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Keeping Tabs: Are Redundant Marking Systems Needed for Rodents?

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Abstract

*We use survival analysis to compare failure of passive integrated transponder (PIT) tags and loss of metal ear tags in 2,277 southern flying squirrels (*Glaucomys volans*), 124 house mice (*Mus musculus*), 112 hispid cotton rats (*Sigmodon hispidus*), and 374 deer (*Peromyscus maniculatus*) and cotton mice (*P. gossypinus*). With the exception of cotton rats, failure rates between ear and PIT tags differed by species. Flying squirrels exhibited the highest proportional loss of both tag types and lost ear tags more readily than PIT tags failed. The opposite was true for cotton rats and deer and cotton mice. Most PIT tags appeared to fail shortly after implantation (≤3 days), except for flying squirrels and, to a lesser extent, cotton rats. Ear tags exhibited a consistent rate of loss in flying squirrels. Body mass did not influence failure of PIT tags; however, flying squirrel body mass was associated with increased loss of ear tags. For flying squirrels PIT tag failure increased with the number of times an individual had already received a PIT tag that failed. We provide recommendations for using PIT and ear tags in marking rodents based on species-specific patterns and suggest the combined use of external and internal markers to obtain the most reliable estimates of population parameters.* (WILDLIFE SOCIETY BULLETIN 34(3):764–771; 2006)

Key words

cotton mice, deer mice, ear tag, flying squirrels, Glaucomys volans, *hispid cotton rats, house mice,* Mus musculus, *passive integrated transponder tags,* Peromyscus gossypinus, P. maniculatus, Sigmodon hispidus, *survival analysis, tag failure*.

Studies of animal populations typically require methods of uniquely marking individuals to follow them through time. These markers may be located externally on the body on appendages, such as the ears, fins, flippers, or legs, or alternatively located subcutaneously, such as passive integrated transponder (PIT tags or visible implant elastomer tags). Although such markers are commonly used in ecological studies involving mark–recapture or tag recovery, little is known about marker retentions and rates of tag shedding and failure are poorly known for most species. Tag failure can negatively bias estimates of survival and positively bias estimates of population size (McDonald et al. 2003). Estimates of population size, mortality, migration, and harvesting rates rely on 2 major assumptions concerning tags: 1) that the tags are retained for the duration of the study and 2) that tagging has no adverse effect on the reproduction, growth, or survival of the individual. Although the latter assumption is often taken into consideration at the onset of a study, the former has only been tested in a few species, with a major emphasis on commercially important species, such as fish (Okland et al. 2003, Ramstad and Woody 2003, Olsen et al. 2004), crustaceans (Montgomery and Brett 1996, Sharp et al. 2000, Comeau and Mallet 2003), and shellfish (Lemarie et al. 2000, Stewart and Creese 2000). Rates of tag shedding and failure may be influenced by sex and age (Diefenbach and Alt 1998, Pistorius et al. 2000), body size (Olsen et al. 2004), species longevity (Felton 1987), and whether the animal has already lost one tag (Diefenbach and Alt 1998). Thus, developing accurate retention models and tag shedding or tag failure corrections requires consideration of these potentially important factors.

Studies of tag retention and shedding in mammals have included New Zealand fur seals (*Arctocephalus forsteri*; Bradshaw et al. 2000), southern elephant seals (*Mirounga leonina*; Pistorius et al. 2000), black bears (*Ursus americanus*; Diefenbach and Alt 1998), California sea otters (*Enhydra lutris*; Siniff and Ralls 1991), and wild ferrets (*Mustela furo*; Morley 2002). These studies determined tag-shedding rates and evaluated the efficacy of the given markers for use on the subject species. Most studies of mammals have not attempted to compare the performance of different tag types. However, Morley (2002) compared survival estimates and failure rates for 2 tag types (metal ear tags and PIT tags) and found no differences in tag retention time and survival between the 2 types.

Ear tagging using uniquely numbered paired metal tags is a common method of marking small mammals for ecological studies (Brady et al. 2000, Dobson et al. 2004, Hadley and Wilson 2004, Manning and Edge 2004). Despite their popularity, these external tags are easily shed, which often is mitigated by attaching 2 ear tags per individual (Seber 1986). Additionally, ear tags often become worn, making the number unreadable (Morley 2002). Recently, PIT tags have become a popular alternative method of identifying animals (for review of history and research, see Gibbons and Andrews 2004). These transponders are implanted under the skin of the animal and are only activated when read with a magnetic reader, causing the transponder to transmit a unique alphanumeric code. Although the tag is implanted subcutaneously, PIT tags often migrate out of the puncture site, resulting in loss of the tag (Harper and Batzli 1996). Additionally, the microchip may not be detected due to electronic failure of the tag. Thus we define "PIT tag failure" as the inability to detect the tag.

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Few, if any, studies have compared factors influencing tag failure across multiple species. The objective of our study was to quantify and compare retention and failure rates of metal ear tags and PIT tags in 4 species of rodents. We used survival analysis to examine tag shedding and failure rates in southern flying squirrels (*Glaucomys volans*), house mice (*Mus musculus*), hispid cotton rats (*Sigmodon hispidus*), and deer (*Peromyscus maniculatus*) and cotton mice (*P. gossypinus*). Survival analyses are used by ecologists to measure and assess time to discrete events, in this case the failure or loss of a tag (for examples of ecological uses see Cockburn et al. 2003 and Green et al. 2004). We hypothesized that failure rates for PIT tags would be greatest shortly after implantation, due to the tag migrating out of the puncture site before complete healing has occurred. In contrast, we predicted rates of ear tag shedding as constant throughout the animal's lifespan. Additionally, we predicted that PIT tag failure would be negatively associated with body mass because larger animals will afford the tag to be implanted further from the puncture site, unlike ear tags. Thus, for ear tags, we predicted shedding would be independent of body size and mass.

Methods

Tag data for this study result from 2 separate studies, one on the reproductive behavior of southern flying squirrels (see Risch 1999) and an ongoing study comparing small mammal populations in genetically modified and conventional crops. The 2 different methodologies of data collection are described separately. All research procedures meet the standards set by the Auburn University Animal Subject Review (protocol # 9603-R-0543), the University of Georgia Animal Subject Review (protocol # A930194), and the guidelines established by the American Society of Mammalogists (Animal Care and Use Committee 1998).

Data Collection (Southern Flying Squirrels)

We conducted this study from August 1992 to December 1998 at the Savannah River Site in South Carolina, USA, on a population of flying squirrels using nest boxes. Details of habitat on the study area, construction and layout of nest boxes, and sampling can be found in Risch (1999) and Fokidis and Risch (2005). We checked nest boxes every 7–14 days from September to June, and then every 28–35 days the rest of the year. We removed squirrels from nest boxes and anaesthetized them with methoxyflurane (Metophane; Pitman-Moore Inc., Mundelein, Illinois). We marked each squirrel with paired, uniquely numbered, self-piercing, metal ear tags (Monel #1005; National Band and Tag Co., Newport, Kentucky) attached at the base of the pinna and with one PIT tag (AVID Identification Systems Inc., Norco, California) injected subcutaneously through the patagium and implanted below the surface of the rump of the animal. We tested all transponders before and after implantation with AVID Powertracker 2 handheld scanners (AVID Identification Systems) by sweeping over all areas of the animal to ensure complete coverage. To minimize handling time, we applied no adhesive or sutures to the puncture site. Data collected from captured individuals included sex, reproductive status and age (according to Sollberger 1943), and body mass (weighed with a Pesola® scale). We recorded recaptured squirrels with failed PIT tags and those with missing ear tags. Individuals with failed PIT tags had another implanted, whereas missing ear tags were not replaced.

Data Collection (Murine Rodents)

We conducted this study on 10 grids located within soybean and cotton fields near Jonesboro, in northeastern Arkansas, USA. Trapping grids consisted of 10×10 collapsible Sherman live traps laid 10 m apart, with several additional trap lines established encompassing the perimeter of the fields. We sampled each trapping grid daily for 15 days, starting from March 2003 to November 2004. We operated grids once at preplanting, twice during the growth period, and at least once at postharvest in each year. We anesthetized all captured animals with isoflurane (Vetus Animal Health Iso-thesia; Burns Veterinary Supply Inc., Westbury, New York), marked them with the same model paired ear tags and PIT tag and in the same manner used with flying squirrels. Data collected from rodents included species, trapping-grid location, sex, reproductive condition (M: inactive, scrotal; F: inactive, estrus, pregnant, lactating, postlactating), and body mass. In addition, we recorded failed PIT tags or missing ear tags. We captured both deer and cotton mice during this study, but to eliminate minor inconsistencies in our identification of these 2 species, we pooled data for these species for subsequent analyses. Failed PIT tags were replaced, unlike ear tags, which were not replaced.

Statistical Analyses

To assess tag failure, we used survival analysis, which distinguishes between *censorship* (where the event of interest did not occur) and *failure* of a tag, and calculates a hazard function, defined as the probability that an event will occur at a specific time (SAS Institute 1999). For each individual in this study, we determined the duration of time from first capture (where the tags were attached or implanted) to tag failure (uncensored data), or the last record of capture (censored data). As all individuals were marked with both tag types (1 PIT tag and 2 ear tags), this allowed us to identify the individual even with 2 of the 3 tags being lost. For comparisons between species, we standardized sampling effort by obtaining the ratio of percent tag failure to the number of times during the study that traps or nest boxes were checked. This minimized differences in sampling effort and sample size between species.

We used univariate analyses to determine whether tag failure was influenced by sex, body mass, year of tag attachment, year of tag failure, and time of year. In addition, for PIT tag data, we also tested whether having previously received a PIT tag that failed influenced the likelihood of having the next PIT tag fail. We analyzed the continuous variables of body mass and time of year using Cox's (1972) proportional hazard regression models (PROC PHREG function; SAS Institute 1999) that estimate hazard functions semiparametrically using censorship data. These models then estimate the effect of continuous predictors on the resulting regression model. For categorical predictors (sex, implant or attach year, year of tag failure, species, whether a PIT tag had previously failed), we used nonparametric log-ranked tests (PROC LIFETEST function; SAS Institute 1999). We generated Kaplan–Meier plots to show rate of tag failure as influenced by the different categorical variables (see, e.g., Green et al. 2004). We

Table 1. Summary of tagging effort and percentage tag loss for 4 rodent species tagged with passive integrated transponder (PIT) and ear tags: southern flying squirrel (*Glaucomys volans*), house mouse (*Mus musculus*), cotton and deer mice (*Peromyscus gossypinus* and *P. maniculatus*) pooled, and hispid cotton rat (*Sigmodon hispidus*). *G. volans* was captured on the Savannah River Site, South Carolina, USA, from Aug 1992 to Dec 1998, and the other rodents were captured from agricultural fields near Jonesboro, Arkansas, USA, from Mar 2003 to Nov 2004.

Type of tag loss	*Glaucomys volans* % (*n*)	*Mus musculus* % (*n*)	*Peromyscus* spp. % (*n*)	*Sigmodon hispidus* % (*n*)
No. with PIT tag and ear tag				
M	60.0% (1,369)	54.8% (68)	60.7% (227)	52.7% (59)
F	40.0% (908)	45.2% (56)	39.3% (147)	47.3% (53)
No. that lost PIT tag				
0 PIT	91.6% (2,086)	94.4% (117)	95.7% (358)	96.4% (108)
1 PIT	7.2% (163)	5.6% (7)	4.0% (15)	3.6% (4)
2 PIT	1% (23)	0	0.3% (1)	0
3 PIT	0.2% (5)	0	0	0
No. that lost ear tag				
Neither	80.9% (1,842)	96.8% (120)	97.9% (366)	95.5% (107)
One	23.9% (543)	3.2% (4)	2.1% (8)	4.5% (5)
Both	4.7% (108)	0	0	0

examined whether sex, body mass, reproductive condition, and age at capture influenced tag retention for each species using analysis of variance. All statistical models were fitted and tested using SAS® version 8 (SAS Institute 1999). Values are presented as mean ± SE.

Results

We checked nest boxes for flying squirrels a total of 472 times during the study, resulting in the capture and marking of 2,277 individuals. Trapping effort for murine rodents amounted to 2,240 trap nights with 124 house mice, 374 deer and cotton mice, and 112 cotton rats captured, marked, and subsequently recaptured during the study. Trapping effort and percent tag failure for all species are provided in Table 1.

For all 4 species, we tagged comparable proportions of males and females (Table 1). All ear tag failure resulted from missing ear tags evident through tearing of the ears. Accounting for differences in sampling effort, failure rates differed by species for both PIT tags ($\chi^2 = 85.57$, df $= 3$, $P < 0.0001$) and ear tags ($\chi^2 = 192.64$, df $= 3$, $P < 0.0001$). For both ear tags and PIT tags, flying squirrels exhibited the highest proportion of tag failure (Table 1).

Forty-nine flying squirrels lost all their tags; thus, we did not identify them. All other individuals for all species retained at least 1 marker, allowing identification for the duration of the study (Table 1). Failure rates of PIT tags were greater than for ear tags in house mice ($\chi^2 = 5.20$, df $= 1$, $P = 0.023$), and in deer and cotton mice ($\chi^2 = 33.89$, df $= 1$, $P < 0.0001$). We observed no difference in failure rates between marker types for cotton rats ($\chi^2 = 3.51$, df $= 1$, $P = 0.061$). Ear tags were more likely to be lost than PIT tags in flying squirrels ($\chi^2 = 8.75$, df $= 1$, $P = 0.003$). Because flying squirrel survival curves for PIT and ear tags intersected (Fig. 1), we further tested for differences between the tag types because log-rank tests often fail to detect differences in this situation (Lin and Wang 2004). Our large sample size allowed us to use a Gehan–Wilcoxon test procedure, which compares squares of differences, instead of squares of sums like the log-ranked test (see Wei and Glidden 1997). The observed difference was still evident with the Wilcoxon test ($Z = 4.60$, df $= 1$, $P = 0.0001$).

Within 3 days of implantation, we recaptured 12 of 213 flying squirrels, 2 of 81 cotton rats, 12 of 276 deer and cotton mice, and 6 of 102 house mice that had unreadable PIT tags. Tag failure appeared to occur most frequently shortly after implantation in flying squirrels, with ear tag loss occurring at a slower rate (Fig. 1). Rates of ear tag loss followed a similar trend to rates of PIT failure in house mice (Fig. 2). Deer and cotton mice and cotton rats experienced greater rates of PIT failure than ear tag loss (Figs. 3, 4, respectively). For both PIT and ear tags, year effects on tag failure were present with early years of the study showing increased tag failure in flying squirrels (Table 2). For cotton rats PIT tag failure was only reported in 2003, with no failed PITs occurring in 2004. We observed no year effect for any tag in deer or cotton mice, where we caught roughly equal numbers and observed equal tag failure between 2003 (51% of total capture) and 2004 (49% of total capture). House mice appeared to exhibit higher proportional PIT failure and ear tag loss in 2004 than in 2003, despite 74% of captures occurring in 2003. However, this difference was not significant (Table 2).

For flying squirrels greatest rates of PIT tag failure occurred from late June through to early December, with only a single PIT failing in early March ($\chi^2 = 72.65$, df $= 1$, $P < 0.0001$). Similarly, increased records of ear tag loss occurred later in the year ($\chi^2 = 71.91$, df $= 1$, $P < 0.0001$). In contrast, we observed no seasonal trend in PIT failure or ear tag loss for house mice (PIT tag: $\chi^2 = 1.35$, df $= 1$, $P = 0.735$; ear tag: $\chi^2 = 6.18$, df $= 1$, $P = 1.02$), cotton rats (PIT tag: $\chi^2 = 6.13$, df $= 1$, $P = 0.612$; ear tag: $\chi^2 = 8.41$, df $= 1$, $P = 0.101$), and deer and cotton mice (PIT tag: $\chi^2 = 11.95$, df $= 1$, $P = 0.081$; ear tag: $\chi^2 = 10.22$, df $= 1$, $P = 0.242$). In flying squirrels heavier individuals were more likely to lose ear tags (Table 2). We found no differences in tag failure between sexes for any of the tags (Table 2). Neither body mass nor sex influenced the failure of any tag in the other 3 rodent species (Table 2). Flying squirrels that had already received and lost a PIT tag were more likely to lose a subsequent PIT tag than those tagged for the first time ($\chi^2 = 10.27$, df $= 3$, $P < 0.016$; Fig. 5) and the proportion of tag loss increased with the number of already lost PIT tags (Table 1). For rodents having already obtained and lost a

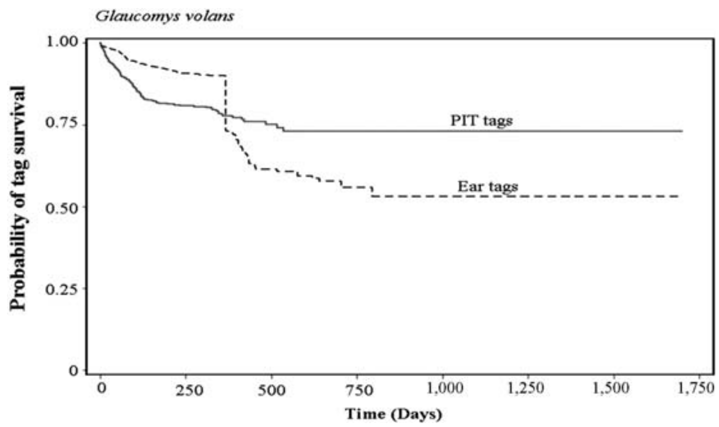

Figure 1. Kaplan–Meier plot estimating differences in probability of passive integrated transponder (PIT) tag and metal ear tag retention for the southern flying squirrel (*Glaucomys volans*). (*Steps* indicate failure of a tag and failures occurring on the same day are recorded as a single step.)

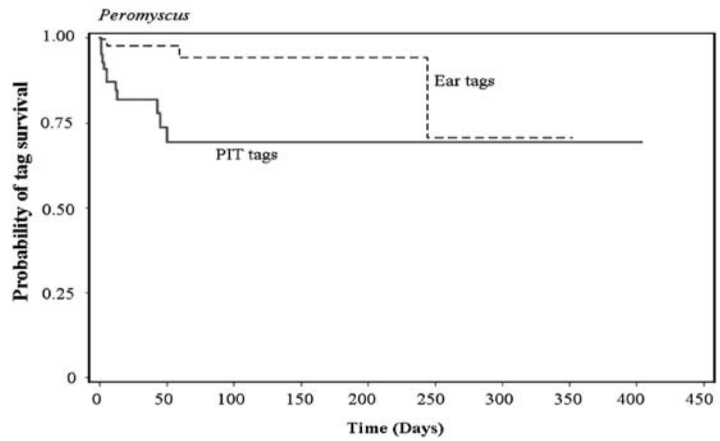

Figure 3. Kaplan–Meier plot estimating differences in probability of passive integrated transponder (PIT) tag and metal ear tag retention for *Peromyscus* spp. (*Steps* indicate failure of a tag and failures occurring on the same day are recorded as a single step.)

PIT tag did not increase likelihood of losing another (deer and cotton mice: $\chi^2 = 0.22$, df $= 1$, $P = 0.637$; house mice: $\chi^2 = 0.17$, df $= 1$, $P = 0.678$; cotton rats: $\chi^2 = 0.28$, df $= 1$, $P = 0.596$).

Discussion and Management Implications

Despite skewed sampling effort and sample sizes making direct comparisons between flying squirrels and murid rodents difficult, we saw significant patterns of tag failure both among and within species. In flying squirrels PIT tags were less likely to be lost than ear tags, whereas the opposite was true for deer, cotton, and house mice. These differences in tag loss may produce capture–recapture model estimates that vary depending on the type of tag used, even though differences in loss of ear tags and PIT failure often were small in this study. McDonald et al. (2003) suggests that even infrequent tag loss can severely bias Jolly–Seber estimates when the species under consideration exhibits low recapture rates. In the rodent species studied, PIT failure was heterogeneous through time with the majority failing shortly after tagging, after which failure rates were lessened. Often PIT tags migrate out of the puncture site and are lost during or shortly after the handling process, but after the puncture wound heals, loss is largely curtailed. Although not employed in our study, PIT loss can be minimized by sealing the puncture site with adhesive or suturing (Morley 2002), but the advantage of this technique has yet to be quantified in any species. Some small mammals may actually be able to open wounds sealed by adhesive.

The PIT tag may, after a time, succumb to electronic failure, which could explain the failures observed in flying squirrels and cotton rats long after the initial implantation wound healed. In contrast to PIT failure, ear tag loss in flying squirrels and, to a lesser degree in deer and cotton mice, exhibited a more homogenous pattern with loss occurring evenly throughout the time the tag was reported in the population. Patterns of tag loss through time may be important to consider because population estimators that account for tag loss often assume equal probability of tag loss throughout the animal's lifespan (Felton 1987). However, as the occurrence of tag loss was relatively low for the murid rodents, caution should be taken in extrapolating influences of external factors on tag retention.

The differences in marker failure between species suggested that some tags are more suitable than others for certain species. This

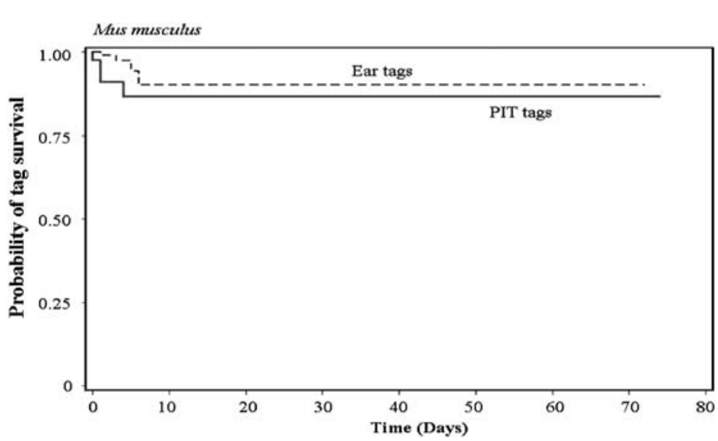

Figure 2. Kaplan–Meier plot estimating differences in probability of passive integrated transponder (PIT) tag and metal ear tag retention for the house mouse (*Mus musculus*). (*Steps* indicate failure of a tag and failures occurring on the same day are recorded as a single step.)

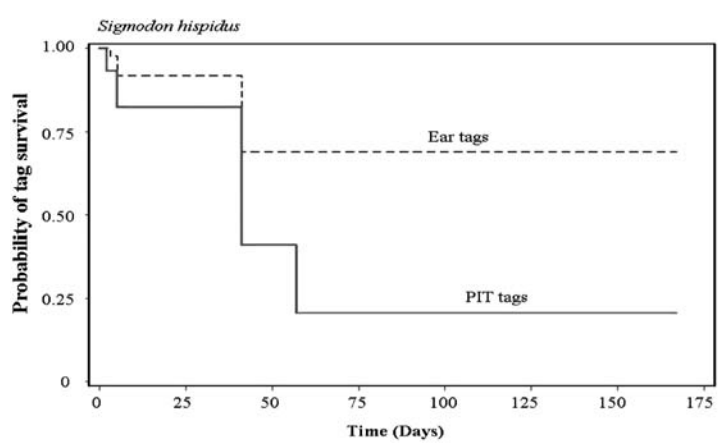

Figure 4. Kaplan–Meier plot estimating differences in probability of passive integrated transponder (PIT) tag and metal ear tag retention for the hispid cotton rat (*Sigmodon hispidus*). (*Steps* indicate failure of a tag and failures occurring on the same day are recorded as a single step.)

Table 2. Influence of 4 variables on passive integrated transponder (PIT) and ear tag failure for 4 rodents as determined through survival analysis. Year of tag attachment, year of tag loss, and sex were tested using nonparametric log-ranked tests and effects of body mass was tested using Cox's (1972) proportional hazard model. Species studied: southern flying squirrel (*Glaucomys volans*), house mouse (*Mus musculus*), cotton and deer mice (*Peromyscus gossypinus* and *P. maniculatus*) pooled, and hispid cotton rat (*Sigmodon hispidus*). *G. volans* was captured on the Savannah River Site, South Carolina, USA, from Aug 1992 to Dec 1998, and the other rodents were captured from agricultural fields near Jonesboro, Arkansas, USA, from Mar 2003 to Nov 2004.

		Species											
		Glaucomys volans			***Mus musculus***			***Peromyscus* spp.**			***Sigmodon hispidus***		
Tag type	**Variable**	χ^2	**df**	***P***	χ^2	**df**	***P***	χ^2	**df**	***P***	χ^2	**df**	***P***
PIT tag	Tag attachment year	61.52	6	<0.0001*,**	1.47	1	0.225	0.75	1	0.387	1.54	1	0.214
	Tag loss year	220.3	6	<0.0001*,**	0.95	1	0.331	1.56	1	0.212	3.86	1	0.046*
	Sex	1.52	1	0.217	0.02	1	0.872	2.01	1	0.571	0.57	1	0.904
	Body mass	0.001	1	0.979	0.51	1	0.476	0.34	1	0.563	0.12	1	0.720
Ear tag	Tag attachment year	223.10	6	<0.0001*,**	2.44	1	0.119	2.23	1	0.135	1.02	1	0.313
	Tag loss year	800.03	6	<0.0001*,**	1.35	1	0.246	2.45	1	0.118	1.98	1	0.160
	Sex	0.0003	1	0.986	0.54	1	0.463	0.01	1	0.944	2.67	1	0.264
	Body mass	7.23	1	0.007*,**	2.61	1	0.106	0.14	1	0.709	0.88	1	0.349

* Significant at $P < 0.05$, ** significant after Bonferroni correction, $P < 0.013$.

study found no difference in loss between PIT and ear tags for cotton rats; thus, using either tag likely would provide similar estimates of population size or survival for this species. For flying squirrels ear tag loss exceeded PIT tag failure, whereas the opposite was observed for deer, cotton, and house mice. Thus, PIT tags may be the preferable method of marking for flying squirrels and ear tags are more suitable for the latter species, to provide less biased parameter estimates.

Missing ear tags usually were noted from torn ear tissue, suggesting tags may be removed by dense vegetation, conspecifics, or even the marked individual. A possible explanation for interspecific differences in ear tag loss may be differences in ear size, with tags attached to smaller ears more likely to be torn off. This does not appear to be the case in our study since higher ear tag loss was reported in species with larger relative ear size (13–23 mm for flying squirrels [Dolan and Carter 1977]; 16–24 mm for cotton rats [Cameron and Spencer 1981]). In contrast, the smallest ears belonging to house mice (10–18 mm; Sealander and Heidt 1990) showed low percent loss of ear tags. Deer and cotton mice were the most likely to retain their ear tags and have ear sizes that are intermediate among the species.

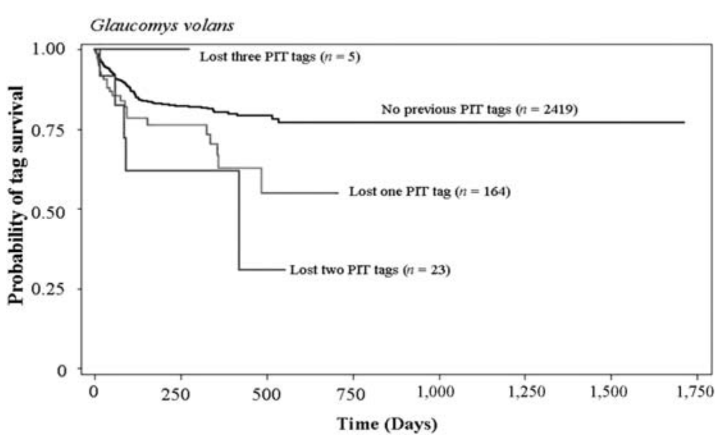

Figure 5. Kaplan–Meier plots showing probability of passive integrated transponder (PIT) tag retention and the effects of tag replacement on proportional tag survival in southern flying squirrels (*Glaucomys volans*). (*Steps* indicate failure of a tag and failures occurring on the same day are recorded as a single step.)

Flying squirrel gliding behavior and arboreal habits also may influence ear tag loss because external tags may get caught on vegetation. In contrast, we captured the murine rodents, which are more terrestrial in their habits, in crop fields and edge-type areas. Vegetation structure is less complex, with fewer woody plants; thus, ear tags may be less likely to be torn off while the animal is mobile.

Both flying squirrels and cotton rats exhibit a loose social organization in which encounters with conspecifics frequently occur (Dolan and Carter 1977, Cameron and Spencer 1981, respectively). Flying squirrel allogrooming between individuals may account for some of the loss in ear tags, especially because most losses occurred during the colder months of the year, when communal nesting occurs (Sollberger 1943). However, this seasonal trend in tag failure may be an artifact of increased sampling effort during the autumn and early winter breeding season.

We believe ear tagging would be an adequate method of marking deer and cotton mice and other *Peromyscus* spp. because 98% retained both ear tags in our study. *Peromyscus* spp. generally are considered to be highly territorial with little contact between conspecifics, except for short aggressive bouts during the breeding season (Eisenberg 1968). In contrast are house mice, which often have antagonistic encounters and are generally considered more social (Vestal 1977). Thus, ear tag loss due to allogrooming behavior or antagonistic encounters would be expected to be infrequent. Cotton rats did not show any differences between ear and PIT tags, and either would be feasible for use in research.

Percentages of tag loss found in our study are comparable to those for other mammals in the literature. Annual loss of flipper tags in southern elephant seals ranged from 5.6% in females to 10% in males, with the intersexual difference attributed to loss from territorial bouts associated with males (Pistorius et al. 2000). In male black bears, 3% lost both ear tags within a year after being attached, and by 4.5–5.5 years, 56% of bears lost both ear tags (Diefenbach and Alt 1998). The values for females were considerably lower, 2% the first year and 5% from 4 to 5 years. Siniff and Ralls (1991) reported annual flipper tag loss rates of

26% for California sea otters, and Morley (2002) found that 6% of ferrets lost both their ear tags, making them unidentifiable. The latter result is similar to our finding in flying squirrels of 5% losing both ear tags. Despite differences in the nature of these external tags and the ecology of the species, individuals that lose tags may represent a substantial portion of the study population. Thus, combining external markers with implanted markers may allow more accurate recapture data to be accumulated.

Studies using PIT tags often replace tags that are lost. In our study the likelihood of losing a replacement PIT increased with the number of replacements in flying squirrels. However, this trend was not observed in the murine rodents, although the sampling period may not have been sufficiently long to record the loss of multiple PIT tags. Current population-size estimate models largely do not account for changes in probability of tag loss with multiple tags. As PIT tags are becoming increasingly popular in animal studies, this factor should be considered in modeling efforts based on capture–recapture data. Contrary to our hypothesis, PIT tag loss did not decrease with body mass for any of the 4 species studied. Heavier flying squirrels were more likely to lose ear tags. This may be an artifact of increased sampling during the autumn and winter when body mass was greater due to hardwood mast fallout; however, PIT tags would be influenced similarly. Larger body size may correlate with increased sociality, but we are not aware of any study that has demonstrated such a relationship in this or similar species.

Our study has demonstrated that rates of tag failure vary with respect to tag type (PIT vs. ear tag) and with respect to species, even those that are similar ecologically. The majority of mark–recapture studies in mammals are done on rodents but, despite this, reports of tag loss and failure in this group are rare. Rodents, due to overall abundance, ease of trapping, and high rates of recapture, often are used as models for studies that rely on mark–recapture information to detail the effects of various environmental and anthropogenic factors. These studies can benefit from data on failure rates of tags and the potential factors influencing failure for different species, which could be important in selecting tag type.

Using PIT tags to monitor flying squirrels would provide more accurate estimates of population size than would ear tags. However, the redundancy in marking attained by using 2 types of tags may be the most appropriate means to monitor flying squirrel populations because loss in both tags occurred and several lost all of their identifying tags. Redundancy in marking may be important particularly in social species, such as flying squirrels, where grooming may potentially occur and influence the loss of external and even internal tags. Passive integrated transponder tags provide good long-term reliability, assuming they are not lost within a few days of marking. This loss could be minimized with the application of an adhesive to seal the puncture site. Morley (2002) experienced no PIT tag failure in 98 ferrets using a tissue adhesive (Vetbond®; 3M, St. Paul, Minnesota).

Coupling PIT tags with ear tags, which provide good short-term reliability, will minimize misidentification and provide more reliable estimates. Accurate monitoring has become increasingly important as flying squirrels are considered major competitors with endangered red-cockaded woodpeckers (*Picoides borealis*) for nesting sites (Conner et al. 1996, Risch and Loeb 2004) and often are managed in woodpecker reintroduction sites. In contrast, using only a single tag type would be sufficient to study the less social murine species we studied because overall tag loss was relatively low.

Additionally, tag loss may be subject to influences from a suite of factors relating to study species, both morphological and behavioral. To maximize accuracy, models that use mark–recapture data, tag recovery, or tag–resight data should account for tag loss (Barker 1997). Before initiating studies using species-specific models of estimating population sizes, survival, and other parameters, one should attempt to examine tag loss within the study context and consider the most appropriate tag type. Using paired ear tags allows one to address tag loss, since one has a redundant system. Using strictly PIT tags, such as is often done with voles whose ears are too small to tag, does not allow one to accurately address tag loss.

Our study provides some information concerning tag loss in several common species. However, preliminary studies of tag retention and failure often are not feasible before the onset of a study. To attain accurate recapture data, we strongly recommend the use of both externally visible markers and implanted tags, such as a PIT or VIE tag. This redundancy will strengthen population estimates based largely on data provided by recaptured animals.

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