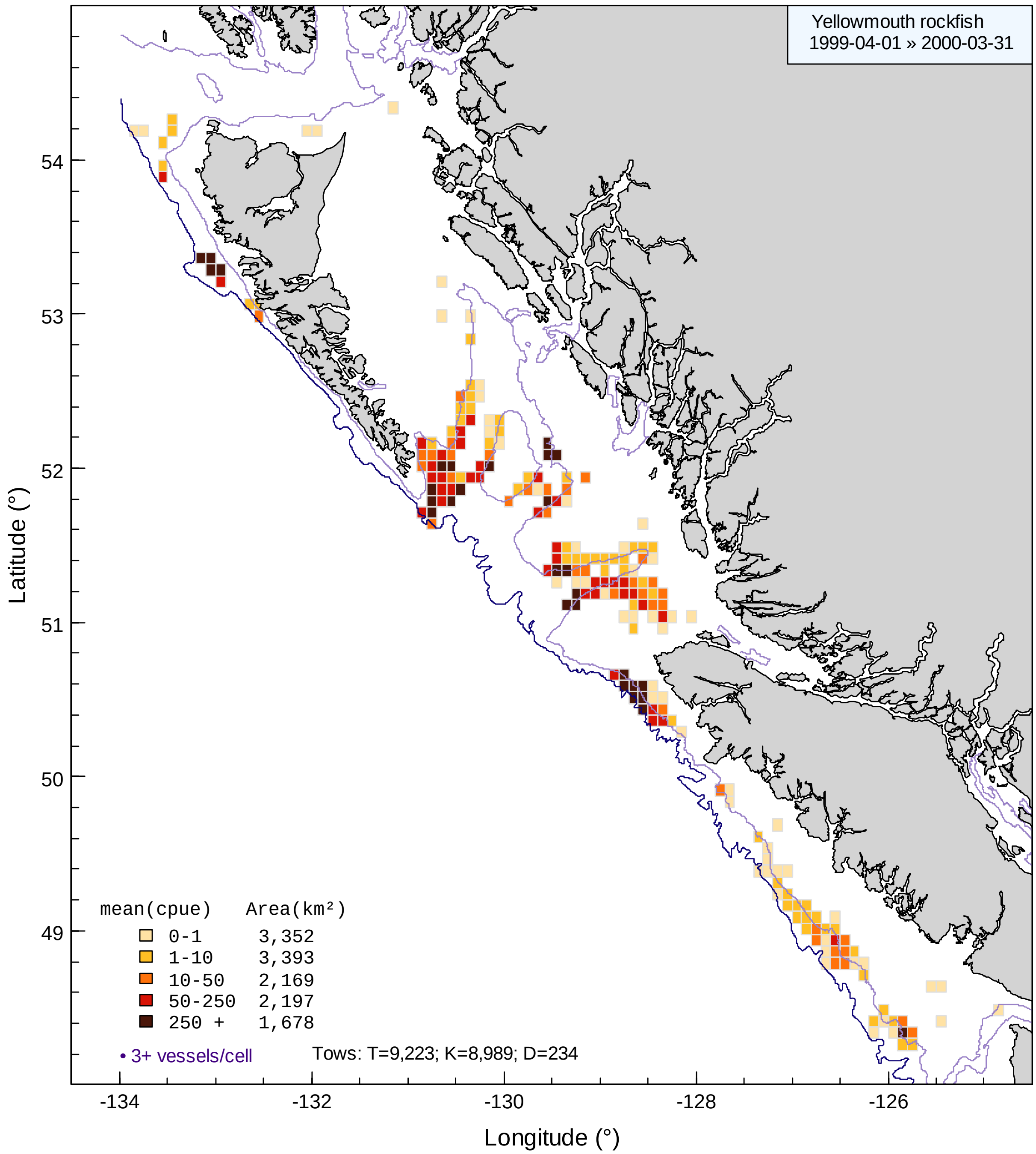

Figure B4. Mean CPUE (kg/h) of yellowmouth rockfish caught by the BC trawl fishery from 4/1/99 to 3/31/00. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

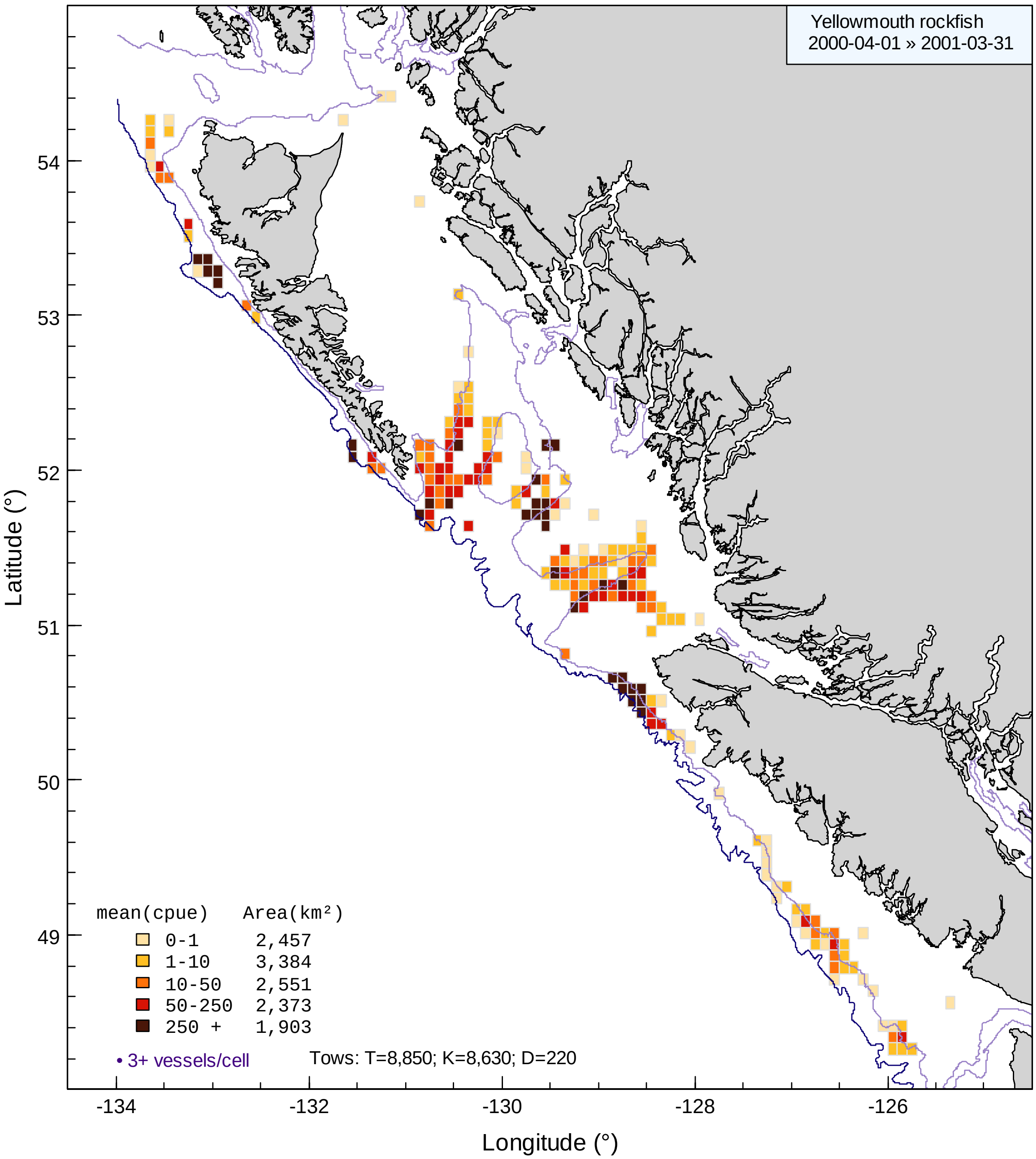

Figure B5. Mean CPUE (kg/h) of yellowmouth rockfish caught by the BC trawl fishery from 4/1/00 to 3/31/01. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

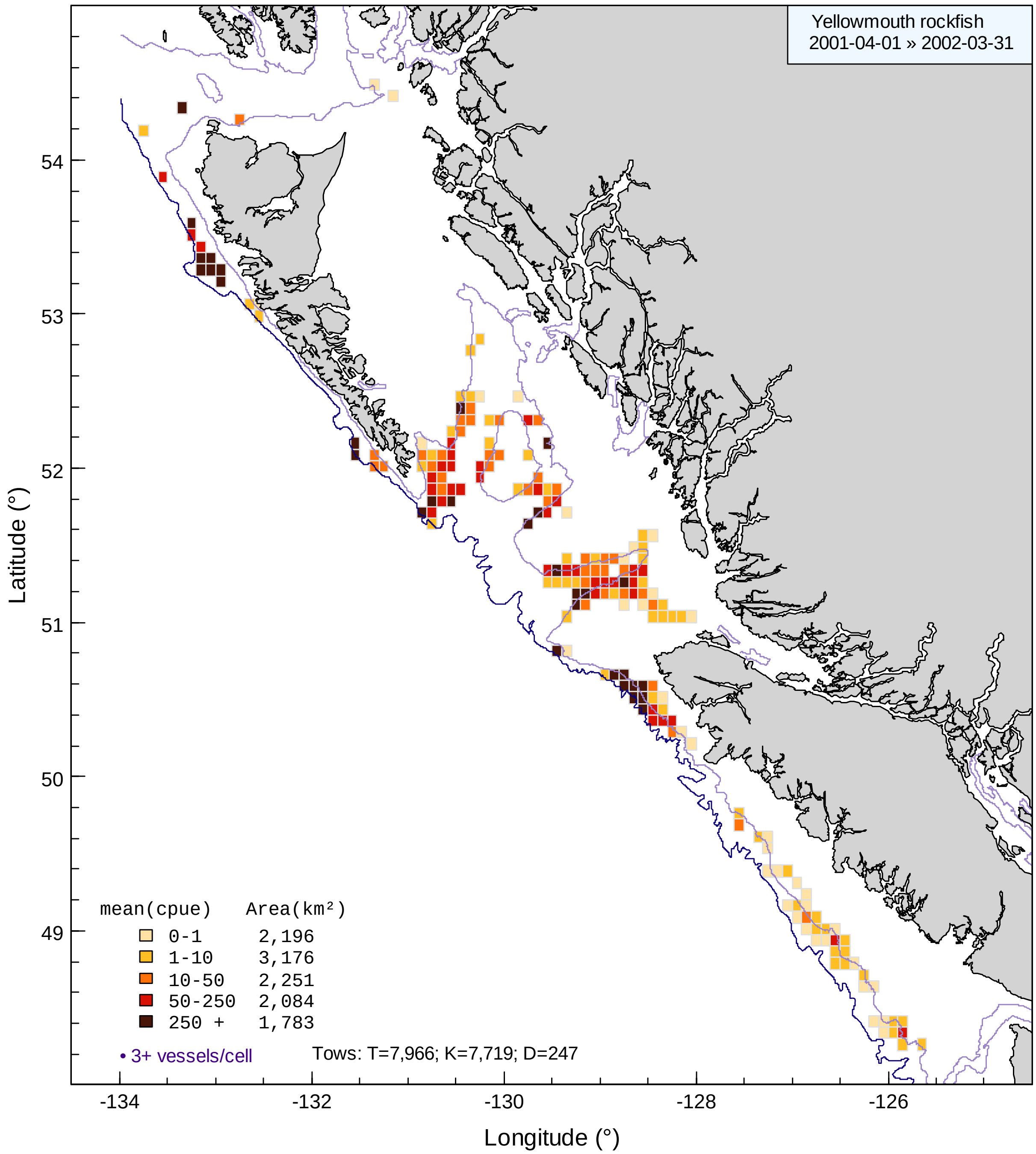

Figure B6. Mean CPUE (kg/h) of yellowmouth rockfish caught by the BC trawl fishery from 4/1/01 to 3/31/02. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

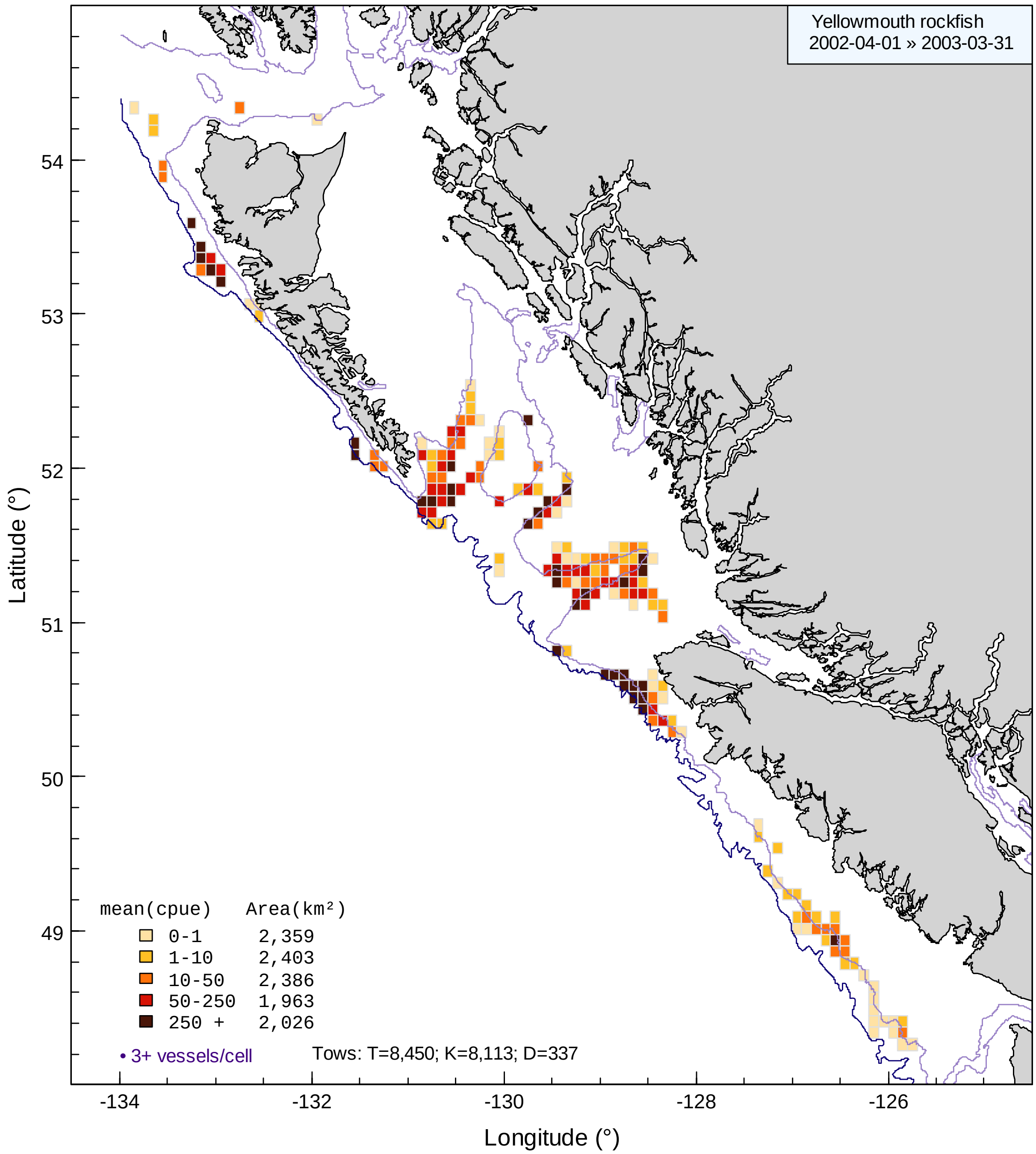

Figure B7. Mean CPUE (kg/h) of yellowmouth rockfish caught by the BC trawl fishery from 4/1/02 to 3/31/03. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

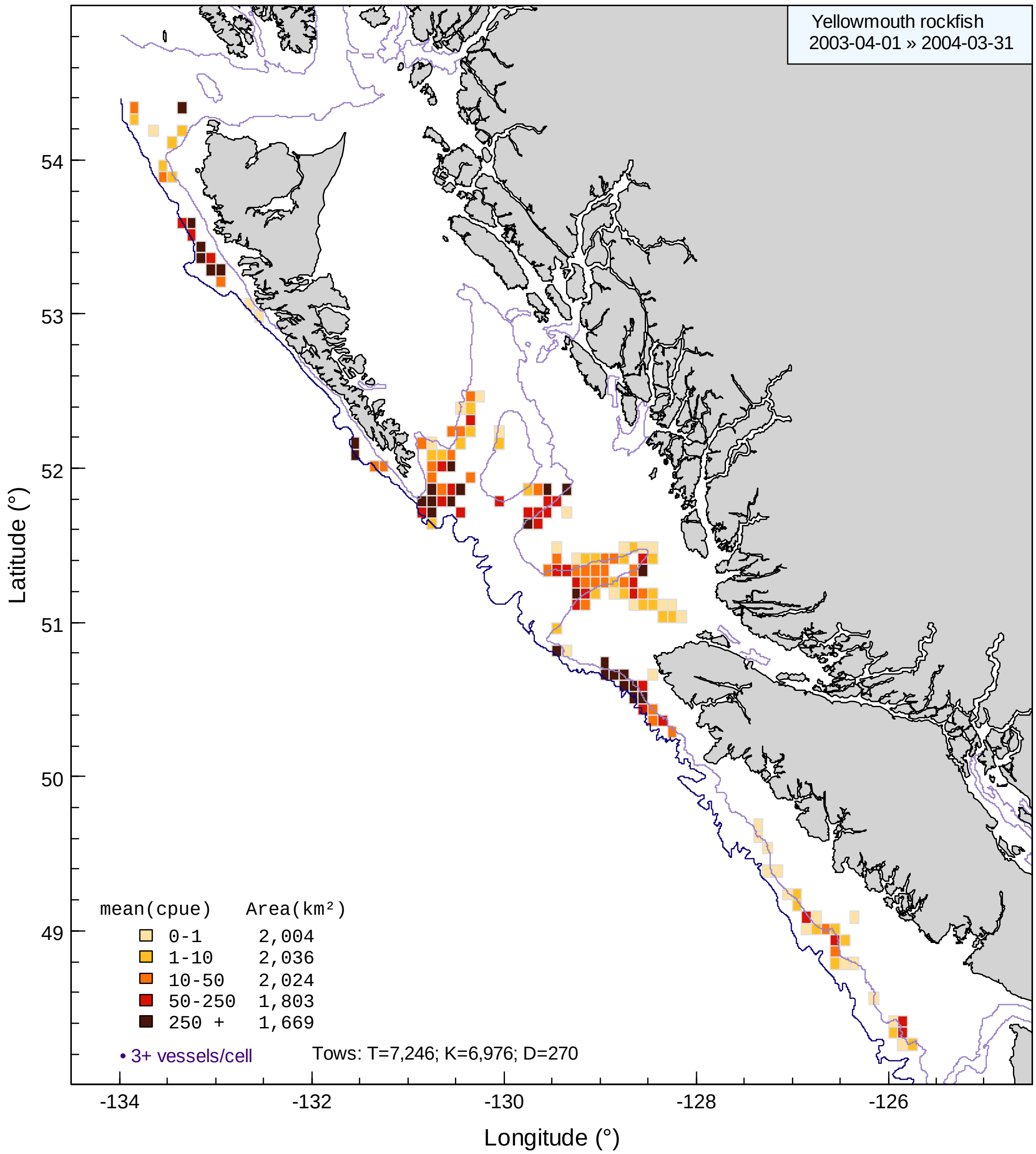

Figure B8. Mean CPUE (kg/h) of yellowmouth rockfish caught by the BC trawl fishery from 4/1/03 to 3/31/04. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

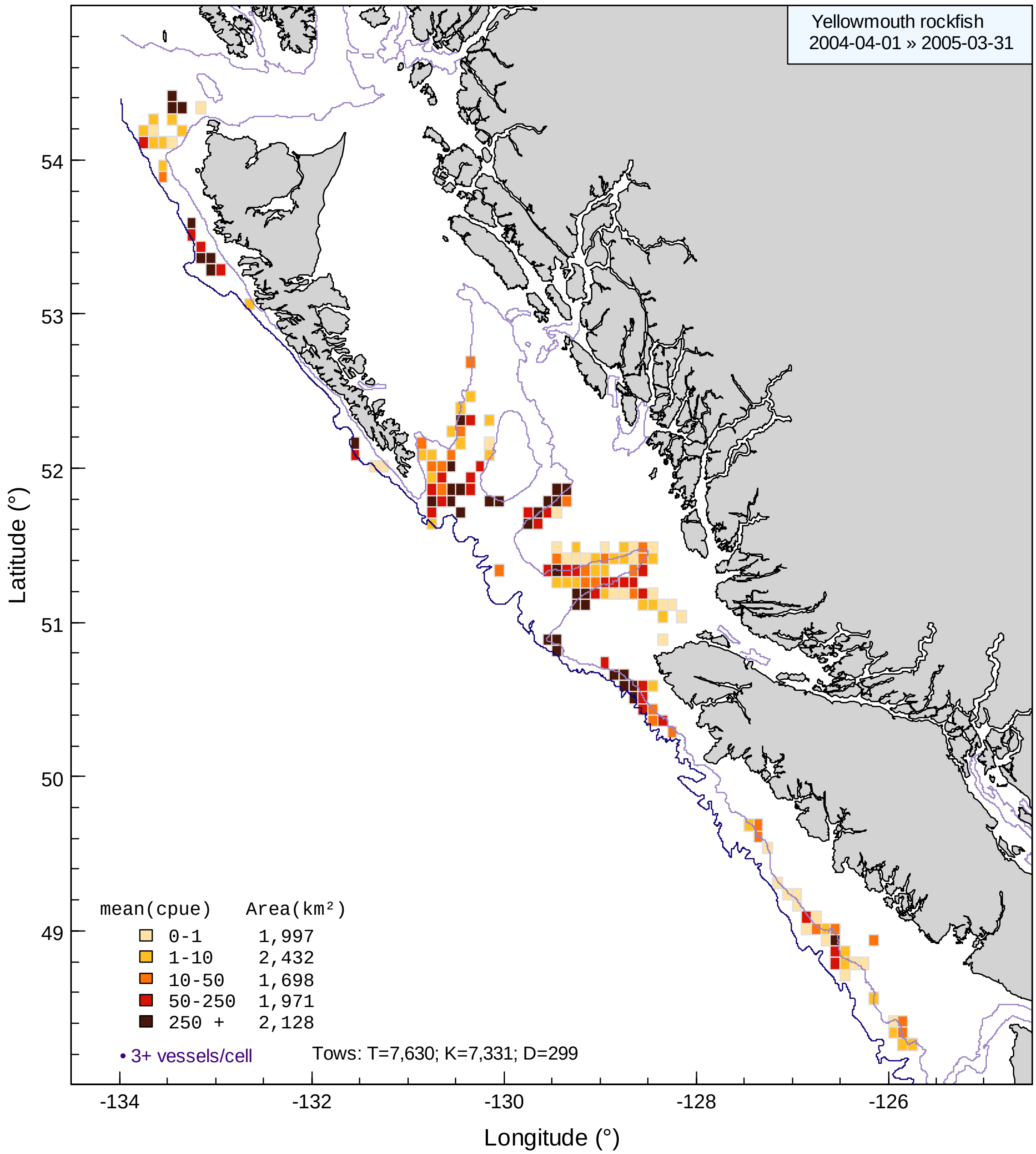

Figure B9. Mean CPUE (kg/h) of yellowmouth rockfish caught by the BC trawl fishery from 4/1/04 to 3/31/05. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

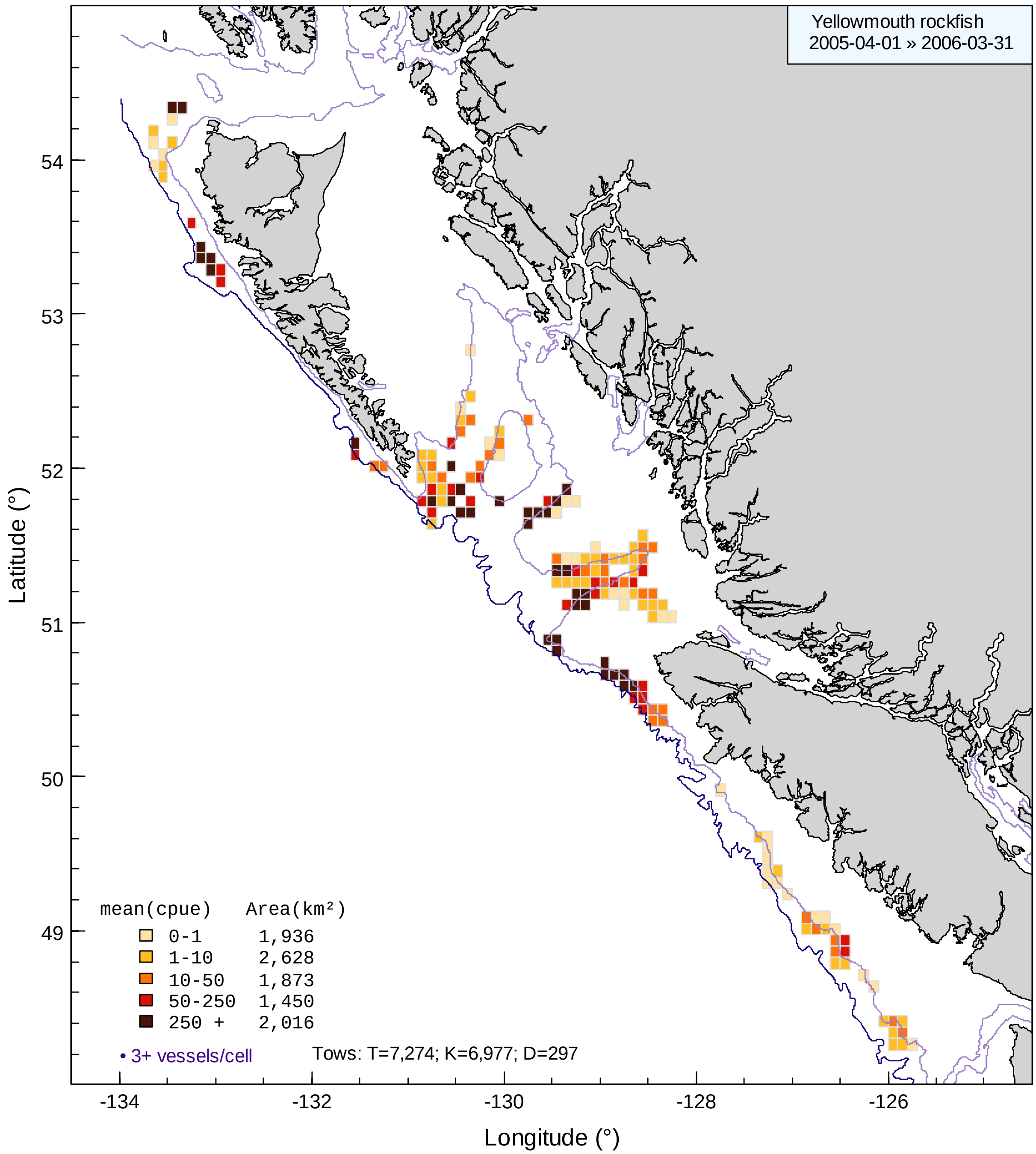

Figure B10. Mean CPUE (kg/h) of yellowmouth rockfish caught by the BC trawl fishery from 4/1/05 to 3/31/06. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

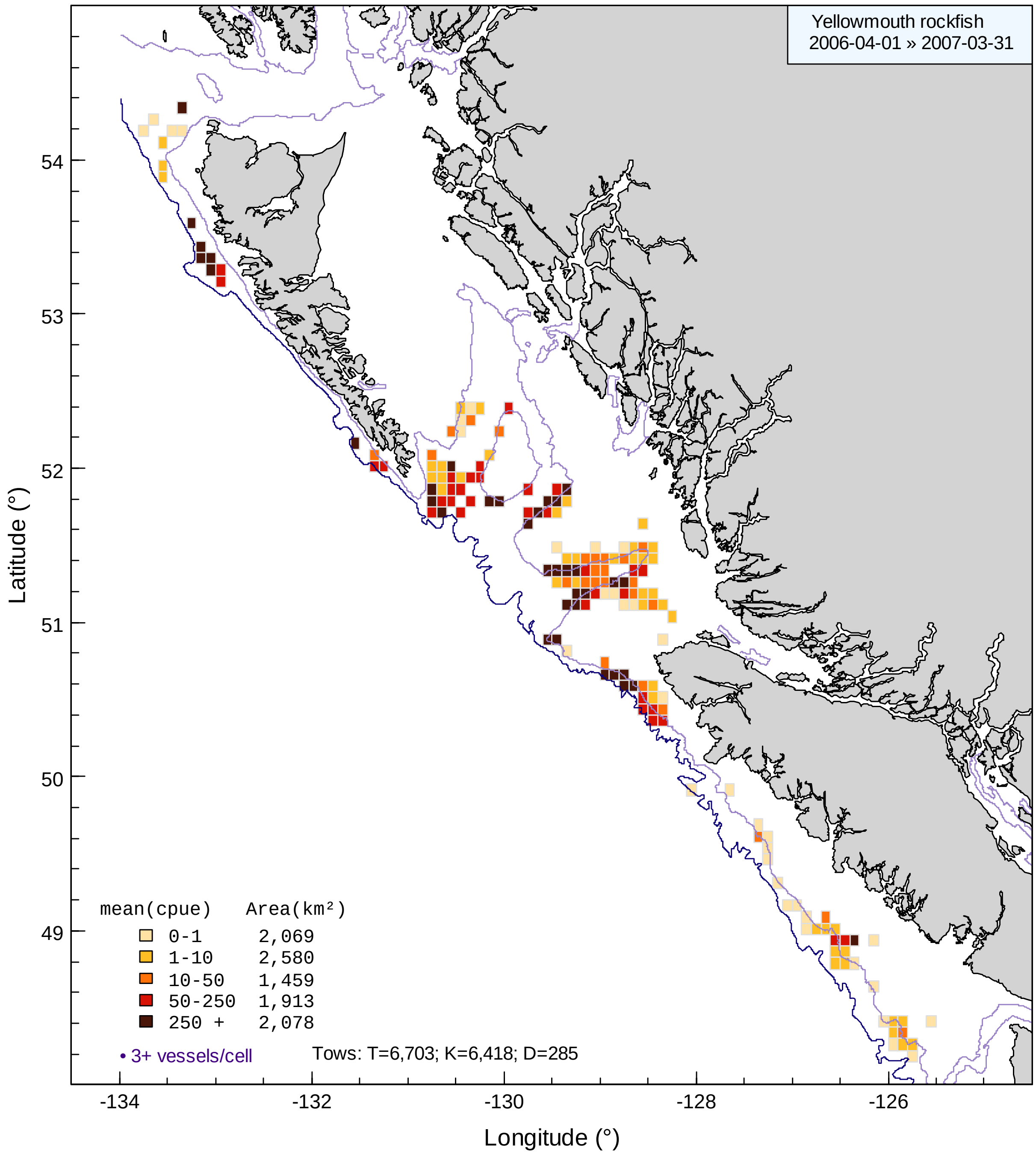

Figure B11. Mean CPUE (kg/h) of yellowmouth rockfish caught by the BC trawl fishery from 4/1/06 to 3/31/07. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

Appendix C. Standardized commercial CPUE analysis

C.1. Preliminary analyses for the GLM

The analysis in this section follows the methods outlined in Appendix A.7. Data were selected from the DFO `PacHarvest` database using the following criteria:

Tow start date between 1 April 1996 and 31 March 2007
Bottom trawl type
Fished in a valid outside DFO Major region (3C, 3D, 5A, 5B, 5C, 5D, or 5E)
Fishing success code <=1 (code 0= unknown; code 1= useable)
Catch of at least one fish or invertebrate species (no water hauls)
Valid depth field
Valid latitude and longitude coordinates
Valid estimate of time towed that was greater than 0 hours and less than 24 hours

The following explanatory variables were offered to the model, based on the tow-by-tow information in each record for the data remaining after the selection procedure:

Fishing year (1 April–31 March)
Month
DFO locality (Rutherford 1999)
Latitude separated in 0.1° bands beginning with 48°N
Vessel
Depth aggregated into 25 m depth bands

Locality, latitude and depth band categories with relatively few observations were pooled into a single ("Plus") category to reduce the number of parameters estimated. Vessels were never pooled. Instead the vessel selection criteria were tightened to reduce the number of categories, if necessary.

A spatial analysis of the distribution of yellowmouth catches was undertaken to determine if there were any clear area separations in the locations of capture for this species and in the distribution of catch rates (Figure 18). The CPUE density distribution (Section 3.2) shows that the distribution of yellowmouth catch is reasonably continuous over the BC coast, but the high CPUE values are concentrated off the northwest end of Vancouver Island and in the gullies of Queen Charlotte Sound (Goose Island and Moresby Gullies). There are also some "hot spots" in Dixon Entrance and on the west coasts of Moresby and Graham Islands. The yellowmouth tows from 1993–94 onwards were divided, on the basis of the starting coordinates for each tow, into six subareas (Table C1). Almost all of the yellowmouth catch from 1996–97 to 2006–07 were successfully assigned to these revised areas, with the exception of catch from the Strait of Georgia (DFO Major Area 4B) and upper Hecate Strait (DFO Major Area 5D) which were deliberately omitted from these redefined areas (Table C2). Landings and consequently the number of positive tows are concentrated in the Queen Charlotte Sound and the NW end of Vancouver Island, with lesser amounts of catch coming from the Queen Charlotte Islands, Dixon Entrance and west coast of Vancouver Island south of the Brooks Peninsula (Table C3). CPUE for this species is high (averaging near to 500 kg/h towed for the Subareas with good catch) and is highest off the west coast of Moresby Island, an area of relatively low total catch.

Table C1. Subarea definitions for yellowmouth rockfish.

Subarea #	**Definition**	**Code (**Table C3)	**Colour (**Figure C1)
1	SW coast Vancouver Island to about 50.0° N;	SW WCVI	black
2	NW coast Vancouver (north of Banks Peninsula)	NW WCVI	green
3	Goose Island gully (lower Queen Charlotte Sound)	GIG	red
4	Moresby and Mitchell gullies and lower Hecate Strait;	MG&HS	blue
5	West coast of Moresby Island	SW QCI	purple
6	Dixon Entrance and the west coast of Graham Island.	DE	orange

Table C2. Distribution of unallocated yellowmouth trawl total catch (landings + discards) over the period 1996/97 to 2006/07 by DFO major reporting area. Only the catches in 4B and 5D were associated with usable coordinates but have not been included in subsequent analyses. The remaining tows could not be allocated to an area.

	DFO Major Area									
	Unknown	**4B**	**3C**	**3D**	**5A**	**5B**	**5C**	**5D**	**5E**	**Total**
Catch (t)	189.2	0.2	1.2	12.1	17.2	10.2	0.9	0.2	42.7	273.9

Table C3. Number of bottom trawl tows with positive catch of yellowmouth rockfish by 1 April–31 March fishing year and defined subarea (Table C1), as well as the mean unstandardised CPUE (kg/h) for each subarea and fishing year.

	Fishing Year											
	96/97	**97/98**	**98/99**	**99/00**	**00/01**	**01/02**	**02/03**	**03/04**	**04/05**	**05/06**	**06/07**	**Total**
	Number positive tows											
SW WCVI	311	274	239	335	240	204	234	133	244	154	135	2503
NW WCVI	435	540	345	440	453	536	537	593	366	316	189	4750
GIG	537	1119	1082	802	679	716	600	477	605	613	748	7978
MG & HS	1120	820	1036	1269	1129	958	1003	1046	1204	978	913	11476
SW QCI	25	8	3	10	276	217	179	83	60	49	47	957
DE	204	153	216	326	310	293	336	317	310	211	177	2853
Total	2632	2914	2921	3182	3087	2924	2889	2649	2789	2321	2209	30517
	Total catch (landings + discards) (t)											
SW WCVI	100	31	57	71	32	45	51	24	65	19	20	515
NW WCVI	516	663	391	416	335	531	472	479	237	193	110	4343
GIG	230	911	644	508	271	352	309	316	535	566	575	5218
MG & HS	433	238	479	636	588	445	532	587	741	823	614	6115
SW QCI	4	2	2	4	205	166	150	122	38	17	36	746
DE	107	40	167	219	233	239	206	215	140	135	135	1838
Total	1391	1885	1741	1855	1663	1778	1721	1743	1756	1754	1490	18775
	Average CPUE (kg/h)											
SW WCVI	265	93	181	181	99	189	280	187	251	113	143	185
NW WCVI	806	896	781	815	742	1264	1049	774	633	559	551	844
GIG	317	590	340	471	282	455	409	623	762	727	536	494
MG & HS	293	245	388	471	409	455	503	610	605	595	410	458
SW QCI	267	365	387	192	840	970	1334	3090	1240	558	1398	1168
DE	415	271	448	487	590	681	517	500	419	486	553	500

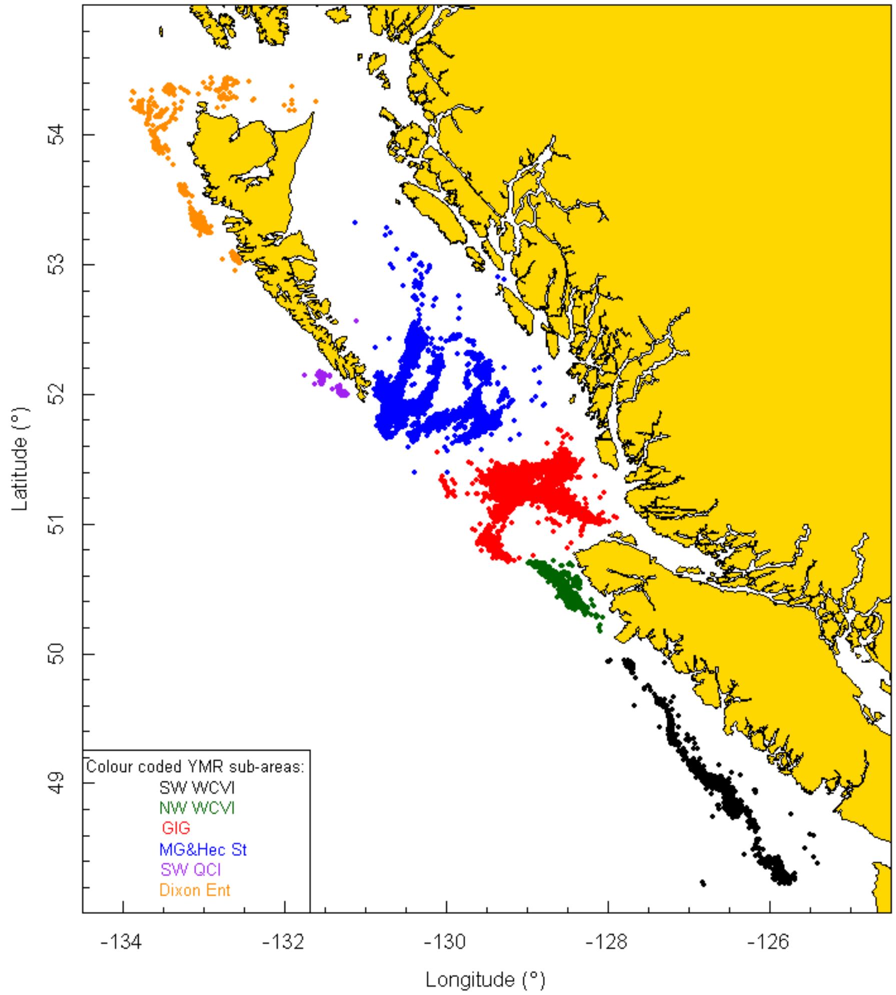

Figure C1. Distribution of positive tows for yellowmouth rockfish for the period 1996–97 to 2006–07, showing the start position of each tow, the subarea and the colour (Table C1) the tow has been assigned.

Preliminary GLM analyses based on the Subareas defined in Table C1 showed both similarities and differences between Subareas. In particular, the analysis of the data from the top end of Vancouver Island (NW WCVI; Table C1) indicated that the most productive latitude band for this analysis was the most northerly one (50.6°–50.7° N) while the analysis immediately to the north (GIG; Table C1) indicated that its most southerly latitude band (50.8°–50.9° N) was also its most productive (Figure C2). This provides a rationale for combining these two areas. Furthermore, the year indices from these two areas show a strong resemblance (Figure C3, left panel). A similar comparison between Subarea 4 (MG&HS; Table C1) with Subarea 6 (DE; Table C1) showed that the confidence bounds on the year indices overlapped in 10 of the 11 years between these two Subareas (Figure C3, right panel). Comparisons of the lognormal annual indices for all four of the major Subareas indicated that, while there was considerable overlap in the indices from these areas, the southerly index series differed from the northerly indices in the initial two or three years and these areas also diverged in recent years (Figure C4). It is quite possible that these differences are related to fishing effects rather than the relative abundance of yellowmouth. On the basis of these analyses, one could separate the data in mid-Queen Charlotte Sound and conduct two analyses: one which combined the data from Subareas

1, 2 and 3 (SW WCVI, NW WCVI and GIG or South BC; Table C1) and the other which combined the data from Subareas 4, 5 and 6 (MG&HS; SW QCI, and DE or North BC; Table C1). Subareas 1 and 5 have been included in these amalgamations to ensure that the entire coast was covered and considering that they contain too little data to justify independent analyses (Table C3).

The data were also examined for the feasibility of using the midwater trawl information, given that yellowmouth rockfish are known to be frequently off the bottom (Brian Mose, Canadian Groundfish Research and Conservation Society, *pers. comm.*). However, the overall percentage of tows which caught yellowmouth rockfish using midwater trawl is low (6%; Table C4) and even lower in the North BC Subareas (4 to 6; Table C4). It was decided to conduct the analyses using only bottom trawl data, thus discarding the midwater trawl data, given the small amount of available data, the uneven distribution across Subareas and that midwater trawl data are likely to provide an even less reliable index of abundance than from bottom trawl.

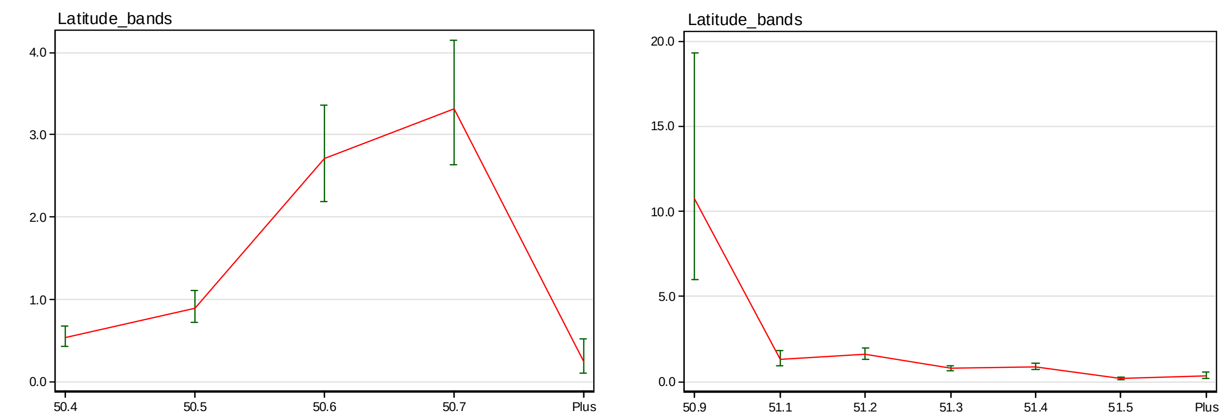

Figure C2. Relative CPUE coefficients for the 0.1° latitude band explanatory variable based on a log-normal GLM (A.7.2): [left panel]: GLM on Subarea 2 (NW WCVI); [right panel]: GLM on Subarea 3 (GIG).

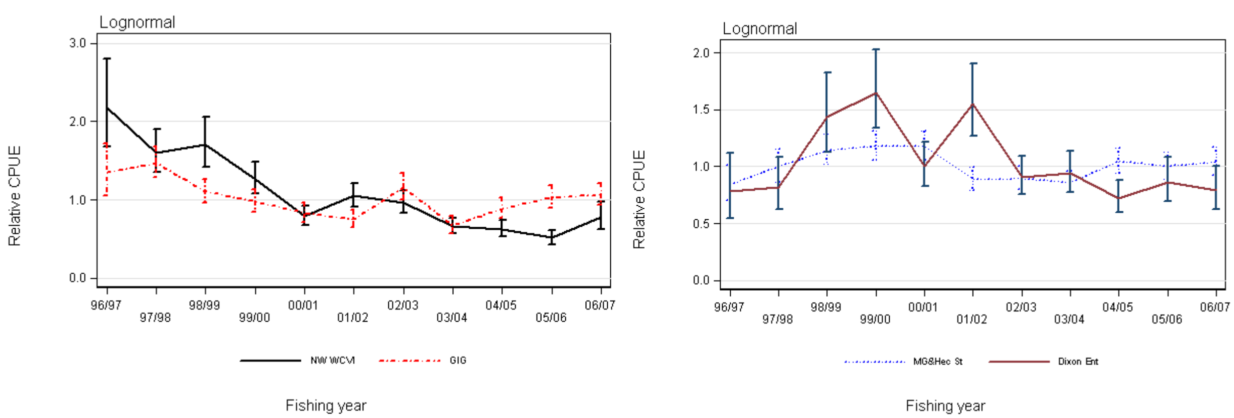

Figure C3. Comparison of the relative indices for the year index based on a log-normal GLM (A.7.2): [left panel]: Subareas 2 and 3 (NW WCVI and GIG); [right panel]: Subareas 4 and 6 (MG&HS and DE).

Table C4. Relative distribution (as a percentage) of tows from 1 April 1996 which caught yellowmouth rockfish in the PacHarvest database by method of capture (bottom or midwater trawl).

Subarea (Table C1)		**% Bottom trawl**	**% Midwater trawl**
1	SW WCVI	96	4
2	NW WCVI	92	8
3	GIG	86	14
4	MG&HS	98	2
5	SW QCI	98	2
6	DE	99	1
	Total	94	6

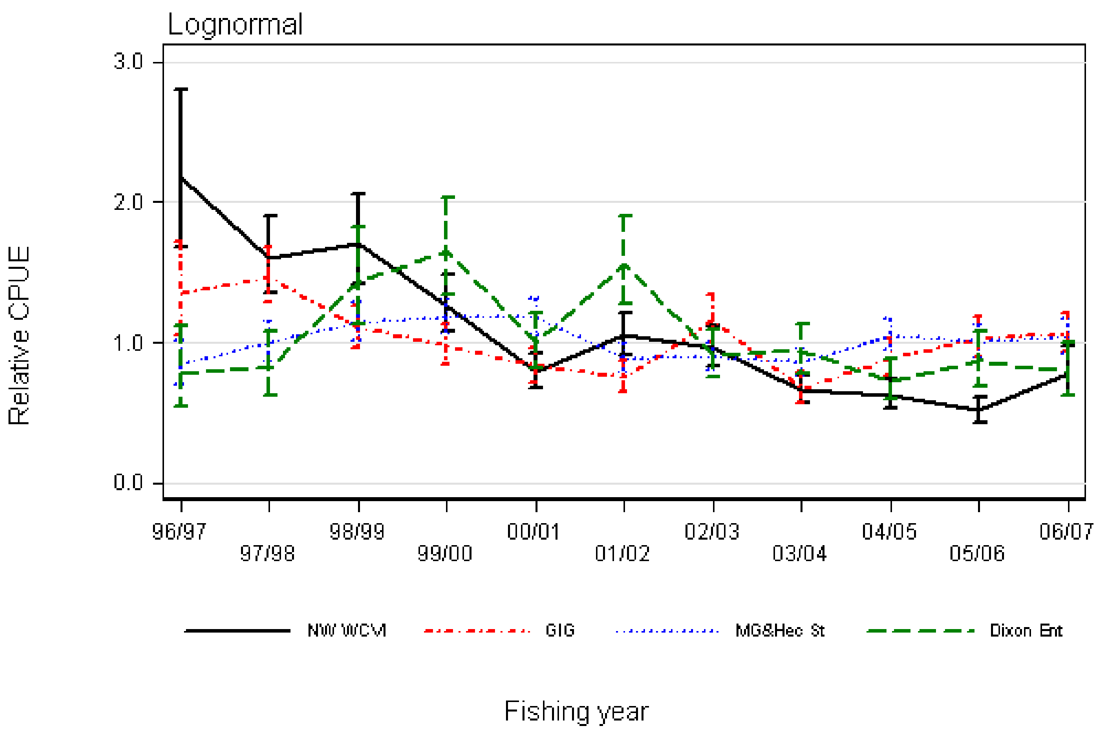

Figure C4. Comparison of the relative indices from the year index based on a log-normal GLM (A.7.2) for Subareas 2, 3, 4 and 6 (NW WCVI, GIG; MG&HS and DE).

C.2. Coastwide GLM analysis using five factors:

Based on the above exploratory analysis, and with the desire to amalgamate the presentation of a GLM analysis for the single designatable unit (spanning the BC coast), we use a standardized model (Appendix A.8) to simplify the results. We use only bottom tows in the analysis and remove all observations that did not catch yellowmouth rockfish. Some would argue that zero-tows provide information and we acknowledge this. However, the lognormal model necessitates that we provide positive values for the dependent observations, and the only way to do this is to transform the entire dataset with some arbitrary value. If we make this value too small, the original positive values can gain great leverage in the analysis. If we transform the data using a large value, we essentially discount the original CPUE observations. We choose to ignore the zero values here.

The additive lognormal model (Appendix A.8) takes the following factors as independent observations:

- fishing year (running from April in one year to March in the next);
- month (where Apr to Dec = 1:9 and Jan to Mar = 10:12);
- depth zone as 50-m intervals from 50 to 500 m;
- latitude bands corresponding to density clusters identified previously: west coast of Vancouver Island (WCVI) from 48°N to 50.2°N, northwest Vancouver Island (Scott) from 50.2°N to 51°N, Queen Charlotte Sound (QCS) = 51°N to 51.6°N, Moresby Gully and Hecate Strait (MG+HS) from 51.6°N to 52.8°N, and northwest Queen Charlotte Islands (Dixon) from 52.8°N to 54.8°N;
- vessels which accounted for ≥ 3% of the yellowmouth rockfish catch during the period April 1996 to March 2007.

The coefficients estimated (Table C5) can be converted to annual indices and effects on CPUE through back-transformation from $\log_2$ scale to normal scale (Appendix A.8). A linear regression through the log-transformed annual indices yields the annual logarithmic growth rate b and the annual relative growth rate $r = 2^b - 1$.

The model results show an annual 2.5% decline in the CPUE index coastwide (Figure C5A). There may be other factors influencing this trend that we have not taken into account. The month effect exhibits sinusoidal periodicity over the course of a fishing year, rising to a peak in August then declining to a trough in December (Figure C5B). The depth effect is predictably strong (as it is for most rockfish species) with positive effects on CPUE at depths between 150 and 300 m (Figure C5C). The latitude bands chosen *a priori* exhibit strong effects – positive at latitudes that include the Scott Islands and Dixon Entrance, negative off the west coast of Vancouver Island and in central Queen Charlotte Sound (Figure C5D). The vessel effect (Figure C5E) can greatly influence the annual CPUE trend depending on which vessels are included in the analysis. For instance, changing the requirement that vessels account for at least 3.5% of the yellowmouth catch reduces the number of vessels to seven and changes the index trend from declining to increasing.

References

Rutherford, K.L. 1999. A brief history of GFCATCH (1954-1995), the groundfish catch and effort database at the Pacific Biological Station. Canadian Technical Report of Fisheries and Aquatic Sciences 2299: 66 pp.

Table C5. Model coefficients (α, β, γ, δ, λ) and standard errors for five factors used in the GLM analysis of yellowmouth rockfish commercial trawl CPUE data (Apr 1996 to Mar 2007).

Year: annual CPUE indices (by fishing year); Month: month effect on CPUE; Depth: depth effect on CPUE where depth is partitioned into 50-m depth zones between 50 m and 500 m; Latitude: latitude effect on CPUE where WCVI = 48°N to 50.2°N, Scott = 50.2°N to 51°N, QCS = 51°N to 51.6°N, MG-HS =51.6°N to 52.8°N, and Dixon = 52.8°N to 54.8°N; Vessel: vessel effect on CPUE where vessels accounted for >= 3% of the yellowmouth catch over the period of the analysis; StdErr: standard error of the estimated coefficients. Model statistics: Residual standard error: 2.777 on 12,140 degrees of freedom; Multiple R-squared: 0.1987; Adjusted R-squared: 0.1957; F-statistic: 66.89 on 45 and 12,140 DF; p-value: < 2.2e-16.

Note: Index = 2^(Coeff + μ); Effect = 2^Coeff.

Year	α	**StdErr**	**Month**	β	**StdErr**	**Depth**	γ	**StdErr**	**Latitude**	δ	**StdErr**	**Vessel**	λ	**StdErr**
1996	0.367	0.128	Apr	0.124	0.075	100	-0.509	0.451	WCVI	-1.880	0.087	1	0.627	0.087
1997	0.070	0.089	May	0.096	0.073	150	-0.664	0.181	Scott	1.556	0.062	2	0.407	0.105
1998	0.007	0.081	Jun	0.289	0.080	200	1.537	0.109	QCS	-1.116	0.063	3	0.365	0.096
1999	0.259	0.075	Jul	0.642	0.082	250	1.680	0.102	MG-HS	0.434	0.057	4	0.313	0.091
2000	-0.206	0.075	Aug	0.781	0.090	300	1.183	0.106	Dixon	1.006	0.103	5	0.298	0.091
2001	-0.059	0.076	Sep	0.232	0.087	350	-0.098	0.125				6	0.218	0.099
2002	-0.052	0.078	Oct	-0.012	0.101	400	-1.075	0.174				7	0.214	0.087
2003	-0.026	0.080	Nov	-0.620	0.094	450	-0.881	0.289				8	0.035	0.144
2004	-0.061	0.076	Dec	-0.926	0.139	500	-1.174	0.482				9	-0.044	0.089
2005	-0.253	0.079	Jan	-0.601	0.096							10	-0.202	0.102
2006	-0.046	0.082	Feb	-0.090	0.082							11	-0.458	0.079
			Mar	0.085	0.086							12	-0.500	0.083
μ	5.540	0.096										13	-1.272	0.089

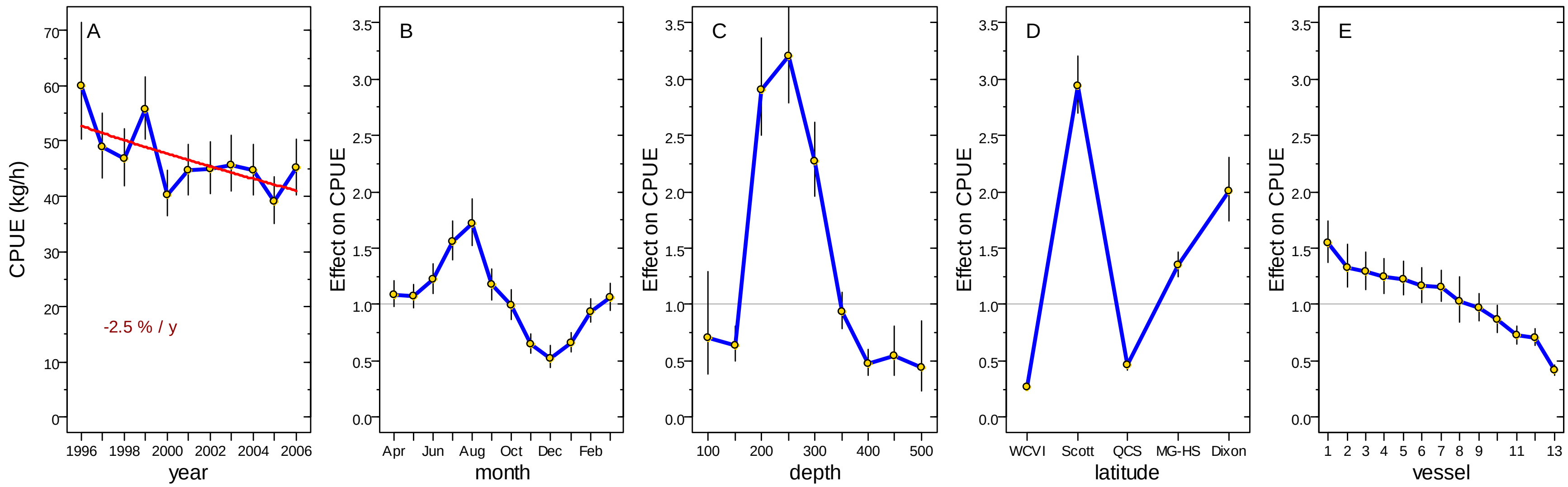

Figure C5. Annual index trend and factor coefficients for the GLM analysis of yellowmouth rockfish commercial trawl CPUE data (Apr 1996 to Mar 2007). (A) annual CPUE indices (by fishing year) with fitted curve indicating instantaneous decline; (B) month effect on CPUE; (C) depth effect on CPUE where depth is partitioned into 50-m depth zones between 50 m and 500 m; (D) latitude effect on CPUE where WCVI = 48°N to 50.2°N, Scott = 50.2°N to 51°N, QCS = 51°N to 51.6°N, MG-HS =51.6°N to 52.8°N, and Dixon = 52.8°N to 54.8°N; (E) vessel effect on CPUE where vessels accounted for >= 3% of the yellowmouth catch over the period of the analysis. The error bars show 95% confidence intervals.