Update of the paper:

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Introduction

A considerable amount of turtle research is dependent on recognition of individual turtles by means of a tagging system. Moorehouse (1933), in his classic study of green turtles at Heron Island, using tags made from copper sheeting wired to the carapace, was able to record successive within-season nesting by the same turtle. There was no record of any of those tags ever having been recovered in a subsequent nesting season. Harrison (Harrison 1956a, Harrison 1956b, Harrison 1958), using a monel flipper tag on green turtles, obtained the first interseasonal tag recoveries for marine turtles but the number of such recoveries was low. With these early tagging studies, there was no attempt to quantify how well the tags would be retained by the turtles. In the early 1970s there was a growing awareness within the turtle research community that the long-term tag-loss problem needed to be addressed if reliable population dynamics studies were to proceed. This is illustrated by the discussions of tag loss and the suggestions for reducing it that featured in the Marine Turtle Newsletter (Balazs 1977, Cornelius 1977, Owens 1977). Mrosovsky (1983) criticized at some length the problem of non-quantification of tag loss in turtle-tagging studies. It has become apparent that many nesting beach taggers are suffering from what Mroovsky (1983) called the "tagging reflex"; that is, the desire to tag turtles simply because they are there.

In CMR models, individuals that have lost their tags are no longer recognizable and are indistinguishable from dead individuals. Therefore, tag loss can lead to biased estimates under CMR models (Arnason and Mills 1981, Nichols and Hines 1993, Seber 1982).

Tag loss reduced the precision of all estimates because tag loss results in fewer marked animals remaining available for estimation (Rotella and Hines 2005).
When tag loss rates varied by tag age, bias occurred for some of the sampling situations evaluated, especially those with low capture probability, a high rate of tag loss, or both. For situations with low rates of tag loss and high capture probability, bias was low and often negligible. Estimates of contributions of demographic components to population's growth rate were not robust to tag loss (Rotella and Hines 2005).

Several studies have provided evidence of dependent tag-loss, and the assumption of independence appears to be biologically unrealistic. Double ear tag-loss in sea otters, *Enhydra lutris*, (Siniff and Ralls 1991) and black bears, *Ursus americanus*, (Diefenbach and Alt 1998), and flipper tag-loss in fur seal pups (Bradshaw et al. 2000), elephant seals from Macquarie Island (McMahon and White 2009), and leatherback sea turtles (Rivalan et al. 2005) were all greater than expected under the independence assumption. In black bears, individual behavior such as fighting, mother–pup grooming or playing probably influences tag-loss (Diefenbach and Alt 1998). In fur seal pups, mechanical abrasion is thought to induce tag-loss, which is likely influenced by substrate, pup behavior and condition (Bradshaw et al. 2000). Dependent tag-loss in leatherback sea turtles is probably related to individual immunity, as the majority of tags are lost as a result of tissue necrosis. Individuals prone to infection may, therefore, be more likely to lose the second tag if the first tag was already lost (Rivalan et al. 2005). Tag-loss in elephant seals at Macquarie Island seems to be more dependent on pup wean mass (McMahon and White 2009).

**Why a new model was needed?**

The model used to study tag loss rate by Rivalan et al. (2005) must be updated for several reasons.

1- In the Rivalan et al. (2005) model, a similar shape can be obtained from a large set of parameters because some of them compensate each other. Thus identifiability of parameters, one of the conditions for the consistency of maximum likelihood estimate (Wald 1949), does not hold and the inverse of the information matrix of Fisher cannot be used to obtain the standard error of parameters. For this reason Rivalan et al. (2005) estimate the standard error for each parameter separately but it could biased the result.

This problem can be solved using a new model describing tag loss:
The daily tag-shedding rate is defined by segments but the function is derivable as all segments are in continuity. The most complex tag loss function uses 6 parameters (Figure 1) but it can be simplified as follow:

\[ \begin{align*}
  &\text{if } t < D_1, \\
  &\text{if } D_1 \leq t < D_2, \\
  &\text{if } D_2 \leq t < D_3, \\
  &\text{if } t \geq D_3,
\end{align*} \]

\[
\begin{align*}
  &1 + \cos\left(\frac{\pi (t + D_1)}{2 D_1}\right) (A - B) + B \\
  &B \\
  &1 + \cos\left(\frac{\pi (t - D_2)}{D_3 - D_2}\right) \frac{1}{2} (B - C) + C \\
  &C
\end{align*}
\]

\(D_1 = D_2 = D_3 = 0\) and \(A = B = C\) for constant daily tag loss rate (1 parameter)

\(D_1\) and \(D_2 = D_3 = +\infty\) and \(A > (B = C)\) for different tag-loss rate just after tagging and constant after (3 parameters) (Figure 2)

Many other combinations can be implemented.

Figure 1: Example of a model with \(A \neq B \neq C\) and \(D_1 < D_2 < D_3\).
The equation 4 in annex A was a simplification of the true equation when $p^2 = 0$ (Rivalan et al. 2005). This simplification was justified because generally the daily tag loss rate $p$ is very low and obviously $p^2$ is still much lower. However, it could bias the result when $p$ is not so low, for example just after tagging. The probability that an individual retained both tags a day $t$ is:

$$\left(1 - p(t)\right)^2 \text{ instead than } 1 - p(t) \times p^*(t) - 2 \times p(t) \times \left(1 - p^*(t)\right)$$

as stated in Annex A, equation 4. This equation 4 was used also for equations 5 to 9.

The model selection was based on AIC whereas Burnham and Anderson (2002) preconized the use of AIC corrected for small size, named AICc. For the case of the Rivalan et al. (2005) paper it will not change anything, but for smaller dataset, it could change the selected model.

The new model can use more easily cofactors, for example tag loss rate dependent on the year or the condition of animal.
New implementation

The new model is coded as R functions.

When the model is applied to the data used in Rivalan et al. (2005) paper, results are qualitatively similar but quantitatively different (compare Figure 3 and figure 3 in Rivalan et al. (2005)). Note that many models were not tested and model selection was not performed for this short note.

![Graph showing daily tag loss rate for leatherbacks in French Guiana.]

Figure 3: Tag loss rate for leatherbacks in French Guiana.

Bibliography


