Estimating tag-shedding rates for skipjack tuna, *Katsuwonus pelamis,* off the Maldives

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One source of uncertainty in fishery assessments based on tag release and recapture data arises from tag shedding—the loss of tags from fish from the time of tagging until tag recovery. Independent estimation of tag-shedding rates from double tagging experiments is an integral part of well-designed tagging experiments. Failure to allow for tag shedding can result in biases in estimates of important parameters derived from tag-recapture data, such as fishery-induced and natural mortality, and migration rates. A wide variety of methods have been proposed for estimating shedding rates using data from double tagging experiments, the variety in part resulting from the nature of the data available from the experiments. The earlier literature has been well integrated and reviewed by Wetherall (1982). More recently, Xiao (1996) has developed a general model that unifies the estimation of tag-shedding rates from double tagging experiments with exact and pooled times at liberty. Some recent examples of application of these methods include Xiao et al. (1999) for school gummy shark and Fabrizio et al. (1999) for lake trout.

Tag shedding is of two types (Wetherall, 1982). Type-I shedding is a one-time event and occurs immediately after tagging, usually as a result of suboptimal placement of tags in the fish. Effectively, it reduces the number of tags initially put out to sea. Type-II shedding is the loss of a tag or both tags over a period of time after the fish has been tagged and released back into the sea. For long-lived species, it may not occur at a constant rate because some tags are likely to have been applied more effectively than others, and some may become firmly embedded (with growth of muscle tissues), such that they are very unlikely to be detached from the fish (Kirkwood, 1981).

The Ministry of Fisheries and Agriculture, Maldives, carried out two tagging experiments: one in 1990–91 (Yesaki and Waheed, 1992) and the other between 1993 and 1995 (Anderson et al., 1996). The latter tagging experiment included a double tagging experiment in which 504 skipjack tuna, *Katsuwonus pelamis,* were double tagged, by using the same type of tags and techniques of tagging as used in the single tagging experiment (Anderson et al., 1996). As of end 1996, a total of 53 of these fish had been recovered. These data are considered to be of immediate importance for designing large-scale experiments in the Indian Ocean, strategic tagging simulation studies (e.g. Bertignac, 1996), and for comparing the estimated rates with those obtained from similar tuna double tagging experiments conducted elsewhere. Our note reports estimates of tag-shedding rates carried out in the Maldives.

Materials and methods

Tagging methods

Tagging was conducted on board local vessels fishing for skipjack tuna with pole-and-line gear using livebait. Plastic dart tags (100 mm × 1.5 mm diameter), manufactured by Hallprint™, Australia, were used throughout the experiment. The captured fish were gently placed on deck, quickly slipped onto a wet wooden measuring board, and held in place by biologists wearing cotton gloves. The first tag was inserted dorsally on the left-hand side, at an acute angle adjacent to the second dorsal fin so that the barb was caught under the fin-ray extension or the neural spine. The second tag was inserted about 1–2 cm posterior to the first on the right-hand side in the same manner. Consecutively numbered pairs of tags were used; even numbers were inserted on the left-hand side and odd numbers on the right. Where possible, fish were returned to the water, facing the vessel's bow, in a slightly head-down fashion. Tagging times (from hooking to release into the sea) ranged from 14 to 18 seconds. More details of the tagging program can be found in Yesaki and Waheed (1992) and Anderson et al. (1996).

Parameter estimation

The method of parameter estimation used here is the maximum likelihood approach introduced by Kirkwood and Walker (1984) and later extended by Hampton and Kirkwood (1990) and Hampton (1997). This method was developed for use with sets of data where recaptured fish are few, and with few fish that have shed a tag, provided that

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exact dates of recovery are known, as was the case with the data from the Maldives.

Following Kirkwood and Walker (1984), consider an originally single tagged fish. Assuming that α is the type-I retention probability (1 – type-I shedding probability) and λ is the type-II shedding rate, assumed to be constant for short-lived species such as the skipjack tuna, then for an originally single tagged fish, the probability of a tag being retained at time t is given by

$$Q(t) = \alpha \exp(-\lambda t). \quad (1)$$

Suppose that fish are double tagged with identical tags and released at time $t = 0$, and let $p_i(t)$ be the probability that the fish is alive and at liberty retaining i (i=0, 1, 2) tags at time t. Then, under the assumption that both tags are retained after immediate shedding and have independent and identical probabilities,

$$p_0(t) = [1 - Q(t)]^2$$

$$p_1(t) = 2Q(t)[1 - Q(t)] \quad (2)$$

$$p_2(t) = Q(t)^2.$$

In practice, identifiable recaptures will consist only of fish retaining either one tag or two tags. If $P'_i(t)$ is the probability that an originally double-tagged fish, recaptured at time t_i, is reported to have retained i tags (i=1, 2), then conditional on the retention of at least one tag, the probability of capturing a fish retaining two tags at time t is

$$P_2'(t) = \frac{p_2(t)}{1 - p_0(t)} \quad (3)$$

and the probability of capturing a fish retaining only one tag at time t is

$$P_1'(t) = \frac{p_1(t)}{1 - p_0(t)}. \quad (4)$$

Suppose n fish were recaptured in the experiment and reported to have retained at least one tag on recapture, and that the ith fish was recaptured at time t_i. Define indicator variables $N_i^{(2)} = 1$, $N_i^{(1)} = 0$ if two tags were reported upon recapture, and $N_i^{(2)} = 0$, $N_i^{(1)} = 1$ if only one tag was reported upon recapture.

It follows from Equations 3 and 4 that if all fish suffer the same risks of mortality, the log likelihood (ψ) of the data conditional on recapture times $\{t_i, i=1, 2, \dots, n\}$ is given by

$$\psi(\alpha, \lambda) = \sum_{i=1}^{n} N_i^{(2)} \ln\left[P_2'(t_i)\right] + N_i^{(1)} \ln\left[P_1'(t_i)\right]. \quad (5)$$

Maximum likelihood estimates of the parameters (α,λ) and their asymptotic standard errors were found by maximizing ψ with respect to them, by using the nonlinear minimization routines in AD Model Builder (Otter Research Ltd., 1996).

Results

The numbers of recoveries of originally double tagged fish reported as retaining one (indicating left- or the right-side tag) or two tags on recapture are shown in Table 1, with their times at liberty.

The maximum likelihood estimate of λ was 0.22/yr (SE=0.13) and that of α was 0.97 (SE=0.03). If α = 1, the maximum likelihood estimate of λ was 0.30/yr (SE=0.065/yr). A likelihood ratio test (Cox and Hinkley, 1974) shows that the full model does not provide a significantly better fit to the data (at 5% level) than its special case (α=1) (P=0.146).

Discussion

One of the most important assumptions in double-tagging experiments and in the model used in our analysis is that shedding rates of the first and second tags is the same (Hearn et al., 1991). A simple way to investigate possible differences in the shedding rates of the first and second tags is to examine the number of returns of fish that have retained either the first or the second tag and their temporal distribution. There were seven recoveries of fish reported to have retained a single tag, of which four fish retained the left tag and three retained the right tag (Table 1). Although few, the similar numbers of recaptured fish with tags on the left side as those on the right side and the temporal distribution of these fish (Table 1) show clearly that there is no evidence of differences in their shedding rates.

Another important assumption, but one that might easily be violated, and that is difficult to test, relates to the way in which double-tagged recoveries were reported. The common assumption (as made here) is that recoveries of fish retaining double tags were always reported as a pair, and never as a “single” tag recovery. It is also assumed that the probability of reporting fish recovered with single or double tags is the same. Hampton (1997) showed that under this assumption, the reporting probability has no influence on the maximum likelihood estimates of α and λ. Given the publicity and incentives to return all the recaptured tags (Anderson et al., 1996), and the procedures adopted in tagging, it is highly unlikely that these reporting-rate assumptions were violated in the Maldives tagging program.

In their original paper describing the method of analysis and application to small data sets, Kirkwood and Walker (1984) noted that potential bias arises because the resulting estimates are conditional on the times of recapture; a different time sequence of recapture times would result in different parameter estimates. Clearly, this potential bias arose in our experiment. Ideally, for robust estimation of the parameters, one would need a data set with large numbers of fish that have shed a tag. This point needs to be borne in mind when designing future tagging experiments for skipjack tuna in the Indian Ocean.

The type-II shedding rate estimate obtained from our experiment is similar to those obtained by Hampton and Kirkwood (1990) for southern bluefin tuna tagged and released during the 1960s and 1970s. However, recent estimates of type-II shedding rates obtained for skipjack tuna from the tropical western Pacific were much lower than those estimated in our study, as were estimates for southern bluefin tuna tagged in 1984 (Table 2). These differences in shedding estimates may be due to differences in the tagging method used and the use of measuring boards instead of cradles. Estimates of λ obtained for fish tagged on measuring boards ranged from 0.17 to 0.22/yr. For fish tagged in cradles, the corresponding range of estimates of λ was 0.05–0.09/yr (Table 2).

In the South Pacific Commission (SPC) double tagging experiments of 1989–92 (Hampton, 1997) and in the CSIRO experiment of 1984 (Hampton and Kirkwood, 1990), specially designed vinyl cradles were used to position the fish dorsal side up, making it easier to insert the tags. It is also likely that such cradles may have helped to keep fish calm, perhaps because the eyes of the fish were covered. In the Maldives experiment, the CSIRO experiments of 1963–77 and the Western Australian Department of Fisheries' experiment of 1970–78 (Hampton and Kirkwood, 1990), measuring boards were used. In many instances in the Maldivian experiment, the fish, particularly large individuals, struggled quite a lot while being tagged. This may have caused additional trauma to the fish and at the same time may have increased the likelihood of the tag being placed suboptimally, thereby increasing the apparent tag-shedding rate. Some fish handlers of the Maldivian tagging program observed that fish struggled less if they were gently laid on the board and the eye was quickly covered with one hand. This technique, however, was not applied universally.

Hampton and Kirkwood (1990) suggested that differences in shedding rates observed in the southern bluefin tuna experiments might also be due to differences in the quality of the tags used. Tags used in the earlier experiments (1960s and 1970s) were inferior, because the streamers were prone to detach. Tags used in later experiments had their heads heat-fused to the shafts and thus were almost impossible to detach under normal conditions (Hampton, 1997). The tags

Table 1

Numbers of recoveries of originally double tagged fish retaining one (indicating which tag, left or right) or two tags on recapture, and times at liberty.

Days at liberty	1 tag	2 tags	Days at liberty	1 tag	2 tags
6		1	61		1
7		1	63		1
8		1	66		1
9		1	71		1
10		2	73		1
11	1 (L)	1	78		1
13		1	90		1
14		3	91		2
15		1	98		1
16		2	142	1 (R)	
17		1	146		1
18	1 (L)		154		1
19		1	191		1
20		2	210		1
21		1	230		1
23		1	240		1
36		1	258	1(L)	
50		1	279	1(R)	
52		1	335		1
59		2	341		1
60	1 (R)		433	1(L)	

Table 2

Comparison of tag shedding rates estimated by using the maximum likelihood method from different double tagging experiments, with data on exact dates of recovery for skipjack (SKJ) and southern bluefin tuna (SBT). CSIRO = Commonwealth Scientific and Industrial Research Organization, Tasmania, Australia; WA Dept. Fish. = Western Australia Department of Fisheries; SPC = South Pacific Commission. P/L = pole and line.

	Parameter estimates ±SE				
Species	α	λ (per yr)	Reference	Experiment	Tagging method
SKJ	0.97 ±0.03	0.22 ±0.13	Our study	Maldives 1993–95	P/L board
SBT	0.93 ±0.02	0.29 ±0.05	Hampton and Kirkwood, 1990	CSIRO 1963–70	P/L board
SBT	0.97 ±0.006	0.17 ±0.01	Hampton and Kirkwood, 1990	CSIRO 1963–70	P/L board
SBT	0.96 ±.0.01	0.17 ±0.04	Hampton and Kirkwood, 1990	CSIRO 1977	P/L board
SBT	0.90 ±0.02	0.19 ±0.05	Hampton and Kirkwood, 1990	WA Dept. Fish. 1970–78	P/L board
SKJ	0.97 ± —	0.09 ± —	Hampton, 1997[1]	SPC 1989–92	P/L cradle
SBT	0.97 ±.007	0.05 ±0.008	Hampton and Kirkwood, 1990	CSIRO 1984	P/L cradle

[1] Estimates obtained by using pooled data.

used in the Maldivian experiment were recently manufactured and therefore this source of bias was unlikely. The higher tag shedding rate observed in the Maldivian data appears most likely to be due to the tagging method employed.

Ideally, experiment-specific double tagging experiments should be carried out to estimate independent experiment-specific tag-shedding rates. The above comparisons suggest that, in cases where independent estimates are not available, care must be exercised when applying estimates of tag-shedding rates obtained from other tagging experiments, especially where different tagging techniques have been used.

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