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ESTIMATES OF RATES OF TAG SHEDDING BY NORTH PACIFIC ALBACORE, *THUNNUS ALALUNGA*

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ABSTRACT

Type-I (immediate) and Type-II (instantaneous) rates of tag shedding by North Pacific albacore, *Thunnus alalunga*, are estimated using data from a double-tagging experiment. Type-I shedding is estimated to be about 0.12 and Type-II to be between 0.086 and 0.098 on an annual basis. The paper also contains a discussion on the accuracy of the estimates, and a method is developed to estimate possible bias due to fishermen reporting double tag recoveries as single tag recoveries. The possible bias is estimated to be low.

A tagging program was initiated in 1971, and is continuing, on North Pacific albacore, *Thunnus alalunga* (Bonnaterre), to examine their migration patterns, to obtain information for use in population studies, and to estimate rates of mortality. Because loss of tags through shedding can cause estimates of mortality to be biased upwards unless corrected for, part of the tagging program in 1972 consisted of an experiment in which 788 albacore were double-tagged to evaluate tag shedding by this species.

Chapman et al. (1965) developed a formulation of the return of single- and double-tagged fish which includes instantaneous loss rates due to fishing mortality, other mortality, and tag shedding. They then solved for the instantaneous rate of tag shedding given data from double-tagging experiments. Bayliff and Mobrand (1972) extended the work of Chapman et al. to provide estimates of the portion of tags which are retained after immediate shedding occurs. Results of the use of the Bayliff and Mobrand procedure to estimate rates of tag shedding from the double-tagging experiment on North Pacific albacore are presented in this paper.

METHODS

The tagging program is being conducted jointly by the National Marine Fisheries Service[2] (NMFS), NOAA, and the albacore fishing industry through the American Fishermen's Research Foundation[3] (AFRF).

Albacore were caught by commercial jig boats and a bait boat on charter to the AFRF. Fishing operations on jig boats were conducted with standard commercial albacore feathered jig-fishing equipment and commercial trolling methods. Most of the fish that were tagged and released from the bait boat were caught by the "winging" method of live-bait, pole-and-line fishing, whereby a fish is caught on an anchovy-baited barbless hook on the end of a short line attached to a stout pole. Immediately after hooking, the fish is lifted out of the water, swung toward the fisher, and caught under the arm of the fisher, who then removes the hook. A small number of the fish tagged from the bait boat were taken by trolling feathered jigs and on rod-and-reel using live anchovy as bait.

Special care was exercised to tag and release only fish judged to be in very good condition. Fish which showed signs of severe bleeding, which were hooked through the roof of the mouth or which showed signs of extreme exhaustion, were not tagged. For each tagged and released fish records were kept of the number of the tag, the date and time of tagging, the length of fish to the nearest lower centimeter, condition of fish, and sea surface temperature. A fish caught by pole and line was measured with a large caliper and tagged with two tags inserted almost simultaneously by a technician while the fisher held the fish under his arm. A fish caught on trolling gear and rod-and-reel was

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[3] AFRF administers revenues derived from an assessment paid on U.S. - landed albacore.

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measured on a Naugahyde-covered foam measuring pad and tagged by a technician while it was on the pad. In order to tag an albacore on each side, using this method, the fish had to be turned from side-to-side.

Spaghetti-dart type Floy[4] tags are being used in the tagging program. The tags are made of yellow Resinite tubing, 12 to 13 cm long and similar in structure to those described by Yamashita and Waldron (1958) and identical to those used by Fink (1965). The tags were inserted on both sides of the fish below the second dorsal fin with the aid of a beveled stainless steel piece of tubing, 14 to 16 cm long and 0.135- or 0.156-inch inside diameter. The tags were inserted so that the barb of the tag was lodged around the pterygiophores of the second dorsal fin.

We estimated rates of tag shedding using the notation and methodology of Bayliff and Mobrand (1972) for yellowfin tuna as did Lenarz et al. (1973) in a similar study on bluefin tuna. Bayliff and Mobrand's equations for returns of tags are:

$$n_{ddk} = F\tau N_D \pi \rho^2 e^{-(F + X + 2L)t_k} \qquad (1)$$

and

$$n_{dsk} = 2F\tau N_D \pi \rho \left(1 - \rho e^{-Lt_k}\right) e^{-(F + X + L)t_k} \qquad (2)$$

where

t_k = time at the middle of the kth recovery period of length τ days ($k = 1, 2$);

n_{ddk} = number of returns of double-tagged fish retaining both tags during the period centered at t_k;

n_{dsk} = number of returns of double-tagged fish retaining only one tag during the period centered at t_k;

N_D = number fish released with double tags;

π = portion of tagged fish which remain alive after the immediate mortality, including Type I tagging mortality, has taken place;

ρ = portion of the tags which are retained after Type-I (immediate) shedding has taken place;

F = instantaneous rate of fishing mortality;

X = instantaneous rate of other mortality (other included natural mortality, Type-II (long-term) tagging mortality, and apparent mortality due to migrations from the fishery); and

L = instantaneous rate of tag shedding (Type-II shedding).

Bayliff and Mobrand (1972), using Equations (1) and (2), showed that

$$\ln \frac{2n_{ddk}}{n_{dsk} + 2n_{ddk}} = -Lt_k + \ln \rho = y_k \qquad (3)$$

where y_k is an estimate of the natural logarithm of the proportion of tags retained up to time t_k. Note that the first factor of the right-hand side of Equation (2) is the integer 2. Both Bayliff and Mobrand (1972) and Lenarz et al. (1973) mistakenly left this multiplier out of the equation in their papers. However, the error was typographical and did not affect their derivations or results. Given n_{ddk}, n_{dsk}, and t_k, L and ρ are estimated using simple linear regression; or as in the case of this study when only two recovery periods are used, the solution of two simultaneous equations. Equations (1) and (2) assume that L and the total of F and X are constant over t_k. Since the albacore fishery is seasonal, the assumption is likely to be violated. The effect of the violation has not been examined.

RESULTS

Release and return data through 1973 are shown in Table 1. The number of returns in 1974 was insufficient for analysis. A chi-square test indicated that gear type did not have a significant effect on the proportions of single- and double-tag returns in 1972 ($\chi^2 = 1.117$, df = 1). Data from both gears were combined for the remainder of the analysis.

Estimates of ρ and L are shown in Table 2. Only returns that could be specified to the nearest week are included in Table 1. Precise dates of recovery

TABLE 1.—Tag releases and returns with information on date of recovery for North Pacific albacore and double-tag study.

Gear type	1972 double-tag releases	1972 returns: Double (n_{dd1})	1972 returns: Single (n_{ds1})	1972 returns: Average days out (t_1)	1973 returns: Double (n_{dd2})	1973 returns: Single (n_{ds2})	1973 returns: Average days out (t_2)
Jig	330	10	5	—	12	5	—
Bait	448	22	5	—	2	3	—
Total	778	32	10	54.71	14	8	451.55

[4]Floy Manufacturing Company, Seattle, Wash. Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

TABLE 2.—Estimates of rates of tag shedding, $\hat{L}$ (on an annual basis), retention, $\hat{\rho}$, from 1972 North Pacific albacore double-tag study.

Item	$\hat{L}$	$\hat{\rho}$
Undated returns excluded	0.098	0.88
Undated returns included	0.086	0.88

TABLE 3.—Tag releases and returns from North Pacific albacore single-tag studies.

Year of release	Number released	Number returned 1971	1972	1973	1974
1971	887	0	16	11	6
1972	1,304		27	47	14
1973	1,806			13	59
1974	2,490				35

could not be assigned to seven double-tag and two single-tag returns in 1972 and one double-tag return in 1973. We assumed that t_k was the same for the returns shown in Table 1 and the returns with unspecified recovery dates and included the 10 additional returns in a recalculation of $\hat{\rho}$ and $\hat{L}$ The results of the recalculations are similar to the original (Table 2). We estimated ρ to be about 0.88 and L on an annual basis to be between 0.086 and 0.098. This means that if no mortality occurs, 8.2 to 9.3% of all unrecovered tags are expected to be lost through shedding annually.

Our estimate of ρ is similar to the results obtained for yellowfin tuna ($\hat{\rho}$ = 0.913) by Bayliff and Mobrand (1972) and bluefin tuna ($\hat{\rho}$ = 0.973) by Lenarz et al. (1973). However, our estimate of L is considerably lower than that obtained for yellowfin tuna ($\hat{L}$ = 0.278) and bluefin tuna (L = 0.310).

Methodology for estimation of the variance of L and ρ when only two periods of recovery are available has not been published. However, we believe that the number of tag returns available for this study is too low for accurate estimates of ρ and L. We made the following calculations to illustrate the relative level of accuracy. If we arbitrarily assume that the returns of double- and single-tagged fish in 1973 were from a binomial distribution with the probability of a returned fish having only one tag being 0.5, the probability of having 8 or fewer fish returned with only one tag out of a sample of 22 fish from such a population is about 0.14. If 11 fish were returned with single tags (the expected value from the assumed distribution) instead of the 8 observed, our estimates of ρ would be 0.895 and our estimate of L would be 0.172. Thus it appears that there is a reasonable chance that our estimate of L (about 0.09) could be considerably lower than the true value.

We are not aware of any other data available from double-tag studies on albacore. However, there is a considerable amount of data available from single-tag studies conducted in recent years on albacore in the eastern North Pacific (Table 3). Return rates in the year after release were 0.018 for the 1971 releases, 0.036 for the 1972 releases, and 0.033 for the 1973 releases of single-tagged fish, for an average of 0.029. If the return rates are divided by 0.88 to account for Type-I tag shedding, the average becomes 0.033. The return rate in the year after release for the double-tag study was 0.027. If the rate is divided by 0.99 $(1 - (1 - \hat{\rho})^2)$ to account for Type-I shedding of both tags, the return rate is 0.027. Thus the return rates from the single-tag studies give further evidence that Type-II shedding is insignificant, because if it were not, return rates adjusted for Type-I shedding from the single-tag releases should be lower than return rates from the double-tag releases, provided mortality rates were similar for these years.

The above estimates are based on the assumption that all double-tag recoveries are reported as double-tag recoveries. A possible source of error is that some fishers may return only one tag from a double-tag recovery. These fishers might return only one tag because of their interest in albacore migrations, but retain the second tag as a souvenir. This would result in our underestimating the value of ρ. To illustrate the extreme case assume that ρ is actually 1.0, but we estimate it to be 0.88 because of incomplete reporting. Then assuming ρ = 1, Equations (1) and (2) become

$$n_{ddk} = F \tau N_D \pi B e^{-(F + X + 2L)t_k} \quad (4)$$

and

$$n_{dsk} = 2F \tau N_D \pi (1 - e^{-Lt_k}) e^{-(F + X + L)t_k} + (1 - B) F \tau N_D \pi e^{-(F + X + 2L)t_k} \quad (5)$$

where B = minimum proportion of double-tag recoveries that are reported as double-tag recoveries.

Manipulation of Equations (4) and (5) results in

$$\frac{(n_{dd2} + n_{ds2})(n_{dd1})}{(n_{dd1} + n_{ds1})(n_{dd2})} = \frac{2e^{Lt_2} - 1}{2e^{Lt_1} - 1} \quad (6)$$

and

$$B = \frac{(2e^{Lt_k} - 1)(n_{ddk})}{n_{ddk} + n_{dsk}}. \quad (7)$$

An estimate of L is obtained from an iterative solution of Equation (6). An estimate of the minimum value of B is obtained from substitution of the estimate of L into Equation (7). Our estimate of L and the minimum value of B, where only returns with specified dates are included in the calculations, are 0.087 and 0.78, respectively. When all of the return dates are included we estimate L to be 0.077 and B to be 0.78. Thus, it appears that the rate of reporting double-tag recoveries as single-tag recoveries is less than 0.22 $(1 - B)$.

However, we have no evidence to indicate that fishers have returned only one tag from fish recovered with two tags. We believe that fishers have turned in both tags of fish recovered with two tags based on interviews with those who have recovered tagged fish, the very good cooperation that we have received from them during the tagging program, and the fact that tags from recovered fish may be returned to the fisher if he wishes to have them.

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