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Estimation of Tag Loss in Marine Turtle Research

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Abstract

From the results from long-term multiple tagging studies of marine turtles in eastern Australia, the probability of tag loss was estimated for standard monel and titanium turtle tags applied at different tagging positions on *Caretta caretta* and *Chelonia mydas* in nesting and feeding-ground studies. Tag loss was variable, being a function of tag design, tagging position, species, study type and tag age. Tag loss was greatest from the more distal tagging positions on the trailing edge of the front flippers. Rear flipper tags were lost at a higher rate than tags in the axillary-tagging position on the front-flipper. Tag loss was greater for turtles tagged in nesting studies than in feeding-ground studies. Monel tags, in general, were lost at a greater rate than titanium tags. There was a species contribution to titanium tag loss but not to monel tag loss. The probabilities of tag loss calculated for this study can be used as correction factors for tag loss in those marine-turtle studies where recapture rates have been measured.

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 I., using tags made from copper sheeting wired to the carapace, was able to record successive within-season nestings by the same turtle. There are no records of any of those tags ever having been recovered in a subsequent nesting season. Harrison (1956*a*, 1956*b*, 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 (Mrosovsky 1985). Mrosovsky (1983) criticised at some length the problem of non-quantification of tag loss in turtle-tagging studies.

To resolve this problem for Australian sea turtle studies, a long-term double-tagging experiment was commenced within the Queensland Turtle Research (QTR) Project in June 1978. It was designed to quantify rates of tag loss from different tagging positions that had been used on various turtles in Australian studies, as well as for different tag designs, turtle species and life-history stages. As the experiment progressed it became apparent that an unknown proportion of breeding turtles can skip more than five years between breeding seasons (Limpus 1989). As a consequence, measuring rates of tag loss over at least a 5-year interval was set as the goal when assessing any one tag design. The first results of this study are presented here.

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Methods

Tags were applied to defined positions on front and rear flippers. For the purposes of this study, corresponding tag positions on the left (L) and right (R) flippers were pooled during analyses. Three positions along the trailing edge of the front flipper were used for tag attachment (Fig. 1).

Position 1 (L1 and R1) was located between the scales immediately distal to the very large scale over phalange 5. This is the position recommended for tag application by Bustard (1968) and used as the standard tagging position for green turtles (*Chelonia mydas*), hawksbill turtles (*Eretmochelys imbricata*) and flatback turtles (*Natator depressa*) in the QTR project prior to June 1978. It was also used with loggerhead turtles (*Caretta caretta*) prior to July 1972.

Position 2 (L2 and R2) was located between the second and third large scale proximal to phalange 5. This is approximately the tagging position recommended by Pritchard *et al.* (1983). This was the standard tagging position with *Caretta caretta* in the QRT project from July 1972 to June 1978.

Position 3 (L3 and R3) was located through or immediately adjacent to the large scale on the proximal rear edge of the flipper immediately adjacent to the axilla. This tagging position has been used by Harrison (1956*a*), Carr and Caldwell (1956), Schulz (1975) and Balazs (1983).

The tagging position on the hind flipper was between the fourth and fifth phalanges.

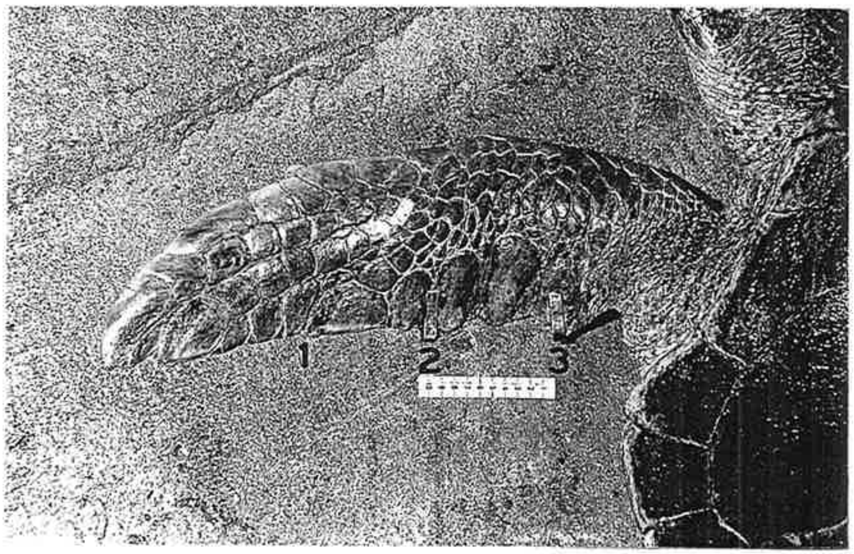


Fig. 1. Front flipper, tagging positions 1–3. See text for specific definition of positions. This turtle has been tagged in the L2 and L3 tagging positions. Scale in cm.

All tags were applied as self-piercing, self-locking tags by means of the respective specific tag applicators supplied by the tag manufacturers. Two standard monel tags (size 1005, styles 49 and 19) used extensively in marine turtle research were purchased from the National Band and Tag Company (Newport, U.S.A.) (see Hughes 1982, fig. 2; Pritchard *et al.* 1983, fig. 17 for illustrations of these tags). Two large-size, titanium turtle tags purchased from Stockbrands Pty Ltd (Perth, Australia) were used: titanium No. 1 was made from grade 120 commercially pure titanium (CPT); titanium No. 2 was made from grade 125 CPT. These tags were very similar in linear dimensions to the above monel tags and had a locking mechanism similar to that of the monel No. 19 tag. Use of the grade 120 CPT tag was discontinued because the metal was too soft to allow the tag to be used reliably as a self-piercing tag. Many problems was encountered with its application. The use of the less flexible grade 125 CPT metal produced a tag that could be applied reliably. One green 9·2-g plastic cattle-ear-tag purchased from Alflex Tag Co. Pty Ltd (Collingwood, Victoria) was used—size combination No. 6 (for female half of tag) and No. 3 (for male half). Thickness and weight of the metal tags are summarised in Table 1.

The monel and titanium tags were applied to approximately the full length of the tag across the flipper. Initially each turtle was tagged with two tags in different positions. On subsequent recaptures, additional tags were added as required to ensure that each turtle was released carrying at least two securely applied tags. In general, old tags were not removed, irrespective of their condition. This often resulted in a turtle carrying more than two tags at any one time. If a tag was intentionally removed, it became ineligible for consideration in estimates of tag loss in subsequent years. When new tag designs were introduced to the study, they were often applied singly to turtles already carrying two other tags. Double-tagging with monel No. 49 tags commenced in June 1978, with *Chelonia mydas* being tagged in L1 and L3 tagging positions and *Caretta caretta* being tagged in L2 and L3 tagging positions. Commencing in January 1981, tagging for all species was changed to L2 and R3 tagging positions and monel No. 19 tags were brought into use. Since February 1982, almost all standard tagging has been with titanium tags in the L3 and R3 tagging positions. Some small series of turtles have been tagged, each with additional monel No. 19, titanium No. 2 or plastic tags on the hind flipper.

The results of tagging two species of marine turtle, *Caretta caretta* and *Chelonia mydas*, are considered in this report. Each species was tagged within two types of studies, representing two different life-history stages for marine turtles: nesting female turtles were tagged and subsequently recaptured at Queensland rookeries at Mon Repos and Wreck Rock beaches on mainland south Queensland and at Heron, Wreck and Northwest Is in the adjacent Capricorn Group of the southern Great Barrier Reef; and turtles were tagged and recaptured within their home feeding grounds on the coral reefs of the Capricorn Group. This latter category included turtles of both sexes, ranging in size from small immatures with curved carapace length (CCL) of 36 cm to adult males and females with CCL up to 122 cm.

Table 1. Thickness and weight of metal turtle tags

See text for detailed description of the tags

Metal	Design	Thickness (mm) Mean ± s.d.	*n*	Weight (g) Mean ± s.d.	*n*
Monel	49	0·91 ± 0·015	34	6·99 ± 0·079	34
	19	0·94 ± 0·025	40	7·04 ± 0·063	40
Titanium	1	1·07 ± 0·039	50	4·01 ± 0·057	50
	2	1·03 ± 0·017	31	4·10 ± 0·062	31

When a turtle was recaptured, all tags still on the turtle were recorded. By checking original tagging records, all tags applied to the turtle were listed. Each tag was considered independently, and for each tag, if the turtle could be identified independently of this tag, the tag was scored for metal type, design, presence/absence and years since application (to the nearest whole year). If the turtle could not be identified independently of the tag under consideration, then that tag was deleted from tag-loss analysis for that capture. For each tag design,

i = tag age, i.e. number of years since tag was applied;

a_i = number of turtles recaptured in year i that were still wearing the tag with a readable number;

b_i = number of turtles recaptured in year i that had lost the tag or with a tag number that could not be read.

The probability of tag loss was analysed with respect to tag age, tag design, tagging position, study type and turtle species by means of unweighted logistic regression (Statistix, version 3.0, Analytical Software, St Paul). Data resulting from factors that made no significant contribution to tag loss were pooled in subsequent analyses to calculate probabilities of tag loss. Therefore, p_i, the probability of the tag being lost or unreadable after i, years, was calculated according to the equation

$$p_i = b_i/(a_i + b_i)$$

with 95% confidence limits for p_i being $\pm 1\cdot 96[p_i(1-p_i)/(a_i+b_i)]^{1/2}$.

Results

Tag loss resulted from diverse causes. Tags applied to positions 1 and 2 on the trailing edge of front flippers could be bitten by the turtle itself. This was particularly so with *Caretta caretta*. Also, tags were regularly bitten by attendant males biting at the flippers of mounted males during courtship. When a tag was bent and tightly squeezed against the underlying flipper, the tissues degenerated, contributing to increased probability of tag loss. Tags at times were sprung open or pulled from the flippers when turtles became entangled in nets and ropes. On the nesting beach it was not uncommon for a turtle still wearing old tags to return to the rookery after several years and for her to lose some or all of these tags as the nesting season progressed, usually during the more vigorous action of digging or filling the body pit. Tags not securely closed at application were more easily lost under the above conditions. Loss within weeks or a month or so of application reflects the problem of faulty application and/or mechanical stress on the tag. For example, of 1411 *Caretta caretta* double-tagged (L2, L3) with monel No. 49 tags while nesting at Mon Repos and Wreck Rock over three nesting seasons (1978–81), 6 were recorded as losing their L3 tag only, 17 their L2 tag only and 1 lost both tags during the course of the nesting season. These represent estimates of tag loss within the season of application of 0·5% and 1·3% for monel No. 49 tags from the front flipper L3 and L2 tagging positions, respectively.

However, the most visible cause of monel-tag loss was corrosion, especially where the tag was embedded in the turtle. Corrosion rates varied between habitats. In the extremes, monel tags used in freshwater habitats on terrapins and crocodiles have shown no corrosion after 13 years while all monel tags applied to marine turtles and two oceanariums were reduced to tag fragments in less than three months (Limpus, unpublished data). Monel tags on marine turtles in the wild show varying degrees of corrosion within a year or so of application. In contrast, no titanium tags showed signs of corrosion after seven years at sea

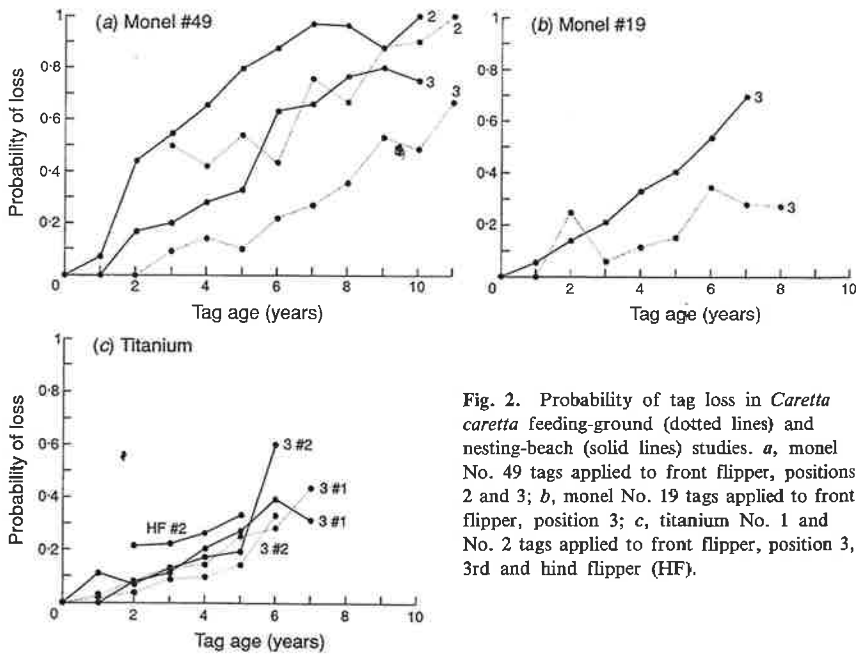


Fig. 2. Probability of tag loss in *Caretta caretta* feeding-ground (dotted lines) and nesting-beach (solid lines) studies. *a*, monel No. 49 tags applied to front flipper, positions 2 and 3; *b*, monel No. 19 tags applied to front flipper, position 3; *c*, titanium No. 1 and No. 2 tags applied to front flipper, position 3, 3rd and hind flipper (HF).

on the turtles. The non-corroding, non-toxic properties of titanium can, however, be a disadvantage in some soft-bottom habitats where large clusters of barnacles can form on the tags: the weight of the barnacles can cause the tag to tear from the flipper. The monel tag, with its contained nickel, has a built-in anti-fouling agent and was never observed encrusted with the thick coralline algae and large barnacle clusters that occurred on many titanium tags. The plastic tags suffered from two problems not encountered with the metal tags: after about three years at sea, the spike that joined the two halves of the tag together became brittle and broke easily, whereas with others, the numbers wore off by abrasion in less than one year. A corresponding brittleness has not developed with two of the original plastic-tag purchase that have been stored within an office filing cabinet for seven years.

Measurements of tag loss from recaptures up until April 1989 are summarised for *Caretta caretta* in Table 2 and Fig. 2. There were insufficient tag recoveries of *Caretta caretta* tagged with monel tags on the hind flipper for useful analysis. The results of stepwise logistic regression of the tag-loss data from *Caretta caretta* tagged with monel tags applied to positions on the front flipper (Table 3) showed that the design of the monel tags (whether No. 19 or No. 49) made no significant contribution to tag loss. There were significant increases in tag loss with increasing tag age. There was greater tag loss associated with *Caretta caretta* studied on nesting beaches than with those studied in their feeding grounds, and tag loss was greatest from the more distal (L2 or R2) tagging positions than from the axillary tagging positions (L3 or R3) on the front flippers. A similar analysis of titanium-tag loss from the front flipper of *Caretta caretta* (Table 3) showed that the design of the titanium tags (whether No. 1 or No. 2) made no significant contribution to tag loss. Tag loss was greater from the tagging position on the hind flipper than from the axillary tagging positions (L3 or R3) on the front flippers. As occurred with the monel tags, there were significant increases in titanium-tag loss with respect to increasing tag age and there was greater titanium-tag loss associated with *Caretta caretta* studied on nesting beaches than with those studied in their feeding grounds.

Measurements of tag loss from recaptures up to April 1989 are summarised for *Chelonia mydas* in Table 4 and Fig. 3. Within the context of the broader comparative study, there were limited recaptures of multiple-tagged *Chelonia mydas* in the nesting studies and no simple model was found to fit all the data from recaptures of *Chelonia mydas* tagged with monel tags. The sample from the nesting studies was more variable than that from the feeding-ground study and a subjective examination indicated that there was greater monel-tag loss associated with nesting than with feeding-ground studies. To enable a more rigorous analysis of at least some of the data from monel tagging of *Chelonia mydas*, further analysis was restricted to the data set from the feeding-ground study only. The results of stepwise logistic regression of the tag-loss data from *Chelonia mydas* in the feeding-ground study and tagged with monel tags applied to positions on the front flipper are summarised in Table 5. There were significant differences in the contribution to tag loss by the two monel tag types: monel No. 19 resulted in lower tag loss than monel No. 49. Tag loss was also a function of where the tag was applied on the front flipper, being greatest from the more distal (L1 or R1) tagging positions than from the axillary (L3 or R3) tagging positions. Tag loss increased significantly with increasing tag age. The results of a similar analysis of the tag-loss data for titanium tags applied in position 3 on the front flipper (Table 5) showed that the design of the titanium tags (whether No. 1 or No. 2) made no significant contribution to tag loss. There was greater tag loss associated with *Chelonia mydas* studied on nesting beaches than with those studied in their feeding grounds. There were significant increases in titanium-tag loss with respect to increasing tag age within the nesting-beach studies but were was approximately zero probability of titanium-tag loss for tag age up to six years in the feeding-ground study.

Visual inspection is sufficient to establish that the plastic tag on the hind-flipper had a greater loss rate (Table 4) than the most secure tags used in this study, i.e. titanium tags applied to the front flipper in position 3 (*Chelonia mydas* in feeding-ground studies,

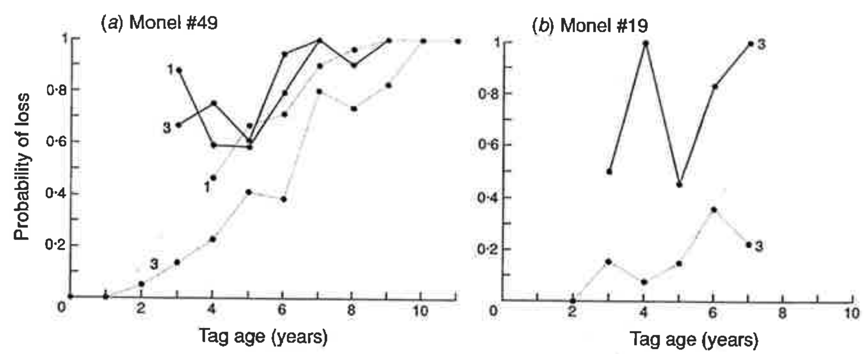
Table 2. Frequency distribution of tag loss for tags applied to *Caretta caretta* in nesting and feeding-ground studies

a_i, number of turtles recaptured in year i still wearing the tag and whose number could be read; b_i, number of turtles recaptured in year i that had lost the tag or with a tag number that could not be read; CL, confidence limits

Tag type and position	Tag age (year i)	Nesting study: Tag count a_i	b_i	Total	Probability of loss ± 95% CL	Feeding-ground study: Tag count a_i	b_i	Total	Probability of loss ± 95% CL
Monel No. 49									
Front flipper, position 2	11			0		0	4	4	1·000±0·000
	10	0	5	5	1·000±0·000	1	9	10	0·900±0·186
	9	1	7	8	0·875±0·229	2	15	17	0·882±0·153
	8	1	27	28	0·964±0·069	5	10	15	0·667±0·239
	7	1	34	35	0·971±0·055	8	25	33	0·758±0·146
	6	7	49	56	0·875±0·087	21	16	37	0·432±0·159
	5	14	55	69	0·797±0·095	11	13	24	0·542±0·200
	4	36	68	104	0·654±0·091	6	4	10	0·400±0·304
	3	65	78	143	0·546±0·082	1	1	2	0·500±0·693
	2	56	44	100	0·440±0·088			0	
	1	13	1	14	0·071±0·134			0	
Front flipper, position 3	11			0		6	12	18	0·667±0·218
	10	1	3	4	0·750±0·424	20	19	39	0·487±0·157
	9	2	8	10	0·800±0·248	21	24	45	0·533±0·146
	8	8	26	34	0·765±0·143	34	19	53	0·358±0·129
	7	16	31	47	0·660±0·135	46	17	63	0·270±0·110
	6	26	45	71	0·634±0·112	53	15	68	0·220±0·099
	5	45	22	67	0·328±0·112	63	7	70	0·100±0·070
	4	69	27	96	0·281±0·090	24	4	28	0·143±0·130
	3	128	32	160	0·200±0·062	10	1	11	0·091±0·170
	2	125	25	150	0·167±0·060	7	0	7	0·000±0·000
	1	18	0	18	0·000±0·000	6	0	6	0·000±0·000
Monel No. 19									
Front flipper, position 3	8	1	1	2	0·500±0·693	16	6	22	0·273±0·186
	7	14	32	46	0·696±0·133	18	7	25	0·280±0·176
	6	45	52	97	0·536±0·099	17	9	26	0·346±0·183
	5	50	34	84	0·405±0·105	28	5	33	0·152±0·122
	4	105	52	157	0·331±0·074	38	5	43	0·116±0·096
	3	120	32	152	0·211±0·065	46	3	49	0·061±0·067
	2	98	16	114	0·140±0·064	9	3	12	0·250±0·245
	1	17	1	18	0·056±0·106	2	0	2	0·000±0·000
Hind flipper	7	0	2	2	1·000±0·000				
	6	0	1	1	—				
	5	0	1	1	—				
	4	2	2	4	0·500±0·490				
	3	0	1	1	—				
	2	1	0	1	—				
	1	1	0	1	—				

Table 2 (*continued*)

Tag type and position	Tag age (year i)	Nesting study: Tag count a_i	b_i	Total	Probability of loss ± 95% CL	Feeding-ground study: Tag count a_i	b_i	Total	Probability of loss ± 95% CL
Titanium No. 1									
Front flipper, position 3	7	11	5	16	0·313±0·227	13	10	23	0·435±0·203
	6	20	13	33	0·394±0·167	28	11	39	0·282±0·141
	5	35	13	48	0·271±0·126	27	9	36	0·250±0·141
	4	62	16	78	0·205±0·090	39	5	44	0·114±0·094
	3	63	8	71	0·113±0·074	52	8	60	0·133±0·086
	2	57	5	62	0·081±0·068	66	6	72	0·083±0·064
	1	8	0	8	0·000±0·000	33	1	34	0·029±0·057
Titanium No. 2									
Front flipper, position 3	6	2	3	5	0·600±0·429	2	1	3	0·333±0·533
	5	58	14	72	0·194±0·091	30	5	35	0·143±0·116
	4	160	33	193	0·171±0·053	65	7	72	0·097±0·068
	3	230	34	264	0·129±0·040	80	8	88	0·091±0·060
	2	288	22	310	0·071±0·027	118	5	123	0·041±0·035
	1	24	3	27	0·111±0·119	97	2	99	0·020±0·028
Hind flipper	5	4	2	6	0·333±0·377				
	4	14	5	19	0·263±0·198				
	3	7	2	9	0·222±0·072				
	2	11	3	14	0·214±0·215				
	1	1	0	1	—				



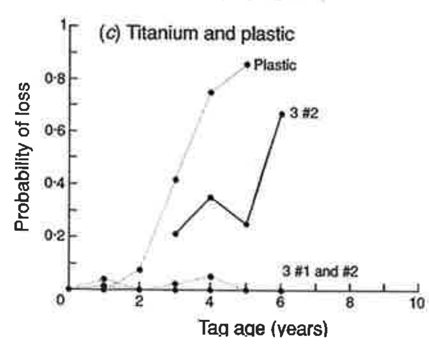


Fig. 3. Probability of tag loss in *Chelonia mydas* in feeding-ground (dotted lines) and nesting-beach (solid lines) studies. *a*, monel No. 49 tags applied to front flipper, positions 1 and 3; *b*, monel No. 19 tags applied to front flipper, position 3; *c*, titanium No. 1 and No. 2 tags applied to front flipper, position 3. Plastic tag applied to hind flipper.

Table 3. Results of stepwise unweighted logistic regression of tag-loss measurements from *Caretta caretta*

A, tag age; S, study type; T, tag type; P, tagging position; LR, log-likelihood ratio; *, source makes a significant contribution to tag loss

Model	Deviance	d.f.	Log-likelihood ratio Source	LR	d.f.	P	
Monel tags in positions on the front flipper							
A+S+T+P	48·81	51					
A+S+P	49·84	52	T	2·06	1	0·25>*P*>0·1	
A+S+T	262·7	52	P	417·8	1	<0·001	*
A+P+T	206·7	52	S	315·8	1	<0·001	*
S+P+T	446·5	52	A	795·4	1	<0·001	*
A+S+P	49·84	52					
A+P	211·5	53	S	323·4	1	<0·001	*
A+S	303·5	53	P	507·4	1	<0·001	*
P+S	449·1	53	A	798·3	1	<0·001	*
Titanium tags in positions on the front flipper (position 3) and hind flipper							
A+S+T+P	12·97	25					
A+S+P	15·07	26	T	4·2	1	0·05>*P*>0·025	*
A+S+T	17·13	26	P	8·16	1	0·005>*P*>0·001	*
A+T+P	19·31	26	S	12·68	1	<0·001	*
S+T+P	86·86	26	A	147·78	1	<0·001	*
A+S+P	15·07	26					
A+S	18·56	27	P	6·98	1	0·01>*P*>0·005	*
A+P	20·35	27	S	10·56	1	0·005>*P*>0·001	*
S+P	108·5	27	A	186·86	1	<0·001	*

Table 4). Similarly, the loss rate of titanium tags was considerably less than that of monel No. 19 tags (front flipper, position 3 on *Chelonia mydas* in feeding-ground studies) (Table 4).

To test the effect of species on tag loss, data sets for each of two tag designs (monel No. 19, titanium No. 1/No. 2 tags) applied on position 3 of the front flipper on both species in the feeding-ground study were selected from Tables 2 and 4 and analysed by unweighted logistic regression (Table 6). With the titanium tags, species contributed significantly to tag loss, with a significant interaction between species and tag type. With the monel No. 19 tags, no significant contribution by species to tag loss was detected.

Discussion

The present study has demonstrated that the probability of tag loss is a function of a range of parameters. For each tag design and tagging position compared, tag loss was greater for turtles studied at nesting beaches than for turtles in the feeding grounds. It is presumed that the biting of flippers that occurs during courtship and the rubbing of flippers against compacted sands, rocks, roots, branches and/or debris during nesting contribute to the greater tag loss recorded for turtles in nesting studies. Comparison of tag loss from different tagging positions on the front flipper when monel No. 49 tags were used indicates that the greatest tag loss occurred from the more distal tagging positions (positions 1 or 2) for both species and was least from the axillary (position 3) tagging position (Figs 2*a*, 3*a*). Monel-tag loss appears to be more severe with *Chelonia mydas* in nesting studies than with *Caretta caretta*. Although the numbers of recaptured turtles were small, the results indicate

Table 4. Frequency distribution of tag loss for tags applied to *Chelonia mydas* in nesting and feeding-ground studies

a_i, number of turtles recaptured in year i still wearing the tag and whose number could be read; b_i, number of turtles recaptured in year i that had lost the tag or with a tag number that could not be read; CL, confidence limits

Tag type and position	Tag age (year i)	Nesting study: Tag count a_i	b_i	Total	Probability of loss ± 95% CL	Feeding-ground study: Tag count a_i	b_i	Total	Probability of loss ± 95% CL
Monel No. 49									
Front flipper, position 1	11			0		0	3	3	1·000±0·000
	10	1	0	1	—	0	10	10	1·000±0·000
	9	0	2	2	1·000±0·000	0	14	14	1·000±0·000
	8	1	9	10	0·900±0·186	1	25	26	0·962±0·074
	7	0	6	6	1·000±0·000	3	26	29	0·897±0·111
	6	1	17	18	0·944±0·106	9	22	31	0·710±0·160
	5	9	14	23	0·609±0·199	7	14	21	0·667±0·202
	4	2	6	8	0·750±0·300	8	7	15	0·467±0·252
	3	1	2	3	0·667±0·533	0	2	2	0·000±0·000
	2			0				0	
	1			0				0	
Front flipper, position 3	11			0		0	5	5	1·000±0·000
	10	1	0	1	—	0	15	15	1·000±0·000
	9	0	4	4	1·000±0·000	4	19	23	0·826±0·155
	8	1	9	10	0·900±0·186	9	25	34	0·735±0·148
	7	0	6	6	1·000±0·000	9	36	45	0·800±0·117
	6	5	19	24	0·792±0·162	35	22	57	0·386±0·126
	5	17	24	41	0·585±0·151	33	23	56	0·411±0·129
	4	9	13	22	0·591±0·205	34	10	44	0·227±0·124
	3	1	7	8	0·875±0·229	19	3	22	0·136±0·143
	2			0		19	1	20	0·050±0·096
	1			0		11	0	11	0·000±0·000
Monel No. 19									
Front flipper, position 3	8			0		1	0	1	—
	7	0	5	5	1·000±0·000	17	5	22	0·227±0·175
	6	4	20	24	0·833±0·149	23	13	36	0·361±0·157
	5	6	5	11	0·455±0·294	17	3	20	0·150±0·156
	4	0	2	2	1·000±0·000	49	4	53	0·075±0·071
	3	2	2	4	0·500±0·490	16	3	19	0·158±0·164
	2			0		38	0	38	0·000±0·000
	1			0				0	
Titanium No. 1									
Front flipper, position 3	7					1	0	1	—
	6					14	0	14	0·000±0·000
	5					18	0	18	0·000±0·000
	4					17	0	17	0·000±0·000
	3					26	0	26	0·000±0·000
	2					13	0	13	0·000±0·000
	1					23	1	24	0·042±0·080

Table 4 *(continued)*

Tag type and position	Tag age (year i)	Nesting study: Tag count a_i	b_i	Total	Probability of loss ± 95% CL	Feeding-ground study: Tag count a_i	b_i	Total	Probability of loss ± 95% CL
Titanium No. 2									
Front flipper,	6	1	2	3	0·667±0·533	1	0	1	–
position 3	5	9	3	12	0·250±0·245	25	0	25	0·000±0·000
	4	22	12	34	0·353±0·161	70	4	74	0·054±0·052
	3	26	7	33	0·212±0·139	126	3	129	0·023±0·026
	2	0	1	1	–	88	0	88	0·000±0·000
	1			0		135	2	137	0·015±0·020
Plastic									
Hind flipper	6					1	0	1	–
	5					1	6	7	0·857±0·259
	4					4	12	16	0·750±0·212
	3					7	5	12	0·417±0·279
	2					12	1	13	0·077±0·145
	1					24	0	24	0·000±0·000

Table 5. Results of stepwise unweighted logistic regression of tag-loss measurements from *Chelonia mydas*

A, tag age; S, study type; T, tag type; P, tagging position; LR, log-likelihood ratio; *, source makes a significant contribution to tag loss

Model	Deviance	d.f.	Log-likelihood ratio: Source	LR	d.f.	P	
Feeding ground, monel tags in positions on the front flipper							
A+P+T	32·18	23					
A+P	52·15	24	T	39·94	1	<0·001	*
A+T	59·27	24	P	54·18	1	<0·001	*
T+P	187·9	24	A	311·44	1	<0·001	*
Titanium tags in position 3 on the front flipper							
A+S+T	12·88	11					
A+S	14·09	12	T	2·41	1	0·25>P>0·1	
A+T	54·7	12	S	83·64	1	<0·001	*
T+S	14·55	12	A	3·34	1	0·1>P>0·05	

that hind-flipper tags have a higher probability of being lost than front-flipper tags of the same metal type and design (titanium No. 2, Table 2) when used in nesting studies with *Caretta caretta*. The plastic tags used on hind flippers of *Chelonia mydas* in a feeding-group study also showed high probability of being lost after two years.

The monel tags with different locking mechanism (No. 49, No. 19) had similar probabilities of being lost when applied at the same tagging position in each of the nesting and feeding studies with *Caretta caretta*, but with *Chelonia mydas* monel No. 19 tags had a lower probability of being lost than monel No. 49 tags (Figs 2*b* and 3*b*, respectively). Within the 5–7-year period of their use, titanium tags gave better retention rates than monel tags applied in the same tagging position for both species in nesting studies and for

Table 6. Results of stepwise unweighted logistic regression of tag-loss measurements, testing for contribution of species (*Caretta caretta*, *Chelonia mydas*) to tag loss

All tags were applied in position 3 on the front flipper of turtles in the feeding-ground study. A, tag age; Sp, species; T, tag type; LR, log-likelihood ratio; *, source makes a significant contribution to tag loss

Model	Deviance	d.f.	Log-likelihood ratio: Source	LR	d.f.	P	
Monel No. 19 tags							
A+Sp	20·08	12					
A	20·13	13	Sp	0·01	1	0·95>P>0·9	
Sp	41·41	13	A	42·66	1	<0·001	*
Titanium tags							
A+Sp+T+(T×Sp)	15·06	19					
A+Sp+(T×Sp)	20·23	20	T	10·34	1	0·005>P>0·001	*
A+T+(T×Sp)	12·9	20	Sp	12·90	1	<0·001	*
Sp+T+(T×Sp)	68·84	20	T×Sp	68·84	1	<0·001	*

Chelonia mydas in feeding-ground studies (Figs 2*c*, 3*c*). However, monel and titanium tags had comparable results when applied in feeding-ground studies with *Caretta caretta*. The two titanium-tag designs have resulted in similar probabilities of being lost when applied in the same tagging position and in the same study situation. In all instances, tag loss is a function of time and it must be expected that, given sufficient time, all tags have the potential to be lost.

Of particular interest in this study has been the comparison of monel and titanium tags. The monel tags, for the most part, had a probability of being lost approaching 100% after a tag age of about 10 years. The less corrodible titanium tags, as judged by their performance at the end of about six years, are expected to out-last the monel tags by many years. Given that lower probability of tag loss will result in higher frequency of recapture of tagged turtles in later years, choice of tag and how it is applied are critical in the design of successful long-term studies.

Probability of tag loss is a function of diverse factors, including composition and design of the tag, where on the turtle it is applied, whether the turtles are being studied at the nesting beach or in feeding grounds, which species is being studied and the time since the tag was applied. Even when corrosion and tag-application problems are reduced to a minimum, the other mechanical causes of tag loss can become significant, given enough time. When initiating a tagging programme with very long-lived active animals such as marine turtles, consideration should be given to the time frame of the behaviour and/or biological problem being addressed. Ideally, the chosen tag should have a probability of being lost that is low throughout the duration of the study. In those studies where recapture rate of tagged turtles is to be measured, correction factors for tag loss should be developed for the specific tag, tagging position, study type and turtle species.

The probabilities of tag loss calculated in this study (Tables 2, 4) can be used when correcting for tag loss in studies of population dynamics where recapture rates are measured. If the study involves turtles that were initially tagged with only one tag, and r_i is the number of single-tagged turtles recaptured after i years of being tagged, and p_i is the corresponding probability of tag loss for that tag's usage, then T_i, the estimated total number of previously tagged turtles that returned after i years, can be calculated according to the following equation:

$$T_i = r_i/(1 - p_i)\,.$$

If the recoveries are of turtles that had been double-tagged, and the corresponding probabilities of tag loss for each of the tags are p_i and q_i, then

$$T_i = r_i / [(1-p_i)(1-q_i)] .$$

If tag loss is to be kept to a minimum, thus enhancing the chances of later recovery, of the various standard positions used the optimal position for applying a flipper tag is through, or immediately adjacent to, the most proximal large scale on the trailing edge of the front flipper. This is defined as the axillary tagging scale. In addition, the optimal tag should not deteriorate or corrode when immersed in the sea over the period of the study. Although monel tags have proved useful in providing many short-term tag recoveries, they are not reliable for long-term studies. In studies of the population dynamics of marine turtles, the period considered needs to be decades. The titanium tags tested in this study and the NBTC inconel No. 625 tag (Balazs 1983, personal communication) meet this latter criterion.

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