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Sablefish Stock Assessment for 2001 and Advice to Managers for 2002

V. Haist, R. Hilborn, M. Wyeth[1]

School of Aquatic and Fisheries Sciences
University of Washington
Seattle, WA 98195

[1]Department of Fisheries and Oceans
Pacific Biological Station
Nanaimo, B.C. V9R 5K6

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1 ABSTRACT

The 2001 sablefish stock assessment addresses the objectives and questions specified by the Department of Fisheries and Oceans (DFO) Groundfish Management Unit in their *Request for Working Paper*. The Pacific Scientific Advice Review Committee (PSARC) document includes summaries of the sablefish fishery and biological information, and provides analyses related to the fishery and tag dynamics.

As in previous sablefish assessments, the primary information we use to assess the stock is tagging data. The tagging analysis conducted for the current assessment uses only tag recoveries in the year following release to estimate exploitation rates and stock abundance. This analysis does not incorporate stock dynamics, so we do not conduct stock projections.

B.C. sablefish stock abundance declined through the early 1990's, and has been relatively stable since 1996. The estimated abundance trends from tagging analysis, commercial CPUE indices, and survey CPUE indices are consistent. We believe the sablefish stock abundance is currently low and stable.

Estimated exploitation rates, in the range of 10-13% in recent years, are at the high end of the range we recommend for the sablefish stock. However, we believe that our estimates are biased high due to the disproportionate release of tagged fish in areas and depth zones of major commercial fishing effort, rather than randomly through the population. Sablefish survey data, including addition sets conducted during the 2000 survey in the 600-800 fm depth range, indicate fairly high fish density at depths greater than 450 fm where only a small fraction of tag releases and fishery effort occurs.

We estimate that approximately 30% of sablefish tagged off the Queen Charlotte Islands move to Alaskan waters. However, on the basis of analyses conducted to date, we are not in a position to provide specific advice regarding management of northern B.C. sablefish.

2 RÉSUMÉ

L'évaluation des stocks de morue charbonnière pour 2001 répond aux objectifs et aux questions précisés par la Section de gestion du poisson de fond du MPO dans sa *Demande de document de travail*. Le document du CEESP comprend des résumés de la pêche à la morue charbonnière et de l'information biologique sur l'espèce, de même que des analyses de la pêche et des données issues de l'étiquetage.

Comme dans les évaluations précédentes, les données issues de l'étiquetage ont été la matière première dont nous nous sommes servi pour évaluer les stocks de morue charbonnière. Cette fois, nous n'avons tenu compte que des étiquettes récupérées l'année suivant le relâchement des spécimens marqués aux fins de l'estimation des taux d'exploitation et de l'abondance des stocks. La présente analyse n'incorpore pas les données issues de l'étiquetage, aussi ne faisons-nous pas de projections à propos des stocks.

Les stocks de morue charbonnière en C.-B. ont diminué tout au long des premières années de 1990 et sont relativement stables depuis 1996. Les tendances dans l'abondance estimée selon l'analyse des données issues de l'étiquetage, les indices de prises par unité d'effort de pêche commerciale et les relevés sont cohérentes. Nous croyons que les stocks de morue charbonnière sont peu abondants et stables.

Les taux d'exploitation estimés, de l'ordre de 10 à 13 % au cours des dernières années, se situent à l'extrémité supérieure de la fourchette que nous recommandons pour les stocks de morue charbonnière. Cependant, nous croyons que nos estimations sont fortement biaisées en raison du relâchement disproportionné de poissons marqués dans des endroits et à des profondeurs où s'exerce le principal effort de pêche commerciale, plutôt qu'au hasard dans l'ensemble de la population. Les données issues des relevés de morue charbonnière, y compris des traits additionnels effectués pendant le relevé de 2000 dans la zone de 600 à 800 brasses de profondeur, révèlent une densité de poissons passablement élevée à plus de 450 brasses de profondeur, alors que seulement une petite fraction des poissons marqués y sont relâchés et une petite partie de l'effort de pêche y est exercée.

Nous estimons qu'environ 30 % des morues charbonnières marquées au large des îles de la Reine Charlotte se déplacent vers les eaux de l'Alaska. Cependant, d'après les analyses effectuées à ce jour, nous ne sommes pas en mesure de fournir des conseils précis sur la gestion de la morue charbonnière dans le nord de la C.-B.

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3 INTRODUCTION

The 2001 sablefish stock assessment addresses the objectives and questions specified by the DFO Groundfish Management Unit in their *Request for Working Paper* (Appendix A). Managers' objectives for this sablefish PSARC working paper are:

1. To review surveys, biological sampling, catch records, logbooks, observer reports and fishing practices for sablefish to provide a basis for management for the 2002/2003 fishery.
2. To provide an assessment of sablefish stock status.
3. To provide stock projections based on various yield options.
4. To recommend appropriate yield options.
5. To determine whether sablefish found in Northern BC are a separate stock from SE Alaska sablefish and consider management options.

Recent sablefish stock assessments have focused on using tag release and recovery data to provide absolute estimates of exploitation rates and stock abundance (Murie et al. 1995b, Saunders et al. 1996, Haist and Hilborn 2000). The methods used have differed in their complexity, from simple models based on the ratio of tagged to untagged fish in the catch of the year following tagging, to complex models that have included bathymetric and spatial structure. Results from the more complex models, which predict tag recoveries over time, have been unsatisfactory (eg. Haist 1998, Haist and Hilborn 2000). The general tag recovery pattern, which holds for tag groups released from 1977 to the present, is that approximately 10% of released tags are recovered in the year following tagging, then over the next 3 to 5 years tag recoveries decline sharply, indicating a total mortality rate of over 0.5. However, small numbers of tags continue to be returned 20 and more years after release. The age structure of the population and the observation of tag recoveries 20+ years after release are inconsistent with the apparent high mortality rate over the initial year.

For this year's assessment we do not use any of the complex models we have used previously. While these models were useful in highlighting inconsistencies between the data and our assumptions regarding sablefish dynamics, we feel they have limited utility for the assessment at this time. The tagging analysis we do for the current assessment uses only tag recoveries in the year following release to estimate exploitation rates and stock abundance. Because this analysis does not incorporate stock dynamics, we do not conduct stock projections.

In this document we summarize the sablefish fishery and biological information and provide analyses related to the fishery and tag dynamics. This includes: information related to the fishery (Section 3); sablefish survey information and potential juvenile indices (Section 4); tag release and recovery data and related analyses (Section 5); tag release-recovery analysis to estimate harvest rates (Section 6); simulations to determine appropriate sablefish harvest rates (Section 7); and finally, we provide advice to managers in response to the questions they raise in the *Request for Working Paper* (Section 8).

4 FISHERY INFORMATION

4.1 LANDING STATISTICS

The commercial fishery for sablefish has been active since the late nineteenth century and was described in detail by McFarlane and Beamish (1983). Annual catches as high as 5956 t were realised during the 1910's, however landings remained modest from 1920 to 1965, ranging between 200 t and 1900 t (Figure 1). Since 1969 landings have generally been in the 4000 t to 5000 t range.

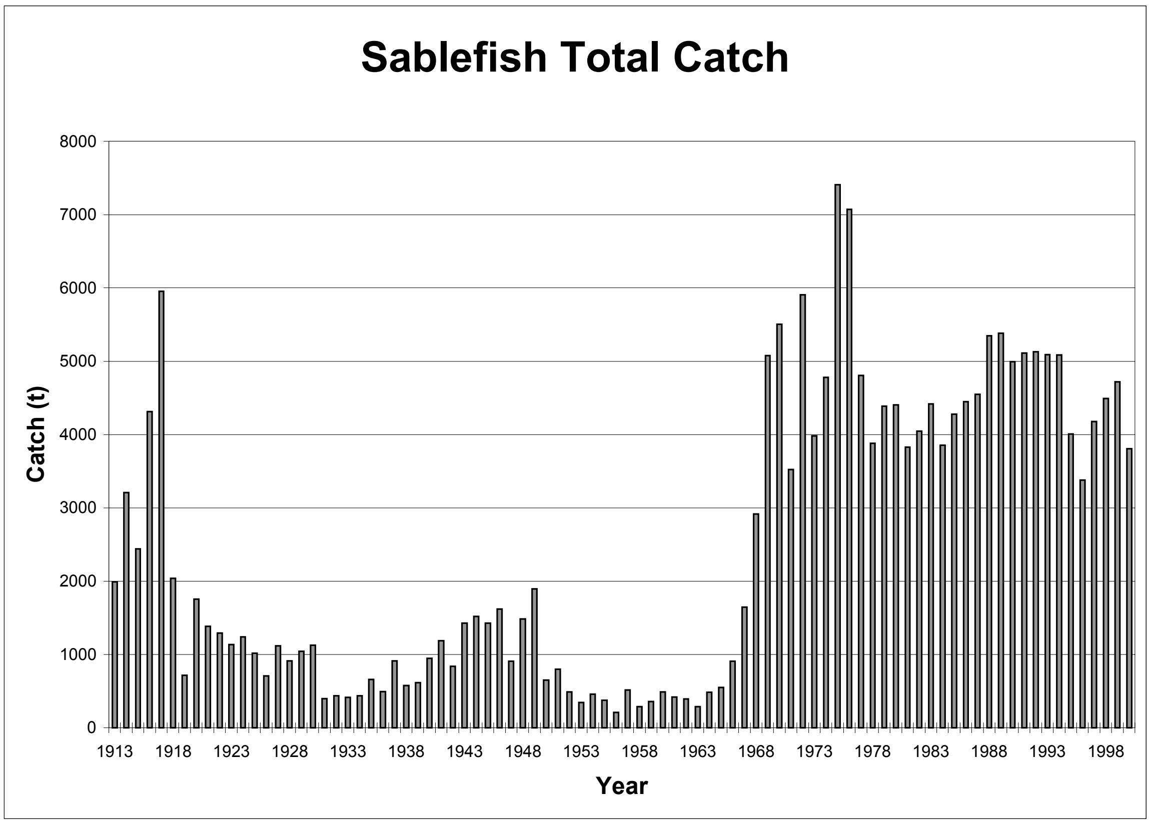

Figure 1. All nation catch (metric tonnes) of sablefish in the Canadian zone by year 1913-2000.

<u>Foreign fishery</u>

Exploitation increased in the late 1960's with the arrival of foreign longline fleets from Japan, the U.S., the USSR and the Republic of Korea (Table 1). The largest annual catches of sablefish occurred during this period with a peak 7408 t removed in 1975. Unrestricted foreign fishing ceased in 1977 with declaration of the Canadian 200 mile Economic Exclusive Zone (EEZ). Some foreign fishing was allowed between 1977 and 1980 to utilise yield declared surplus to Canadian domestic fleet needs.

Table 1. Catch (metric tonnes) of sablefish in Canadian waters by gear type. (LL=longline, Other=troll, handline, sunken gillnet (1968 only) and catch incidental to the longline halibut fishery).

Year	LL	%	Trawl	%	Trap	%	Other	%	Total	Foreign	Grand total
1913									1988.0		1988.0
1914									3209.0		3209.0
1915									2441.0		2441.0
1916									4312.0		4312.0
1917									5956.0		5956.0
1918									2039.0		2039.0
1919									716.0		716.0
1920									1754.0		1754.0
1921									1383.0		1383.0
1922									1293.0		1293.0
1923									1135.0		1135.0
1924									1238.0		1238.0
1925									1017.0		1017.0
1926									705.0		705.0
1927									1118.0		1118.0
1928									911.0		911.0
1929									1042.0		1042.0
1930									1124.0		1124.0
1931									397.0		397.0
1932									436.0		436.0
1933									413.0		413.0
1934									435.0		435.0
1935									659.0		659.0
1936									490.0		490.0
1937									912.0		912.0
1938									576.0		576.0
1939									617.0		617.0
1940									948.0		948.0
1941									1188.0		1188.0
1942									835.0		835.0
1943									1426.0		1426.0
1944									1519.0		1519.0
1945									1428.0		1428.0
1946									1619.0		1619.0
1947									905.0		905.0
1948									1483.0		1483.0
1949									1895.0		1895.0
1950									648.0		648.0
1951	772.8	97.04%	23.1	2.90%	0.0	0.00%	0.5	0.06%	796.4		796.4
1952	453.2	92.91%	34.0	6.97%	0.0	0.00%	0.6	0.12%	487.8		487.8
1953	335.6	97.36%	8.0	2.32%	0.0	0.00%	1.1	0.32%	344.7		344.7
1954	432.3	94.18%	26.4	5.75%	0.3	0.07%	0.0	0.00%	459.0		459.0
1955	359.0	96.12%	14.5	3.88%	0.0	0.00%	0.0	0.00%	373.5		373.5
1956	172.8	82.32%	37.1	17.68%	0.0	0.00%	0.0	0.00%	209.9		209.9
1957	465.6	90.76%	47.1	9.18%	0.3	0.06%	0.0	0.00%	513.0		513.0
1958	167.1	58.57%	117.6	41.22%	0.6	0.21%	0.0	0.00%	285.3		285.3

Table 1 (cont.). Catch (metric tonnes) of sablefish in Canadian waters by gear type. (LL=longline, Other=troll, handline, sunken gillnet (1968 only) and catch incidental to the longline halibut fishery).

Year	LL	%	Trawl	%	Trap	%	Other	%	Total	Foreign	Grand total
1959	298.3	83.89%	57.3	16.11%	0.0	0.00%	0.0	0.00%	355.6		355.6
1960	423.3	86.71%	64.9	13.29%	0.0	0.00%	0.0	0.00%	488.2		488.2
1961	321.3	76.63%	98.0	23.37%	0.0	0.00%	0.0	0.00%	419.3		419.3
1962	277.7	70.75%	113.7	28.97%	0.0	0.00%	1.1	0.28%	392.5		392.5
1963	222.3	77.35%	64.9	22.58%	0.0	0.00%	0.2	0.07%	287.4		287.4
1964	274.5	68.68%	125.1	31.30%	0.0	0.00%	0.1	0.03%	399.7	83.0	482.7
1965	193.2	42.42%	261.9	57.51%	0.0	0.00%	0.3	0.07%	455.4	92.0	547.4
1966	325.7	51.24%	309.7	48.73%	0.0	0.00%	0.2	0.03%	635.6	269.0	904.6
1967	252.9	64.53%	138.9	35.44%	0.0	0.00%	0.1	0.03%	391.9	1254.0	1645.9
1968	292.3	63.08%	156.0	33.66%	0.0	0.00%	15.1	3.26%	463.4	2455.0	2918.4
1969	162.3	52.17%	148.2	47.64%	0.0	0.00%	0.6	0.19%	311.1	4763.0	5074.1
1970	142.1	54.84%	116.5	44.96%	0.0	0.00%	0.5	0.19%	259.1	5246.0	5505.1
1971	123.0	39.37%	189.4	60.63%	0.0	0.00%	0.0	0.00%	312.4	3211.0	3523.4
1972	399.7	36.73%	688.5	63.27%	0.0	0.00%	0.0	0.00%	1088.2	4818.0	5906.2
1973	119.8	12.63%	82.8	8.73%	745.8	78.64%	0.0	0.00%	948.4	3032.0	3980.4
1974	41.3	8.39%	121.8	24.76%	327.1	66.48%	1.8	0.37%	492.0	4287.0	4779.0
1975	152.2	16.87%	279.8	31.01%	469.4	52.02%	0.9	0.10%	902.3	6506.0	7408.3
1976	89.4	11.58%	379.0	49.10%	303.4	39.31%	0.1	0.01%	771.9	6302.0	7073.9
1977	77.1	7.11%	786.4	72.49%	214.6	19.78%	6.8	0.63%	1084.9	3718.0	4802.9
1978	57.2	6.89%	130.5	15.72%	634.6	76.45%	7.8	0.94%	830.1	3051.0	3881.1
1979	277.0	13.58%	276.1	13.54%	1480.1	72.58%	6.0	0.29%	2039.2	2348.0	4387.2
1980	248.8	6.55%	335.3	8.83%	3210.8	84.54%	3.0	0.08%	3797.9	606.0	4403.9
1981	326.2	8.52%	228.8	5.97%	3275.4	85.51%	0.0	0.00%	3830.3		3830.3
1982	343.7	8.50%	245.9	6.08%	3437.9	84.97%	18.4	0.45%	4045.9		4045.9
1983	451.5	10.22%	274.1	6.20%	3678.0	83.23%	15.4	0.35%	4419.0		4419.0
1984	365.2	9.47%	187.0	4.85%	3275.4	84.95%	28.0	0.73%	3855.6		3855.6
1985	458.3	10.72%	233.1	5.45%	3501.3	81.89%	82.8	1.94%	4275.5		4275.5
1986	619.2	13.92%	551.8	12.40%	3277.1	73.66%	0.8	0.02%	4448.9		4448.9
1987	1133.4	24.91%	406.9	8.94%	2954.3	64.92%	56.1	1.23%	4550.7		4550.7
1988	1194.3	22.34%	638.6	11.95%	3509.7	65.65%	3.2	0.06%	5345.8		5345.8
1989	928.7	17.26%	623.4	11.59%	3828.3	71.15%	0.1	0.00%	5380.5		5380.5
1990	1372.1	27.47%	460.7	9.22%	3162.1	63.31%	0.0	0.00%	4994.9		4994.9
1991	1089.2	21.31%	438.8	8.58%	3582.0	70.08%	1.5	0.03%	5111.5		5111.5
1992	889.1	17.34%	448.4	8.74%	3789.2	73.89%	1.1	0.02%	5127.8		5127.8
1993	371.6	7.30%	543.4	10.68%	4168.4	81.93%	4.3	0.08%	5087.7		5087.7
1994	511.0	10.05%	482.4	9.49%	4090.6	80.46%	0.0	0.00%	5084.0		5084.0
1995	281.7	7.03%	406.5	10.14%	3319.0	82.83%	0.0	0.00%	4007.2		4007.2
1996	253.6	7.51%	211.0	6.24%	2914.4	86.25%	0.0	0.00%	3379.0		3379.0
1997	412.8	9.88%	285.0	6.82%	3480.2	83.30%	0.0	0.00%	4178.0		4178.0
1998	445.9	9.93%	328.0	7.30%	3718.1	82.77%	0.0	0.00%	4492.0		4492.0
1999	608.1	12.89%	399.6	8.47%	3709.4	78.64%	0.0	0.00%	4717.1		4717.1
2000	750.5	19.71%	326.3	8.57%	2729.6	71.70%	0.4	0.01%	3806.8		3806.8

1913-1999, (Haist and Hilborn, 2000)
2000, Archipelago Marine Research, Landing Validation databases; Longline includes 0.1 t of sablefish caught incidental to the rockfish longline fishery.

Domestic fishery

Canadian landings since 1951 have been caught with longline, trawl, and trap gear (Table 1). Since 1980, Canadian annual catches have averaged 4502 t and ranged from 3379 t in 1996 to 5381 t in 1989. Fisheries have been managed under quotas allocated to "T" licence (trawl gear) and "K licence (longline and trap gear) fleets. Additional sablefish are caught as by-catch in the halibut fishery and there are small allocations to research charters and to First Nations food fisheries.

Since 1977 the trawl component of the catch has always been the smallest, ranging from 5-16% of the total (Table 1). Since 1981, trawl landings have been limited by a quota allocation based on the historic average catch (8.75% of the commercial Total Allowable Catch (TAC)).

Longline was the dominant gear type in most years prior to 1973 (Table 1). In 1973, the trap fishery began to develop in earnest, thereby reducing the dominance of longline gear. Since then, the percentage of longline-caught fish in the total catch has fluctuated between 6.6% (1980) and 27.5% (1990). Over the period 1977-2000 longline landings averaged 560 t/y. The trap fishery for sablefish began in 1973 and averaged 449 t over the first six years. Since 1978, trap landings have ranged between 1480 t (1979) and 4168 t (1993).

4.2 FISHERIES MANAGEMENT

In 1981 the Department introduced a limited entry (48 licences) "K" tab licence under which fishers could land sablefish using either longlined hooks or traps. The management history, including opening dates by year, is presented in Table 2. While the management approach has consistently been based on catch quotas, the method chosen to manage the quotas has varied considerably. During the period 1981-1984 fishing was unrestricted until the quota was taken. The total number of days to take the quota declined from 245 days to 181 days. From 1985-1987 the fishery was split into two openings with provision for a third if quota remained. However, with increasing fleet efficiency and participation in the fishery, it was difficult for managers to predict the duration of the fishery.

In 1988 and 1989, fishers were given their choice of one of five openings. They were allowed to choose an opening they felt to be optimal regarding market conditions and conflicts with other available fisheries (i.e. herring, halibut, etc.). It was however, difficult for DFO to determine the number of days required to take the quota, again because of variable participation and increasing fleet efficiency. As a consequence, total quota overruns increased to 29.8% and 21.6% in 1988 and 1989, respectively.

In 1990, Individual Vessel Quota's (IVQ) were introduced and remain in effect through 2001. Vessels were allocated proportional quota shares based on historical catch and overall vessel length. In 1999 the use of escape-rings in sablefish traps was required by regulation; in 1998 some sablefish trap vessels voluntarily used escape-rings.

Table 2. History of sablefish "K" fishery including opening and closing dates, fishing days and management regime from 1981-01.

Year	Date		# Days Open	Total # Days Open	Management Regime	Quota		
	Opening	Closing				Total	K Fleet	T Fleet
1981	1-Feb	4-Oct	245	245	Derby Fishery	3500	3190	310
1982	1-Feb	22-Aug	202	202	Derby Fishery	3500	3190	310
1983	1-May	26-Sep	148	148	Derby Fishery	3500	3190	310
1984	1-Mar	22-Aug	181	181	Derby Fishery	3500	3190	310
1985	1-Feb	8-Mar	36	95	Derby Fishery	4000	3650	350
	29-Mar	2-May	36		Derby Fishery			
	19-Jul	11-Aug	23		Derby Fishery			
1986	17-Mar	21-Apr	35	63	Derby Fishery	4000	3650	350
	12-May	9-Jun	28		Derby Fishery			
1987	16-Mar	10-Apr	25	45	Derby Fishery	4100	3740	360
	1-Sep	21-Sep	20		Derby Fishery			
1988	Seven 20 Day Fishing Periods Between March And Sept				Derby Fishery	4400	4015	385
1989	Eight 14 Day Fishing Periods Between March And Oct				Derby Fishery	4400	4015	385
1990	21-Apr	31-Dec	255	255	Individual Vessel Quotas	4670	4260	410
1991	1-Jan	31-Dec	365	365	Individual Vessel Quotas	5000	4560	440
1992	1-Jan	31-Dec	365	365	Individual Vessel Quotas	5000	4560	440
1993	1-Jan	31-Dec	365	365	Individual Vessel Quotas	5000	4560	440
1994	1-Jan	31-Dec	365	365	Individual Vessel Quotas	5000	4521	433
1995	1-Jan	31-Dec	365	365	Individual Vessel Quotas	4140	3709	356
1996	1-Jan	31-Dec	365	365	Individual Vessel Quotas	3600	3169	304
1997	1-Jan	31-Dec	365	365	Individual Vessel Quotas	4500	4023	386
1998	1-Jan	31-Dec	365	365	Individual Vessel Quotas	4500	4023	386
1999	1-Jan	31-July-00	455	455	Individual Vessel Quotas	4500	6395	386
2000	1-Aug	31-July-01	365	365	Individual Vessel Quotas	4000	3555	350
2001	1-Aug	31-July-02			Individual Vessel Quotas	4000	3568	350

Notes:
In 1988 each "K" vessel permitted to fish in one of the seven scheduled openings.
In 1989 each "K" vessel permitted to fish in one of the eight scheduled openings.
Individual Vessel Quotas in the K fishery since 1990 and the T fishery since 1997.
K quotas under the IVQ program do not include underage and overage carryover from previous year.
Since 1997 the T fishery season goes from April 1 through March 31.
1999 K season is 19 months long as part of transition to new annual season commencing August 1, quota is adjusted accordingly.
Since 1994, 45.36 tonnes removed annually from TAC for native food requirements.
In 1995, 29.48 tonnes removed from TAC for scientific research.
In 1996, 81.65 tonnes removed from TAC for scientific research.
1997 - 2001, 45.36 tonnes removed annually from TAC for scientific research.
Data collected from management plans.

IVQ Fishery

During the period 1990-93, the first three years of IVQ management, the proportion of catch attributed to longline was high (17-27%) but then dropped to below 10 percent over the 1993-98 period. The initial increase was due to large vessels developing longline operations for other groundfish species that included their sablefish quota. In this way the vessels could fish most of the year. The subsequent decline was due to a movement away from the multi-species longline approach in favour of dedicated trap fishing with transferred quota. The transferred quota allows the vessels to fish sablefish most of the year and traps were chosen as the most effective gear. An increase in the proportion of the catch taken by longline in 1999 and 2000 may reflect a move back to a multiple target species approach.

The impact of IVQ's on the distribution of trap effort was considerable. There was an abrupt shift in trap effort from the south (Major Areas 3 to 5) to the north (Major Areas 6 and 9) in 1991 (Figure 4) as fishers under the IVQ program were attracted by higher catch rates and larger fish in the north. The percentage of total trap catch taken from the north increased to 84% and 92% in 1991 and 1992, respectively from an average of 55% over the period 1977-1990. In recent years there has been a shift back to the south as the percentage of catch in the north has dropped to 44% in 1998 (Figures 4). The shift is due in part to declining CPUE in the north and in part to a direct request to the industry to balance the effort rather than having to implement area-specific quotas.

The sablefish trap fishery extends from approximately 150-650 fm (275-1200 m) although over 75% of the fishing effort is expended between 250-450 fm (460-825 m) (Figure 2). The longline fishery generally occurs in more shallow depths, with 80% of the fishing effort less than 250 fm (460 m).

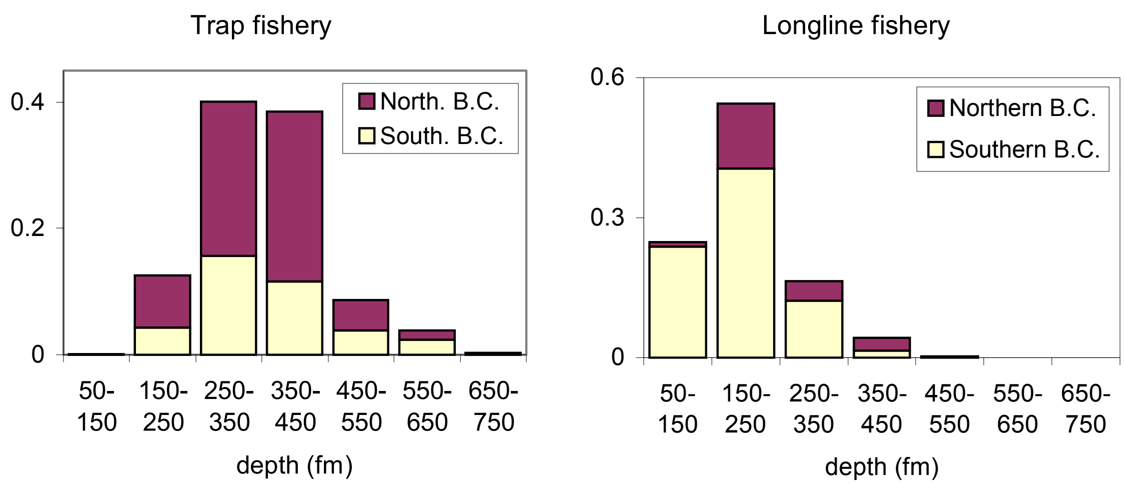

Figure 2 Distribution of K fishery effort (# traps for trap fishery and # hooks for longline fishery) by gear type, depth strata, and region, 1995-2001.

4.3 COMMERCIAL CPUE ESTIMATES

Yearly estimates of commercial trap fishery CPUE are calculated for the period 1979-2000. For the period 1979-1995, the total retained weights were obtained from sales slips and landing validation logs. Effort data (number of traps fished) and retained and discard weights were captured from logbooks. Not all catches had effort information. The landing validation logs for the period 1996-present are not merged with the logbook data. As such, it is not possible to compare the logbook catch and effort data with the total retained weight. Nonetheless, logbook compliance is expected to be 100% and the total coast-wide landings are similar to the total estimates recorded in the logbook. As such, for 1996 through 2000 we used the logbook as the estimate of total retained weight.

The CPUE was calculated as the sum of the retained and discarded weights divided by the sum of traps fished using only fishing events where effort data was recorded. Over the period 1979-1995, the percent of the total retained weight with associated effort information ranged from 51.5% to 100% (Figure 3) with an average of 83.8%. The discard proportion of the weight used in the CPUE estimate was multiplied by the total retained weight to give an estimate of total discard weight. Total annual catch was calculated as the sum of the total retained weight and the estimated total discard weight. Total annual effort was calculated by dividing the CPUE estimate into the total annual catch.

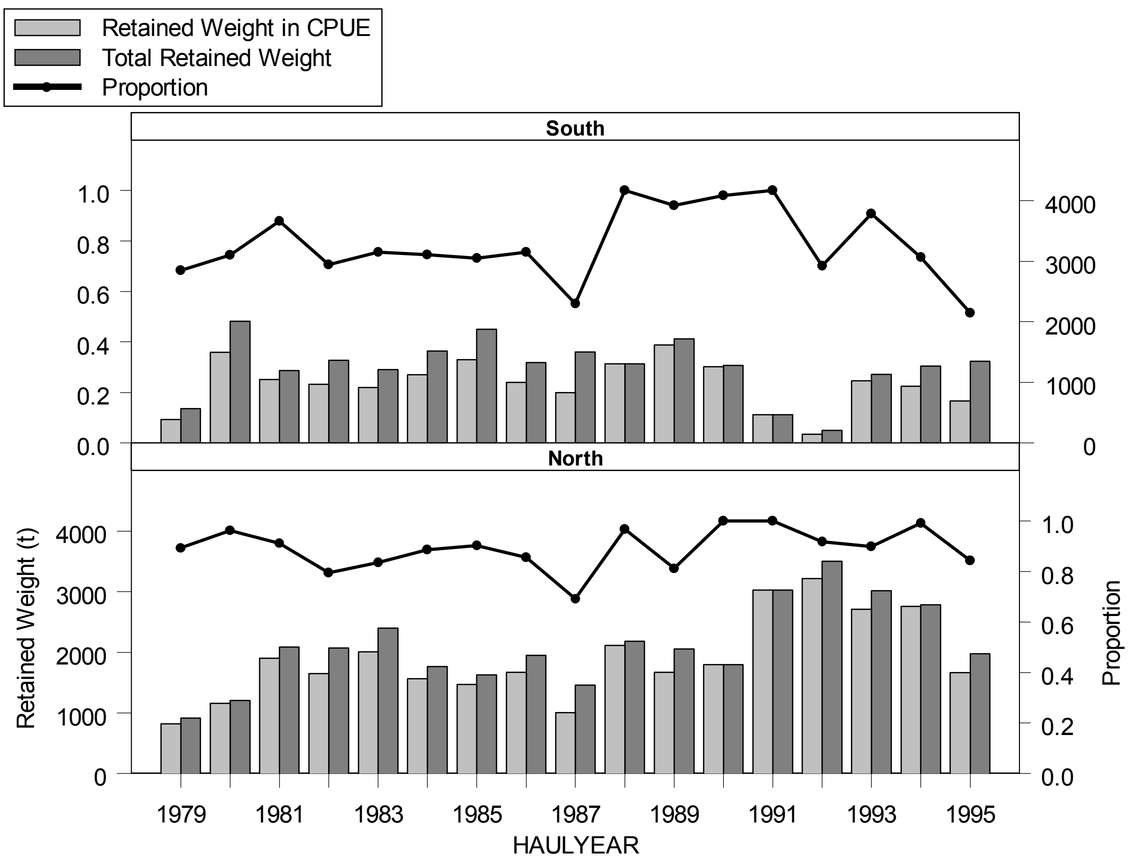

Figure 3. Proportion of the total retained catch included in the CPUE estimate

The estimates of commercial trap fishery CPUE for the southern and northern regions are shown in Figure 4. No adjustment has been made to account for the effect of trap escape-rings on the CPUE estimates. Escape ring use was voluntary in 1998 and mandatory since 1999.

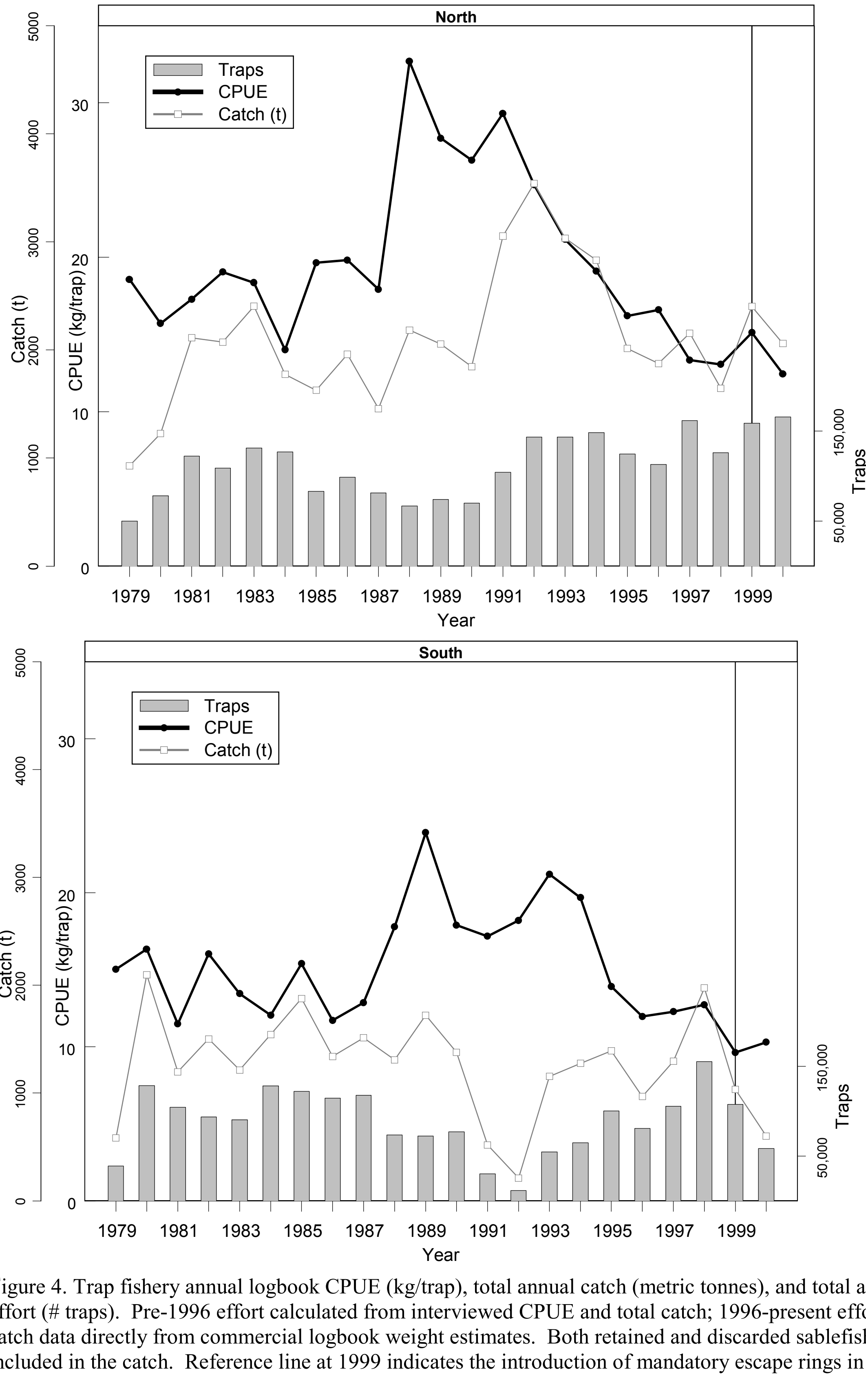

Figure 4. Trap fishery annual logbook CPUE (kg/trap), total annual catch (metric tonnes), and total annual effort (# traps). Pre-1996 effort calculated from interviewed CPUE and total catch; 1996-present effort and catch data directly from commercial logbook weight estimates. Both retained and discarded sablefish are included in the catch. Reference line at 1999 indicates the introduction of mandatory escape rings in traps.

4.4 BIOLOGICAL CHARACTERISTICS

Escape-rings became mandatory in the sablefish trap fishery in 1999, however some trap vessels voluntarily modified their traps with escape-rings in 1998. To evaluate the potential effect of the escape-rings on biological characteristics of the catch we compare bio-sample information prior to 1998 with samples collected from 1999 onward. Biological samples have been collected voluntarily during commercial trap fishing operations since 1995. Random samples of fish from the catch (not landings) are collected and frozen for subsequent processing.

There is considerable difference between sample variation in the biological characteristics of the catch, some of which is attributable to seasonal and bathymetric effects. However, sampling effort has been fairly limited, particularly in the earlier years, so we summarize the data only by time period, gear type, and region. Table 3 shows the average proportion of males in the catch samples for the periods prior to and post escape-rings. In northern B.C. the sex ratio of the trap-fishery (T-K) catch does not appear to have changed with the introduction of escape-rings. In southern B.C. the proportion of males in the catch samples is higher for the escape-ring period, a result that is counter-intuitive given that escape-rings should select for the generally larger females. Males tend to be more predominant in the seamount catches (T-S), a fishery where escape-rings are not required.

Table 3. The average and standard deviation (in brackets) of the proportion males and the number of samples (N) for samples collected from the commercial longline (L-K), trap (T-K), and seamount trap (T-S) fisheries, summarized for the 1995-97 and 1999-01 periods.

	Northern B.C.				Southern B.C.			
	1995-97		1999-01		1995-97		1999-01	
fishery	prop. male	N	prop. male	N	prop. male	N	prop. male	N
L – K	0.46 (0.12)	2	0.37 (0.04)	5	0.39 (0.18)	12	0.49 (0.18)	10
T – K	0.45 (0.22)	33	0.44 (0.24)	77	0.57 (0.18)	23	0.42 (0.20)	40
T – S	0.64 (0.21)	3	0.70 (0.11)	7	0.79 (0.14)	17	0.73 (0.12)	26

The length frequency distributions from the trap-fishery (T-K) catch samples may suggest an impact from escape-rings, particularly in southern B.C. (Figure 5). The proportion of fish that are less than 60cm is substantially lower for the 1999-2001 period than for the 1995-1997 period. In northern B.C. the difference in the length frequency distributions from the two periods is less pronounced. However, differences in length-frequency distributions between the two time periods can't be attributed to an escape-ring effect because differences in age-composition, in particular through recruitment, will confound the escape-ring effect.

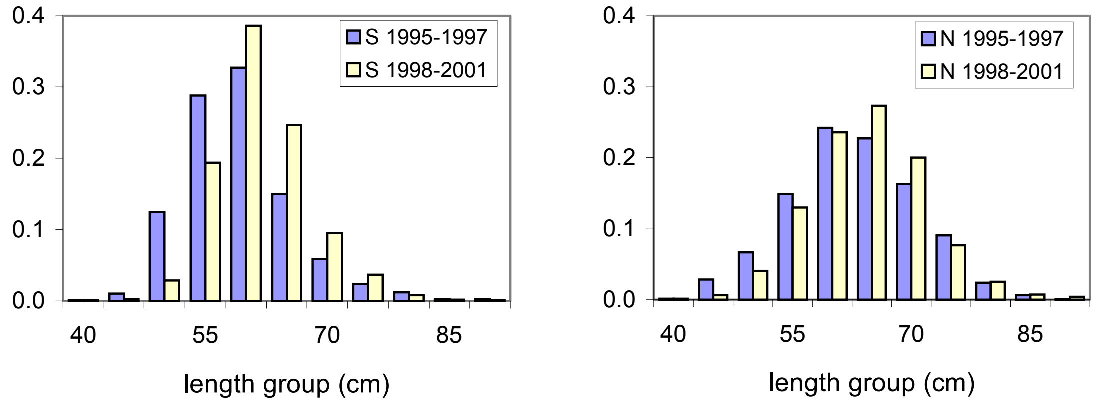

Figure 5. The length frequency distribution for commercial trap fishery samples collected in northern (N) and southern (S) B.C. regions during the periods 1995-1997 and 1998-2000.

5 SURVEY INFORMATION

5.1 TRAP SURVEYS

Survey Design

Since 1984, biological samples have been collected annually during October/November, using chartered trap vessels, with the goal of sampling exploited stocks from the west coast of Vancouver Island to the Queen Charlotte Islands. Initially samples were collected during the course of normal commercial fishing. In 1988 a more structured survey design, including eight indexing sites and three depth strata was developed. The sites were chosen because they were fished during commercial sablefish openings (Smith et al. 1996). The purpose of the survey was to investigate the variation in size and age-related parameters associated with area and depth. In 1990 the number of depth strata was expanded to four (250-349 fm, 350-449 fm, 450-549 fm, and 550+ fm), and in 1992 an additional shallow (150-249 fm) stratum was added. The index sites from south to north are Barkley Canyon, Esperanza, Quatsino, Triangle Island, Cape St. James, Gowgaia, Buck Point, Hippa Island and Langara (Figure 6). It has not been possible to sample all sites each year (Appendix Table B1).

A standardized method of gear deployment has been used throughout the surveys and is described in Smith et al. (1996). Briefly, each set consists of 25 Korean traps attached to a groundline at 46m intervals, baited with 1-1.5kg of frozen squid, and soaked for 24 hours. Note that in 1988 and 1989 an additional 2.5-3 kg of hake was used in the bait. The catch in number and weight are recorded for each trap, and biological sub-samples of length, sex, maturity and otoliths for age determination are collected. Approximately 2/3 of the fish are tagged and released.

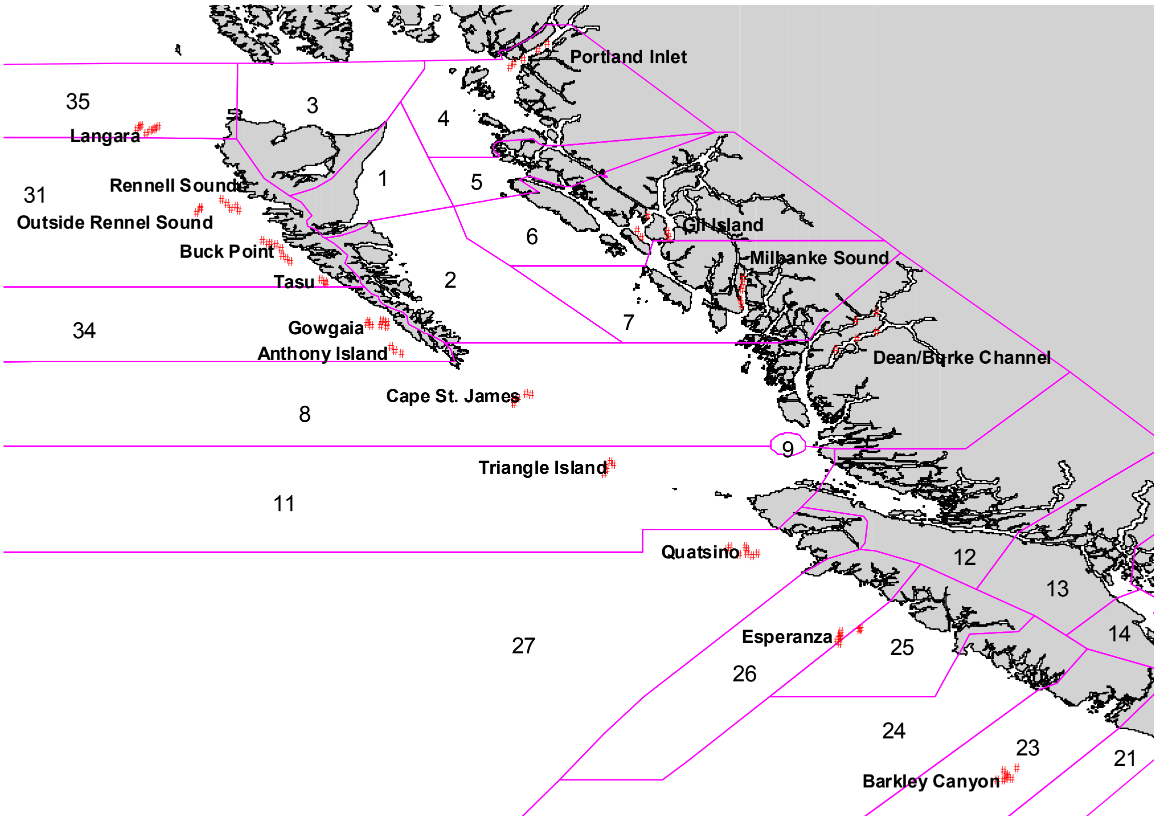

Figure 6. Location of sablefish survey sets in 2000, including the extra "deep" sets. Minor areas, used to code sablefish data, are also shown.

In addition to the fish tagged and released at the standard index survey sites, since 1995 sets have made during the fall survey for the explicit purpose of tagging sablefish. Tagging sets differ from the index survey sets in that each set consists of 65 traps and the bait includes 3-5kg of hake in addition to the 1-1.5kg of squid. In recent years the tagging objective has been to tag fish from one additional set at each of the eight index survey sites and to tag 2000 fish at each of six additional locations (Rennell Sound, Tasu Sound, Middle Ground, Pisces Canyon, off Estevan Point and Father Charles Canyon). Tagging sets are generally conducted in the 250-450 fm depth range.

<u>2000 Survey</u>

During the 2000 survey, additional sets were made to assess sablefish abundance and biological characteristics at depths greater than those surveyed at the standard index survey sites. Although the deepest stratum in the standard survey is 550+fm, most sets have been made at depths only slightly greater than 550 fm. The targeted depth range for the 2000 "deep" sets was 600-800fm. The survey objective was to make three sets (25 traps each) at each of nine specified locations.

The average depth of the 2000 "deep" sets was 695 fm whereas the average for the 550+ stratum (stratum 5) was 575 fm. A comparison of average catch rates (kg/trap) from the deeper sets with those from the shallower depths of the standard index sites indicates that sablefish are relatively abundant in the deeper waters. (Table 4). Clearly, the deep extent of the range of the distribution has not been explored through the survey. The average weight of fish caught in the deep survey sets tended to be higher than the average fish weight in shallower strata (Table 5).

Table 4. Average catch per trap (kg) for the standard index sites, for the “deep” sets, and for tagging sets in the 2000 sablefish survey.

	survey index sites						tagging sets
depth–stratum - range (fm)	1 150-250	2 250-350	3 350-450	4 450-550	5 550+	deep 600-800	
Locality	Average catch (kg/ trap)						
barkley	10.7	5.9	25.7	25.6	27.5	25.4	32.2
esperanza	20.9	15.4	5.2	15.5	7.8	4.6	32.3
quatsino	8.5	10.0	9.3	15.4	6.0	5.9	18.2
triangle	16.5	15.6	11.8	4.6	5.8		29.2
cape st. james	6.5	15.0	8.8	6.3	1.2		18.4
flamingo						5.4	15.7
gowgaia	2.1	17.6	8.4	6.4	4.5	3.3	26.3
tasu						9.1	35.2
buck point	10.0	13.2	3.0	5.0	4.0		25.3
rennell						1.5	16.1
hippa	4.7	9.7	5.6	5.1	2.0		15.7
langara	9.8	4.7	3.6	4.2	1.8	2.1	19.0

Fishermen have suggested that the inclusion of hake in the bait used for tagging sets will increase the amount of sablefish caught and also, that it will attract different size-classes of sablefish than the squid-only bait. A bait-loading study to investigate the relationship between the amount of bait used and CPUE showed that over the range of bait-levels evaluated (up to 1 kg squid and 10 kg hake), CPUE increased (Leaman pers. com.). During the 2000 survey, catch rates (kg/trap) were substantially higher for the tagging sets than for the survey sets (Table 4).

Table 5. Average fish weight (kg) in survey sets and tagging sets conducted for the 2000 sablefish survey. The values that are underlined indicate the depth strata that encompass the depth range of the tagging sets.

	"standard" survey sets						tagging
depth stratum	1	2	3	4	5	deep	sets
Locality	Average fish weight (kg)						
barkley	3.4	2.5	1.9	2.1	2.5	3.3	3.0
esperanza	3.2	3.1	2.2	2.1	2.6	3.5	2.8
quatsino	2.8	2.5	2.4	1.9	2.7	4.1	2.3
triangle	3.2	2.9	2.3	3.7	4.0		2.8
cape st. james	3.2	2.9	2.9	3.6	3.5		2.5
flamingo						4.5	
gowgaia	3.6	2.9	3.1	3.1	3.4	4.9	3.2
tasu						4.8	3.5
buck point	3.4	2.9	2.5	2.9	3.2		2.6
rennell						3.8	1.9
hippa	3.0	4.0	2.8	3.6	3.8		2.6
langara	3.7	2.6	2.7	3.5	4.0	4.9	2.6

General Linear Model (GLM) Analysis

A GLM model was fit to the 1988-2000 sablefish catch rate data from the survey index sites to estimate annual indices of relative abundance. The catch rate data (number of fish per trap) were square root transformed and a normal distribution assumed for the residuals. Year, locality and depth stratum were treated as categorical variables, and models were fit to the northern B.C. and southern B.C. survey data independently.

The model was fit to each categorical variable separately to determine their relative importance in accounting for variation in the density estimates. For both regions, the year variable had the highest explanatory power while the second variables were locality for southern B.C. and depth stratum for northern B.C. (Table 6). The estimated year indices are shown in Figure 7.

Table 6 R^2 values from the GLM fits to 1988-2000 sablefish survey data.

	R^2 for single variable			R^2 for
Region	year	locality	depth	full model
Southern B.C.	0.448	0.251	0.026	0.650
Northern B.C.	0.543	0.024	0.142	0.625

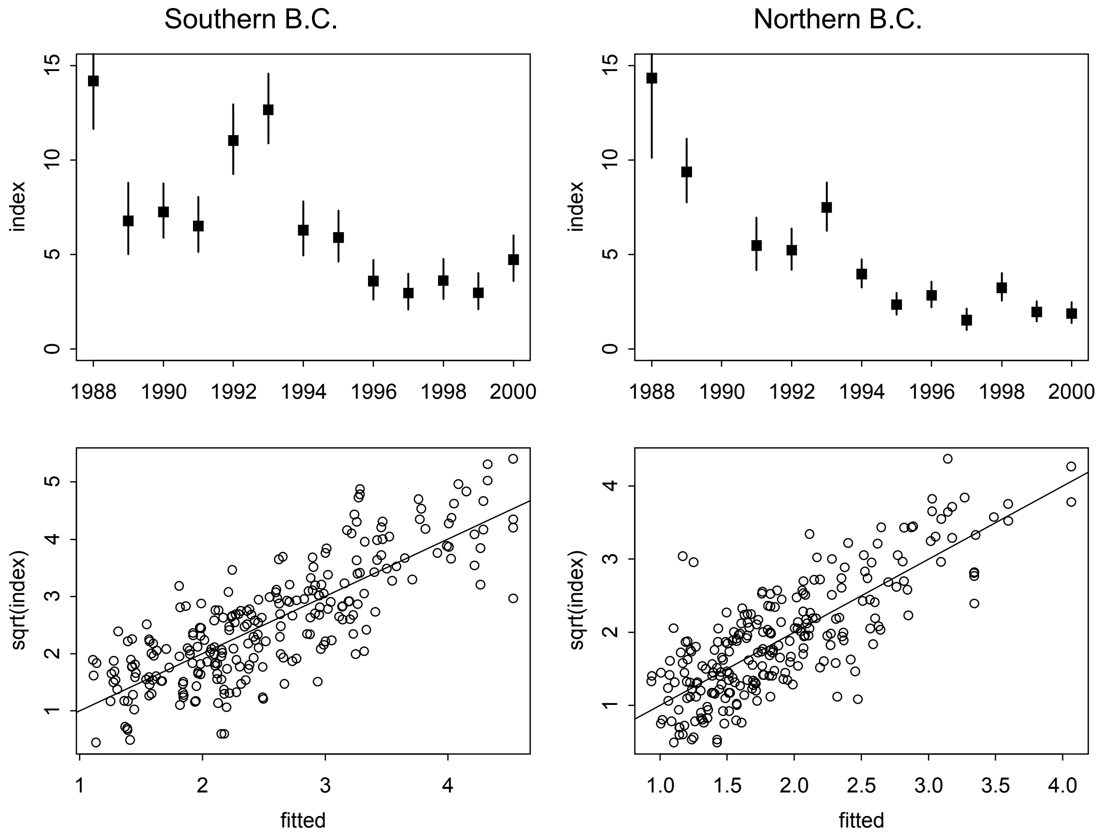

Figure 7. Estimated year indices (± 1.96 standard errors, upper panels) and observed versus fitted model values (lower panel) for GLM fits to the southern B.C. and northern B.C. survey data. Note that the y-axis of the lower panels are in the square-root transformed scale while in the upper panels they are not transformed.

The estimated year indices show significant declines from the late 1980's through the early 1990's (Figure 7). However, because the trap-baiting differed in 1988 and 1989 these two years are not comparable to the later years. The standard errors of the estimates are higher for the earlier years, which is at least partly attributable to fewer survey samples in those years (Appendix Table B1).

5.2 Juvenile Abundance Indices

Within B.C., juvenile sablefish are found in Hecate Strait inlets and in Hecate Strait waters. Catch rate information, which may provide juvenile abundance indices, is available from a few sources: the commercial trawl fishery observer program; the Hecate Strait survey program; and the sablefish survey. The time-series for these programs tend to be short, however, we summarize the data here to initiate the evaluation of their utility to index juvenile sablefish abundance. King et al. (2000) developed sablefish recruitment indices from these data sources in conjunction with fishery and survey age-frequency data.

The trawl fishery observer program has been in place since 1996 and provides reasonably accurate estimates of both retained and discarded sablefish that are caught incidentally in the trawl fishery. The geographical distribution of annual effort was relatively constant over the period 1996-2000. The only areas not resulting in sablefish catches were at the most shallow depths fished. Yearly CPUE estimates were obtained from data in the observer logs for Hecate Strait (Major Areas 7 and 8). A CPUE index is calculated as the sum of both retained and discarded catch divided by the total duration of fishing events.

A multi-species bottom trawl survey has been conducted in Hecate Strait approximately every second year since 1984 (Fargo and Tyler 1991; Perry et al. 1994). The trawl survey design is fixed station. A grid, comprised of 19 km^2 blocks, is overlaid on the area, and an attempt is made to conduct one bottom-trawl tow in each 10-fathom (fm) depth interval in each of the grid blocks. Each survey is comprised of approximately 100 tows of 15-30 minute duration. Since 1984, eight bottom trawl surveys have been conducted during the May/June period. The 2001 survey did not conform to the sampling design and abundance indices for that year may not be comparable to previous years.

A high proportion of the Hecate Strait bottom trawl tows do not catch sablefish (60%) leading to a highly skewed distribution of tow-by-tow catch rates (Figure 8). A CPUE index is calculated for each survey year as the sum of catch (kg) divided by the sum of effort (hours).

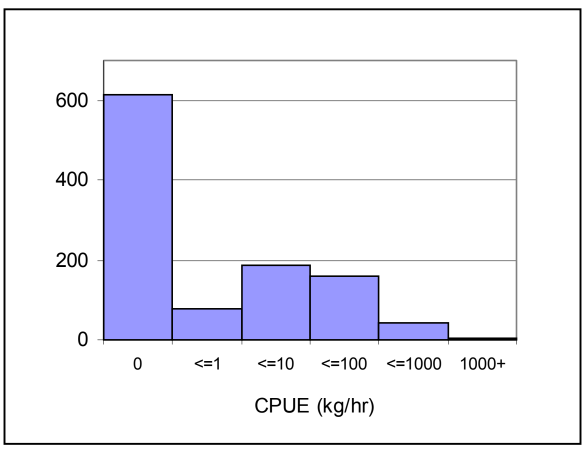

Figure 8. Frequency distribution of CPUE by set for Hecate Strait survey trawl tows, 1984-2001

Table 7. Average and standard deviation of length (in brackets) for the Hecate Strait survey and Sablefish Inlet survey data.

Hecate Strait Survey		Sablefish Inlet Survey	
year	mean length (cm)	year	mean length (cm)
1984	31.8 (5.0)	1994	57.3 (6.7)
1987	42.5 (10.2)	1995	60.1 (7.0)
1989	46.8 (5.8)	1996	62.4 (9.3)
1991	37.7 (7.1)	1997	60.2 (8.5)
1993	32.8 (5.4)	1998	58.3 (7.1)
1998	40.0 (8.6)	1999	57.9 (6.9)
2000	36.5 (5.3)		
2001	31.6 (2.2)		

The annual sablefish survey program included four survey sites in Hecate Strait inlets beginning in 1995. The survey protocol is similar to that for the standard index survey sites; that is, 25 traps per set and baiting with 1-1.5 kg of frozen squid. Not all sites have been sampled each year (Table 8). Also, set duration has not been consistent over the survey, but we do not attempt to standardize for this because we do not know the catch rate-set duration relationship. Table 8 summarizes the catch rate information by location and year. Annual CPUE indices for the survey are calculated as the mean of location specific average catch rates.

Table 8. The average and standard deviation (in brackets) of CPUE (kg/trap) and the number of sets (n) by location and year.

LOCATION	1995		1996		1997		1998		1999		2000	
	kg/trap	n	kg/trap	n	kg/trap	n	kg/trap	n	kg/trap	n	kg/trap	n
Chatham Sound	21.7 (5.7)	2	26.2 (20.8)	5	30.6 (7.3)	2	73.6	1			28.3 (10.9)	2
Gil Island	18.3 (12.4)	5	31.8 (11.4)	5	29.5 (7.5)	4			66.8 (5.6)	4	33.6 (7.3)	5
Milbanke Sound	25.9 (11.9)	3	12.0 (4.4)	5	19.6 (7.6)	5	26.2 (9.9)	5	31.8 (12.4)	5	11.5 (5.5)	5
Portland Inlet	6.5 (6.4)	3			11.2 (7.2)	3	30.0	1	66.4 (19.2)	5	5.3 (6.1)	3

The Hecate Strait Observer and Hecate Strait Inlets CPUE indices show similar trends over the short time period where values for both indices are available (Figure 9). Both show higher catch rates in 1998 and 1999 than in other years. The Hecate Strait survey index does not show an increase in 1998 over other years (Figure 9). However, the size distributions of sablefish caught in the Hecate Strait survey, which uses a small mesh codend, indicate much smaller fish than those caught in the Hecate Straits Inlets trap survey (Table 7). Size distribution information from the Hecate Strait Observer program was not available, however, the commercial index is likely to reflect larger sablefish because of the larger mesh codends used in the fishery.

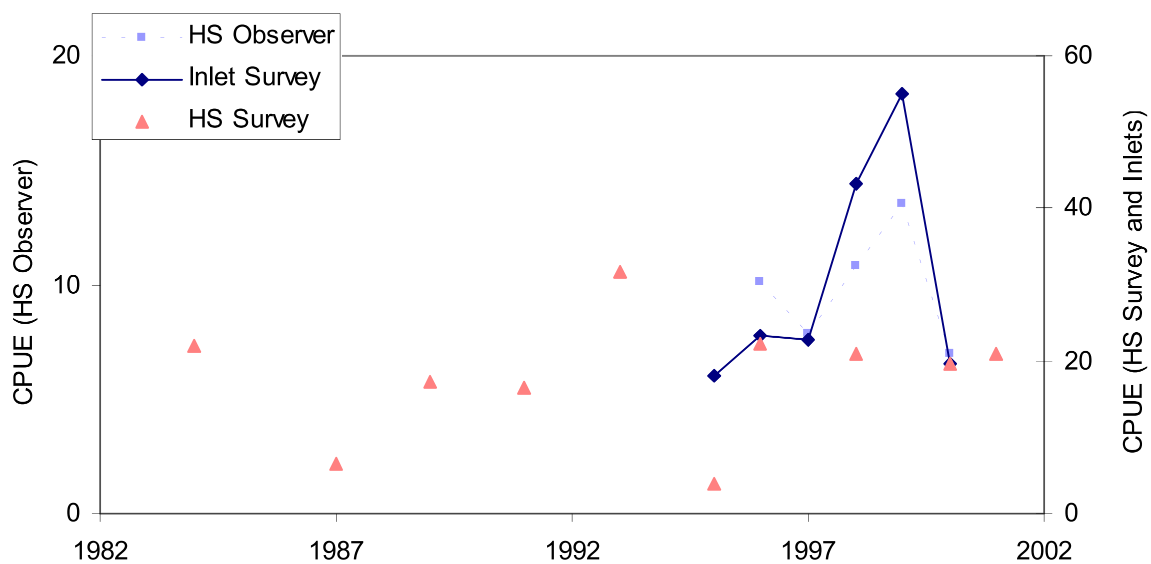

Figure 9. Potential recruitment indices for B.C. sablefish.

Additional work is required to develop these data as potential juvenile abundance indices. Each data series should be standardized, either through GLM or survey-design based methods to account for changes in effort over time. Additionally, the sablefish length-frequency information should be analyzed to determine which component of the sablefish population is reflected in each survey.

6 SABLEFISH TAGGING DATA

A sablefish tagging program in B.C. waters was initiated in 1977 for the primary purpose of stock identification (Beamish and McFarlane 1988, Murie et al. 1995a). This program continued into the mid 1980's with tagging effort directed at different components of the population over time to address specific questions. In 1991 tagging was re-initiated as part of the annual fall sablefish survey program. Sablefish were tagged at each of the eight survey index sites and survey depth stratum. Additional tagging locations have been added since 1994, however most of these tag releases are in the 250-450 fm depth range (Figure 10). Tag releases are not random with respect to the vulnerable population, rather they tend to be in locations and depth zones that reflect where most of the fishing effort occurs (Figure 11). Over 80% of tags released between 1991 and 2000 were in the 250-450 fm depth range.

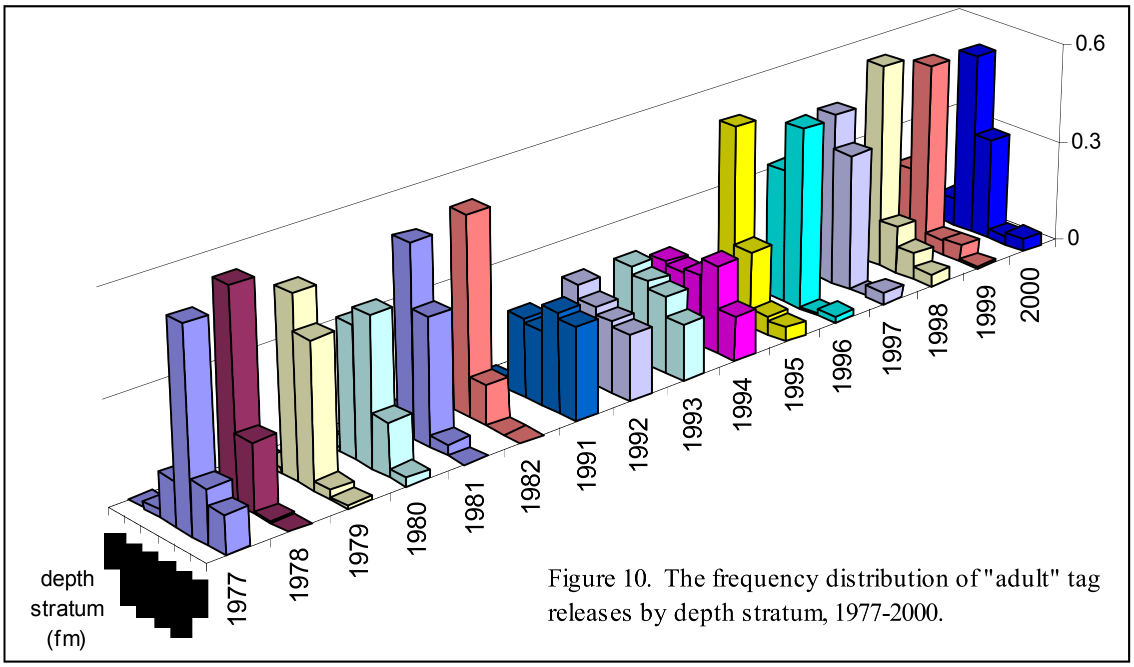

Figure 10. The frequency distribution of "adult" tag releases by depth stratum, 1977-2000.

In this section we discuss a number of issues that involve the sablefish tag release and recovery data including: tag recoveries during the 2000 sablefish survey; movement to Alaska; and recovery rates from CSA-coded tag releases. Unless specifically noted, all tag release-recovery analyses are based on "adult", offshore releases. These are releases in major areas 3 to 6 and 9 (excluding Fitzhugh Sound), which are not coded "juvenile" (J).

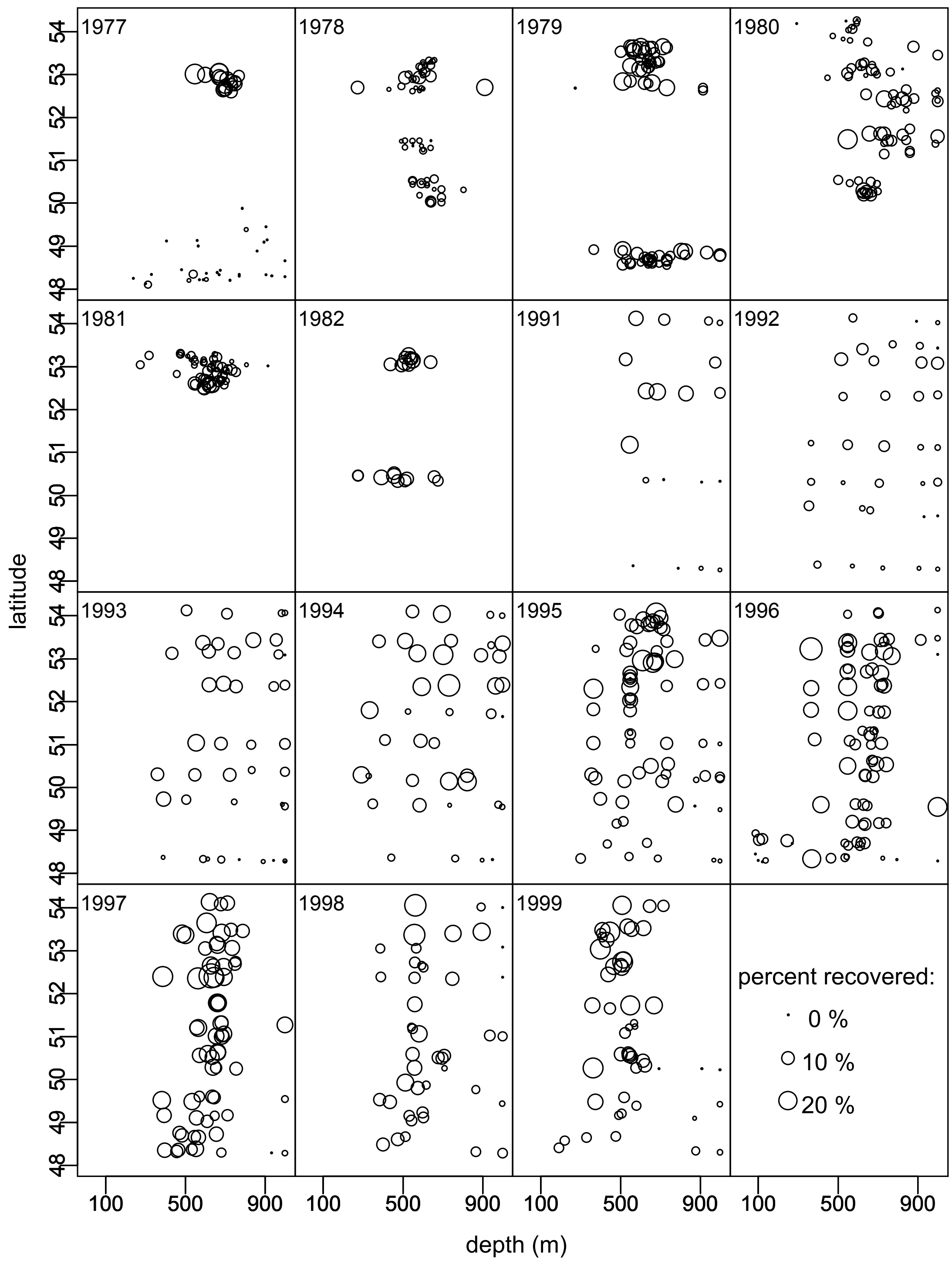

Figure 11. Latitude and depth of release for adult sablefish tagged 1977-1999. The size of the circles, plotted at the release point, is proportional to the percent of tags recovered in the year following tagging. Only tag groups with >=30 releases are plotted. Tag groups released at depths greater than 1000 m are plotted at 1000m.

6.1 2000 Survey Tag Recoveries

An analysis was initiated to investigate if tag recovery rates during the annual sablefish survey could be used to estimate reporting rates for the commercial trap fishery. Survey tag recovery information, available for the 1999 and 2000 sablefish trap surveys, indicated extremely high tag recovery rates. If commercial vessels recovered tags at the same rate as the survey vessel, then 60% of the tags released in 1999 would have been recovered in the 2000 commercial trap fishery.

Further investigation of the survey tag recoveries showed the recoveries to be highly clumped with a high proportion of the tags recovered in only a few survey sets (Table 9). For the 1999 tag releases and 2000 recoveries, where specific set location information was available, the sets with high recoveries were in close proximity to the tag-release set (Figures 12a, 12b). Tag recoveries in the commercial fishery from these sets (1999 tag release sets 39-41 and 11-13) were low (<3%), however there was little commercial effort close to the tag-release locations (Figures 12a, 12b).

Table 9. The distribution of tag recoveries by set and number of years-at-large for tags recovered during the 1999 and 2000 research survey. Data is shown only for sets with 10 or more tag recoveries. Each set of values for a years-at-large category shows the number of recoveries from distinct tagging sets.

		Minor	tagged fish		years-at-large						
year	set	Area	count	%	1	2	3	4	5	15	18
1999	2	23	21	2.9	15,1	2	1,1	1			
1999	12	25	23	4.4	9,3,1	5,1,1		3			
1999	13	25	15	2.7	4,4,2,1	1	1	2			
1999	39	11	62	6.4	35,6,1	17,1	1				1
1999	40	11	58	6.4	41,4	1	6,1,1	3,1			
1999	41	8	11	2.6	1		5,2,2,1				
1999	56	34	18	3.6	12,3	1		1	1		
1999	57	34	10	3.0	8,1	1					
2000	14	25	28	4.0	1,1	23,1	1	1			
2000	15	25	27	3.6	4,2	12,2,1,1	3,1	1			
2000	16	25	34	3.5	13,1	8,1	2,1,1,1,1,1		3,1		
2000	41	8	10	7.3	2,1	1	1,1		2,2		
2000	52	11	77	10.4	34,4,1	23,3	11	1		1	
2000	53	11	83	10.0	35,4,1,1	32,2		4,3	1		
2000	54	11	36	5.8	4,1,1,1	14,2,1	1,1	1	9		
2000	105	31	16	2.9	3		1	12			
2000	111	31	17	4.1	10			6,1			

Multiple tag recoveries in commercial fishing sets from a single tag release set are rare. To investigate if the commercial fleet recovered tags at similar rates to the survey vessel, given similar distances of recovery effort from the tag-release set, we calculated a relative tag density measure. For each of the 1999 tag release locations, the average distance to each trap fished in 2000 (survey and commercial trap fishery) was measured. Three

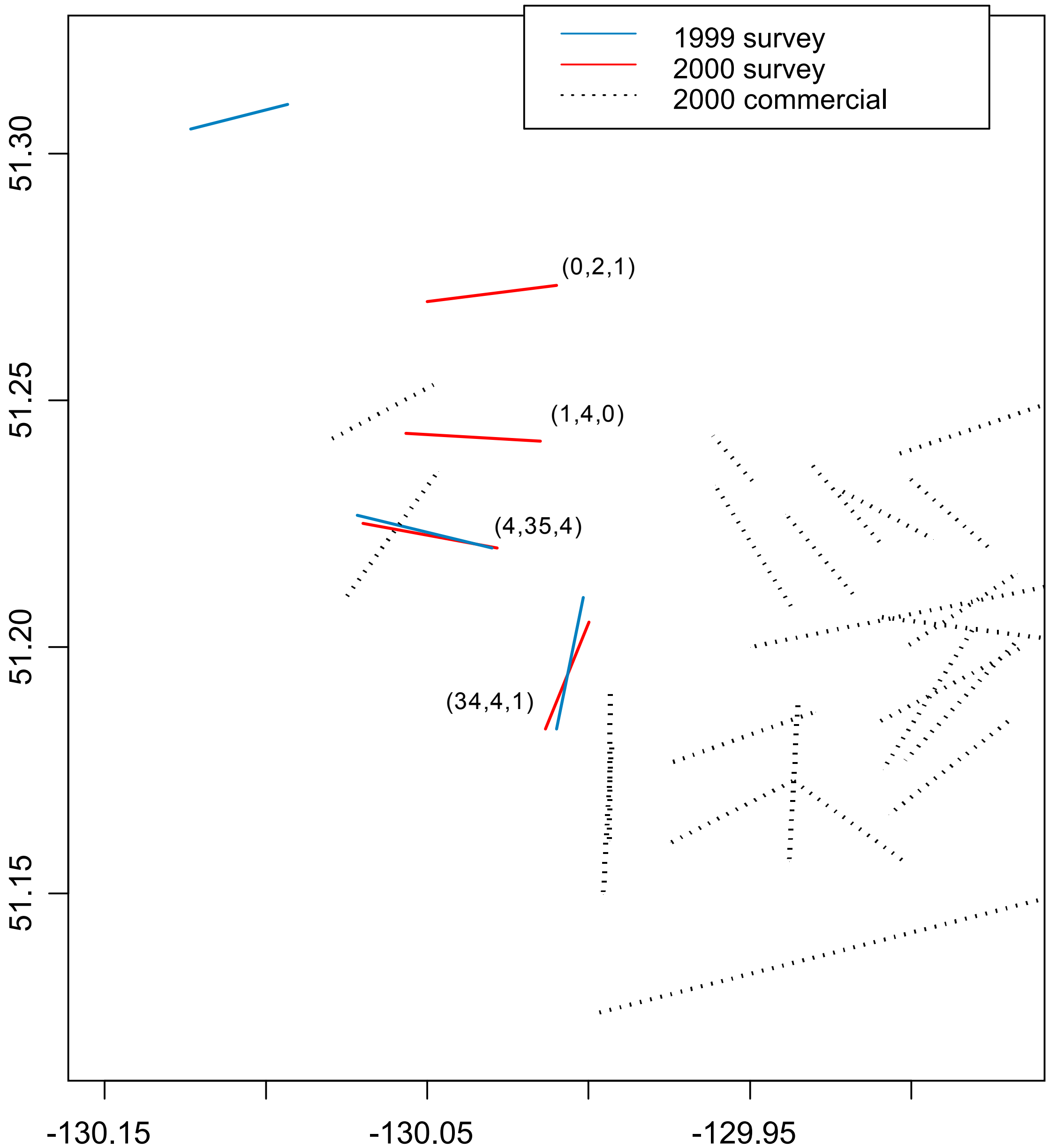

Figure 12a. Geographic location of 3 tagging sets in 1999 (sets 39,40,and 41) and 4 survey sets in 2000 (sets 52,53,54,55). Commercial sablefish trap and longline sets conducted during 2000 are also shown. The numbers in brackets are the number of sablefish tagged in 1999 and recovered during the 2000 survey for each of the 3 tag release sets. 60 tags from the 3 release groups were recovered during the 2000 fishery (2.8% of tag releases). Of these 5 (2,2,1) were recovered in the set that transects the location of the set 40 release group.

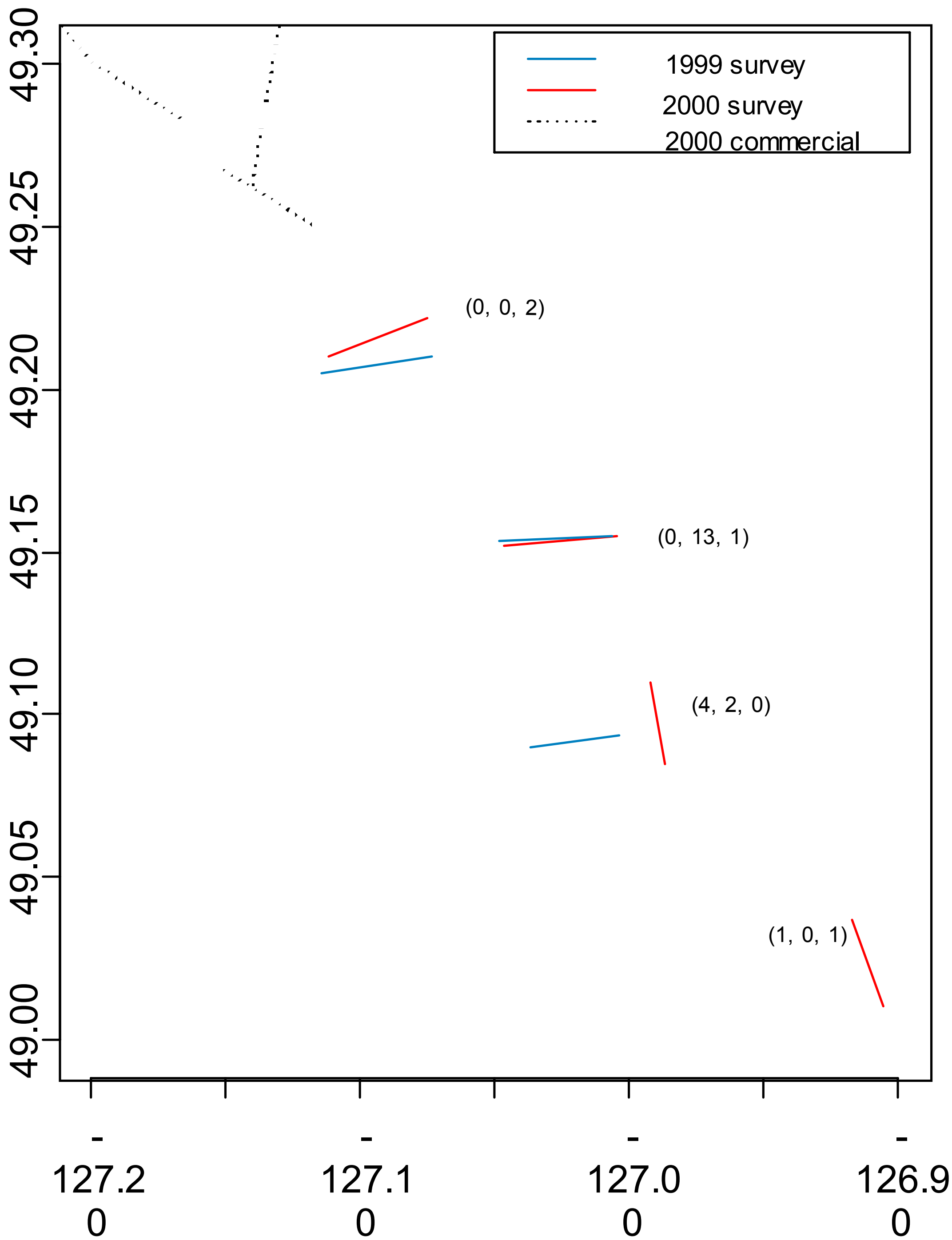

Figure 12b. Geographic location of 3 tagging sets in 1999 (sets 11,12,and 13) and 4 survey sets in 2000 (sets 14, 15, 16, 17). Commercial sablefish trap and longline sets conducted during 2000 are also shown. The numbers in brackets are the number of sablefish tagged in 1999 and recovered during the 2000 survey for each of the 3 tag release sets. 44 tags from the 3 release groups were recovered during the 2000 fishery (2.9% of tag releases). Of these 13 were recovered in trawl sets made in the vicinity of the tag releases.

distance measures were calculated. These were the minimum distance from each of the two end-points and from the mid-point of the tag release set to the line representing the recovery set. The mean of these three measurement was used to characterize the distance from tag releases to recovery effort. The number of tags recovered and the number of traps fished were partitioned by distance categories to estimate tag recovery rates by distance from release (number of tag recoveries per 1000 traps fished) for each tag release group. Results are summarized across tag release groups in northern and southern B.C., weighting each release group by the number of tag releases. The number of tags recovered and number of traps fished by distance from release category are summarized in Table 10 for the 2000 sablefish survey and 2000 commercial trap fishery. Relative tag densities by distance category (tag recoveries per 1000 releases and 1000 traps fished) are shown in Figure 13.

Table 10. Estimates of tags recovery (per 1000 releases) for 1999 releases and number of traps fished (1000's) by distance category for the 2000 survey and 2000 trap fishery in northern and southern B.C. Values are standardized across tag release groups by the number of tags released.

			distance category (nautical miles)						
		region	<0.2	0.2-1	1-5	5-20	20-100	100+	Total
Survey	tags/1000 releases	S.BC	6.93	0.34	2.79	0.68	0.34	0.51	11.6
	traps (1000's)	S.BC	0.01	0.01	0.10	0.22	0.99	2.66	4.0
	tags/1000releases	N.BC		0.50	2.69	0.67	0.34	0.17	4.4
	traps (1000's)	N.BC		0.01	0.12	0.30	1.26	2.31	4.0
Trap Fishery	tags/1000 releases	S.BC	0.25	1.77	4.64	8.78	7.85	9.37	32.7
	traps (1000's)	S.BC	0.02	0.23	1.73	9.20	42.82	195.88	249.9
	tags/1000 releases	N.BC		4.71	11.26	25.88	39.33	11.76	92.9
	traps (1000's)	N.BC		0.94	4.27	19.25	98.60	126.82	249.9

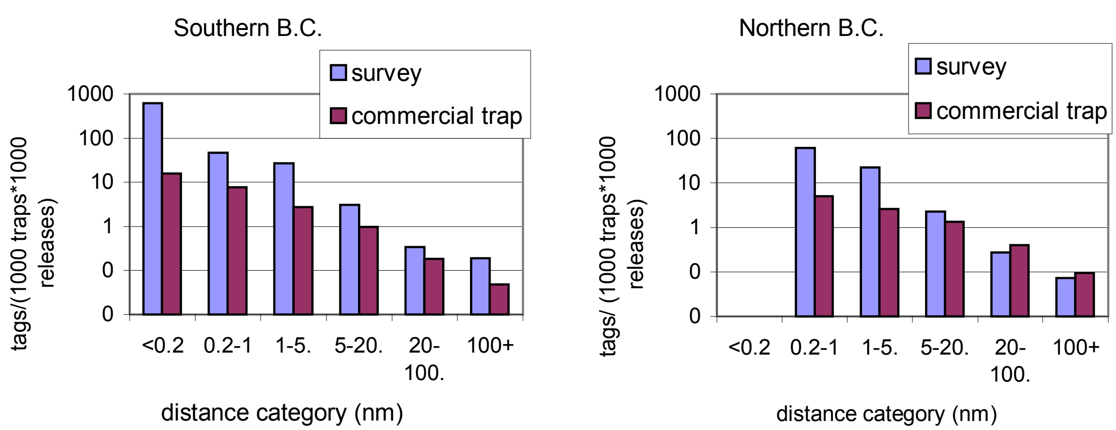

Figure 13. Relative tag density (tags/1000 traps • 1000 releases) estimated from survey and commercial trap fishery recoveries

For the southern B.C. region, the relative tag densities estimated from the survey data are higher than those estimated from the commercial fishery data for all distance categories. In part this can be attributed to the use of escape-rings in the commercial traps. With the escape-rings smaller tagged sablefish are not retained in the traps. However, the magnitude of the differences for the shorter distance categories (<5 nm) is too large to explain with only the escape-ring difference. For the northern B.C. region, estimates of tag density from the survey data relative to those from the commercial fishery data are higher for the shorter distance categories and lower for the longer distance categories. Differences in the tag density estimates between the survey and fishery data may result from a number of factors. These include: differences in tag reporting rates; escape-ring use in the commercial fishery; seasonal changes in fish (i.e. tag) distribution; and variability due to small sample size (few sets in the survey). An extension of the analysis conducted here to include more years of survey and fishery tag recoveries and to model seasonal and other factors that may influence tag recovery rates would be useful to extend our understanding of sablefish tag recovery patterns.

With estimates of the amount of sablefish habitat by distance category, the relative tag density estimates can be used to calculate the relative number of tags in each distance category. Ideally the potential sablefish habitat measurements would be done for each tag release group, using a Geographic Information System (GIS) that identifies coastwide habitat. This information is not yet available so we estimate the relative amount of sablefish habitat for each distance category based on a few simplifying assumptions. These are: the width of the sablefish habitat band along the coast is constant; there are no boundary effects for distances less than 100 nm; and the average distance in the 100+ category is 250 nm. The estimates of the distribution of tagged sablefish by distance from release, based on these assumptions, are shown in Figure 14.

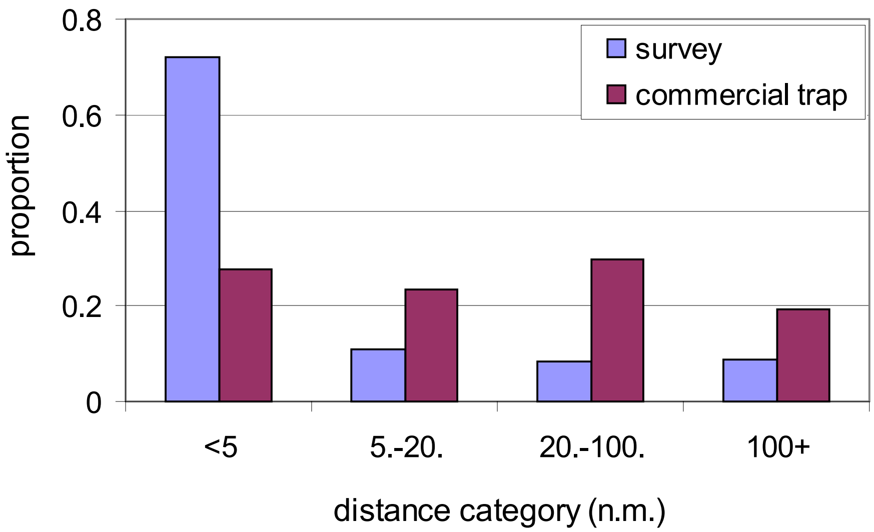

Figure 14. Distribution of tagged sablefish by distance from release, estimated based on 2000 survey and 2000 commercial trap fishery tag recoveries and effort.

6.2 Tag Release-Recovery Simulation

An assumption when using tag release-recovery data to estimate population abundance is that all tags have the same probability of recovery. However, the close proximity of many survey tag recoveries to their release site suggests that tags released near regions of high fishing effort will have higher recovery rates than those released near regions of low fishing effort. This is supported by the range in the proportion of tags recovered in the year following release observed across tag release groups (Figure 10). If fish in all tag release groups had the same probability of being recaptured during the following year, the proportions recovered by release group should be less variable.

The effect of having two types of tag release groups, one subject to high fishing mortality rates and another subject to low fishing mortality rates was investigated with a simple simulation. Two tag groups, of equal size at release, were simulated with a natural mortality rate of 0.1 and either a 0.45 or a 0.05 fishing mortality rate for a 25-year period (Appendix Table B2). When data from the two release groups are combined, the true tag mortality (Z) and the values estimated from the tag-return data are quite different (Figure 15). Initially the Z that is estimated is largely based on tag recoveries from the high-F tag release group. Over times, as this group is fished out of the population and the low-F tag release groups dominates the tag recoveries, the estimated Z converges to the true value. With tag release groups that are subject to different fishing mortality rates, it is not possible to obtain unbiased estimates of Z from the time-series of tag recoveries.

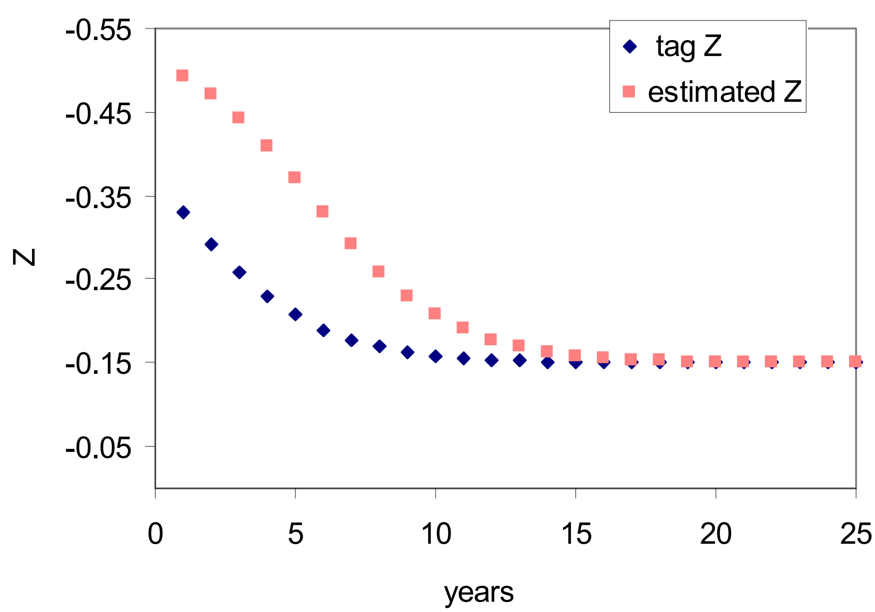

Figure 15. Simulation results for two tag groups, one with F=0.45 and the other with F=0.05, showing the true tag Z for the combined groups and the estimated Z based on tag recoveries.

Previous sablefish stock assessments have included analyses that attempt to model the tag dynamics over time. None of the modelling efforts have been satisfactory in their ability to find coherent explanations for the decline in tag recoveries observed over the first 3 to 5 years-at-large. Although the simulation described above is overly simplistic, with no fish movement and only two tag release groups, it does provide a potential explanation for the sablefish tag recovery observations. For this year's sablefish assessment, we do not use models that attempt to describe the tag dynamics and fit tag recoveries over time.

It is worth noting that estimates of stock abundance based on the ratio of tagged to untagged fish in the catch (shortly after tagging) will be unbiased IF the tags are released randomly in the population.

6.3 Movement to Alaska

Within B.C. coastal waters, sablefish have been managed as a discrete population. Over the years there have been numerous sablefish tagging programs in both Canadian and US waters, and analyses of these data have resulted in inconsistent conclusions regarding sablefish migration.

Kimura et al. (1998) analyze US sablefish tagging data and conclude that there are two sablefish populations along the coast, an Alaska population and a west coast population, separated at approximately 50°N. They estimate that movement between these populations is less than 5%. Additionally, they found greater movement among areas (defined as units that encompass approximately 2.5° latitude) for the Alaska population than for the west coast population.

Beamish and McFarlane (1988) analyze BC tagging data, and estimate that 15.8% of sablefish tagged off the Queen Charlotte Islands eventually move to Alaskan waters. Heifetz and Fujioka (1991) estimate annual movement rates of less than 2% from the eastern Gulf of Alaska to B.C. These movement rates are lower than those suggested by the Kimura et al. (1998) analysis.

In this section we extend the analysis of Beamish and McFarlane (1988), including tag releases in the 1990's and tag recoveries thru 2001.

Table 11. Regional distribution of sablefish tagged in B.C. waters and recovered in Alaskan fisheries

Alaska region	number	prop.
South-eastern	397	0.36
Yukutat	235	0.22
Kokiak	180	0.17
Chirikof	66	0.06
Shumagin	143	0.13
Aleutian	68	0.06

For sablefish tagged in B.C. waters and recovered in Alaskan waters, 55% have specific information on recovery location. These show a cline in recoveries along the Alaskan coast with the highest proportion recovered just north of the border (South-eastern Alaska) and the lowest proportion recovered in the Aleutian Island chain (Table 11). Note that these are raw recovery observations and we have not attempted to standardize the recoveries by the relative exploitation rates among the Alaska regions.

Because of differences in tag reporting rates and exploitation rates between B.C. and Alaskan fisheries, the distribution of tag recoveries will not reflect the distribution of tagged fish. We use published estimates of these variables, which are available for the 1980's and 1990's for Alaskan fisheries but only for the 1990's for B.C. fisheries. The estimates of reporting rates for Alaskan commercial fisheries are based on comparison of fishery and survey tag recoveries (Heifetz and Maloney, 2001). Note that these reflect reporting rates of Alaskan tagged sablefish and may not reflect the reporting rate for B.C. tagged sablefish. Exploitation rates, calculated as catch divided by exploitable biomass, are from the 2000 Alaska sablefish stock assessment (Sigler et al. 2000, Table 5.6). Estimates of B.C. commercial fishery tag reporting rates, based on vessel-by-vessel comparison of tag returns, were reported in Haist et al. (1999, Appendix C), and estimates of northern B.C. exploitation rates are from the current assessment (Section 6).

For the years where comparable estimates are available, the exploitation rates and tag reporting rates tend to be higher in B.C. fisheries (Figure 16). The average ratios of the B.C. to Alaska exploitation rates and reporting rates are 1.64 and 1.50, respectively. For years where there are no estimates of B.C. exploitation rates or reporting rates we use the average of the ratios. The method to standardize Alaskan tag recoveries is then

$$\text{Standardized Alaskan tag returns} = \text{Reported Alaskan tag returns} \bullet \frac{\text{B.C. reporting rate}}{\text{Alaskan reporting rate}} \bullet \frac{\text{B.C. exploitation rate}}{\text{Alaskan exploitation rate}}$$

We note that the ratio of reporting rates assumed by Beamish and McFarlane (1988) was 2 for all regions of Alaska except for southeast where it was assumed to be 1. Their estimate of the ratio of exploitation rates was 1.67. These values are very similar to those used here.

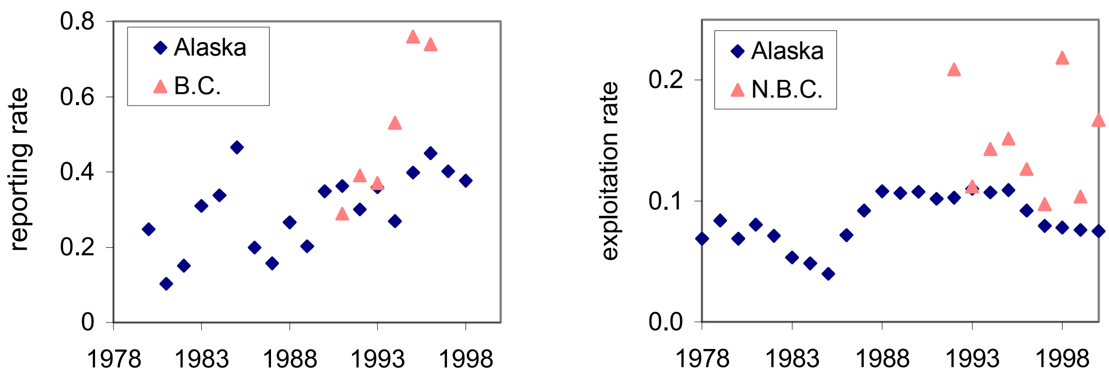

Figure 16. Estimates of tag reporting rates in Alaskan and B.C. fisheries (left panel), and estimates of sablefish exploitation rates in Alaska and northern B.C.

The proportion of tag recoveries, from sablefish tagged off the Queen Charlotte Islands (Major Area 9), which come from Alaskan fisheries increases over time (Figure 17). This holds for both the early (1977-1982) tag releases and the later (1991-1999) tag releases. It appears that after about 10 years the proportion of tags recovered in Alaskan waters decreases. For the 1977-1982 releases, the proportion of tags that are recovered in Alaskan fisheries, from the time of release through 2001, is 14.8%. When standardized for the lower exploitation rates and reporting rates in Alaska, this value increased to 29.6%. These values are lower than the average proportion returned from Alaska seen in Figure 17 because most tag recoveries occur in the first few years.

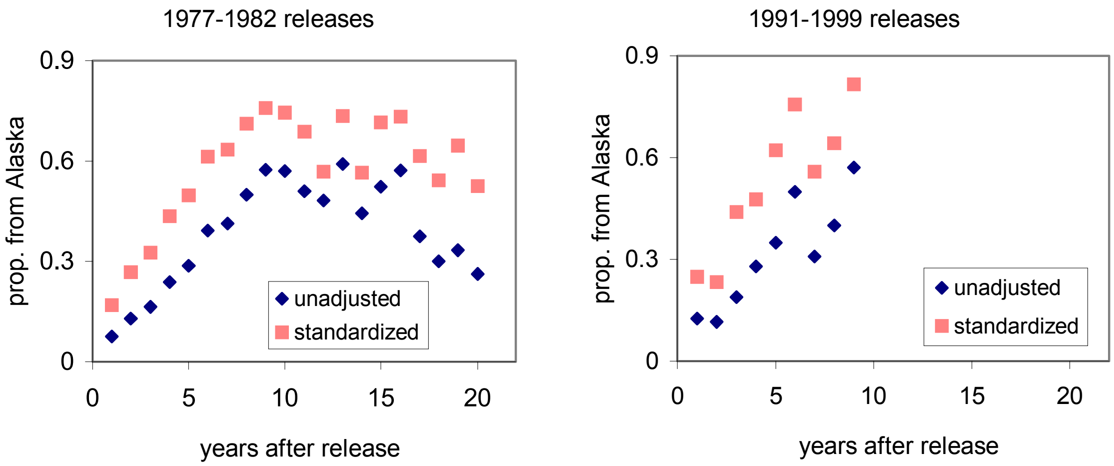

Figure 17. Unadjusted and standardized estimates of the proportion of tagged sablefish in Alaskan waters for the 1977-1982 and 1991-1999 tag releases.

Although we assume similar differences between Alaskan and B.C. exploitation rates and reporting rates, our estimate of the proportion of sablefish that move into Alaskan waters differs from that reported by Beamish and McFarlane (1988). To ascertain the reason for this difference we compare values reported in their study to those estimated in the current analysis. For results to be comparable we limit the tag return data we use to that reported thru 1985. We use slightly few tag release data (1.6%) than in the Beamish and McFarlane (1988) study and have fewer (2.4%) unadjusted tag recoveries thru 1985 (Table 12). Our standardized estimate of tags returned from Alaskan fisheries is also somewhat lower (4.1%). The major difference between the two analyses appears to be the estimates of total standardized tag returns. In our analysis the only tag recovery numbers that are adjusted are those from Alaska. Beamish and McFarlane (1988) standardize B.C. tag recoveries as well as the Alaskan recoveries. Their approach, standardizing by the CPUE in each B.C. region and year, has the effect of inflating the B.C. tag returns. This does not appear to be appropriate when comparing tag returns from Alaska and B.C., because the Alaska recoveries are standardized relative to unadjusted B.C. recoveries. Note that the percent of B.C. tagged sablefish that migrate to Alaska and reported in Table 12 (22.6) differs from the value reported above (29.6) because of recoveries since 1986.

Table 12. Comparison of tag recovery estimates reported by Beamish and McFarlane (1988) and equivalent values calculated in this study. Tag releases were all off the Queen Charlotte Islands (Major Area 9) and results are presented for unadjusted, standardized (stand.) and standardized recoveries with area of recovery information. The values used to estimate % of tags in Alaska are underlined

	1977-1982	total tag recoveries thru 1985				
	tag releases	unadjusted	stand.	stand. with area info.	Alaska stand.	% tag in Alaska
Beamish and McFarlane (1988)	34710	5558	9098		1422	15.6
this study	34170	5426	6235	6032	1363	22.6

Our analysis suggests that over their life span, approximately 30% of the fish tagged off the Queen Charlotte Islands move into Alaskan waters. Kimura et al. (1998) analyzed the combined Alaskan and southern U.S. sablefish tagging data, which included tag releases from 1971 to 1993. They separated the west coast into 27 areas, each about 2.5° of latitude (150 nm), similar in size to the area off the Queen Charlotte Islands. For the three Alaskan areas just north of the B.C. border (the Eastern Gulf), they found that 43% of fish that were less than 57 cm and 26% of fish that were greater than 57 cm at tagging were recovered in areas north or west of their tagging area, results that are similar to our estimates. A smaller percentage (20%) was recovered in areas south of where they were tagged.

Heifetz and Fujioka (1991), analyzing only the Alaskan sablefish tagging data, report that 8.6% of Alaska tag releases were recovered in B.C. Their estimates of annual movement rates from the Eastern Gulf to B.C. are low, ranging from 0.8% to 2.6% for small (<57 cm) and large (>66 cm) sablefish, respectively. They assumed: (1) reporting rates in B.C. were 3.75 times those in Alaska, and (2) exploitation rates in B.C. were similar to those in the Eastern Gulf (Table 2, Heifetz and Fujioka, 1991).

Distance Moved

Percentiles of the distribution of the distance between release and recovery, for sablefish tagged off the Queen Charlotte Islands, are shown in Figure 18. We calculate these values based on two criteria in the tag-recovery data extraction because of concern with the quality of the recovery location information for many of the records. It is clear, looking at the pattern of tag recovery information, that many tags are coded with information that is generic for the trip where the tags were recovered, rather than specific information for each tag recovery. Also, there are a number of tag returns that are coded with erroneous information. Since 1997, most tag recoveries are coded with information that relates the tag recovery to the specific set in which it was recovered. Our first data extraction uses only tag recoveries where the recovery set is coded. This limits the recovery information to tags recovered in B.C. fisheries. The second extraction used all recoveries that have latitude and longitude information.

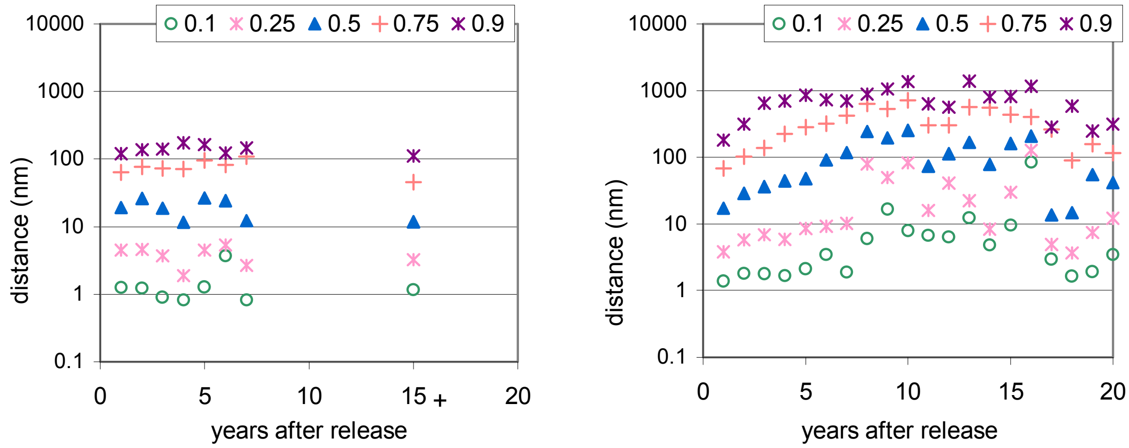

Figure 18. Percentiles of the distribution of distance between release and recovery location for sablefish recovered from 1 to 20 years after release. The panel on the left is based on recoveries where the set is known and the panel on the right is based on all recovered tags. Note that tag recovered 15 or more years after release are grouped in the left panel.

When all the tag recovery data is used, the distance between release and recovery location increases over for the first 10 years and then appears to decline. This pattern is consistent with the increase and decline in the proportion of tags recovered from Alaska (Figure 17). However, when the tag recoveries are limited to those where we believe the location information is good, thereby limiting recoveries to B.C. waters, there does not appear to be a relationship between distance moved and time from release.

<u>Decline in Tag Recoveries</u>

One hypothesis for the large decline in tag recoveries over the first five years following release, is that significant numbers of tagged fish recovered in Alaskan fisheries are not reported. To evaluate this hypothesis we compare estimates of the tag mortality rate calculated for the unadjusted and the standardized tag returns. We estimate the tag mortality rate as the slope of the log of the number recovered from one to five years following release. For the unadjusted tag returns, the estimates of Z are 0.60 and 0.56 for the 1977-1982 and 1991-1995 tag releases, respectively (Figure 19). For the standardized tag returns, the values fall to 0.54 and 0.46. It does not appear that differences between B.C. and Alaska reporting rates and exploitation rates can fully account for the high apparent Z.

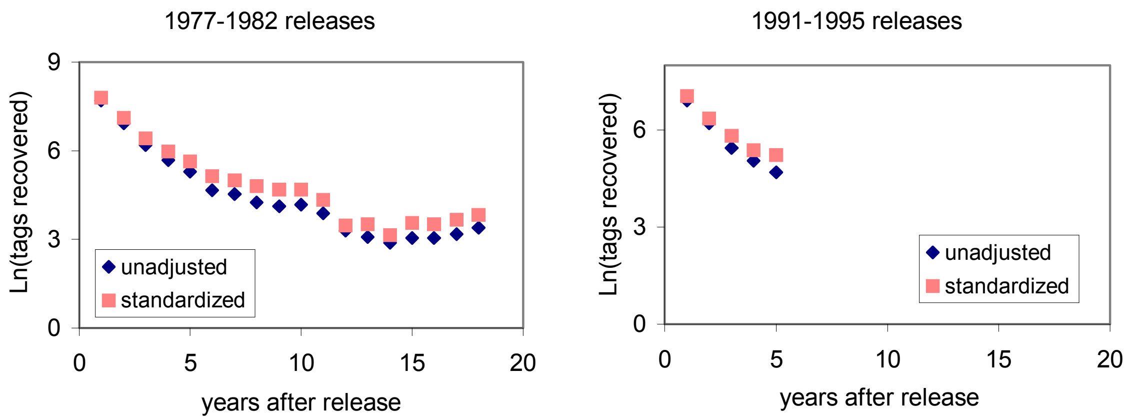

Figure 19. The natural log of the number of tags recovered versus years from release, for tag releases off the Queen Charlotte Islands between 1977-1982 and 1991-1995.

6.4 CSA-TYPE TAG RETURNS

The information written on tags released during the 2000 sablefish tagging program was different than the information on previous years tags. To check whether the new tag type (CSA-type tags) had lower commercial fishery return rates, a sub-set of the fish were tagged with the older-type tags (B-type tags). Approximately equal numbers of the two tag-types were released from 7 tagging sets in southern B.C. Table 13 summarizes the release and recovery information for these sets.

The null hypothesis to test for differences between the tag return rate for the two tag types is formulated as follows:

H_0: tag return rate for B-type tags = tag return rate for CSA-type tags

H_a: tag return rate for B-type tags > tag return rate for CSA-type tags

The test hypothesis was evaluated using bootstrap methods (re-sampling across sets). The estimated p-value was 0.225, therefore the null hypothesis is not rejected.

There were no Alaskan tag recoveries from the seven sets where both CSA-type and B-type tags were released, hence we are unable to test whether Alaskan tag recovery rates were influenced by the new tag type. In 2001, tags of both types will again be released, in particular in northern B.C., so that potential effects on Alaskan recovery rates can be evaluated.

Table 13. Summary of tag release and recovery information for tagging sets where both CSA-type and B-type tags were released.

			TAGS RELEASED		TAGS RECOVERED	
set number	minor area	depth (m)	B-type	CSA-type	B-type	CSA-type
11	24	399	306	284	8	13
12	24	509	366	374	13	3
13	24	555	414	400	3	4
14	25	566	304	299	6	8
15	25	590	323	398		5
16	25	507	482	465	10	10
22	25	498	200	489	4	20
Total tags			2395	2709	44	63
Proportion returned					0.0184	0.0233

7 ESTIMATION OF STOCK SIZE AND HARVEST RATE FROM TAG RETURNS

As in recent years we use tag returns the year following tagging to estimate the stock size and exploitation rate. Table 14 shows the number of tags released and the number recovered the next year as well as other data. The following criteria were used to select the tag releases and recovery from the database. Releases were included if they met the following criteria (1) the individuals were greater than 450 mm, (2) the individuals were not identified as juveniles, (3) tagging took place outside of the inlets, and (4) tagging occurred from August thru December. Recoveries were considered if they met the following criteria (1) recovered by commercial trap vessel (2) the recovery did not take place as part of the tagging program.

Table 14. Summary of tag release, tag recovery, and catch data used in harvest rate analysis. Note that tag return rate estimates are from Haist et al. (1999, Appendix B), and "catch sorted" are the landings adjusted by the sorting and average weight ratios shown in Table 15.

Release Year	Number released	Recovery year	Recoveries the following year	Estimated tag return rate	Landings by trap vessels (t)	Catch sorted by trap vessels (adjusted for avg. weight)	Landings by all gear (t)
1991	2,430	1992	81	39%	3,789	4,722	5,128
1992	3,578	1993	90	37%	4,168	5,449	5,088
1993	7,004	1994	321	53%	4,091	5,304	5,084
1994	3,594	1995	245	76%	3,319	4,337	4,007
1995	12,653	1996	888	74%	2,914	3,835	3,379
1996	9,119	1997	659	75%	3,480	4,613	4,178
1997	7,117	1998	758	75%	3,718	5,100	4,492
1998	15,914	1999	869	75%	3,709	3,698	4,717
1999	17,763	2000	1,006	75%	2,730	2,701	3,806
2000	19,764	2001	305	75%	1,047	1,049	

We estimated the exploitation rate and population size as follows:

The number of tags returned in the year following release can be calculated as

$$R_y = T_y u_y r_y \qquad (1)$$

where,

- R_y is the number of tags returned from the trap fishery in year y that were released the previous year
- T_y is the number of tagged fish alive at the beginning of year y released in the previous year
- u_y is the fraction of the total population that is examined for tags in the trap fishery in year y
- r_y is the proportion of tags examined in year y that are returned.

The fraction examined for tags is higher than the harvest rate because undersized individuals are captured in the traps and released, but if an undersized individual has a tag it is retained. Also, since 1998 traps used in the fishery have escape-rings so that smaller fish are less vulnerable to the fishery than to the tagging program. Estimates of the ratio of the number of fish sorted to the number landed and the ratio of the average weight in the landed catch to that in the vulnerable population are shown in Table 15.

Table 15. Estimates of the ratio of the number of fish sorted to the number landed and the ratio of the average weight in the vulnerable population to that in the landedings by trap vessels (from Haist and Hilborn (2000), Appendix C)

region	period	$\frac{\text{\# sorted}}{\text{\# landed}}$ (s_y)	$\frac{\text{avg. wt. population}}{\text{avg. wt. landed}}$ (w_y)
Southern B.C.	pre-escape-ring	2.02	0.738
	escape-ring	1.52	0.696
Northern B.C.	pre-escape-ring	1.50	0.817
	escape-ring	1.25	0.775

The fraction of the vulnerable population that is examined for tags is calculated as

$$u_y = \frac{s_y w_y C_y}{B_y} \qquad (2)$$

where,

- C_y is the catch landed by the trap fishery in year y
- B_y is the biomass of the vulnerable population
- s_y is the ratio of the number of fish sorted to the number of fish landed by the trap fishery

w_y is the ratio of the average weight of fish in the vulnerable population to the average weight of fish landed by the trap

The number of tags alive at the beginning of the year is the number released the year before (X_{y-1}) multiplied times tag shedding (1-*l*) and tagging mortality (1-*m*). The combination of survival from tagging (0.9) (Beamish and McFarlane, 1988) and from tag-shedding (0.93) (Haist and Hilborn 2000, Appendix D) is 0.837. This ignores any natural or fishing mortality between the time of tagging and the beginning of the year.

$$T_y = X_{y-1}(1-l)(1-m) \tag{3}$$

Rearranging and solving for the biomass in year *y* we obtain

$$B_y = \frac{X_{y-1}(1-l)(1-m)s_y w_y C_y r_y}{R_y} \tag{4}$$

From the data in Table 14, we can then compute the biomass by year. These are shown in Figure 20. Note that these are coastwide estimates of the biomass that is vulnerable to tagging (i.e. trap gear). We can also calculate the exploitation rate as the total catch (by all gears), divided by the estimated biomass. This is shown in Figure 21. Note that we are using trap-fishery catch and tag recovery data for the first 4 months of 2001 to estimate 2001 biomass, and we assume the 2001 total landings will equal the TAC (4000 t) to estimate the 2001 exploitation rate.

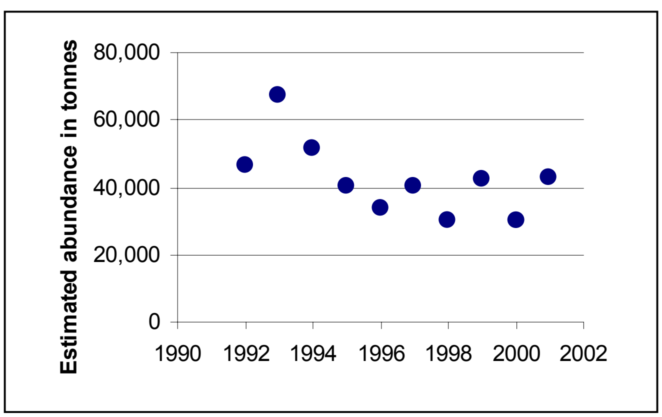

Figure 20. Estimated abundance (tonnes), 1991-2001.

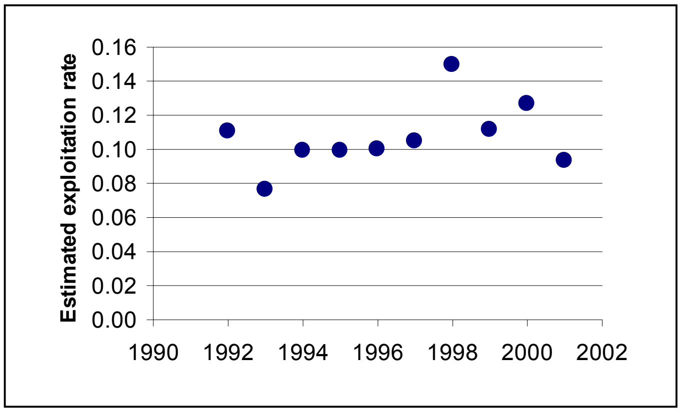

Figure 21. Estimated exploitation rate, 1991-2001.

Potential Bias and Uncertainty in Abundance Estimates

In this section we examine a number of sources of potential bias and uncertainty in the tagging-based abundance estimates. These include:

1) model parameter values (equation 4)
2) migration, recruitment and natural mortality between time of release and recapture
3) differential fishing mortality in conjunction with non-random tag releases

Although we use the best available information related to model parameter estimates, some of the values are either known or likely to be biased. The following table summarizes what we know or believe about the biases and uncertainty.

parameter	bias and uncertainty	effect on Biomass estimate
tag-shedding (1-l)	unbiased, cv = 2%	small
tagging mortality (1-m)	unknown	?
reporting rate (r_y)	likely neg. bias, potentially 25%	possibly large under-estimate
#sampled/#landed (s_y), wt. pop./landed (w_y)	- inter-annual variation in size dist. - uncertainty in escape-ring select. - uncertainty in grading selectivity	?
landings (C_y)	cv likely small	small
tag returns (R_y)	small neg. bias, < 1%	small, over-estimate

The tag-shedding rate, estimated through a double-tagging experiment, is not likely to be biased and has a small coefficient of variation (cv). The tagging mortality rate is an assumed value so potential bias is unknown. Tag reporting rates are estimated based on a vessel-by-vessel comparison of tag return rates that assumes that a small number of vessels report all tags. Because there will be some variation in the tag return rate across vessels, the estimated reporting rates are likely to under-estimate the true values and hence generate a negative bias in the abundance estimate. Fishers believe that almost all tags are now reported, so bias in this parameter could be as high as 25%. Both the estimated ratio of the number of fish sampled to those landed and the ratio of the average fish weight in the population to that in the landed catch are based on estimates of escape-ring selectivity, fish grading selectivity, and the average length distributions in the populations. Each of these components introduces uncertainty to the tagging model parameter estimates. In particular, inter-annual variation in the size distribution is ignored which may bias the parameter values for some years. The cv's of the landings estimates is likely small and unbiased. The number of tags returned do not include a small number of tags where the coded tag number could not be resolved, which introduces a small bias to the abundance estimates.

Bias from ignoring migration, recruitment and natural mortality between the time of tagging and time of recovery was examined across a range of plausible values for those rates. We assume an average of 8 months between tagging and recovery, which would result in an average natural mortality of 5-6%. For the combined emigration plus natural mortality rates and the combined immigration plus recruitment rates we examined values in the range of 10 to 20%, where the rates are relative to the number of fish at the time of tagging. The following tables provide estimates of the bias in the abundance estimate relative to the number at the time of tagging and the number at the time of recapture (number of fish estimated divided by actual number).

Bias relative to number at time of tagging

emigration plus natural mortality	immigration plus recruitment 10%	15%	20%
10%	1.11	1.17	1.22
15%	1.12	1.18	1.24
20%	1.13	1.19	1.25

Bias relative to number at time of recapture

emigration plus natural mortality	immigration plus recruitment 10%	15%	20%
10%	1.11	1.11	1.11
15%	1.18	1.18	1.18
20%	1.25	1.25	1.25

When tag releases are non-random with respect to the population and there is incomplete mixing of tagged fish through the population, the tag-recovery based abundance estimates will likely be biased. Approximately 80% of the sablefish tag releases and 80% of the trap-fishery catch and effort are in the 250-450 fm depth stratum. The proportion of the population in this depth stratum and the rate of movement between this depth stratum and other depths are not known. We conducted simulations across a range of plausible values for the population distribution and movement between two strata to investigate the potential bias in abundance estimates. The percentage of tag releases and the percentage of catch in the 250-450 fm depth stratum were fixed at 80% of the total for the simulations. The following table shows the resulting biases in the abundance estimates.

% of population	movement probability			
in 250-450 fm	0.05	0.15	0.25	0.35
30	0.59	0.66	0.74	0.84
40	0.67	0.73	0.80	0.87
50	0.76	0.80	0.85	0.90

It is likely there will be both positive and negative biases affecting the tagging-based sablefish abundance estimates. The negative biases resulting from non-random tag releases in conjunction with incomplete mixing and from under-estimation of the tag-reporting rate likely outweigh the positive biases resulting from migration, recruitment and natural mortality effects.

8 HARVEST RATE EVALUATION

A commonly used approach to evaluate appropriate harvest levels for fish stocks is based on spawning biomass per recruit (SBR) analysis (Sissenwine and Shepherd, 1987). This approach has the advantage that information regarding the spawner-recruit relationship is not required and the analysis is based on information that is generally available such as the natural mortality rate, maturation/fecundity schedule, and fishery selectivity-at-age. Simulation analysis, based on a broad range of stock and fishery dynamics, suggest that fishing mortality rates that reduce the SBR to 35-40% of the virgin level are appropriate groundfish management targets, that is, they provide a reasonable trade-off between realized catch and spawning potential (Clark 1991, Clark 1993, Mace 1994). The higher SBR target reflects simulations that considered auto-correlation in recruitment.

An analysis of B.C. sablefish fishery dynamics estimated that fishing mortality rates in the range of 0.11 to 0.13 (F on fully-selected age-classes) would result in SBR levels around 0.4 to 0.45 of the virgin level (Saunders et al. 1996). This analysis is consistent with a similar analysis of Alaskan sablefish fishery dynamics, where $F_{0.4}$ is estimated as 0.12 (Sigler et al. 2000).

The previous sablefish SBR analysis provided results relative to fully-selected fishing mortality rates, a quantity that we currently do not measure. The harvest rates estimated from the tag recovery analysis (Section 6) measure the proportion of the total vulnerable (to tagging) biomass that is harvested. The relationship between this quantity and the fully selected fishing mortality rate is not clear. We address this consideration with a simulation analysis that accounts for our current understanding of the sablefish population/fishery interaction.

Our simulation analysis differs from SBR analysis in that we explicitly include the potential effect of a stock-recruitment relationship. We do this by specifying values of the “steepness” parameter of a Beverton-Holt type stock-recruitment relationship. Steepness is defined as the fraction of the virgin recruitment that is expected at 20% of the virgin spawning stock biomass (Francis, 1992). A meta-analysis of many sets of stock and recruitment data sets indicated an average steepness value of 0.8 for long-lived species (M <0.2 and age-at-maturity > 4) (Myers et al. in prep). However, recently Dorn (2000) conducted a meta-analysis based on west coast rockfish stocks and estimated an average steepness of 0.65. We investigate steepness values of 0.6, 0.8, and 1.0. The value of 1.0 is included so that results can be compared to standard SBR reference points.

In addition to considering uncertainty in the stock-recruitment steepness parameter we conduct our analyses assuming different values for the natural mortality rate (*M*) and for different stock-productivity parameters. We consider two values for *M*, 0.08 and 0.1, which encompass the range assumed in Canadian and US sablefish stock assessments (Sigler et al. 2000, Haist and

Hilborn 2000, Schirripa and Methot 2001). Two sets of stock productivity parameters are simulated, one reflecting growth, maturation, and vulnerability for the northern B.C. sablefish stock and the other reflecting these characteristics for the southern B.C. stock. Parameter values are shown in Appendix Table B3. We simulate a trap-like sablefish fishery, thus including escape-ring selectivity and grading selectivity relationships.

The key quantities measured in the simulation are the fraction of the virgin female spawning stock biomass (*SSB*) that remains at different fishing mortality (*F*) levels and the fraction of the vulnerable biomass (*B*) that is harvested. Simulations are deterministic, and quantities are measured only on a relative scale. The following describes the main calculations:

SSB is the sum of the product of: vulnerability-at-age, proportion mature-at-age, weight-at-age, numbers-at-age (female only).

B is the sum of the product of: vulnerability-at-age, weight-at-age, numbers-at-age.

F_a is the product of: vulnerability-at-age, escape-ring selectivity-at-age, grading selectivity-at-age, and fully selected *F*.

Of the parameters that varied among different simulation trials, the stock productivity characteristics had the least influence on the results. Figure 22 compares results based on the southern and northern stock characteristics for the two pairs of natural mortality and steepness parameters that had the most divergent results (*M*=0.1, *h*=1.0 and *M*=0.08, *h*=0.6).

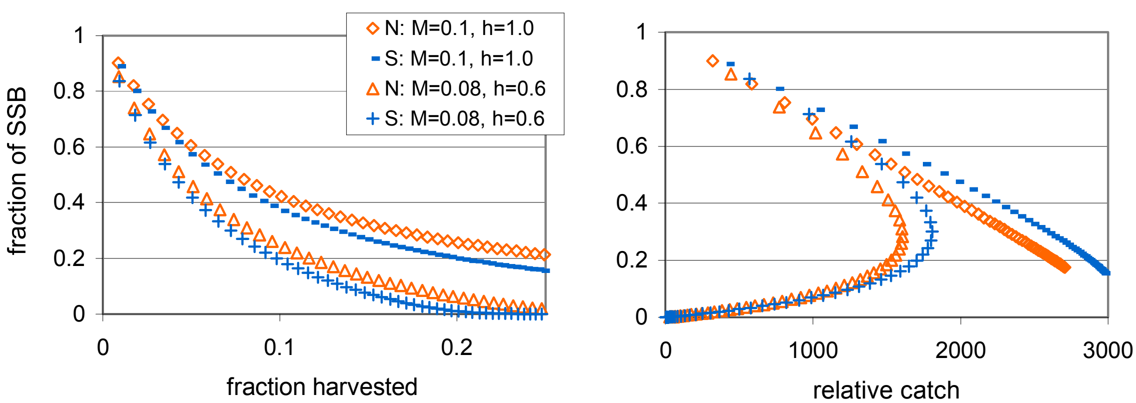

Figure 22. Results from simulation trials based on the northern (N) and southern (S) stock characteristics.

These results suggest that although a slightly higher fraction of the northern stock vulnerable biomass can be harvested at a given fraction of the *SSB*, the relative catch is higher in the southern stock. Assuming no relationship between *SSB* and subsequent recruitment (*h*=1.0), 40% of virgin *SSB* is attained with harvest rates of 11% and 9% for the northern stock and southern stock, respectively.

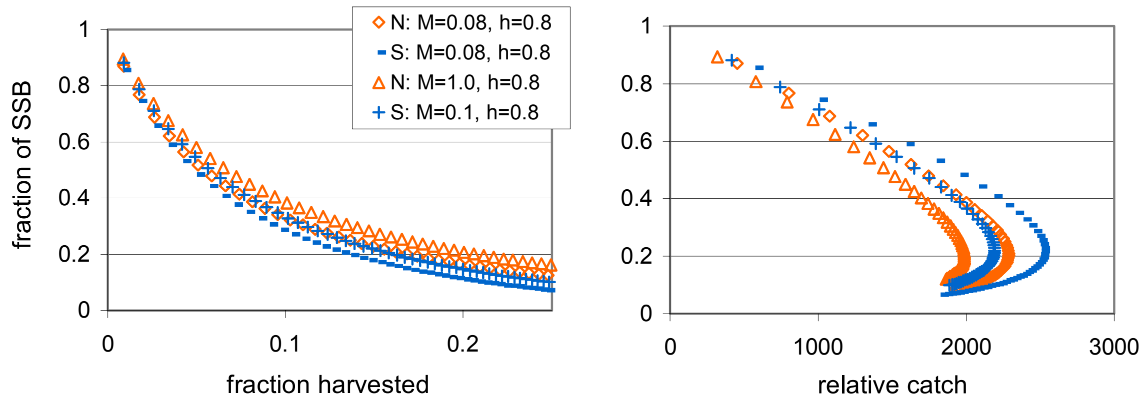

Figure 23. Results from simulation trials based on the northern (N) and southern (S) stock characteristics.

Assuming a stock-recruitment relationship, the relative catch is maximized at 20% to 30% of virgin *SSB*, depending on the steepness. At spawning levels below 30% of virgin there is little or no gain in the relative catch. Therefore, target harvest rates that maintain the female spawning abundance at 30% to 35% of the virgin level provide a reasonable trade-off between realized catch and reproductive potential.

Dependent on the natural mortality and steepness assumptions, harvest levels that generate 30% to 35% of virgin *SSB* range from 0.06-0.11 and 0.07-0.14, for the southern and northern stock characteristics, respectively (Table 16).

Table 16. The percentage of vulnerable biomass harvested that maintains *SSB* at 30-35% of virgin, under alternate *M* and steepness assumptions.

M	0.08		0.10	
steepness	0.6	0.8	0.6	0.8
Southern stock	6-7	8-9	7-9	9-11
Northern stock	7-8	9-11	9-10	11-14

9 ADVICE TO MANAGERS

In this section we address the questions identified by the DFO Groundfish Management Unit in their *Request for Working Paper* (Appendix A).

1. What is the stock status of BC sablefish?

For B.C. sablefish, there are three time-series that may reflect the relative or absolute stock abundance. These are: the trap fishery CPUE (Figure 4), the sablefish survey index site CPUE, (Figure 7), and the abundance estimates from the tag release-recovery analysis (Figure 20). In recent sablefish stock assessments, the fishery CPUE index was not considered a valid index of abundance because of concerns that bait-loading and other fishing strategies to increase catch in the late 1980's (pre-IVQ strategies) inflated the index relative to other years (Saunders et al. 1996). However, we note that the general trends in the trap fishery CPUE is similar to those of the survey and the tagging-based abundance estimate, so include its consideration here because it is the longest available time-series. It is also likely that the survey index site CPUE estimates are high in 1988 and 1989 relative to the later years because hake was included in the bait (Section 4.1). Our concerns with the abundance estimates from the tag release-recovery analysis relate to the distribution of tag releases. These are not random with respect to the vulnerable population, but rather sablefish tend to be tagged in locations and depths similar to where the majority of the fishing effort occurs.

Overall, the trends in the three abundance indicators are similar. That is, a decline in abundance from the late 1980's and early 1990's through to 1996, and relatively constant since then. The trap fishery CPUE index, which extends back to 1979, suggests that abundance in 1997, the last year prior to the use of escape-rings, was slightly lower than during the 1979-1985 period.

Unfortunately, we have only short time-series of abundance indices for B.C. sablefish, so it is not possible to ascertain current status relative to historical levels. However we note that the Alaska sablefish stock, which is assessed using a long time-series of survey data, appeared to reach historical high levels in the mid to late 1980's due to the recruitment of the strong 1977 year-class (Sigler et al. 2000). Since then spawning biomass declined to about 50% of the peak level, and stock abundance is currently thought to be low and stable. Current status of sablefish in B.C. is likely also low and stable.

2. What are appropriate harvest levels?

The harvest rate simulation analysis suggests that harvest rates in the range of 6 to 14% of the vulnerable biomass provide a reasonable trade-off between maximizing catch and maintaining female spawning biomass. The range reflects differences between northern and southern B.C. stock characteristics, and different assumptions regarding natural mortality and the stock-recruitment relationship.

During the 1990's the coastwide harvest rates have generally been between 10 and 12% (Figure 20). While these values are at the high end of the range that we suggest is appropriate for B.C. sablefish stocks, they need to be qualified. Our estimates of the harvest rates are based on tag releases that are not random with respect to the vulnerable population, rather they tend to be in locations and depths that overlap where most of the fishery effort occurs (Figure 24). Directed survey effort in 2000 suggests that sablefish density remains relatively high at depths between 450 and 800 fathoms, yet over 85% of both tag releases and trap fishery effort has been in depths less than 450 fm. This is likely to result in over-estimation of the harvest rates and underestimation of stock abundance.

Given our belief that the harvest rate estimates are biased and the observation that B.C. sablefish abundance has been relatively stable since 1996, the current harvest level (TAC of 4000 t.) appears to be reasonable. Of these considerations, the relative stability of the abundance estimates is the more important. If stock abundance were to decline, or the exploitation rate to increase, from current levels, then the harvest should be reduced.

A decision rule that prescribes how future TAC levels will be calculated, based on agreed-to and measurable stock indicators, would be useful for future management of the sablefish fishery. This rule should: 1) define the data that will be used, 2) define how the data will be analysed to determine a harvest level, and 3) be tested through simulation to ensure it is robust to uncertainties about stock dynamics. We note that a current DFO initiative to develop an operational management plan for B.C. sablefish has the potential to develop a decision rule for this fishery.

3. Is the northern BC sablefish stock separate from SE Alaska stock? Evaluate tagging and other relevant biological and fishery data to determine stock structure, distribution, mixing, etc. Given an understanding of stock distribution, what management options should be considered?

We estimate that approximately 30% of sablefish tagged off the Queen Charlotte Islands move to Alaskan waters (Section 5.3). Our estimate of movement is consistent with rates reported by Kimura et al. (1988) for Alaskan regions, and supports the hypothesis that sablefish in the eastern north Pacific comprise two populations.

On the basis of analyses conducted to date, we are not in a position to provide specific advice regarding management of northern B.C. sablefish.

4. Is the current carryforward/overage policy of 5% consistent with the stock assessment advice and biology of sablefish?

The carryforward/overage policy allows each ITQ holder to maintain a 5% discrepancy between his/her individual quota and their actual landings each year. The potential impact of this policy is that the TACC may be under or over-harvested by 5% in one year with the difference made up in the following year. Given the longevity of sablefish this should have no impact on the population(s).

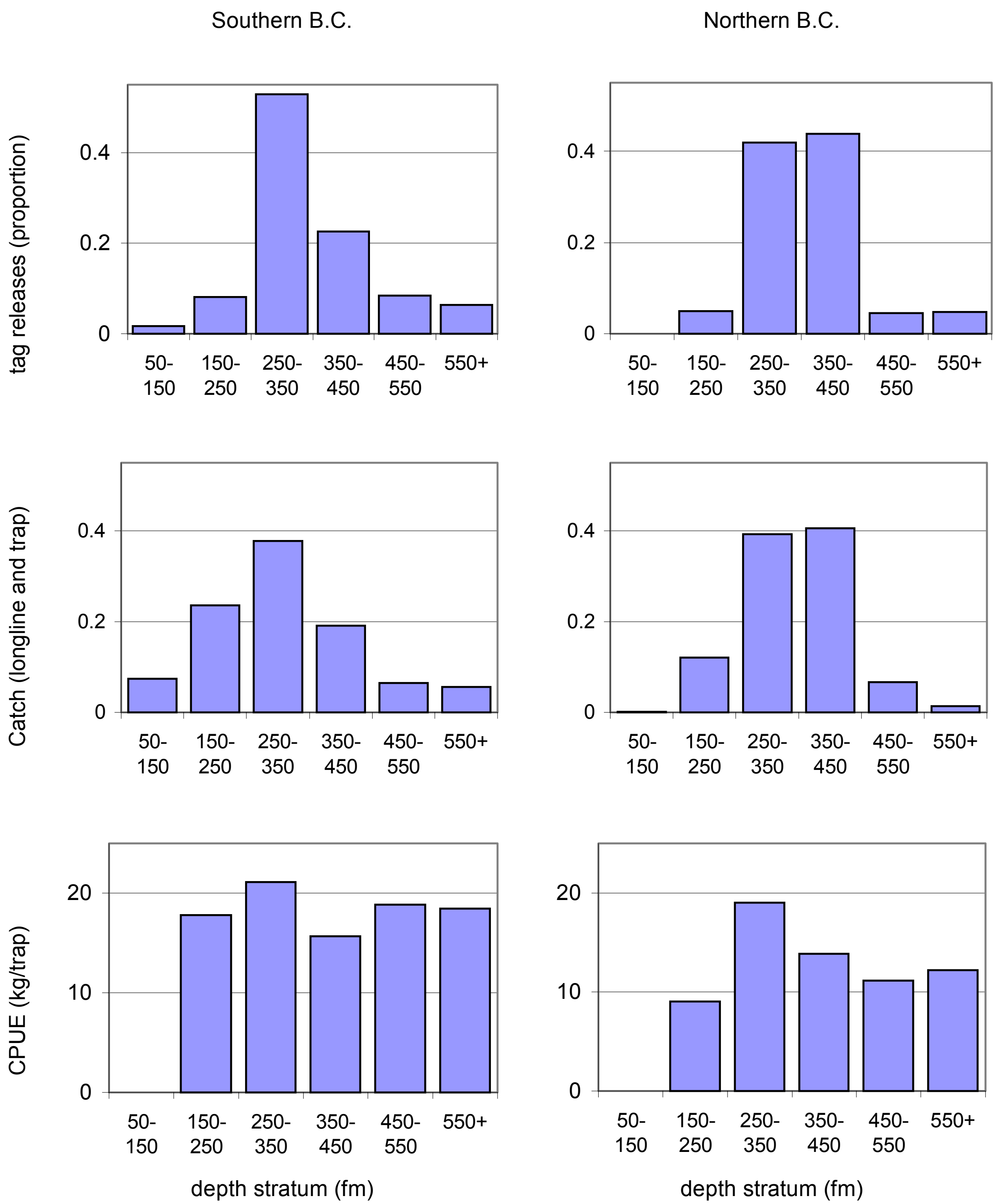

Figure 24. Distribution of tag releases (1991-2000) and catch (longline and trap, 1995-2000), and the average survey index site CPUE (1991-2000), by depth stratum for southern and northern B.C.

10 ACKNOWLEDGEMENTS

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12 APPENDIX A. REQUEST FOR WORKING PAPER.

PSARC GROUNDFISH SUBCOMMITTEE
Request for Working Paper

Date Submitted: June 26, 2001

Individual or group requesting advice: Groundfish Management Unit

Proposed PSARC Presentation Date: November, 2001

Subject of Paper (title if developed):

Sablefish Assessment and Recommended Yield Options or 2002

Stock Assessment Lead Author: V. Haist (Canadian Sablefish Association)
M. Saunders (DFO contact)

Fisheries Management Author/Reviewer: C. Eros/D. Trager

Rational for request:
An annual assessment is conducted for Sablefish with yield options provided for Canadian harvests (commercial, First Nations, recreational, experimental). In addition, RMEC has directed that northern stock distribution between Canada and the US be examined.

Question(s) to be addressed in the Working Paper:
1. What is the stock status of BC sablefish?
2. What are appropriate harvest levels?
3. Is the northern BC sablefish stock separate from SE Alaska stock? Evaluate tagging and other relevant biological and fishery data to determine stock structure, distribution, mixing, etc. Given an understanding of stock distribution, what management options should be considered?
4. Is the current carryforward/overage policy of 5% consistent with the stock assessment advice and biology of sablefish?

Objective of Working Paper: *(StAD staff to develop further jointly with management)*
1. To review surveys, biological sampling, catch records, logbooks, observer reports and fishing practices for sablefish to provide a basis for management for the 2002/2003 fishery.
2. To provide an assessment of sablefish stock status.
3. To provide stock projections based on various yield options.
4. To recommend appropriate yield options.
5. To determine whether sablefish found in Northern BC are a separate stock from SE Alaska sablefish and consider management options.

13 APPENDIX B. TABLES

Table B1. Number of sets fished in each locality and depth stratum, 1988-2000. The number of traps fished per set was approximately 100 in 1988, 65 in 1989, and 25 from 1990 onward.

locality	depth	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Barkley	1		1			1	1		1	1	1	1	1	1
	2	4		2	2	1	2	1	1	1	1	1	1	1
	3	2	1	2	2	1	2	1	1	1	1	1	1	1
	4		1	2	2	1	2	1	1	1	1	1	2	1
	5			1	2	1	2	1	1	1	1	1		1
Esperanza	1					1	1	1	1	1	1	1	1	1
	2	1	1	2		1	1	1	1	1	1	1	1	1
	3	1	1	2		1	1	1	1	1	1	1	1	1
	4	1	1	2		1	1	1	1	1	1	1	1	1
	5			2		1	1	1	1	1	1	1	1	1
Quatsino	1	1	1			1	1	1	1	1	1	1	1	1
	2			2	2	1	1	1	1	1	1	1	1	1
	3	1	1	2	2	1	1	1	1	1	1	1	1	1
	4		1	2	2	1	1	1	1	1	1	1	1	1
	5			2	2	1	1	1	1	1	1	1	1	1
Triangle	1					1		1	1	1	1	1	1	1
	2	2	1		1	1	1	1	1	1	1	1	1	1
	3		1		1	1	1	1	1	1	1	1	1	1
	4				1	1	1	1	1	1	1	1	1	1
	5				1	1	1	1	1	1	1	1	1	1
	3-4		1											
Buck Point	1		1			1	1	1	1	1	1	1	1	1
	2				1	1	1	1	1	1	1	1	1	1
	3		2		1	1	1	1	1	1	1	1	1	1
	4				1	1	1	1	1	1	1	1	1	1
	5				1	1	1	1	1	1	1	1	2	1
	2-3							1						
Cape St. James	1	1						1	1	1	1	1	1	1
	2	2	1					1	1	1	1	1	1	1
	3		1					1	1	1	1	1	1	1
	4		1					1	1	1	1	1	1	1
	5							1	1	1	1	1	1	1
Gowgaia	1							1	1	1	1	1	1	1
	2		2		1	1	1	1	2	1	1	1	1	1
	3		1		1	1	2	2	4	1	1	1	1	1
	4		2		1	1	1	1	1	1	1	1	1	1
	5				1	1	1	1	1	1	1	1	2	1
Hippa	1						1	1	1	1		1	1	1
	2					1	1	1	1	1		1	1	1
	3					1	1	2	1	1		1	2	1
	4					1	1	1	1	1		1		1
	5					1	1	1	1	1		1	2	1
Langara	1					1		1	1	1	1	1	1	1
	2		3		1	1	1	1	1	1	1	1		1
	3				1	1	1	2	2	1	1	1	1	1
	4				1	1	1	1		1	1	1	1	1
	5				1	1	1	1	1	1	1	1	2	1

Appendix Table B2. Simulated number of tagged fish in population and recovered in fishery, for two tag groups, one with high F (0.45) and one with low F (0.05). A natural mortality rate of 0.1 is assumed.

	high F		low F		Total		Z	
yr	tags in population	tags recovered	tags in population	tags recovered	tags in population	tags recovered	in tag population	estimated from tag recoveries
1	1000.00	346.13	1000.00	46.43	2000.00	392.56	-0.33	-0.49
2	576.95	199.70	860.71	39.96	1437.66	239.66	-0.29	-0.47
3	332.87	115.22	740.82	34.40	1073.69	149.61	-0.26	-0.44
4	192.05	66.47	637.63	29.61	829.68	96.08	-0.23	-0.41
5	110.80	38.35	548.81	25.48	659.61	63.83	-0.21	-0.37
6	63.93	22.13	472.37	21.93	536.29	44.06	-0.19	-0.33
7	36.88	12.77	406.57	18.88	443.45	31.64	-0.18	-0.29
8	21.28	7.37	349.94	16.25	371.22	23.61	-0.17	-0.26
9	12.28	4.25	301.19	13.98	313.47	18.23	-0.16	-0.23
10	7.08	2.45	259.24	12.04	266.32	14.49	-0.16	-0.21
11	4.09	1.41	223.13	10.36	227.22	11.77	-0.16	-0.19
12	2.36	0.82	192.05	8.92	194.41	9.73	-0.15	-0.18
13	1.36	0.47	165.30	7.67	166.66	8.15	-0.15	-0.17
14	0.78	0.27	142.27	6.61	143.06	6.88	-0.15	-0.16
15	0.45	0.16	122.46	5.69	122.91	5.84	-0.15	-0.16
16	0.26	0.09	105.40	4.89	105.66	4.98	-0.15	-0.16
17	0.15	0.05	90.72	4.21	90.87	4.26	-0.15	-0.15
18	0.09	0.03	78.08	3.63	78.17	3.66	-0.15	-0.15
19	0.05	0.02	67.21	3.12	67.26	3.14	-0.15	-0.15
20	0.03	0.01	57.84	2.69	57.87	2.70	-0.15	-0.15
21	0.02	0.01	49.79	2.31	49.80	2.32	-0.15	-0.15
22	0.01	0.00	42.85	1.99	42.86	1.99	-0.15	-0.15
23	0.01	0.00	36.88	1.71	36.89	1.71	-0.15	-0.15
24	0.00	0.00	31.75	1.47	31.75	1.48	-0.15	-0.15
25	0.00	0.00	27.32	1.27	27.33	1.27	-0.15	-0.15
25	0.00	0.00	23.52	1.09	23.52	1.09	-0.15	-0.15

Appendix Table B3. Parameter estimates used in harvest rate simulations. Vulnerability values are based on logistic-type functions with age at 50% available set at 5 for the southern stock and 7 for the northern stock. Maturity schedules were estimated from the data presented in Saunders et al. (1996, Table 5.15). Length and weight-at-age are based on the relationships reported in Saunders et al (1996, Table 5.6). Escape-ring and grading selectivity are estimated from the relationships reported in Haist and Hilborn (2000, Appendix C).

		females					males			
age	Vulner-ability	maturity	length	wt	escape-ring sel.	grading sel.	length	wt	escape-ring sel.	grading sel.
South										
1	0.019	0.056	33.5	0.3	0.024	0.000	38.22	0.48	0.048	0.000
2	0.050	0.139	44.1	0.8	0.103	0.000	45.39	0.86	0.121	0.000
3	0.123	0.304	52.3	1.4	0.242	0.000	50.75	1.25	0.210	0.000
4	0.273	0.543	58.7	2.0	0.393	0.193	54.77	1.61	0.297	0.000
5	0.500	0.764	63.7	2.7	0.518	0.793	57.77	1.92	0.369	0.066
6	0.727	0.898	67.6	3.3	0.609	0.920	60.02	2.19	0.426	0.431
7	0.877	0.960	70.6	3.8	0.673	0.993	61.70	2.40	0.468	0.543
8	0.950	0.985	73.0	4.2	0.718	1.000	62.96	2.56	0.499	0.668
9	0.981	0.994	74.9	4.6	0.749	1.000	63.90	2.70	0.522	0.793
10	0.993	0.998	76.3	4.9	0.772	1.000	64.61	2.80	0.540	0.850
11	0.997	0.999	77.4	5.1	0.788	1.000	65.13	2.87	0.552	0.906
12	0.999	1.000	78.3	5.3	0.800	1.000	65.53	2.93	0.562	0.906
13	1.000	1.000	79.0	5.5	0.809	1.000	65.82	2.98	0.568	0.906
14	1.000	1.000	79.5	5.6	0.815	1.000	66.04	3.01	0.574	0.913
15	1.000	1.000	79.9	5.7	0.820	1.000	66.21	3.04	0.577	0.913
16	1.000	1.000	80.3	5.8	0.824	1.000	66.33	3.05	0.580	0.913
17	1.000	1.000	80.5	5.8	0.827	1.000	66.42	3.07	0.582	0.913
18	1.000	1.000	80.7	5.9	0.829	1.000	66.49	3.08	0.584	0.913
19	1.000	1.000	80.9	5.9	0.831	1.000	66.55	3.09	0.585	0.913
20+	1.000	1.000	81.0	6.0	0.832	1.000	66.58	3.09	0.586	0.913
North										
1	0.003	0.090	38.8	0.5	0.052	0.000	36.32	0.41	0.037	0.000
2	0.007	0.211	47.4	1.0	0.151	0.000	44.80	0.82	0.113	0.000
3	0.019	0.421	54.1	1.5	0.282	0.000	50.85	1.26	0.212	0.000
4	0.050	0.664	59.2	2.1	0.405	0.319	55.17	1.65	0.306	0.000
5	0.123	0.843	63.1	2.6	0.504	0.793	58.25	1.98	0.381	0.193
6	0.273	0.936	66.2	3.0	0.576	0.913	60.44	2.24	0.436	0.431
7	0.500	0.975	68.5	3.4	0.628	0.953	62.01	2.44	0.476	0.668
8	0.727	0.991	70.3	3.7	0.666	0.993	63.12	2.59	0.503	0.793
9	0.877	0.997	71.6	4.0	0.693	1.000	63.92	2.70	0.523	0.793
10	0.950	0.999	72.7	4.1	0.712	1.000	64.49	2.78	0.537	0.850
11	0.981	1.000	73.5	4.3	0.726	1.000	64.89	2.84	0.546	0.850
12	0.993	1.000	74.1	4.4	0.737	1.000	65.18	2.88	0.553	0.906
13	0.997	1.000	74.6	4.5	0.745	1.000	65.39	2.91	0.558	0.906
14	0.999	1.000	75.0	4.6	0.751	1.000	65.53	2.93	0.562	0.906
15	1.000	1.000	75.3	4.7	0.756	1.000	65.64	2.95	0.564	0.906
16	1.000	1.000	75.5	4.7	0.759	1.000	65.71	2.96	0.566	0.906
17	1.000	1.000	75.6	4.7	0.762	1.000	65.77	2.97	0.567	0.906
18	1.000	1.000	75.8	4.8	0.764	1.000	65.81	2.97	0.568	0.906
19	1.000	1.000	75.9	4.8	0.765	1.000	65.83	2.98	0.569	0.906
20+	1.000	1.000	75.9	4.8	0.766	1.000	65.85	2.98	0.569	0.906