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

Examen du sébaste à bandes rouges (*Sebastes babcocki)* sur la côte du Pacifique du Canada : biologie, répartition et abondance

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Abstract

We summarise the available information on a data-limited species, redbanded rockfish *Sebastes babcocki*. Specifically, this paper reviews the current data on the biology, distribution, and abundance trends. This species has a mean weight of 1.337 kg/fish. Allometric growth shows no difference between the sexes; however, mature females achieve a larger size than males of equal age. With an estimated age-of-50%-maturity at 11.5 years, and an assumed natural mortality rate of 0.035, generation time is roughly 40 years. Model estimates of total mortality rate for the years 1997/98 range from 0.04 to 0.07, with no variation among areas of purported light and heavy exploitation. According to commercial trawl records, redbanded rockfish prefer depths between 132 m and 421 m. Using this preference, a bathymetric analysis estimates the potential extent of occurrence at 47,877 km^2 and the area of occupancy at 27,432 km^2. However, based on trawl observations alone, the area of occupancy could easily equal 33,200 km^2. Within its habitat, the two dominant concurrent species are Pacific ocean perch *Sebastes alutus* and arrowtooth flounder *Atheresthes stomias*. Total removal of redbanded rockfish from BC coastal waters by the commercial fleet from 1996 to Sep 2005 equals approximately 3 million fish. Survey indices of abundance are currently not useful for assessing redbanded rockfish population trends. The Hecate Strait assemblage and WCVI shrimp surveys are too shallow; the US triennial survey too uncertain, and the QCS synoptic survey too short. The commercial trawl CPUE indices show a slightly increasing trend in 3CD and slightly declining trends in 5AB and 5CD. The commercial longline CPUE indices show very strong trends, but these probably reflect fluctuations in catch activity rather than changes in fish population density.

Résumé

Nous résumons l'information existante sur le sébaste à bandes rouges (*Sebastes babcocki*), une espèce à l'égard de laquelle les données sont limitées. Le document passe tout particulièrement en revue les données actuelles sur la biologie, la répartition et l'abondance. Cette espèce a un poids moyen de 1,337 kg/poisson. La croissance allométrique ne montre aucune différence entre les sexes; toutefois, les femelles matures atteignent une plus grande taille que les mâles du même âge. Puisque l'âge à la maturité chez 50 % des poissons est estimé à 11,5 ans, et que le taux de mortalité naturelle serait d'environ 0,035, la durée de génération est d'à peu près 40 ans. L'estimation du taux de mortalité totale tirée du modèle pour les années 1997-1998 oscille entre 0,04 et 0,07, sans variation entre les zones d'exploitation prétendument faibles et fortes. Selon les données sur la pêche commerciale au chalut, le sébaste à bandes rouges privilégie les profondeurs de 132 m à 421 m. À partir de cette information, une analyse bathymétrique permet d'estimer l'étendue potentielle de l'occurrence de l'espèce à 47 877 km^2 et la zone d'occupation à 27 432 km^2. Cependant, si l'on se fie uniquement aux observations dans les chaluts, la zone d'occupation pourrait facilement s'étendre à 33 200 km^2. Dans cet habitat, les deux espèces dominantes qui sont aussi présentes sont le sébaste à longues mâchoires (*Sebastes alutus*) et la plie à grande bouche (*Atheresthes stomias*). Le total des prélèvements de sébaste à bandes rouges par la flottille commerciale dans les eaux de la C.-B., de 1996 à septembre 2005, se chiffre à environ trois millions de poissons. Les indices d'abondance fournis par les relevés ne sont pas utiles présentement pour évaluer les tendances des populations de sébastes à bandes rouges. Les relevés des assemblages de poisson de fond du détroit d'Hécate et ceux de la crevette de la côte ouest de l'île de Vancouver ne sont pas assez profonds. Le relevé triennal des É.-U. est trop incertain et les relevés synoptiques du détroit de la Reine-Charlotte sont trop courts. Les indices des prises par unité d'effort fournis par la pêche commerciale au chalut affichent une légère tendance à la hausse dans 3CD et à la baisse dans 5AB et 5CD. Les indices des prises par unité d'effort fournis par la pêche commerciale aux lignes montrent de très fortes tendances, mais celles-ci découlent probablement des fluctuations de l'activité de capture plutôt que de changements dans la densité de la population de poisson.

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1. Introduction

We summarise the available information on a data-limited species, redbanded rockfish *Sebastes babcocki*. Specifically, this paper reviews the current data on the biology, distribution, and abundance trends.

The species derives its name from John Pease Babcock, a former administrator in California and British Columbia (Hart 1973). Potential confusion with *S. rubrivinctus* exists historically; however, this latter species probably does not occur north of Heceta Bank, Oregon (Love et al. 2002). Redbanded rockfish sport a distinctive colouration – bodies of white or pale pink with four vertical red/orange bands (Figure 1).

Figure 1. Redbanded rockfish *Sebastes babcocki*
Source: http://pacpbsgfiis/gfimages/photos/020516_08W.jpg.

According to Love et al. (2002), redbanded rockfish range from the Bering Sea and the Aleutian Islands (Alaska) to San Diego in southern California. Their reported depth of habitation ranges from 50-625 m. These rockfish prefer hard bottoms where they shelter in crevices between boulders, but also occur over mixed substrata of mud, cobblestones, and pebbles. They can either form small groups or occur singly. The oldest recorded individual was captured in southern Alaska in 1986, and the Alaska Department of Fish and Game determined its age at 106 years (Munk 2001).

Life history information on redbanded rockfish remains limited. They presumably share many characteristics with all species in the genus. Love et al. (2002) assume most, if not all, *Sebastes* are viviparous, though the extent of energy transfer directly from the mother varies among species. *Sebastes* females release developed larvae (parturition) during the night to reduce mortality from predation and during the season of highest primary productivity (Apr-May in BC). As redbanded rockfish can be classified as a deep shelf/slope species, the larvae and juveniles probably live in the epipelagic and upper mesopelagic zones before settling.

2. Biology

2.1. Mean weight

The mean weight of redbanded rockfish is expressed as the mean of PMFC-area specimen weights that have been normalized using the square root transformation:

$$\bar{W}_A = \left(\frac{1}{n_A} \sum_{i=1}^{n_A} w_i^{0.5} \right)^2 , \tag{1}$$

where n_A = the number of specimens in area A;
w_i = weights for specimens $i = 1, \ldots, n_A$.

The PMFC area weights $\bar{W}_A$, are then weighted by the proportion of specimens in each area $p_A = n_A / \sum n_A$. Data come from GFBio. The weighted mean is

$$\bar{W}' = \sum p_A \bar{W}_A = 1.337 \text{ kg/fish} . \tag{2}$$

Table 1. Calculation of mean redbanded rockfish weight (g) by PMFC area.

PMFC Area	A	3C	3D	5A	5B	5C	5D	5E	Total
GFBio area code		3	4	5	6	7	8	9	
Mean weight by area (g)	$\bar{W}_A$	622	1,150	1,184	1,313	1,517	2,032	1,368	
Number of specimens	n_A	74	259	231	1,547	678	61	355	3,205
Proportion of all specimens	p_A	0.023	0.081	0.072	0.483	0.212	0.019	0.111	1.0
Mean contribution (g)	$p_A \bar{W}_A$	14.4	93.0	85.3	633.6	320.8	38.7	151.5	1,337

2.2. Length-weight relationship

2.2.1. Data selection

Data were selected from the DFO GFBio database using minimal qualifications:

- species identified as redbanded rockfish (code = 401);
- specimen identified as either male or female (codes = 1 and 2, respectively);
- positive lengths and weights.

The above qualification yielded 2,400 redbanded rockfish specimens with the following distributions:

- by sex – males (1187), females (1213);
- by area – 3C (74), 3D (259), 5A (206), 5B(1230), 5C (247), 5D (34), 5E(350);
- by gear – bottom trawl (2059), trap (25), gillnet (4), longline (312);
- by year – 1989 (4), 1995 (50), 1996 (133), 1997 (44), 1999 (226), 2000 (45), 2002 (30), 2003 (985), 2004 (883);

- by trip type – research (473), charter (1556), observed commercial (168), non-observed commercial (203).

2.2.2. Results

Data for all available lengths and weights in GFBio were used to derive an empirical length-weight relationship. This assumes that all measurements are independent of collection method, area, and fishery. After fitting the data with a lognormal linear model (8) using standard minimization tools in S-PLUS (Venables and Ripley 2000), the relationships for males, females, and both are virtually identical. In other words, there appears to be no sex-specific difference in allometric growth.

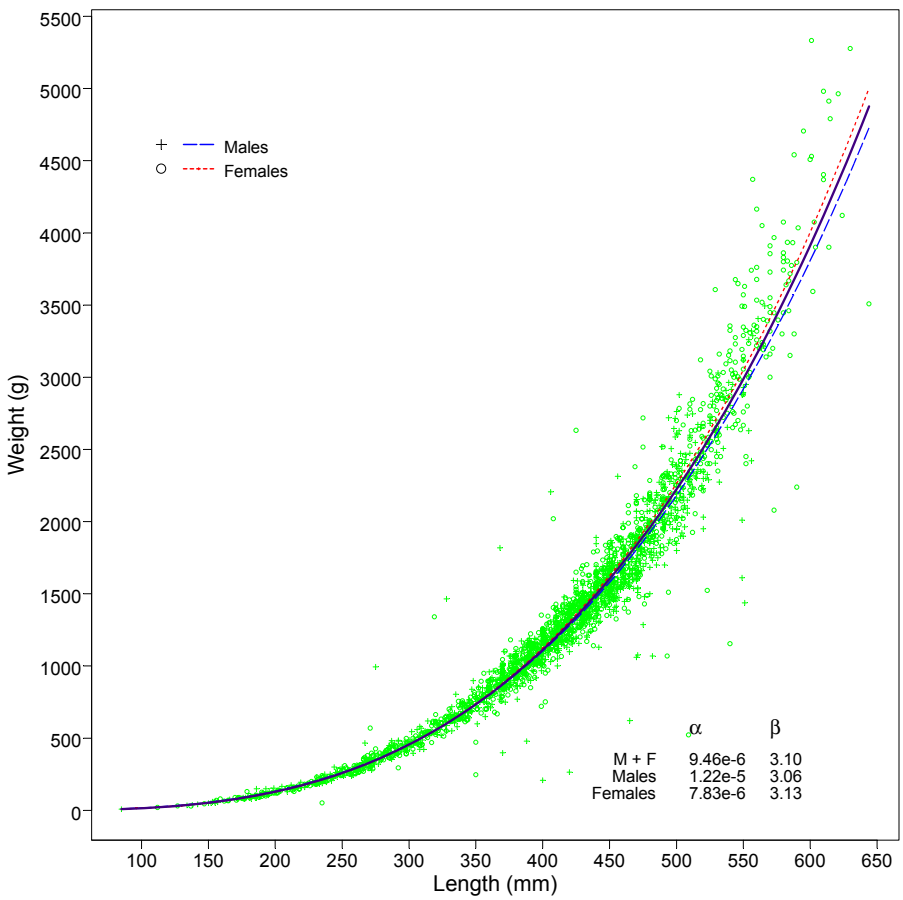


Figure 2. Redbanded rockfish weight vs. length fitted using a lognormal linear model: $\log W = \log \alpha + \beta \log L$.

2.3. Length-age relationship

2.3.1. Data selection

Data were selected from the DFO GFBio database using minimal qualifications:

- species identified as redbanded rockfish (code = 401);

- specimen identified as either male or female (codes = 1 and 2, respectively);
- break-and-burn age readings only (post 1977);
- positive lengths and ages.

The above qualification yielded 2,868 redbanded rockfish specimens with the following distributions:

- by sex – males (1244), females (1624);
- by area – 3D (687), 5A (590), 5B(50) , 5C (30), 5E(1511);
- by gear – bottom trawl (50), longline (2818);
- by year – 1995 (130), 1996 (101), 1997 (1043), 1998 (1537), 2000 (57);
- by trip type – charter (2637), observed commercial (50), non-observed commercial (181).

2.3.2. Results

The von Bertalanffy fits through the data using (11) show that mature females are larger than mature males (Figure 3). Estimates of t_0 are not well-specified. Otoliths for younger and/or smaller fish have been taken by charter surveys; however, the ages have not yet been read.

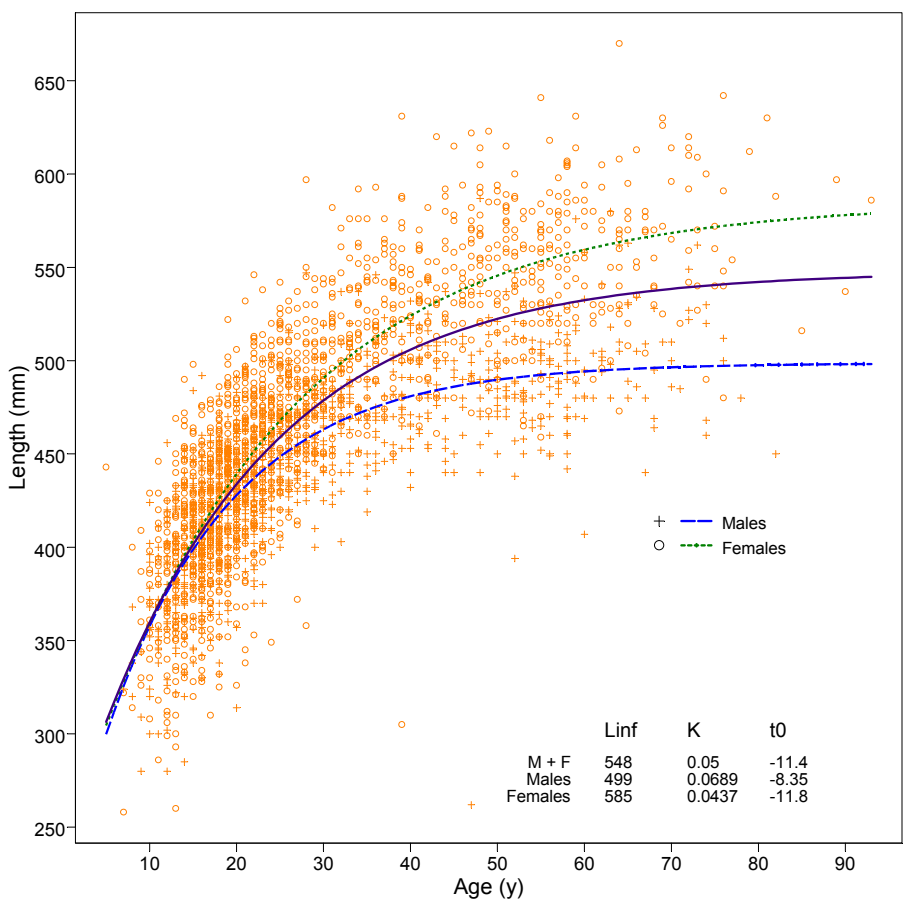


Figure 3. Length-at-age relationship using the von Bertalanffy growth equation: $L_i = L_\infty \left(1 - e^{-K(t_i - t_0)}\right)$.

2.4. Maturity, mortality, and generation time

2.4.1. Maturity

A frequency chart of all available maturity data (1967-2005) for redbanded rockfish (Figure 4) suggests that females mature in July, are fertilized in September and experience parturition in May. Westrheim (1975) noted that parturition for *S. babcocki* occurred during April in BC and during May in the southeastern Gulf of Alaska. The insemination season for males appears to occur from July to October (Figure 4).

Ideally, an age-at-maturity analysis might use only samples collected at times of peak development stages (males – inseminations season, females – parturition season; Westrheim 1975); however, these restrictions are too limiting for the redbanded data set. Rather, we define maturity to be stage 3 and up, and use only years that have break-and-burn ages to construct a maturity ogive (Figure 5). To smooth the maturity data, the ages are binned in 2-year age groups. For each group, the proportion of mature individuals is calculated (Table 2) and the age of 50% maturity k is interpolated from the curves. Generally, k = 18 y. Assuming a natural mortality rate M = 0.035, the generation time (12) is roughly 46 y.

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

Age	All				Males				Females			
Group	p	n	a	σ	p	n	a	σ	p	n	a	σ
7-8	0.125	8	7.6	0.52	0.25	4	7.8	0.5	0	4	7.5	0.58
9-10	0.19	37	9.7	0.45	0.235	17	9.8	0.39	0.15	20	9.7	0.49
11-12	0.21	97	11.6	0.48	0.27	44	11.6	0.49	0.15	53	11.6	0.48
13-14	0.25	185	13.6	0.50	0.30	74	13.6	0.50	0.22	111	13.6	0.50
15-16	0.32	268	15.5	0.50	0.33	127	15.5	0.50	0.32	141	15.6	0.50
17-18	0.46	278	17.5	0.50	0.48	126	17.5	0.50	0.45	152	17.5	0.50
19-20	0.57	245	19.5	0.50	0.62	104	19.5	0.50	0.539	141	19.5	0.50
21-22	0.72	229	21.5	0.50	0.70	98	21.6	0.49	0.733	131	21.5	0.50
23-24	0.81	188	23.5	0.50	0.77	90	23.5	0.50	0.847	98	23.4	0.5
25-26	0.87	148	25.5	0.50	0.882	68	25.5	0.50	0.86	80	25.4	0.499
27-28	0.963	136	27.6	0.50	0.964	55	27.6	0.498	0.963	81	27.5	0.501
29-30	0.928	111	29.4	0.49	0.893	56	29.4	0.489	0.964	55	29.4	0.494
31-32	0.961	77	31.4	0.50	0.97	33	31.5	0.51	0.955	44	31.4	0.487
33-34	0.98	61	33.5	0.50	1	22	33.2	0.429	0.974	39	33.6	0.498
35-36	1	29	35.0	0.00	1	15	35.0	0	1	14	35.0	0

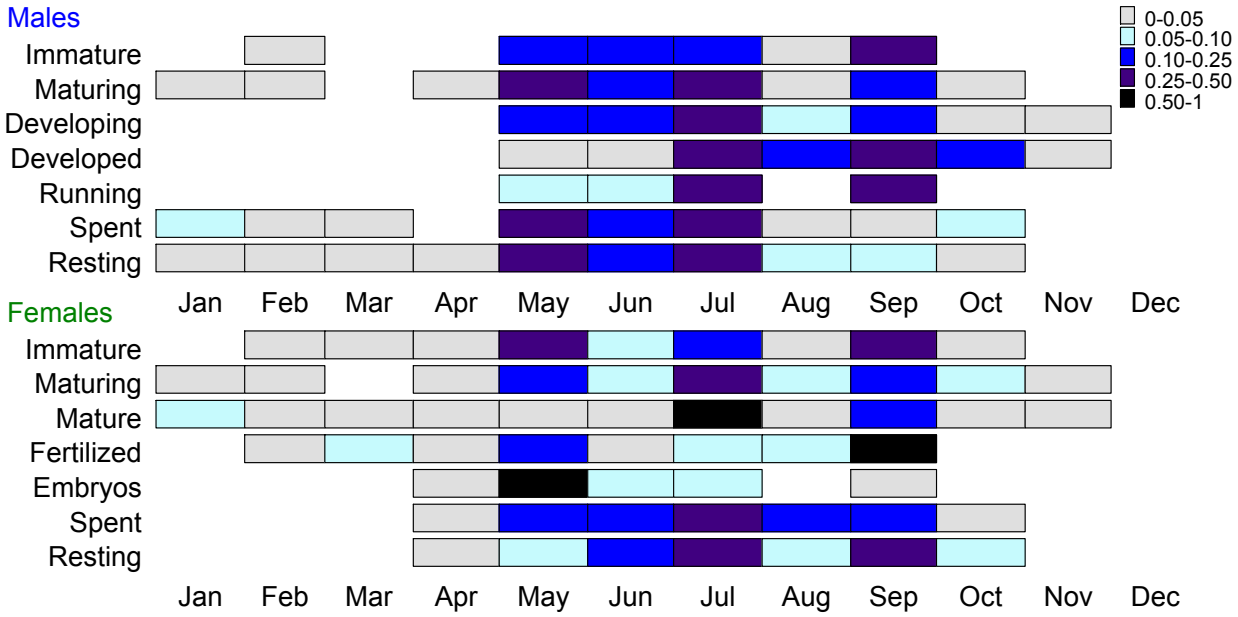


Figure 4. Relative frequency of maturity codes for redbanded rockfish in GFBio. Frequencies are expressed as proportions in any one maturity category (legend upper right).

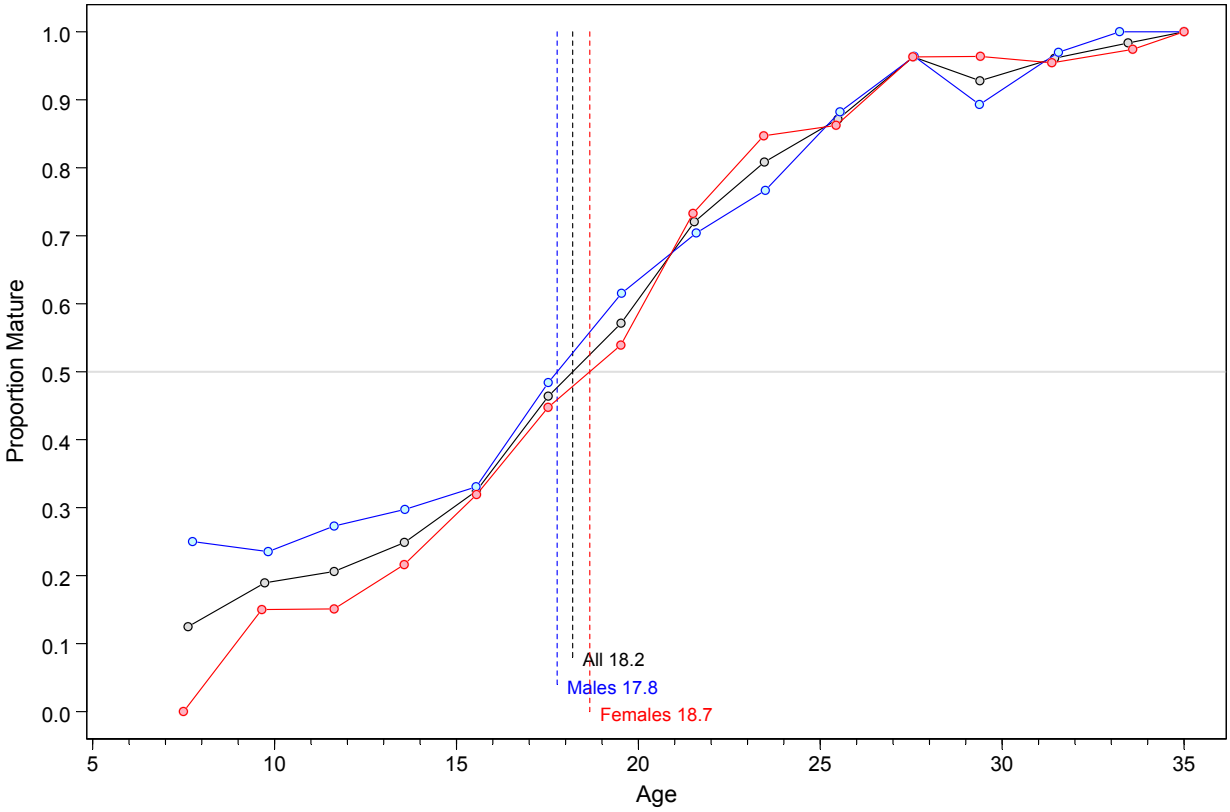


Figure 5. Maturity ogives for redbanded rockfish using ages grouped at 2-year age intervals. The age of each group is expressed as the mean of the observed ages in each group. Vertical dashed lines indicate ages at 50% maturity for males, females, and all available specimens, including those without a sex determination.

2.4.2. Mortality coastwide

Data used in catch-curve analysis (Schnute and Haigh, in review ICES J. Mar. Sci.) to estimate total mortality Z were selected from the DFO GFBio database using the following qualifications:

- species identified as redbanded rockfish (code = 401);
- randomly sampled.

The above qualification yielded 3,334 redbanded rockfish specimens from surveys with the following distributions:

- by sex – males (1503), females (1824), unknown (7);
- by area – 3D (689), 5A (716), 5B(388) , 5C (30), 5E(1511);
- by gear – bottom trawl (514), longline (2820);
- by year – 1967 (412), 1969 (52), 1995 (130), 1996 (101), 1997 (1043), 1998 (1539), 2000 (57);
- by trip type – research (464), charter (2639), observed commercial (50), non-observed commercial (181).

The age data for 1967 and 1969 are from research trawl surveys while data from 1998 on come from charter surveys. To assess total mortality Z, we pool charter survey data from 1997, 1998, and 2000 only and use the combined age vector in a catch-curve analysis. We do not use the data from the 1960s (fish originally identified as *Sebastes rubrivinctus*) as the ageing technology at the time (otolith surface readings, Chilton and Beamish 1982) underestimated the proportion of older-aged fish and consequently overestimated the proportion of younger fish.

Catch-curve analysis using the method of Schnute and Haigh (in review, ICES J. Mar. Sci.) suggests that the average total mortality Z (natural + fishing) for the survey years 1998-2000 was 0.057 (). The 2.5% and 97.5% quantiles of the Bayes posterior samples are 0.0466 and 0.0661, and the mode of 0.061 is skewed right. There is no known estimate of natural mortality for redbanded rockfish; however, given its longevity we suspect that M will be similar to that for rougheye rockfish ($M = 0.035$, McDermott 1994). Fisheries stock analysts in Alaska currently use $M = 0.06$ for redbanded rockfish based on catch-curve analysis (Clausen 2005). We adopt an estimate based on the gonad somatic index (GSI) model of Gunderson and Dygert (1988) as it is generally more conservative. Regardless, the mean fishing mortality F for this stock appears to be no greater than M.

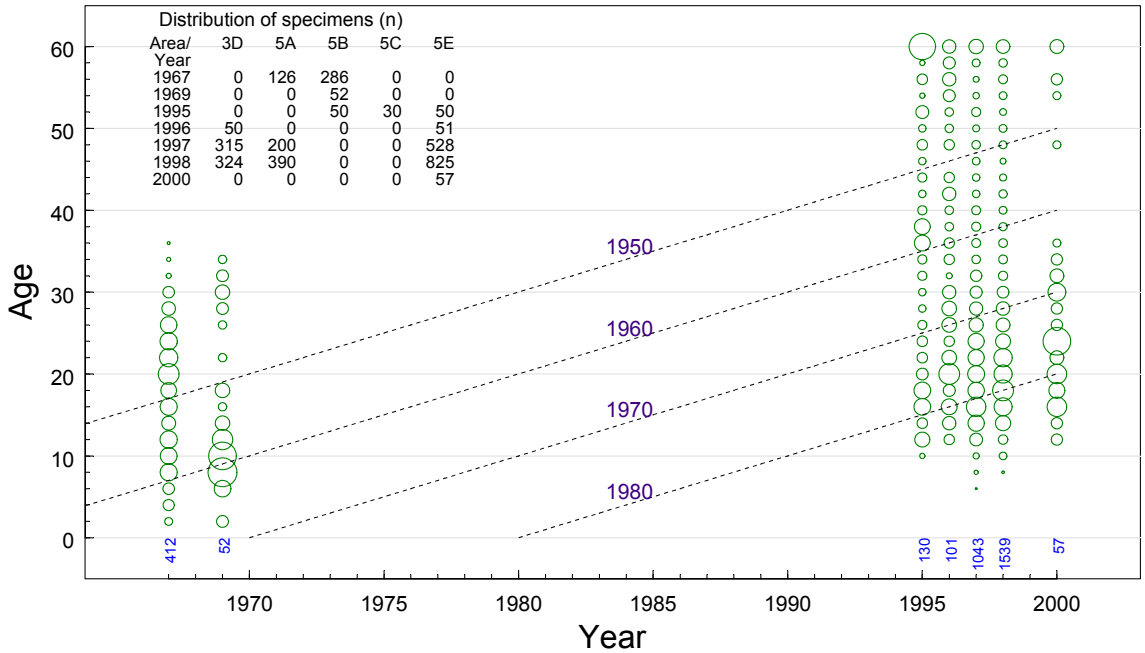


Figure 6. Bubble plot of observed age proportions using 2-y bins for redbanded rockfish coastwide. Ages 60 and above are aggregated. Diagonal lines indicate reference birth years. Numbers below the horizontal line at age 0 show the number of fish aged each year. Table in upper left gives the number of specimens aged by PMFC area and calendar year.

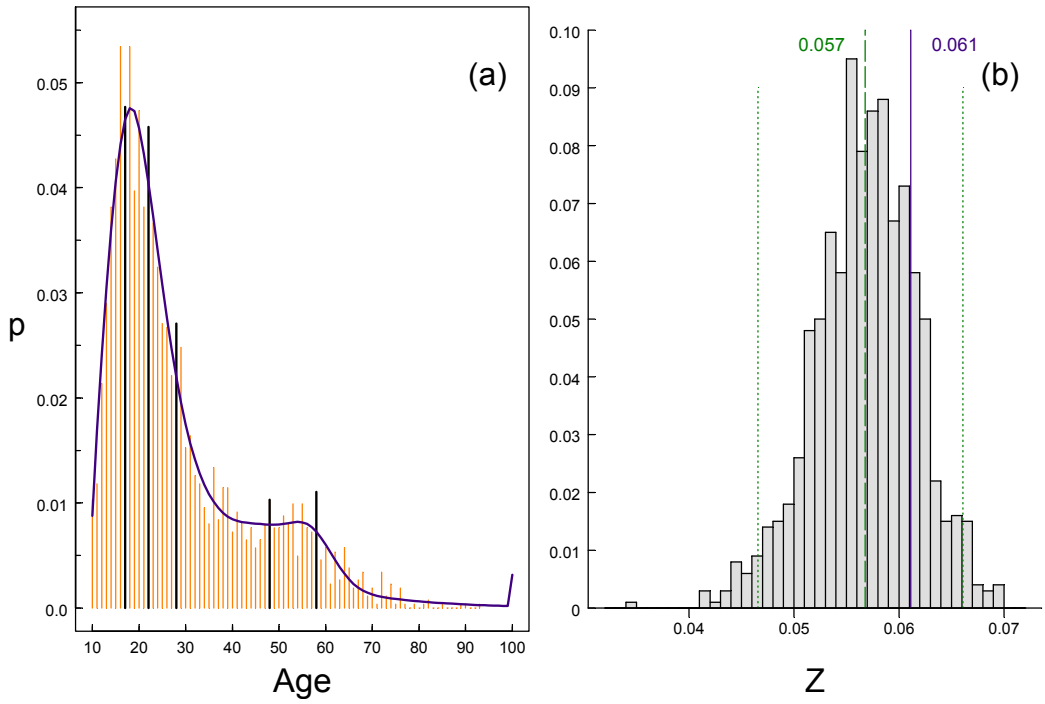


Figure 7. Catch-curve analysis for (a-b) charter survey data for 1997, 1998, and 2000 combined (n = 2639).
(a) Observed proportions-at age (vertical bars) and predicted (solid curves) using the catch-curve model in Schnute and Haigh (2006). The recruitment anomalies assumed are highlighted as dark vertical bars.
(b) Posterior samples of Z as histograms. Solid vertical lines indicate the mode from the model fits. Dashed vertical lines indicate the mean Z-values, dotted vertical lines indicate the 2.5% and 97.5% quantiles.

2.4.3. Mortality at sites featuring light and heavy exploitation

In 1997 and 1998, a collaborative project between DFO and the hook and line industry identified areas of "light" and "heavy" exploitation by longline fishermen along the northern and southern regions of the BC coast. The details of this project appear in Kronlund and Yamanaka (2001), and analyses therein pertain to yelloweye rockfish *Sebastes ruberrimus*. Chartered fishermen also sampled redbanded rockfish in three of the documented survey areas – Tasu (light exploitation) and Flamingo (heavy) along the SW coast of the Queen Charlotte Islands, and Triangle (light) along the NW coast of Vancouver Island. They also sampled redbanded rockfish in a fourth area – Brooks (heavy) just north of Brooks Peninsula ().

Data used in catch-curve analyses for the four populations come from the DFO GFBio database. The primary qualifications on the data are

- block designations TASU, FLAMINGO, TRIANGLE, and BROOKS;
- depths between 165 m and 260 m to represent a common depth for all areas.

The above qualification yielded 2,401 redbanded rockfish specimens from charter survey longline sets with the following distributions:

Feature	Specific	Tasu	Flamingo	Triangle	Brooks
sex	males	253	259	254	301
	females	326	386	285	336
year	1997	173	345	155	315
	1998	406	300	384	324

Cumulative age frequencies (Figure 9) indicate similar age structures for all but the Triangle region, which exhibits an older age distribution. All areas, however, show similar tails in their age distributions (age > 40 y). Despite the different age structures in the regions, the catch-curve analyses (Figure 10) indicate no differences in the estimate of the mean mortality Z. At first glance this is surprising, but the model adjusts for selectivity differences and recruitment variability. Consequently, it becomes more sensitive to the distribution of older age classes. If older fish persist as consistently as they do in the four regions, then the posterior distributions of the Z parameter will appear very similar. The difference in the cumulative age frequency curve (Figure 9) for Triangle compared to the other three areas may simply reflect a difference in selectivity rather than a difference in exploitation rate. Catching redbanded rockfish in Triangle is considered problematic due to the predominance of yelloweye rockfish here.

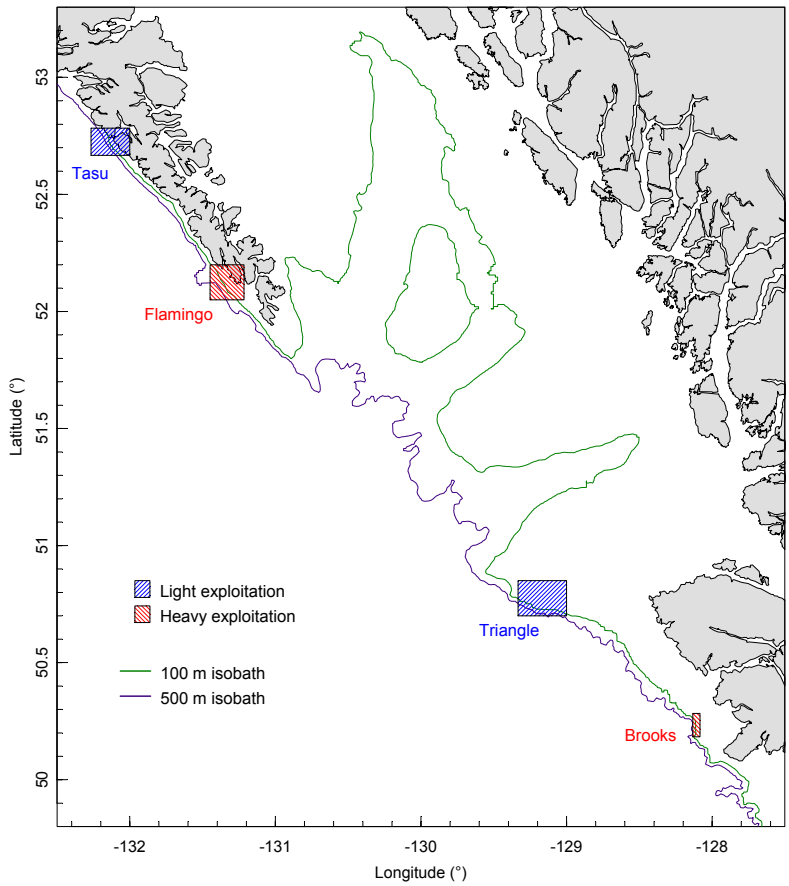


Figure 8. Map showing areas of light and heavy exploitation by longline fishermen. Samples of redbanded rockfish taken from these areas. Details in Kronlund and Yamanaka (2001).

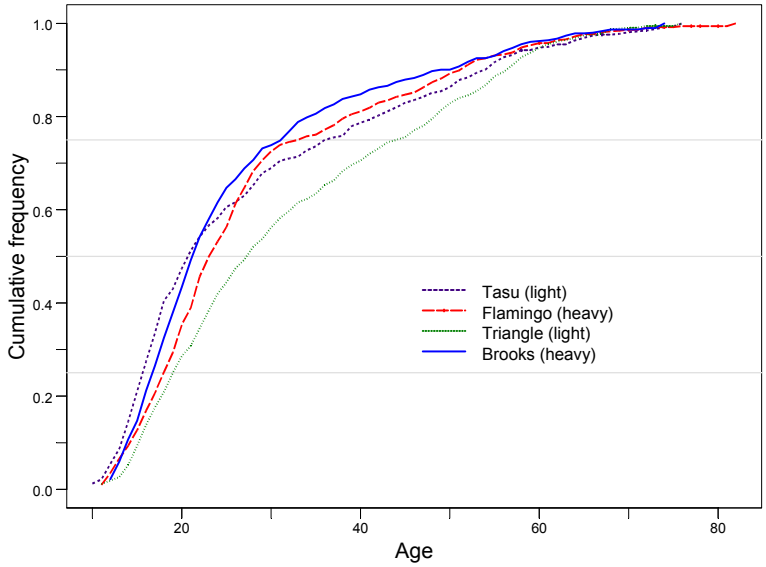


Figure 9. Cumulative proportions-at-age for four surveyed populations (1997 and 1998 combined) with reportedly light and heavy exploitation pressure (Kronlund and Yamanaka 2001) – Tasu (n = 579) and Flamingo (n = 645) along the SW coast of the Queen Charlotte Islands; Triangle (n = 539) and Brooks (n = 639) along the NW coast of Vancouver Island.

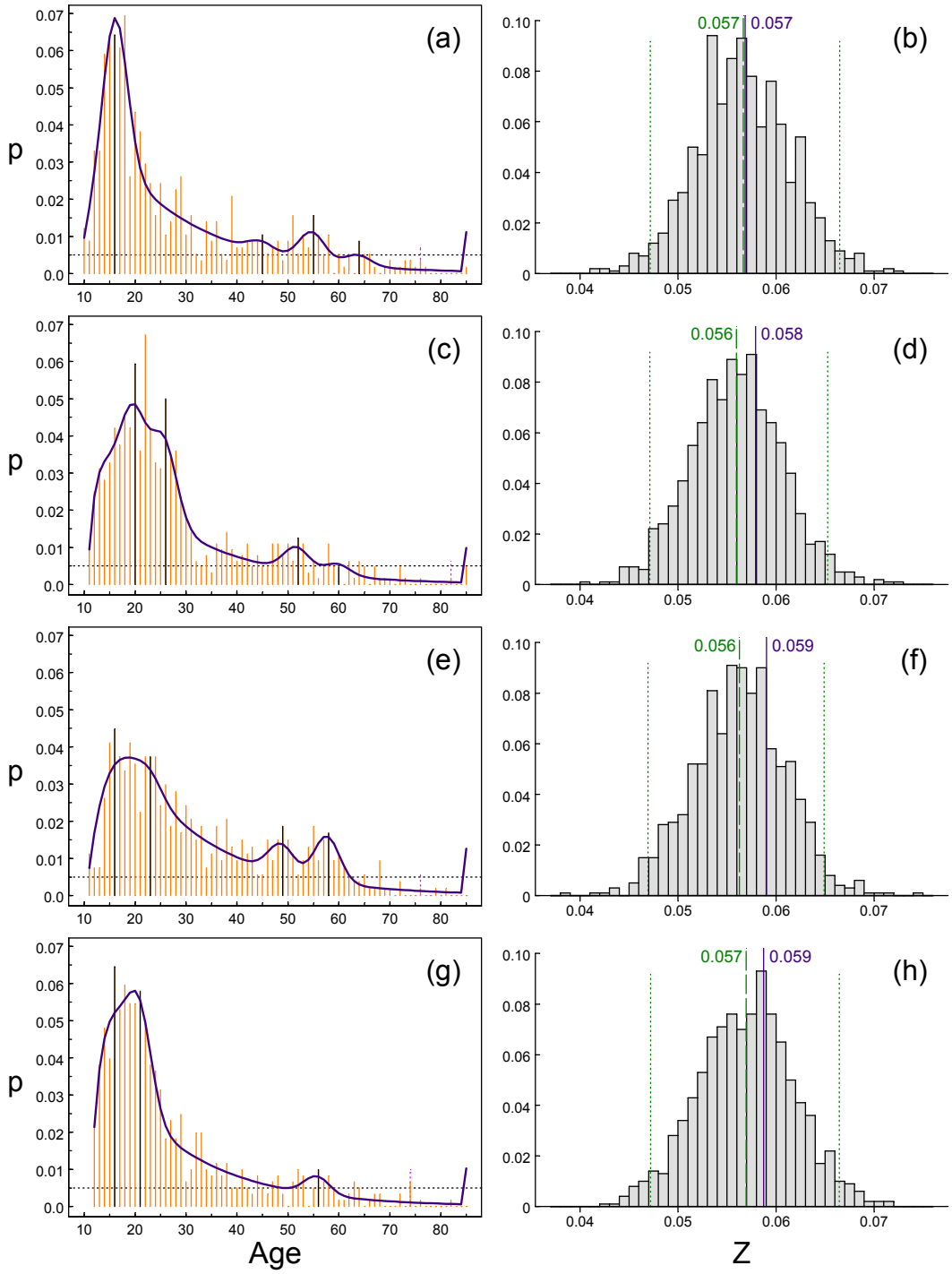


Figure 10. Catch-curve analysis for various populations (1997 and 1998 data combined) arranged north to south: (a-b) Tasu (lightly exploited), (c-d) Flamingo (heavily exploited), (e-f) Triangle (lightly exploited), and (g-h) Brooks (heavily exploited). (a,c,e,g) Observed proportions-at age (vertical bars) and predicted (solid curves) using the catch-curve model in Schnute and Haigh (2006). The recruitment anomalies assumed are highlighted as dark vertical bars. (b,d,f,h) Logistic-normal posterior samples of *Z* as histograms. Solid vertical lines indicate the mode from the model fits. Dashed vertical lines indicate the mean *Z*-values, dotted vertical lines indicate the 2.5% and 97.5% quantiles.

3. Distribution

3.1. Depth preference

The depths of all fishing events (1996-2005) that captured redbanded rockfish were extracted from the observer trawl database PacHarvTrawl. The 2.5% and 97.5% quantiles of these observations – 132 m and 421 m – are used as a proxy for the preferred depth range of redbanded rockfish.

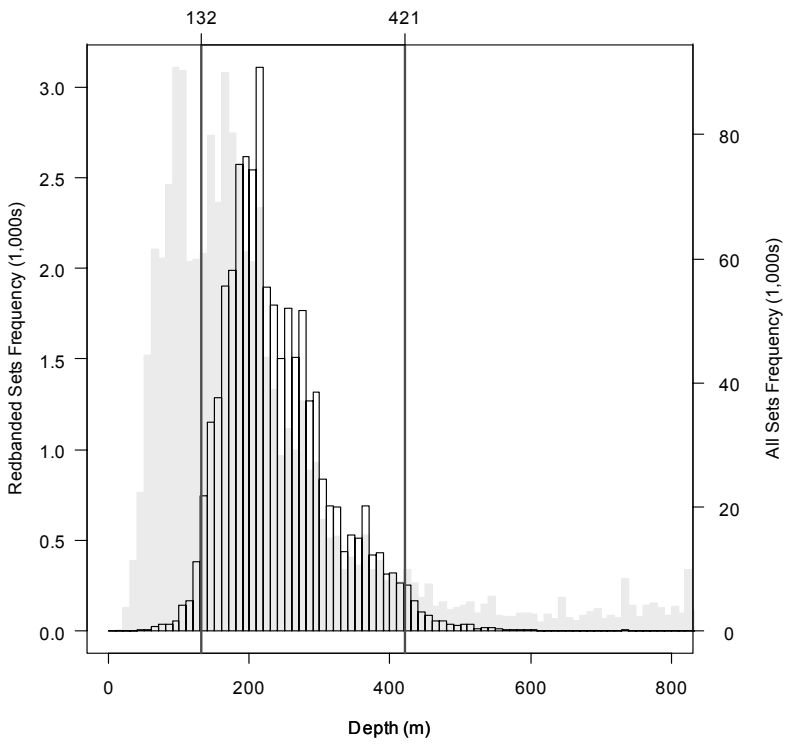


Figure 11. Histogram of depth-of-capture for redbanded rockfish from commercial trawl logs (1996-2005). The vertical lines denote the 2.5% and 97.5% quantiles. The distribution of all trawl sets is shown in light grey bars.

3.2. Bathymetric coverage

Fishing events that captured redbanded rockfish were extracted from the observer trawl database PacHarvTrawl, from the hook and line database PacHarvHL, and from research surveys. Start locations of tows were plotted in ArcView and then converted to a 5 km × 5 km raster grid. Grid cells containing one or more events were deemed to be "occupied" by redbanded rockfish. The resulting raster layer comprised cells of binary values – either "true" (occupied) or "false" (not occupied). This raster layer was added to a second raster layer consisting of ocean depth at a resolution of 1 km^2 over the preferred depth range of redbanded rockfish (see Section 3.1). From the combined raster layer, the area of potential and occupied habitat was obtained over depth intervals of 100 m (Table 3). The preferred habitat appears in Figure 12.

Table 3. Bathymetric determination of total available and observed occupied areas by 100-m depth interval for redbanded rockfish. Based on events from commercial fishing and surveys located in 25 km^2 grid cells overlaid on a 1 km^2 ocean depth grid.

Depth Range (m)	Total Area (km^2)	Occupied Total Area (km^2)	Preferred Area (km^2)	Occupied Preferred Area (km^2)
0 - 100	46,127	5,028	-	-
100 - 200	36,433	17,015	23,336	12,980
200 - 300	16,468	10,234	16,468	10,234
300 - 400	7,276	3,742	7,276	3,742
400 - 500	2,766	1,826	797	476
500 - 600	1,784	1,145	-	-
600 - 700	1,570	968	-	-
700 - 800	1,421	712	-	-
Total	113,845	40,670	47,877	27,432

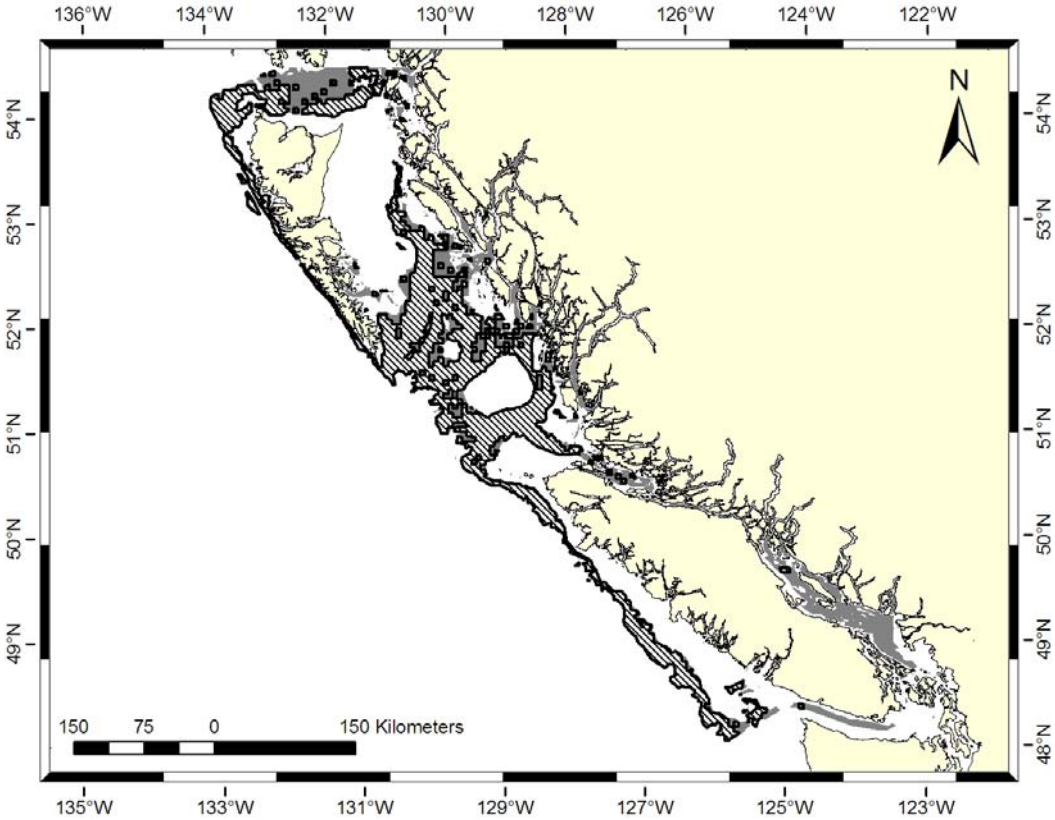


Figure 12. Estimated habitat of redbanded rockfish in Canadian waters, based on preferred depth distribution of 132 m to 421 m. The maximum potential habitat based on depth preference is 47,877 km^2 (solid shading). The occupied preferred habitat based on commercial and survey observations (5×5 km grid) is 27,432 km^2 (diagonal shading), or 57.3% of the potential habitat.

3.3. Density proportional to CPUE

3.3.1. Data selection

Data were selected from the DFO PacHarvTrawl database using the following qualifications:

- species identified as redbanded rockfish (code = 401);
- observer logs (code=1);
- calendar years = 1996 to 2005;
- depth range = 0 to 800 m;
- gear type = bottom trawl (code=1);
- effort >0 hours and ≤ 24 hours;
- successful hauls (code=0:1);
- valid spatial coordinates.

Data were selected from the DFO PacHarvHL database using the following qualifications:

- species identified as redbanded rockfish (code = 401);
- fishery = ZN hook and line (code=5);
- fisher logs (code=2);
- calendar years = 1996 to 2004;
- depth range = 0 to 800 m;
- gear type = longline (code=5);
- effort > 0 hours and ≤ 24 hours;
- valid spatial coordinates.

3.3.2. Methods

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 comprising 5 km × 5 km cells. In each grid cell, the mean CPUE was calculated:

$$\bar{U}_c = \frac{1}{n_c} \sum_{j=1}^{n_c} U_j \qquad (3)$$

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

3.3.3. Results

The dataset from the trawl fishery gives the most comprehensive density distribution of redbanded rockfish along the BC coast (Figure 13). The highest densities seen by trawlers occur in shallower waters in Queen Charlotte Sound and Hecate Strait. By contrast, the ZN longline fishery appears to avoid these areas and experiences higher densities in deeper waters of the central coast (Figure 14). The halibut longline fishery catches redbanded rockfish over a large area (Figure 15), but at lower rates than the ZN fishery. This is presumably because they are targetting halibut and capturing redbanded as bycatch only.

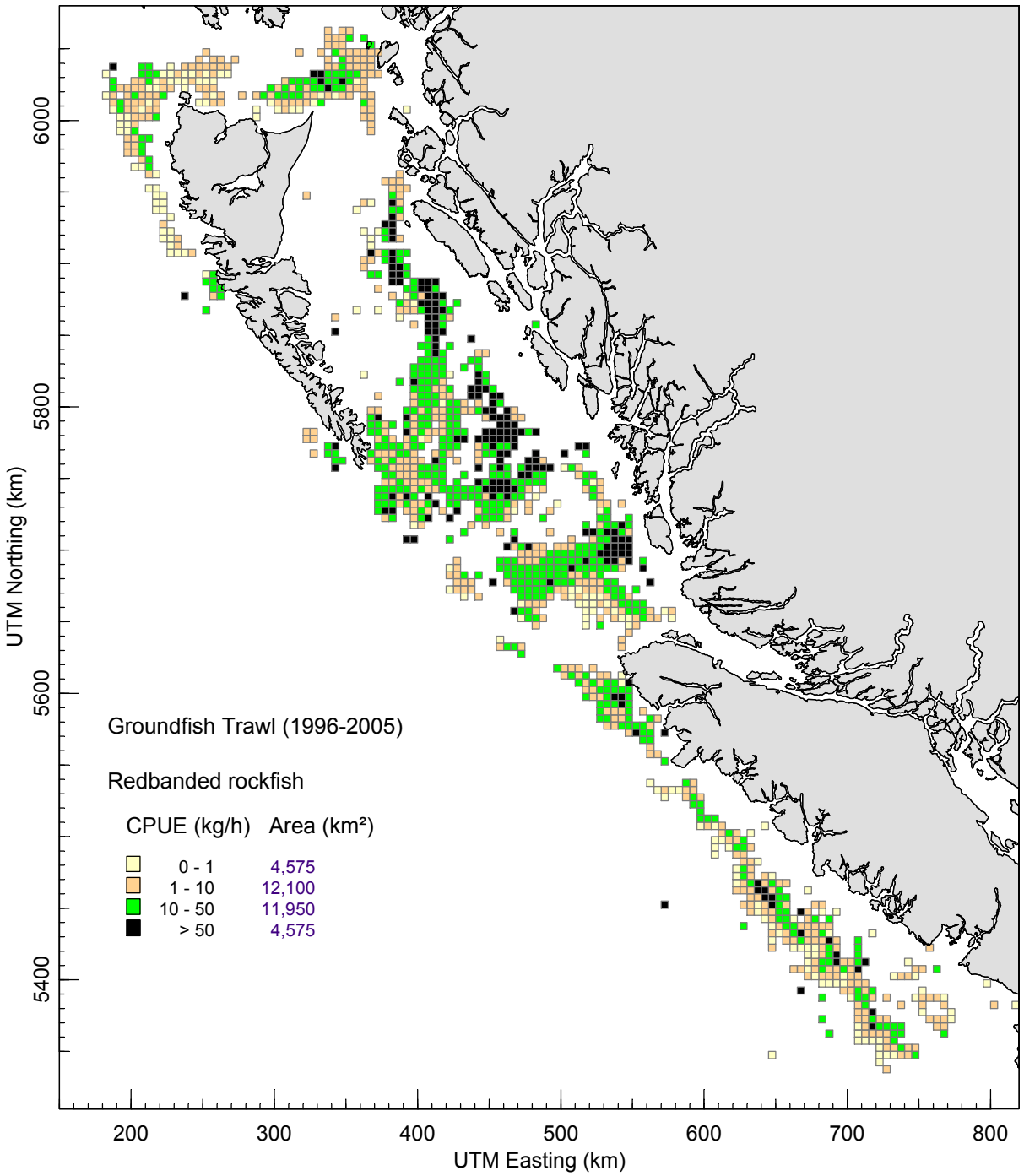


Figure 13. Mean CPUE (kg/h) of redbanded rockfish caught by the trawl fishery in 25 km^2 grid cells along the BC coast. The shaded cells give an approximation of the area of occupancy (33,200 km^2) between 0 and 800 m from 1996 to 2005.

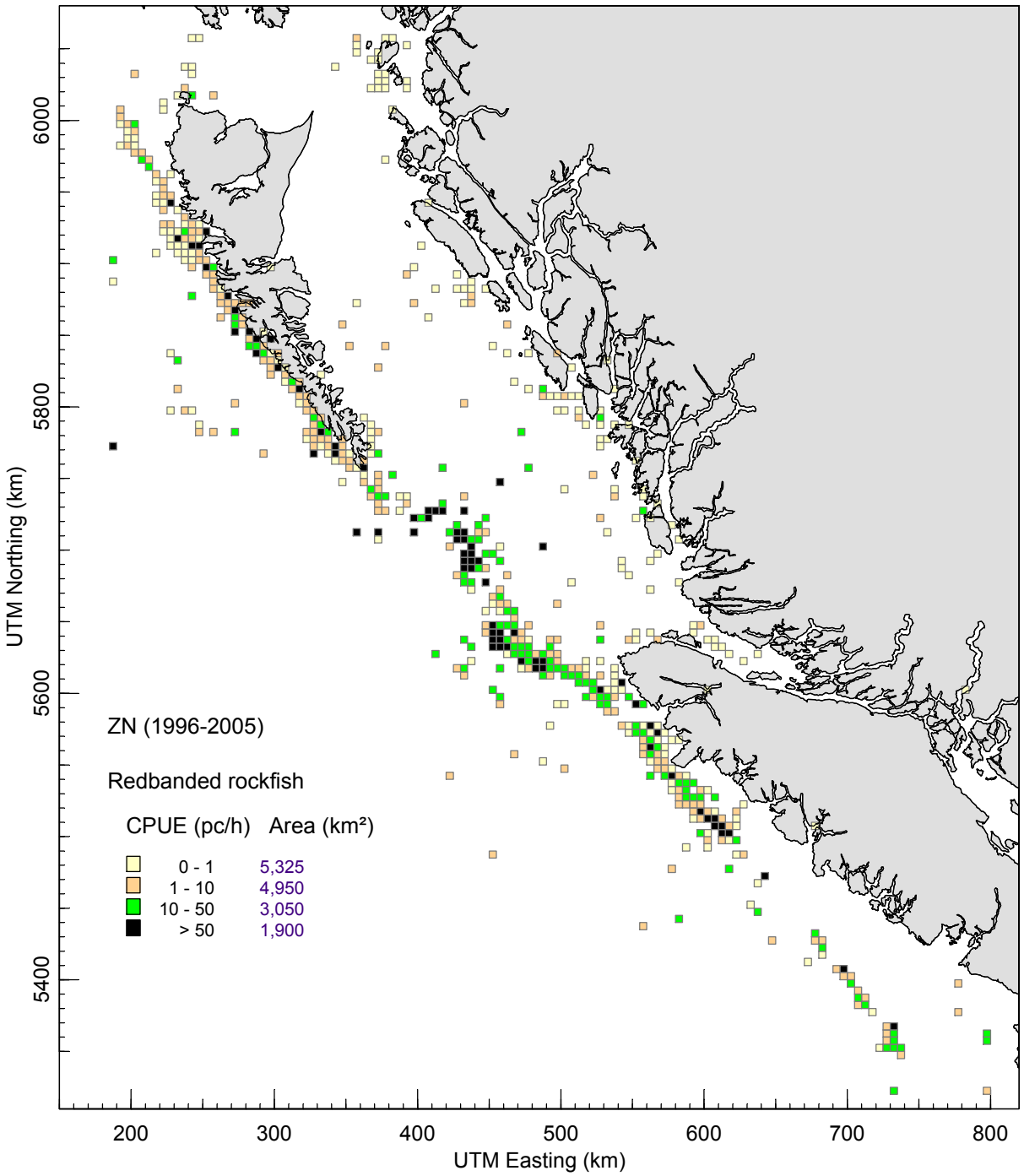


Figure 14. Mean CPUE (pieces/h) of redbanded rockfish caught by the ZN longline fishery in 25 km^2 grid cells along the BC coast. The shaded cells give an approximation of the area of occupancy (15,225 km^2) between 0 and 800 m from 1996 to 2005.

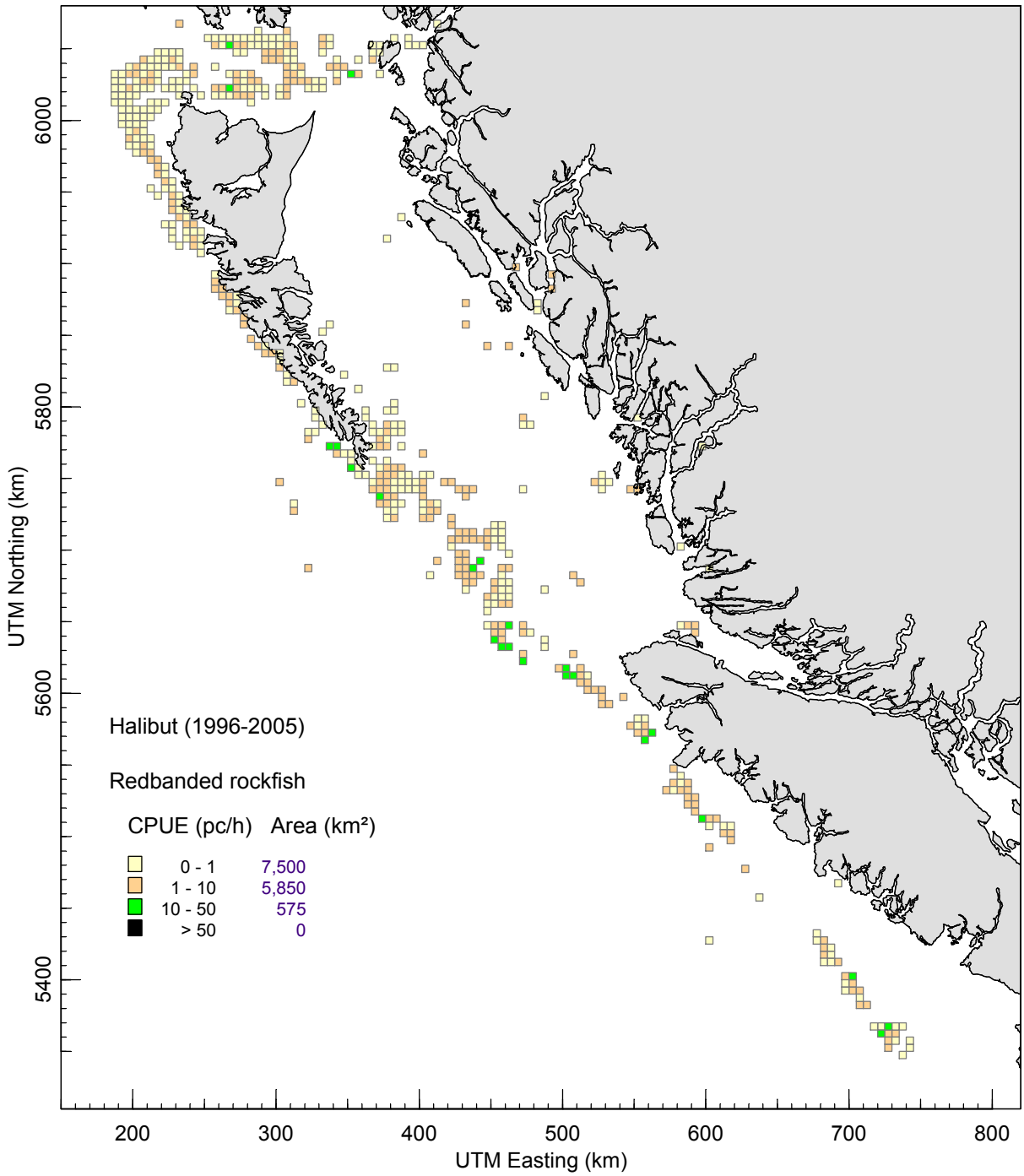


Figure 15. Mean CPUE (pieces/h) of redbanded rockfish caught by the halibut longline fishery in 25 km^2 grid cells along the BC coast. The shaded cells give an approximation of the area of occupancy (13,925 km^2) between 0 and 800 m from 1996 to 2005.

3.4. Concurrence of species in trawl tows

Within the depth range 132-421 m (Section 3.1), the total catch weight (landings + discards from the PacHarvTrawl database) for each species caught in commercial trawl tows that

contained at least one redbanded rockfish are converted to proportions of the total catch weight of all species caught, and ranked in descending order. The top 20 species are displayed as a horizontal bar chart (Figure 16).

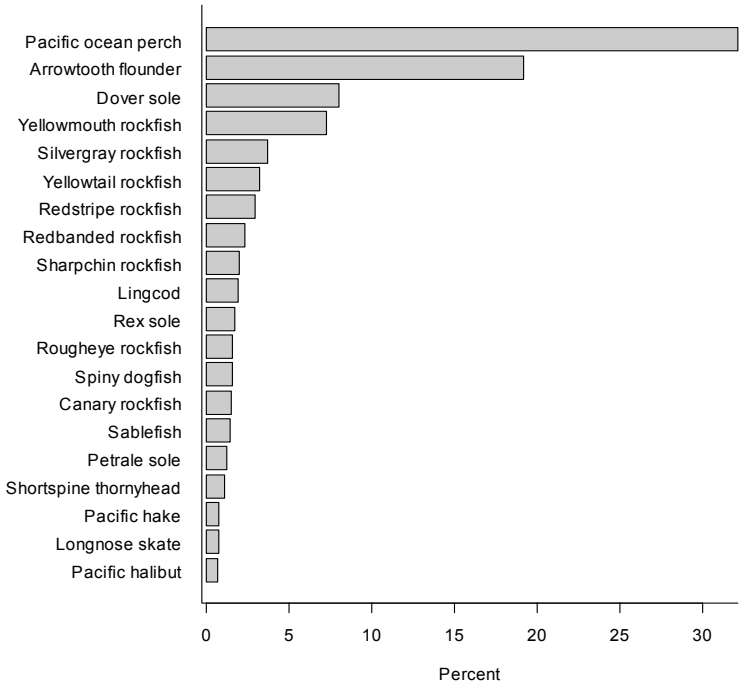


Figure 16. Concurrence of species in trawl tows (1996-2005) that occurred in the depth ranges preferred by redbanded rockfish (132-421 m) and caught at least one redbanded. Abundance expressed as a percent of total catch weight.

4. Population Trends

4.1. Biomass removals

Removals of redbanded rockfish give an indication of the biomass that was available in the mesobenthic communities along the BC coast. Trawl catch (Table 4) peaked in 1992 at 1,032 t and has since stabilized at 200-300 t since the inception of the onboard observer program in 1996. Trawl catches of this species are highest along the central coast (5ABC). The Zn hook and line fishery (Table 5) generally accounts for less than 200 t catch annually. In recent years, removals have been highest from the central coast (5AB). Unlike the trawlers, Zn fishermen caught substantial amounts of redbanded rockfish from WQCI (5E); however, this activity appears to have dropped off considerably. The Schedule II fishery catches very little redbanded rockfish (Table 6), as does the sablefish trap fishery (not presented but approximately 1 t coastwide from 1999-2005; data in PacHarvSable). The bycatch of redbanded rockfish by the halibut fishery (L-license) has experienced a notable increase over the past decade (Table 7). These fishermen are removing this rockfish primarily from the QCI and WCVI regions. Over all fisheries, the coastwide catch from 1966 to 2005 is at least 12,069 t (Table 8) or approximately 9 million fish using the conversion 1.337 kg/fish (Section 2.1). The current standing stock is not known.

Estimates of the acceptable biological catch (ABC) from the Gulf of Alaska range from 63 to 314 t during the years 1994-2002 (Table 9). On average, the current removals from the BC coast (mean = 515 t, 1996-2004) are three times higher than the estimated ABC for the GoA (mean = 172 t, 1994-2002). Whether the habitat/carrying capacity for redbanded rockfish in the GoA is comparable to that in BC waters is not known.

Table 4. Annual (calendar year) catch (kept + discarded; tonnes) of redbanded 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). Catches are rounded to the nearest tonne; entries marked '---' indicate no recorded catch. Data from 1966 to 1995 are stored in GFCatch database; data from 1996 on reside in PacHarvTrawl.

Year	3C	3D	4B	5A	5B	5C	5D	5E	UNK	CST
1966	---	1	---	4	2	---	0	---	---	6
1967	---	---	---	2	3	---	0	---	---	4
1968	---	---	---	5	---	---	---	---	---	5
1969	---	5	---	16	8	---	1	---	---	30
1970	0	---	0	4	14	---	54	---	---	73
1971	---	---	---	5	8	0	12	---	---	25
1972	---	---	---	---	---	---	16	---	---	16
1973	---	---	---	2	6	---	9	---	---	17
1974	---	---	---	1	5	---	1	---	---	7
1975	---	---	---	---	29	---	4	---	---	33
1976	---	---	---	0	67	5	11	---	---	84
1977	0	---	---	1	19	0	13	2	---	36
1978	1	0	---	18	55	16	14	5	---	109
1979	1	16	---	27	4	19	29	3	---	98
1980	---	9	0	16	101	58	15	2	---	203
1981	0	0	---	1	47	25	10	11	---	93
1982	12	3	1	9	41	11	21	7	---	105
1983	17	10	---	12	19	8	3	13	0	82
1984	---	10	---	5	75	18	5	16	---	129
1985	2	7	---	8	13	1	10	6	---	47
1986	0	23	---	13	33	8	6	8	---	91
1987	7	21	---	38	115	14	1	11	---	207
1988	27	25	---	35	181	10	2	34	---	314
1989	54	78	---	62	201	24	6	18	---	442
1990	26	53	---	84	356	114	10	3	---	646
1991	48	38	---	82	290	59	24	21	---	561
1992	45	91	---	136	554	153	34	19	---	1,032
1993	59	97	---	77	500	114	40	28	---	915
1994	60	61	0	96	341	81	30	13	---	682
1995	26	44	0	47	196	112	47	15	---	487
1996	12	27	0	19	148	87	14	9	---	316
1997	13	13	---	34	159	53	9	5	---	288
1998	12	16	---	28	120	38	8	4	---	226
1999	18	17	---	24	140	58	10	3	---	269
2000	18	16	---	31	157	47	11	8	---	289
2001	14	21	---	19	113	123	11	7	---	308
2002	13	19	---	26	133	47	5	10	---	255
2003	15	27	---	33	109	37	8	5	---	234
2004	16	19	0	25	118	38	10	8	---	234
2005	13	24	0	30	97	41	12	4	---	220
UNK	---	---	---	---	---	0	---	---	23	23
Total	528	791	2	1,073	4,577	1,420	528	299	23	9,241

Table 5. Annual (calendar year) catch (kept + discarded; tonnes) of redbanded 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). Catches are rounded to the nearest tonne; entries marked '---' indicate no recorded catch. Data are stored in the PacHarvHL database. Catches from 1986 to 1994 are taken from fisher-log records; catches from 1995 on come from either validated dockside records or fisherlogs, whichever is highest.

Year	3C	3D	4B	5A	5B	5C	5D	5E	UNK	CST
1986	---	---	---	---	---	---	---	---	0	0
1987	---	---	---	---	---	---	---	---	0	0
1988	---	---	---	---	---	---	---	---	0	0
1989	---	0	---	0	---	0	---	---	14	15
1990	2	5	---	8	8	0	1	2	13	40
1991	3	10	0	10	9	1	1	3	6	43
1992	0	2	---	4	5	0	0	11	1	23
1993	4	8	0	8	4	0	0	8	3	35
1994	1	10	0	97	2	1	1	63	12	187
1995	0	38	4	93	14	6	5	73	33	266
1996	3	34	6	73	2	3	1	53	14	190
1997	0	17	0	28	1	1	0	49	17	114
1998	1	9	0	30	1	6	0	25	2	74
1999	0	89	0	87	1	1	1	22	3	205
2000	1	24	11	91	94	6	7	35	22	291
2001	3	8	0	94	58	7	5	21	7	204
2002	4	11	0	73	48	1	0	13	3	153
2003	---	7	0	130	93	3	0	9	1	243
2004	0	7	0	78	81	1	0	4	0	170
UNK	---	---	---	---	---	---	---	1	---	1
Total	22	280	23	904	422	36	23	394	150	2,255

Table 6. Annual (calendar year) catch (kept + discarded; tonnes) of redbanded rockfish by the Schedule II 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). Catches are rounded to the nearest tonne; entries marked '---' indicate no recorded catch. Data are stored in the PacHarvHL database. Catches from 1996 on come from either validated dockside records or fisherlogs, whichever is highest.

Year	3C	3D	4B	5A	5B	5C	5D	5E	UNK	CST
1996	---	---	---	0	---	---	---	---	---	0
1997	---	0	---	---	---	0	---	0	0	0
1998	---	0	---	0	---	---	---	0	---	0
1999	0	0	---	---	---	---	0	0	---	0
2000	---	---	---	---	---	---	---	---	---	---
2001	---	0	---	---	---	0	---	---	---	0
2002	0	---	0	---	---	0	---	---	0	0
2003	0	---	0	0	---	---	0	0	---	0
2004	0	2	0	3	---	---	---	0	---	5
Total	0	2	0	3	---	0	0	0	0	6

Table 7. Annual (calendar year) bycatch (tonnes) of redbanded rockfish by the halibut fishery in geographic regions along the BC coast (CC = central coast, NC = north coast, QCI = Queen Charlotte Islands, SG = Strait of Georgia, WCVI = west coast of Vancouver Island, CST = coastwide). 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	CC	NC	QCI	SG	WCVI	CST
1995	0	0	1	0	0	2
1996	1	0	3	0	1	5
1997	1	0	4	0	1	6
1998	2	1	13	0	2	19
1999	4	1	20	0	7	32
2000	12	1	44	0	20	78
2001	15	1	54	0	22	92
2002	10	2	64	---	29	104
2003	6	1	59	---	36	102
2004	15	1	79	---	33	128
Total	65	9	341	1	153	568

Table 8. Annual (calendar year) catch (kept + discarded; tonnes) of redbanded rockfish coastwide by various BC fisheries. Catches are rounded to the nearest tonne; entries marked '---' indicate no recorded catch. Trawl data from 1966 to 1995 are stored in the GFCatch database; data from 1996 on reside in PacHarvTrawl. 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	Trawl	Zn HL	Shed II	Halibut	Total HL	Total
1966	6	---	---	---	---	6
1967	4	---	---	---	---	4
1968	5	---	---	---	---	5
1969	30	---	---	---	---	30
1970	73	---	---	---	---	73
1971	25	---	---	---	---	25
1972	16	---	---	---	---	16
1973	17	---	---	---	---	17
1974	7	---	---	---	---	7
1975	33	---	---	---	---	33
1976	84	---	---	---	---	84
1977	36	---	---	---	---	36
1978	109	---	---	---	---	109
1979	98	---	---	---	---	98
1980	203	---	---	---	---	203
1981	93	---	---	---	---	93
1982	105	---	---	---	---	105
1983	82	---	---	---	---	82
1984	129	---	---	---	---	129
1985	47	---	---	---	---	47
1986	91	0	---	---	0	91
1987	207	0	---	---	0	207
1988	314	0	---	---	0	314
1989	442	15	---	---	15	457
1990	646	40	---	---	40	686
1991[d]	561	43	---	---	43	605
1992	1,032	23	---	---	23	1,055
1993	915	35	---	---	35	949

Year	Trawl	Zn HL	Shed II	Halibut	Total HL	Total
1994[d]	682	187	---	---	187	869
1995[d,t]	487	266	---	2	268	755
1996[o]	316	190	0	5	195	511
1997[q,t]	288	114	0	6	121	408
1998	226	74	0	19	94	320
1999	269	205	0	32	237	506
2000[t]	289	291	---	78	369	658
2001	308	204	0	92	297	604
2002	255	153	0	104	257	511
2003	234	243	0	102	345	579
2004	234	170	5	128	303	537
2005	220	NA	NA	NA	NA	220
UNK	23	---	---	---	---	23
Total	**9,241**	**2,253**	**6**	**568**	**2,828**	**12,069**

[d] Dockside monitoring program (DMP) started: 1991 – halibut; 1994 – trawl; 1995 – Zn HL
[o] Observer program started: 1996 – trawl
[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 9. Estimates of catch (t) and acceptable biological catch (t) for redbanded rockfish in the Gulf of Alaska between 1994 and 2002. pRBR = proportion by weight of redbanded rockfish in the "other slope rockfish" category of the commercial catch; ORF_c = commercial catch of "other slope rockfish"; ORF_s = survey catch of "other slope rockfish"; RBR = portion of total ORF estimated to be redbanded: pRBR*(ORF_c+ORF_s); ABC_{orf} = acceptable biological catch of ORF; ABC_{rbr} = estimated acceptable biological catch of redbanded rockfish: pRBR* ABC_{orf}. Source: Clausen (2005).

Year	pRBR	ORF_c	ORF_s	RBR	ABC_{orf}	ABC_{rbr}
1994	0.014	1,613	0	23	8,300	116
1995	0.016	1,397	0	22	7,110	114
1996	0.034	881	17	31	7,110	242
1997	0.012	1,217	0	15	5,260	63
1998	0.023	861	2	20	5,260	121
1999	0.027	788	52	23	5,270	142
2000	0.043	577	0	25	4,900	211
2001	0.064	559	1	36	4,900	314
2002	0.045	774	0	35	5,040	227

4.2. QCS synoptic bottom trawl survey

4.2.1. Background and data

The Queen Charlotte Sound (QCS) synoptic bottom trawl survey was initiated in 2003 (Stanley et al. 2004) and has run annually since. 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.

Strata population parameters (p, μ, ρ) for redbanded rockfish in the QCS synoptic survey appear in Table 10, as do the moment estimates of biomass, variance, and CV (described in Appendix A.6).

Table 10. Population parameters and moment estimates for redbanded 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 redbanded 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				5,334	30		0		
2003	19	0.518	0.119	1.698	0.347	5,873	56	27	337.7	14,371	0.355
2003	20	0.100	0.083	0.903	1.226	3,134	30	27	233.8	1,854	0.184
2003	21	0.167	0.052	0.802	1.556	625	6	5	27.0	118	0.402
2003	22	1				2,279	5		0		
2003	23	0.769	0.041	0.792	1.592	4,926	39	9	46.2	331	0.394
2003	24	0.037	0.111	1.975	0.256	4,688	54	52	502.8	19,152	0.275
2003	25	0.579	0.016	0.614	2.650	1,343	19	8	9.1	10	0.346
2004	18	0.978	0.006	0.147	46.000	5,334	46	1	0.6	0	1.000
2004	19	0.510	0.028	1.141	0.768	5,873	49	24	80.9	494	0.275
2004	20	0.097	0.066	1.038	0.928	3,134	31	28	186.0	1,450	0.205
2004	21	0.500	0.047	0.794	1.587	625	8	4	14.8	61	0.532
2004	22	1				2,279	20		0		
2004	23	0.795	0.038	1.023	0.956	4,926	39	8	38.6	343	0.480
2004	24	0.125	0.079	2.113	0.224	4,688	40	35	322.0	13,603	0.362
2004	25	0.571	0.044	1.150	0.757	1,343	7	3	25.1	399	0.794
2005	18	0.968	0.341	0.180	31.000	5,334	31	1	58.6	3,435	1.000
2005	19	0.508	0.193	1.561	0.410	5,873	61	30	557.4	30,516	0.313
2005	20	0.034	0.087	0.763	1.716	3,134	29	28	262.5	1,519	0.148
2005	21	0.250	0.044	0.696	2.065	625	8	6	20.7	53	0.350
2005	22	0.750	0.041	0.025	1568.000	2,279	8	2	23.3	204	0.613
2005	23	0.689	0.193	1.498	0.445	4,926	45	14	295.1	18,253	0.458
2005	24	0.079	0.058	1.038	0.929	4,688	38	35	252.3	2,101	0.182
2005	25	0.375	0.011	0.599	2.789	1,343	8	5	9.6	13	0.383

Table 11. Queen Charlotte Sound synoptic trawl survey strata definitions.

Stratum Code	Depth Range (m)	Area (km^2)
18	South: 50 - 125	5,334
19	South: 125 - 200	5,873
20	South: 200 - 330	3,134
21	South: 330 - 500	625
22	North: 50 - 125	2,279
23	North: 125 - 200	4,926
24	North: 200 - 330	4,688
25	North: 330 - 500	1,343

4.2.2. Results

At present, the time series available is only three years long, which is too short to detect trends for this species. The bootstrapped biomass index shows no clear trend (Figure 17). The deeper strata consistently catch redbanded rockfish ($p < 0.50$; Table 10) and the precision of its abundance index is considered "excellent" (sampling $\text{CV} < 0.20$; Stanley et al. 2004). Over time, this survey will provide the most useful population indicator for redbanded rockfish in QCS.

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

Table 12. Biomass index (t) and confidence limits from 1000 bootstrapped biomass estimates. n = number of tows, n^+ = number of tows catching redbanded rockfish, $\mathrm{E}[B]$ = expected biomass (t), $\overline{B}$ = mean bootstrapped biomass (BB), $B_{0.50}$ = median BB, $B_{0.05}$ = 5% quantile of BB, $B_{0.95}$ = 95% quantile of BB, CV=coefficient of variation.

Year	n	n+	$\mathrm{E}[B]$	$\overline{B}$	$B_{0.50}$	$B_{0.05}$	$B_{0.95}$	CV
2003	239	128	1,126	1,133	1,119	832	1,602	0.160
2004	240	103	673	680	662	504	1,091	0.184
2005	228	121	1,390	1,386	1,386	1,026	1,894	0.165

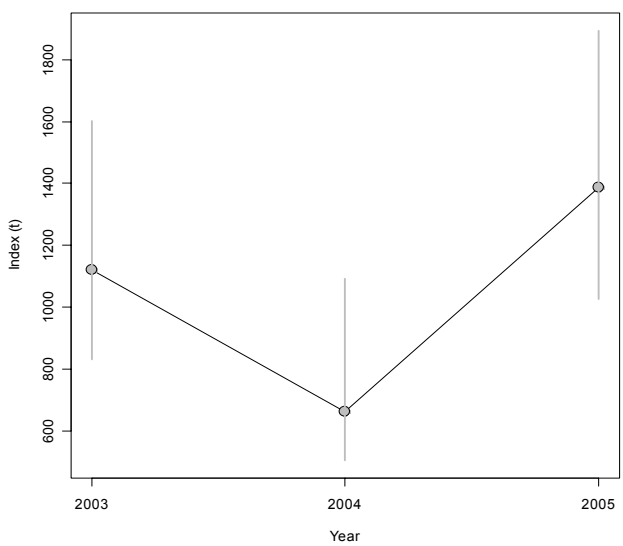


Figure 17. Relative index for redbanded rockfish in Queen Charlotte Sound from the QCS bottom trawl survey. Vertical bars indicate 90% confidence intervals from 1,000 bootstrapped biomass index estimates.

4.2.3. WCVI synoptic survey

The WCVI synoptic survey started in 2004 and uses the same depth strata as those in the QCS synoptic survey. The initial index point appears in .

Table 13. Annual index values for redbanded rockfish caught in the Queen Charlotte Sound shrimp trawl survey, 1999 to 2004. I = moment index value (t); $\overline{I}$ = mean bootstrapped index (t); $I_{0.50}$ = median bootstrapped index (t); $I_{0.05}$ = 5% confidence limit of the bootstrapped index (t); $I_{0.95}$ = 95% confidence limit (t); CV = coefficient of variation of I. Although the catchability is assumed to be 1, we do not know its true value.

Year	I	$\overline{I}$	$I_{0.50}$	$I_{0.05}$	$I_{0.95}$	CV
2004	217	222	211	129	484	0.333

4.3. Hecate Strait assemblage survey

4.3.1. Data selection

This analysis is based on tow-by-tow data from the Hecate Strait (HS) assemblage survey for all years from 1984 to 2003 (Figure 18). We have adopted most of the recommendations for this survey contained in Sinclair (1999). These recommendations include:

- distributing the tows into strata represented by 10 fathom depth intervals;
- only analysing the data in the range of 10 to 80 fathoms (to ensure comparability between surveys); and
- instead of applying a constant factor of 0.0486 km^2/h to convert the estimates of CPUE in kg/h to swept area estimates, we have used mean doorspread (43 m) and vessel speed (5.1 km/h) for those tows which do not have these values. This made little practical difference compared to using the constant factor suggested by Sinclair (1999).

Table 14. Number of tows by depth zone and year of the Hecate Strait assemblage survey. The final row shows the estimated size (km^2) of each stratum for the survey.

Year	10-19 fm	20-29 fm	30-39 fm	40-49 fm	50-59 fm	60-69 fm	70-79 fm	Total
1984	19	19	23	25	23	23	14	146
1987	15	12	12	11	16	10	9	85
1989	17	12	12	15	12	9	13	90
1991	18	12	15	10	21	15	6	97
1993	16	20	11	15	10	15	7	94
1995	16	19	15	16	14	14	7	101
1996	25	24	21	10	11	10	4	105
1998	14	11	17	13	13	14	4	86
2000	18	22	19	14	15	11	6	105
2002	17	17	15	16	11	10	5	91
2003	15	16	16	18	15	9	5	94
Area (km^2)	2,657	1,651	908	828	912	792	612	8,360

We were not able to reconstruct exactly the distribution of tows by depth zone and survey year as presented by Sinclair (1999) in his Table 4, but the differences were relatively small (compare Table 14 with Table 4 in Sinclair (1999)). These differences may be due to different conversion assumptions as the depth data are provided in metres and the depth intervals are defined in fathoms. Alternatively, the original data may have been recorded in fathoms and there may be a loss in precision when converting from fathoms to metres and back to fathoms. Three definitions of depth based on the two depth fields provided (depth at the beginning of each set, depth at the end of each set, and mean depth for the set) were tested to see if the Sinclair Table 4 distribution could be duplicated. All three definitions performed similarly, but depth at the beginning of the set was adopted, as this distribution seemed to be the closest to that provided in the Sinclair Table 4.

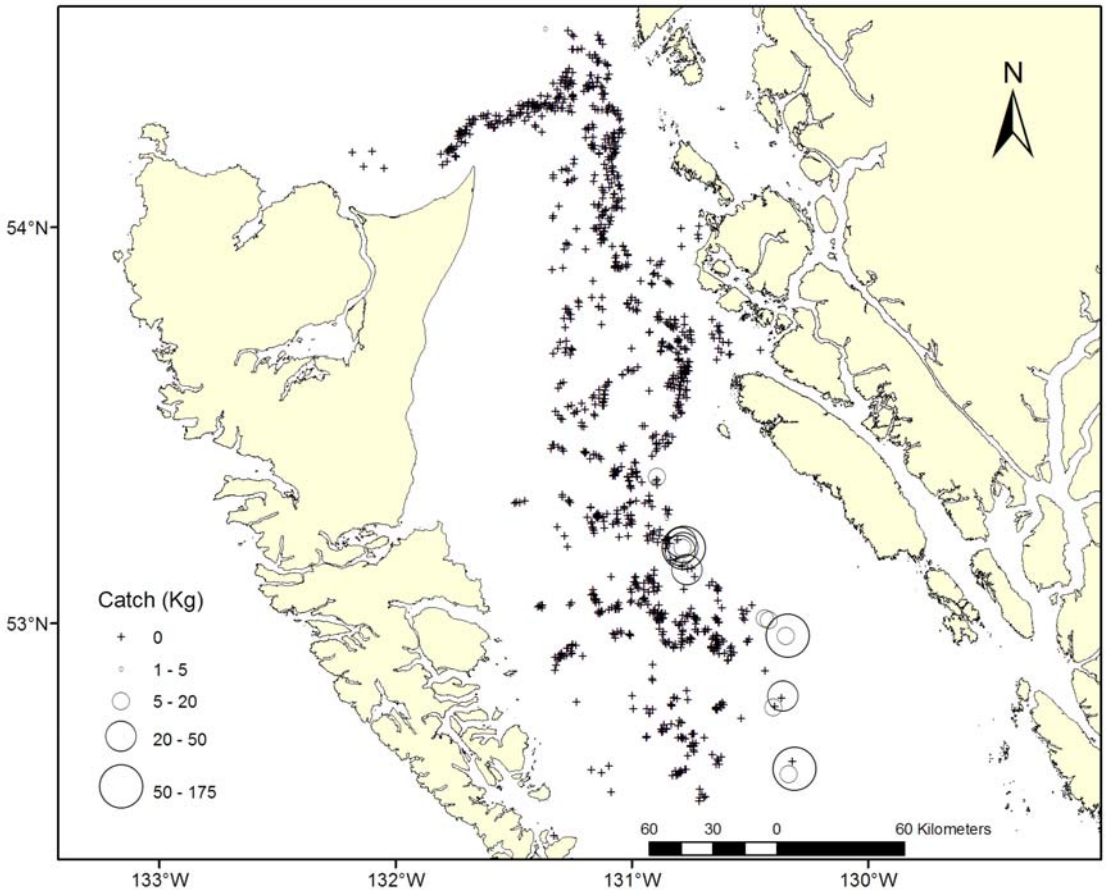


Figure 18. Tow locations using start position for all survey tows in the Hecate Strait assemblage trawl survey. Tows that took redbanded rockfish are indicated by a variable circle, which is proportional to the catch weight (kg).

4.3.2. Methods

Swept-area biomass formulae appear in Appendix A.5. These calculations assume that tow locations are selected randomly within a stratum relative to the biomass of redbanded rockfish. This was not an assumption made by the original survey design. Additionally, the depth strata we use here (Table 14) were not used when conducting the survey. One thousand bootstrap replicates with replacement were made on the survey data to estimate bias corrected 95% confidence regions for each survey species (Efron 1982).

4.3.3. Results

This species usually occurs only in the deepest stratum (70-79 fathoms or 128-146 m) and is not present in every year of the survey (Figure 19). Given this species' occurrence at deeper depths in the commercial fishery and the restricted depth range of the HS survey, it is unlikely that this survey would provide a reliable index of abundance for this species.

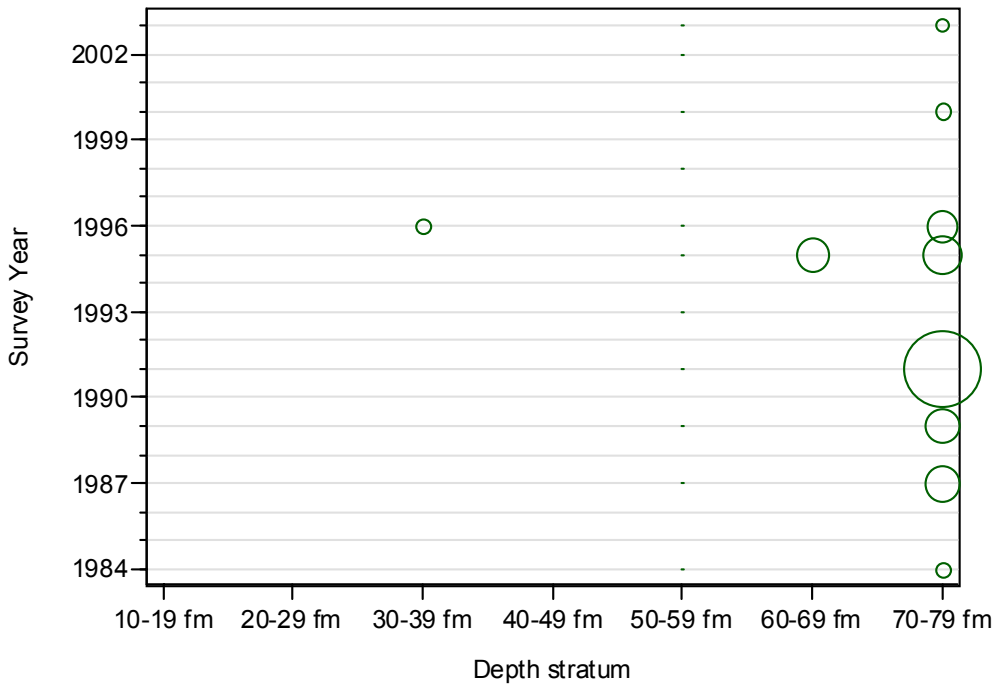


Figure 19. Survey catch of redbanded rockfish by 10-fathom depth intervals and year for all tows. Maximum catch: 148 kg in 1991/70-79 fathom stratum.

Table 15. Biomass estimates for redbanded rockfish from the HS assemblage survey from 1984 to 2003. Biomass estimates are based on a post-stratification of this survey into 10-fathom depth zones and assume that the survey tows were randomly selected within these depth zones. Bootstrap bias-corrected confidence intervals and CVs are based on 1000 random draws with replacement. The analytic CV is based on the assumption of random tow selection within a stratum.

Survey year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
1984	4	4	0	11	0.686	0.679
1987	18	18	0	56	0.843	0.890
1989	18	19	0	62	0.840	0.851
1991	138	138	0	480	0.916	0.891
1993	0	0	–	–	–	–
1995	50	51	0	141	0.710	0.718
1996	32	32	2	113	0.817	0.845
1998	0	0	–	–	–	–
2000	12	12	0	47	0.998	1.000
2002	0	0	–	–	–	–
2003	4	4	0	15	0.972	1.000

Estimated biomass for redbanded rockfish from the HS assemblage survey varies between 0 and 138 t (Table 15). Confidence bounds are wide with the estimated CVs for redbanded rockfish ranging from 0.7 to 1.0 (Figure 20). The proportion of tows which contain redbanded rockfish has always been below 0.1 and appears to have dropped in recent surveys (Figure 21). It is unlikely that this survey will provide a useable index of abundance for this species.

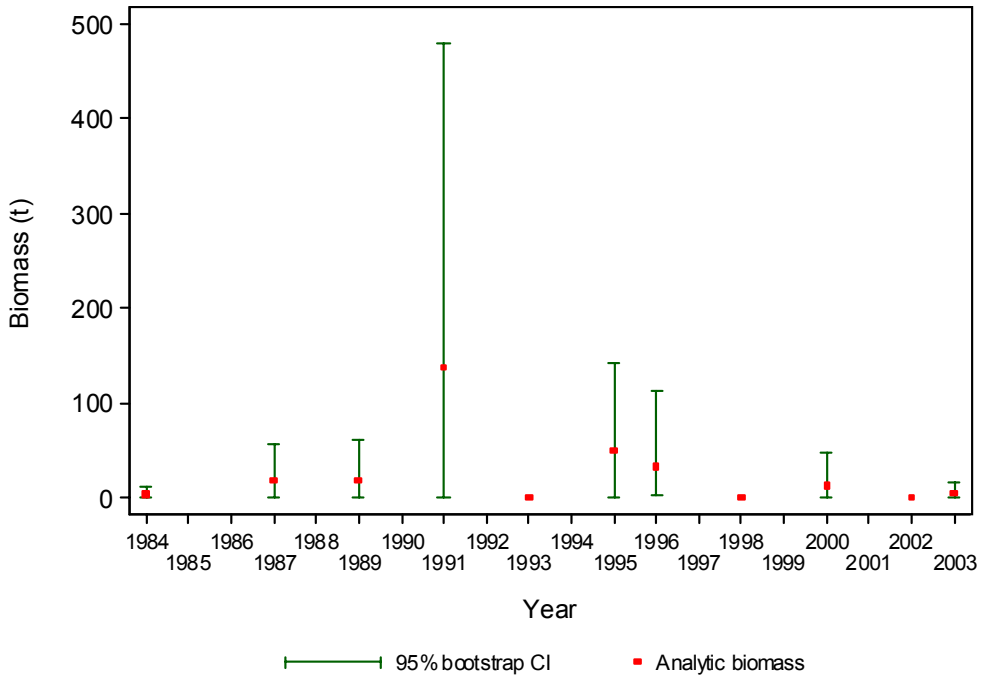


Figure 20. Plot of biomass estimates for redbanded rockfish from the Hecate Strait assemblage trawl survey for the period 1984 to 2003. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

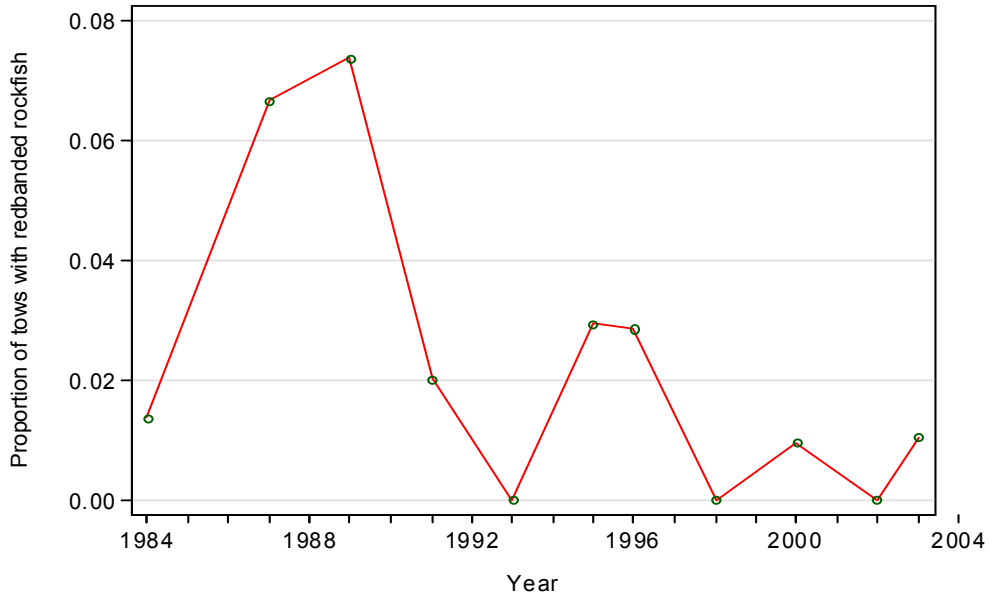


Figure 21. Proportion of tows by year which contain redbanded rockfish for the Hecate Strait assemblage trawl survey.

4.4. WCVI shrimp trawl survey

4.4.1. Data selection

Tow-by-tow data from a west coast Vancouver Island (WCVI) shrimp trawl survey are available for 31 years spanning the period from 1972 to 2005. 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 WCVI 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 16). 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 revised area weights in square kilometres for the redefined strata are presented in Table 17.

There are almost no tows below 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 17).

No tows were recorded in Area 125 for the 1989 and 1991 survey years (Table 17). 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.

Table 16. WCVI shrimp trawl survey – number of sets made by each vessel by month and survey year.

Vessel/Year	April	May	June	July	August	September
Caligus						
1999		2				
2000		6				
2001		7				
Challenger						
1977						13
Deliverance						
1977						15
Frosti						
2005		94				
G. B. Reed						
1975		85				
1976		89				
1977		76		12		
1978		100				
1979		76				
1980		85				
1981		88				
1982		81				
1983		77				
1985		50	32			
Neo-Caligus						
2002		6				
2003	1	4				
2004		2				
2005		3				
Ocean King						
1978						81
Pacific Trident						
1977						21
Ricker						
1987					68	
1988	17	62				
1990	61	21				
1991	2	84				
1992		83				
1993	29	74				
1994	31	69				
1995		86				
1996	6	94				
1997		115				
1998		95				
1999		110				
2000		99				
2001		99				
2002	39	65				
2003	47	45				
2004	4	97				
Sharlene K.						
1989		67				
Sunnfjord						
1977						19

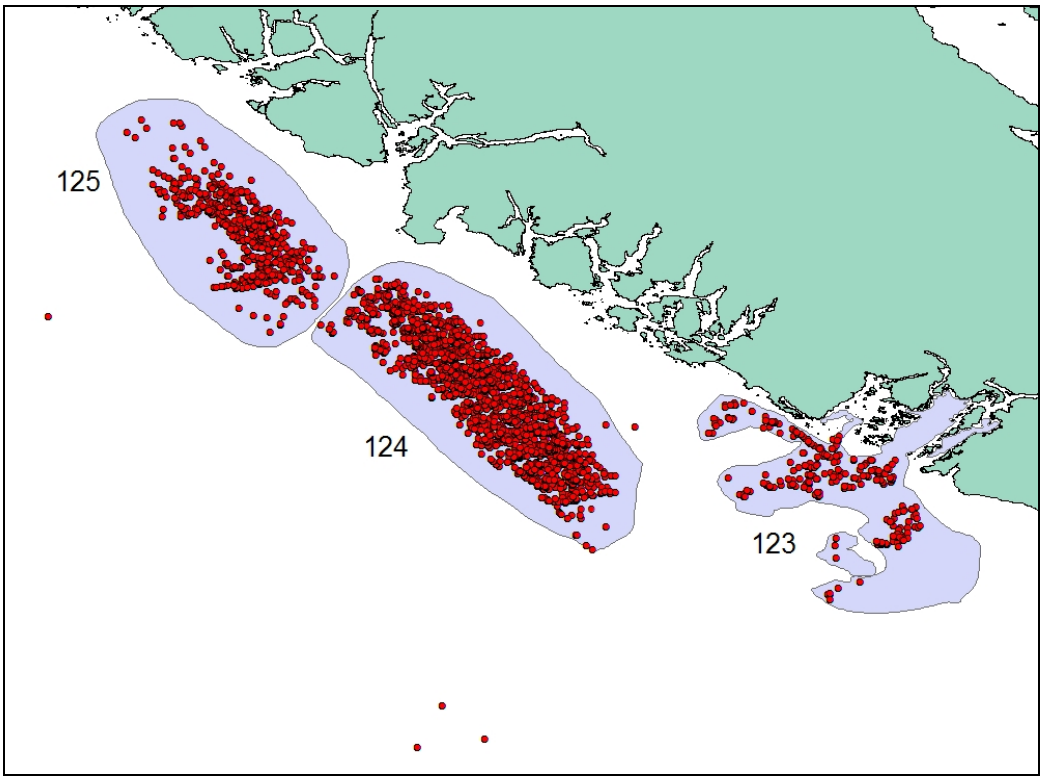


Figure 22. Map of the locations of all trawls in areas 123, 124 and 125 that were associated with the WCVI shrimp trawl survey. Areas 124 and 125 are the strata that have been surveyed consistently over the history of the survey and which are in locations most likely to catch redbanded rockfish.

Table 17. List of tows used from the WCVI shrimp trawl survey by survey year and stratum, including the number and weight of redbanded rockfish for tows dropped from the analysis and tows shifted from 124 to 123.

	Stratum		Total	Dropped tows		Shifted from 124 to 123	
Year	124	125	tows	Number	Redbanded (kg)	Number	Redbanded (kg)
1975	62	17	79	6	0		
1976	70	18	88	1	0		
1977	62	26	88	0	0		
1978	85	15	100	0	0		
1979	52	24	76	0	0		
1980	59	26	85	0	0		
1981	58	30	88	0	0		
1982	56	25	81	0	0		
1983	51	26	77	0	0		
1985	59	22	81	0	0		
1987	55	13	68	0	0		
1988	69	10	79	0	0		
1989	67	0	67	0	0		
1990	72	10	82	0	0		
1991	86	0	86	0	0		
1992	77	6	83	0	0		
1993	70	33	103	0	0		
1994	67	30	97	0	0		
1995	63	23	86	0	0		
1996	56	17	73	0	0	1	0
1997	61	21	82	0	0	2	0

Year	Stratum 124	Stratum 125	Total tows	Dropped tows Number	Dropped tows Redbanded (kg)	Shifted from 124 to 123 Number	Shifted from 124 to 123 Redbanded (kg)
1998	45	22	67	0	0	1	0
1999	51	31	82	0	0	1	0
2000	43	30	73	0	0	2	0
2001	49	22	71	0	0	2	0
2002	50	26	76	0	0	1	0
2003	46	19	65	0	0	1	0
2004	49	26	75	0	0	2	0
2005	46	25	71	0	0	1	0
Total	1736	593	2329	7	0	14	0
Area (km^2)[1]	2591	2065	4656				
Area (km^2)[2]	2166	1493	3659				

[1] Total area out to 260 m maximum depth
[2] Area out to 160 m maximum depth

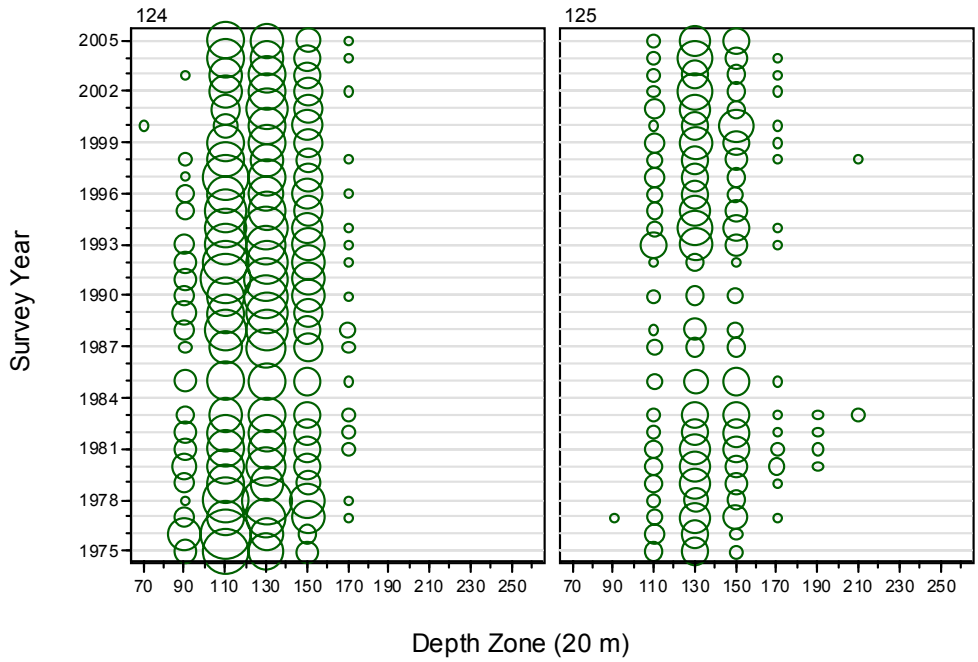


Figure 23. Distribution of tows in 20-m depth zones by survey year and area stratum for all selected tows. Each 20-m depth bin is indicated by the mid-point of the bin (i.e., 110 m = 100-120 m). Tow depth determined by the mean of the start and end depths. Circles are weighted by the number of sets observed in each depth bin. Maximum number sets: stratum 124 (1976/110 m) = 36 sets; stratum 125 (2002/130 m = 18 sets.

4.4.2. Methods

Swept-area biomass estimate formulae are detailed in Appendix A.5. One thousand bootstrap replicates with replacement were made on the survey data to estimate bias corrected 95% confidence regions for each survey year (Efron 1982). The original survey design used latitudinal transects and selected the stations randomly along the transect. We depart from the original stratification in two respects. First, we assume that tow locations were selected randomly within a stratum relative to the biomass of redbanded rockfish. Additionally, we use a different definition of area (Figure 22).

4.4.3. Results

This species has not been represented in every year over the history of the survey and all catches of redbanded rockfish have been at depths greater than 100 m (Figure 19). Given that this survey does not extend consistently beyond 160 m and that redbanded rockfish are consistently captured at deeper depths in the commercial fishery (see Appendix ***), it is likely that this survey will not provide a reliable abundance index for this species.

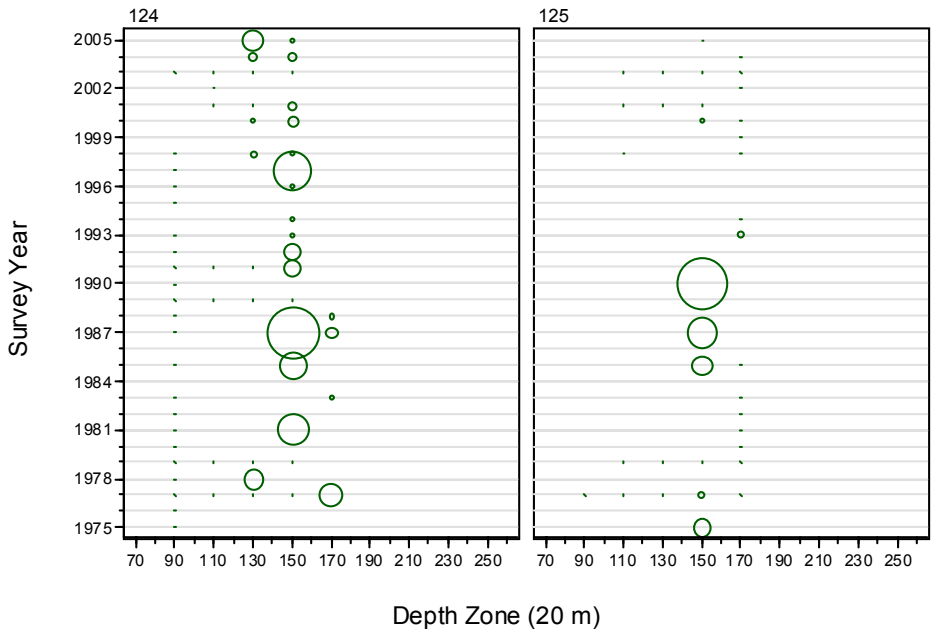


Figure 24. Survey catch of redbanded rockfish by 20-m depth intervals and year for all tows. Maximum catch: stratum 124 (1987/150 m) = 40 kg; stratum 125(1990/150 m) = 33 kg.

Redbanded rockfish have appeared in this survey sporadically, resulting in only a few years which show much catch for this species (e.g., 1987, 1990, and 1997; Figure 25, Table 18). All years have very high coefficients of variation and consequently are highly uncertain. Therefore, it is not possible to use this survey to monitor this species. The proportion of tows which contain redbanded rockfish show a very low incidence of this species throughout the period of this survey (Figure 26).

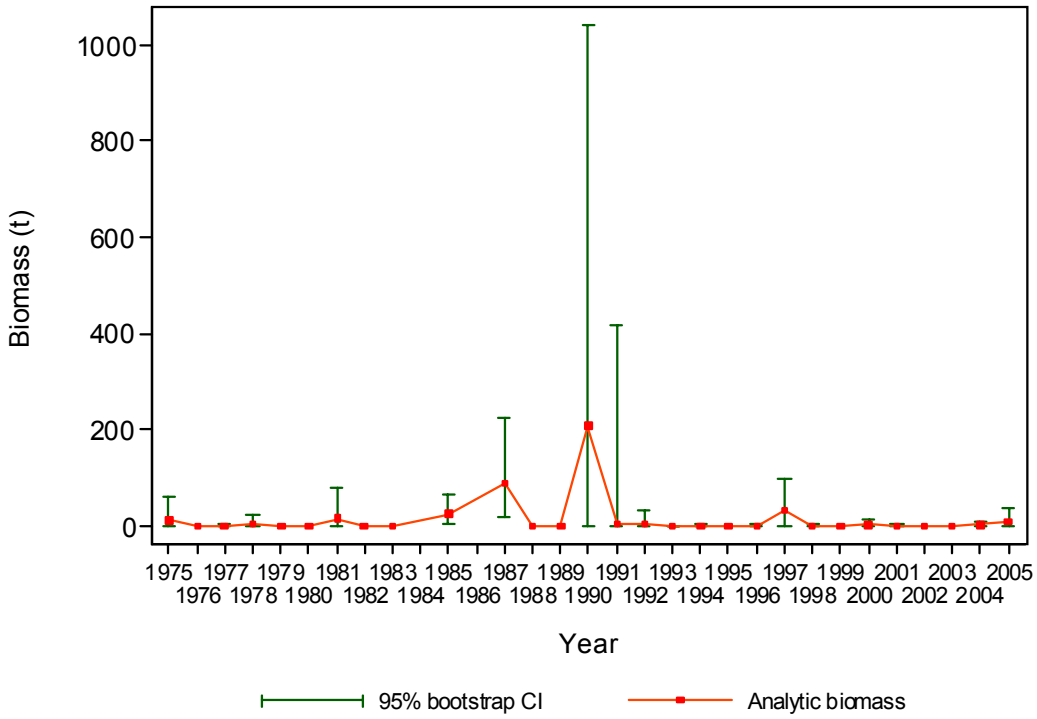


Figure 25. Biomass estimates for redbanded rockfish from the WCVI shrimp trawl survey for the period 1975 to 2005. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

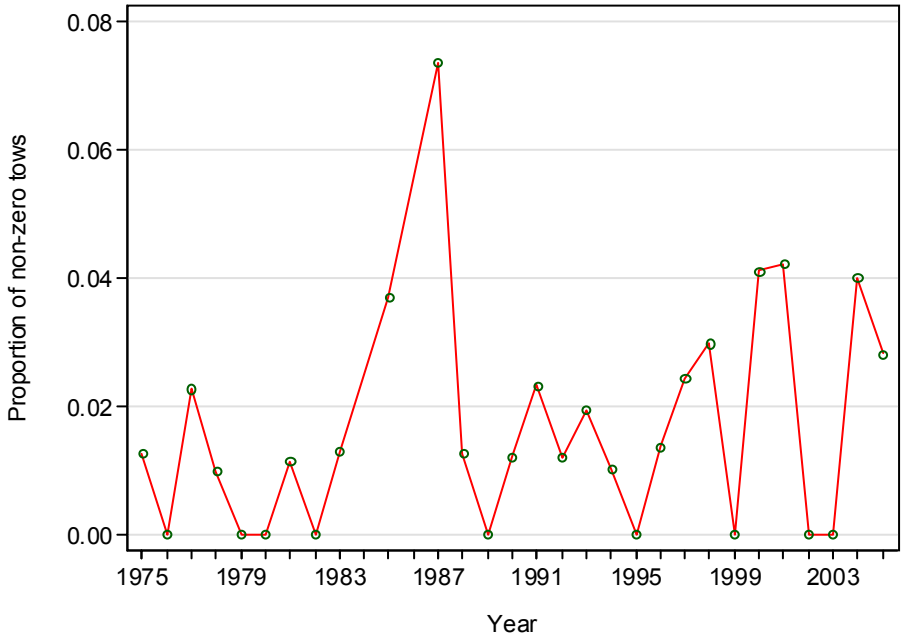


Figure 26. Proportion of tows by year which contain redbanded rockfish for the WCVI shrimp trawl survey.

Table 18. Biomass estimates for redbanded rockfish from the WCVI shrimp trawl survey for the survey years 1975 to 2005. 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 is based on the assumption of random tow selection within a stratum.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV
1975	12	12	0	60	0.98	1.00
1976	0	0	–	–	–	0.00
1977	1	1	0	2	0.95	1.00
1978	4	5	0	22	0.97	1.00
1979	0	0	–	–	–	0.00
1980	0	0	–	–	–	0.00
1981	16	17	0	81	0.99	1.00
1982	0	0	–	–	–	0.00
1983	0	0	–	–	–	0.00
1985	25	25	4	65	0.62	0.62
1987	90	88	19	225	0.57	0.56
1988	0	0	–	–	–	0.00
1989	0	0	–	–	–	0.00
1990	208	220	0	1041	0.95	1.00
1991	5	220	0	417	0.95	0.95
1992	4	4	0	31	1.01	1.00
1993	0	0	0	2	1.01	1.00
1994	0	0	0	3	1.00	1.00
1995	0	0	–	–	–	0.00
1996	1	0	0	2	0.99	1.00
1997	34	36	0	101	0.68	0.71
1998	1	1	0	2	0.74	0.75
1999	0	0	–	–	–	0.00
2000	3	3	0	13	0.88	0.90
2001	1	1	0	5	1.01	0.97
2002	0	0	–	–	–	0.00
2003	0	0	–	–	–	0.00
2004	3	3	0	8	0.67	0.70
2005	9	9	0	38	1.03	0.99

4.5. QCS shrimp trawl survey

A swept-area shrimp trawl survey of Queen Charlotte Sound has been conducted yearly since 1998 (Boutillier and Olsen, 2000). Although the original design employs uniform sampling stations and uses spatial interpolation to estimate biomass, we re-analyzed the surveys as if they were randomly stratified.

Before conducting this analysis, we examined the set locations from each survey to ensure that spatial and depth coverage remained consistent over the history of the surveys. We concluded that the first survey conducted in 1998 was sufficiently unique to warrant its removal from the series. In particular, the set locations in this year extended further north than in subsequent years, and did not extend into the deeper regions of the southwest. For similar reasons, we removed the 2005 survey.

The proportion of zero-catch tows p in the QCS shrimp trawl survey has increased over time for redbanded rockfish (Table 19), which has effectively increased the CV on the biomass index I. Given the wide confidence intervals (Figure 27) on this index, the downward trend is probably not significant. The intervals on I for 1999 and 2003 do not overlap.

Table 19. Annual index values for redbanded rockfish caught in the Queen Charlotte Sound shrimp trawl survey, 1999 to 2004. I = moment index value (kg); $\bar{I}$ = mean bootstrapped index (kg); $I_{0.50}$ = median bootstrapped index (kg); $I_{0.025}$ = 2.5% confidence limit of the bootstrapped index (kg); $I_{0.975}$ = 97.5% confidence limit (kg); CV = coefficient of variation of I; N = total number of sets conducted, n = number of sets catching redbanded rockfish; p = proportion zero-catch tows; W = catch weight (kg) of redbanded rockfish.

Year	I	$\bar{I}$	$I_{0.50}$	$I_{0.025}$	$I_{0.975}$	CV	N	n	p	W
1999	145,968	145,573	142,049	97,577	258,004	0.244	88	40	0.545	258
2000	73,875	74,382	73,947	46,799	111,308	0.216	86	40	0.535	171
2001	64,180	64,404	63,488	40,255	104,513	0.245	75	30	0.600	125
2002	54,296	55,272	54,248	27,075	106,580	0.344	75	17	0.773	85
2003	24,570	24,697	24,036	12,893	46,219	0.331	63	16	0.746	42
2004	75,885	77,698	73,224	35,275	209,067	0.430	69	18	0.739	129

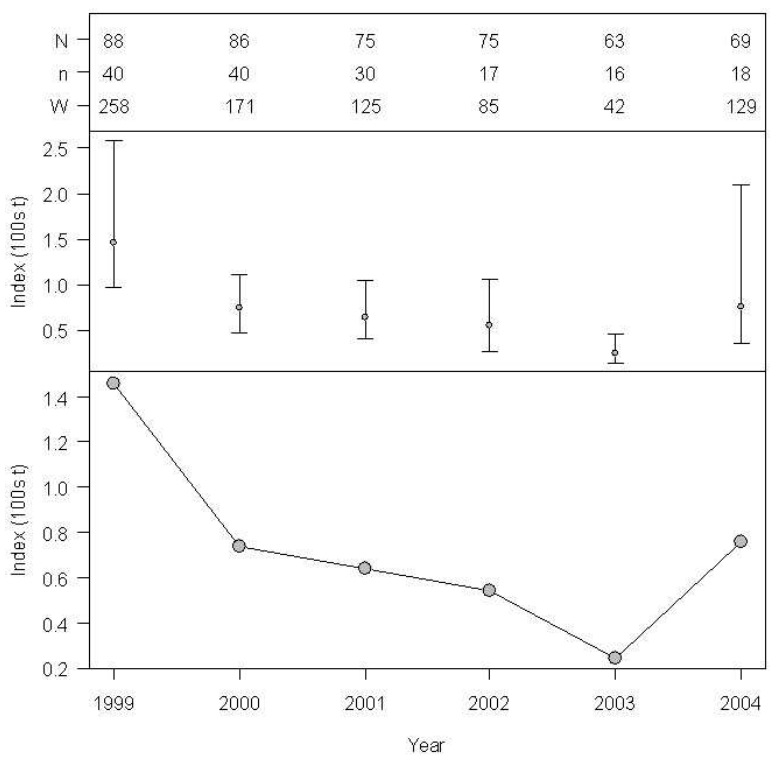
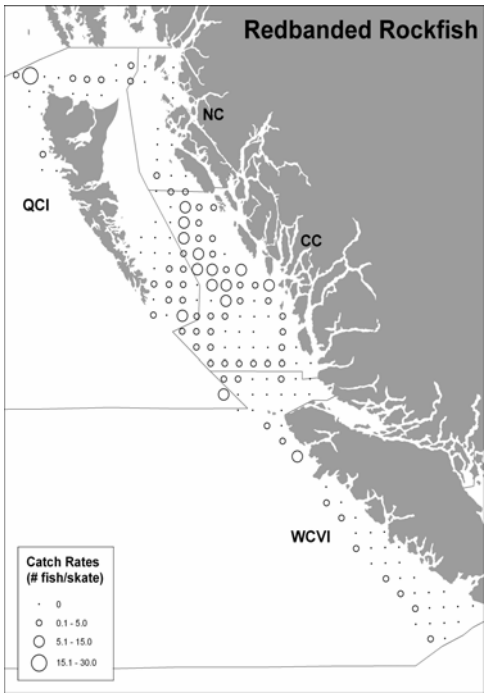


Figure 27. Biomass indices for redbanded rockfish caught in the Queen Charlotte Sound shrimp trawl survey, 1999 to 2004 (2005 possibly not usable). Top panel – number of sets conducted (N), the number of sets in which redbanded rockfish were caught (n), and the total catch weight (kg) of redbanded rockfish (W). Middle panel – bootstrapped biomass indices (means) with 95% confidence intervals. Bottom panel – moment values of the abundance index (biomass estimates with unknown catchability).

4.6. IPHC standardized stock assessment survey

The International Pacific Halibut Commission's (IPHC) standardized stock assessment (SSA) survey is a fixed-station longline survey that extends from southern Oregon to the Bering Sea and has been conducted annually in various configurations since 1963 (www.iphc.washington.edu). It provides distribution, biomass, age, growth and maturity data that are used in the IPHC's annual stock assessment of Pacific halibut *Hippoglossus stenolepis*. In addition to halibut, numerous other groundfish species are caught on the survey including fifteen species of rockfish in BC waters. Lochead et al. (2005) nicely summarize the 2004 spatial distribution of redbanded rockfish catch rates (Figure 28) and this species' abundance indices for 1995, 2003, and 2004 (Figure 29). Although the index trend is downwards, the indices are not statistically different among years.



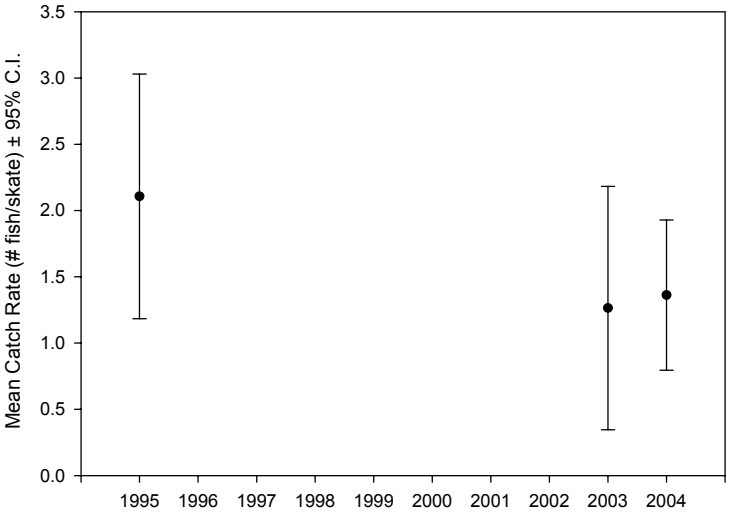


Figure 28. Spatial distribution of catch rate (numbers of fish per skate) for redbanded rockfish from the 2004 IPHC SSA survey. Source: Lochead et al. (2005).

Figure 29. Redbanded rockfish mean catch rates (# fish / skate) plus or minus 95 % confidence intervals. Catch rates are not significantly different among years (Kruskal-Wallis one-way nonparametric ANOVA: $H = 0.3812$, $p = 0.8278$, $df = 2$). Source: Lochead et al. (2005).

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 30; Table 20). These tows are assigned to strata by the NFMS, but the size and definition of these strata have changed over the life of the survey (Table 21). NMFS also provided information on the country designation of each tow. 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 30). NMFS designations were accepted for tows located near the marine border.

All useable tows have an associated net width and distance travelled, allowing the calculation of areas swept by each tow. Biomass indices and the associated analytical CVs for redbanded rockfish were calculated for the total Vancouver INPFC region and for each of the Canadian and US sub-regions, using appropriate area estimates for each stratum and year (Table 21). Strata that were not surveyed consistently in all seven years of the survey were dropped from the analysis (Table 20; Table 21), allowing the remaining data to provide a comparable set of data for each year from 1989 onwards (Table 22). The strata definitions used in the 1980 and 1983 surveys were considerably different than those used in subsequent surveys, particularly in Canadian waters (Table 22). Therefore, the 1980 and 1983 indices were scaled up by the ratio 1.24 (= 9,166/7,399 km^2) of the total stratum areas relative to the 1989 and later surveys. This scaling attempts to make the coverage from the first two surveys comparable to those from surveys conducted in the years 1989 on. In general, the size of the area fished was about twice as large in Canadian waters as that in US waters, although there were more tows performed in US waters (Table 22).

Table 20. Number of tows by stratum and by survey year for the NFMS 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 21).

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

Table 21. Stratum definitions by year used in the NMFS triennial survey to separate out the survey results by country and by INPFC area. Stratum definitions in grey are those strata which have been excluded from the final analysis due to incomplete coverage across the seven survey years or to locations outside of the Vancouver INPFC area.

Year	Stratum No.	Area (km^2)	Start	End	Country	INPFC area	Depth range
1980	10	3537	47°30	US-CA border	US	Vancouver	55-183 m
1980	11	6572	US-CA border	49°15	CA	Vancouver	55-183 m
1980	30	443	47°30	US-CA border	US	Vancouver	184-219 m
1980	31	325	US-CA border	49°15	CA	Vancouver	184-219 m
1980	50	758	47°30	US-CA border	US	Vancouver	220-366 m
1980	51	503	US-CA border	49°15	CA	Vancouver	220-366 m
1983	10	1307	47°30	47°55	US	Vancouver	55-183 m
1983	11	2230	47°55	US-CA border	US	Vancouver	55-183 m
1983	12	6572	US-CA border	49°15	CA	Vancouver	55-183 m
1983	30	66	47°30	47°55	US	Vancouver	184-219 m
1983	31	377	47°55	US-CA border	US	Vancouver	184-219 m
1983	32	325	US-CA border	49°15	CA	Vancouver	184-219 m
1983	50	127	47°30	47°55	US	Vancouver	220-366 m
1983	51	631	47°55	US-CA border	US	Vancouver	220-366 m
1983	52	503	US-CA border	49 °15	CA	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	CA	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	CA	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	CA	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	CA	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	CA	Vancouver	367-500 m
1995&after	38S	175	47°50	48°20	US	Vancouver	367-500 m

Table 22. Number of useable 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 (Table 21) 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; Table 21) 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	–	–	–

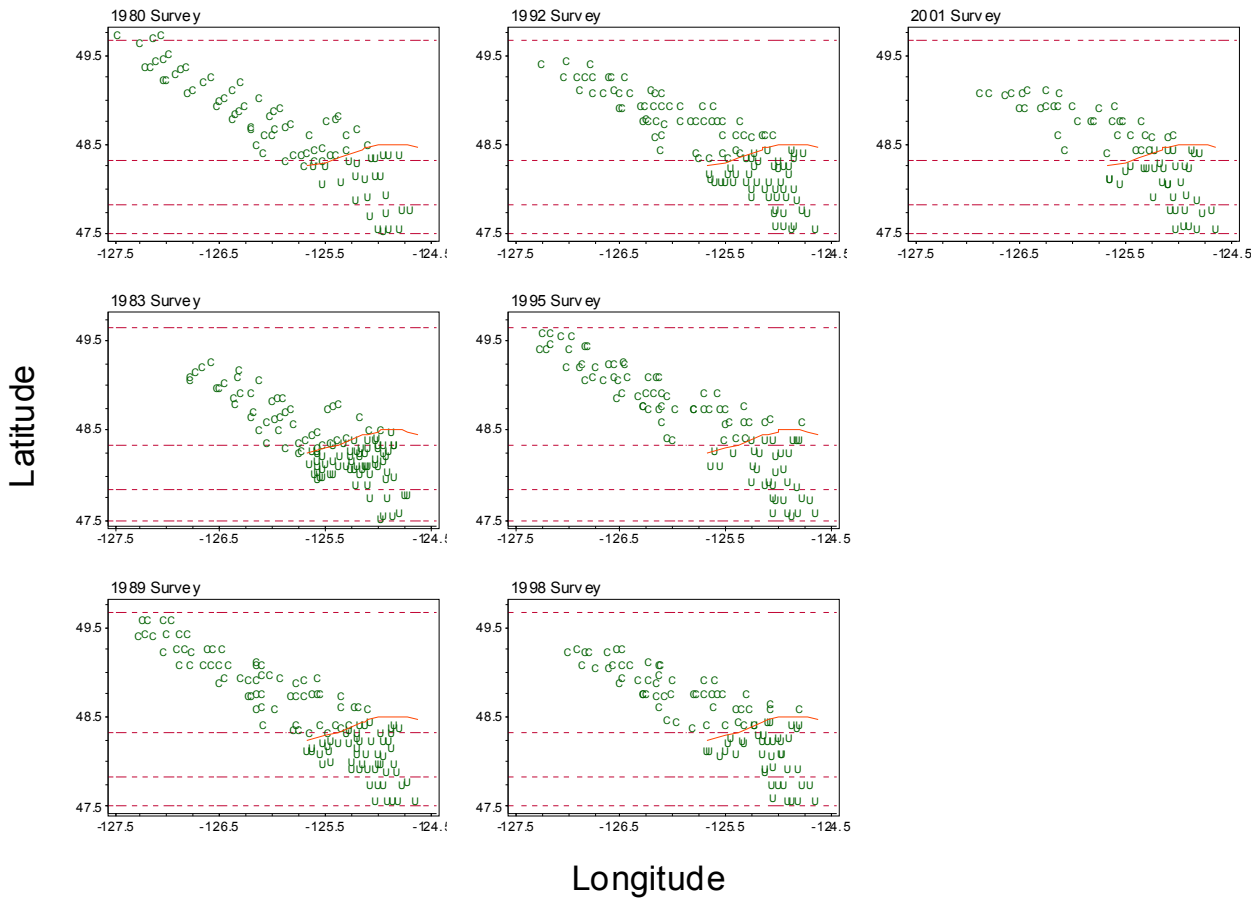


Figure 30. Plot of tow locations in the Vancouver INPFC region for each of the seven triennial surveys that surveyed Canadian waters. The approximate position of the US/Canada marine boundary is shown and each tow is coded with a "C" or a "U", depending on to which nation the tow is assigned in the database. The horizontal lines are the stratum boundaries: 47°30', 47°50', 48°20' and 49°40'.

4.7.2. Methods

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

$$B_{yic} = B_{yi} \frac{A_{yic}}{A_{yi}} \tag{4}$$

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:

$$V_{yic} = V_{yi} \frac{A_{yic}^2}{A_{yi}^2} \tag{5}$$

The partial variance V_{yic} for country c was used in (25) 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 (24) and the associated standard errors were adjusted to a constant area covered using the ratios of area surveyed provided in Table 22. 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 to make them equivalent to the coverage of the surveys from 1989 onwards.

Biomass estimates were bootstrapped for 5,000 random draws with replacement to obtain bias-corrected (Efron 1982) 95% confidence regions for each year and for three area categories (total Vancouver region, Canada Vancouver only, and US Vancouver only).

The swept-area biomass estimates (24) and the associated standard errors were adjusted to a constant area covered using the ratios of area surveyed provided in Table 22. 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 (= 9,166/7,399 km^2) 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 (Efron 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.

4.7.3. Results

Redbanded rockfish were caught sporadically throughout the surveys, primarily in US waters of the Vancouver INPFC region (Figure 31; Figure 32). The northern extension of the survey has varied between years (Figure 31). This difference has been compensated for by using a constant survey area for all years. Coverage by depth has been consistent for all seven years of the survey (Figure 32).

The biomass estimates for this species are low, generally between 500 and 1,000 t for the entire Vancouver INPFC stratum (Table 23). The series of biomass estimates shows a decreasing trend for the US-Vancouver sub-region while there is no trend in the Canadian-Vancouver sub-region (Figure 33). The trend for the Total Vancouver INPFC region is similar to the US-Vancouver series. The redbanded rockfish biomass estimates have very imprecise CVs, ranging from about 24% in 1998 to 67% in 2001 for the total Vancouver region (Table 23). This indicates that the confidence in the overall series trend should be low. 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.

There have only been a few tows that caught more than 10 kg of redbanded rockfish (21 of 697 useable tows over the seven survey years). The majority of tows that captured redbanded rockfish recorded catch weights between 0 and 10 kg (104 tows); 572 tows recorded no redbanded rockfish. The proportion of tows containing redbanded rockfish has been relatively constant, between 15-20%, for the total Vancouver INPFC region. This proportion experiences greater variability in the two sub-regions (Figure 34).

The low incidence of redbanded rockfish in this survey and associated small catches translate into large uncertainty in the biomass indices. Trends generated from this survey should be interpreted with caution. It is possible that the methodology in this trawl survey will not provide reliable biomass indices for redbanded rockfish.

Table 23. Biomass estimates for redbanded 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 (24). The bootstrap estimates are based on 5000 random draws with replacement.

Estimate type	Year	Biomass	Mean bootstrap biomass	Lower bound biomass	Upper bound biomass	CV bootstrap	CV analytical
Total Vancouver	1980	695	692	216	1,399	0.43	0.45
	1983	567	556	241	1,165	0.41	0.41
	1989	340	339	162	576	0.31	0.32
	1992	442	431	228	713	0.28	0.29
	1995	203	202	80	375	0.37	0.38
	1998	215	214	128	325	0.24	0.24
	2001	316	303	49	869	0.67	0.69
Canada Vancouver	1980	200	199	32	600	0.69	0.70
	1983	235	235	75	453	0.41	0.42
	1989	234	234	100	417	0.34	0.36
	1992	323	321	147	532	0.30	0.31
	1995	157	158	55	305	0.40	0.41
	1998	112	112	57	179	0.27	0.28
	2001	221	208	11	649	0.77	0.77
US Vancouver	1980	447	445	77	1,042	0.52	0.55
	1983	306	297	75	833	0.61	0.60
	1989	106	105	35	225	0.45	0.44
	1992	119	110	47	249	0.44	0.40
	1995	46	44	16	79	0.34	0.32
	1998	103	102	48	184	0.34	0.34
	2001	95	95	21	226	0.54	0.55

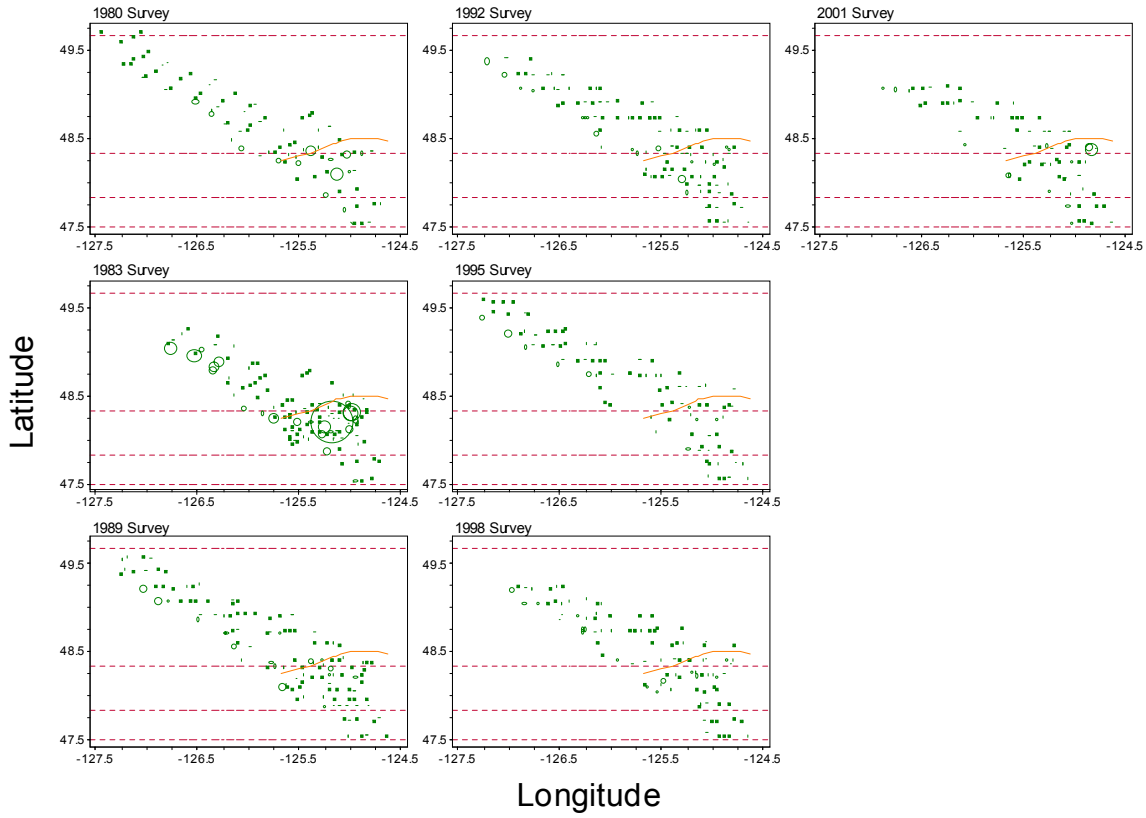


Figure 31. Plot of valid tows, weighted by the catch of redbanded rockfish, in the Vancouver INPFC region for the seven triennial surveys that surveyed Canadian waters. Catches in each year are scaled to the weight of the largest catch of redbanded rockfish (129 kg in 1995). Tows with zero catch of redbanded rockfish are coded with a "■". The approximate position of the US/Canada marine boundary is shown. The horizontal lines are the stratum boundaries: 47°30', 47°50', 48°20' and 49°40'.

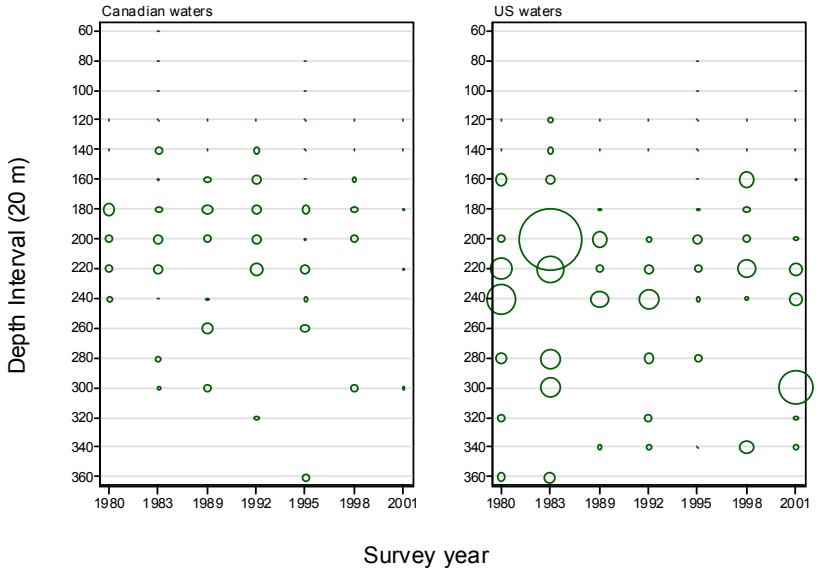


Figure 32. Distribution of redbanded rockfish catch weights for each survey year summarised into 20-m depth intervals for all valid tows (Table 21) in Canadian and US waters of the Vancouver INPFC area. Depth intervals are labelled with the deepest limit of the interval. Maximum circle size = 186 kg.

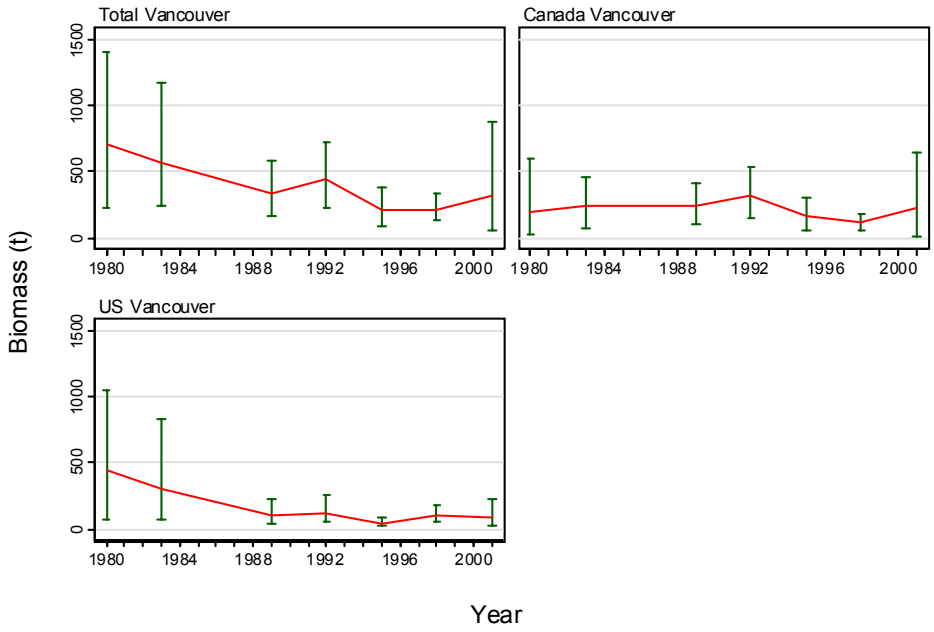


Figure 33. Three biomass estimates for redbanded rockfish in the INPFC Vancouver region (total region, Canadian waters only and US waters only) with 95% bias-corrected error bars estimated from 5000 bootstraps.

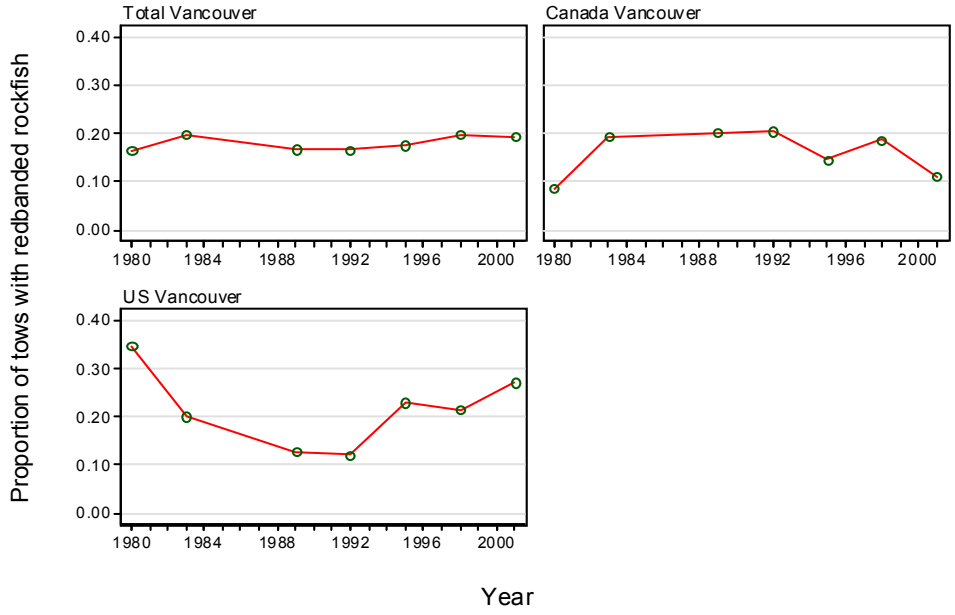


Figure 34. Proportion of tows with redbanded rockfish by year for the Vancouver INPFC region (total region, Canadian waters only and US waters only).

4.8. NMFS Gulf of Alaska bottom trawl survey

The US NMFS conducted bottom trawl surveys in the Gulf of Alaska (GoA) on a triennial basis from 1984 to 1999 and on a biennial basis from 2001 to 2005. Clausen's (2005) assessment focuses primarily on shortraker rockfish *Sebastes borealis*; however, the report also provides estimates of absolute abundance (biomass) for redbanded rockfish (Table 24). The surveys covered all areas of the GoA to a depth of 500 m (in some surveys to 1,000 m). In 2001, the eastern statistical areas Yakutat and Southeastern were not sampled; subsequently, the population estimates for these areas are averages from the 1993, 1996, and 1999 surveys. Additionally, the 1984 and 1987 survey estimates should be treated with caution due to various factors (different survey design, mixed net designs). The estimates have been standardised as best possible to render them comparable with later survey indices.

Clausen (2005) mentions that the bottom trawl surveys may offer a poor methodology for assessing abundance for species occupying shallower depth ranges (300-500 m) due to a predominance of non-trawlable (steep and rocky) ground at these depth ranges. He also reports that many of the rockfish species form aggregations, a condition that inflates CVs. Longline surveys are perhaps better suited for these areas. Regardless, from the trawl survey results, redbanded rockfish are most abundant in the eastern GoA – statistical areas Southeastern and Yakutat (Figure 35). The confidence intervals for the entire gulf are so large that no discernible trend can be declared. If nothing else, the population appears to be stable.

Table 24. Biomass estimates (t) for redbanded rockfish in the Gulf of Alaska (GoA) by statistical area and for the entire gulf. Estimates are for all areas and depths sampled in bottom trawl surveys conducted between 1984 and 2005. Statistical areas: S = Shumagin, C =Chirikof, K =Kodiak, Y =Yakutat, SE = Southeastern. *B* = biomass estimate for the entire gulf (GoA); CL0.025 = 2.5% confidence limit on *B*; CL0.975 = 97.5% confidence limit on *B*; *V* = variance of *B*; CV = coefficient of variation of *B*. Source: Clausen (2005).

	Stat Area					GoA				
Year	S	C	K	Y	SE	*B*	$CL_{0.025}$	$CL_{0.975}$	*V*	CV
1984	0	39	130	727	534	1,430	531	2,330	198,019	0.311
1987	21	391	213	762	435	1,822	600	3,044	353,367	0.326
1990	0	32	187	1,420	1,646	3,285	887	5,683	1,302,634	0.347
1993	11	116	318	1,084	2,147	3,675	1,513	5,837	1,105,665	0.286
1996	61	40	160	1,497	2,836	4,594	1,476	7,711	2,379,370	0.336
1999	118	45	358	1,344	9,076	10,941	1,350	20,532	20,254,925	0.411
2001*	61	51	303	1,308	4,686	6,409	0	15,063	19,497,202	0.689
2003	19	672	218	548	1,984	3,441	1,907	4,974	563,886	0.218
2005	41	180	830	2,211	2,405	5,667	3,051	8,283	1,466,795	0.214

* The 2001 survey did not sample the eastern Gulf of Alaska (Yakutat and Southeastern areas). Substitute estimates of biomass for these areas in 2001 were obtained by averaging the Yakutat and Southeastern biomass in the 1993, 1996, and 1999 surveys. These eastern Gulf of Alaska estimates have been included in the 2001 biomass estimates, confidence bounds, biomass variances, and biomass CVs listed in this table.

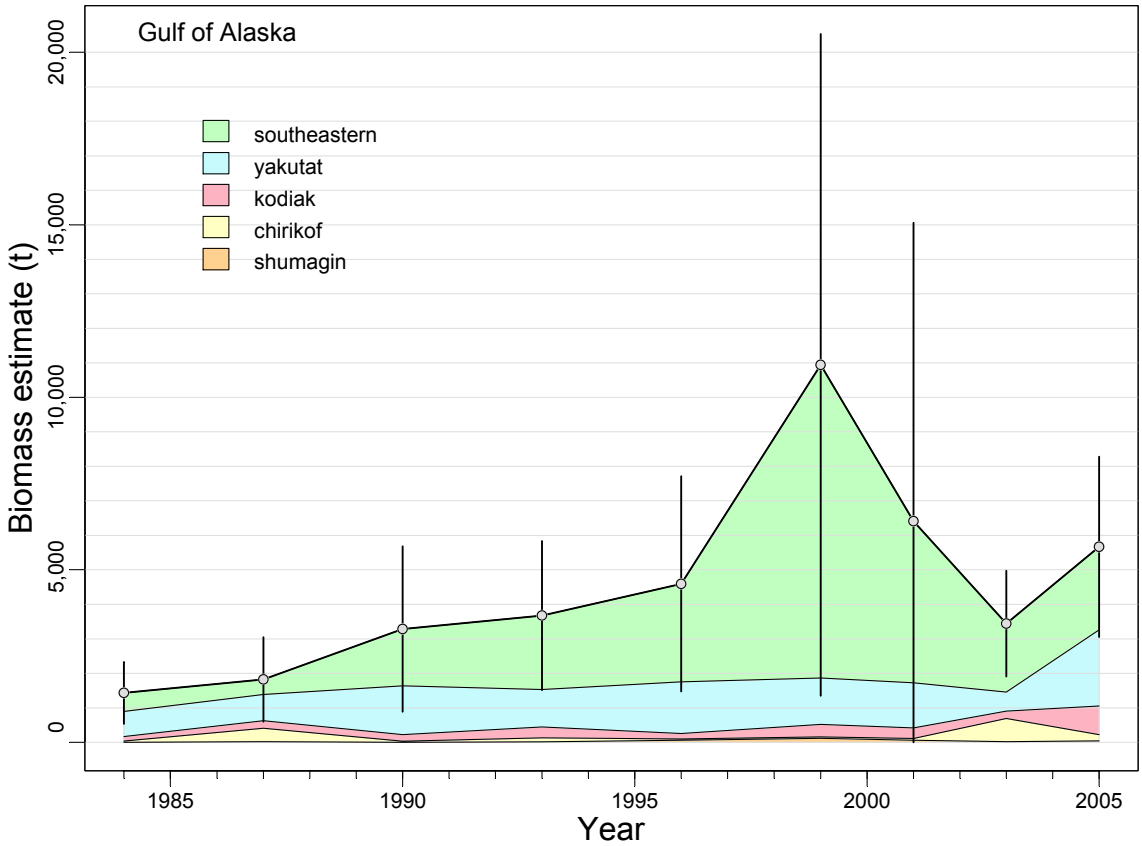


Figure 35. Biomass estimates *B* (t) of redbanded rockfish in the Gulf of Alaska (GoA). Points and 95% confidence intervals refer to *B* in the entire GoA. Shaded regions below the topmost curve show the contribution to *B* by each statistical area within the GoA. See caveat regarding 2001 estimates in Table 24. Source: Clausen (2005)

4.9. GLM analysis of commercial trawl CPUE

4.9.1. Data Selection

Trawl catch and effort data pertaining to redbanded rockfish are available from two DFO databases: GFCatch which covers the period from 1954 to December 1995 (Rutherford 1999) and PacHarvTrawl which covers the period from 1996 to the present. An extract was obtained from PacHarvTrawl in November 2005, which contained data up to the end of September 2005, using the following criteria:

- Tow start date between 1 April 1996 and 31 September 2005;
- Bottom trawl type;
- Fished in a valid outside PMFC major region (3C, 3D, 5A, 5B, 5C, or 5D);
- Fishing success code <=1 (code 0= unknown; code 1= useable);
- Catch of at least one fish or invertebrate species (no water hauls);
- Valid depth;
- Vessel had been in the fishery for at least three years with a minimum of five trips in each of those years;

- Valid latitude and longitude co-ordinates;
- 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:

- Calendar year;
- Month;
- DFO locality (Rutherford 1999);
- Latitude separated in 0.1° bands beginning with 48°N;
- Vessel;
- Depth aggregated into 20-m depth bands;
- PMFC major region (3C, 3D, 5A, 5B, 5C, or 5D).

Categories with relatively few observations were pooled into a single ("Plus") category to reduce the number of parameters estimated.

4.9.2. Methods

A stepwise multiple linear regression (where data are modelled assuming lognormal variability) was used to estimate trends in abundance from CPUE data derived from the commercial catch and effort database, as outlined in Appendix A.7. This approach, which is commonly used to analyse fisheries catch and effort data, is described by Hilborn and Walters (1992) and Quinn and Deriso (1999).

4.9.3. Catches

Total annual landings and discards for redbanded rockfish are presented by major DFO region from 1979/80 to 2004/05 (Table 25). Landings are generated from dockside monitoring programmes which have been in place since 1995. Prior to that year, landings are only available from logbooks maintained by fishermen which have been cross-validated with landing slips issued by the receiving processing plant. Discard estimates are considered to be unreliable prior to 1996 because they are based on voluntary reporting and are known to be incomplete. Discards since February 1996 are based on estimates made by an independent observer programme and are considered more reliable than those obtained from logbooks.

Table 25. Total landed and discarded catches for redbanded rockfish in the combined GFCatch/PacHarvTrawl databases, summarised by 1 April–31 March fishing year for the major DFO reporting areas, combined as indicated. Data from 1 April 1979 to 27 December 1995 are from the GFCatch database (Rutherford 1999). Data from 16 February 1996 to 30 September 2005 are from the PacHarvTrawl database. The groundfish fishery was closed from 28 December 1995 to 15 February 1996. These catches have been summarised without data selection criteria.

		PMFC Major Area					
Year	**Other[1]**	**3CD**	**4B**	**5AB**	**5CD**	**5E**	**Total**
Landed Catches (t)							
79/80		23.6	0.0	28.4	47.0	2.4	101.4
80/81		0.3	0.4	116.7	73.4	2.0	192.7
81/82		1.7	0.0	47.6	34.6	11.4	95.3
82/83		14.8	0.9	49.4	32.5	11.9	109.6
83/84	0.1	25.4	0.0	66.2	15.2	15.4	122.2
84/85		14.5	0.0	48.3	19.2	8.8	90.8
85/86		9.5	0.0	20.3	12.0	6.6	48.4
86/87		21.8	0.0	46.8	14.1	11.5	94.2
87/88		27.0	0.0	201.2	17.4	10.8	256.4
88/89		82.9	0.0	219.6	13.3	31.8	347.5
89/90		120.3	0.0	279.3	55.6	15.1	470.4
90/91		70.2	0.0	471.0	107.4	4.7	653.4
91/92		85.9	0.0	420.0	121.3	26.6	653.8
92/93		140.4	0.0	593.1	149.3	18.0	900.8
93/94		164.0	0.0	569.3	147.0	25.0	905.4
94/95		107.8	0.0	447.5	110.5	18.6	684.5
95/96	0.8	62.5	0.0	197.6	160.4	6.9	428.1
96/97	6.9	41.1	0.0	192.7	99.9	9.0	349.7
97/98	2.1	27.5	0.0	161.8	54.7	5.2	251.3
98/99	1.4	26.9	0.0	135.1	45.8	3.1	212.3
99/00	1.2	35.0	0.0	190.4	70.3	3.5	300.4
00/01	1.5	32.9	0.0	165.6	86.8	7.9	294.7
01/02	2.8	34.3	0.0	127.9	121.4	7.4	293.8
02/03	1.4	33.4	0.0	175.2	38.1	10.9	259.0
03/04	1.8	37.1	0.0	119.1	48.7	5.9	212.5
04/05	1.7	41.3	0.0	154.7	36.6	5.6	239.8
05/06[2]	1.6	12.5	0.0	90.5	38.5	0.9	143.9
Total	23.2	1,294.6	1.3	5,335.4	1,770.9	286.8	8,712.2
Discarded							
96/97	0.0	1.6	0.0	5.9	2.5	0.7	10.8
97/98	0.0	1.3	0.0	3.9	0.9	0.3	6.4
98/99	0.0	1.0	0.0	1.4	0.5	0.0	2.9
99/00	0.0	0.7	0.0	1.6	0.5	0.0	2.9
00/01	0.0	0.4	0.0	2.5	0.7	0.0	3.6
01/02	0.0	0.6	0.0	0.9	0.4	0.0	1.9
02/03	0.0	1.2	0.0	0.8	0.8	0.1	3.0
03/04	0.0	1.7	0.0	2.1	0.2	0.1	4.1
04/05	0.0	1.9	0.0	1.2	0.4	0.2	3.7
05/06[2]	0.0	0.2	0.0	0.4	0.1	0.0	0.8
Total	0.0	11.0	0.0	23.3	7.6	1.7	43.6

[1] includes catches in unknown areas and areas outside of Canadian waters
[2] 01 April 2005 to 30 September 2005 only

4.9.4. Results – 3C & 3D (west coast Vancouver Island)

The 1% and 99% quantiles of depth from the selected data are 137 m and 528 m, with sporadic observations at deeper depths (Figure 36). Consequently, the GLM model used all valid tows occurring between 100 and 540 m.

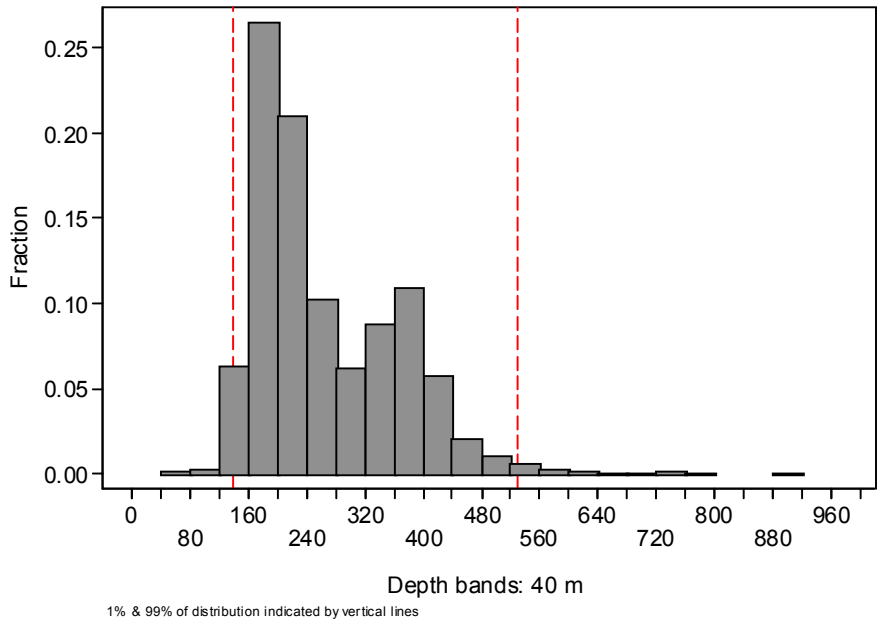


Figure 36. Depth distribution of tows with landed redbanded rockfish catch in the combined Areas 3C and 3D from 1996/97 to 2004/05 in 20 m intervals. Each bin interval is labelled with the upper bound of the interval. Vertical lines: 1%=137 m; 99%=528 m.

This analysis was confined to the period when the fleet had 100% observer coverage and when estimates of the discard catch are available. Stepwise selection accepted all the available explanators in a GLM that related the log of total catch (landed plus discarded catch) per hour of towing to the additive effects of fishing year, depth band category, latitude band, vessel, month, and DFO locality. Depth entered the model as a factor with 11 levels determined by 40 m depth intervals while latitude was partitioned into 21 bands of width 0.1°. The final model accounted for 18% of the variation ().

Table 26. Order of acceptance of variables into the 1996/97–2004/05 3CD model of positive total catches (landed plus discarded) of redbanded rockfish with the amount of explained deviance (R^2) for each additional model variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.

Variable	1	2	3	4	5	6	7
Year*	**0.011**						
Depth bands*	0.073	**0.081**					
0.1° Latitude bands*	0.038	0.047	**0.120**				
Vessel*	0.038	0.047	0.106	**0.147**			
Month*	0.016	0.026	0.100	0.134	**0.163**		
DFO locality*	0.034	0.043	0.114	0.136	0.163	**0.178**	
PMFC major area	0.016	0.026	0.092	0.122	0.149	0.165	0.178
Improvement in deviance	0.000	0.070	0.039	0.027	0.016	0.015	0.000

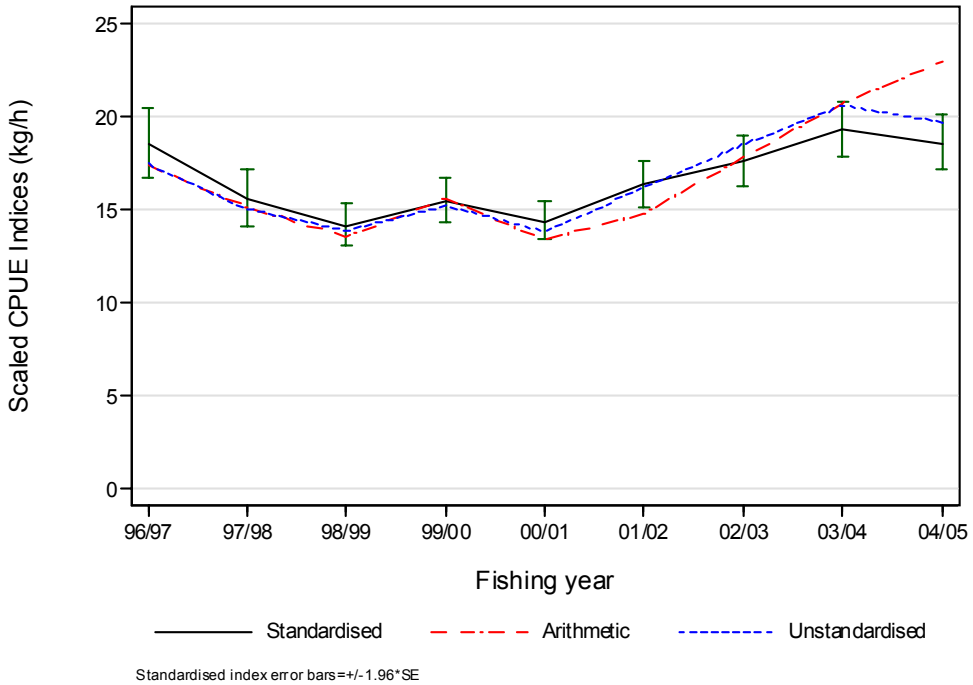


Figure 37. Three annual series based on CPUE analyses (total catch per hour of towing) for 3CD landed redbanded rockfish catches for 1996 to 2005. The solid line is a standardised analysis (31) correcting for year of catch, depth band category, 0.1° latitude band and vessel effects. The other two series correspond to annual indices calculated using (34) and (35) respectively.

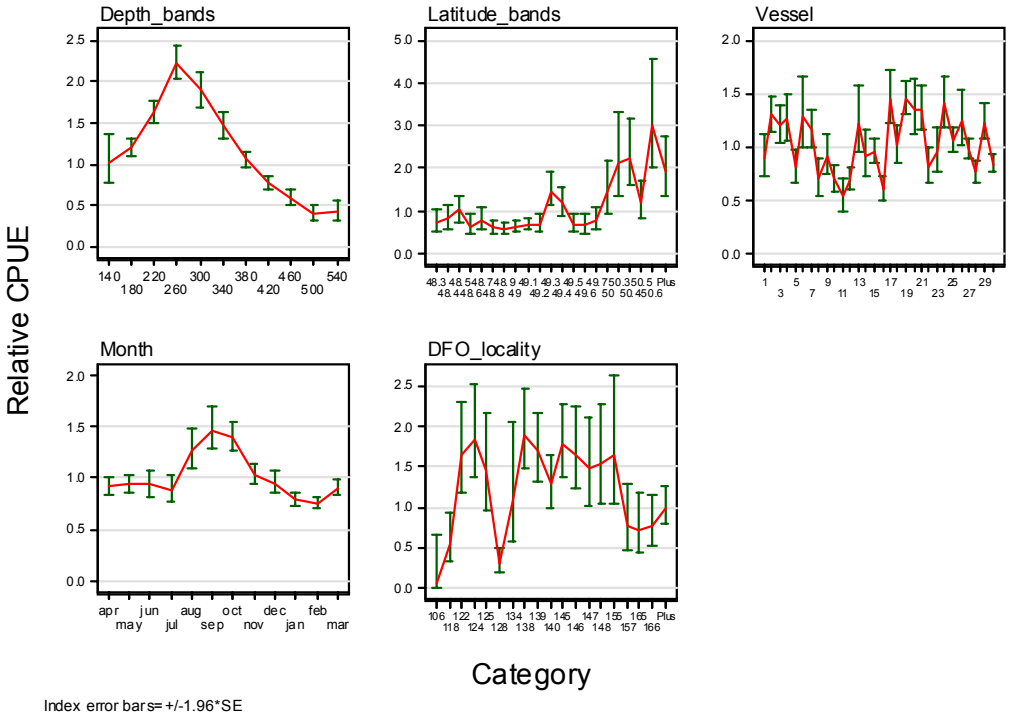


Figure 38. Plots of the coefficients for the categorical explanatory variables included in the standardised GLM analysis presented in Figure 37.

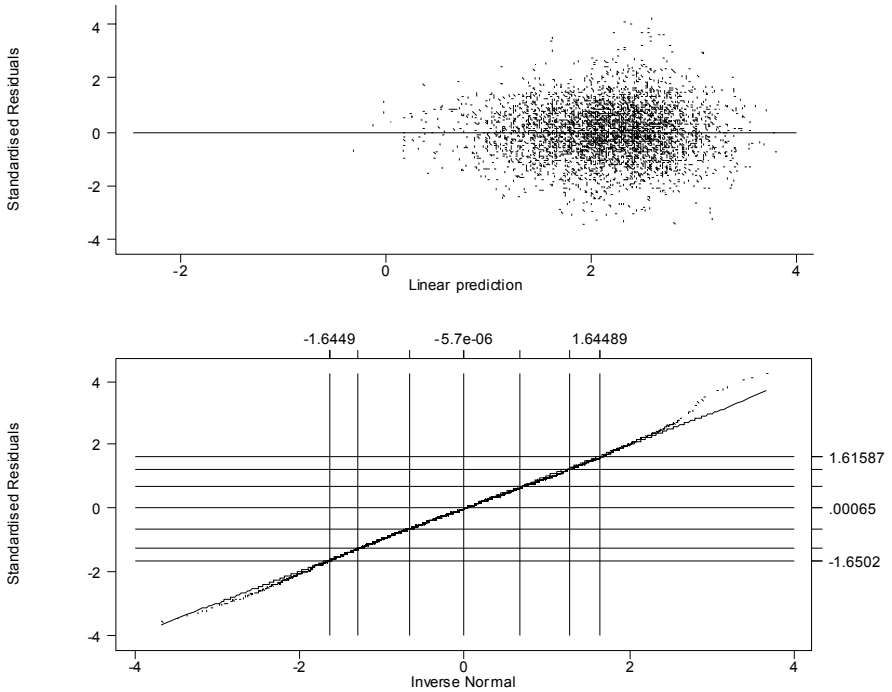


Figure 39. Standardised (Pearson) residuals for the 3CD GLM analysis presented in Figure 37. The outside horizontal and vertical lines represent the 5th and 95th percentiles of the theoretical and observed distributions.

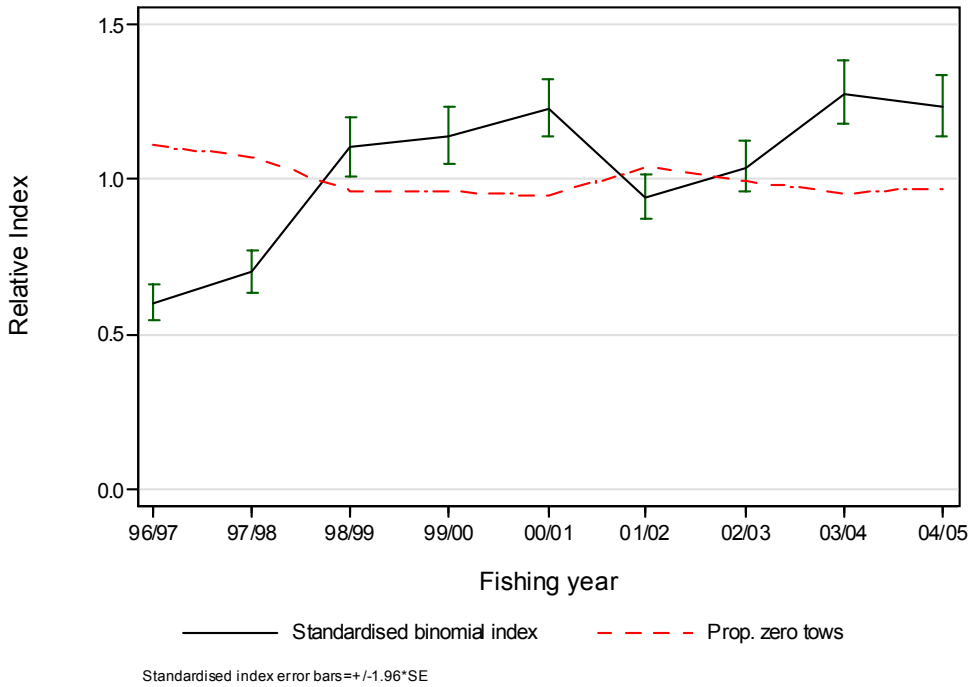


Figure 40. Year effects from a standardised binomial logit model fit to the presence/absence of redbanded rockfish using the same dataset that provided the lognormal regression model (Figure 40). Also shown is the relative proportion of tows with zero redbanded rockfish by fishing year (mean=0.71). Each series has been normalised to its geometric mean.

Table 27. Arithmetic and standardised CPUE indices (kg/h) with standard errors and upper and lower bounds of the standardised index for the 3CD model of non-zero total catches (landed plus discarded) of redbanded rockfish. The standardised series has been scaled to the geometric mean of the arithmetic series.

Year	Arithmetic	Standardised	Lower bound	Upper bound	Standard error
96/97	17	18	17	20	0.050
97/98	15	16	14	17	0.051
98/99	14	14	13	15	0.043
99/00	16	15	14	17	0.040
00/01	13	14	13	15	0.038
01/02	15	16	15	18	0.039
02/03	18	18	16	19	0.040
03/04	21	19	18	21	0.039
04/05	23	19	17	20	0.040

The selected lognormal model shows a slight declining trend in the first three to five years of the series to a low point which spans the period 1998/99 to 2000/01, followed by an increasing trend to 2003/04 and a levelling off in 2004/05 (Figure 37 and Table 27). Arithmetic and unstandardised catch rates are very similar to the standardised series, except in the final fishing year, when the arithmetic series continues to climb while the other two series drop slightly. Plots of the coefficients of the explanatory variables all appear reasonable (Figure 38). Model residuals show small deviations from the log-normal error assumption at the upper tail of the distribution, but these appear to be minor (Figure 39). A binomial model fit to the presence/absence of redbanded rockfish using the same dataset used for the lognormal model shows a generally increasing trend from the beginning of the series with no trend in the proportion of zero catches over the nine years of data (Figure 40).

A comparison of the annual coefficients estimated by the binomial and lognormal models shows reasonable correspondence between all three series for analyses where the data begin in 1996/97 (lognormal, binomial and arithmetic; Figure 41). This comparison is relevant because all three series are considered to be analogous estimators of the relative abundance of redbanded rockfish in 3CD.

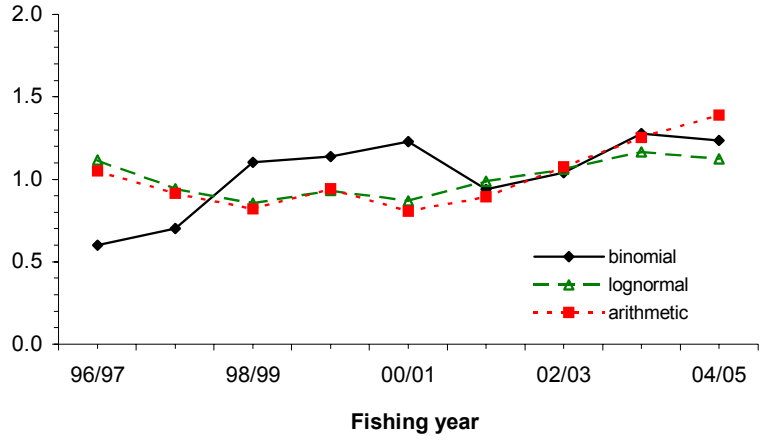


Figure 41. Comparison of the annual series from the lognormal (31) and binomial (31) standardised models beginning in 1996/97 (with vessels in the fishery for at least 5 years). Also shown is the arithmetic index (34) for the same dataset.

4.9.5. Results – 5A & 5B (Queen Charlotte Sound)

The 1% and 99% quantiles of depth from the selected data are 119 m and 418 m, with sporadic observations at deeper depths (Figure 42). Consequently, the GLM model used all valid tows occurring between 100 and 440 m.

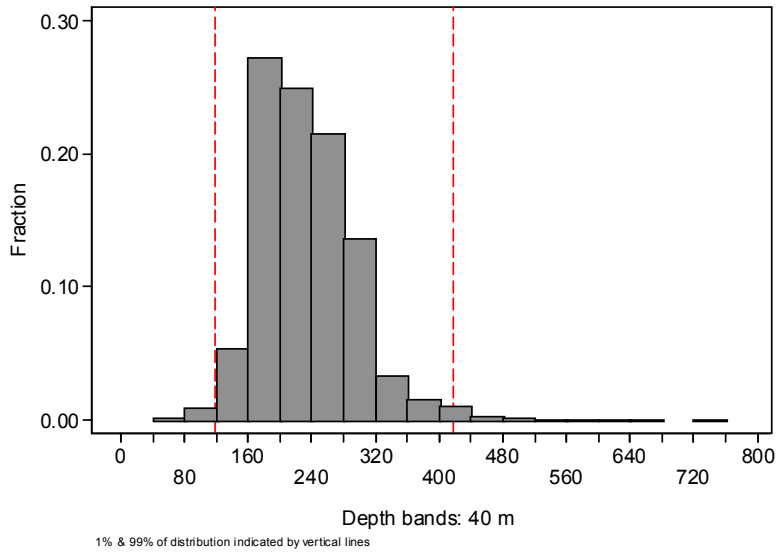


Figure 42. Depth distribution of tows with landed redbanded rockfish catch in the combined Areas 5A and 5B from 1996/97 to 2004/05 in 40 m intervals. Each bin interval is labelled with the upper bound of the interval. Vertical lines: 1%=119 m; 99%=418 m.

This analysis was confined to the period when the fleet had 100% observer coverage and when estimates of the discard catch are available. Stepwise selection resulted in a GLM that related the log of total catch (landed plus discarded catch) per hour of towing to the additive effects of fishing year, DFO locality , vessel, latitude and depth band category. Depth entered the model as a factor with 8 levels determined by 40 m depth intervals while latitude was categorised into sixteen 0.1° bands. The final model accounted for 18% of the variation (Table 28).

Table 28: Order of acceptance of variables into the 1996/97–2004/05 5AB model of positive total catches (landed plus discarded) of redbanded rockfish with the amount of explained deviance (R^2) for each additional model variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.

Variable	1	2	3	4	5	6	7
Year*	**0.001**						
DFO locality	0.102	**0.103**					
Vessel*	0.036	0.038	**0.133**				
0.1° Latitude bands*	0.087	0.089	0.130	**0.158**			
Depth bands*	0.021	0.023	0.122	0.151	**0.178**		
Month	0.007	0.009	0.110	0.139	0.162	0.187	
PMFC major area	0.037	0.038	0.107	0.137	0.160	0.180	
Improvement in deviance	0.000	0.102	0.030	0.025	0.021	0.008	

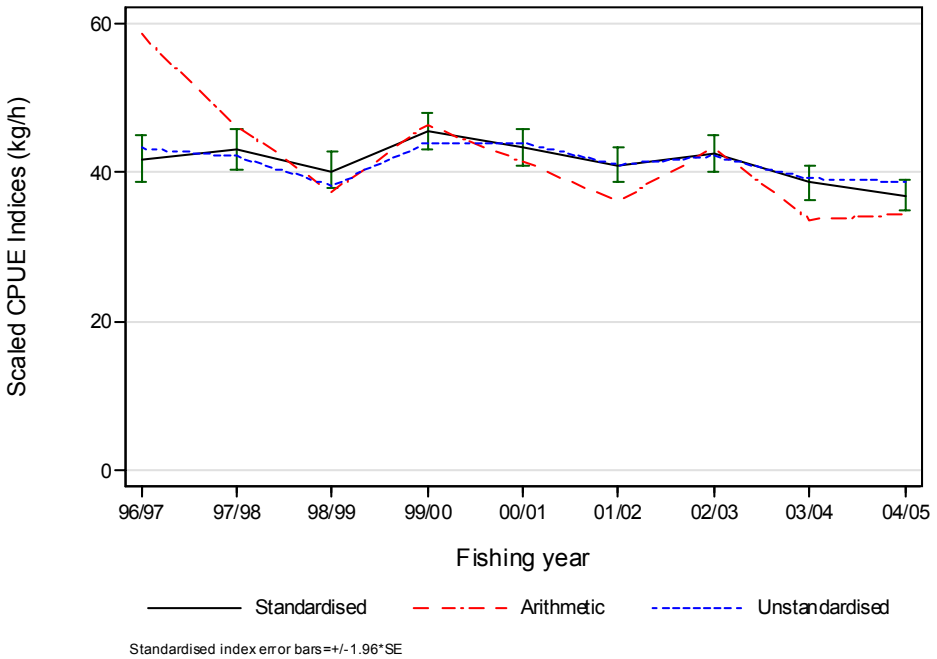


Figure 43. Three annual series based on CPUE analyses (total catch per hour of towing) for 5AB landed redbanded rockfish catches for 1996/97 to 2004/05. The solid line is a standardised analysis (31) correcting for year of catch, DFO locality, 0.1° latitude band, 40 m depth band and vessel effects. The other two series correspond to annual indices calculated using (34) and (35) respectively.

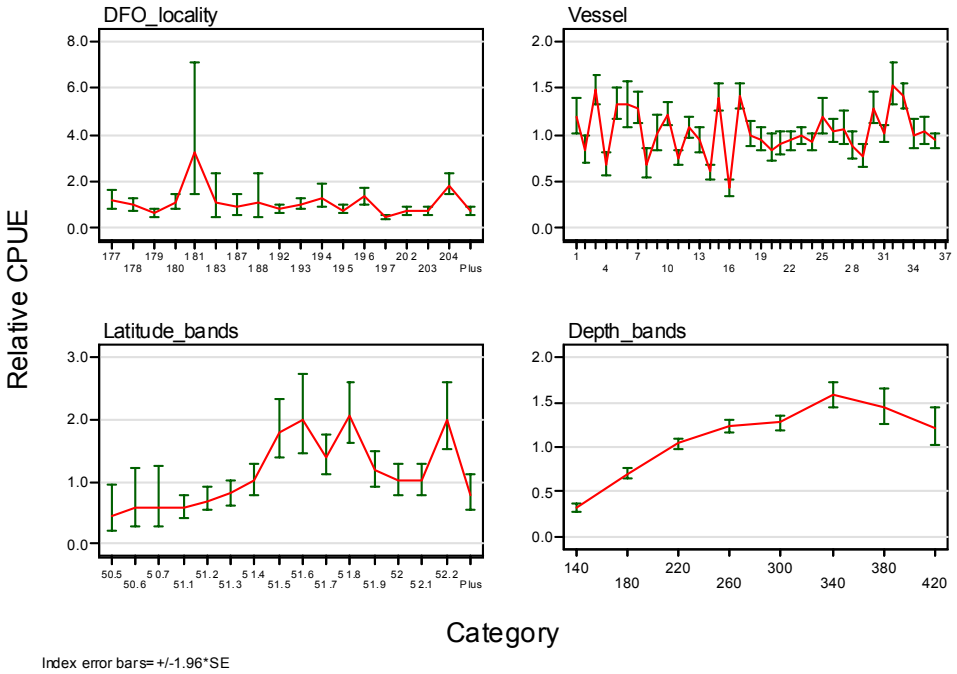


Figure 44. Plots of the coefficients for the categorical explanatory variables included in the standardised GLM analysis presented in Figure 43.

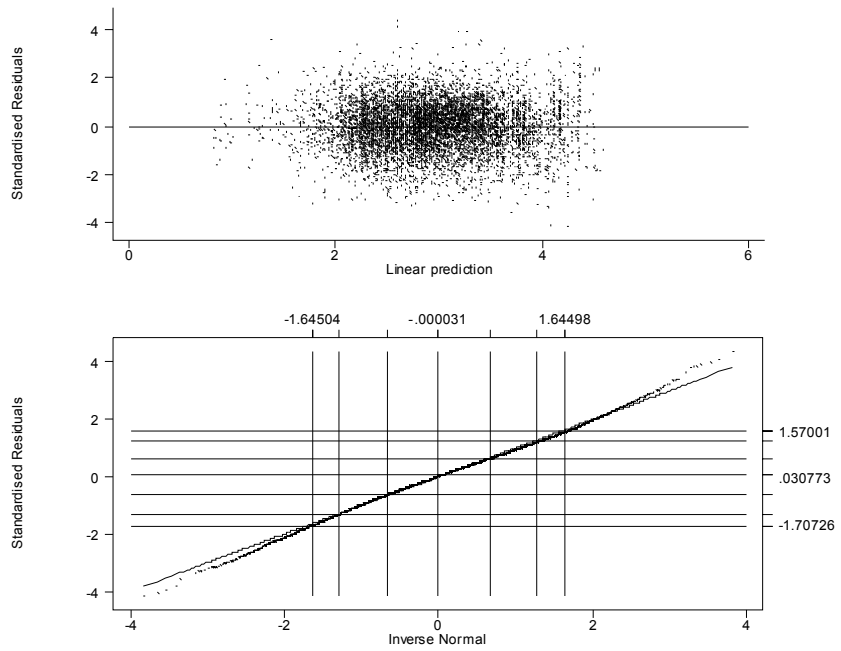


Figure 45. Standardised (Pearson) residuals for the 5AB GLM analysis presented in Figure 43. The outside horizontal and vertical lines represent the 5th and 95th percentiles of the theoretical and observed distributions.

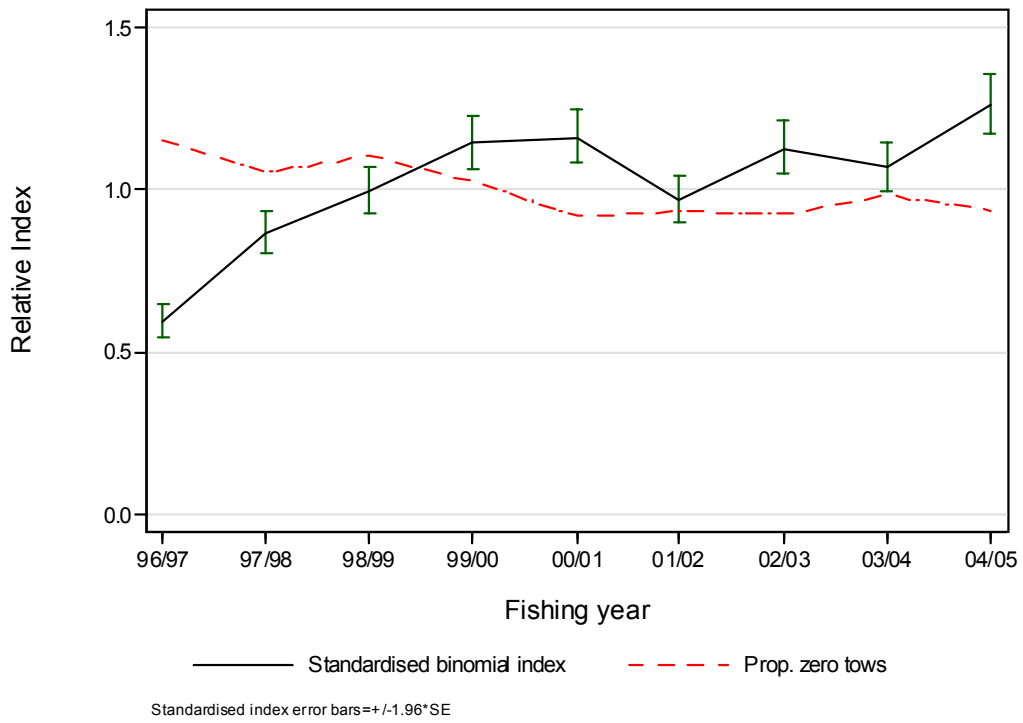


Figure 46. Year effects from a standardised binomial logit model fit to the presence/absence of redbanded rockfish using the same dataset that provided the lognormal regression model (Figure 43). Also shown is the relative proportion of tows with zero redbanded rockfish by fishing year (mean=0.58). Each series has been normalised to its geometric mean.

Table 29. Arithmetic and standardised CPUE indices (kg/h) with standard errors and upper and lower bounds of the standardised index for the 5AB model of non-zero total catches (landed plus discarded) of redbanded rockfish. The standardised series has been scaled to the geometric mean of the arithmetic series.

Year	Arithmetic	Standardised	Lower bound	Upper bound	Standard error
96/97	58.5	41.7	38.6	45.0	0.039
97/98	46.3	43.1	40.4	45.9	0.033
98/99	37.3	40.2	37.8	42.7	0.031
99/00	46.4	45.5	43.0	48.1	0.029
00/01	41.5	43.4	41.1	45.8	0.028
01/02	36.2	40.9	38.6	43.4	0.030
02/03	43.4	42.6	40.2	45.1	0.029
03/04	33.6	38.6	36.4	40.9	0.029
04/05	34.4	37.0	35.0	39.1	0.028

The selected lognormal model shows no trend over the period of the series while the arithmetic catch rate appears to decline over the same period (Figure 43 and Table 29). The unstandardised series is identical to the standardised index, indicating that the difference between the series is the difference between taking a nominal arithmetic mean from a set of data and taking the geometric mean from the same data. Plots of the coefficients of the explanatory variables appear reasonable (Figure 44). Model residuals show few deviations from the log-normal error assumption, with small deviations at the upper and lower tails of the empirical distribution (Figure 45). A binomial model fit to the presence/absence of redbanded rockfish using the same dataset shows an increasing trend from the beginning of the series and a slow decreasing trend in the proportion of zero catches over the nine years of data (Figure 46).

A comparison of the annual coefficients estimated by the binomial and lognormal models shows reasonable correspondence between all three series (lognormal, binomial and arithmetic; Figure 47) in the centre of the series, with some divergence at each end of the series. The result of this divergence is to cause an increasing trend in the binomial series while the trend is decreasing in the arithmetic and lognormal series. This comparison is relevant because all three series are considered to be analogous estimators of the relative abundance of redbanded rockfish in 5AB.

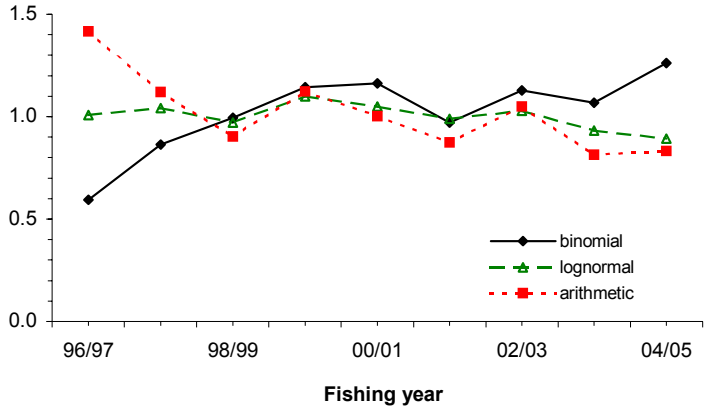


Figure 47. Comparison of the annual series from the lognormal (31) and binomial (31) standardised models beginning in 1996/97 (with vessels in the fishery for at least 5 years). Also shown is the arithmetic index (34) for the same dataset.

4.9.6. Results – 5C & 5D (Hecate Strait)

The 1% and 99% quantiles of depth from the selected data are 94 m and 386 m, with sporadic observations at deeper depths (Figure 48). Consequently, the GLM model used all valid tows occurring between 80 and 420 m.

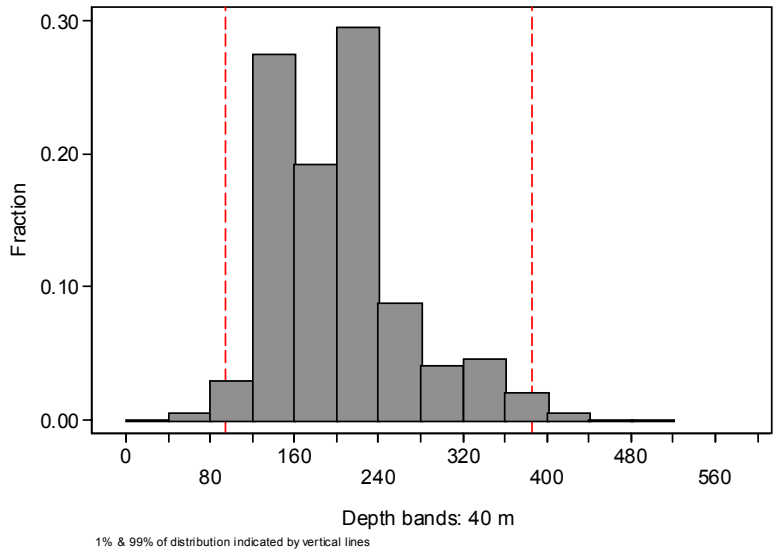


Figure 48. Depth distribution of tows with landed redbanded rockfish catch in the combined Areas 5C and 5D from 1996/97 to 2003/04 in 40 m intervals. Each bin interval is labelled with the upper bound of the interval. Vertical lines: 1%=94 m; 99%=386 m.

This analysis was confined to the period when the fleet had 100% observer coverage and when estimates of the discard catch are available. Stepwise selection resulted in a GLM that related the log of total catch (landed plus discarded catch) per hour of towing to the additive effects of calendar year, depth, DFO locality, latitude band and vessel Depth entered the model as a factor with 8 levels determined by 40 m depth intervals while locality was categorised into 15 levels. The final model accounted for 37% of the variation (Table 30).

Table 30. Order of acceptance of variables into the 1996/97–2004/05 5CD model of positive total catches (landed plus discarded) of redbanded rockfish with the amount of explained deviance (R^2) for each additional model variable. Variables accepted into the model are marked with an *. Year was forced as the first variable.

Variable	1	2	3	4	5	6	7
Year*	**0.016**						
DFO locality*	0.293	**0.299**					
Depth bands*	0.215	0.225	**0.345**				
0.1° Latitude bands *	0.203	0.214	0.324	**0.362**			
Vessel*	0.115	0.130	0.313	0.357	**0.372**		
Month	0.162	0.176	0.308	0.351	0.366	0.375	
PMFC major area	0.010	0.027	0.304	0.348	0.366	0.376	
Improvement in deviance	0.000	0.283	0.046	0.017	0.010	0.004	

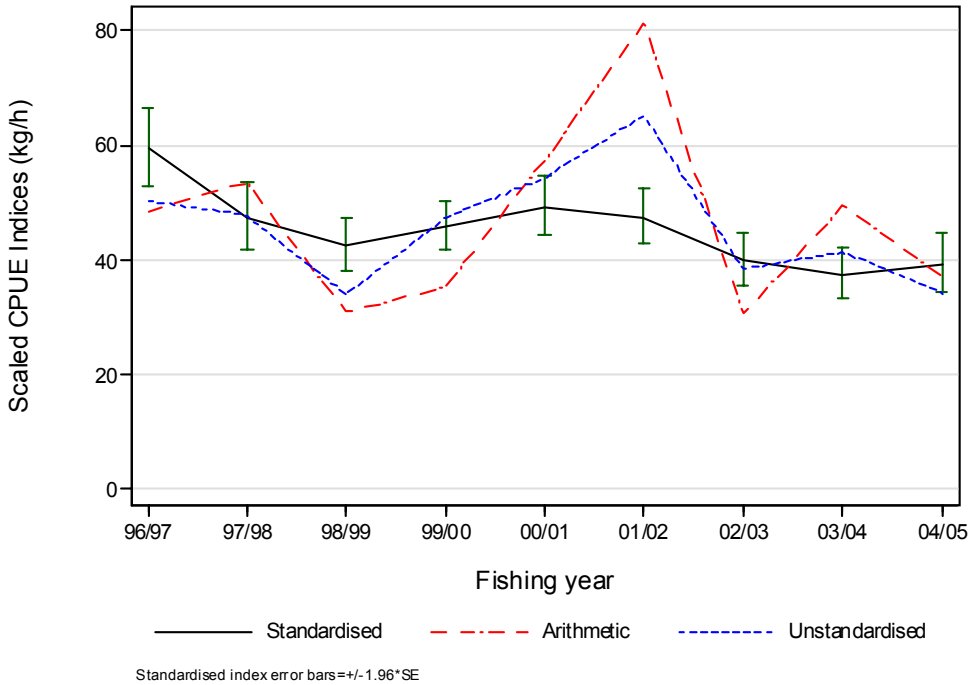


Figure 49. Three annual series based on CPUE analyses (total catch per hour of towing) for 5CD landed redbanded rockfish catches for 1996/97 to 2004/05. The solid line is a standardised analysis (31) correcting for year of catch, DFO locality, depth band category, latitude band and vessel effects. The other two series correspond to annual indices calculated using (34) and (35) respectively.

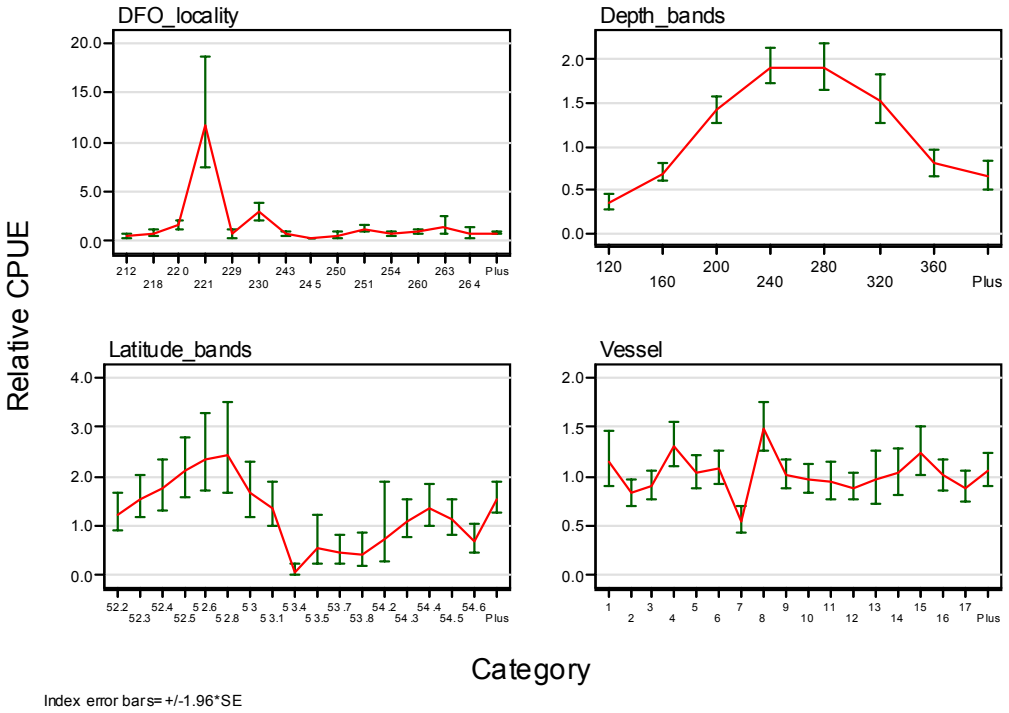


Figure 50. Plots of the coefficients for the categorical explanatory variables included in the standardised GLM analysis presented in Figure 49.

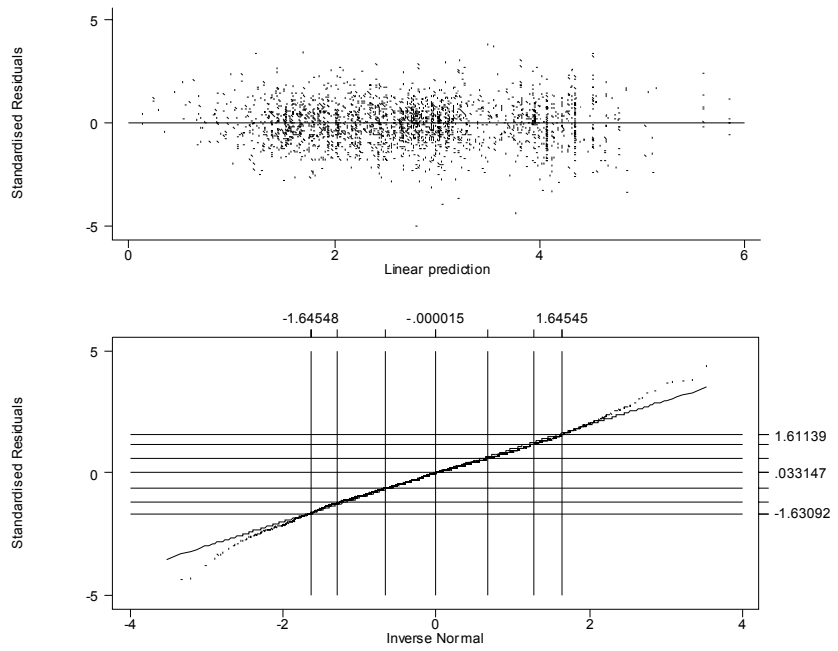


Figure 51. Standardised (Pearson) residuals for the 5CD GLM analysis presented in Figure 49. The outside horizontal and vertical lines represent the 5th and 95th percentiles of the theoretical and observed distributions.

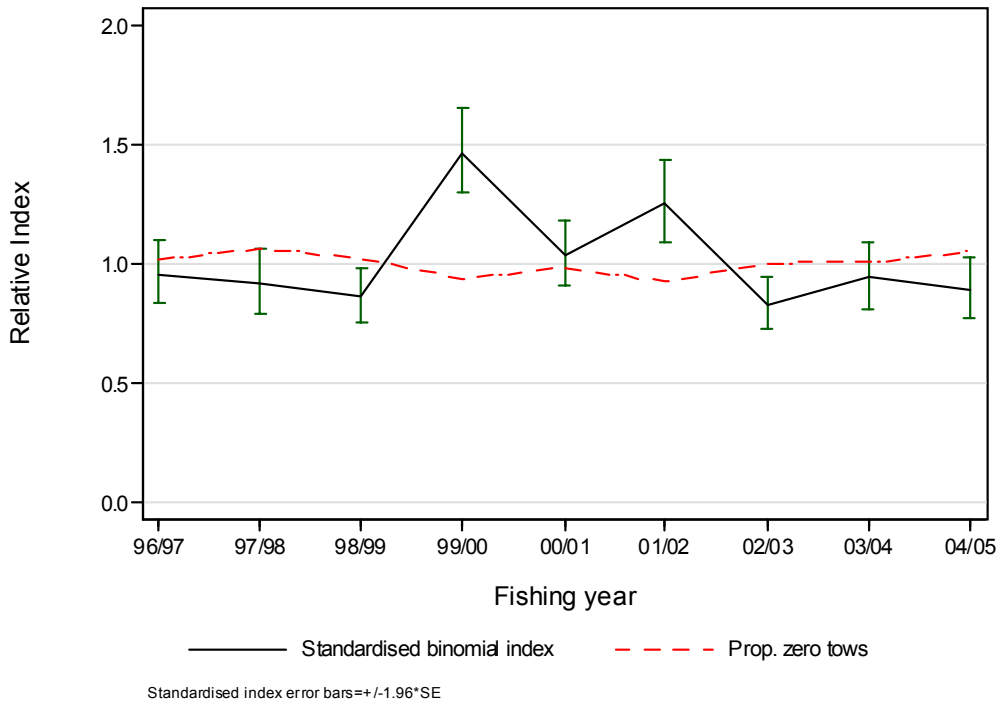


Figure 52. Year effects from a standardised binomial logit model fit to the presence/absence of redbanded rockfish using the same dataset that provided the lognormal regression model (Figure 49). Also shown is the relative proportion of tows with zero redbanded rockfish by fishing year (mean=0.74). Each series has been normalised to its geometric mean.

Table 31. Arithmetic and standardised CPUE indices (kg/h) with standard errors and upper and lower bounds of the standardised index for the 5CD model of non-zero total catches (landed plus discarded) of redbanded rockfish. The standardised series has been scaled to the geometric mean of the arithmetic series.

Year	Arithmetic	Standardised	Lower bound	Upper bound	Standard error
96/97	49	59	53	67	0.059
97/98	53	47	42	54	0.065
98/99	31	42	38	47	0.056
99/00	35	46	42	50	0.048
00/01	57	49	44	55	0.052
01/02	81	47	43	53	0.053
02/03	30	40	36	45	0.059
03/04	49	37	33	42	0.062
04/05	37	39	34	45	0.066

The selected lognormal model shows a gradual decreasing trend over the nine years of the series (Figure 49 and Table 31). Arithmetic (34) and unstandardised (35) show greater variability than the standardised series, with large deviations from the standardised series in the late 1990s and early 2000s. Plots of the coefficients of the explanatory variables appear reasonable, with the depth coefficients consistent with those estimated in 5AB and 3CD (Figure 50). Model residuals fit the model assumption of log-normal error well, with only small deviations from the lognormal assumption at the tails of the distribution (Figure 51). A binomial model fit to the presence/absence of redbanded rockfish using the same dataset shows little trend in either of the annual indices or in the proportion of zero catches (Figure 52).

A comparison of the annual coefficients estimated by the binomial and lognormal models shows some correspondence between all three series for analyses where the data begin in 1996/97 (lognormal, binomial and arithmetic; Figure 53). The two standardised series (lognormal and binomial follow the same trend with the binomial series being more variable. The arithmetic series may follow a similar trend but is even more variable than the other two series. This comparison is relevant because all three series are considered to be analogous estimators of the relative abundance of redbanded rockfish in 5CD.

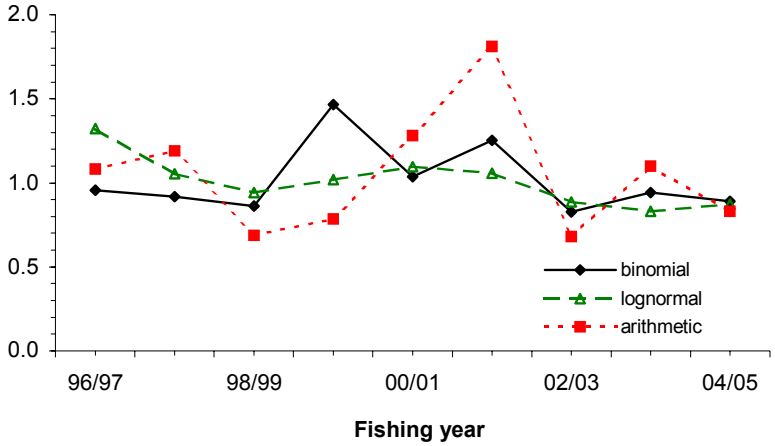


Figure 53. Comparison of the annual series from the lognormal (31) and binomial (31) standardised models beginning in 1996/97 (with vessels in the fishery for at least 5 years). Also shown is the arithmetic index (34) for the same dataset.

4.9.7. Comparison of trend lines: 3CD, 5AB and 5CD

The 1996/97 to 2004/05 lognormal standardised series (31) for 3CD, 5AB and 5CD show very similar trends, with slow declining trends in the two more northern areas and no trend or slowly increasing trend off the west coast of Vancouver Island (Figure 54, right panel). The short-term arithmetic series (34) based on the same data show fewer similarities across the same three areas (Figure 54, left panel). The general pattern of the series generated by the binomial presence/absence models is similar across all three areas (Figure 55). Region 5CD seems to be slightly more pessimistic than the other two areas in recent years under the assumptions of this model.

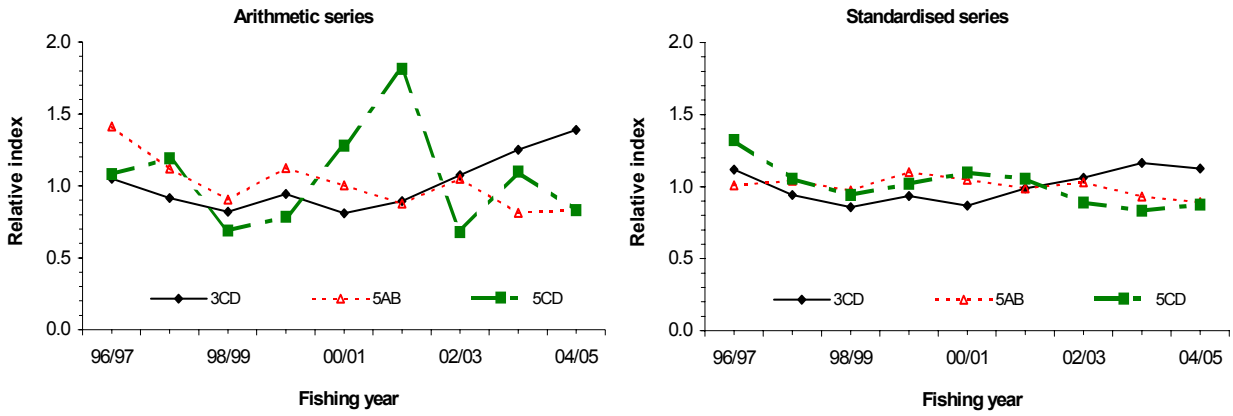


Figure 54. Comparison of annual series estimated by two CPUE models for 3CD, 5AB and 5CD for the period 1996/67 to 2004/05. Right panel – annual arithmetic series (34); left panel – annual standardised series based on the lognormal distribution (31).

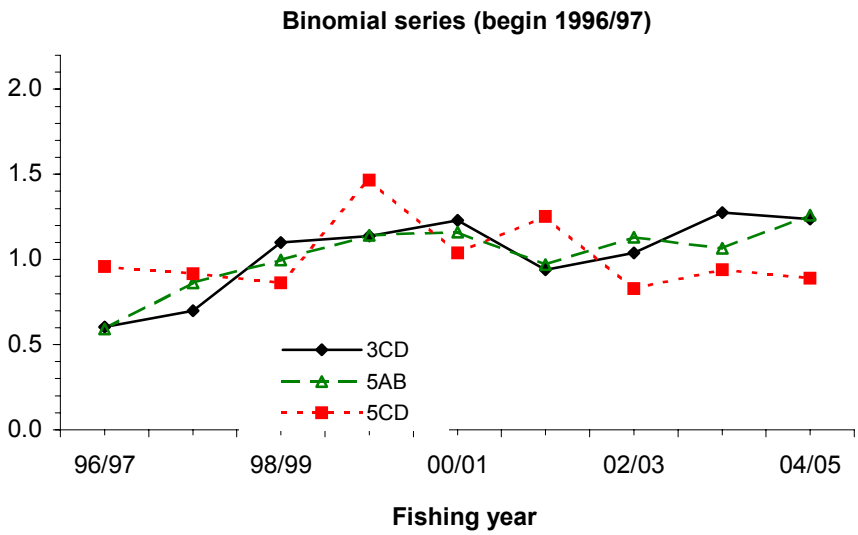


Figure 55. Comparison of annual series estimated by the binomial (logit) CPUE models for 3CD, 5AB and 5CD: period 1996/97 to 2004/05.

4.10. GLM analysis of commercial longline CPUE

4.10.1. Data selection

Longline catch (pieces) and effort (hours) data for redbanded rockfish are available in the DFO database PacHarvHL. Data on the Zn longline fishery exist from 1989 on; however, only the years 1994-2004 contained sufficient records for our analysis. Below are the full criteria:

- Tow start date between 1 Jan 1994 and 31 December 2004;
- Longline sets;
- Area fisheries – PMFC areas 3CD, 5AB, 5E;
- Fishing success code <=1 (code 0= unknown; code 1= useable);
- Catch of at least one rockfish species (no water hauls);
- Valid depth;
- Vessel had been in the area fishery for at least four years;
- Valid estimate of time towed that was greater than 0 hours and less than 24 hours.

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

- Calendar year;
- Month;
- Fishing depth as 100-m intervals (1-100m, 101-200m, etc.);
- Vessel as an anonymous CFV number.

4.10.2. Results

The GLM analysis on Zn longline CPUE data (Table 32, Figure 56) show divergent annual trends for the areas of the coast where longliners fish the most (Figure 14). The least definite trend occurs in PMFC area 3CD where the number of available sets are low. In fact, no longline sets qualified in 2003 and 2004. The central coast, PMFC area 5AB, shows a strong upward trend that appears to reflect the increased commercial activity in this region (Table 4). Strong effects on CPUE include the depth bin from 201-300 m and the fishing power of CFV 17 (all vessels remain anonymous). Only longline fishermen exploit the redbanded rockfish populations along the west coast of QCI (PMFC area 5E) because the bottom bathymetry in this area is too rough for the commercial trawl fleet. The index trend in 5E shows a steady decline which likely reflects declining commercial activity in this region (Table 4). This may reflect factors other than abundance, such as market demand and cost of fuel. Five vessels exert high influence on CPUE in 5E.

The validity of using these longline CPUE indices to track abundance remains questionable. A suspicious tracking of catch appears to characterize these CPUE trends. It is possible that the measure of effort used in this analysis, soak time duration, may not impart the usual density connotations to CPUE values.

Table 32. Annual index values from the GLM analysis on Zn longline CPUE (pieces/h) data. n = number of longline sets, I = standardised index value (pc/h), CL_{025} = 2.5% confidence limit (pc/h), CL_{975} = 97.5% confidence limit (pc/h).

	3CD				5AB				5E			
year	n	I	CL_{025}	CL_{975}	n	I	CL_{025}	CL_{975}	n	I	CL_{025}	CL_{975}
1994	60	3.3	2.3	4.7	220	1.3	1.0	1.6	15	2.6	1.1	6.3
1995	21	16.3	9.7	27.3	93	2.9	2.1	3.9	112	2.1	1.6	2.7
1996	161	4.1	3.0	5.6	129	2.7	2.1	3.4	131	3.3	2.5	4.4
1997	37	5.3	3.4	8.2	63	2.3	1.6	3.1	101	2.6	1.9	3.4
1998	32	2.1	1.4	3.1	102	5.1	4.0	6.7	167	1.8	1.4	2.3
1999	33	7.3	4.8	11.1	251	3.1	2.6	3.7	178	1.5	1.2	1.8
2000	25	4.4	2.6	7.6	178	4.1	3.3	5.1	237	1.1	0.9	1.3
2001	10	1.6	0.7	3.6	375	3.9	3.2	4.6	113	1.0	0.7	1.3
2002	38	6.0	3.2	11.3	379	10.1	8.3	12.4	105	0.4	0.3	0.5
2003					398	15.6	13.1	18.7	98	0.5	0.4	0.7
2004					417	14.5	12.1	17.2	97	0.6	0.4	0.8

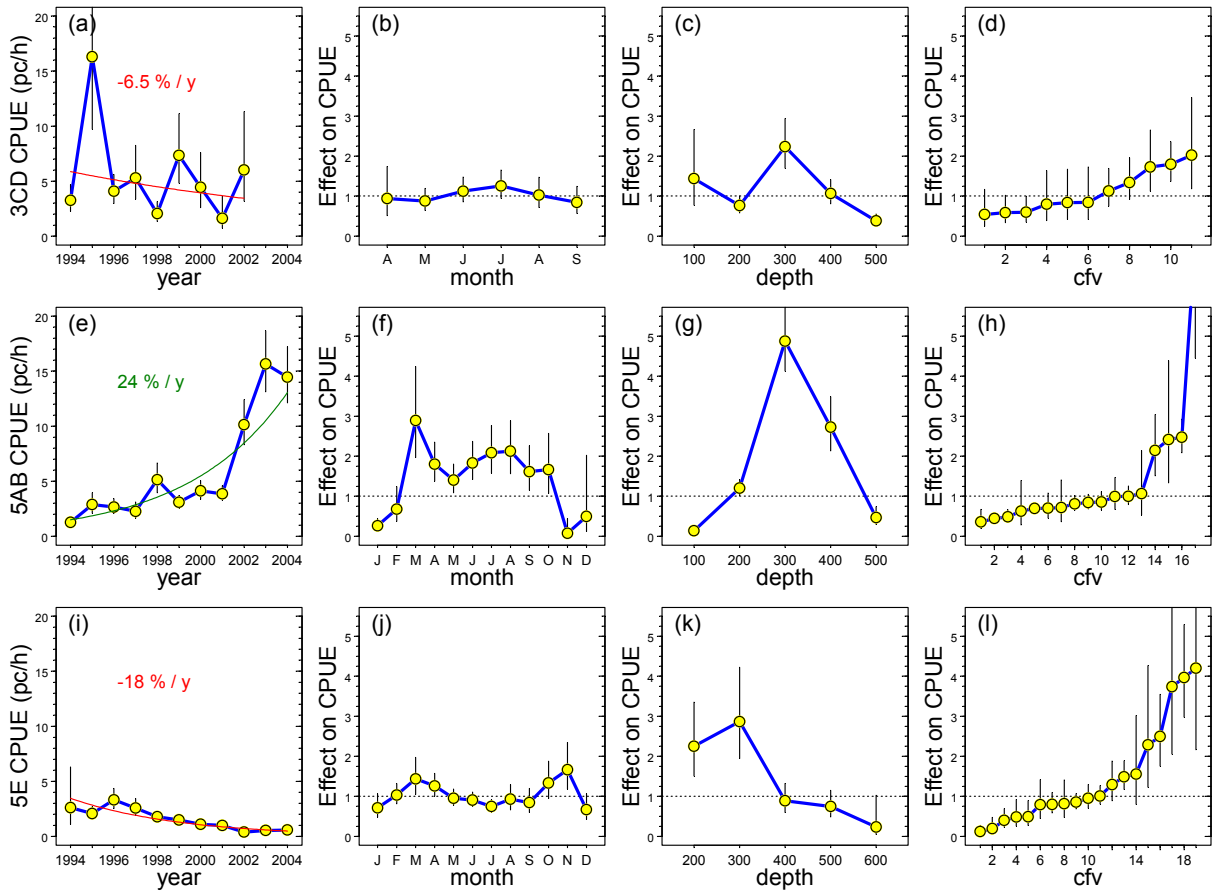


Figure 56. Annual index trends and factor coefficients for the GLM of Zn longline CPUE data (1994-2005). (a-d) 3CD, (e-h) 5AB, and (i-l) 5E. (a,e,i) annual CPUE indices with fitted curve through the points, (b,f,j) month effect on CPUE, (c,g,k) depth zone effect where indicated depth shows the maximum of a 100 m depth interval, (d,h,l) vessel effect ordered from lowest to highest.

5. Discussion

Insufficient data exist to answer the question "Are the current catches of redbanded rockfish sustainable?". If we assume that habitat suitability between the Gulf of Alaska (GoA) and BC are comparable, we might consider the implications of a current BC removal that is three times higher than the acceptable biological catch for the GoA. However, none of the indicators we looked at gave cause for alarm. The synoptic surveys should provide good indicators of population trends in future. 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.
- Catch-curve analyses indicate that mean exploitation rate F over the history of the fishery is likely lower than the natural mortality rate M. There is no information on the current exploitation rate.
- The analysis that compares exploitation rates in areas considered lightly and heavily fished by longliners could detect no difference in the estimated total mortality Z. The older age classes were well-represented in each area.
- None of the available long-term survey time series is able to give a good indication of the historical trend for this species. Either the survey design is not optimal (Hecate Strait assemblage survey, WCVI shrimp trawl survey) or the variability of catch is too high (QCS shrimp trawl survey, NMFS US west coast trawl survey, NMFS Gulf of Alaska trawl survey). The NMFS US west coast survey is potentially the best suited of the available long-term time series to monitor this species; however, it has been discontinued in Canadian waters and the results to 2001 are equivocal – the series in Canadian waters shows no trend while that for US waters shows a decline. Catches of redbanded rockfish in all three surveys are low and sporadic, suggesting that trawl survey methodology is not always an ideal monitoring tool.
- The IPHC SSA survey appears to have some potential as a monitoring tool, although none of the currently available indices are statistically different among years.
- The more recent HS, QCS, and WCVI synoptic surveys show more promise. In particular, the deeper strata of the QCS survey consistently catch redbanded rockfish ($p < 0.50$) and the precision of its abundance index is considered "excellent" (sampling CV < 0.20; Stanley et al. 2004). Given the suitability of the QCS synoptic survey, the long-term trend for redbanded rockfish should be evident as the series progresses.
- GLM analyses of trawl fishing catch and effort data collected since 1996 could detect no strong trend in the estimated year effects based on total (kept + discarded) removals in the three main areas fished. Both 5AB and 5CD may show some decline over the nine years of record which indicates that this analysis should be revisited in a few years.
- GLM analyses of the Zn longline CPUE data show a strong upward trend in 5AB and a strong downward trend in 5E. These indices may reflect factors other than population density, including commercial requirements, cost of fishing, and other effects unrelated to abundance.

6. Acknowledgements

We thank our colleague Norm Olsen for many of the fine figures that appear in this paper. The groundfish personnel in the Marine Ecosystems and Aquaculture Division truly appreciate Norm's continued efforts to provide standardised analyses of the vast amounts of information housed in numerous databases. We also recognise 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. The document has also benefited from useful suggestions by the two reviewers Dana Haggarty and Rick Stanley, and from input by numerous other participants at the PSARC meeting held in Nanaimo (Coast Bastion Inn, Jan 18, 2006). We remain grateful for Jon Schnute's guidance.

Since 2003, DFO has worked with representatives from the groundfish industry as well as First Nations, recreational fishing, conservation and coastal community representatives through the Commercial Groundfish Integrated Advisory Committee (CGIAC). This advisory committee considers new developments and initiatives (specifically with regard to (i) Inshore Rockfish Conservation Strategy, (ii) Pacific Fishery Monitoring and Reporting Framework, (iii) Selective Fishing Policy, and (iv) Species at Risk Act) and their potential impact on commercial groundfish fisheries in the Pacific Region. A sub-committee of the CGIAC, the Commercial Industry Caucus (CIC), which includes fishing industry representatives directly involved in the commercial groundfish fisheries, has worked to develop recommendations in accordance with criteria set out by DFO.

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Appendix A. Analytical Methods

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

$$W_i = \alpha L_i^{\beta} e^{\sigma \varepsilon_i}, \tag{6}$$

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

$$\ln W_i = \ln \alpha + \beta \ln L_i + \sigma \varepsilon_i \tag{7}$$

yields the negative log likelihood:

$$\ell(\alpha, \beta, \sigma) = n \log \sigma + \frac{1}{2\sigma^2} \sum_{i=1}^{n} \left(\ln W_i - \ln \alpha - \beta \ln L_i \right)^2 . \tag{8}$$

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 (9) 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

$$L_i = L_\infty \left[1 - e^{-K(t_i - t_0)} \right] e^{\sigma \varepsilon_i}, \tag{9}$$

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

$$\ln L_i = \ln L_\infty + \ln\left[1 - e^{-K(t_i - t_0)}\right] + \sigma\varepsilon_i \,, \tag{10}$$

and the negative log likelihood is

$$\ell\left(L_\infty, K, t_0, \sigma\right) = n \log\sigma + \frac{1}{2\sigma^2}\sum_{i=1}^{n}\left[\ln L_i - \ln L_\infty - \ln\left(1 - e^{-K(t_i - t_0)}\right)\right]^2 \,. \tag{11}$$

A.3. Generation Time

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

$$t_{gen} = k + \frac{1}{e^M - 1} \,, \tag{12}$$

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

A crude approximation to generation time is frequently adopted:

$$t_{gen} = k + \frac{1}{M} \,, \tag{13}$$

which approaches (12) as $M \to 0$.

A.4. Catch-curve analysis

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

$$S_a = e^{-K(a-k)}; \quad a = k, \ldots, B \tag{14}$$

$$\beta_a\left(\beta_k, \alpha\right) = \begin{cases} 1 - \left(1 - \beta_k\right)\left(\dfrac{b_0 - a}{b_0 - k}\right)^\alpha; & a = k, \ldots, b_0 - 1 \\ 1; & a = b_0, \ldots, B \end{cases} \tag{15}$$

$$R_a\left(\rho_1,\ldots,\rho_m,\tau\right)=1+\pm\sum_{h=1}^{m}\rho_h\exp\left[-\frac{1}{2}\left(\frac{a-b_h}{\tau}\right)^2\right];\quad a=k,\ldots,B \tag{16}$$

$$p_a\left(\Theta\right)=\frac{S_a\beta_a R_a}{\sum_{a=k}^{B}S_a\beta_a R_a};\quad a=k,\ldots,B \tag{17}$$

$$p_A\left(\Theta\right)=\sum_{a=A}^{B}p_a\left(\Theta\right) \tag{18}$$

Calculations depend on a fixed design vector

$$\Phi=\left(k,A,B;b_0;m,b_1,\ldots,b_m\right), \tag{19}$$

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

$$\Theta=\left(Z;\alpha,\beta_k;\tau,\rho_1,\ldots\rho_m\right), \tag{20}$$

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 $j=1,\ldots,n_{yi}$,

$$U_{yi}=\frac{1}{n_{yi}}\sum_{j=1}^{n_{yi}}\frac{C_{yij}}{E_{yij}}, \tag{21}$$

where C_{yij} = catch (kg) in tow j, stratum i, year y;
E_{yij} = effort (h) in tow j, stratum i, year y;

n_{yi} = number of tows in stratum i, year y.

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

$$\delta_{yi} = \frac{1}{vw} U_{yi}, \tag{22}$$

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

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

$$\delta_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{D_{yij} w_{yij}}, \tag{23}$$

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

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

$$B_y = \sum_{i=1}^{m} \delta_{yi} A_i = \sum_{i=1}^{m} B_{yi}, \tag{24}$$

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

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

$$V_y = \sum_{i=1}^{m} \frac{\sigma_{yi}^2 A_i^2}{n_{yi}} = \sum_{i=1}^{m} V_{yi}, \tag{25}$$

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

$$CV_y = \frac{\sqrt{V_y}}{B_y}. \tag{26}$$

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 $h = 1, \ldots, m$:

$$\mathrm{E}\left[\hat{B}_h\right] = (1 - p_h)\,\mu_h A_h\,, \tag{27}$$

$$\mathrm{V}\left[\hat{B}_h\right] = \frac{1}{n_h}\left(\rho_h^2 + p_h\right)(1 - p_h)\,\mu_h^2 A_h^2\,, \tag{28}$$

$$\mathrm{CV}\left[\hat{B}_h\right] = \sqrt{\frac{\rho_h^2 + p_h}{n_h(1 - p_h)}}\,. \tag{29}$$

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

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

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

$$U_{ijk} = U_0 \prod_i \prod_j P_{ij}^{X_{ij}} e^{\varepsilon_{ijk}}\,, \tag{30}$$

where U_{ijk} = the observed CPUE for tow k at the jth level of factor i;
U_0 = the reference CPUE;
P_{ij} = coefficient for factor i at level j;
X_{ij} = 1 when the jth 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 (30) yields an additive linear regression model with p factors and $n_{i=1,\ldots,p}$ levels:

$$\ln U_{ijk} = \ln U_0 + \sum_{i=1}^{p}\sum_{j=1}^{n_i-1} X_{ij} \ln P_{ij} + \varepsilon_{ijk} \quad \text{or} \quad Y_{ijk} = \beta_0 + \sum_{i=1}^{p}\sum_{j=1}^{n_i-1} \beta_{ij} X_{ij} + \varepsilon_{ijk} . \tag{31}$$

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 (30) and (31) 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

$$\beta'_j = \frac{\beta_j}{\bar{\beta}} . \tag{32}$$

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

$$b'_j = \mathrm{e}^{(\beta_j - \bar{\beta})} . \tag{33}$$

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:

$$^{+}U_j = \frac{\sum_{k=1}^{M_j} C_{jk}}{\sum_{k=1}^{M_j} E_{jk}} \tag{34}$$

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

$$^{*}U_j = \exp\left[\frac{1}{M_j}\sum_{k=1}^{M_j} \ln\frac{C_{jk}}{E_{jk}}\right] \tag{35}$$

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 (35) 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 (34) and (35) 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:

$$ {}^{+}U'_j = {}^{+}U_j \Big/ \overline{{}^{+}U} \tag{36} $$

and

$$ {}^{*}U'_j = {}^{*}U_j \Big/ \overline{{}^{*}U} . \tag{37} $$

The procedures described by (30), (31), and (35) 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 (30) and (31). 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 (PacHarvTrawl 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.