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

Examen du sébaste tacheté Le *Sebastes crameri* le long de la côte du Pacifique du Canada : biologie, distribution et tendances relatives de l'abondance

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Abstract

We summarize the available information on darkblotched rockfish *Sebastes crameri*. 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 1.318 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 for males. Length-age analyses suggest females ultimately reach larger sizes than males; however, the data are very sparse and only comprise surface-read otoliths (known to overestimate young ages and underestimate old ages). Natural mortality M is not known but assumed to be 0.07, based on US observations. Maturity ogives yield lengths at 50% maturity of 32.1 cm for males and 35.3 cm for females. Using von Bertalanffy growth parameters from US models, ages at 50% maturity k are calculated to be 7.6 y for males and 8.7 y for females. Assuming $k = 8$ y and $M = 0.07$, the generation time is 22.3 y. Depth-of-capture frequency in commercial trawl tows suggests that most of the population occurs between 150 m and 435 m. Using this bathymetry interval, the estimated potential habitat is 42,848 km². The estimated area of occupancy based on trawl tow observations covers 30,760 km^2 using a DFO grid (0.1° longitude × 0.075° latitude) or 9,232 km² using a COSEWIC grid (2 km² × 2 km²). Within its preferred depth range, darkblotched rockfish is caught with numerous other species including Pacific ocean perch *Sebastes alutus*, arrowtooth flounder *Atheresthes stomias*, yellowmouth rockfish *S. reedi*, and Dove sole *Microstomus pacificus*. Total removal of darkblotched rockfish from BC coastal waters by Canadian and US commercial fleets since 1930 equals at least 4,200 t. Survey indices of abundance are currently not useful for assessing darkblotched rockfish population trends. The GB Reed, WCVI shrimp trawl, QCS shrimp trawl, and US NMFS surveys all generate indices with low precision. The synoptic groundfish surveys offer the best tool for monitoring this species in future. To date, the index trend in Queen Charlotte Sound from 2003 to 2007 appears flat. The commercial trawl CPUE indices coastwide show a decline of 3.9% per year from 1996 to 2006, with a flat trend from 1998 on. 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 in 1997.

Résumé

Le présent texte résume les renseignements disponibles sur le sébaste tacheté (*Sebastes crameri*). 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 1,318 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 $\beta > 3$ pour les mâles. Les analyses de longueur selon l'âge ont démontré que les femelles deviennent plus longues que les mâles. Toutefois, les données sont rares et sont basées seulement sur la lecture de l'âge des otolithes pour examen de la surface (connue pour surestimer l'âge minimum et sous-estimer l'âge maximum). La mortalité naturelle M n'est pas connue, mais est évaluée à 0,07, selon des observations américaines. Les courbes de fréquences cumulées de maturité évaluent la longueur à 50 p. 100 de la maturité à 32,1 cm pour les mâles et à 35,3 cm pour les femelles. Selon les paramètres de croissance de von Bertalanffy basés sur un modèle américain, l'âge à 50 p. 100 de la maturité k est évalué à 7,6 ans pour les mâles et à 8,7 ans pour les femelles. Si on part de l'hypothèse que $k = 8$ ans et $M = 0,07$, la durée de génération sera de 22,3 ans. Selon la fréquence de profondeur des prises lors des coups de filet des chaluts commerciaux, la majorité de la population se situe entre 150 m et 435 m. Selon l'intervalle bathymétrique, la zone d'habitat est évaluée à 42 848 km². La zone d'occupation évaluée selon des observations lors des coups de filet des chaluts couvre 30 760 km^2 en se servant de la grille (0,1° de longitude × 0,075° de latitude) du ministère des Pêches et Océans, et 9 232 km² en se servant de la grille (2 km² × 2 km²) du COSEPAC. Lorsque le sébaste tacheté 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 bouche jaune (*Sebastes reedi*) et la limande-sole (*Microstomus pacificus*). Le nombre total de sébastes tachetés retirés des eaux côtières de la Colombie-Britannique par les flottes commerciales canadiennes et américaines depuis 1930 s'élève à plus de 4 200 t. Les indices d'abondance des relevés ne sont pas utiles actuellement pour l'évaluation des tendances de la population du sébaste tacheté. Les relevés du *G.B. Reed* et ceux des relevés par chalut à crevettes de la côte Ouest de l'Île de Vancouver et du détroit de la Reine-Charlotte ainsi que le relevé américain du *National Marine Fisheries Service* (service national des pêches maritimes) fournissent tous des indices avec peu de précision. Les évaluations synoptiques sur les poissons de fond seront très utiles pour surveiller les espèces dans l'avenir. Jusqu'à ce jour, la tendance des indices dans le détroit de la Reine-Charlotte entre 2003 et 2007 semble uniforme. Les indices de captures par unité d'effort (CPUE) le long de la côte par des chaluts commerciaux démontrent une baisse de 3,9 p. 100 par année entre 1996 et 2006, avec une tendance uniforme depuis 1998. 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 en 1997 de la gestion de quota individuel de bateau (QIB).

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1. Introduction

We summarize the available information on a data-limited species, darkblotched rockfish *Sebastes crameri* (Jordan 1896), 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 nineteenth century rockfish biologist, Frank Cramer, of Stanford University (Love 2002). Its common name stems from a dark blotch on the gill cover (Figure 1). Also apparent are 4-5 reddish-brown wide vertical bars or blotches on the dorsal surface of the body. Maximum length is 58 cm. Genetic studies suggest that darkblotched rockfish is closely related to yellowmouth rockfish *S. reedi* (Love et al. 2002).

Figure 1. Darkblotched rockfish *Sebastes crameri*
Source: http://pacpbsgfiis/gfimages/photos/020811_02W.jpg. Photo: Terri Bonnet

Taxonomic hierarchy* for *Sebastes crameri* (Jordan in Gilbert, 1897)
Taxonomic Serial No. (TSN) 166715:

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 crameri* (Jordan in Gilbert, 1897)	darkblotched rockfish

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

According to Love et al. (2002), darkblotched rockfish range from the southeast Bering Sea and the Aleutian Islands (Alaska) to Santa Catalina Island (southern California). The rockfish assemblage along the coast of Washington-Oregon finds darkblotched rockfish in conjunction with Pacific ocean perch predominant; while further south this species shares the dominant position with splitnose rockfish (Rogers 2005). In BC, the species is not so prominent. The reported depth of habitation for darkblotched rockfish ranges from 25-904 m, with a preferred range of 140-210 m. Adults typically occur on mud bottoms near cobbles or boulders. Darkblotched rockfish migrate to deeper waters with increasing size and age, and the majority of larger fish (>40 cm length) comprise females (Rogers 2005). The oldest recorded individual has been aged at 105 years (Love et al. 2002).

In BC, 50% of males mature at 32 cm while 50% of females mature at 35 cm. Mating occurs from August to December, eggs are fertilized from October to March, and larvae are released from November to June (Nichol and Pikitch 1994). Large females (57.5 cm) can produce up to 610,000 eggs (Phillips 1964). All *Sebastes* females retain larvae after eggs hatch and release live young in one batch. Darkblotched rockfish primarily eat krill, gammarid amphipods, copepods, and salps, with an occasional fish and octopus (Phillips 1964). Predators on this species include chinook salmon *Oncorhynchus tshawytscha* and albacore tuna *Thunnus alalunga* (Love et al. 2002).

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 darkblotched rockfish caught by the observed commercial trawl fishery is 1.318 kg ($\hat{\sigma}$ = 0.406 kg, n = 208). This value can be used when expressing commercial catch, 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 for males exceed 3 while those for females sometimes fall below 3.

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	---	---	---	---	---	---	---	---	---
Research	458	-11.368	0.049	3.127	0.014	0.701	0.428	0.011	2.078
Charter	290	-11.255	0.036	3.089	0.011	0.747	0.509	0.011	2.642
Obs Comm	102	-11.471	0.323	3.149	0.088	1.169	0.324	0.521	1.903
Res+Chart	748	-11.299	0.029	3.105	0.009	0.719	0.461	0.011	2.642
Commercial	102	-11.471	0.323	3.149	0.088	1.169	0.324	0.521	1.903
Females									
Non Obs Comm	---	---	---	---	---	---	---	---	---
Research	419	-11.308	0.050	3.109	0.014	0.768	0.504	0.008	2.676
Charter	291	-11.151	0.038	3.053	0.011	0.974	0.717	0.017	3.190
Obs Comm	106	-10.452	0.286	2.873	0.076	1.461	0.426	0.722	2.579
Res + Chart	710	-11.201	0.030	3.074	0.009	0.852	0.608	0.008	3.190
Commercial	106	-10.452	0.286	2.873	0.076	1.461	0.426	0.722	2.579
Males+Females									
Non Obs Comm	---	---	---	---	---	---	---	---	---
Research	877	-11.338	0.035	3.118	0.010	0.733	0.466	0.008	2.676
Charter	581	-11.195	0.026	3.068	0.008	0.861	0.632	0.011	3.190
Obs Comm	208	-10.857	0.199	2.982	0.054	1.318	0.406	0.521	2.579
Res + Chart	1,458	-11.246	0.021	3.088	0.006	0.784	0.542	0.008	3.190
Commercial	208	-10.857	0.199	2.982	0.054	1.318	0.406	0.521	2.579

2.1.2. Length frequencies

Relative frequencies of sampled darkblotched rockfish lengths by trip type (research, charter, and observed domestic commercial) and calendar year appear in the histogram matrix below (Figure 2). Only matrix cells containing more than 40 sampled fish are displayed. Mean lengths generally lie between 30 and 40 cm, except for fish from the 2005 charter samples which appear to have a spike of juveniles (10 cm).

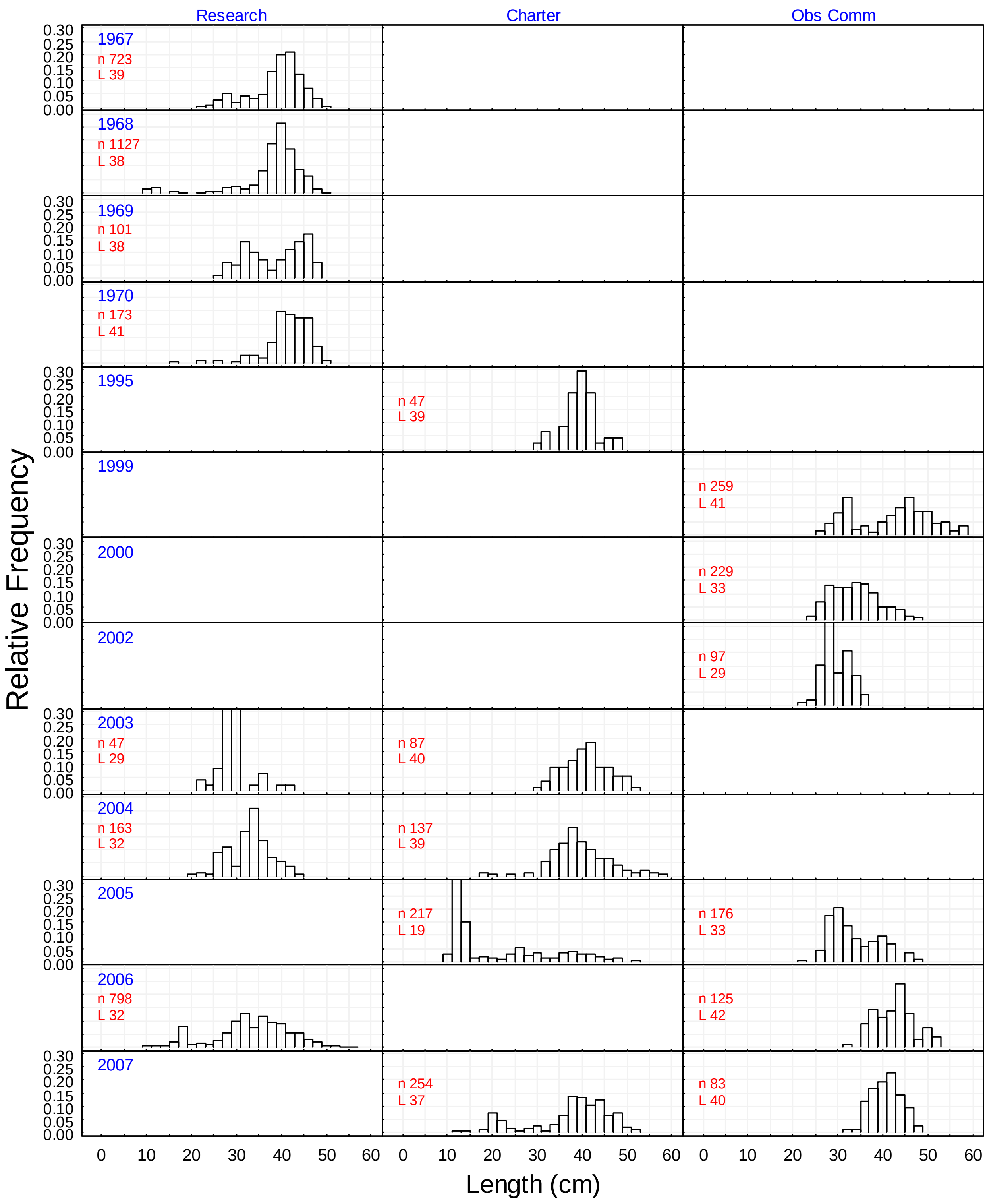

Figure 2. Relative frequency of darkblotched rockfish lengths (cm) by calendar year and trip type. Lengths are binned using 2-cm intervals. n = number of fish, L = mean length (cm).

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 darkblotched rockfish (code = 410);
- 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);

The above qualification yielded 99 darkblotched rockfish specimens, all from 1969. These otoliths were analyzed by surface readings (prior to break and burn), and consequently would give ages biased low. The specimens had the following distributions:

- by sex – males (33), females (66);
- by area – 3C (54), 5A (22), 5B(23);
- by gear – bottom trawl (99);
- by year – 1969 (99);
- by trip type – research (99).

The von Bertalanffy fits (A.2.3) through length-age research data (Figure 3) show that mature females are larger than mature males. The curve for males and females combined appears biased by the larger number of female samples. Rogers (2005) presents a revised set of parameter estimates for males ($L_\infty = 37.88$, $K = 0.2546$, $t_0 = 0.2311$) and females ($L_\infty = 42.94$, $K = 0.2010$, $t_0 = 0.1036$) from a recent U.S. darkblotched rockfish assessment.

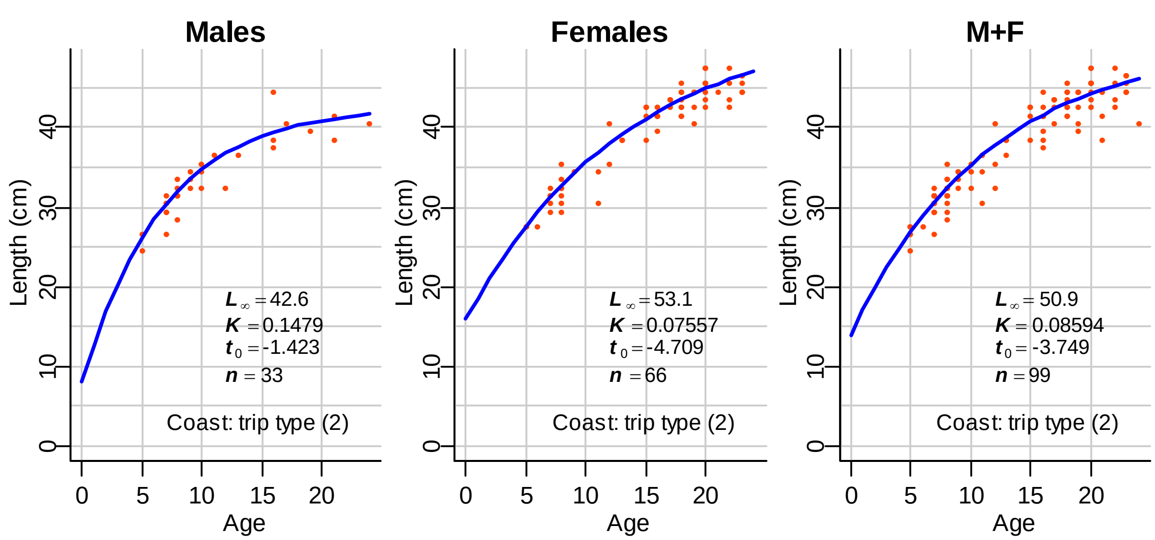

Figure 3. Length-at-age relationships for specimens collected on non-observed domestic commercial trips (trip type = 1) using the von Bertalanffy growth equation (see Appendix A.2). M+F = male and female specimens combined; n = number of specimens.

2.3. Mortality, maturity, and generation time

2.3.1. Mortality

Quinn and Deriso (1999) present a simple formula, based on Hoenig's (1983) finding that natural mortality M 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

$$M = -\log(0.01)/t_m$$

remains useful for rockfish that have been aged without bias. However, all our age data for darkblotched rockfish come from surface-readings only (biased low at older ages), which precludes the calculation. The US National Fisheries Marine Service suggests that an appropriate value of M for darkblotched rockfish is 0.07 (Rogers 2005).

2.3.2. Maturity

A frequency chart of all available maturity data (1967-2007) for darkblotched rockfish (Figure 4) suggests that females mature from June to November, are fertilized in February (possibly earlier but data not available), and bear young in February. Westrheim (1975) noted that parturition for *S. crameri* peaks in February in BC, while Nichol and Pikitch (1994) observed most parturition during February and March in waters off Oregon. 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 4). In Oregon, spawning for males occurs from September to November (Nichol and Pikitch 1994).

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 crameri*, this period appears to cover a full calendar year, though the timing is different for the two sexes(Figure 4). We define maturity to be stage 3 and up, and use length data (ages are biased) to construct a maturity ogive (Figure 5). To smooth the maturity data, the lengths are binned in 5 cm groups. For each group, the proportion of mature individuals is calculated (Table 2) and the lengths of 50% maturity L_{50} (32.1 cm for males, 35.3 cm for females) are interpolated from the curves. These values are approximately 2 cm shorter than those reported in the literature (34 cm and 37 cm, respectively, for WCVI, Westrheim 1975).

Due to the paucity of our age data and the inaccuracy of the older ageing method, we use the von Bertalanffy parameters presented in Rogers (2005) to calculate the age of 50% maturity k using

$$k = t_0 - \log\left(1 - L_{50}/L_\infty\right)/K .$$

For males, k = 7.6 y while for females k = 8.7 y. Assuming a natural mortality rate $M = 0.07$ and using $k = 8$ y, the generation time calculation (A.3.2) yields 22.3 y.

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

Age	**All**				**Males**				**Females**			
Group	p	n	l	σ	p	n	l	σ	p	n	l	σ
6-10	0.000	9	9.4	0.30	0.000	6	9.5	0.19	0.000	1	9.0	---
11-15	0.006	154	12.1	1.22	0.000	72	12.1	1.18	0.012	82	12.1	1.26
16-20	0.000	99	17.2	1.10	0.000	57	17.3	1.04	0.000	42	17.0	1.16
21-25	0.036	83	22.7	1.71	0.020	51	22.8	1.70	0.063	32	22.5	1.74
26-30	0.057	244	27.9	1.37	0.075	120	27.7	1.38	0.040	124	28.1	1.34
31-35	0.413	416	32.8	1.47	0.579	209	32.9	1.51	0.246	207	32.7	1.43
36-40	0.809	692	38.1	1.50	0.809	320	37.7	1.47	0.809	372	38.4	1.45
41-45	0.972	926	42.6	1.40	0.938	161	42.1	1.32	0.979	765	42.7	1.40
46-50	0.992	246	46.8	1.10	1.000	22	46.4	1.02	0.991	224	46.9	1.10
51-55	0.952	21	51.9	1.42	1.000	2	50.7	0.57	0.947	19	52.0	1.43
56-60	1.000	1	56.1	---	---	---	---	---	1.000	1	56.1	---

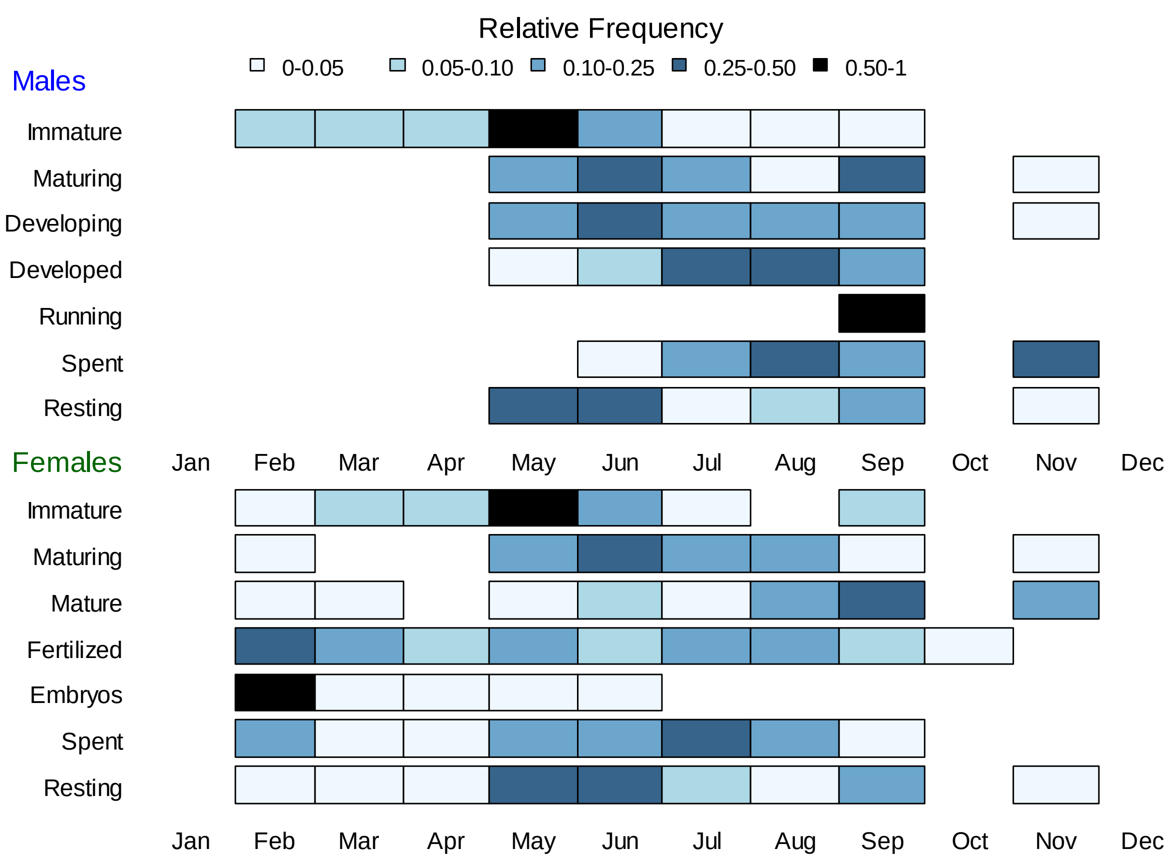

Figure 4. Relative frequency of maturity codes (data stored in DFO's GFBioSQL database) for darkblotched rockfish . Frequencies are expressed by month for each maturity category.

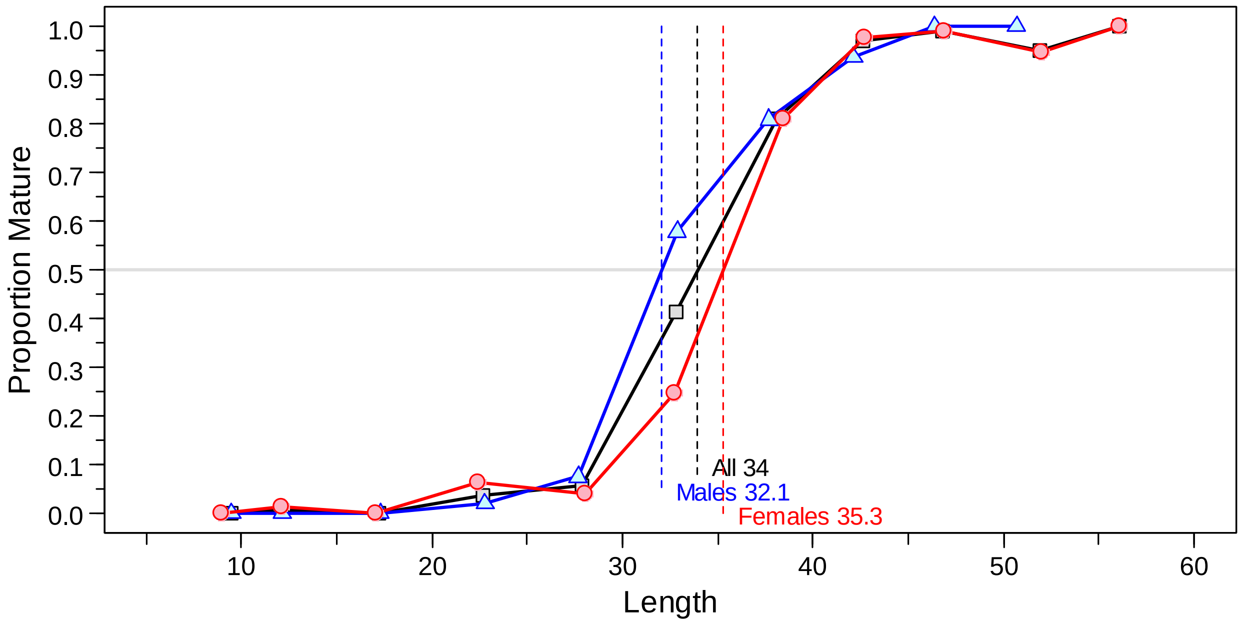

Figure 5. Maturity ogives for darkblotched rockfish using length grouped at 5-cm intervals. The length of each group is expressed as the mean of the observed lengths in each group. Vertical dashed lines indicate lengths at 50% maturity for males, females, and all available specimens, including those 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 darkblotched rockfish were extracted from the observer trawl database. The 2.5% and 97.5% quantiles of these observations – 150 m and 435 m (Figure 6) – act as a proxy for the preferred depth range of darkblotched rockfish. The relative cumulative catch by depth is superimposed on the histogram to show that the depth of median cumulative darkblotched catch (291 m) corresponds primarily with the second mode of the bimodal distribution. Most of the darkblotched catch falls within the preferred depth range. For reference, the total trawl effort appears as a shaded histogram in the background. The areas under both histograms each sum to one.

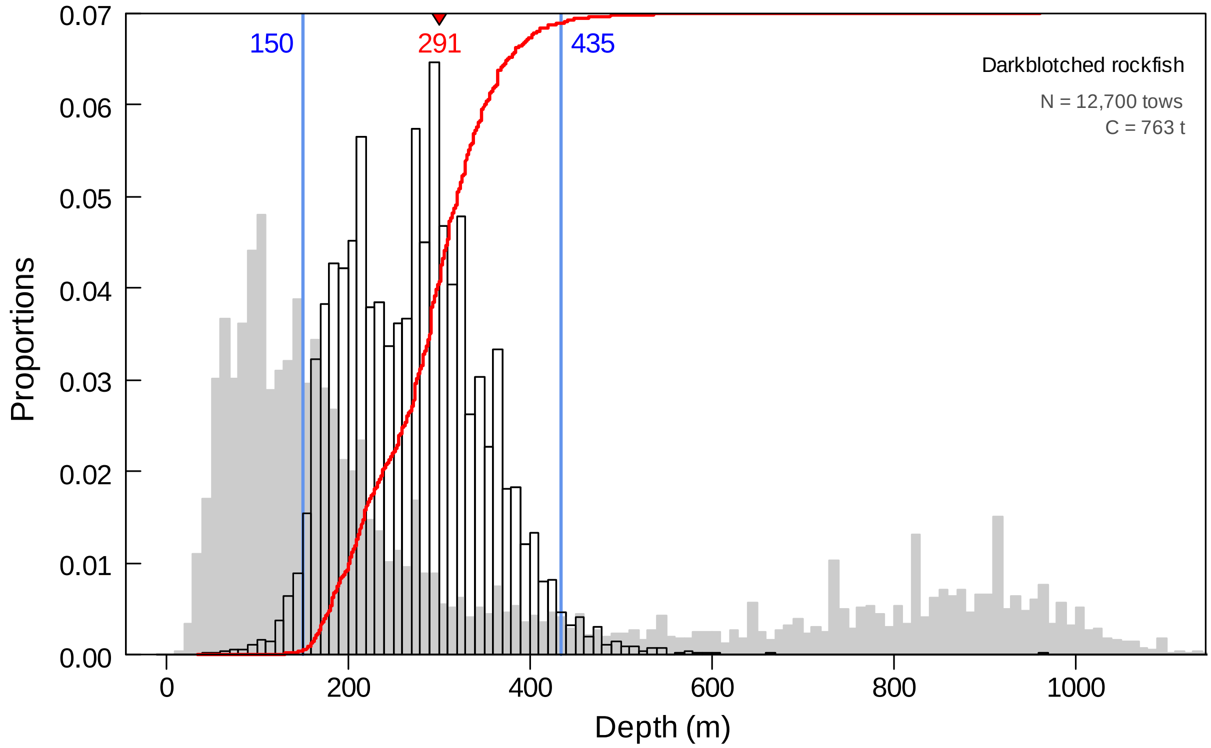

Figure 6. Relative frequency of tows in 10-m depth bins that capture darkblotched rockfish from commercial trawl records (1996-2007). The vertical solid lines denote the 2.5% and 97.5% quantiles. The shaded histogram in the background reports the relative trawl effort on all species. The cumulative catch of darkblotched rockfish, superimposed on the histogram in relative space (0 to 1), provides confirmation that the bulk of darkblotched 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 6), we can identify potential habitat for darkblotched rockfish as the bottom bathymetry that lies between 150 and 435 m (Figure 7). A mechanical survey of this sort obviously picks up regions where darkblotched 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 (42,848 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 8 shows how the surficial geology of the Queen Charlotte basin and Hecate Strait overlap the potential habitat of darkblotched 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. Love et al. (2002) mention that darkblotched rockfish typically occur on mud bottoms near cobbles or boulders. The table above suggests that this species occurs more frequently over bottoms characterized by sand, gravel, and till rather than mud, at least in the Queen Charlotte basin.

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

Surficial geology category	% Frequency
Outwash Sand & Gravel	20.8
Till	16.3
Glaciomarine Mud	15.4
Bedrock	11.3
Holocene Sand & Gravel	10.3
Holocene Mud	9.6
Sand & Gravel / Glaciomarine Mud	9.0
Sand & Gravel / Bedrock	7.3
Sand & Gravel	0.2

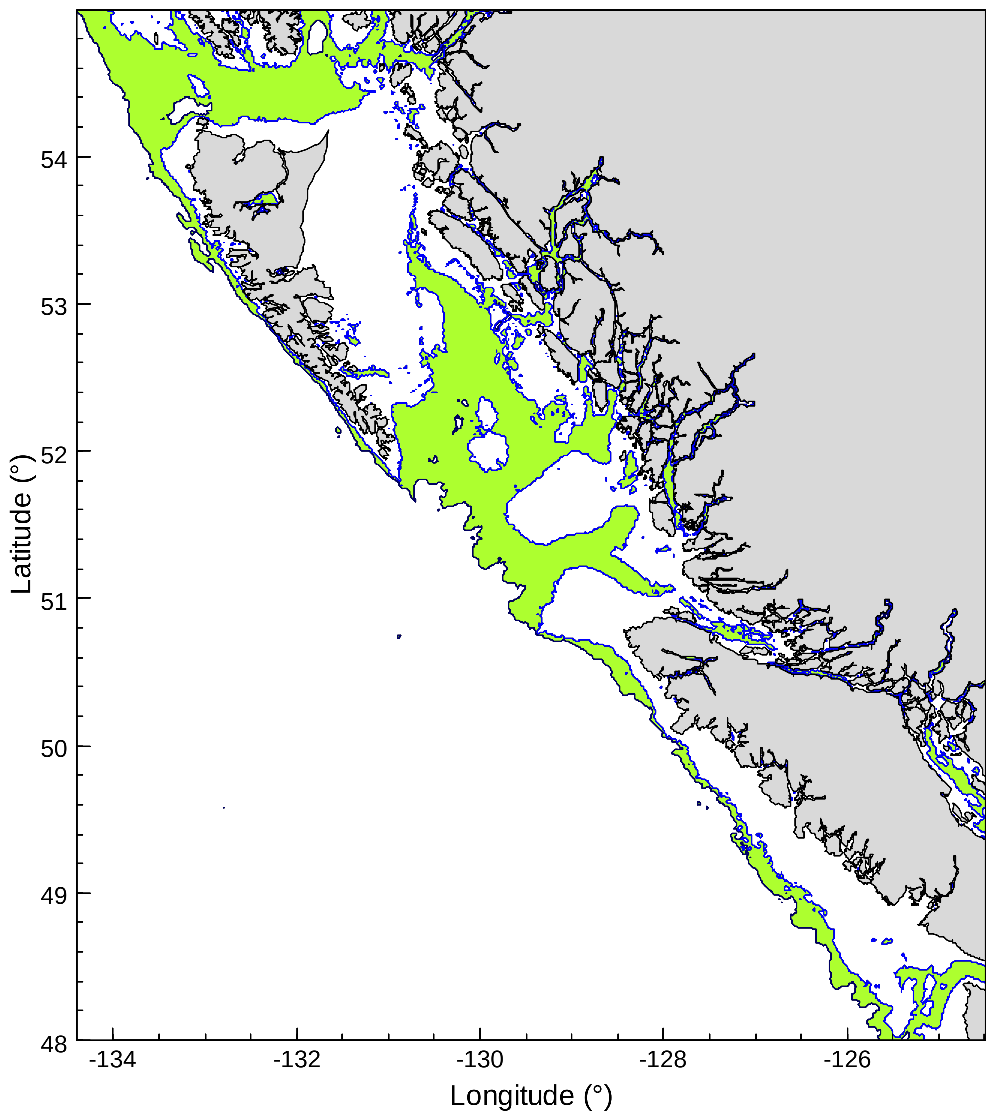

Figure 7. Highlighted bathymetry (green) between 150 and 435 m serves as a proxy for darkblotched rockfish habitat along the BC coast.

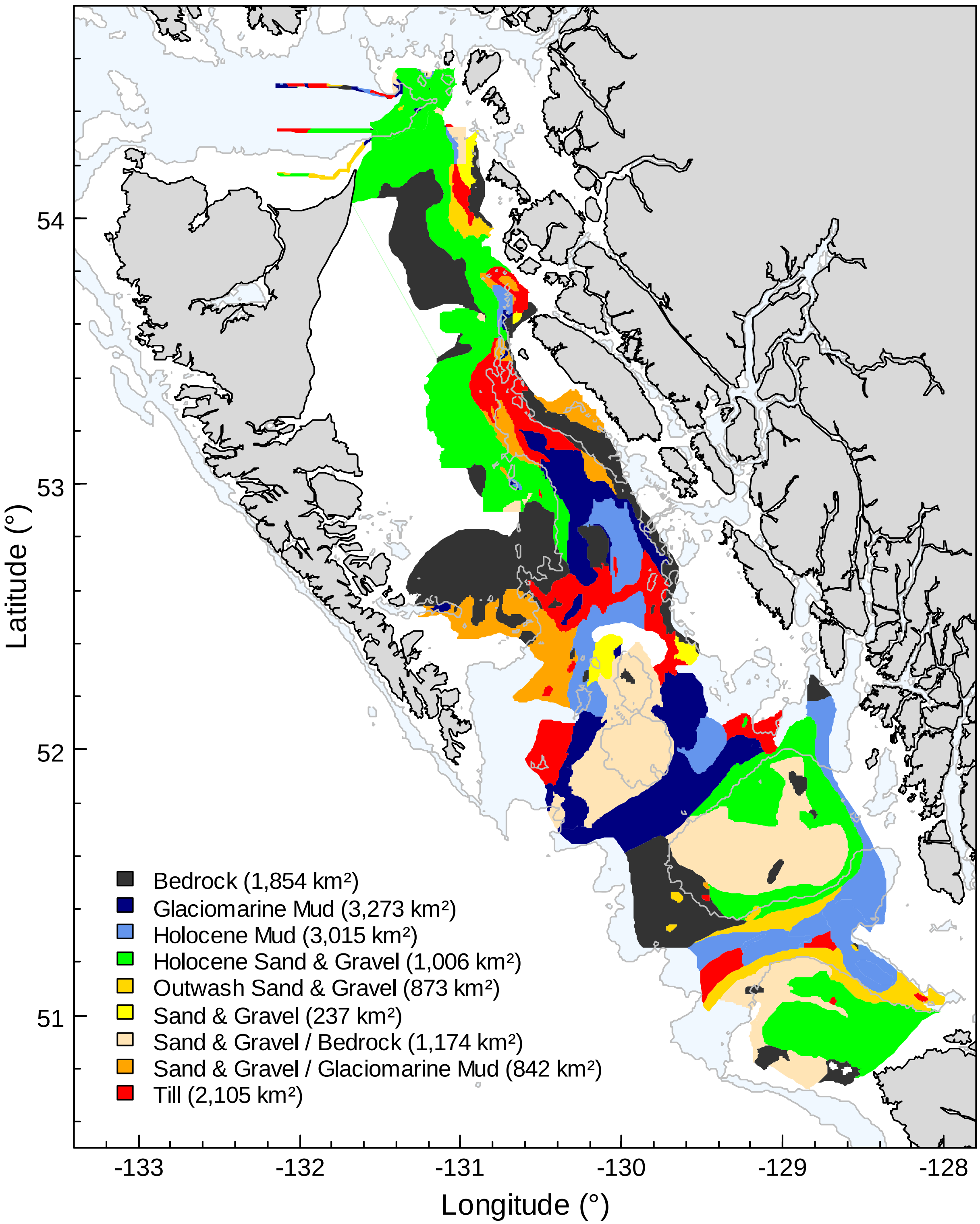

Figure 8. Surficial geology of the Queen Charlotte basin and Hecate Strait. The bathymetry contour (150-435 m) of Figure 7 lies beneath the highlighted geology. The legend shows geology categories and the area (km²) intersecting the bathymetry interval.

3.3. Density proportional to CPUE

Observer trawl data were selected using the following qualifications:

- species identified as darkblotched 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 darkblotched 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 darkblotched 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 darkblotched rockfish along the BC coast (Figure 9). The highest densities seen by trawlers occur in Moresby Gully and off NW Vancouver Island. The inclusion of grid cells containing fewer than three vessels yields an estimated occupied area of 30,760 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 9,232 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. This may signal the bycatch status of this species, but probably more accurately reflects its lesser abundance in the rockfish communities targeted by bottom trawlers.

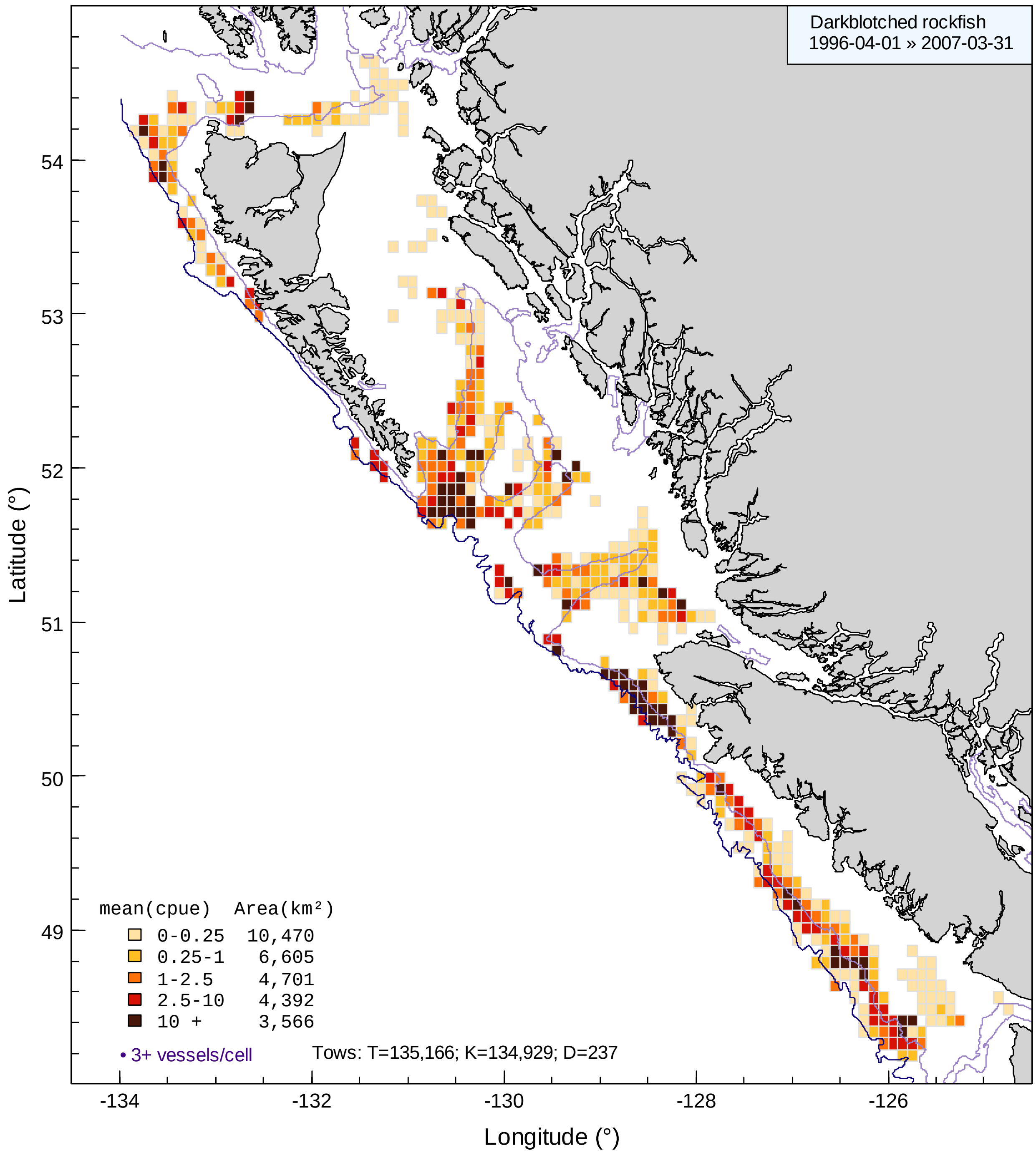

Figure 9. Mean CPUE (kg/h) of darkblotched rockfish caught by the trawl fishery in 0.1° × 0.075° grid cells along the BC coast. Isobaths displayed are 200 m and 1000 m.

3.4. Concurrence of species in trawl tows

Within the depth range 150-435 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 darkblotched 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 10). The depth at which darkblotched rockfish occurs most frequently is dominated by Pacific ocean perch *Sebastes alutus* and arrowtooth flounder *Atheresthes stomias*, with a substantial presence of yellowmouth rockfish *S. reedi* and Dove sole *Microstomus pacificus*.

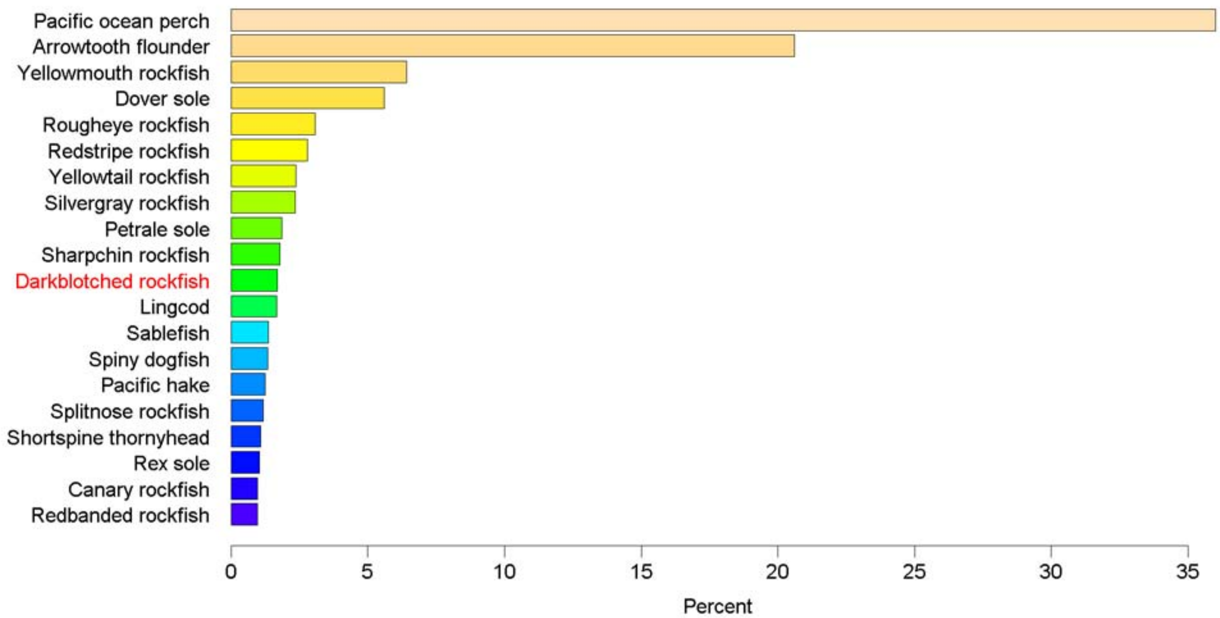

Figure 10. Concurrence of species in trawl tows (1996-2007) capturing darkblotched rockfish at depths 150-435 m. Abundance is expressed as a percent of total catch weight.

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; 167,241 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 (centre is defined as the item which has the smallest sum of distances to the other items in the cluster) 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 11. 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, redstripe and yellowmouth 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. Darkblotched catch appears to be heaviest (red medoid) in the three gullies of QCS (particularly Moresby) and in a few hotspots in Dixon Entrance.

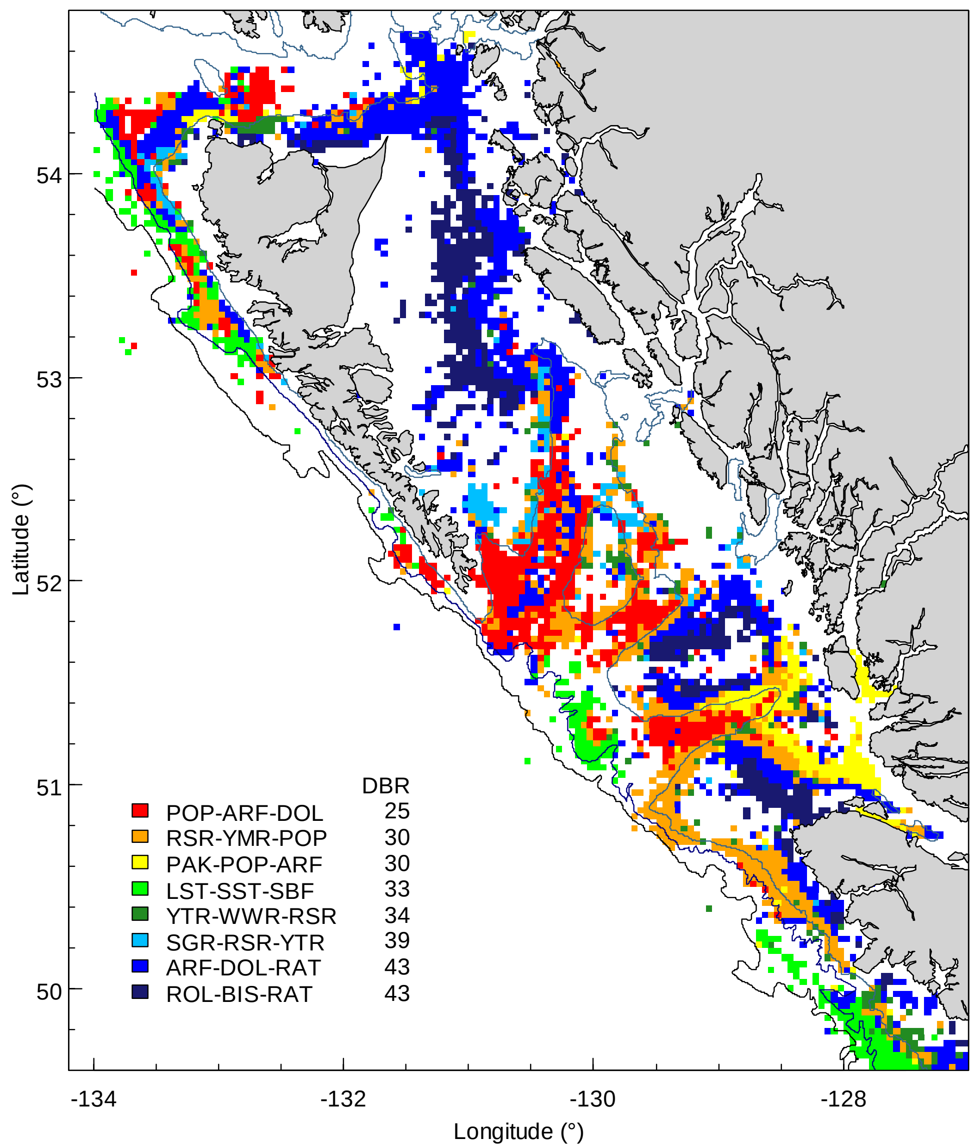

Figure 11. Groundfish groups identified by `clara` (clustering large applications) in R's package `cluster` and summarized using `PBSmapping`'s spatial functions for the north and central coast of BC. Isobaths trace the 200, 1000, and 1800 m depth contours. The legend identifies eight clusters by the top three species comprising the medoids; the clusters are ordered by the contribution of darkblotched rockfish (**DBR**) to each medoid. Species codes:

ARF arrowtooth flounder *Atheresthes stomias*,
BIS big skate *Raja binoculata*,
DOL Dover sole *Microstomus pacificus*,
LST longspine thornyhead *Sebastolobus altivelis*,
PAC Pacific cod *Gadus macrocephalus*,
ROL rock sole *Lepidopsetta bilineatus*,
RSR redstripe rockfish *Sebastes proriger*,
SBF sablefish *Anoplopoma fimbria*,
SGR silvergray rockfish *Sebastes brevispinis*,
SST shortspine thornyhead *Sebastolobus alascanus*,

PAK Pacific hake *Merluccius productus*,
POP Pacific ocean perch *Sebastes alutus*,
RAT spotted ratfish *Hydrolagus colliei*,
WWR widow rockfish *Sebastes entomelas*,
YMR yellowmouth rockfish *Sebastes reedi*,
YTR yellowtail rockfish *Sebastes flavidus*.

Off the WCVI (Figure 12), 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 a thin strip of higher darkblotched catch along contours typical for this species.

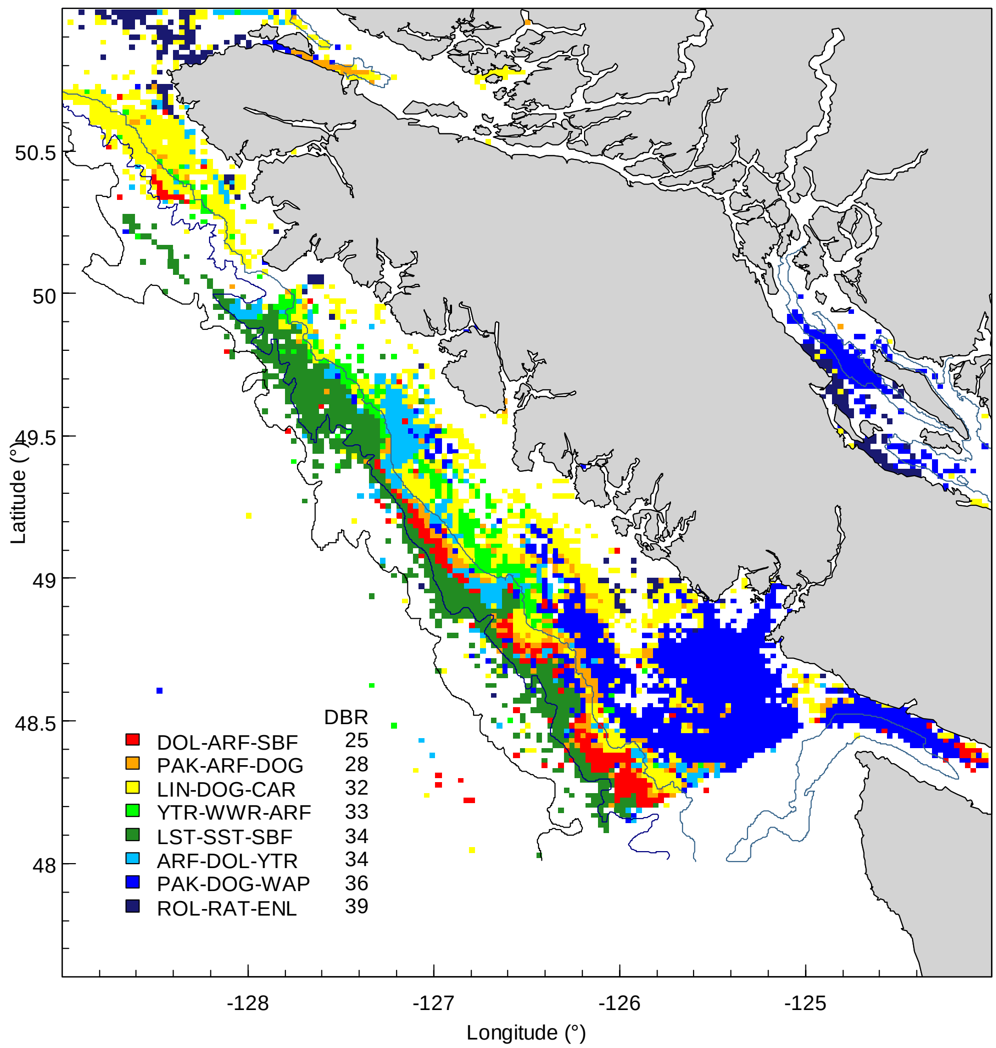

Figure 12. Groundfish groups identified by `clara` (clustering large applications) in R's package `cluster` and summarized using `PBSmapping`'s spatial functions for the west coast of Vancouver Island. Isobaths trace the 200, 1000, and 1800 m depth contours. The legend identifies eight clusters by the top three species comprising the medoids; the clusters are ordered by the contribution of darkblotched rockfish (**DBR**) 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*,
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*,

LST longspine thornyhead *Sebastolobus altivelis*, **YTR** yellowtail rockfish *Sebastes flavidus*,
PAK Pacific hake *Merluccius productus*.

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). To date, no quotas are in place for darkblotched rockfish.

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 darkblotched rockfish of 67.6% during the overharvest period compared with a decline in POP relative abundance of 55.8%. The survey catch of darkblotched declined from 2,921 kg to 751 kg while the survey CPUE declined from 31.1 kg/h to 7.51 kg/h (-75.8%).

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 have no reported abundance indices for darkblotched rockfish (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 trip limits on rockfish without specific total allowable catches (TACs) 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

Year	Management Programs Initiated (•) and Commercial Harvest Periods (♠)
	♠ 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 ♠ 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. Trip limits on rockfish other than those specified in fishery harvest plans for the 2008/09 fishing year.

Fishery	Rockfish covered by TACs	Allowable catch of non-TAC rockfish per trip
Lingcod	YYR, QBR, CPR, CHR, TIR, SGR	500 lbs if ≤ 10,000 lbs of lingcod landed 750 lbs if > 10,000 lbs of lingcod landed
Dogfish	CAR, RER, SKR, YYR, QBR, CHR, CPR, TIR, SGR, SST	Greater of 500 lbs or 2% of dogfish landed/trip
Inside ZN	QBR, CPR, CHR, TIR, YYR	≤ Total QBR + CPR + CHR + TIR (lbs) landed
Outside ZN	YYR, QBR, CPR, CHR, TIR, CAR, SGR, SKR, RER, SST	8,000 lbs
Halibut	YYR, RER, SKR, QBR, CPR, CHR, TIR, SGR, CAR, SST	8,000 lbs
Sablefish	CAR, SGR, YYR, QBR, CPR, CHR, TIR, RER, SKR, SST	12,000 lbs
Trawl Option A	QBR, CPR, CHR, TIR, YYR, CAR, SGR, SKR, RER, SST, LST, YMR, POP, WWR, RSR, YTR	15,000 lbs
Trawl Option B	No rockfish catch allowed	0 lbs

Rockfish codes: CAR canary, CHR china, CPR copper, LST longspine thornyhead, POP pacific ocean perch, QBR quillback, RER rougheye, RSR redstripe, SGR silvergray, SKR shortraker, SST shortspine thornyhead, TIR tiger, WWR widow, YMR yellowmouth, YTR yellowtail, YYR yelloweye

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 darkblotched rockfish landings extend back only to 1977. 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 darkblotched rockfish (DBR) to other rockfish (ORF) in the trawl fishery from 1996 to 2006 has remained fairly constant, at least on a coast wide basis where the ratio fluctuates about 0.013 (Figure 13). This may be an artifact of current management quotas but the ratio does indicate that this remains a minor species in the BC trawl fishery. A similar treatment comparing DBR to total rockfish (TRF, including POP) also yields stable ratios (Figure 14) and might be used in future to reconstruct removals from 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 DBR/TRF = 0.0057 (below) suggests a darkblotched catch of 164-362 t in 1966 alone. Finally, proportion analysis shows levels of discarding (Figure 15), which tend to be quite high for this species. Table 7 presents the mean values for 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 13 to Figure 15):

Table 7. Ratios of darkblotched catch (mean of mean annual ratios of catch from trawl fishery, 1996-2006) by PMFC area. **DBR** = total catch (landings + discards) of darkblotched rockfish, **ORF** = total catch of all rockfish other than Pacific ocean perch, **TRF** = total catch of all rockfish, **DBRd** = discarded catch of darkblotched.

Ratio	3C	3D	5A	5B	5C	5D	5E	CST
DBR/ORF	0.02036	0.01789	0.00590	0.01568	0.00307	0.00297	0.01017	0.01313
DBR/TRF	0.01119	0.01026	0.00334	0.00324	0.00160	0.00171	0.00219	0.00570
DBRd/DBR	0.27496	0.29208	0.45125	0.18836	0.38818	0.43952	0.11870	0.26029

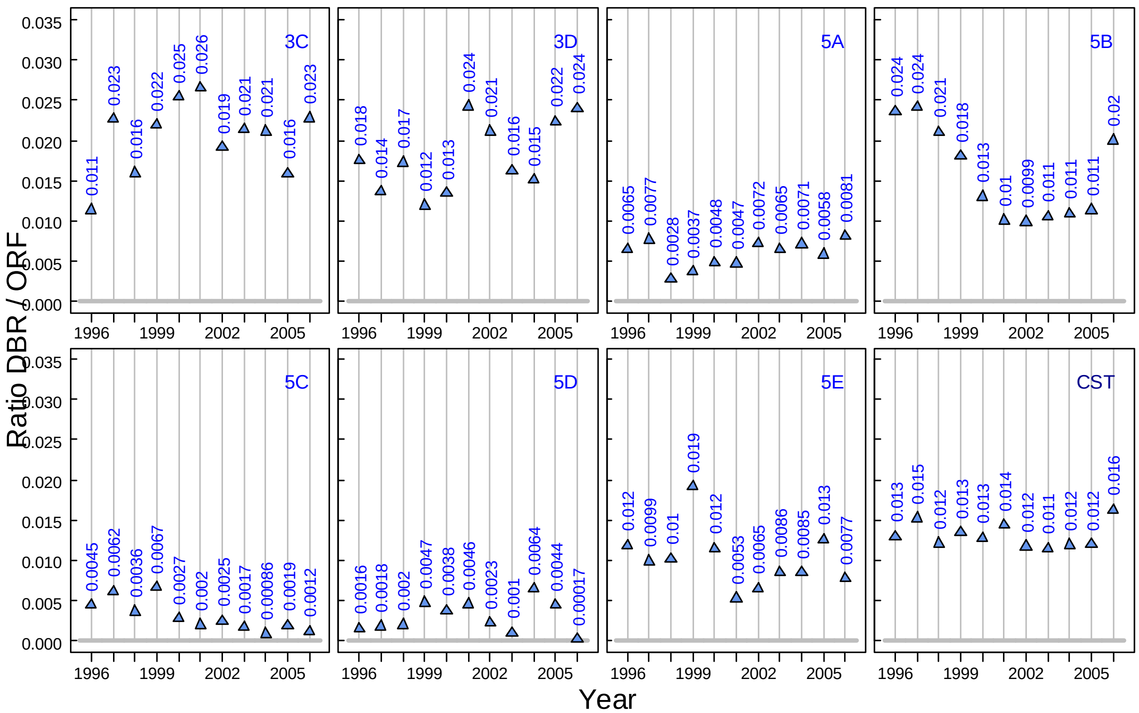

Figure 13. Distribution of proportions of darkblotched rockfish catch to the catch of all rockfish other than Pacific ocean perch in the trawl fishery by fishing year (Apr to Mar). Horizontal grey bars within the boxplots indicate median ratios. Blue triangles indicate mean ratios (also presented as numbers). Panels summarize ratios by Pacific Marine Fisheries Commission (PMFC) areas; the final panel summarizes ratios on a coastwide basis.

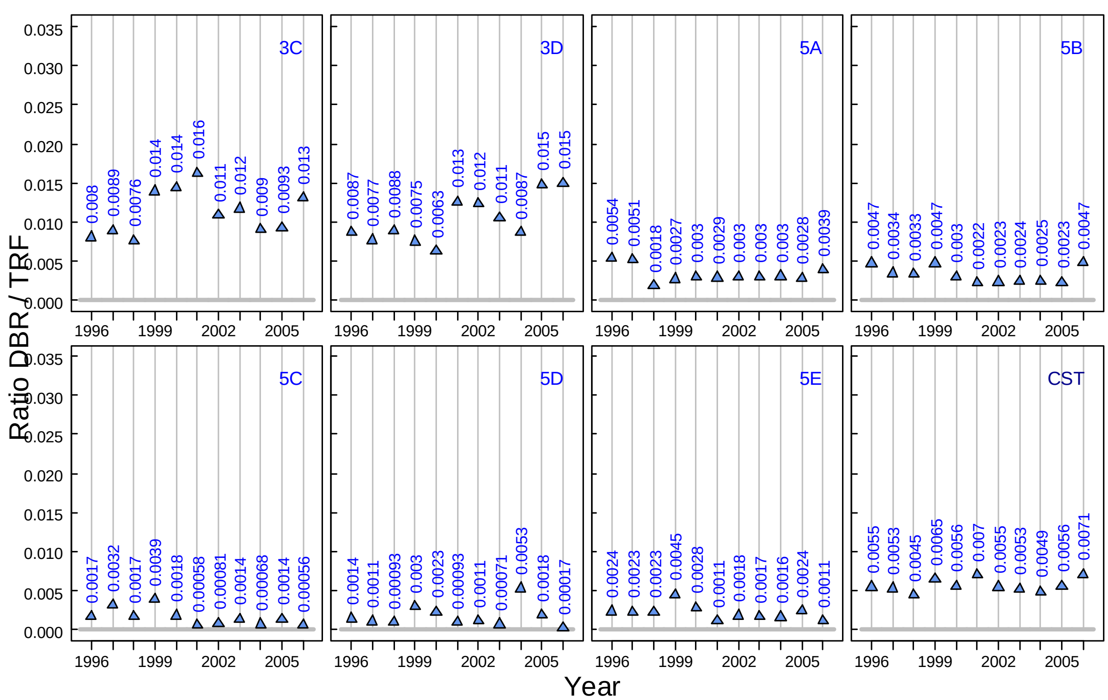

Figure 14. Distribution of proportions of darkblotched rockfish catch to the catch of all rockfish, including Pacific ocean perch in the trawl fishery by fishing year (Apr to Mar). Horizontal grey bars within the boxplots indicate median ratios. Blue triangles indicate mean ratios (also presented as numbers). Panels summarize ratios by Pacific Marine Fisheries Commission (PMFC) areas; the final panel summarizes ratios on a coastwide basis.

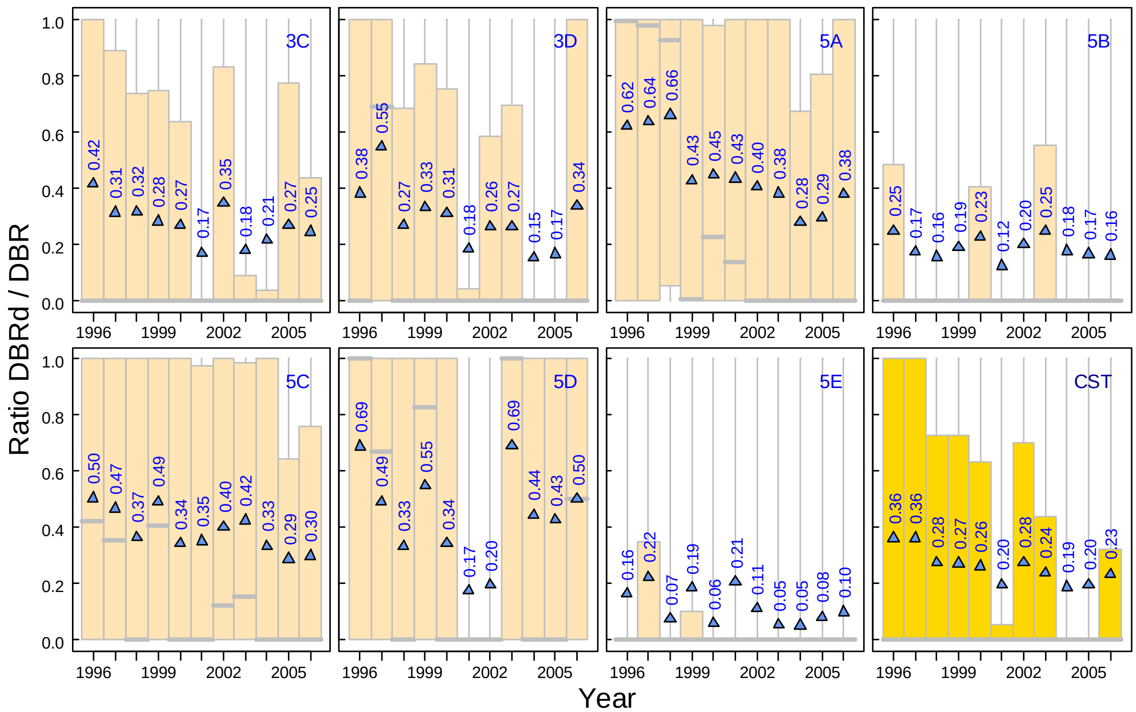

Figure 15. Distribution of proportions of discarded catch to total catch for darkblotched rockfish in the trawl fishery by fishing year (Apr to Mar). Horizontal grey bars within the boxplots indicate median ratios (primarily 0). Blue triangles indicate mean ratios (also presented as numbers). Panels 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 catch of 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 DBR/ORF derived above and the discard rates DBRd/DBR, we calculate estimates of darkblotched catch for the years 1930-1975 by US vessels (Table 10) and 1945-1982 for Canadian vessels (Table 11). Our assumption that observed DBR/ORF and DBRd/DBR 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 darkblotched landings starting in 1983, we base our darkblotched catch for 1976-1982 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 darkblotched 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 16), which peaked in 1995 at 117 t and has averaged 62 t annually during the years 1997-2007. Trawl catches of this species are highest in PMFC areas 3CD

(WCVI) and 5B (Moresby Gully region). Very little of the coastwide removals results from hook and line fisheries (ZN: Table 13, Schedule II, L-License). The total coastwide catch since 1930 is at least 4,200 t (Table 15) or approximately 3 million fish using the conversion 1.318 kg/fish (Section 2.1.1). As darkblotched rockfish has always been a bycatch species, the mean annual catches by decade have not substantially changed over time (Figure 16). The current standing stock is not known.

The estimated biomass of darkblotched rockfish in the Gulf of Alaska is not large (200-300 t, Table 16). Along the US west coast, catches declined from an average of 880 t during 1994-98 to an average of 281 t during 1999-2004 (Table 17). Estimated biomass declined 3.9%/y from 1994 to 1999 and increased 16.4%/y from 1999 to 2004. Current removals of darkblotched off the US west coast are more than double the current BC rate (62 t/y, Figure 16).

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 darkblotched rockfish (DBR) 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 DBR/ORF by PMFC area (first proportions in header)] ×
[1 + observed discard rate d by PMFC area (second proportion in header)].

Year	3C p=0.0204 d=0.2750	3D 0.0179 0.2921	5A 0.0059 0.4513	5B 0.0157 0.1884	5C 0.0031 0.3882	5D 0.0030 0.4395	5E 0.0102 0.1187	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	0.0	0.0	0.0	0.0	0.0	0
1935	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0
1936	0.2	0.1	0.0	0.2	0.0	0.0	0.0	0
1937	0.1	0.1	0.0	0.2	0.0	0.0	0.0	0
1938	0.2	0.1	0.1	0.3	0.0	0.0	0.0	1
1939	0.2	0.1	0.1	0.3	0.0	0.0	0.0	1
1940	0.5	0.3	0.1	0.6	0.0	0.0	0.0	2
1941	0.2	0.1	0.1	0.2	0.0	0.0	0.0	1
1942	3.4	2.2	1.1	4.2	0.0	0.0	0.0	11
1943	10.8	7.1	3.4	13.7	0.0	0.1	0.0	35
1944	4.5	3.0	1.4	5.7	0.0	0.1	0.0	15
1945	47.2	31.1	14.8	59.6	0.1	0.6	0.0	153
1946	23.8	15.7	7.5	30.0	0.1	0.3	0.0	77
1947	12.4	8.2	3.9	15.7	0.0	0.2	0.0	40
1948	20.2	13.3	6.3	25.5	0.0	0.3	0.0	66
1949	24.5	16.2	7.7	31.0	0.1	0.3	0.0	80
1950	22.6	17.3	8.7	23.1	0.1	0.4	0.0	72
1951	22.0	11.1	4.9	31.9	0.0	0.2	0.0	70
1952	16.9	12.3	5.6	25.3	0.0	0.2	0.0	60
1953	8.7	5.6	2.8	8.5	0.0	0.1	0.0	26
1954	9.1	6.4	2.2	9.0	0.0	0.1	0.0	27
1955	8.2	8.6	5.5	6.7	0.0	0.2	0.0	29
1956	7.4	9.4	5.8	5.9	0.0	0.1	0.0	29
1957	9.9	10.0	2.4	6.0	0.0	0.1	0.0	28
1958	7.5	6.8	3.6	3.6	0.0	0.1	0.0	22
1959	27.4	8.2	4.0	2.5	0.0	0.2	0.0	42
1960	27.7	8.6	1.8	4.5	0.0	0.1	0.0	43
1961	28.2	16.0	3.5	4.8	0.0	0.0	0.0	53
1962	34.7	25.5	5.4	12.3	0.0	0.1	0.0	78
1963	15.4	19.5	4.8	15.1	0.1	0.0	0.0	55
1964	14.6	7.9	3.8	9.1	0.0	0.1	0.0	35
1965	17.1	11.2	5.0	12.1	0.1	0.1	0.0	46
1966	16.5	18.6	12.3	15.6	0.0	0.0	0.0	63
1967	7.7	14.6	7.0	19.6	0.0	0.0	0.0	49
1968	12.8	17.7	11.7	21.7	0.0	0.0	0.0	64
1969	15.9	26.8	21.8	39.2	0.0	0.0	0.0	104
1970	15.9	31.6	13.4	29.0	0.0	0.0	0.0	90
1971	14.7	19.4	12.3	28.1	0.0	0.0	0.0	75
1972	9.2	18.6	13.0	32.0	0.0	0.0	0.0	73
1973	7.2	18.5	17.8	40.2	0.0	0.0	0.0	84
1974	2.3	21.8	9.7	23.5	0.0	0.0	0.0	57
1975	7.5	14.5	4.2	16.3	0.0	0.0	0.0	43

Table 11. Estimated catch (t) of darkblotched rockfish (DBR) in BC waters (PMFC areas) by Canadian trawl vessels from 1945 to 1982. Note: Canadian ORF catches for 1945-49 and 1976-82 come from `GFCatch` (not presented). Calculation:
[ORF catches (converted to tonnes where appropriate) appearing in Table 8 and Table 9] ×
[observed proportions *p* DBR/ORF by PMFC area (first proportions in header)] ×
[1 + observed discard rate *d* by PMFC area (second proportion in header)].

Year	**3C** ***p*=0.0204** ***d*=0.2750**	**3D** **0.0179** **0.2921**	**5A** **0.0059** **0.4513**	**5B** **0.0157** **0.1884**	**5C** **0.0031** **0.3882**	**5D** **0.0030** **0.4395**	**5E** **0.0102** **0.1187**	**Coast** **Σ PMFC** **Catch (t)**
1945	4.1	8.0	0.1	0.0	0.0	0.0	0.0	12
1946	0.8	2.2	0.5	0.5	0.0	0.0	0.0	4
1947	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0
1948	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0
1949	0.1	0.1	0.0	0.1	0.0	0.1	0.0	0
1950	0.4	0.1	0.1	0.2	0.0	0.2	0.0	1
1951	0.6	0.1	0.0	0.6	0.0	0.2	0.0	2
1952	1.5	0.0	0.1	1.7	0.0	0.2	0.0	3
1953	0.4	0.0	0.0	0.2	0.0	0.0	0.0	1
1954	1.4	0.1	0.0	1.0	0.0	0.0	0.0	3
1955	0.8	0.1	0.0	1.1	0.0	0.0	0.0	2
1956	0.3	0.0	0.0	0.7	0.0	0.0	0.0	1
1957	0.3	0.0	0.2	0.8	0.0	0.0	0.0	1
1958	0.2	0.0	0.2	0.8	0.0	0.0	0.0	1
1959	0.3	0.0	0.7	2.8	0.0	0.1	0.0	4
1960	0.2	0.0	0.1	0.4	0.0	0.0	0.0	1
1961	0.4	0.1	0.1	0.7	0.0	0.1	0.0	1
1962	0.4	0.3	0.2	3.4	0.0	0.2	0.0	5
1963	0.3	0.0	0.2	1.4	0.0	0.1	0.0	2
1964	0.3	0.1	1.4	1.7	0.0	0.1	0.0	4
1965	0.2	0.8	0.9	1.8	0.0	0.0	0.0	4
1966	0.5	0.3	0.5	1.4	0.0	0.1	0.0	3
1967	0.4	0.2	1.2	0.5	0.0	0.1	0.0	2
1968	0.3	1.1	1.3	1.0	0.0	0.0	0.0	4
1969	0.9	2.1	1.8	0.9	0.0	0.1	0.0	6
1970	1.6	1.8	1.5	2.4	0.1	0.8	0.0	8
1971	2.7	1.4	1.7	3.4	0.0	0.8	0.0	10
1972	1.1	0.5	3.4	11.9	0.0	1.7	0.0	19
1973	1.2	0.8	5.4	4.1	0.1	1.0	0.0	13
1974	1.8	0.8	1.8	4.9	0.1	1.2	0.0	11
1975	1.0	0.5	1.4	8.9	0.1	0.9	0.0	13
1976	3.4	4.0	2.8	13.8	0.2	1.7	0.0	26
1977	11.5	3.0	7.0	19.6	0.3	2.7	0.0	44
1978	2.2	3.5	8.8	40.0	1.0	2.7	18.6	77
1979	2.1	4.1	7.2	33.9	3.0	3.0	20.1	73
1980	2.1	5.5	3.4	23.8	3.0	1.3	9.0	48
1981	2.1	2.6	1.9	19.7	1.8	0.6	8.8	38
1982	5.7	8.8	7.2	22.4	1.0	0.6	7.1	53

Table 12. Annual (management fishing year) catch (landed + discarded; tonnes) of darkblotched 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
1977	---	---	---	---	0.0	---	---	0.8	---	1
1978	---	---	---	---	---	---	---	2.3	---	2
1979	2.7	0.9	---	---	---	---	---	1.8	---	5
1980	---	---	---	---	0.1	---	---	---	---	0
1981	0.0	---	---	---	0.1	0.0	---	---	---	0
1982	5.8	1.4	---	---	---	0.4	---	10.2	---	18
1983	0.4	---	---	4.8	17.6	9.2	---	14.7	---	47
1984	0.2	0.0	---	0.5	25.6	2.4	---	18.1	---	47
1985	7.2	5.7	---	0.6	0.1	---	---	11.5	---	25
1986	---	1.1	---	0.3	---	1.1	---	35.2	---	38
1987	8.4	18.3	---	0.8	11.9	2.7	---	45.9	---	88
1988	12.5	26.0	---	15.1	6.8	2.8	---	19.8	---	83
1989	24.2	31.2	---	4.1	28.4	0.0	---	11.6	---	100
1990	15.4	19.2	---	17.5	19.0	0.2	---	9.3	---	81
1991	24.3	8.4	---	2.8	7.8	2.1	---	---	---	45
1992	16.6	10.5	---	19.4	19.9	1.2	---	---	---	68
1993	18.7	37.3	---	15.8	14.7	2.9	1.2	1.9	---	92
1994	28.7	28.9	0.0	16.6	28.3	3.0	0.0	2.2	---	108
1995	13.6	19.0	---	22.2	51.8	3.7	0.5	6.6	---	117
1996[O]	10.7	27.8	---	8.0	34.3	3.3	0.3	3.6	---	88
97[I]	2.6	5.3	---	7.1	3.7	0.0	0.0	2.3	---	21
1997	19.5	16.4	---	14.2	19.3	3.2	0.3	4.3	---	77
1998	17.8	10.7	---	8.2	18.4	1.3	0.4	5.6	---	62
1999	17.6	14.3	---	5.9	26.8	1.1	0.7	6.7	---	73
2000	23.1	21.8	---	8.3	13.8	0.6	0.1	4.6	---	72
2001	25.1	20.3	---	6.3	8.3	0.5	2.4	2.9	---	66
2002	20.9	23.7	---	8.0	13.4	0.7	0.6	4.3	---	72
2003	19.0	12.5	0.0	4.8	14.9	0.2	0.1	4.0	---	56
2004	14.7	12.6	0.0	5.5	15.6	0.3	0.3	3.5	---	53
2005	11.3	17.6	---	7.8	12.2	0.8	0.8	4.3	---	55
2006	19.4	19.7	0.0	8.7	19.1	0.4	0.0	3.2	---	70
2007	14.8	15.5	4.8	14.2	0.1	0.1	7.1	---	---	57
UNK	---	---	---	---	---	---	---	---	75.9	76
Total	395	426	5	227	432	44	15	241	76	1,862

[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 darkblotched 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 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	---	0.01	---	0.22	---	---	0.00	0.01	0.04	0.29
1996	---	0.10	---	0.02	---	0.05	---	0.89	---	1.07
97 [I]	---	---	---	---	---	---	---	0.01	0.00	0.01
1997	---	0.11	---	0.01	---	0.00	---	---	0.01	0.13
1998	---	0.00	---	0.03	---	0.01	---	0.01	0.02	0.08
1999	---	0.03	0.00	0.02	0.01	0.00	---	0.03	0.00	0.09
2000	---	0.01	0.00	0.01	0.00	---	0.00	0.01	---	0.04
2001	---	0.01	0.04	0.00	0.00	0.03	0.02	0.02	0.02	0.15
2002	---	0.01	---	0.00	0.02	0.00	---	0.02	---	0.06
2003	---	0.04	---	0.01	0.01	0.04	0.02	0.01	---	0.14
2004	---	0.02	---	0.03	---	0.02	0.01	0.03	0.00	0.12
2005	---	0.01	---	0.00	0.00	---	---	0.00	---	0.02
2006	0.00	---	---	---	---	---	---	---	---	0.00
2007	---	0.01	0.00	0.00	0.01	---	0.00	---	---	0.02
Total	0.00	0.36	0.05	0.37	0.05	0.15	0.06	1.04	0.11	2.19

[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 darkblotched 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	---	---	---	---	0.00	0.00	---	---	0.07	0.08
1996	---	---	---	---	---	0.00	---	0.00	0.05	0.05
97 [I]	---	---	---	---	---	---	---	---	0.00	0.00
1997	0.01	0.01	0.00	---	0.00	0.00	0.00	0.00	0.08	0.11
1998	0.00	0.07	0.01	0.01	0.01	0.01	0.01	---	---	0.12
1999	0.00	0.09	0.00	0.00	0.03	0.01	0.01	0.01	---	0.14
2000	---	0.07	---	---	0.00	---	---	0.01	---	0.08
2001	---	0.19	---	---	0.01	---	---	0.02	---	0.22
2002	---	0.23	---	---	0.01	---	---	0.04	---	0.29
2003	---	0.24	---	---	0.01	---	---	0.06	---	0.32
2004	---	0.72	---	---	0.03	---	---	0.06	0.00	0.81
2005	---	0.39	---	---	0.03	---	---	0.04	---	0.47
2006	0.06	0.41	0.12	0.20	---	0.04	0.00	---	---	0.84
2007	0.00	0.32	0.10	0.10	0.00	---	0.01	---	---	0.53
Total	0.08	2.73	0.24	0.32	0.15	0.07	0.02	0.25	0.21	4.07

[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 darkblotched 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	---	0	---	---	---	---	0
1936	---	0	---	---	---	---	0
1937	---	0	---	---	---	---	0
1938	---	1	---	---	---	---	1
1939	---	1	---	---	---	---	1
1940	---	2	---	---	---	---	2
1941	---	1	---	---	---	---	1
1942	---	11	---	---	---	---	11
1943	---	35	---	---	---	---	35
1944	---	15	---	---	---	---	15
1945	12	153	---	---	---	---	166
1946	4	77	---	---	---	---	81
1947	0	40	---	---	---	---	41
1948	0	66	---	---	---	---	66
1949	0	80	---	---	---	---	80
1950	1	72	---	---	---	---	73
1951	2	70	---	---	---	---	72
1952	3	60	---	---	---	---	64
1953	1	26	---	---	---	---	26
1954	3	27	---	---	---	---	29
1955	2	29	---	---	---	---	31
1956	1	29	---	---	---	---	30
1957	1	28	---	---	---	---	30
1958	1	22	---	---	---	---	23
1959	4	42	---	---	---	---	46
1960	1	43	---	---	---	---	43
1961	1	53	---	---	---	---	54
1962	5	78	---	---	---	---	83
1963	2	55	---	---	---	---	57
1964	4	35	---	---	---	---	39
1965	4	46	---	---	---	---	49
1966	3	63	---	---	---	---	66
1967	2	49	---	---	---	---	51
1968	4	64	---	---	---	---	68
1969	6	104	---	---	---	---	110
1970	8	90	---	---	---	---	98
1971	10	75	---	---	---	---	85
1972	19	73	---	---	---	---	91
1973	13	84	---	---	---	---	96
1974	11	57	---	---	---	---	68
1975	13	43	---	---	---	---	55
1976[L]	26	---	---	---	---	---	26
1977	44	---	---	---	---	---	44

Year	CA Trawl	US Trawl	Zn HL	Shed II	Halibut	Total HL	Total
1978	77	---	---	---	---	---	77
1979[L]	73	---	---	---	---	---	73
1980	48	---	---	---	---	---	48
1981	38	---	---	---	---	---	38
1982	53	---	---	---	---	---	53
1983	47	---	---	---	---	---	47
1984	47	---	---	---	---	---	47
1985	25	---	---	---	---	---	25
1986	38	---	---	---	---	---	38
1987	88	---	---	---	---	---	88
1988	83	---	---	---	---	---	83
1989	100	---	---	---	---	---	100
1990	81	---	---	---	---	---	81
1991[D]	45	---	---	---	---	---	45
1992[L]	68	---	---	---	---	---	68
1993	92	---	---	---	---	---	92
1994[D]	108	---	---	---	---	---	108
1995[T]	117	---	0.29	---	0.08	0.36	118
1996[D,O]	88	---	1.07	---	0.05	1.12	89
1997[Q,T]	77	---	0.13	---	0.11	0.24	77
1998	62	---	0.08	---	0.12	0.21	63
1999	73	---	0.09	---	0.14	0.23	73
2000[T]	72	---	0.04	---	0.08	0.12	72
2001	66	---	0.15	---	0.22	0.37	66
2002	72	---	0.06	---	0.29	0.35	72
2003	56	---	0.14	---	0.32	0.45	56
2004	53	---	0.12	0.01	0.81	0.93	54
2005	55	---	0.02	---	0.47	0.48	55
2006	70	---	0.00	---	0.84	0.85	71
2007	57	---	0.02	---	0.53	0.55	57
UNK	76	---	---	---	---	---	76
Total	2,313	1,897	2	0	4	6	4,216

[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 biomass (t) for darkblotched rockfish in the Gulf of Alaska (Heifetz et al. 2000) from triennial trawl surveys (NPMFC).

Year	1984	1987	1990	1993	1996	1999
Biomass (t)	6	33	184	300	121	272

Table 17. Estimates of catch (t) and biomass (t) for darkblotched rockfish along the Pacific coast of the USA between Canada and Mexico (Rogers 2005, Summary Table, p. 10).

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Catch (t)	918	790	790	862	1,041	434	436	272	192	127	227
Biomass (t)	5,828	5,308	5,027	4,961	4,951	4,606	5,067	5,799	6,964	8,279	9,595

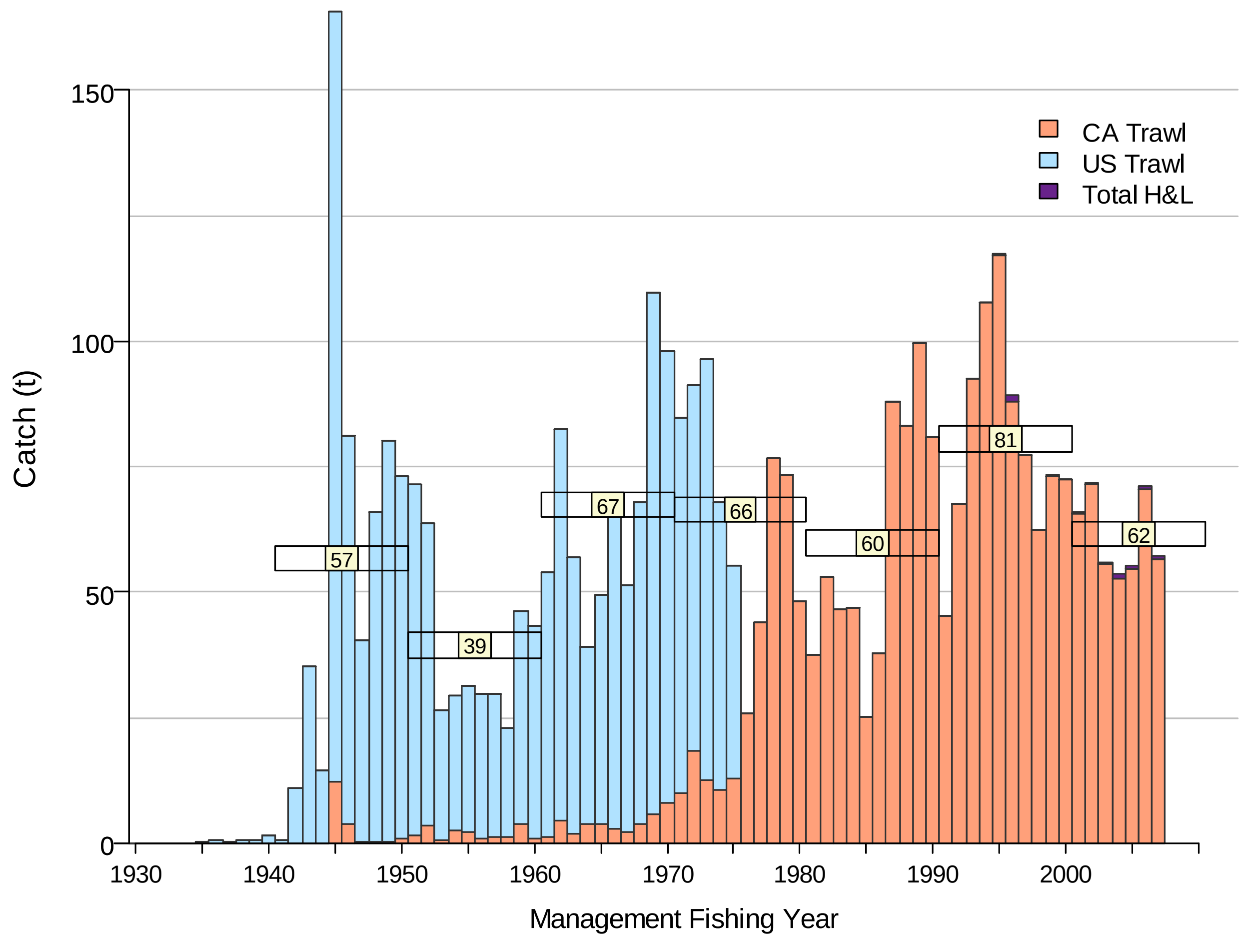

Figure 16. Catch history of darkblotched rockfish by US and Canadian fleets along the BC coast. Mean annual catches by decade are displayed in horizontal boxes.

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 darkblotched rockfish in the QCS synoptic survey appear in Table 18, 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 & Haigh 2003), should the reader wish to do so. The population parameters and moment estimates agree with observations from the trawl industry in that darkblotched rockfish appear more abundant at mid-depth (stratum 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 17). 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 darkblotched rockfish in QCS.

The biomass estimates from this survey (Table 19) assume a catchability quotient $q = 1$; however, catchability for this species remains unknown and probably lies well below unity. Annual catches of darkblotched rockfish during the 2003 to 2005 period in PMFC 5AB were 20 t, 21 t, and 20 t. Aside from the anomalous 2004 index, the series appears flat. If biomass removals are too small to have an impact on the index in a sensible manner, stock assessment scientists may have trouble estimating q (and subsequently absolute biomass) for this species.

Table 18. Population parameters and moment estimates for darkblotched 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 darkblotched 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	0.964	0.003	0.290	11.919	5,582	56	2	0.5	0	0.724
2003	20	0.690	0.098	2.258	0.196	2,931	29	9	88.7	5,064	0.802
2003	21	0.500	0.039	0.629	2.526	496	6	3	9.6	28	0.546
2003	22	1.000	---	---	---	2,024	5	---	0.0	---	---
2003	23	1.000	---	---	---	4,332	39	---	0.0	---	---
2003	24	0.846	0.060	1.110	0.811	3,976	52	8	36.5	346	0.510
2003	25	0.895	0.015	0.129	60.500	1,220	19	2	2.0	2	0.675
2004	18	1.000	---	---	---	5,093	42	---	0.0	---	---
2004	19	1.000	---	---	---	5,582	48	---	0.0	---	---
2004	20	0.645	0.092	1.853	0.291	2,931	31	11	95.8	3,407	0.609
2004	21	0.875	0.056	0.354	8.000	496	8	1	3.5	12	1.000
2004	22	1.000	---	---	---	2,024	20	---	0.0	---	---
2004	23	0.947	0.007	0.316	10.027	4,332	38	2	1.6	1	0.724
2004	24	0.821	0.095	1.456	0.471	3,976	39	7	68.1	1,950	0.648
2004	25	0.857	0.043	0.378	7.000	1,220	7	1	7.5	57	1.000
2005	18	0.966	0.004	0.186	29.000	5,093	29	1	0.6	0	1.000
2005	19	0.917	0.006	1.074	0.866	5,582	60	5	2.9	4	0.644
2005	20	0.690	0.009	0.699	2.048	2,931	29	9	7.9	8	0.362
2005	21	0.875	0.044	0.354	8.000	496	8	1	2.7	7	1.000
2005	22	1.000	---	---	---	2,024	8	---	0.0	---	---
2005	23	0.978	0.004	0.149	45.000	4,332	45	1	0.4	0	1.000
2005	24	0.946	0.007	0.471	4.500	3,976	37	2	1.5	1	0.764
2005	25	0.750	0.112	1.299	0.592	1,220	8	2	34.3	1,432	1.104
2007	18	1.000	---	---	---	5,093	33	---	0.0	---	---
2007	19	0.839	0.010	1.261	0.629	5,582	62	10	9.4	22	0.493
2007	20	0.500	0.131	1.959	0.261	2,931	24	12	192.2	13,361	0.601

year	h	p	μ	ρ	ν	A	n	n^+	B	V	CV
2007	21	0.429	0.031	0.519	3.717	496	7	4	8.8	13	0.418
2007	22	0.895	0.021	1.187	0.710	2,024	19	2	4.5	23	1.073
2007	23	0.965	0.001	0.087	132.401	4,332	57	2	0.1	0	0.697
2007	24	0.938	0.040	0.110	82.539	3,976	48	3	9.9	31	0.563
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 19. Relative darkblotched biomass index (t) and confidence limits from 1000 bootstrapped biomass estimates. n = number of tows, n^+ = number of tows catching darkblotched 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	24	149.3	145.8	49.2	353.4	0.507
2004	234	22	197.4	196.5	78.4	413.8	0.399
2005	224	21	50.2	51.1	12.0	145.5	0.674
2007	257	33	206.7	207.3	66.7	456.5	0.471

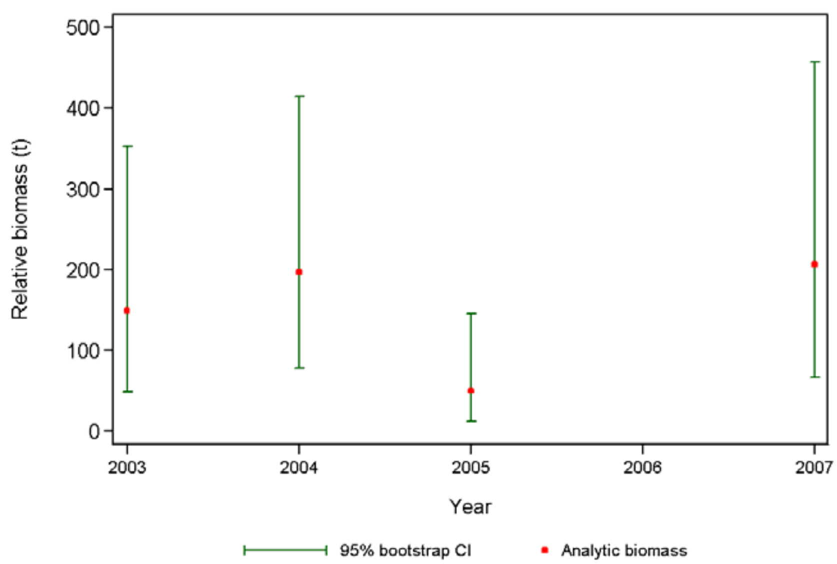

Figure 17. Relative index for darkblotched rockfish in Queen Charlotte Sound from the QCS bottom trawl survey. Vertical bars indicate 95% confidence intervals from 1,000 bootstrapped biomass index estimates.

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 darkblotched rockfish in the WCVI synoptic survey appear in Table 20, as do the moment estimates of biomass, variance, and CV (described in Appendix A.6). Considering the p-values and CVs below, these index points should provide population trend information for this species in future. The two index points appear in Figure 18 and Table 21.

Table 20. Population parameters and moment estimates for darkblotched 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 darkblotched 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	0.892	0.124	1.917	0.272	4,313	37	4	57.7	3,803	1.069
2004	67	0.429	0.040	0.756	1.750	804	14	8	18.2	41	0.354
2004	68	0.625	0.054	0.425	5.532	789	8	3	15.8	67	0.518
2006	65	0.982	0.001	0.132	57.000	7,012	57	1	0.1	0	1.000
2006	66	0.841	0.038	1.567	0.407	4,313	69	11	26.0	203	0.548
2006	67	0.571	0.169	1.511	0.438	804	21	9	58.4	1,080	0.563
2006	68	0.263	0.094	1.304	0.588	789	19	14	54.7	420	0.374

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

Table 21. Relative darkblotched biomass index (t) and confidence limits from 1000 bootstrapped biomass estimates. n = number of tows, n^+ = number of tows catching darkblotched rockfish, $\mathrm{E}[B]$ = expected biomass (t), $\overline{B}$ = 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+	$\mathrm{E}[B]$	$\overline{B}$	$B_{0.05}$	$B_{0.95}$	CV
2004	98	15	88.5	90.3	26.6	229.3	0.591
2006	166	36	147.6	146.0	78.9	256.1	0.307

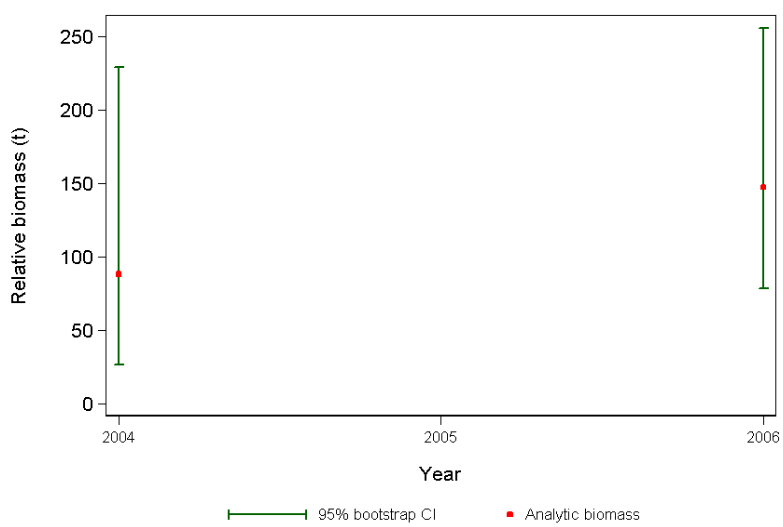

Figure 18. Relative index for darkblotched rockfish on the west coast of Vancouver Island from the WCVI synoptic bottom trawl survey. Vertical bars indicate 90% confidence intervals from 1,000 bootstrapped biomass index estimates.

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 darkblotched rockfish in the WQCI synoptic survey appear in Table 22, as do the moment estimates of biomass, variance, and CV (described in Appendix A.6). Judging by the p-values and the strata CVs from this one year, this survey may not prove highly useful for indexing darkblotched rockfish, despite a spatial analysis indicating a regional population centre (Figure 9).

Table 22. Population parameters and moment estimates for darkblotched 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 darkblotched 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	0.895	0.266	1.772	0.318	1,326	57	6	37.1	926	0.820
2006	127	0.885	0.014	0.493	4.110	1,090	26	3	1.7	1	0.613
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 19).

Table 23. 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)	Minimum depth (m)	maximum 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 24. Catch weight (kg) of darkblotched 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	1	29	36	253	2,907	3,226
1966	0	0	17	7	31	55
1967	0	1	4	9	17	31
1969		6	8	5	112	130
1971		2	7	23	14	45
1973		16	2	3	4	26
1976		5	30	69	191	295
1977	0	0	13	61	23	97
1984		0	12	8	3	23
Total	1	60	129	438	3,301	3,929

The original depth stratification of these surveys was in 20 fathom intervals, with the important strata for darkblotched 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 23).

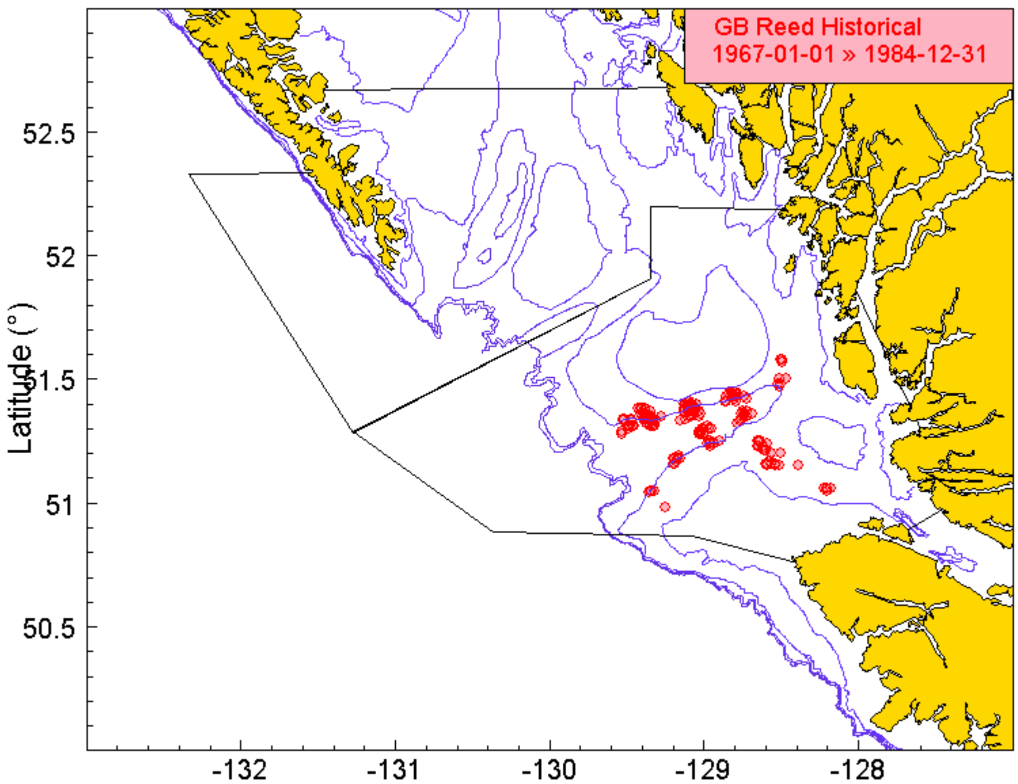

Figure 19. The full range of selected tows for the historical GB Reed surveys, showing the 100, 200, 300 and 400 m isobaths. The deep edge of the survey area is 549 m (300 fathoms) and the shallow cut-off is 37 m (20 fathoms). Only the tows lying between 146 m and 428 m were used in the analysis and the stratum boundaries for the current Q. Charlotte Sound synoptic survey are also shown.

Table 25. 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

Almost no Darkblotched rockfish were taken in the most shallow stratum, and almost 3,000 kg were taken in the deepest (257–428 m) stratum in the first (1965) survey (Table 24). 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 25).

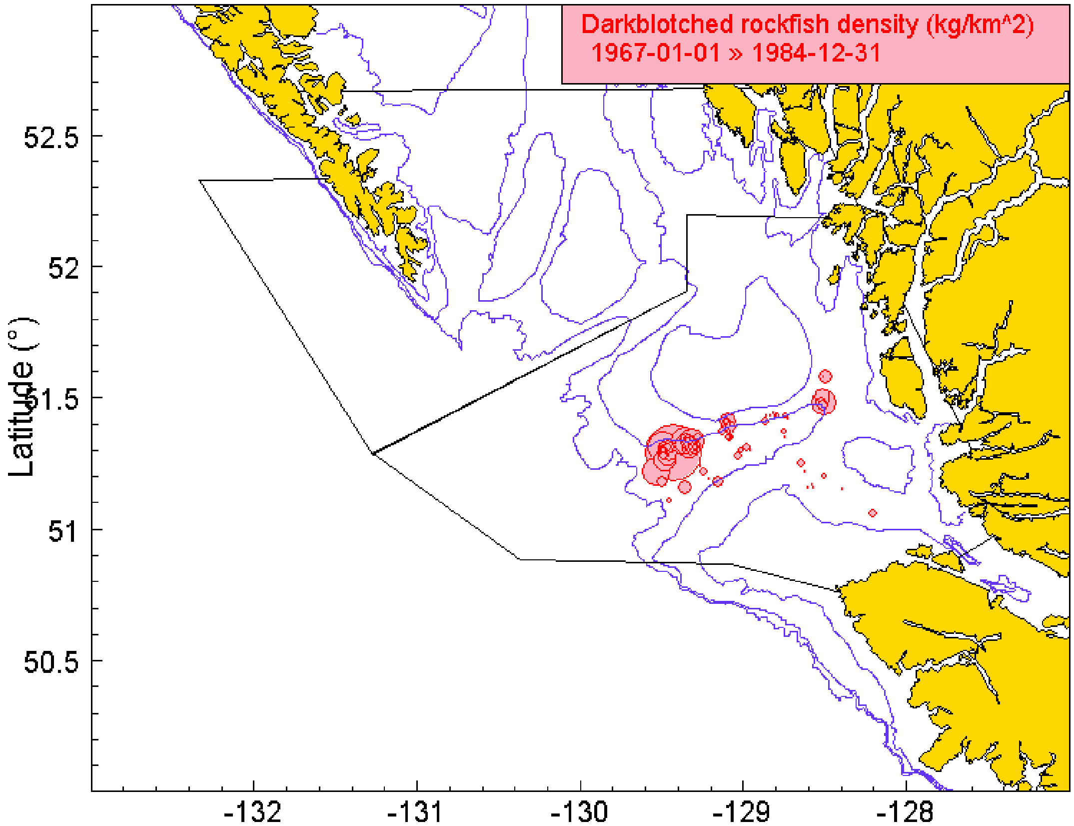

Figure 20. Map of the locations of all trawls from the historical GB Reed trawl survey (1967–1984) which caught darkblotched rockfish. Only tows in Goose Island Gully which were used in the biomass index calculation are shown. Circles are proportional to catch density (largest circle=0.573 kg/km^2). Also shown are the 100, 200 and 300 m isobaths.

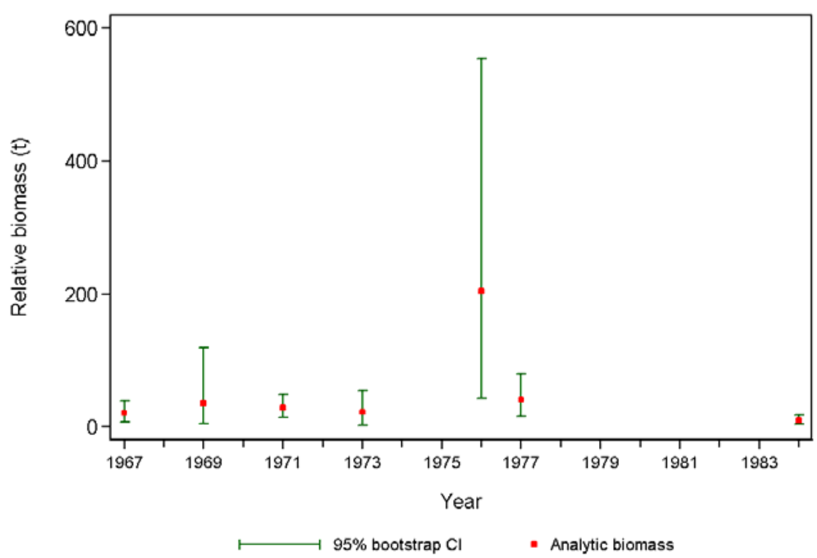

Figure 21. Relative biomass estimates for darkblotched rockfish from the historical Goose Island Gully GB Reed trawl surveys for the period 1967 to 1984. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

4.4.2. Results

A map showing the locations where darkblotched rockfish were caught in Goose Island Gully indicates that this species was primarily caught along the 200 m depth contour and in the trench of the gully (Figure 20). Estimated biomass levels in the Goose Island Gully for darkblotched rockfish from the historical GB Reed trawl surveys appear to have been relatively low and constant through the 7 years of this survey, with the exception of 1976 which has a larger biomass estimate associated with a very large relative error (Figure 21; Table 26). The 1984 biomass estimate is low relative to the other estimates, but its upper bound exceeds the lower bounds of all other indices except for 1976. All surveys have CVs greater than 30% and three of surveys (1969, 1973 and 1976) have CVs near to or greater than 60%, indicating that the precision of these survey indices is low. The proportion of tows which contained darkblotched rockfish was relatively constant over the first six of seven surveys, ranging from 35% to 50% with no apparent trend (not shown). However, the proportion of tows which held darkblotched dropped to below 20% in the 1984 survey.

Table 26. Relative biomass estimates for darkblotched 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 25) 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	21.1	21.2	7.9	39.4	0.395	0.396
1969	36.1	35.8	5.4	118.8	0.732	0.722
1971	28.8	28.9	14.4	49.0	0.323	0.320
1973	22.3	21.3	2.9	55.4	0.596	0.595
1976	204.6	205.7	43.4	554.4	0.657	0.649
1977	41.2	40.9	16.0	79.9	0.378	0.368
1984	9.6	9.8	3.5	18.2	0.378	0.378

4.5. WCVI shrimp trawl survey

4.5.1. Data selection

Tow-by-tow data from a west coast Vancouver Island shrimp trawl survey are available for 33 years spanning the period from 1972 to 2007. However, rockfish were not identified to the species level for the 1972 and 1973 surveys and 1974 is a missing year. Therefore, for rockfish species, this survey begins in 1975 and is the longest series available to monitor this species in Canadian waters.

These survey data were analysed following the recommendations made by Starr et al. (2002) in their reanalysis of the data from the same survey for west coast Vancouver Island pacific cod, with some modifications. These recommendations and modifications include:

- post-stratifying the data into two areas, Areas 124 and 125 (Figure 22) because these are the areas that have been monitored the most consistently over the history of the survey. The main modifications applied included dropping some tows which occurred in the most northerly part of Area 125 in 1975 and 1976 because these tows were not repeated in later surveys.

- moving tows east of the longitude 125° 54’ from Area 124 to 123 as these tows were made in inshore waters and were spatially more closely associated with Area 123.
- only using tows made by the following vessels: *G.B. Reed*, *Ricker*, *Sharlene K*. and the *Frosti* (Table 27). The latter two vessels are included because they are the only vessels which operated in 1989 and 2005 respectively. This vessel selection also rules out tows made in September 1977 and September 1978 which appear to be outside the scope of this survey.

The number of tows available for use in the analysis and the area weights in square kilometres for the defined strata are presented in Table 28.

There are almost no tows at depths more shallow than 100 m in Area 125 (Figure 23) although there is reasonable coverage in the 80-100 m depth zone in Area 124. Coverage is continuous in all survey years up to the 140-160 m depth zone in both of the area strata, but the coverage in the 160-180 m depth zone is sporadic in many of the survey years. This analysis used 80 m to 160 m as the depth range for all survey years. This should not affect the comparability of Area 125 because there is a consistent lack of tows in depths less than 100 m across all surveys (Figure 23). Stratum area weights were used which reflect the reduced area associated with the truncated depth range (Table 28).

No tows were recorded in Area 125 for the 1989 and 1991 survey years (Table 28). The catch rates estimated for Area 124 were also applied to the Area 125 stratum to ensure that the indices for these survey years were comparable to the indices in the years when Area 125 was surveyed.

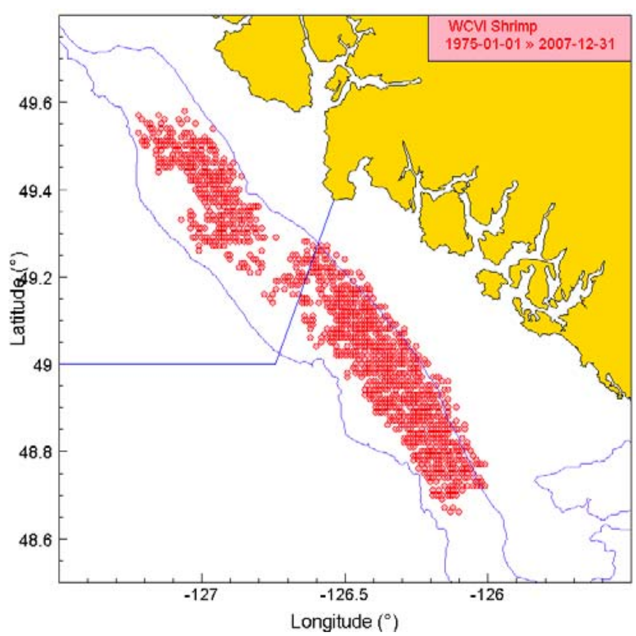

Figure 22. Map of the locations of all trawls in areas 124 and 125 that were used for the west coast Vancouver Island shrimp trawl survey. Areas 124 and 125 are the strata that have been surveyed consistently over the history of the survey and which are in locations most likely to catch darkblotched rockfish.

Table 27. Number of sets made by each vessel involved in the west coast Vancouver Island shrimp trawl by month and survey year. All sets south of 50°N are included, not just sets used in the analysis.

Vessel &	**Month**					
Year	**April**	**May**	**June**	**July**	**August**	**September**
Challenger						
1977						13
Deliverance						
1977						15
Frosti						
2005		108				
G. B. Reed						
1975		92				
1976		90				
1977		76				
1978		101				
1979		77				
1980		85				
1981		88				
1982		82				
1983		77				
1985		51	32			
Pacific Trident						
1977						21
Ocean King						
1978						95
Ricker						
1987					68	
1988	19	62				
1990	61	21				
1991	2	85				
1992		83				
1993	29	74				
1994	31	73				
1995		88				
1996	6	105				
1997		130				
1998		114				
1999		129				
2000		117				
2001		116				
2002	56	65				
2003	62	45				
2004	20	97				
2006	31	81				
2007	41	66				
Sharlene K.						
1989		67				
Sunnfjord						
1977						19

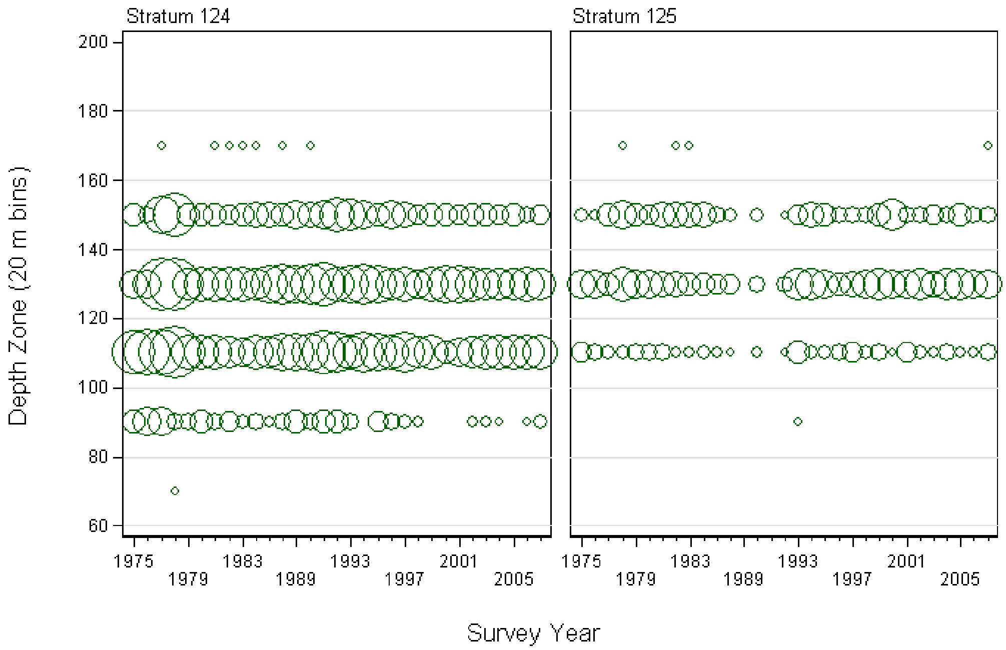

Figure 23. Distribution of tows in 20 m depth zones by survey year and area stratum for all tows. Each 20 m depth bin is indicated by the mid-point of the bin (i.e.: 110 m= 100-120 m). Tow depth determined by the start depth. Circles are weighted by the number of sets observed in each depth bin. Maximum circle size: stratum 124=48 tows and stratum 125=20 tows, both in the 130 m depth bin.

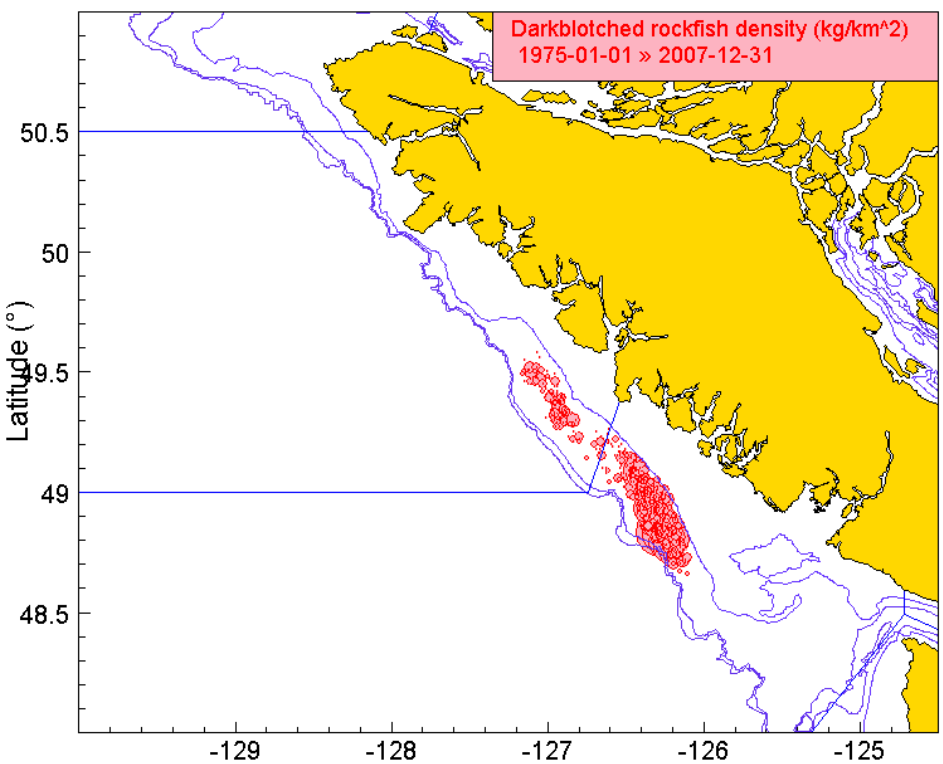

Figure 24. Map of the locations of all trawls from the WCVI shrimp trawl survey (1975–2007) which caught darkblotched rockfish. Circles are proportional to catch density (largest circle=2.16 kg/km^2). Also shown are the 100, 200 and 300 m isobaths and the PMFC major area boundaries for Areas 123 and 124.

Table 28. List of tows used from the WCVI shrimp trawl survey by survey year and stratum, including the number and weight of darkblotched rockfish for tows dropped from the analysis and tows shifted from 124 to 123. All tows with starting depths >160 m have been excluded.

	Stratum				Stratum		
Year	**124**	**125**	**Tows**	**Year**	**124**	**125**	**Tows**
1975	61	18	79	1993	69	31	100
1976	70	18	88	1994	66	29	95
1977	52	20	72	1995	60	23	83
1978	83	16	99	1996	55	17	72
1979	51	24	75	1997	60	21	81
1980	59	22	81	1998	42	20	62
1981	53	25	78	1999	48	30	78
1982	54	23	77	2000	41	29	70
1983	49	22	71	2001	45	22	67
1985	57	21	78	2002	48	25	73
1987	52	12	64	2003	46	19	65
1988	66	10	76	2004	46	25	71
1989	67	0	67	2005	45	25	70
1990	68	10	78	2006	48	21	69
1991	87	0	87	2007	47	22	69
1992	75	6	81				
Total					1770	606	2376
Area (km^2)*					1844	1396	3240

* Area out to 160 m maximum depth

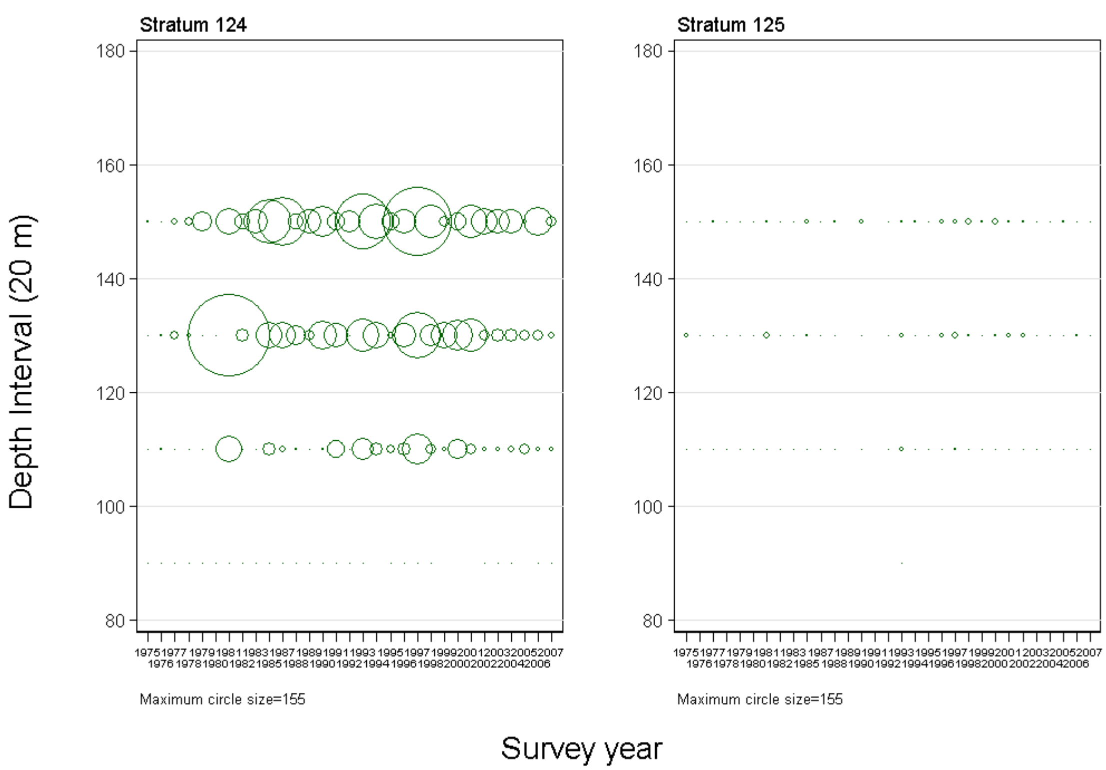

Figure 25. Distribution of catch weight of darkblotched rockfish by stratum (Table 28), survey year and 20 m depth zone. Depth zones are indicated by the centre of the depth interval. Minimum depth observed for DBR: 98 m; maximum depth observed for DBR: 165 m. Depth is the start depth for the tow.

4.5.2. Results

Catches of darkblotched rockfish have been recorded along the shelf for the full range of the usable tows, with greater apparent abundance in Area 124 relative to Area 125 (Figure 24). The distribution of Darkblotched rockfish catches by depth is concentrated between 120 and 160 m (Figure 25). Estimated biomass levels for darkblotched rockfish from the WCVI shrimp trawl survey was low at the beginning of this survey, peaked in the late 1990s and has then trended downward (Figure 26; Table 29). However, CVs are high and variable for this species, ranging from 21% to 98% over the 31 available survey years, indicating that the reliability of the observed trends will be low. The incidence of darkblotched rockfish is relatively common in many of the survey years, but highly variable (ranging between 0 and nearly 80%, depending on the survey year and the stratum).

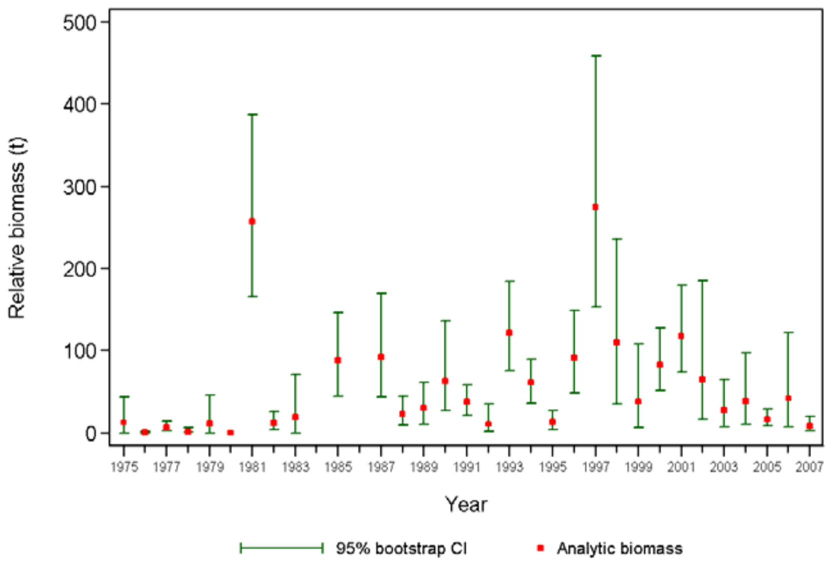

Figure 26. Relative biomass estimates for darkblotched rockfish from the WCVI shrimp trawl survey for the period 1975 to 2007. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

Table 29. Relative biomass estimates for darkblotched rockfish from the WCVI shrimp trawl survey for the survey years 1975 to 2007. Biomass estimates are based on a post-stratification of this survey into two strata (Figure 22) 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. –: not applicable.

Survey Year	Relative biomass (t)	Mean bootstrap biomass (t)	Lower 95% bound biomass (t)	Upper 95% bound biomass (t)	Bootstrap CV	Analytic CV
1975	12.6	12.7	0.0	43.6	0.899	0.910
1976	0.7	0.6	0.0	1.8	0.704	0.705
1977	6.7	6.6	3.0	14.7	0.412	0.411
1978	1.8	1.8	0.2	6.4	0.834	0.790
1979	11.5	11.4	0.0	46.0	0.977	1.000
1980	0	0	–	–	–	0.000
1981	257.5	258.5	165.5	388.0	0.219	0.218
1982	12.1	12.0	3.2	26.2	0.493	0.479
1983	19.2	20.3	0.0	70.8	0.957	1.000
1985	88.8	90.6	44.2	146.3	0.298	0.306

Survey Year	Relative biomass (t)	Mean bootstrap biomass (t)	Lower 95% bound biomass (t)	Upper 95% bound biomass (t)	Bootstrap CV	Analytic CV
1987	92.3	90.9	43.7	169.7	0.359	0.363
1988	22.9	23.1	9.3	44.2	0.372	0.358
1989	30.5	30.0	10.6	60.7	0.422	0.392
1990	63.2	64.1	26.7	136.7	0.422	0.417
1991	38.0	38.2	21.0	57.8	0.247	0.264
1992	11.0	10.4	1.2	35.1	0.760	0.754
1993	121.9	122.6	75.5	183.9	0.225	0.222
1994	61.7	62.0	35.3	90.0	0.230	0.239
1995	13.2	13.2	3.8	26.8	0.438	0.452
1996	91.4	91.6	48.6	149.0	0.280	0.279
1997	275.2	278.0	153.4	458.9	0.280	0.284
1998	110.3	111.7	34.4	236.3	0.459	0.468
1999	38.1	37.3	6.7	108.2	0.661	0.673
2000	82.8	82.2	51.3	127.7	0.232	0.226
2001	118.0	116.9	74.1	179.6	0.223	0.223
2002	65.1	63.7	16.3	185.5	0.651	0.666
2003	28.0	28.7	7.8	64.9	0.517	0.517
2004	38.4	38.4	10.1	97.2	0.560	0.579
2005	16.6	16.5	8.5	28.6	0.304	0.315
2006	42.3	43.4	7.0	121.5	0.708	0.698
2007	8.2	8.2	2.5	20.1	0.551	0.558

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 27). 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 30). 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 27). Stratum 111 has been discarded as its location is not considered good habitat for rockfish species and no darkblotched 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 31). 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 31).

Table 30. 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 darkblotched 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 28), so there was no need to truncate the tows at depth to ensure comparability across survey years.

Table 31. 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

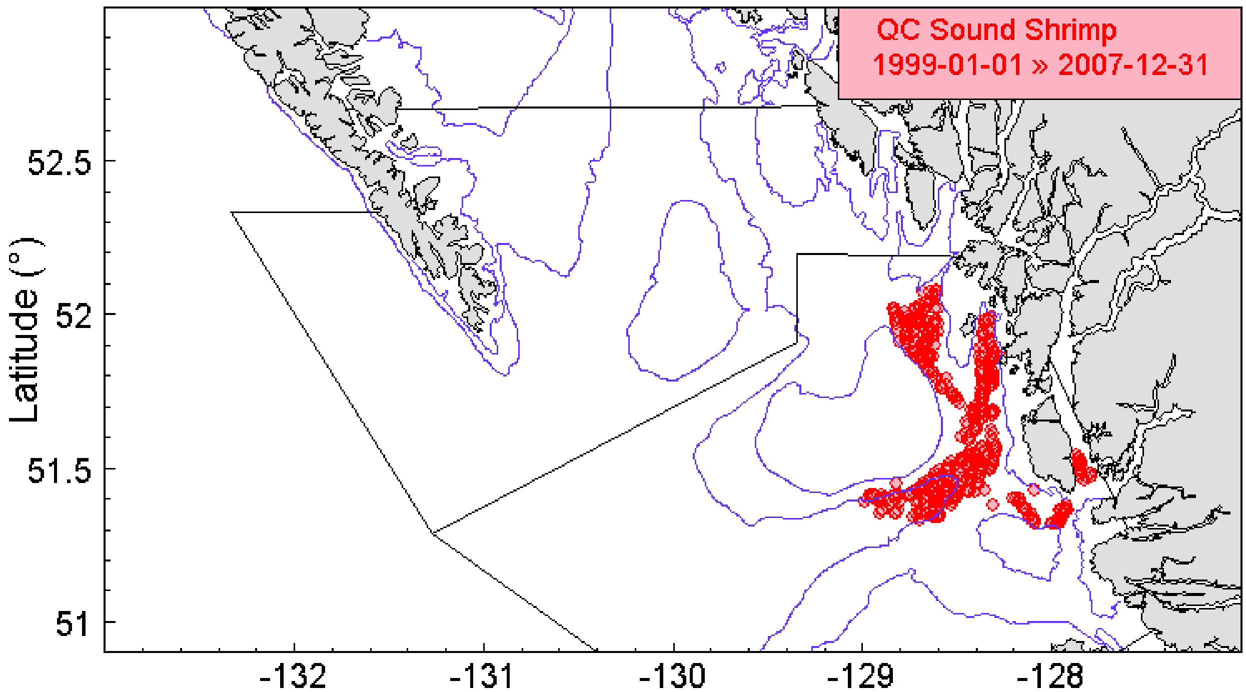

Figure 27. Map showing the locations of valid tows (Stratum numbers 109, 110, 111) conducted by the Queen Charlotte Sound shrimp survey over the period 1999 to 2007. The tows on the inside of Calvert Island represent Stratum 111 which was not used in the analysis of this survey for darkblotched rockfish.

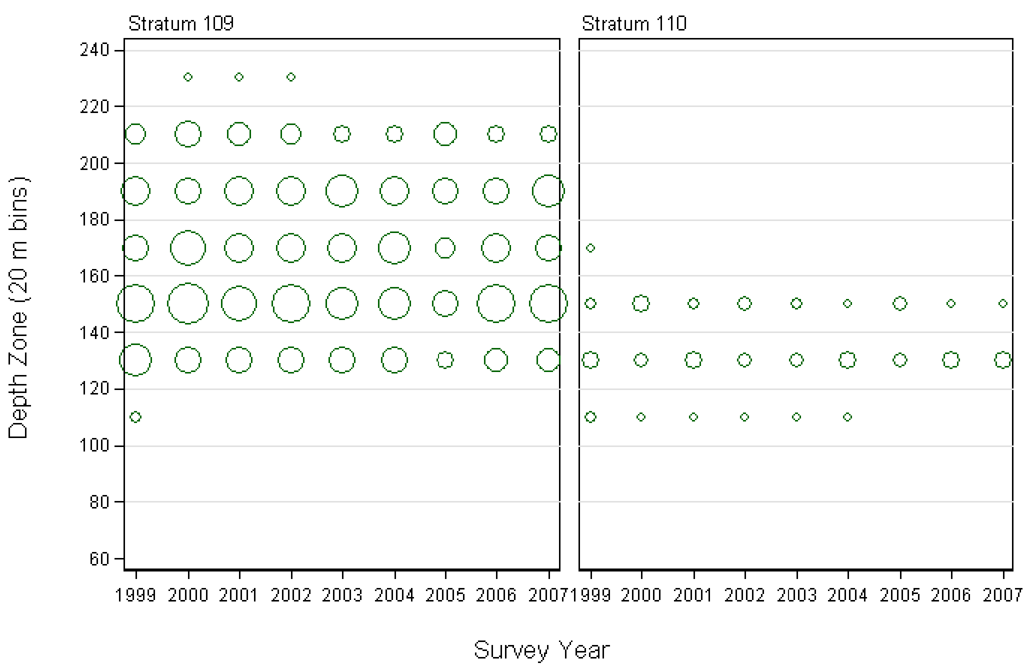

Figure 28. Distribution of tows by stratum, survey year and 20 m depth zone. Depth zones are indicated by the centre of the depth interval, weighted by the number of tows. Maximum circle size: Stratum 109=26 tows (150 m bin); Stratum 110=5 tows (130 m bin). Depth is the mean of the start and end depths for the tow.

4.6.2. Results

Catches of darkblotched rockfish tend to be distributed along the trench of Goose Island Gully and along the shelf edge of the outside islands (Figure 29). Darkblotched rockfish were mainly taken at depths from 150 to 210 m and very few were taken in Stratum 110 at any depth (Figure 30).

Estimated relative biomass levels for darkblotched rockfish from the QC Sound shrimp trawl survey are relatively small and highly variable (Figure 31; Table 32). Two survey years (2001 and 2002) stand as being higher and even the CVs are highly variable ranging between 19% and 64% (Table 32). The proportion of tows which took darkblotched rockfish is also highly variable between surveys and can take high values, going over 80% in Stratum 109 and 70% in Stratum 110 in 2001, which dropping to low levels in both strata in 2004 and 2005 (not presented). The high level of variability demonstrated by this species in this survey indicates that it is probably not a strong candidate for long-term monitoring of this species.

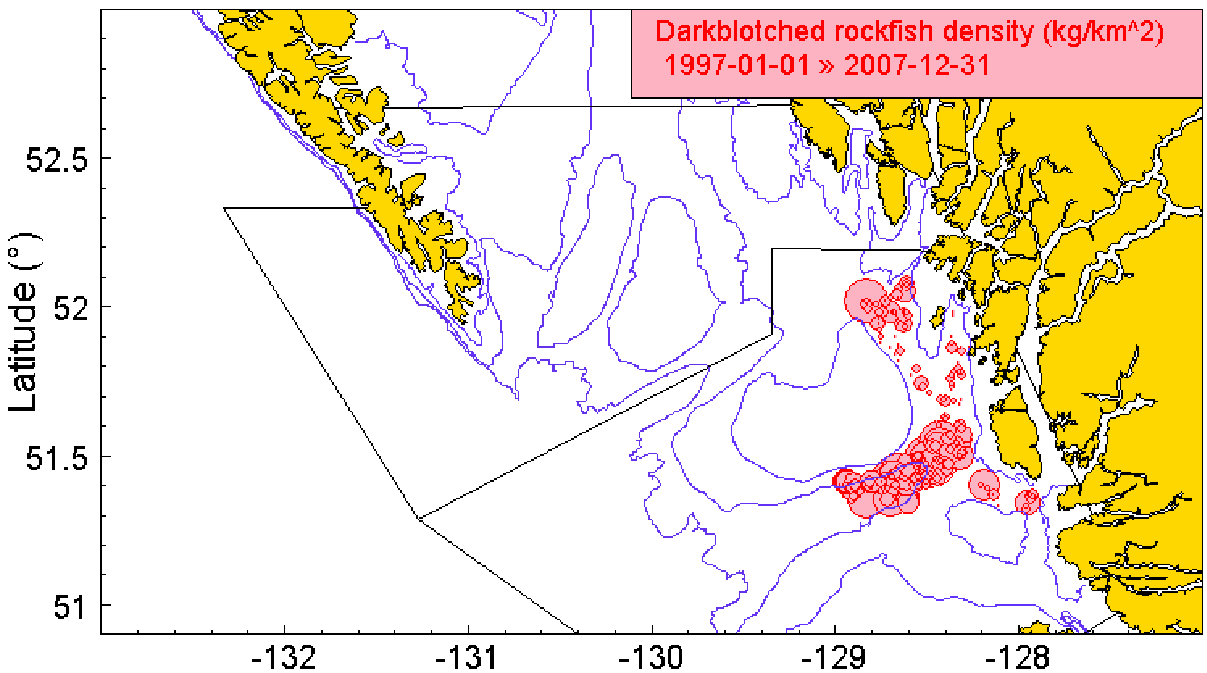

Figure 29. Map of the locations of all trawls from the Queen Charlotte Sound shrimp trawl survey (1999–2007) which caught darkblotched rockfish. Circles are proportional to catch density (largest circle=0.345 kg/km^2). Also shown are the 100, 200 and 300 m isobaths and the area stratum boundaries for the Queen Charlotte Sound synoptic survey.

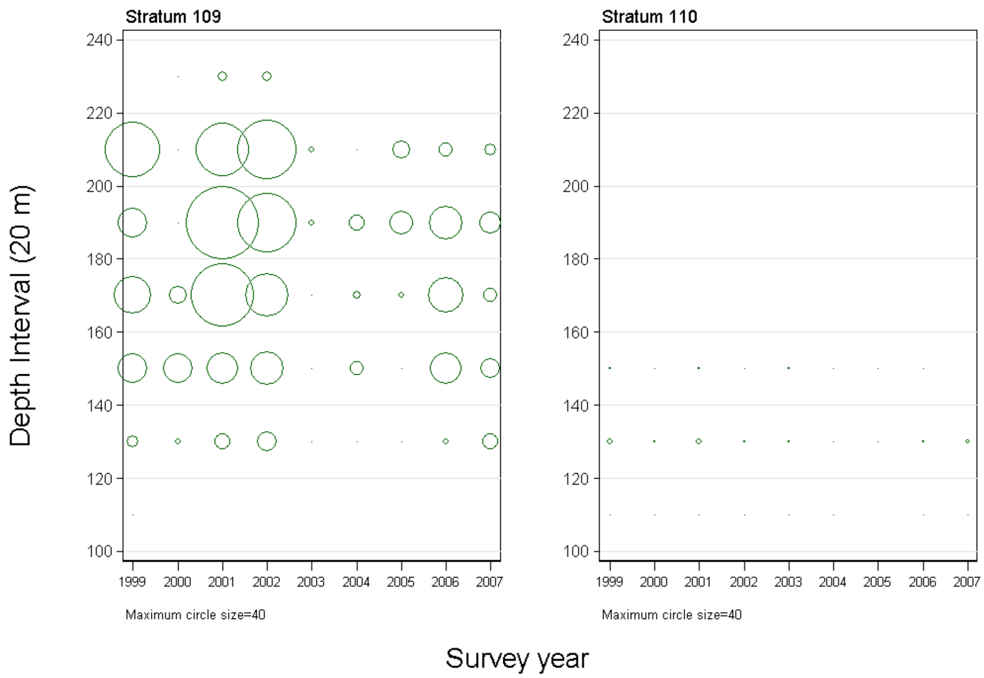

Figure 30. Distribution of catch weight of darkblotched rockfish (DBR) by stratum (Table 31), survey year and 20 m depth zone. Depth zones are indicated by the centre of the depth interval. Maximum circle size: Stratum 109=40 kg (190 m bin). Minimum depth observed for DBR: 117 m; maximum depth observed for DBR: 221 m. Depth is determined by the depth at the start of the tow.

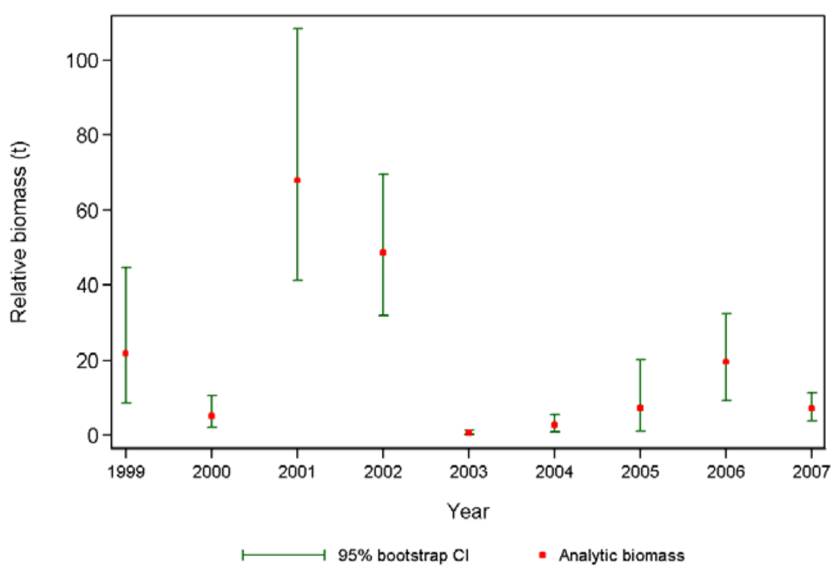

Figure 31. Relative biomass estimates for darkblotched rockfish from the QC Sound shrimp trawl survey for 1999 to 2007. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

Table 32. Relative biomass estimates for darkblotched 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	21.9	21.9	8.6	44.7	0.408	0.403
2000	5.2	5.1	2.1	10.6	0.397	0.389
2001	68.0	67.2	41.3	108.2	0.247	0.241
2002	48.7	48.8	32.0	69.7	0.193	0.200
2003	0.7	0.7	0.2	1.4	0.418	0.403
2004	2.9	2.9	0.9	5.6	0.413	0.424
2005	7.3	7.1	1.2	20.1	0.641	0.656
2006	19.6	19.5	9.2	32.4	0.302	0.309
2007	7.3	7.3	3.8	11.4	0.261	0.271

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 32). 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 34). 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 32). The NMFS designations were accepted for tows located near the marine border.

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 darkblotched 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 34). Strata that were not surveyed consistently in all seven years of the survey were dropped from the analysis (Figure 32; Table 34), allowing the remaining data to provide a comparable set of data for each year from 1989 onwards (Table 35).

The strata definitions used in the 1980 and 1983 surveys were considerably different than those used in subsequent surveys, particularly in Canadian waters (Table 35). 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 35). This is because the size of the total area fished was about twice as large in Canadian waters than in US waters (Table 35).

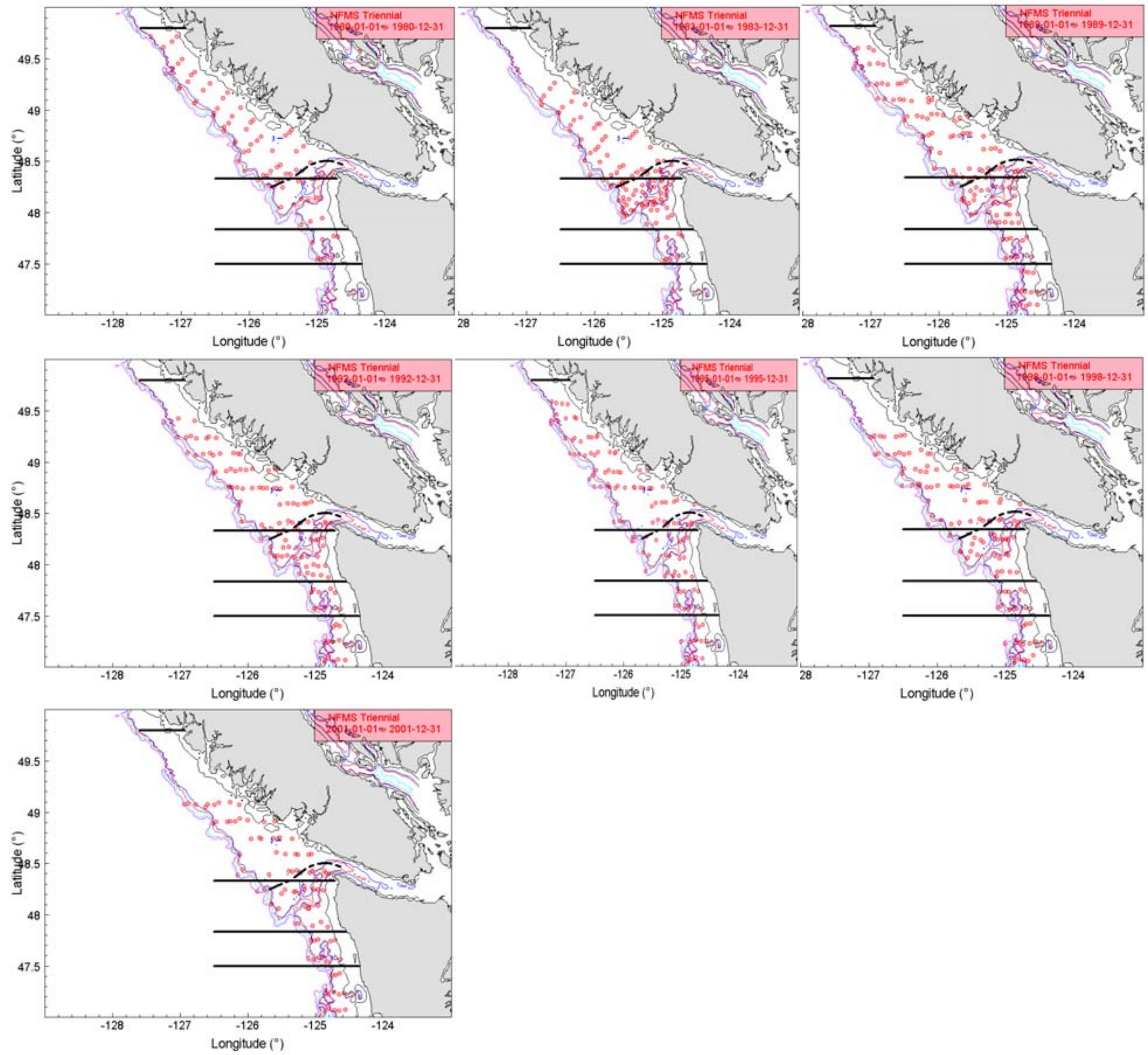

Figure 32. Plot of tow locations in the Vancouver INPFC region for each of the seven triennial surveys that surveyed Canadian waters. Dashed line shows approximate position of the US/Canada marine boundary. Horizontal lines are the stratum boundaries: 47°30′, 47°50′, 48°20′ and 49°50′. Tows south of the 47°30′ line were not included in the analysis. Isobaths act as stratum boundaries at 55, 183, 220, 366, and 500 m.

Table 33. 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 34).

Stratum No.	**1980**		**1983**		**1989**		**1992**		**1995**		**1998**		**2001**	
	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

Stratum No.	1980		1983		1989		1992		1995		1998		2001	
	Can	US	Can	US	Can	US	Can	US	Can	US	Can	US	Can	US
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**

Table 34. Stratum definitions by year used in the NMFS triennial survey to separate out the survey results by country and INPFC area. Stratum definitions in grey 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 35. 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.

	Number tows			Area surveyed (km^2)		
Survey year	Canadian waters	US waters	Total	Canadian waters	US waters	Total
1980	59	26	85	7,399	4,738	12,137
1983	47	70	117	7,399	4,738	12,137
1989	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 data were analysed using the swept-area biomass formulae in (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:

$$B_{yic} = B_{yi} \frac{A_{yic}}{A_{yi}} \tag{2}$$

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:

$$V_{yic} = V_{yi} \frac{A_{yic}^2}{A_{yi}^2} \tag{3}$$

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 35. 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 darkblotched rockfish occurred in US waters in 2001. The remaining catches of this species in 2001 and earlier years were much smaller and barely register on the plots compared to the one large catch (Figure 33). The northern extension of the survey has varied between years (Figure 33), 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, but the single large catch of darkblotched also skews this plot (Figure 34).

The relative biomass estimates from this survey for darkblotched show an increasing but imprecise trend from 1989 to 1998 in Canadian waters and no trend over the same period in the US waters (Figure 35; Table 36). The single large tow in 2001 in US Vancouver caused a large increase in the US waters biomass estimate and an equally large CV (near to 1.0; Table 36). Concurrently, the Canadian waters biomass estimate is the lowest in the series. High CVs (range: 33 to 94%) are associated with all biomass indices, indicating that these estimates probably have low reliability (Table 36). Therefore it is difficult to conclude much from this series other than there is little evidence for any trend, either up or down, in this region. 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.

Of the 697 tows in this data set, 182 caught darkblotched rockfish over the entire history of the survey. The US waters consistently reported a higher proportion of tows with darkblotched rockfish than in the Canadian waters in each survey year, with the Canadian waters ranging from 11 to 33% of the tows with darkblotched while the US waters varied between 23 and 37% of the tows with darkblotched.

Table 36. Relative biomass estimates for darkblotched 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	180	180	60	384	0.456	0.470
	1983	526	509	201	1,142	0.444	0.437
	1989	432	423	223	774	0.318	0.341
	1992	722	725	289	1,382	0.380	0.397
	1995	916	914	405	1,594	0.329	0.339
	1998	1,090	1,086	485	2,024	0.355	0.363
	2001	1,160	1,009	53	2,299	0.828	0.921
Canada Vancouver	1980	127	128	15	337	0.644	0.668
	1983	233	234	54	529	0.505	0.506
	1989	132	132	24	359	0.640	0.654
	1992	358	359	88	935	0.593	0.603
	1995	596	598	190	1,163	0.416	0.430
	1998	740	741	213	1,564	0.453	0.463
	2001	25	25	8	51	0.421	0.426

Estimate type	Survey Year	Relative biomass (t)	Mean bootstrap biomass	Lower bound biomass	Upper bound biomass	Bootstrap CV	Analytic CV
US Vancouver	1980	55	54	10	114	0.487	0.510
	1983	272	257	50	742	0.673	0.651
	1989	300	292	155	475	0.289	0.336
	1992	365	367	108	764	0.455	0.487
	1995	320	316	137	553	0.334	0.331
	1998	350	345	155	692	0.385	0.386
	2001	1,135	984	28	2,271	0.849	0.942

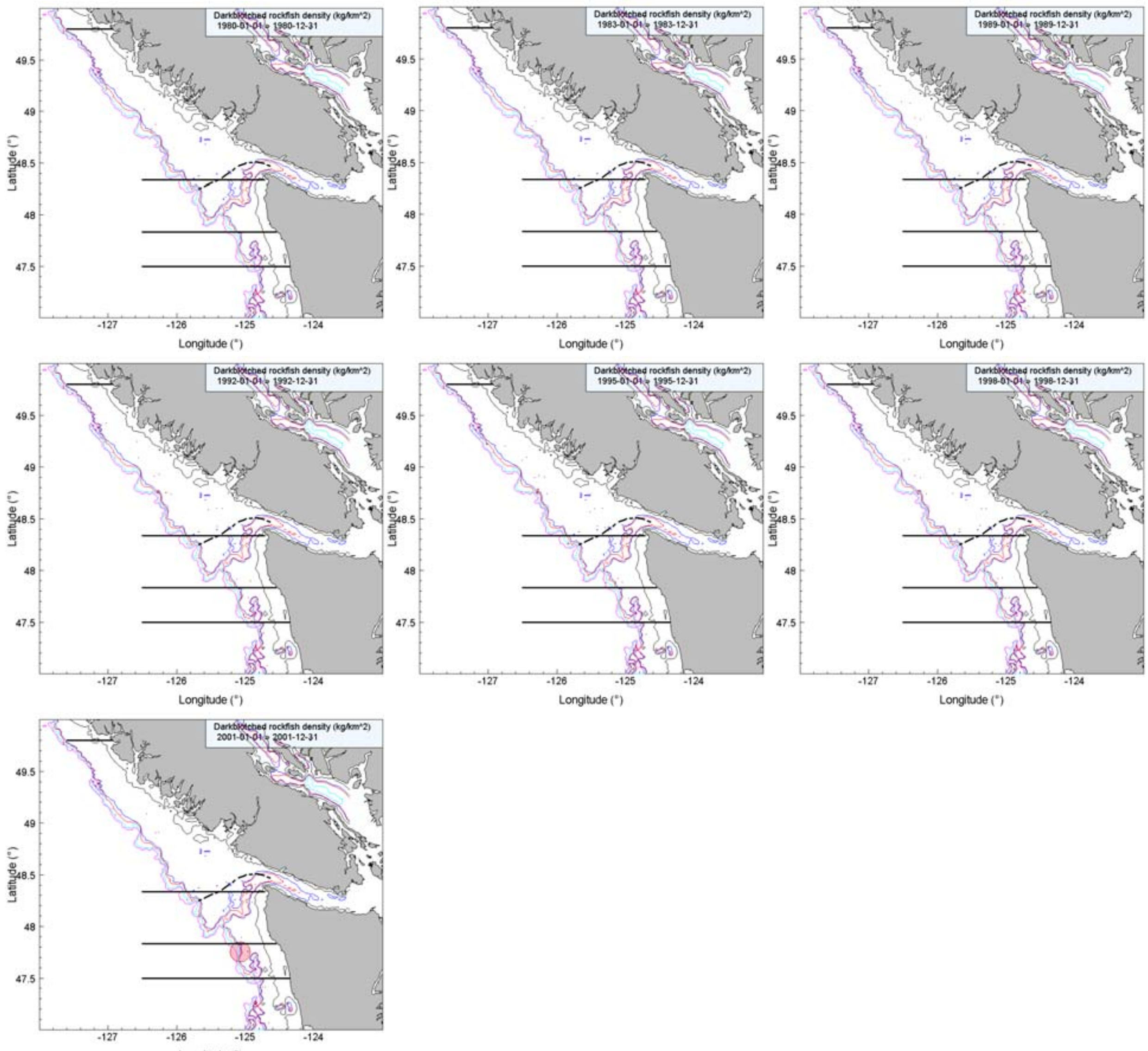

Figure 33. Plot of valid tows, weighted by the density of darkblotched rockfish, in the Vancouver INPFC region for the seven triennial surveys that surveyed Canadian waters. Catches in each year are scaled to the weight of the largest density of darkblotched rockfish (17,131 kg/km^2 in 2001). The approximate 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'.

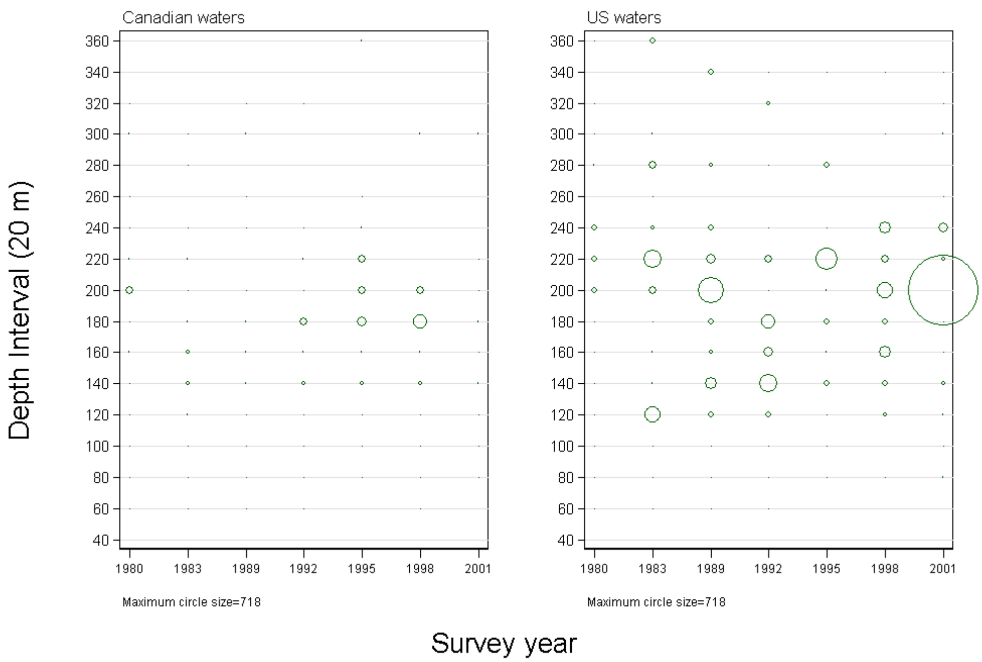

Figure 34. Distribution of darkblotched rockfish catch weights for each survey year summarised into 20 m depth intervals for all valid tows (Table 34) in Canadian and US waters of the Vancouver INPFC area. Depth intervals are labelled with the mid-point of the interval.

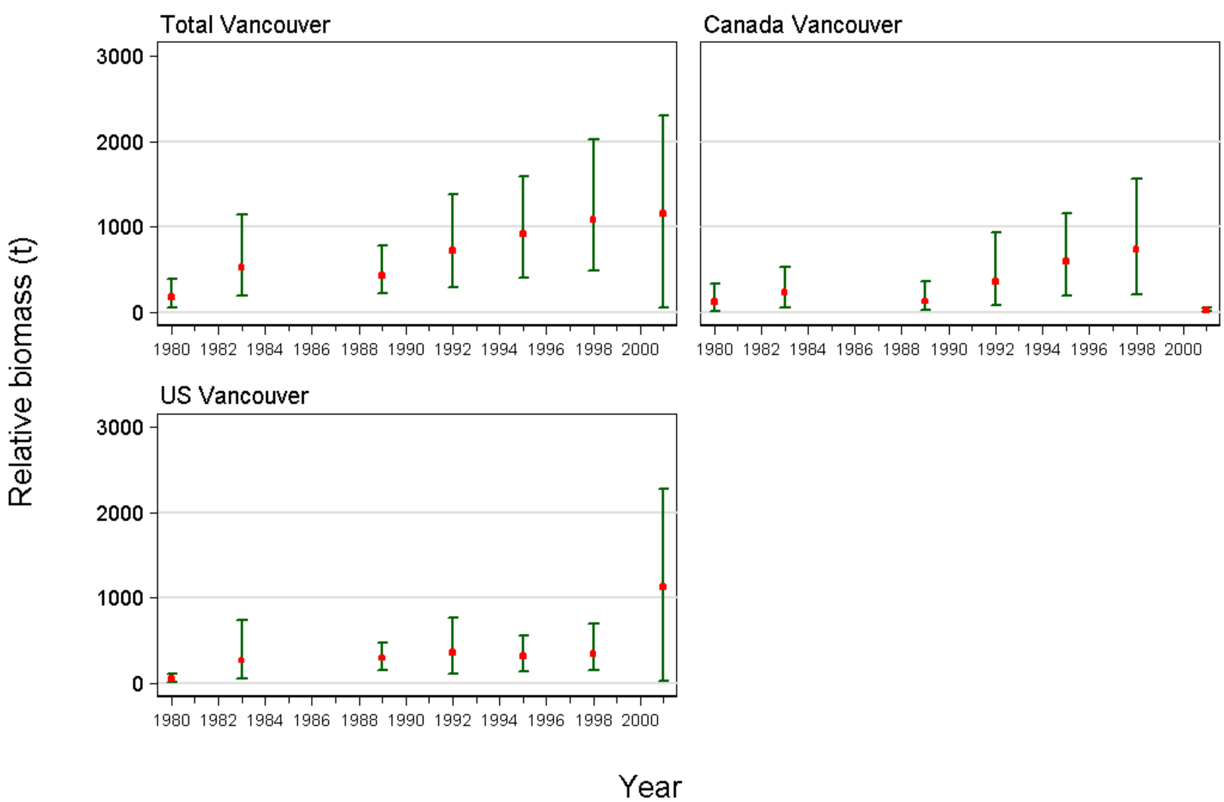

Figure 35. Relative biomass estimates for darkblotched rockfish in the INPFC Vancouver region (total region, Canadian waters only, and US waters only) with 95% bias corrected error bars estimated from 5000 bootstraps.

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 darkblotched rockfish would probably not render reliable or useful commercial CPUE analyses.

A summary of the darkblotched rockfish CPUE trend for the BC coast (Figure 36) shows an annual decline of 3.9% per year from 1996 to 2006, although the index has been relatively flat from 1998 on. 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.

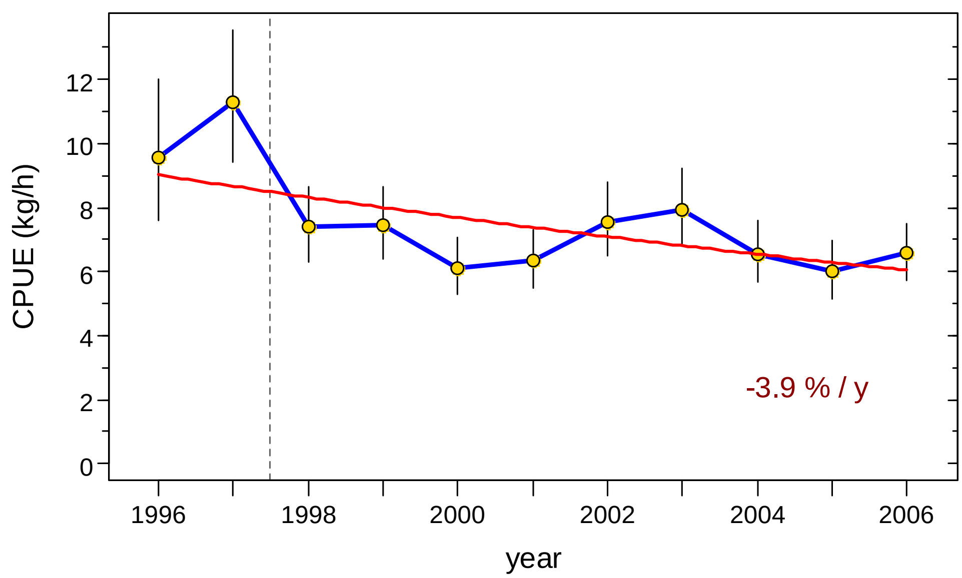

Figure 36. Annual index trend in darkblotched rockfish commercial trawl CPUE data (1996-2006) using a GLM analysis with five factors: year, month, depth, latitude, and vessel (see Appendix C for details). The error bars show 95% confidence intervals. The vertical dashed line indicates period of adjustment (see text).

Darkblotched rockfish remains a bycatch species that is not controlled by any catch quotas. Consequently, the dependence of CPUE on fishing behaviour will only manifest itself if darkblotched spatial distributions match those of other quota species (a highly likely scenario). Aside from fishing behaviour effects, large-scale changes in abundance should be reflected in the

CPUE signal, 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 darkblotched rockfish *Sebastes crameri* 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.

The Canadian commercial trawl fleet captures this species in low numbers as bycatch to the important Pacific ocean perch *S. alutus* fishery. 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. The highest concentrations occur along the shelf northwest of Vancouver Island and in Moresby Gully southeast of the Queen Charlotte Islands.
- Little ageing information exists. The early otolith specimens (from 1969) should be re-analysed (if still available) using break and burn technology to assess mortality rates that might reflect natural mortality. Additionally, any other existing otoliths should be flagged for processing.
- The long-term indices (GB Reed, WCVI shrimp, QCI shrimp) all exhibit high CVs for this species. Index peaks (GB Reed: 1976; WCVI: 1981, 1997; QCI: 2001) might indicate large recruitment events; however, none of these surveys cover the high-density centres mentioned above. The anomalies are likely due to occasional tows containing many darkblotched rockfish.
- The triennial US NMFS survey shows increasing, non-significant trends for darkblotched along the WCVI.
- The set of groundfish synoptic surveys initiated in 2003 offer the best hope for monitoring this species in future, although the index imprecision may hamper the detection of abundance changes. The QCS survey thus far, shows a flat trend.
- GLM analysis of commercial trawl fishing catch and effort data collected since 1996 shows an annual CPUE decline of 3.9%/year from 1996 to 2006, with a relatively flat trend since 1998. 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.

7. References

Barrie, V., Bornhold, B.D., Conway, K.W., and Luternauer, J.L. 1991. Surficial geology of the northwestern Canadian continental shelf. Continental Shelf Research 11(8-10): 701-715.

Boutillier, J.A., and Olsen, N. 2000. Shrimp Survey Bulletin 00-04: Results of the Queen Charlotte Sound Shrimp Survey. Shrimp Trawl Homepage, Shellfish - Pacific Region. http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/shellfish/shrimp/default.htm.

Hart, J.L. 1973. Pacific fishes of Canada. Bulletins of the Fisheries Research Board of Canadian 180. Reprinted 1988. 740 pp.

Heifetz, J. Ianelli, J.N., Clausen, D.M., Courtney, D.L., and Fujioka, J.T. 2000. Section 6: Slope rockfish. In: 2000 Groundfish Stock Assessment and Fishery Evaluation (SAFE) Reports, North Pacific Fishery Management Council, Anchorage, AK. 63 pp.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. U.S. Fisheries Bulletin 82: 898-903.

Johnstone, K. 1977. The Aquatic Explorers: A History of the Fisheries Research Board of Canada. University of Toronto Press, Toronto, Ontario. 342 pp.

Jordan, D.S. 1896. Notes on fishes little known or new to science. Proceedings of the California Academy of Science, 2(6): 201-244.

Kaufman, L. and Rousseeuw, P.J. (1990). Finding Groups in Data: An Introduction to Cluster Analysis. Wiley, New York.

Ketchen, K.S. 1980. Reconstruction of Pacific ocean perch (*Sebastes alutus*) stock history in Queen Charlotte Sound Part I. Estimation of foreign catches, 1956-1976. Canadian Manuscript Report of Fisheries and Aquaculture Sciences 1570. 46 pp.

Leaman, B.M., and Stanley, R.D. 1993. Experimental management programs for two rockfish stocks off British Columbia, Canada, p. 403-418. *In* S.J. Smith , J.J. Hunt, and D. Rivard [ed.]. Risk evaluation and biological reference points for fisheries management. Canadian Special Publication of Fisheries and Aquatic Sciences 120.

Love, M.S., Yoklavich, M., and Thorsteinson, L. 2002. The Rockfishes of the Northeast Pacific. University of California Press, Berkley, California. 405 pp.

Nichol, D.G., and Pikitch, E.K. 1994. Reproduction of darkblotched rockfish off the Oregon coast. Transactions of the American Fisheries Society 123: 469-481.

Richards, L.J. 1994. Trip limits, catch, and effort in the British Columbia rockfish trawl fishery. North American Journal of Fisheries Management 14: 742-750.

Rogers, J.B. 2005. Status of the darkblotched rockfish (*Sebastes crameri*) resource in 2005. In: Status of the Pacific Coast Groundfish Fishery through 2005, Stock Assessment and Fishery Evaluation: Stock Assessments and Rebuilding Analyses (Volume III). Stock Assessment and Fishery Evaluation (SAFE) Documents, Newport, OR. 133 pp. URL: http://www.pcouncil.org/groundfish/gfsafe0406/gfsafe0406.html

Schnute, J. 1981. A versatile growth model with statistically stable parameters. Canadian Journal of Fisheries and Aquatic Sciences 38: 1128-1140.

Schnute, J.T., and Haigh, R. 2007. Compositional analysis of catch curve data, with an application to *Sebastes maliger*. ICES Journal of Marine Science 64: 218-233.

Schnute, J.T., Olsen, N., and Haigh, R. 1999. Slope rockfish assessment for the west coast of Canada in 1998. Canadian Stock Assessment Secretariat Research Document 99/184. 104 pp.

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

Sinclair, A.F., Conway, K.W., and Crawford, W.R. 2005. Associations between bathymetric, geologic and oceanographic features and the distribution of the British Columbia bottom trawl fishery. *In* Theme Session L: The Spatial Dimension of Ecosystem Structure and Dynamics. ICES Annual Science Conference, Aberdeen, Scotland, Sep. 20-24, 2005. CM 2005/L:25. 31 pp.

Stanley, R., Starr, P., Olsen, N., and Haigh, R. 2004. Summary of results of the 2003 Queen Charlotte Sound bottom trawl survey. Canadian Science Advisory Secretariat, Research Document 2004/028. 50 pp.

Stanley, R.D., Starr, P., and Olsen, N. 2007. Status report on canary rockfish (*Sebastes pinniger*). Canadian Science Advisory Secretariat, Research Document 2007/xxx. xx pp.

Westrheim, S.J. 1975. Reproduction, maturation, and identification of larvae of some *Sebastes* (Scorpaenidae) species in the northeast Pacific Ocean. Journal of the Fisheries Research Board of Canada 32: 2399-2411.

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.

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

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

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

$$p_a\left(\Theta\right)=\frac{S_a\beta_aR_a}{\sum_{a=k}^{B}S_a\beta_aR_a};\;\; a=k,\ldots,B \tag{A.4.4}$$

$$p_A\left(\Theta\right)=\sum_{a=A}^{B}p_a\left(\Theta\right) \tag{A.4.5}$$

Calculations depend on a fixed design vector

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

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

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

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

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

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 $\left\{C_{yij},E_{yij}\right\}$ for tows $j=1,\ldots,n_{yi}$,

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

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:

$$\delta_{yi} = \frac{1}{vw} U_{yi}, \quad \text{(A.5.2)}$$

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

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

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:

$$B_y = \sum_{i=1}^{m} \delta_{yi} A_i = \sum_{i=1}^{m} B_{yi}, \quad \text{(A.5.4)}$$

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:

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

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 ($\mathrm{km^2}$) 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 $n_{i=1,\ldots,p}$ 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:

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

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.

References

Akaike, A. 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control AC-19: 716-723.

Francis, R.I.C.C. 1999. The impact of correlations on standardised CPUE indices. New Zealand Fishery Assessment Research Document 1999/42. 30 p. (Unpublished report held in NIWA library, Wellington, New Zealand)

Francis, R.I.C.C. 2001. Orange roughy CPUE on the South and East Chatham Rise. New Zealand Fishery Assessment Report 2001/26. 30 p.

Quinn, T.R. and R.B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press. 542 pp.

Schnute, J.T., and Haigh, R. 2003. A simulation model for designing groundfish trawl surveys. Canadian Journal of Fisheries and Aquatic Sciences. 60: 640-656.

Schnute, J.T., and Haigh, R. 2007. Compositional analysis of catch curve data, with an application to *Sebastes maliger*. ICES Journal of Marine Science 64: 218-233.

Schnute, J., Haigh, R., Krishka, B., Sinclair, A., and Starr, P. 2004. The British Columbia longspine thornyhead fishery: analysis of survey and commercial data (1996-2003). Canadian Science Advisory Secretariat, Research Document 2004/059. 75 p.

Vignaux, M. 1993. Catch per unit effort (CPUE) analysis of the hoki fishery, 1987–92. N.Z. Fisheries Assessment Research Document 93/14. 23 p. (Unpublished report held in NIWA library, Wellington, New Zealand)

Vignaux, M. 1994: Catch per unit effort (CPUE) analysis of west coast South Island and Cook Strait spawning hoki fisheries, 1987–93. N.Z. Fisheries Assessment Research Document 94/11. 29 p. (Unpublished report held in NIWA library, Wellington, New Zealand)

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 darkblotched 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	15,361	2,760
1997	13,544	2,384
1998	11,935	2,000
1999	14,055	2,492
2000	13,161	2,352
2001	11,659	2,072
2002	11,281	2,072
2003	9,698	1,736
2004	11,902	2,036
2005	11,273	1,972
2006	12,258	2,360
1996-2006	30,760	9,232

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.

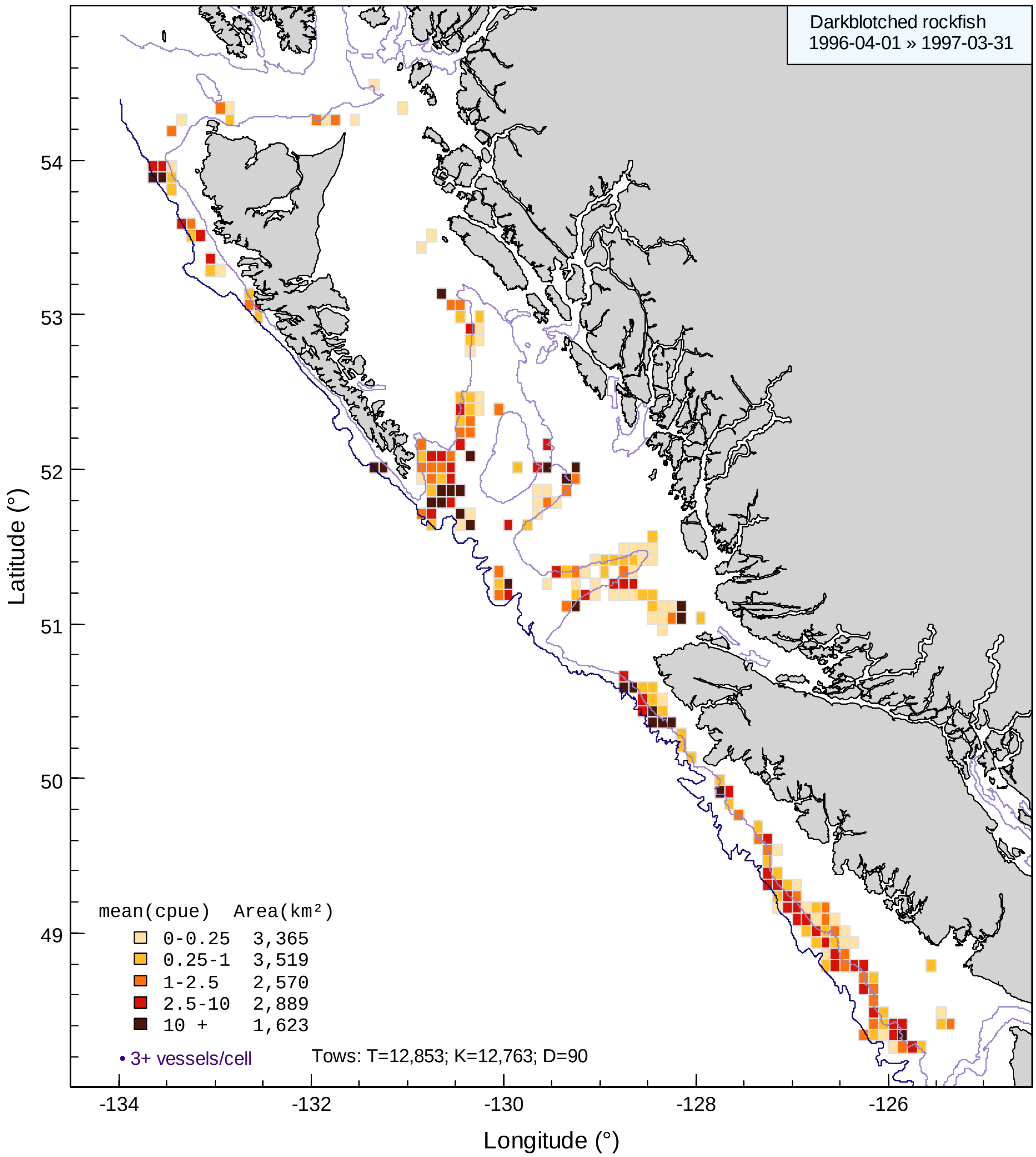

Figure B1. Mean CPUE (kg/h) of darkblotched rockfish caught by the BC trawl fishery from 4/1/96 to 3/31/97. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

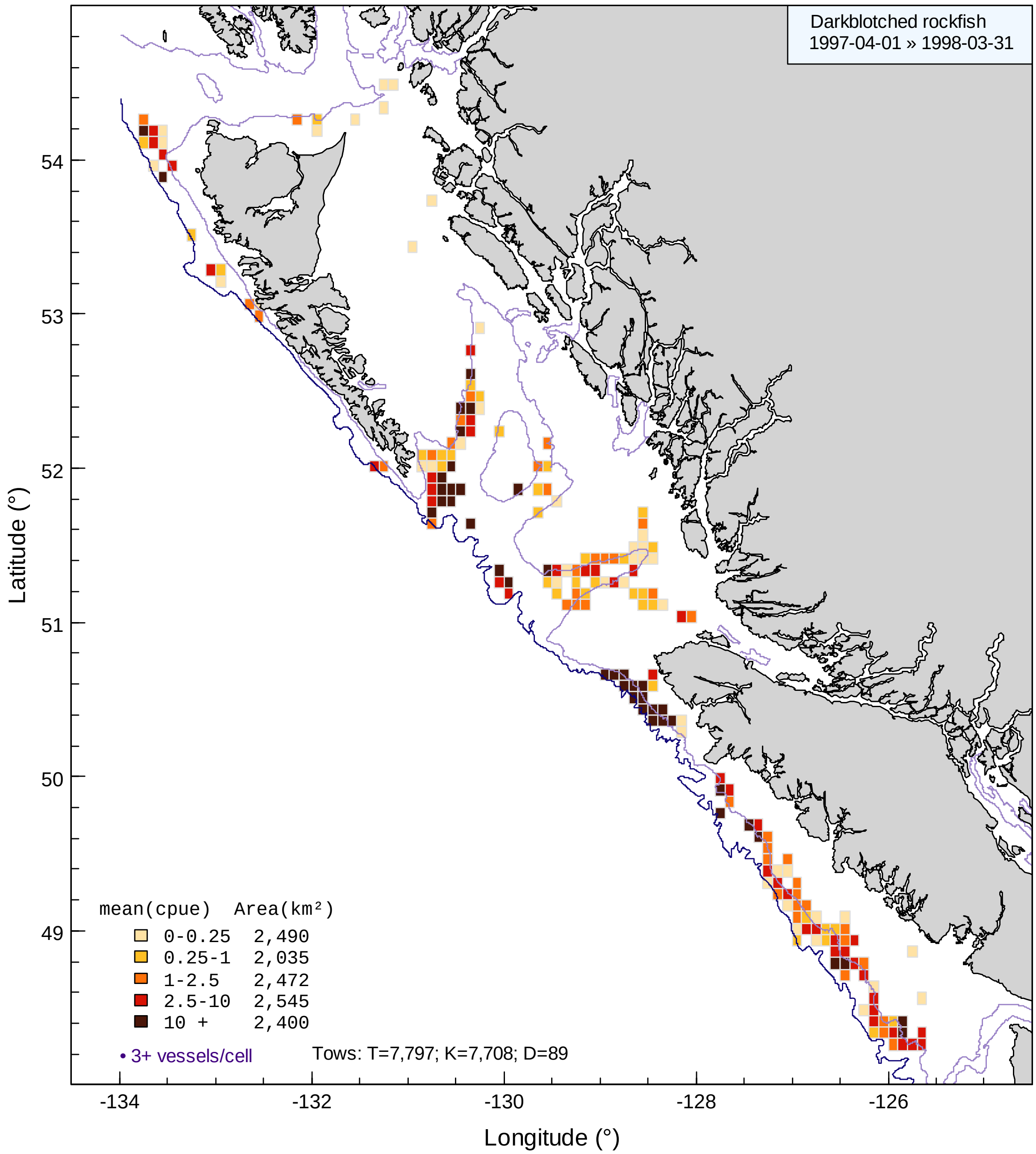

Figure B2. Mean CPUE (kg/h) of darkblotched rockfish caught by the BC trawl fishery from 4/1/97 to 3/31/98. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

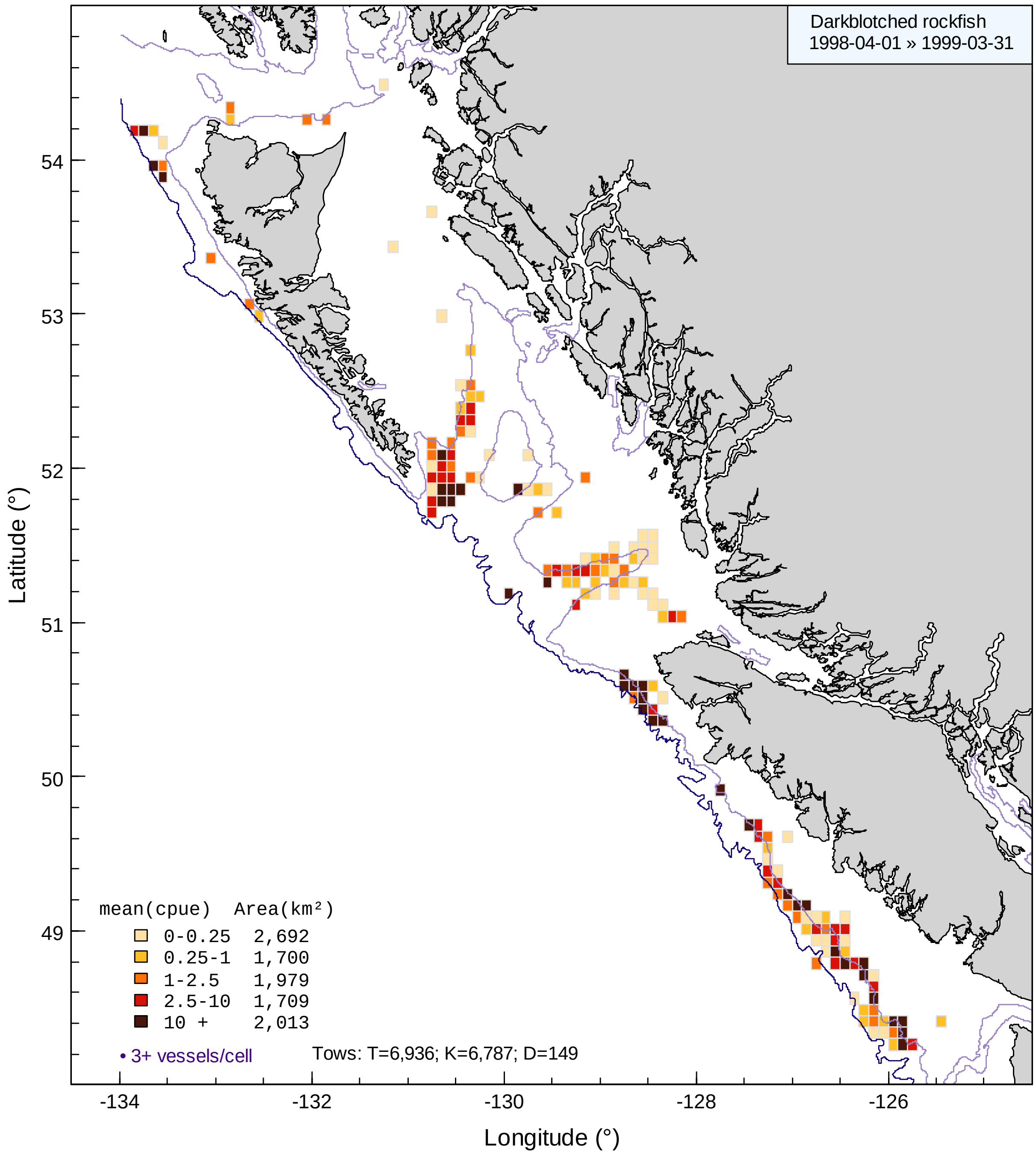

Figure B3. Mean CPUE (kg/h) of darkblotched rockfish caught by the BC trawl fishery from 4/1/98 to 3/31/99. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

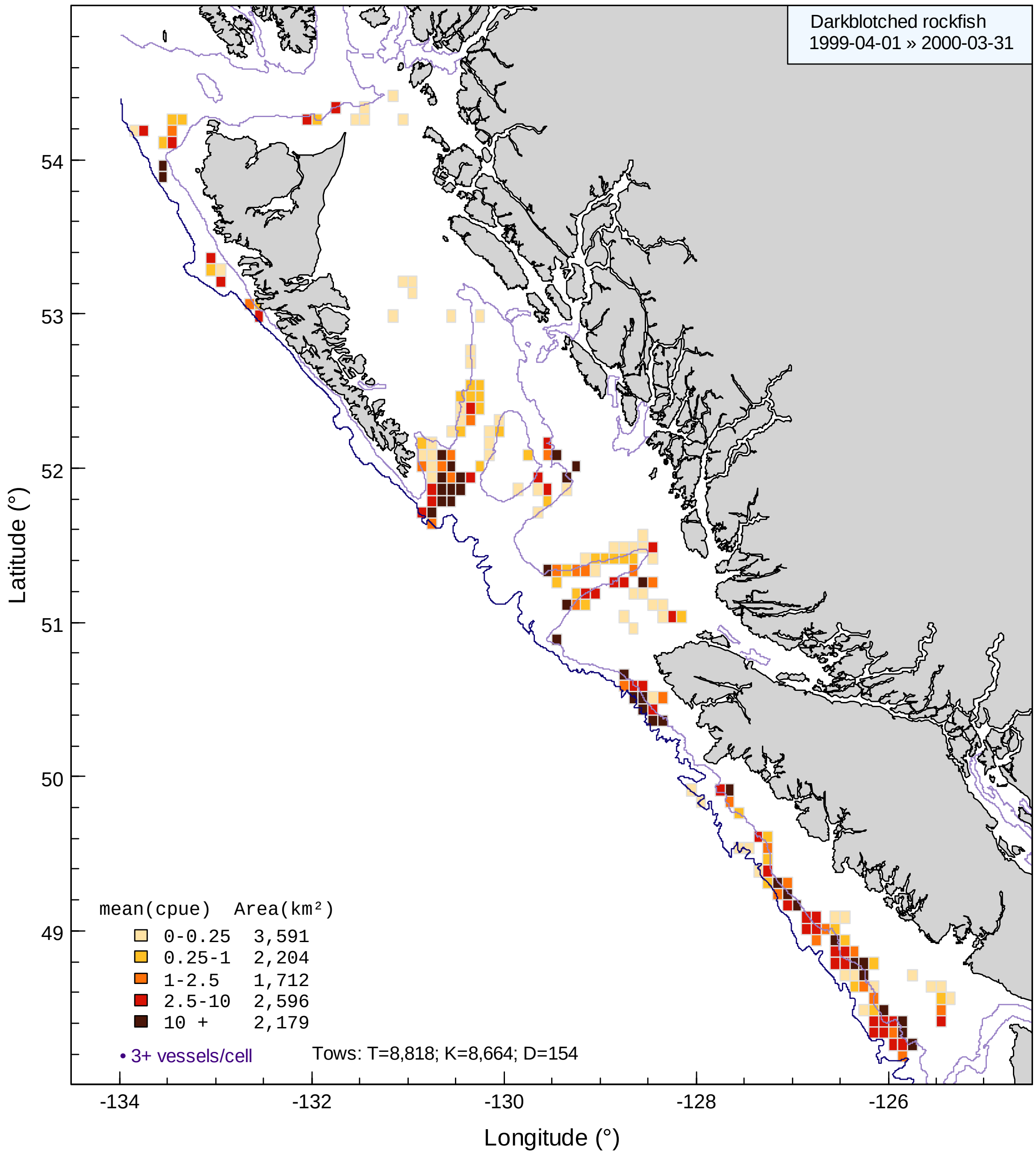

Figure B4. Mean CPUE (kg/h) of darkblotched rockfish caught by the BC trawl fishery from 4/1/99 to 3/31/00. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

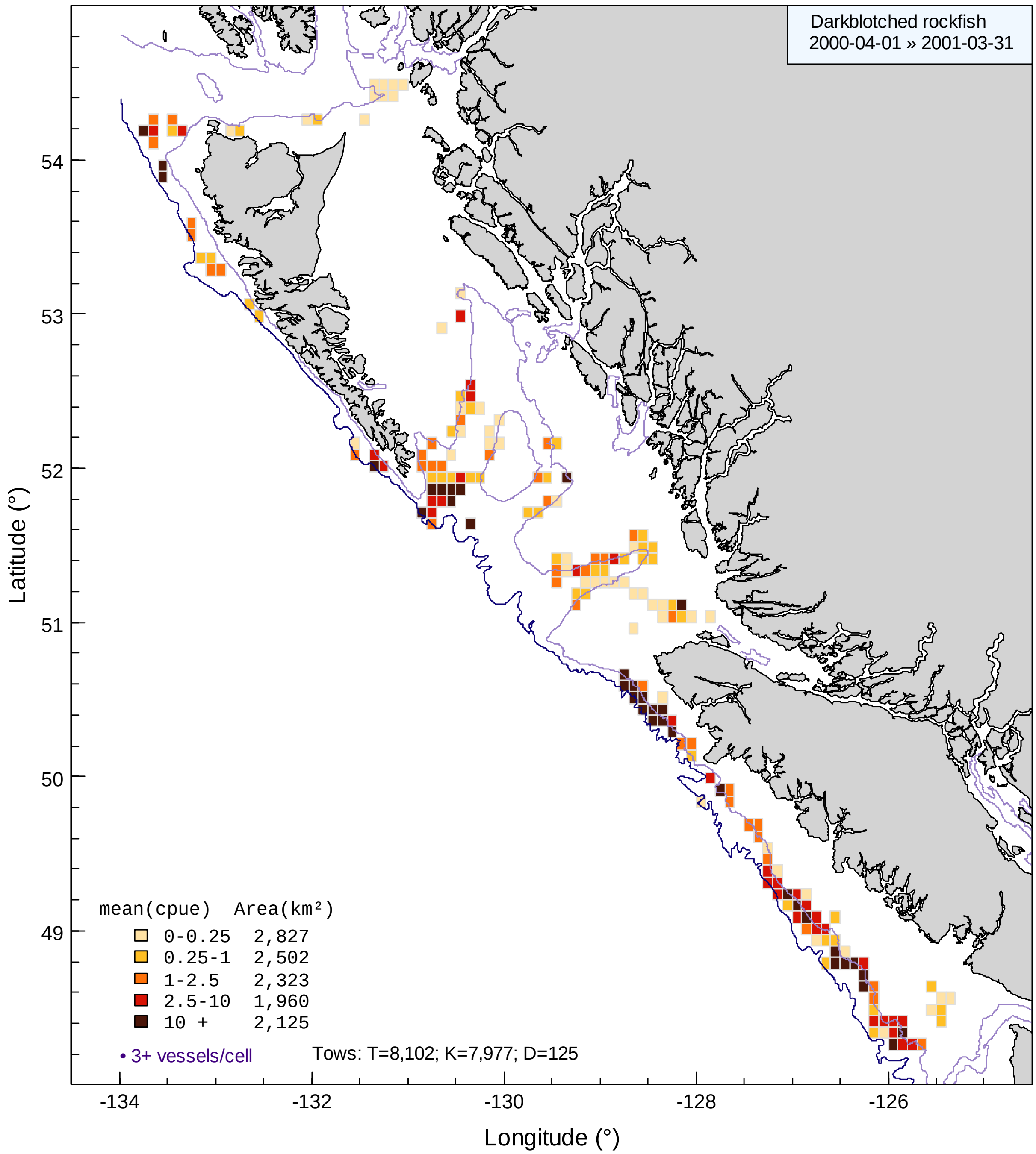

Figure B5. Mean CPUE (kg/h) of darkblotched rockfish caught by the BC trawl fishery from 4/1/00 to 3/31/01. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

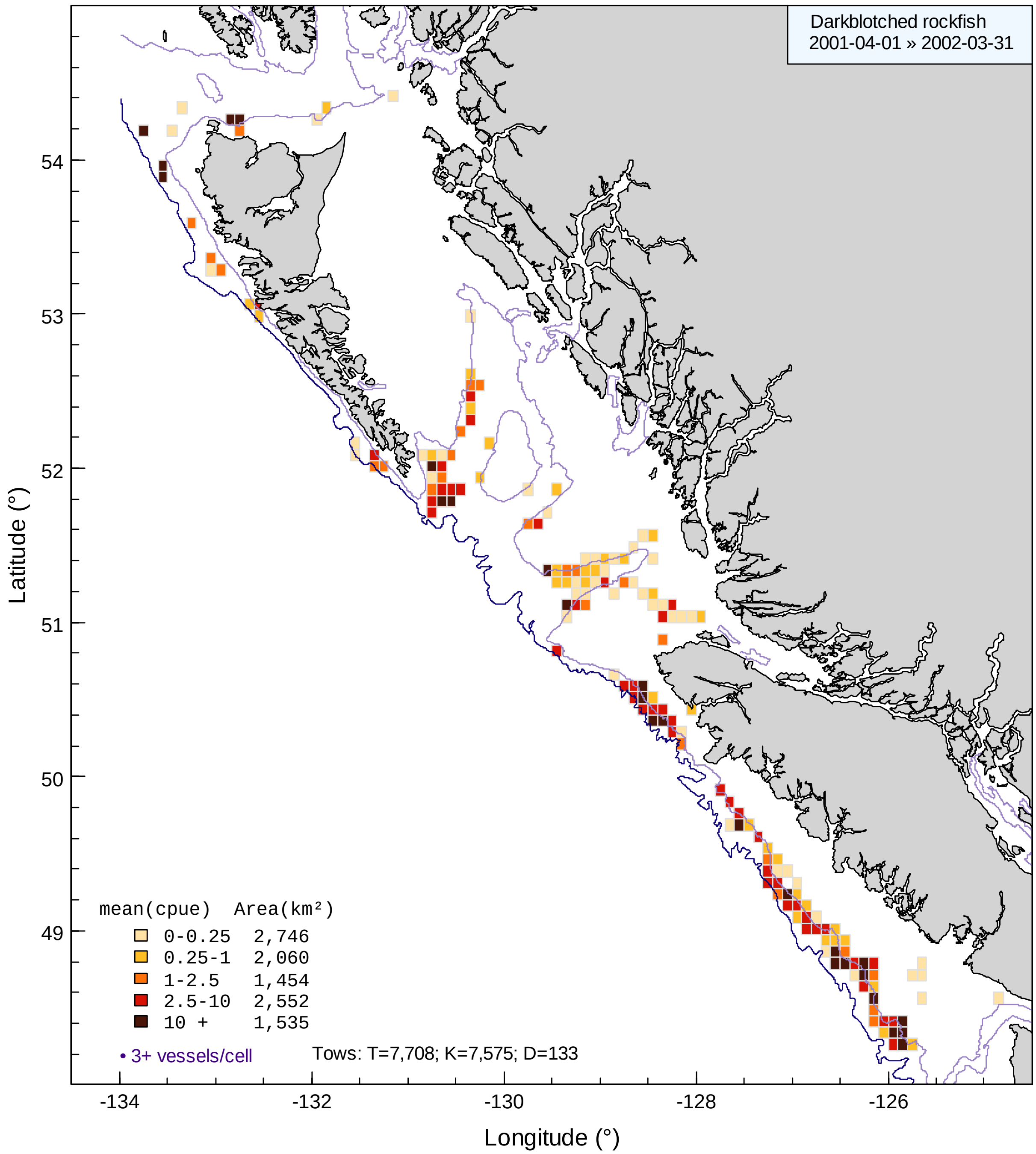

Figure B6. Mean CPUE (kg/h) of darkblotched rockfish caught by the BC trawl fishery from 4/1/01 to 3/31/02. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

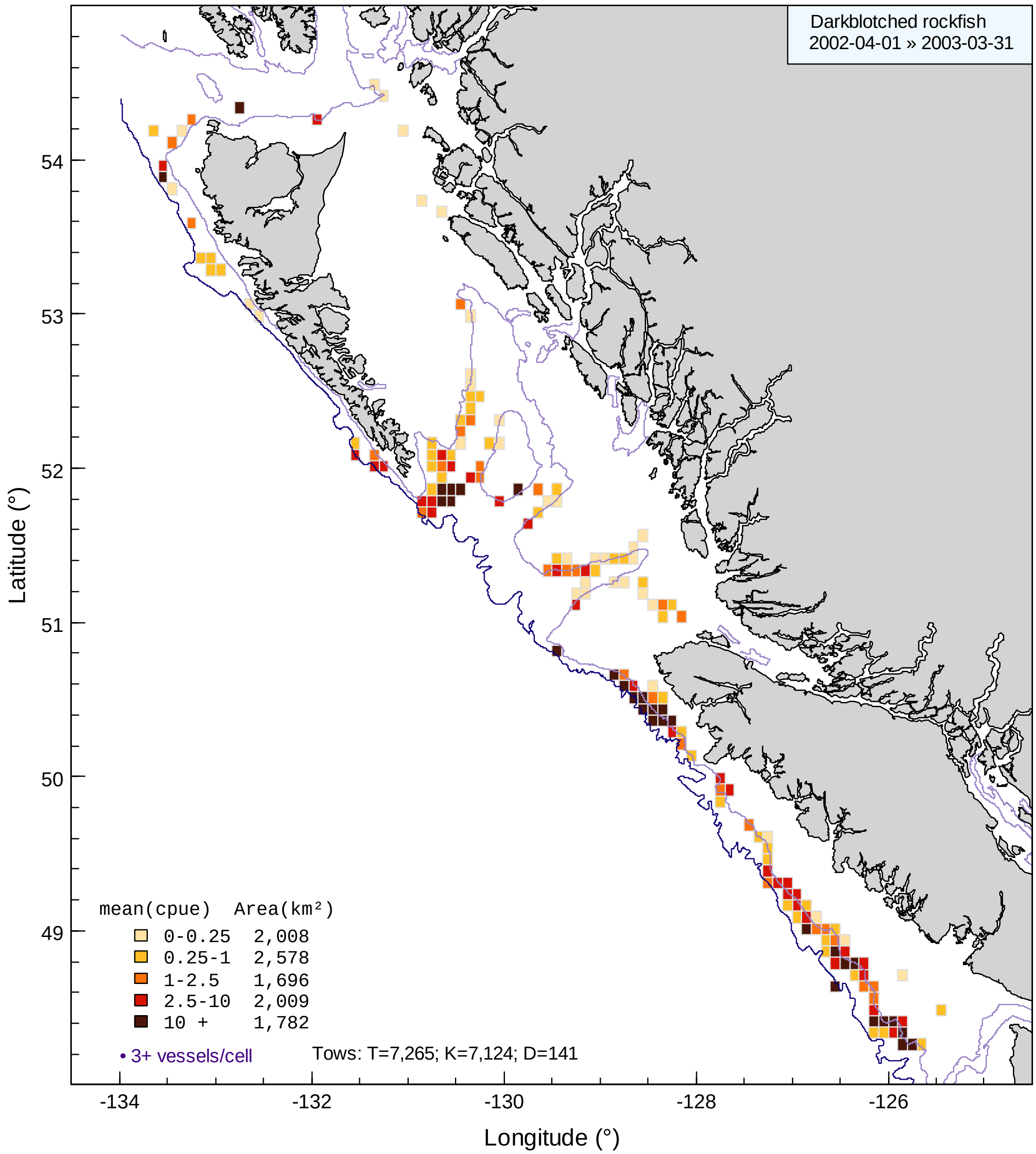

Figure B7. Mean CPUE (kg/h) of darkblotched rockfish caught by the BC trawl fishery from 4/1/02 to 3/31/03. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

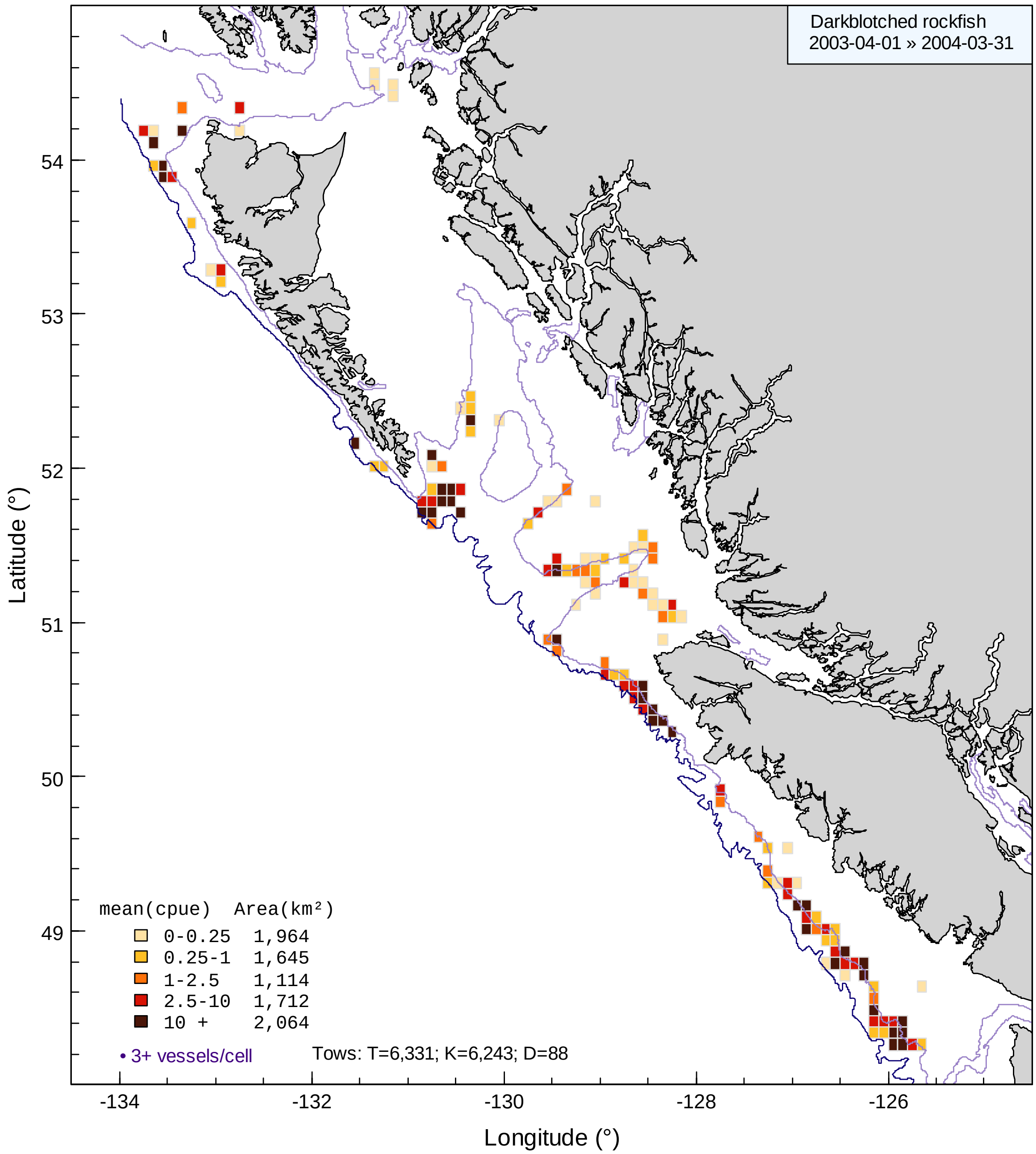

Figure B8. Mean CPUE (kg/h) of darkblotched rockfish caught by the BC trawl fishery from 4/1/03 to 3/31/04. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

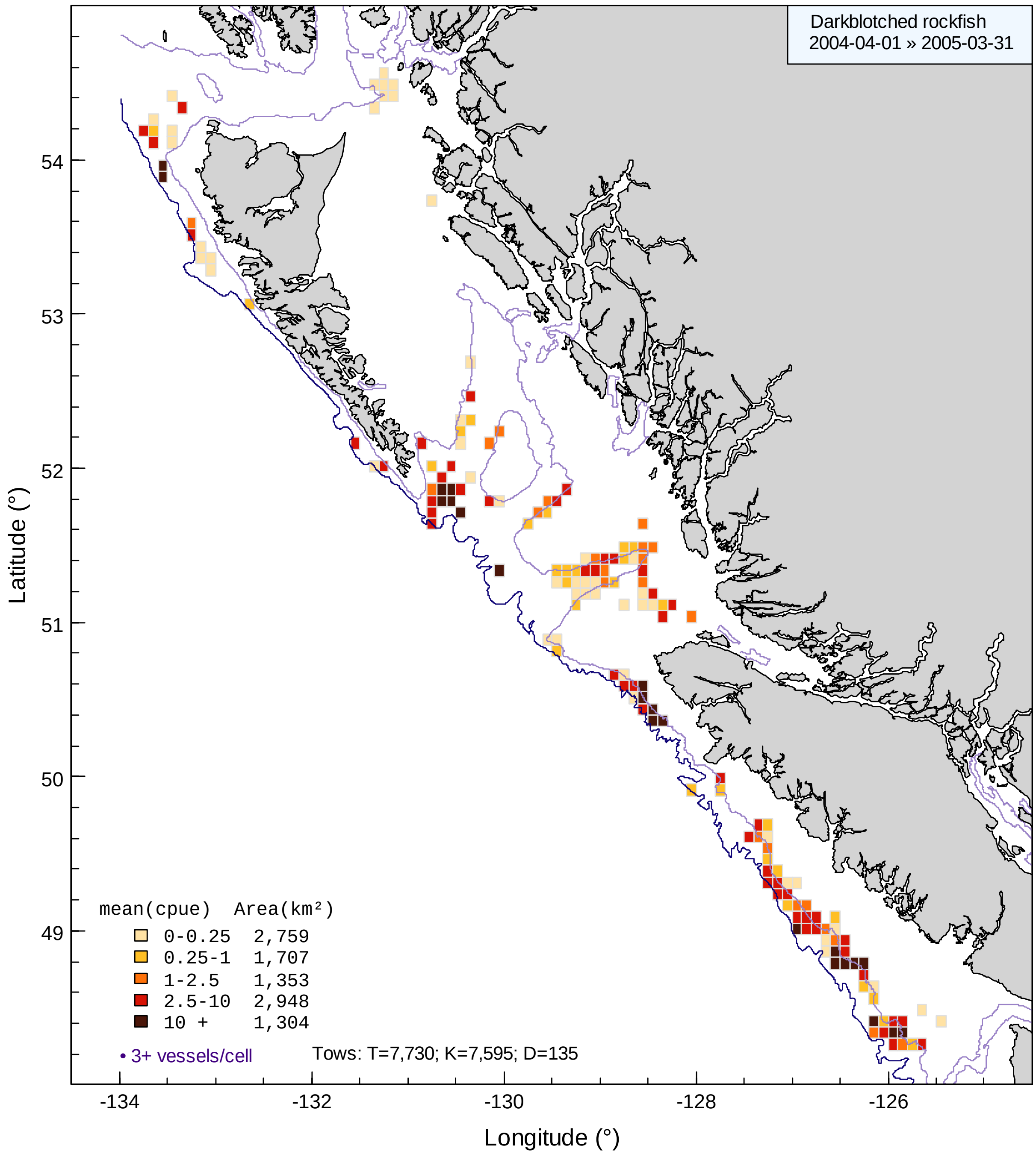

Figure B9. Mean CPUE (kg/h) of darkblotched rockfish caught by the BC trawl fishery from 4/1/04 to 3/31/05. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

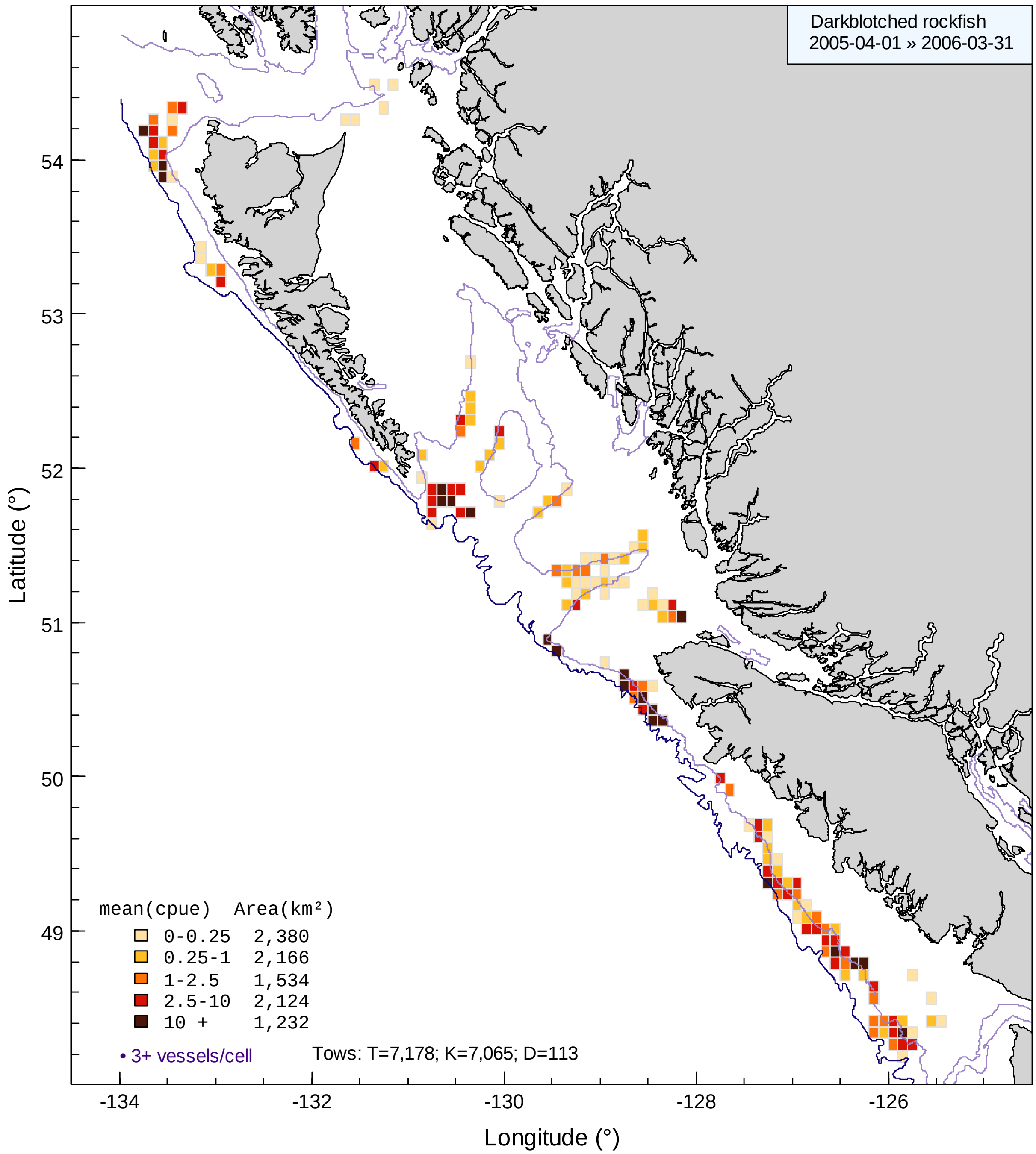

Figure B10. Mean CPUE (kg/h) of darkblotched rockfish caught by the BC trawl fishery from 4/1/05 to 3/31/06. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

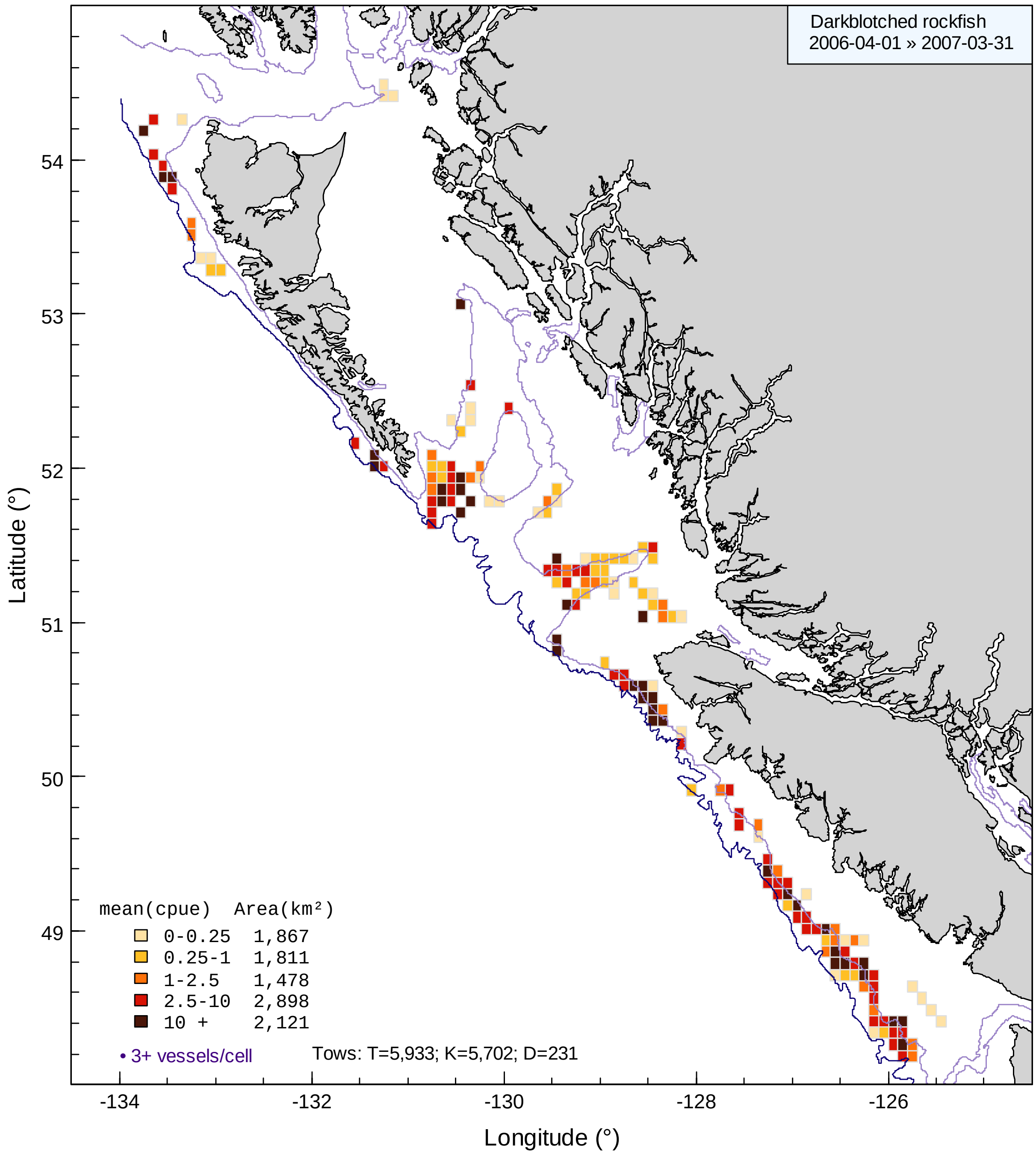

Figure B11. Mean CPUE (kg/h) of darkblotched rockfish caught by the BC trawl fishery from 4/1/06 to 3/31/07. Isobaths: 200 m & 1000 m. Number of tows: T = available, K = kept for display, D =discarded.

Appendix C. Standardized commercial CPUE analysis

The analysis in this appendix 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.

C.1. Spatial analysis prior to GLM

The spatial analysis of darkblotched rockfish (Figure 9) shows that there is a break in darkblotched catch and CPUE at the top of Vancouver Island, between Goose Island and Moresby Gullies, extending into the lower Hecate Strait, and Dixon Entrance and the west coast of the Queen Charlotte Islands. The darkblotched tows from 1993–94 onwards were divided, on the basis of the starting coordinates for each tow, into four subareas (Table C1). Almost all of the darkblotched 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). Catches and consequently the positive tows were concentrated off the west coast of Vancouver Island and the upper Queen Charlotte Sound, with Dixon Entrance and the lower Queen Charlotte Sound showing lower catches and fewer tows (Table C3). CPUE for this species is low (averaging less than 50 kg/h towed) and follows a similar pattern as the catch. CPUE in Dixon Entrance is similar to that along Vancouver Island and in northern Queen Charlotte Sound.

Table C1. Subarea definitions for darkblotched rockfish.

Subarea #	Definition	Code (Table C3)	Colour (Figure C1)
1	West coast Vancouver Island to about 50.8° N;	WCVI	black
2	Goose Island gully (lower Queen Charlotte Sound), to about 51.5° N west of –128.8° W west of –128.8° W and to about 51.8° N east of –128.8° W;	GIG	green
3	Moresby, Mitchell and lower Hecate Strait up to about 53.5° N;	MG&HS	red
4	Dixon Entrance and the entire west coasts of Graham and Moresby Islands.	DE	blue

Table C2. Distribution of unallocated darkblotched 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)	73.5	0.0	0.6	1.2	0.0	1.1	0.0	0.0	0.4	76.9

Table C3. Number of tows with positive catch of darkblotched rockfish by April–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											
WCVI	614	644	510	549	595	679	600	501	522	518	551	6,283
GIG	147	135	131	117	134	117	106	97	130	103	178	1,395
MG&HS	416	319	309	478	291	222	264	235	318	292	365	3,509
DE	110	84	78	154	160	97	130	97	107	133	89	1,239
Total	1,287	1,182	1,028	1,298	1,180	1,115	1,100	930	1,077	1,046	1,183	12,426
	Total catch (landings + discards) (t)											
WCVI	46.9	48.0	33.3	36.2	51.8	50.2	51.8	35.6	31.7	35.3	45.4	466.3
GIG	5.8	5.6	5.6	4.4	2.8	2.4	2.2	2.7	3.3	2.2	6.3	43.3
MG&HS	37.5	18.7	17.0	25.2	12.2	7.5	12.6	13.0	13.7	12.2	15.4	185.0
DE	6.2	4.5	5.9	7.4	4.7	5.2	4.9	4.1	3.8	5.0	3.2	54.9
Total	96.4	76.8	61.8	73.1	71.4	65.4	71.5	55.5	52.6	54.7	70.3	749.5
	Average CPUE (kg/h)											
WCVI	44.6	50.7	43.2	42.2	57.2	45.8	53.3	44.8	34.8	36.9	43.6	45.2
GIG	29.7	24.1	32.1	30.8	13.1	18.1	21.0	21.0	11.3	22.6	18.7	22.0
MG&HS	63.6	56.7	49.4	47.8	35.7	32.2	37.5	64.0	44.9	34.6	32.1	45.3
DE	55.0	58.6	64.9	60.2	29.8	64.9	43.1	47.2	38.2	35.7	38.6	48.7

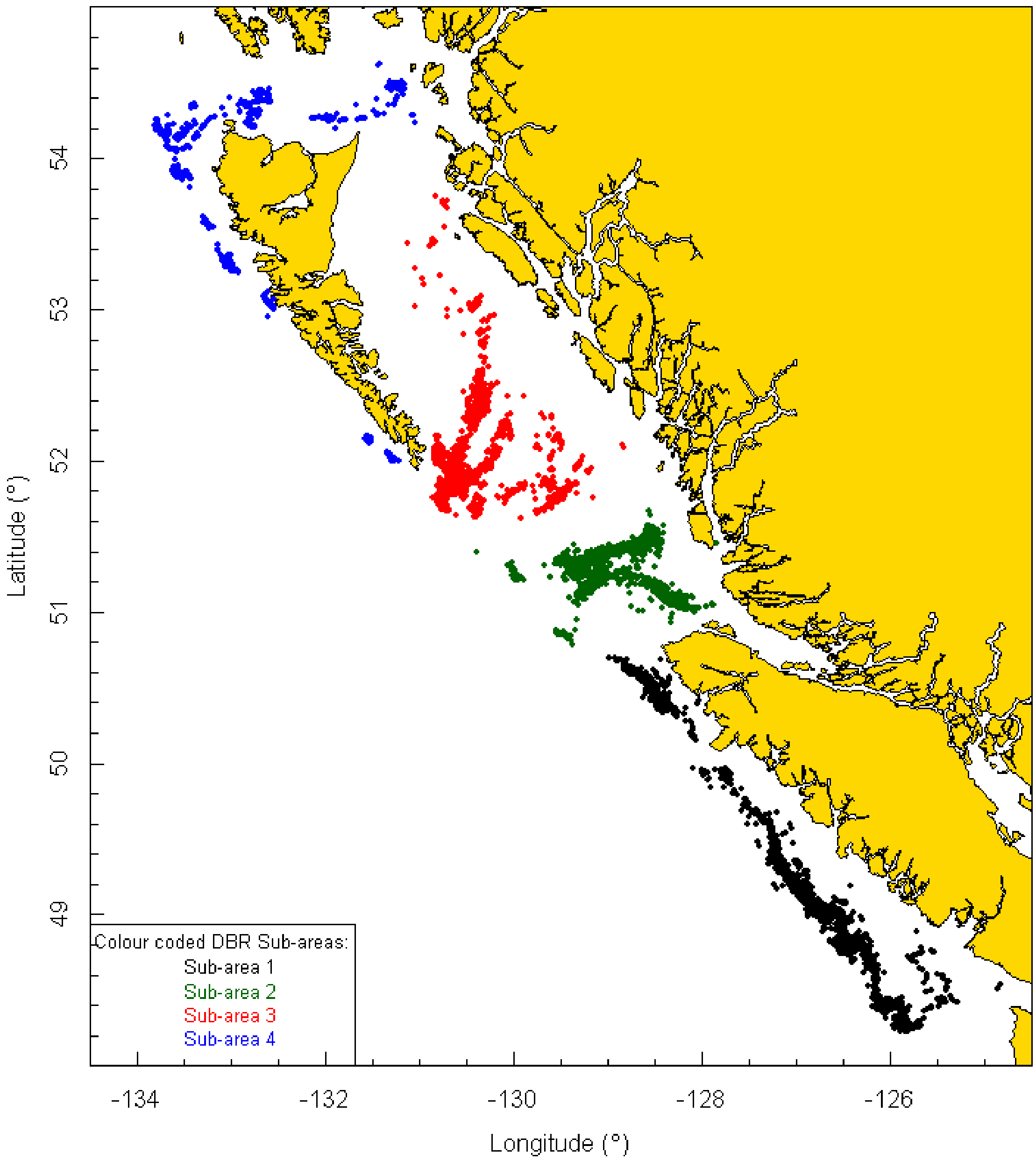

Figure C1. Distribution of positive tows for darkblotched rockfish for the period 1996–97 to 2006–07, showing the start position of each tow and the subarea (Table C1) that the tow has been assigned.

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 darkblotched 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 75-m intervals from 75 to 525 m;
- latitude bands corresponding to density clusters identified previously: west coast of Vancouver Island (WVI) from 48°N to 50.1°N, northwest Vancouver Island (NVI) from 50.1°N to 50.8°N, Queen Charlotte Sound (QCS) = 50.8°N to 51.6°N, Moresby Gully (MG) from 51.6°N to 52.2°N, Hecate Strait (HS) from 52.2°N to 53.8°N, and northwest Queen Charlotte Islands (Dixon) from 53.8°N to 54.8°N;
- vessels which accounted for ≥ 3% of the darkblotched rockfish catch during the period April 1996 to March 2007.

The coefficients estimated (Table C4) 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 3.9% decline in the CPUE index coastwide (Figure C2A). There may be other factors influencing this trend that we have not taken into account. The month effect exhibits no real pattern except for lower than average CPUE during the summer months Jun-Aug (Figure C2B). The depth effect is predictably strong (as it is for most rockfish species) with positive effects on CPUE at depths between 150 and 375 m (Figure C2C). The latitude bands chosen *a priori* exhibit one strong positive effect off the NW coast of Vancouver Island, with lesser effects elsewhere: positive along the WCVI and in Moresby Gully, negative in central Queen Charlotte Sound and Hecate Strait (Figure C2D). Only a few vessels had a strong positive influence on CPUE (Figure C2E).

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 C4. Model coefficients (α, β, γ, δ, λ) and standard errors for five factors used in the GLM analysis of darkblotched 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 75-m depth zones between 75 m and 525 m; Latitude: latitude effect on CPUE where WVI = 48°N to 50.1°N, NVI = 50.1°N to 50.8°N, QCS = 50.8°N to 51.6°N, MG =51.6°N-52.2°N, HS =52.2°N to 53.8°N, and Dixon = 53.8°N to 54.8°N; Vessel: vessel effect on CPUE where vessels accounted for >= 3% of the darkblotched catch over the period of the analysis; StdErr: standard error of the estimated coefficients. Model statistics: Residual standard error: 2.268 on 4,172 degrees of freedom; Multiple R-squared: 0.145; Adjusted R-squared: 0.1368; F-statistic: 17.68 on 40 and 4,172 degrees of freedom; 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	0.373	0.168	Apr	0.000	0.102	150	-0.917	0.236	WVI	0.367	0.090	1	0.687	0.114
1997	0.612	0.134	May	0.180	0.101	225	0.560	0.092	NVI	1.142	0.099	2	0.434	0.121
1998	0.001	0.115	Jun	-0.299	0.138	300	0.883	0.091	QCS	-0.903	0.112	3	0.158	0.114
1999	0.010	0.112	Jul	-0.338	0.134	375	1.109	0.095	MG	0.175	0.091	4	0.031	0.113
2000	-0.274	0.106	Aug	-0.155	0.152	450	-0.136	0.133	HS	-0.758	0.198	5	0.003	0.108
2001	-0.220	0.105	Sep	0.360	0.150	525	-1.499	0.240	Dixon	-0.022	0.191	6	-0.035	0.104
2002	0.033	0.112	Oct	0.104	0.152							7	-0.157	0.095
2003	0.105	0.112	Nov	0.017	0.115							8	-0.159	0.118
2004	-0.170	0.107	Dec	0.133	0.158							9	-0.434	0.133
2005	-0.301	0.109	Jan	0.046	0.121							10	-0.529	0.112
2006	-0.168	0.100	Feb	-0.031	0.103									
			Mar	-0.018	0.107									
μ	2.884	0.087												

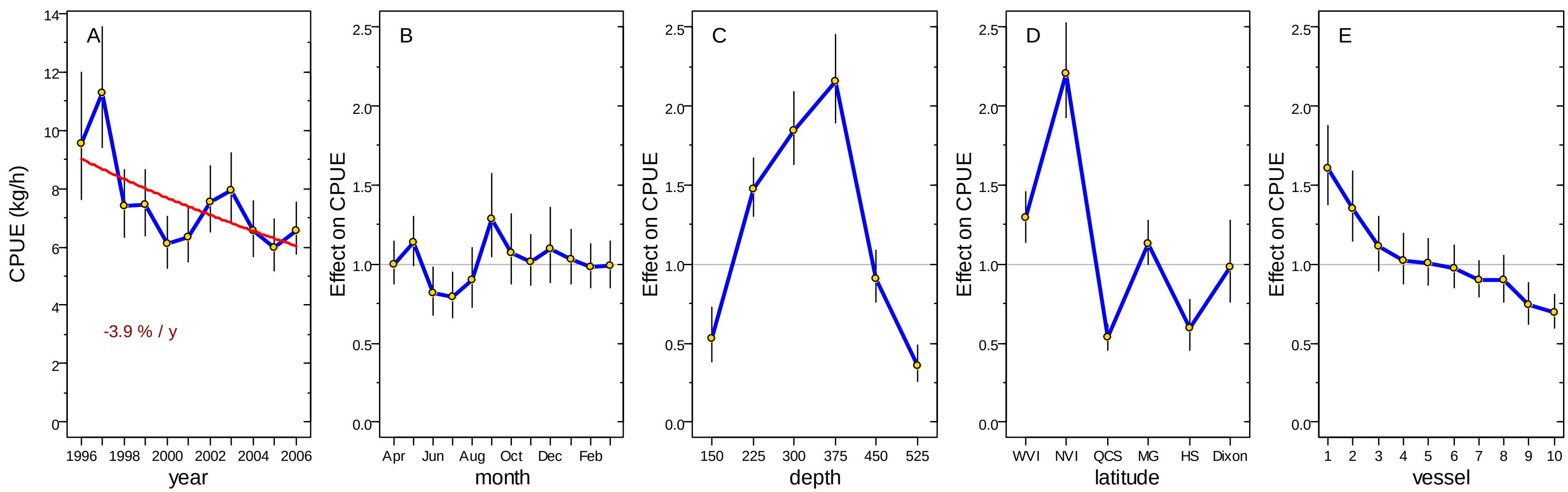

Figure C2. Annual index trend and factor coefficients for the GLM analysis of darkblotched rockfish commercial trawl CPUE data (Apr 1996 to Mar 2007). (A) annual CPUE indices (by fishing year) with fitted curve indicating instantaneous decline; (B) month effect on CPUE; (C) depth effect on CPUE where depth is partitioned into 75-m depth zones between 75 m and 525 m; (D) latitude effect on CPUE where WVI = 48°N to 50.1°N, NVI = 50.1°N to 50.8°N, QCS = 50.8°N to 51.6°N, MG =51.6°N-52.2°N, HS =52.2°N to 53.8°N, and Dixon = 53.8°N to 54.8°N; (E) vessel effect on CPUE where vessels accounted for >= 3% of the darkblotched catch over the period of the analysis. The error bars show 95% confidence intervals.