Estimation of Tag-Reporting Rates for Sablefish in the Northeastern Pacific Ocean

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ABSTRACT: An essential component of any mark and recapture study that seeks to estimate fish population abundance, exploitation rates, or migration rates from tagging data is the tag-reporting rate. We obtained tag-reporting rates for the sablefish *Anoplopoma fimbria* fishery during 1980–1998 by comparing tag returns in the fishery to tag returns from a scientific survey where all tag recoveries were assumed to be reported. Analytical formulae were derived for the measurement error associated with the estimates. When pooled over geographic areas or years, estimates of reporting rates were reasonably precise with coefficients of variation (CVs) usually less than 25%. Reporting rates were highest in the central (0.385) and eastern (0.315) Gulf of Alaska, intermediate in the western Gulf of Alaska (0.269), and lowest in the Aleutians (0.174) and Bering Sea (0.169). Rates pooled over all areas increased from lows of 0.102–0.248 in 1980–1982 to a peak of 0.465 in 1985 before declining to 0.199 in 1986 and 0.157 in 1987. The reporting rate increased gradually and fluctuated between 0.376 and 0.450 since 1995. The increase in reporting in 1995 was coincidental with the implementation of the Individual Fishing Quota (IFQ) system. The linear increase in reporting rates during 1986–1998 was significant. Factors that may have influenced the reporting rate were the number of tags available for recovery, the length of the commercial fishing season, the presence of scientific observers on commercial vessels, and the tag reward program. Pooled over all years and areas the tag-reporting rate has been 0.276 with a CV of 4.2%.

INTRODUCTION

The proportion of recovered tags that are returned, the tag-reporting rate, is an important component of any mark and recapture study used to estimate fish abundance, exploitation rates, or migration rates from tagging data (Seber 1982; Hearn et al. 1999). Methods to estimate reporting rates include tag-seeding experiments (Campbell et al. 1992; Hampton 1996), sequential observations of tags at different stages of catch handling (Hilborn 1988), and comparison of tag returns to those in a control sample with a reporting rate near or equal to unity (Paulik 1961).

Sablefish *Anoplopoma fimbria* is a long-lived and migratory species (Bracken 1982; Sasaki 1985; Fujioka et al. 1988; Maloney and Heifetz 1997). Results from tagging studies of sablefish have been used to estimate movement rates, evaluate harvest strategies, and determine ageing accuracy (Heifetz and Fujioka 1991; Heifetz et al. 1997; Heifetz et al. 1999). The age-structured model used to estimate absolute abundance and recommend catch quotas for sablefish in Alaska relies primarily on relative abundance indices and age composition from annual longline surveys (Sigler 1999, 2000). There is a wealth of tagging data available for Alaskan sablefish that can provide auxiliary information for age-structured analyses. Within the framework of an age-structured model, such data can be included by tracking cohorts of tagged fish (e.g., Haist 1998). Although there has been a desire to integrate tagging data into the age-structured model, the tagging data have not been used, in part because the magnitude and accuracy of the tag-reporting rate has not been formally evaluated. Estimates of tag-reporting rates independent of the age-structured model are desired because this parameter is confounded with tag loss and fishing and total mortality estimates (Heifetz and Fujioka 1991; Haist 1998).

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Our objectives were to describe a method for estimating fishery tag-reporting rates for sablefish in the commercial fishery in Alaska during 1980–1998. These estimates were obtained by comparing tag returns in the commercial fishery to tag returns from a scientific survey where all tag recoveries are assumed to be reported. Measurement error associated with the estimates was derived, and geographic and temporal trends in the estimates were examined.

METHODS

Estimation of Tag-Reporting Rate

As in Paulik (1961) and Seber (1982), we assumed that tag returns can be classified into 2 categories. The first category, we call the "survey," has a known reporting rate of unity or near unity. The second category, we call the "fishery," has an unknown tag-reporting rate. The survey and fishery may take place in distinct geographic areas and multiple years.

Let

n_{ij} = the total catch in numbers from the survey in area *i* and year *j*,

N_{ij} = the total catch in numbers from the fishery in area *i* and year *j*,

r_{ij} = the number of tags caught in the survey in area *i* and year *j*, and

R_{ij} = the number of tags reported from the fishery in area *i* and year *j*.

The estimated tag ratio in the survey is

$$S_{ij} = \frac{r_{ij}}{n_{ij}} \ ,$$

and the reported tag ratio in the fishery is

$$F_{ij} = \frac{R_{ij}}{N_{ij}} \, .$$

If the tag ratio in the survey is assumed to provide an estimate of the tag ratio in the fishery (including unreported tags), an estimate of the fishery reporting rate for a particular area *i* and year *j* is

$$\beta_{ij} = \frac{F_{ij}}{S_{ij}}$$

(Seber 1982; Heifetz and Fujioka 1991). From the delta method (Seber 1982), the variance for β_{ij} (ignoring possible covariances and dropping time and area subscripts for simplicity) is

$$\sigma_\beta^2 = \frac{\sigma_F^2 + \dfrac{F^2\sigma_S^2}{S^2}}{S^2} \ . \qquad (1)$$

The equations for the variance of F_{ij}, σ_F^2, and the variance of S_{ij}, σ_S^2, depend on the specifics of the sampling procedure. For example, the stations of many surveys are typically sampled so that data may be available on the number of tags and the total number of fish examined for tags at each station. Dropping time and area subscripts for simplicity

$$S = \frac{\sum_k r_k}{\sum_k n_k} = \frac{\bar{r}}{\bar{n}} \ ,$$

where *k* denotes survey stations. This is a typical ratio estimate whose variance is given by

$$\sigma_S^2 = \frac{1}{h\bar{n}^2}\left(\sigma_n^2 S^2 + \sigma_r^2 - 2\rho\sigma_n\sigma_r S\right) \ , \qquad (2)$$

where *h* is the number of survey stations, σ_n^2 and σ_r^2 are the estimated variances of *n* and *r* among survey stations, and ρ is the correlation between *n* and *r*. Note that equation (2) is equivalent to that in Rice (1988, p. 195) with the finite population correction omitted. If the number of tags reported from the fishery and total catch in the fishery are known without error, then from equation (1) the variance of *F* can be set to zero to give

$$\sigma_\beta^2 = \frac{F^2}{h\bar{n}^2 S^4}\left(\sigma_n^2 S^2 + \sigma_r^2 - 2\rho\sigma_n\sigma_r S\right) \ . \qquad (3)$$

The method used to compute variance is a large-sample approximation. As an alternative, nonparametric bootstrap variance estimates can be computed (Efron and Tibshirani 1986), especially if confidence limits are desired. For example, using the bootstrap method, *h* survey stations would be sampled randomly with replacement from the observed stations and the reporting rate computed from the sampled stations. This procedure would be repeated many times.

Assumptions of this method are: (1) all tagged fish caught on the survey are reported; (2) age compositions of the survey and fishery catches are identical; and (3) tagged fish are mixed completely throughout the survey and fishery areas. Note that Hearn et al. (1999) described a generalization of this method in which assumption (2) can be relaxed if age compositions are available for the survey and fishery catch and for the tagged fish. If these age compositions are available, estimates of age-specific reporting rates can be obtained.

Application to Sablefish

We used tag-recovery data from sablefish released by the National Marine Fisheries Service (NMFS) in Alaskan waters. Using Sasaki's (1985) methods, NMFS has released about 300,000 tagged sablefish in Alaskan waters since 1979. Recoveries of these tagged fish in waters off British Columbia, Washington, Oregon, and California, and inside waters of Alaska such as Prince William Sound, Chatham Strait, and Clarence Strait are not included in our analysis because our survey does not cover these areas. Tags recovered during the year of release also were not used because commercial vessels fishing soon after the survey would have greater opportunity than the survey vessel to recover them. Each year some tags are returned with no information on catch location. Because these tags make up only a small percentage (< 2.5% over all years) of fishery tag returns and would have little influence on estimates of reporting rates, they were considered as not reported.

A total of 11,020 commercially recovered tags had sufficient catch information to be included in this study. Of these fish, 81% were caught with longlines, 9% were caught with trawls or pots, and the type of gear of 10% was not known. We considered discarding all fishery tag recoveries from trawl, pot, and unknown gear types because the survey uses only longline gear. To examine the effect on the reporting rate of including all tags, we computed separate reporting rates for longline only and for all gear types combined for a subset of the data. In general, there was no significant difference ($P > 0.05$, Fisher–Behrens statistic; Quinn and Deriso 1999) in reporting rates for all gear types combined and longline gear only, although the point estimate of the reporting rate for all gear types was usually slightly higher than the longline reporting rate. In most years the non-longline catch was only 10–12% of the total sablefish catch, and most of the tags of unknown gear type were probably longline. Thus, we included all recoveries in the analysis.

Commercial fishery catch for each year and regulatory area is reported as weight. Data on number of fish, average weight of individual fish, or length and age composition of the commercial fishery catch were not available before 1990. For a given year and area we converted the commercial catch data to numbers of fish by dividing total catch weight by the mean weight of survey fish. Rather than apply a weight-to-number conversion to the commercial data from 1980–1989 and use the fishery numbers for the data from 1990–1998, we chose to standardize the data by converting weight to numbers for all years. The mean weight of survey fish was calculated using length frequencies and a length–weight relationship. To justify this method of estimating numbers of fish, the length frequencies of fish in the survey and the fishery should be the same. Age-structured modeling of the Alaskan sablefish population indicates that fishery and survey selectivity, and hence length and age compositions, are similar (Sigler et al. 1999). For a subset of the 1990 to 1998 data, we computed reporting rates using mean weight in the fishery derived from length frequencies from the longline fishery. The estimated reporting rates were almost identical to those obtained using mean weight of survey fish in the conversion of catch weight to numbers of fish.

A total of 832 tags have been recovered from the Japan–U.S. cooperative longline survey (cooperative survey) and the NMFS longline survey (domestic survey). The cooperative survey was conducted annually by Japan during 1978–1994. This survey sampled fixed stations equidistantly spaced along the continental slope in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska (GOA; Figure 1). The domestic survey has been conducted since 1987 using chartered commercial fishing vessels. The domestic survey covers the same stations in the GOA at the same time of year as the cooperative survey and, in addition, samples major deepwater gullies on the continental shelf (Figure 1). Until 1996 the domestic survey did not include stations in the eastern Bering Sea or Aleutian Islands that were routinely sampled by the cooperative survey. Thus, a time series of surveys exists from 1978 to 1998, with overlapping sampling in the GOA for 1987–1994.

During the surveys biologists monitor each hook as the gear is hauled, and all fish are enumerated as they are brought onto the survey vessel. In addition, a biologist routinely handles and measures most sablefish as they arrive on the processing deck. Hence, the assumption that all tagged sablefish caught during the survey are reported is reasonable.

The variance of the reporting rate was determined using equation (3). We present the coefficients of variation (CV), which are computed from the square root of the variance divided by the estimate of β. We favor the coefficient of variation as a measure of accuracy because it expresses variability as a proportion of the estimate.

RESULTS

Estimates of annual tag-reporting rates by area for sablefish in Alaska were highly variable (Table 1). The estimates ranged from 0.043 in the Bering Sea in 1997 to 1.85 in the central GOA in 1984, and CV values ranged from 16% to 168%. Estimates greater than 1.0 have no meaning and were associated with high CVs. In general, CVs were highest in the Bering Sea and Aleutians and lowest in the eastern and central GOA. High CVs were usually associated with low survey tag recoveries (Figure 2). When the number of survey tags was less than about 10, CVs were generally greater than 30%.

Estimates of reporting rates were all <1.0 and had low CVs when pooled over areas or years (Tables 2 and 3). Rates were highest in the central (0.385) and eastern (0.315) GOA, intermediate in the western GOA (0.269), and lowest in the Aleutians (0.174) and Bering Sea (0.169). Most CVs were less than 25%. The most precise estimates (i.e., lowest CVs) were in the 3 GOA areas (all < 12%). Statistically, the reporting rates were significantly greater ($P \leq 0.05$) in the central and eastern GOA than in the Aleutians and Bering Sea and significantly greater in the central GOA than in the western GOA (Table 3). Statistical significance was based on comparison of the Fisher–Behrens statistic to the critical value of a normal distribution (Quinn and Deriso 1999). Bonferonni adjustments of significance levels, to account for multiple comparisons, were carried out with the sequential procedure of Hochberg (1988).

Tag-reporting rates increased from lows in 1980–1982 of 0.102–0.248 to a peak in 1985 of 0.465 before dropping back to 0.199 in 1986 and 0.157 in 1987 (Table 1 and Figure 3). The reporting rate increased gradually since 1995 and fluctuated between 0.376 and 0.450. There was a significant linear increase ($P = 0.002$, $r^2 = 0.67$) in reporting during 1986–1998. Pooled over all years and areas the tag-reporting rate has been 0.276 with a CV of 4.2%.

DISCUSSION

We described a method for estimating tag-reporting rates for sablefish based on survey and fishery data. The basis of this method is given in Paulik (1961). Although other methods exist for estimating reporting rates (Hearn et

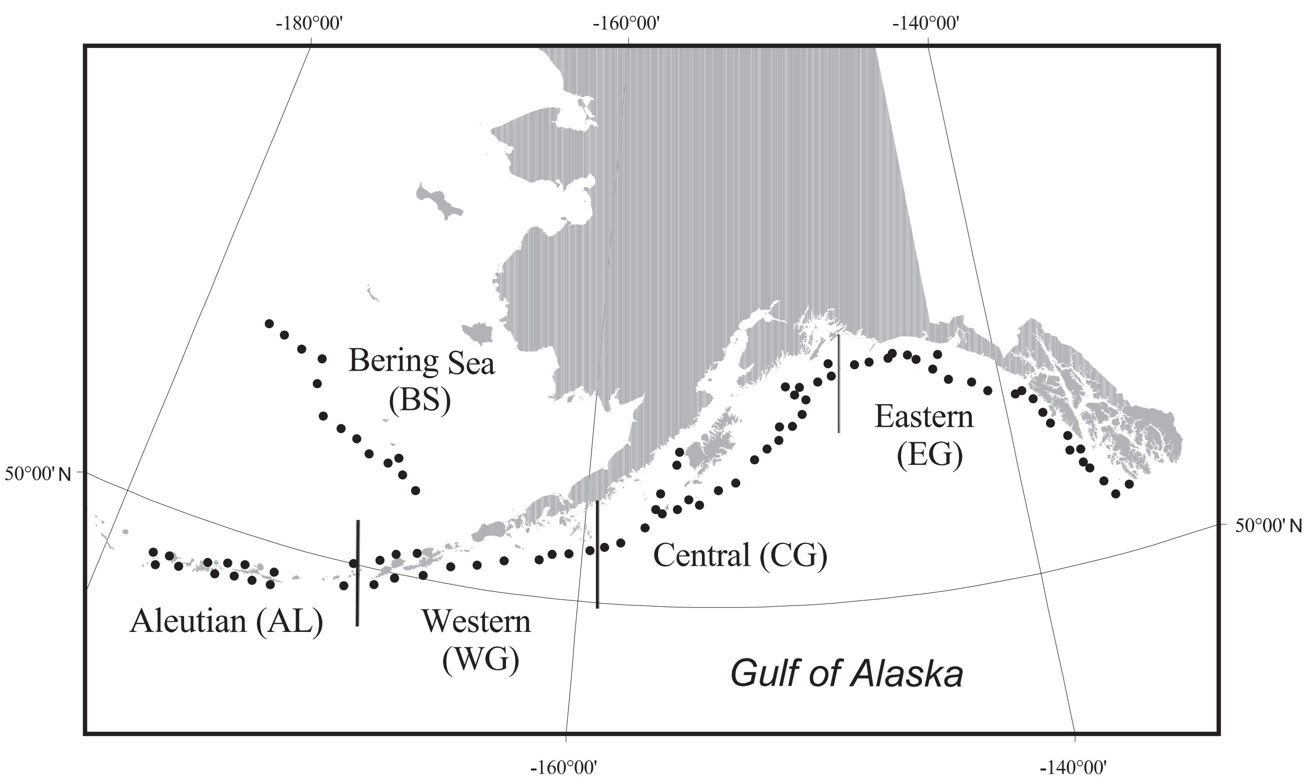

Figure 1. Location of sablefish longline survey stations in the Bering Sea, Aleutian Islands, and western, central, and eastern Gulf of Alaska.

Table 1. Number of tags recovered in the survey and fishery, estimated number of sablefish caught in the fishery, number of sablefish examined in the survey, number of survey stations, estimated tag-reporting rate, and coefficient of variation (CV) by year and area. AL = Aleutians; BS = Eastern Bering Sea; WG = Western Gulf of Alaska; CG = Central Gulf of Alaska; EG = Eastern Gulf of Alaska; GOA = Gulf of Alaska (i.e., WG+CG+EG).

		Fishery		Survey			Reporting Rate	
Year	Area	Tags (R)	Numbers (N)	Tags (r)	Numbers (n)	Stations (h)	Estimate (β)	CV (%)
1980	AL	3	115,537	1	6,490	21	0.169	106.5
	BS	3	969,136	0	1,117	4		
	WG	22	524,086	0	5,299	10		
	CG	34	1,104,264	3	13,115	16	0.135	53.4
	EG	116	1,386,620	4	19,588	18	0.410	58.6
	GOA	172	3,014,970	7	38,002	44	0.310	40.2
	All areas	178	4,099,643	8	45,609	69	0.248	37.4
1981	AL	4	223,933	0	7,577	23		
	BS	8	1,138,995	0	1,783	4		
	WG	21	635,940	3	9,255	10	0.102	73.3
	CG	75	1,354,119	5	15,818	16	0.175	49.8
	EG	185	1,588,259	30	31,153	20	0.121	26.0
	GOA	281	3,578,318	38	56,226	46	0.116	23.6
	All areas	293	4,941,246	38	65,586	73	0.102	24.1
1982	AL	12	408,718	3	8,533	27	0.084	72.0
	BS	26	1,372,519	4	19,931	33	0.094	58.5
	WG	34	571,601	2	11,840	10	0.352	66.4
	CG	64	1,067,408	9	22,171	17	0.148	37.5
	EG	200	1,242,709	26	29,916	20	0.185	33.5
	GOA	298	2,881,718	37	63,927	47	0.179	26.2
	All areas	336	4,662,955	44	92,391	107	0.151	23.3
1983	AL	27	261,389	1	7,949	24	0.821	99.4
	BS	78	1,158,180	1	18,921	33	1.274	101.1
	WG	54	537,987	7	14,788	10	0.212	33.4
	CG	120	1,146,197	4	22,914	17	0.600	57.5
	EG	297	1,304,642	25	25,540	20	0.233	22.6
	GOA	471	2,988,826	36	63,242	47	0.277	19.5
	All areas	576	4,408,395	38	90,112	104	0.310	19.5
1984	AL	10	396,041	4	11,429	27	0.072	81.7
	BS	36	1,433,038	8	24,274	32	0.076	31.2
	WG	57	458,843	10	16,462	10	0.205	32.2
	CG	182	1,324,783	2	26,938	17	1.850	68.9
	EG	328	1,546,056	14	28,595	20	0.433	36.1
	GOA	567	3,329,682	26	71,995	47	0.472	24.6
	All areas	613	5,158,761	38	107,698	106	0.337	19.8
1985	AL	54	539,740	4	14,370	27	0.359	59.7
	BS	116	1,071,831	4	26,942	33	0.729	47.6
	WG	114	722,742	7	20,465	10	0.461	53.3
	CG	189	1,338,087	10	34,817	17	0.492	32.8
	EG	371	1,284,423	25	40,043	20	0.463	23.3
	GOA	674	3,345,252	42	95,325	47	0.457	18.6
	All areas	844	4,956,823	50	136,637	107	0.465	16.9
1986	AL	112	1,084,733	3	12,061	26	0.415	68.9
	BS	39	1,623,240	5	24,139	32	0.116	49.4
	WG	81	1,369,466	3	17,855	10	0.352	69.1
	CG	217	2,995,872	13	32,716	17	0.182	22.5
	EG	350	2,618,208	32	48,549	20	0.203	18.0
	GOA	648	6,983,546	48	99,120	47	0.192	14.6
	All areas	799	9,691,519	56	135,320	105	0.199	13.9

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Table 1. (continued)
AL = Aleutians; BS = Eastern Bering Sea; WG = Western Gulf of Alaska; CG = Central Gulf of Alaska; EG = Eastern Gulf of Alaska; GOA = Gulf of Alaska (i.e., WG+CG+EG).

		Fishery		Survey			Reporting Rate	
Year	Area	Tags (R)	Numbers (N)	Tags (r)	Numbers (n)	Stations (h)	Estimate (β)	CV (%)
1987	AL	64	1,357,815	7	11,359	26	0.076	53.1
	BS	85	1,818,921	2	8,681	30	0.203	66.2
	WG	53	1,306,591	8	30,603	20	0.155	27.4
	CG	184	3,592,731	13	60,405	37	0.238	24.7
	EG	287	3,255,133	43	81,700	42	0.168	23.2
	GOA	524	8,154,455	64	172,708	99	0.173	17.0
	All areas	673	11,331,191	73	192,748	155	0.157	15.8
1988	AL	74	1,331,414	6	10,752	27	0.100	47.5
	BS	26	1,627,880	3	12,162	28	0.065	52.9
	WG	43	1,276,139	5	29,158	20	0.196	37.9
	CG	253	4,649,620	12	75,223	43	0.341	26.3
	EG	490	3,918,764	31	91,789	41	0.370	18.3
	GOA	786	9,844,523	48	196,170	104	0.326	14.3
	All areas	886	12,803,817	57	219,084	159	0.266	13.2
1989	AL	22	1,127,609	8	19,335	25	0.047	25.1
	BS	27	518,366	4	17,529	27	0.228	29.3
	WG	38	1,390,212	6	23,398	20	0.107	43.3
	CG	175	3,905,749	10	77,070	46	0.345	26.5
	EG	363	3,388,878	39	87,699	58	0.241	20.7
	GOA	576	8,684,839	55	188,167	124	0.227	15.5
	All areas	625	10,330,814	67	225,031	176	0.203	13.0
1990	AL	36	843,750	3	5,674	26	0.081	50.2
	BS	46	916,619	0	7,225	30		
	WG	45	654,613	9	18,958	20	0.145	31.3
	CG	278	4,047,928	8	66,385	47	0.570	31.8
	EG	459	3,180,209	29	92,181	59	0.459	21.7
	GOA	783	7,882,750	46	177,524	126	0.383	16.4
	All areas	864	9,643,119	49	190,423	182	0.348	15.7
1991	AL	39	650,187	5	4,447	27	0.053	47.5
	BS	21	427,459	3	3,249	25	0.053	52.0
	WG	54	562,317	3	15,209	20	0.487	105.8
	CG	235	3,446,368	5	61,274	46	0.836	42.0
	EG	258	2,700,613	24	101,623	55	0.405	25.3
	GOA	547	6,709,298	32	178,106	121	0.454	22.3
	All areas	607	7,786,944	40	185,802	173	0.362	18.8
1992	AL	17	433,336	3	3,924	27	0.051	62.2
	BS	14	194,640	2	4,091	24	0.147	70.8
	WG	66	827,360	6	13,356	20	0.178	41.3
	CG	215	3,271,485	13	61,974	46	0.313	24.4
	EG	340	1,793,140	41	112,188	58	0.519	16.2
	GOA	621	5,891,985	60	187,518	124	0.329	12.9
	All areas	652	6,519,961	65	195,533	175	0.301	12.5
1993	AL	69	773,653	0	5,373	26		
	BS	24	234,626	2	1,678	29	0.086	168.5
	WG	18	237,422	4	24,223	20	0.459	30.5
	CG	244	3,500,787	7	59,626	46	0.594	39.4
	EG	325	2,708,291	38	110,494	59	0.349	19.4
	GOA	587	6,446,500	49	194,343	125	0.361	16.0
	All areas	680	7,454,779	51	201,394	180	0.360	16.1

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Table 1. (continued)

		Fishery		Survey			Reporting Rate	
Year	Area	Tags (*R*)	Numbers (*N*)	Tags (*r*)	Numbers (*n*)	Stations (*h*)	Estimate (β)	CV (%)
1994	AL	40	502,982	0	3,595	26		
	BS	22	225,402	1	4,802	28	0.469	102.8
	WG	9	186,078	2	24,192	21	0.585	67.7
	CG	126	2,529,887	10	53,848	48	0.268	33.4
	EG	303	2,711,333	40	89,951	59	0.251	20.8
	GOA	438	5,427,298	52	167,991	128	0.261	17.8
	All areas	500	6,155,682	53	176,388	182	0.270	17.6
1995	AL	33	415,667	0	0	0		
	BS	13	321,538	0	0	0		
	WG	72	547,040	1	12,652	11	1.665	102.7
	CG	206	2,124,237	11	38,717	34	0.341	29.5
	EG	300	2,353,599	17	55,471	36	0.416	28.2
	GOA	578	5,024,876	29	106,840	81	0.424	20.2
	All areas	624	5,762,081	29	106,840	81	0.399	20.2
1996	AL	20	282,204	0	3,000	14		
	BS	12	191,675	0	0	0		
	WG	50	487,437	0	10,717	10		
	CG	172	1,667,087	9	47,057	36	0.539	37.8
	EG	268	1,782,508	20	49,551	33	0.372	27.4
	GOA	490	3,937,032	29	107,325	79	0.461	23.1
	All areas	522	4,410,911	29	110,325	93	0.450	23.1
1997	AL	26	289,688	0	0	0		
	BS	6	200,200	3	4,273	16	0.043	50.7
	WG	31	505,813	2	10,533	10	0.323	68.0
	CG	132	1,625,455	3	39,798	33	1.077	53.8
	EG	178	1,445,202	17	55,069	74	0.399	23.6
	GOA	341	3,576,470	22	105,400	117	0.457	21.3
	All areas	373	4,066,358	25	109,673	133	0.402	19.8
1998	AL	16	188,768	1	5,693	14	0.483	105.9
	BS	10	157,300	0	0			
	WG	42	471,299	3	10,717	10	0.318	51.4
	CG	117	1,548,363	5	30,310	26	0.458	43.8
	EG	190	1,392,955	13	36,191	24	0.380	27.1
	GOA	349	3,412,617	21	77,218	60	0.376	21.8
	All areas	375	3,758,685	22	82,911	74	0.376	21.3

al. 1999), the method we chose was most appropriate for the available data. We have considered using other available data such as the tag returns from individual vessels. To use these data requires the assumption that some vessels return all tags. We note that tag returns from individual vessels are being used to estimate tag-reporting rates for British Columbia sablefish (R. Hilborn, University of Washington, personal communication) and could be explored for Alaskan sablefish. For our application, the method relied on 3 assumptions: (1) all tagged sablefish caught on the survey are reported; (2) age compositions of the survey and fishery catches are identical; and (3) tagged fish are mixed completely throughout the survey and fishery areas. For sablefish in Alaska, the first 2 assumptions are met. The sablefish catch on the survey is monitored so closely that it is likely that all tagged fish are observed. Age compositions derived from length frequencies and age-structured modeling of survey and fishery catches are similar.

We attempted to satisfy the third assumption by excluding any tags recovered during the same year they were released, allowing more time for dispersal of newly tagged fish and ensuring that commercial vessels fishing soon after the survey do not have a greater opportunity than the survey vessel to recover those tagged fish. However, the longline survey fishes the same stations every year, and nearly two-thirds of the tagged sablefish included in our study were released at these stations. Although sablefish undertake signifi-

Table 2. Number of tags recovered in the survey and fishery, estimated number of sablefish caught in the fishery, number of sablefish examined in the survey, number of survey stations, estimated tag-reporting rate, and coefficient of variation (CV) by area pooled over years (1980–1998). AL = Aleutians; BS = Eastern Bering Sea; WG = Western Gulf of Alaska; CG = Central Gulf of Alaska; EG = Eastern Gulf of Alaska; GOA = Gulf of Alaska (i.e., WG+CG+EG).

	Fishery		Survey			Reporting Rate	
Area	Tags (R)	Numbers (N)	Tags (r)	Numbers (n)	Stations (h)	Estimate (β)	CV (%)
AL	678	11,227,164	49	141,561	413	0.174	16.4
BS	612	15,601,565	42	180,797	408	0.169	15.2
WG	904	13,272,986	81	319,680	272	0.269	11.4
CG	3,218	46,240,427	152	840,176	605	0.385	7.9
EG	5,609	41,601,542	508	1,187,291	736	0.315	5.7
GOA	9,731	101,114,955	741	2,347,147	1,613	0.305	4.5
All areas	11,021	127,943,684	832	2,669,505	2,434	0.276	4.2

cant migrations (Bracken 1982; Sasaki 1985; Fujioka et al. 1988; Maloney and Heifetz 1997), a portion of the population may be sedentary, especially larger sablefish (Heifetz and Fujioka 1991). Such a tendency may result in underestimated reporting rates because the tag ratio in the survey may be inherently higher than in the fishery even with 100% reporting in the fishery. Given the magnitude of the migration rates estimated by Heifetz and Fujioka (1991), we suspect that the influence of non-mixing on reporting rates is negligible. In addition, commercial sablefish fishers are known at times to select the survey stations as fishing locations (M. F. Sigler, NMFS Auke Bay Laboratory, Juneau, personal communication), which may balance any bias caused by non-mixing. A quantitative evaluation of this assumption would require comparing our estimates to estimates obtained using only fishery catches and tag returns from areas near survey stations. However, obtaining such data is not possible for the sablefish fishery because most individual tag

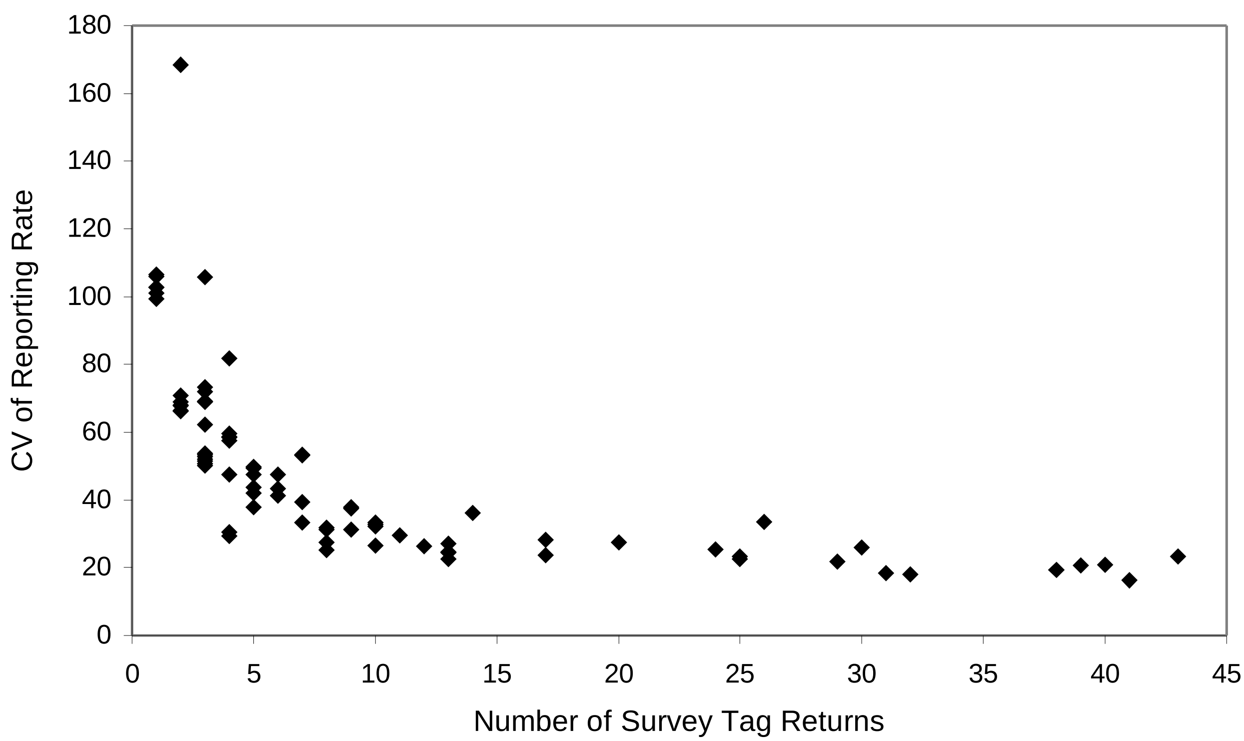

Figure 2. Relationship between the coefficient of variation (CV) of the estimated tag-reporting rate and number of survey tag returns for sablefish in Alaska.

Table 3. Probability levels for pairwise comparisons of tag-reporting rates by area pooled over years based on the Fisher–Behrens statistic (Quinn and Deriso 1999). Asterisk denotes significance at $P \leq 0.05$, after Bonferroni correction for multiple tests using the method of Hochberg (1988).

Area	Bering Sea	Western GOA	Central GOA	Eastern GOA
Aleutians	0.8843	0.0247	<0.0001*	<0.0001*
Bering Sea		0.0125	<0.0001*	<0.0001*
Western GOA			0.0073*	0.1924
Central GOA				0.0488

returns from the fishery cannot be associated with an amount of catch at a precise location.

When pooled over areas or years the tag-reporting rates were reasonably precise. There appear to be different reporting rates by area. In general, the Bering Sea and Aleutian areas had lower reporting rates than the Gulf of Alaska areas. Not known is why there are differences in estimated reporting rates among areas. We provided a cursory examination of the spatial and temporal aspects of sablefish tag reporting rates. A more comprehensive evaluation of area and year interactions, perhaps within the maximum-likelihood framework described by Hearn et al. (1999), should be the focus of future analyses.

Factors which may influence the tag-reporting rate for sablefish at various times are the number of tags available for recovery, the length of the commercial season, the presence of observers on commercial vessels, and the tag reward program. Nearly half (45%) of the tagged sablefish were released in the 5 years from 1979–1983. The relatively high number of tagged fish available during those years may have increased the awareness of fishermen and resulted in the higher reporting rates for 1983–1985. The increasing domestic participation in the fishery at this time may also have played a role in the high reporting rates.

Until 1984 the fishing season for sablefish in the GOA was year-round. The season was shortened to 7.6 months in 1984 and to 3.0 months in 1985. From 1986 through 1994 season length ranged from 1.8 months to 0.3 months (1994). Season length was restored to 8 months with the implementation of the Indi-

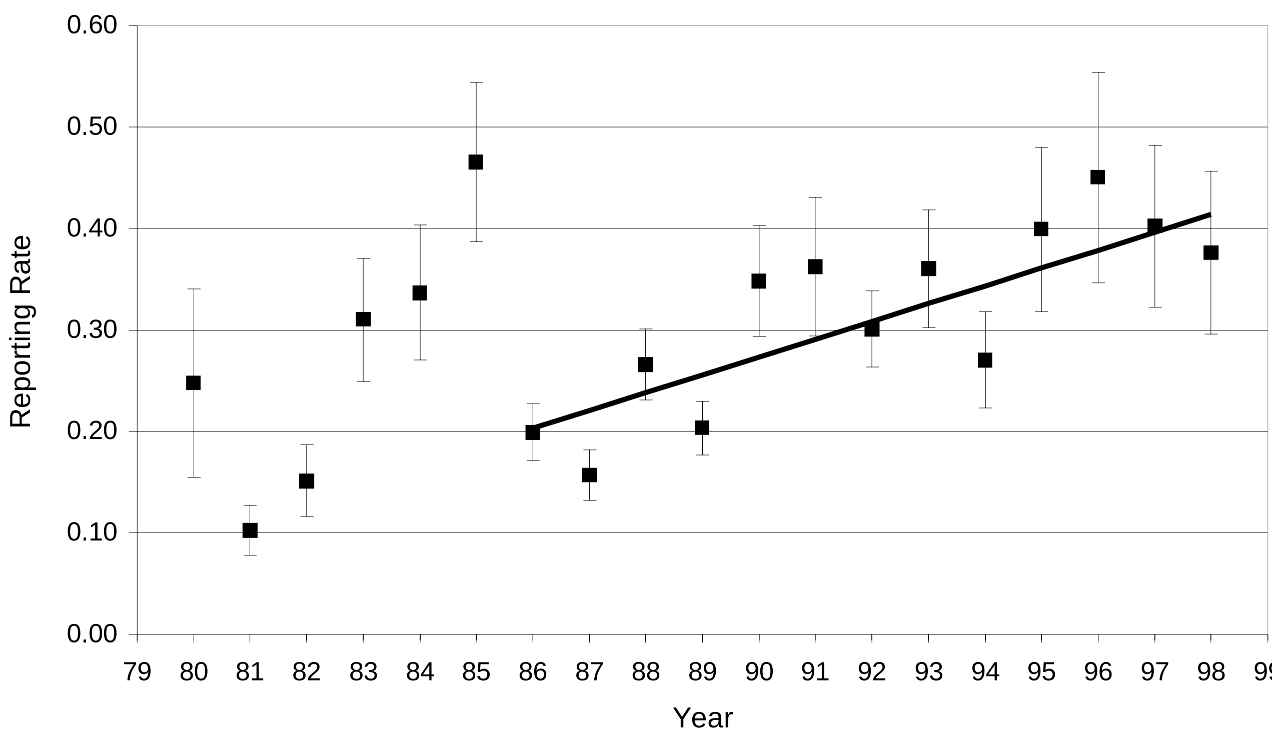

Figure 3. Estimated tag-reporting rates (± 1 standard error) by year for the sablefish fishery in Alaska, and relationship between reporting rate and year for 1986–1998 ($r^2 = 0.67$).

vidual Fishing Quota (IFQ) system in 1995. The short derby-like fisheries of the late 1980s and early 1990s could have had a detrimental effect on reporting rates because fishermen were under pressure to haul gear and deliver fish as fast as possible. The fishing season has remained at 8 months since 1995, and reporting rates have remained higher than at any time other than the peak year of 1985. The tag-reporting rates for British Columbia sablefish also increased with British Columbia's implementation of IFQs (R. Hilborn, University of Washington, personal communication).

Before 1987 a small cash reward was offered for recovered tags, and fishermen received a letter with release and recovery information. Beginning in 1987 a baseball cap was offered as an alternative to cash, and in 1992 an annual drawing for cash prizes of $1,000, $500, and $250 was instituted as further encouragement to return tags. These new incentives and the attached publicity may be partly responsible for the gradual increase in reporting rates since 1987.

In conclusion, we have provided estimates of tag-reporting rates that should enable use of the extensive tagging data for sablefish within the stock assessment model used to recommend catch quotas. The present configuration of the age-structured model used in Alaska's sablefish assessment obtains abundance of the population pooled over areas (Sigler 1999). All parameters are assumed to be constant over area. Thus, a logical next step would be to explore including in the age-structured model the tagging data with our estimates of the year-specific reporting rates pooled over areas. A more sophisticated model that includes migration will need to consider the spatial variation in tag-reporting rates. The framework for such a model has been described by Heifetz and Quinn (1998) and Haist (1998).

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