Estimates of tag loss from double-tagged sablefish, *Anoplopoma fimbria*

William H. Lenarz
Tiburon Laboratory
National Marine Fisheries Service, NOAA
3150 Paradise Drive, Tiburon, California 94920
E-mail address: billl@tib.nmfs.gov

Franklin R. Shaw
Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA
7600 Sand Point Way NE, Seattle, Washington 98115-0070

Abstract.—Between 1986 and 1988, 10,545 double-tagged sablefish were released off California, Oregon, and Washington. Tags recovered from these fish have provided one of the best sets of data available for estimating tag-shedding rates. We developed a new model and a maximum-likelihood procedure to estimate the rates. Both initial and long-term shedding rates were low, but posteriorly placed tags were shed at about twice the rate of anteriorly placed tags. Bootstrapping indicated that the estimates were precise and accurate. Shedding rates for sablefish were considerably lower than most published estimates for other species. Although the rates were low, the extra tag increased recoveries by nine percent over a six-year period.

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The sablefish, *Anoplopoma fimbria* (Pallas, 1811), is a long-lived species (Beamish and McFarlane, 1987) of considerable commercial importance (Kinoshita, 1987; Korson and Kinoshita, 1989; Kinoshita et al., 1996) and is found in the north Pacific Ocean from Baja California, north to the Bering Sea, and south to Japan in the western Pacific (Sasaki, 1985). Scientists have used tagging to study population size, mortality, migration, and movement of this species for more than four decades (Holmberg and Jones, 1954; Wespestad et al., 1983; Beamish and McFarlane, 1988; Fujioka et al., 1988; Heifetz and Fujioka, 1991).

Estimates of mortality and exploitation rates, along with estimates of population size, can be biased owing to loss or shedding of tags (Wetherall, 1982). Estimated rates of tag loss are used to correct the bias. The placement of two tags in the same fish (double-tagging) is the most common technique used to obtain data for estimation of tag loss rates (Beverton and Holt, 1957; Gulland, 1963; McFarlane et al., 1990). In this study we estimate the rate of tag loss from sablefish, using results from a double-tagging experiment.

Methods

Sablefish were captured with fish traps (Parks and Shaw, 1994), double tagged, and released by the Alaska Fisheries Science Center (AFSC) during 1986, 1987, and 1988. The Southwest Fisheries Science Center (SWFSC) used bottom trawl gear (Butler et al., 1989) to capture additional sablefish for double tagging in 1987. Identical tags and tagging procedures were used during the three years.

Captured sablefish were routinely put into "live" tanks supplied with fresh-running seawater immediately after the catch was brought on board (Shaw, 1984). No anesthetic was used. Usually within 15 minutes of the completion of each haul, sablefish were dip-netted from the live tank and placed in a padded tagging cradle. Each sablefish was tagged with two identical anchor tags (Floy FD-68). Tags were 60 mm long, 2 mm in diameter, yellow in color, and labeled with a unique number and with instructions on where to return the tag. The primary tag was placed below the anterior end of the first dorsal fin, and the secondary or extra tag was placed near the posterior end of the same fin. Each tag was inserted between and engaged behind the pterygiophores of the dorsal fin. Fork length, tag number, and the geographical position and date of release were recorded for each fish. Only fish judged to be in viable condition were tagged.

Wetherall (1982) reviewed literature on analytical methods for estimating tag-shedding rates. For mathematical convenience, tag shedding is usually described by tag-retention models. Following Wetherall (1982) and common practice, we assume that the retention rate of a tag of type i through the mid-point of the jth recovery period (ret_{ij}) is

$$ret_{ij} = \rho_i e^{-L_i t_j}, \qquad (1)$$

where ρ_i = retention rate during initial brief time after tagging for tag type i;
L_i = instantaneous tag shedding rate for tag type i;
i = 1 for anterior tag;
i = 2 for posterior tag; and
t_j = time at liberty at midpoint of jth recovery period.

We used a weighted linear regression approach, as suggested by Wetherall (1982) for multiple releases, for an exploratory analysis of the data. The results indicated that ρ_i did not vary with tag type, but that L_i did. The regression approach assumed that the error terms were independent and normally distibuted. We believed that these assumptions may not be valid and that it would be more appropriate to use a maximum-likelihood procedure for the analysis. We also decided to assume that ρ is independent of tag type. Because the linear regression approach was used only for an exploratory analysis of the data, we neither describe it nor present the results from using it in this paper.

We developed a new model and used maximum-likelihood principles to estimate the parameters, following the suggestions of Wetherall (1982). We combined recoveries from the three release periods and estimated confidence bounds for the parameters (ρ, L_1, and L_2) by bootstrapping (Efron and Tibshirani, 1993).

The probability that a tag of type i is shed by the jth recovery period is

$$J_{ij} = 1 - \rho e^{-L_i t_j}. \qquad (2)$$

Then the probability that a recovered tag-bearing fish has only tag type 1 during the jth recovery period is

$$P_{1j} = \frac{J_{2j}(1-J_{1j})}{1-J_{1j}J_{2j}}.$$

The probability that a recovered tag-bearing fish has only tag type 2 during the jth recovery period is

$$P_{2j} = \frac{J_{1j}(1-J_{2j})}{1-J_{1j}J_{2j}}.$$

The probability that a recovered tag-bearing fish has both tags is

$$P_{3j} = \frac{(1-J_{1j})(1-J_{2j})}{1-J_{1j}J_{3j}}.$$

We assumed that the proportions of tag recoveries among recovery type followed a multinomial distribution. After terms not affected by the parameter estimates were dropped, the log likelihood of the observed recoveries is

$$\mathscr{L} = \sum_{j=1}^{T}\Big[r_{1j}\ln(J_{2j}) + r_{2j}\ln(J_{1j}) + (r_{1j}+r_{3j})\ln(1-J_{1j})$$
$$+(r_{2j}+r_{3j})\ln(1-J_{2j}) - (r_{1j}+r_{2j}+r_{3j})\ln(1-J_{1j}J_{3j})\Big];$$

where T = number of recovery periods;
when i = 1 or 2,
r_{ij} = number of fish recovered with only a type i tag during jth recovery period; and
when i = 3,
r_{ij} = number of fish recovered with both tags.

We used the NLIN procedure (SAS Institute Inc., 1990) with the Gauss-Newton method, which requires derivatives of the log likelihood with respect to the parameters, to estimate the parameters of the model. The derivatives are

$$\frac{\delta\mathscr{L}}{\delta\rho} = \sum_{j=1}^{T}\Big[r_{1j}/(\rho - e^{L_2 t_j}) + r_{2j}/(\rho - e^{L_1 t_j}) +$$
$$(r_{1j}+r_{2j}+2r_{3j})/\rho -$$
$$(r_{1j}+r_{2j}+r_{3j})(1/\rho - 1/(div)e^{(L_1+L_2)t_j})\Big],$$

$$\frac{\delta\mathscr{L}}{\delta L_1} = \sum_{j=1}^{T}\Big[r_{2j}\rho t_j / e^{L_1 t_j} - \rho) - (r_{1j}+r_{3j})t_j -$$
$$(r_{1j}+r_{2j}+r_{3j})t_j e^{-L_1 t_j}(\rho e^{-L_2 t_j} - 1)/div\Big],$$

$$\frac{\delta\mathscr{L}}{\delta L_2} = \sum_{j=1}^{T}\Big[r_{1j}\rho t_j /(e^{L_2 t_j} - \rho) - (r_{2j} - r_{3j})t_j -$$
$$(r_{1j}+r_{2j}+r_{3j})t_j e^{-L_2 t_j}(\rho e^{-L_1 t_j} - 1)/div\Big],$$

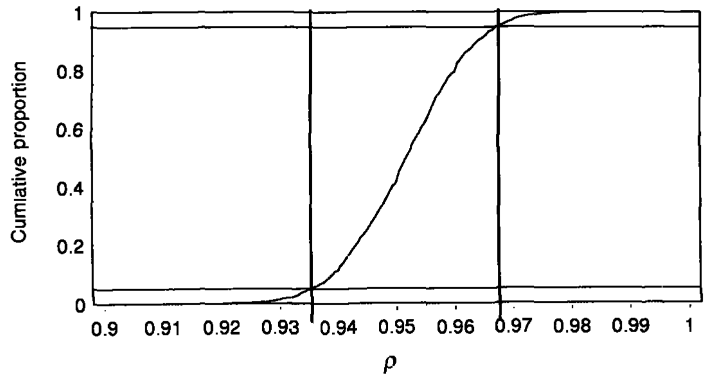

Figure 1

Estimated distribution function of initial tag-retention rate, $\hat{\rho}$, for sablefish from a 2,000 replicate bootstrap. Intersections of the vertical lines with the distribution function mark the estimated 90% confidence band.

where $div = e^{-L_1 t_j} + e^{-L_2 \rho t_j} - \rho e^{-(L_1+L_2)t_j}$.

We employed Mathematica (Wolfram, 1991) as an aid in deriving the derivatives.

We programmed a parametric bootstrap with 2,000 replicates in SAS to estimate confidence limits and bias. Since the bias estimates were very low, we used the uncorrected percentile method to estimate 90% confidence limits (Efron and Tibshirani, 1993).

Results

The SWFSC double tagged 229 fish during its egg-production survey cruise in early 1987. These fish were caught by bottom trawl and represented what was left over after needs for extensive biological samples were satisfied. The AFSC double tagged 10,316 fish during its sablefish abundance-indexing surveys in the fall of 1986, 1987, and 1988. The fish were caught by fish traps and represented a significant portion of the catches by the AFSC. There were five recoveries of trawl-caught fish and 1,552 recoveries of trap-caught fish through the end of March 1995. Because there was an insufficient number of recoveries from trawl-caught fish to allow for examination of recoveries by release gear types, we combined trawl and trap releases of tagged sablefish. We used recoveries of tag-bearing fish that were at liberty for no more than six years so that each release would have the same number of full years at liberty. Recoveries of tag-bearing fish were summarized by year of release and years at liberty (Table 1).

Bootstrap estimates of the averages and medians of the parameters, ρ and L_i, were very close to the maximum-likelihood estimates, indicating that the estimation procedure was unbiased (Table 2). The bootstrap-estimated distribution functions indicated that the density functions were unimodal, smooth, and symmetrical (Figs. 1 and 2). The 90% confidence band for ρ does not overlap with 1 (Fig. 1), indicating that although initial shedding is low, it is greater than 0. The 90% confidence bands for L_1 and L_2 do not overlap (Fig. 2), indicating that the instantaneous shedding rate is greater for posterior tags than for anterior tags. The model provided an excellent fit to the observed pattern of tag recoveries (Fig. 3).

Discussion

The double-tagging experiment with sablefish revealed that both immediate ($1-\rho$) and long-term instantaneous (L_i) tag loss rates were low and that long-term loss rates were higher for the posterior tagging position. The model fitted the recovery data very well, indicating that loss rates did not change with time at liberty during the first six years. Loss rates may have been higher for tags from the first release year because the ratio of single to double tag recoveries was higher than that during the other years (Table 1). Since tags and tagging procedures were identical in all three years, we assumed that any differences in loss rates were random.

Fishermen may have occasionally reported only one tag from recaptures of fish bearing two tags (Laurs et al., 1976; Wetherall, 1982). A reward was given for each tag returned to encourage complete reporting of tags, and single tags were checked to determine if the other tag of the pair had been reported at

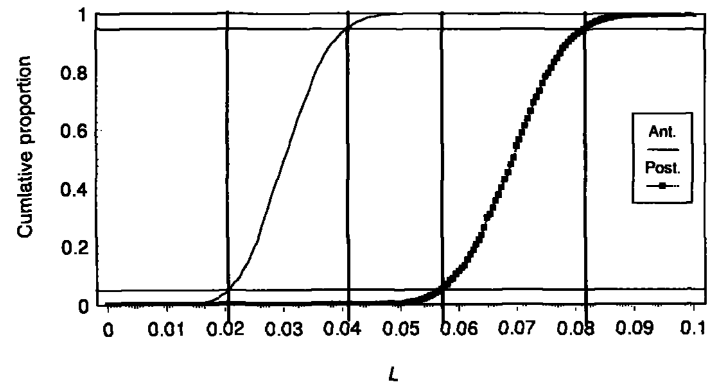

Figure 2

Estimated distribution functions of instantaneous tag-shedding rates, $\hat{L}_i$, of anterior and posterior tags for sablefish from a 2,000 replicate bootstrap. Intersections of the vertical lines with the distribution functions mark the estimated 90% confidence bands.

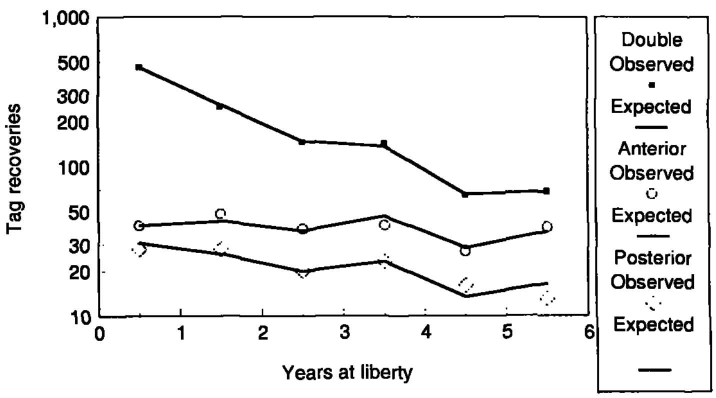

Figure 3

Observed and expected double- and single-tagged (anterior and posterior tags separately) recoveries of sablefish. Expected values were calculated from maximum-likelihood parameter estimates.

another time. Although we believe that most, if not all, reports of single tag recaptures were accurate, misreporting may have caused underestimation of ρ.

Tag-loss rates in this study are similar to those of Beamish and McFarlane (1988) for sablefish. They used two types of tags (anchor and suture) and did not find a significant difference in the rate of loss by tag type. From a line fitted by eye through the data, they found a loss rate of approximately 10% during the first year and 2% per year thereafter. Examination of Figure 2 of their paper indicated that ρ was about 0.95.

We present tag-loss rates from sablefish and other species in Table 3. Values were taken from the literature and standardized, as much as was feasible within limitations, owing to the variety of models used and plethora of reporting styles. The median estimate of L was 0.15, and the range was 0.00 to 3.93. Estimates of L for most species were higher than that for sablefish. The distribution of L estimates had a relatively long upper tail. Only a few of the other studies provided estimates of ρ, and the estimates for sablefish were in the middle of the range of the other estimates.

Although tag-shedding rates for sablefish were low, it still appears worthwhile to double tag. During the six-year recovery period, 128 sablefish were recovered with only a posterior tag. Thus, by double tag-

Table 1

Double-tag releases and recoveries of sablefish, *Anoplopoma fimbria*, during first six years at liberty. Number of releases are shown in parentheses.

	Recoveries			
		Single tag		
Years at liberty (Midpoint)	Both tags	Anterior	Posterior	Total
1986 releases (2,652)				
0.5	116	21	12	49
1.5	77	10	13	100
2.5	29	8	6	43
3.5	37	11	5	53
4.5	16	18	3	37
5.5	31	17	8	56
Total	306	85	47	438
1987 releases (1,872)				
0.5	74	3	5	82
1.5	16	4	1	21
2.5	19	7	2	28
3.5	19	3	4	26
4.5	11	5	2	18
5.5	11	6	1	18
Total	150	28	15	193
1988 releases (6,021)				
0.5	272	16	11	299
1.5	159	34	14	207
2.5	98	23	12	133
3.5	86	26	14	126
4.5	37	4	11	52
5.5	26	16	4	46
Total	678	119	66	863
Total releases (10,545)				
0.5	462	40	28	530
1.5	252	48	28	328
2.5	146	38	20	204
3.5	142	40	23	205
4.5	64	27	16	107
5.5	68	39	13	120
Total	1,134	232	128	1,494

Table 2

Maximum-likelihood estimates of rates of immediate tag retention ($\hat{p}$) and tag-shedding rates for anterior tags ($\hat{L}_1$) and posterior tags ($\hat{L}_2$)for sablefish. Also shown are estimates of the averages, medians, standard deviations, and ranges of the rates from 2,000 bootstrap replicates.

	Parameter		
	$\hat{p}$	$\hat{L}_1$	$\hat{L}_2$
Maximum-likelihood estimate	0.9516	0.0304	0.0694
Bootstrap average	0.9517	0.0304	0.0693
Median	0.9519	0.0302	0.0694
Standard deviation	0.0098	0.0062	0.0075
Minimum	0.9176	0.0108	0.0457
Maximum	0.9855	0.0515	0.0968

ging the fish, the total recoveries appeared to be increased by 9%. The cost of the double tagging was low compared to the cost that would have been incurred by increasing time at sea by 9%.

The parameter estimates of this study indicated that by the middle of the sixth recovery period, 19% of the anterior tags ($\hat{J}_{1,6}$) and 35% of the posterior tags ($\hat{J}_{2,6}$) had been shed, and 7% of the fish had lost both tags (($\hat{J}_{1,6}$) ($\hat{J}_{2,6}$)). Thus, even though shedding rates are low for sablefish, these rates are sufficiently high to affect analysis of tag-return data from this long-lived species.

Tag-shedding rates were high enough in many of the reviewed studies to warrant incorporation of tag-loss rates in analysis of tag-return data. Double tagging is necessary to estimate tag-loss rates. Thus we recommend that double tagging be considered, when feasible, for at least a portion of any tagging study. The number of fish released in our study was not affected by double tagging. It is possible, however, that in some situations double tagging could increase the time required to process fish so as to decrease the number of fish released. The tradeoff between the potential reduction in number of fish released and the potential increase in number of fish recovered should be considered when designing a tagging program.

In summary, analysis of returns from double-tag releases indicates that initial shedding of tags was 0.048. The long-term instantaneous rates of shedding were 0.030 and 0.069 for the anterior and posterior positions, respectively. Because there was a difference in the long-term instantaneous rates and because fish released with single tags are only tagged in the anterior position, corrections made for single-tagging experiments should be done only with the anterior tag loss rates.

Acknowledgments

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Table 3

List of immediate ($1-\hat{p}$) and long-term instantaneous (L) tag-loss rates found in the literature. Some authors did not estimate $\hat{p}$.

Species (and tag type)	Authors	Immediate $1-\hat{p}$	Annual $\hat{L}$
Plaice (silver wire)	Gulland, 1963		0.162
Plaice (stainless steel)	Gulland, 1963		0.025
Pacific yellowfin tuna	Chapman et al., 1965		0.814
Pacific yellowfin tuna	Bayliff and Mobrand, 1972	0.087	0.278
Southern bluefin tuna	Hynd, 1969		0.26
Southern bluefin tuna	Kirkwood, 1981		0.205
Southern bluefin tuna (60's and 70's)	Hampton and Kirkwood, 1990		0.173–0.301
Southern bluefin tuna (80's)	Hampton and Kirkwood, 1990		0.056
Atlantic bluefin tuna	Lenarz et al., 1973	0.027	0.310
Atlantic bluefin tuna	Baglin et al., 1980	0.042	0.186
North Pacific albacore	Laurs et al. 1976	0.12	0.086–0.098
Australian salmon	Kirkwood and Walker, 1984		0.29
Stripey sea perch (dart)	Whitelaw and Sainsbury, 1986		2.116
Stripey sea perch (anchor)	Whitelaw and Sainsbury, 1986		0.415
Sablefish	Beamish and McFarlane, 1988	0.05	0.020
Sablefish (anterior)	This study	0.048	0.030
Sablefish (posterior)	This study	0.048	0.069
Rig (anterior)	Francis, 1989		0.039
Rig (posterior)	Francis, 1989		0.013
Largemouth bass (anterior)	Hightower and Gilbert, 1984		3.977
Largemouth bass (posterior)	Hightower and Gilbert, 1984		1.370
Striped bass (anchor)	Waldman et al., 1991		0.229
Striped bass (internal anchor)	Waldman et al., 1991		0.004
White bass	Muoneke, 1992	0	0.285
Lingcod	Smith et al., 1990		0.137
Black rockfish	Lai and Culver, 1991		0.131
Brown trout	Faragher and Gordon, 1992		0.181
Rainbow trout	Faragher and Gordon, 1992		0.201
Cutthroat trout (coded wire)	Blankenship and Tipping, 1993		0.000
Cutthroat trout (visible impl)	Blankenship and Tipping, 1993		0.035
Northern pike (anchor)	Pierce and Tomcko, 1993		0.015
Northern pike (Dennison)	Pierce and Tomcko, 1993		0.015
White sturgeon (anterior)	Rien et al., 1991		0.041
White sturgeon (posterior)	Rien et al., 1991		0.128
Channel catfish (spaghetti)	Timmons and Howell, 1995		0.286
Channel catfish (anchor)	Timmons and Howell, 1995		0.252
Blue catfish (spaghetti)	Timmons and Howell, 1995		0.177
Blue catfish (anchor)	Timmons and Howell, 1995		0.083
Smallmouth buffalo (spaghetti)	Timmons and Howell, 1995		0.489
Smallmouth buffalo (anchor)	Timmons and Howell, 1995		0.036
Bigmouth buffalo (spaghetti)	Timmons and Howell, 1995		0.611
Bigmouth buffalo (anchor)	Timmons and Howell, 1995		0.000
Paddlefish (spaghetti)	Timmons and Howell, 1995		0.036
Paddlefish (anchor)	Timmons and Howell, 1995		0.022

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