**Introduction**

1. c-r assumes no tags lost or overlooked
2. Problems with bias in survival/abundance when tags are lost; possibly ok with lambda (Rotella)
3. Development of models to incorporate tag loss (Kremers; Cowen and Schwarz) – independence?
4. Variety of methods for estimation of tag loss:
   1. Independence assumption
   2. Cross-sectional/longitudinal
   3. Finite/instantaneous rates

**Issues:**

**Sampling: animals with 2 tags more likely to be seen than with 1 tag**

**Status: status of both tags more likely to be recorded when both tags present**

**the latter is worsened with longitudinal data because it can be seen across years with different tags .**

**Idea: Use CJS model for each tag, set p=1 and use “.” for unknown tag status. Use status of other tag to modify other tag survival. Use 00?**

**Estimation models for tag loss**

**Bradshaw et al:**

Could identify those with double tag-loss but not as individuals

Is cross-sectional because they could only identify number with 2 missing tags

Specified as finite rate

**Diefenbach et al.**

Could identify individuals with double tag-loss from permanent lip-tattoos

Longitudinal using release – recapture time at liberty model; used different conditional prob

Specified as finite rate

**Pistorius et al.**

Assumed independence

Longitudinal using release-recapture time at liberty model; includes covariates

Specified as instantaneous rate

Barrowman, N. J. and R. A. Myers (1996). "Estimating tag-shedding rates for experiments with multiple tag types." Biometrics **52**(4): 1410-1416.

Bradshaw, C. J. A., R. J. Barker, et al. (2000). "Modeling tag loss in New Zealand fur seal pups." Journal of Agricultural Biological and Environmental Statistics **5**(4): 475-485.

Mark-recapture studies of pinnipeds commonly use double-tagging to reduce bias of parameter estimates and to allow estimation of tag retention rates. However, most tag retention estimates assume independence of tag loss. Here we were able to identify when individual New Zealand fur seal (Arctocephalus forsteri) pups had lost both tags; therefore, we tested the assumption of no association between the tag-loss rates of left and right tags. We also tested for differences in tag retention among three different types of plastic tag (Allflex(R) cattle, mini and button tags), between two attachment types (i.e., fixed or swivel), and whether retention varied among years and colonies sampled. We found strong evidence of within-individual tag loss association for most tags in most years, but little evidence that this varied among colonies. We found that ignoring within-individual association of tag loss led to a bias in estimated tag retention of 7.4-10.1%. Smaller rocks and greater crevice and ledge densities in colonies were associated with lower probabilities of tag retention. We suggest researchers should attempt to use permanent marks in combination with tags to assess unbiased estimates of tag retention.

Cadigan, N. G. and J. Brattey (2003). "Semiparametric estimation of tag loss and reporting rates for tag-recovery experiments using exact time-at-liberty data." Biometrics **59**(4): 869-876.

We present a semiparametric likelihood approach to estimating reporting rates and tag-loss rates from the tags returned from capture-recapture studies. Such studies are commonly used to estimate critical population parameters. Tag loss rates are estimated using double-tagged animals, while reporting rates are estimated using information from high-reward tags. A likelihood function is constructed based on the conditional distribution of the type of tag returned (low or high reward, single or double tag), given that a tag has been returned. This involves many sparse 5 x 1 tag-return contingency tables, and choosing a good functional form for the tag loss rate is difficult with such data. We model tag-loss rates using monotone-smoothing splines, and use these nonparametric estimates to diagnose the parametric form of the tag-loss rate. The nonparametric methods can also be used directly to model tag-loss rates.

Diefenbach, D. R. and G. L. Alt (1998). "Modeling and evaluation of ear tag loss in black bears." Journal of Wildlife Management **62**(4): 1292-1300.

Demographic models that use marked animals to estimate survival rates and population size assume no tag loss occurs, otherwise estimates are biased. Most studies of tag loss have assumed loss of 1 tag was independent of loss of the other, as did a prior study of ear tag loss in Pennsylvania black bears (Ursus americanus). We used permanently marked (tattooed) black bears to model ear tag loss rates so we could identify bears recovered missing both ear tags, and thus test the independence assumption. We found ear tag loss in male bears increased with time between tagging and recovery. Also, for males, the probability of losing a second ear tag was greater if it had already lost an ear tag. For a tagging-recovery interval of 0.5-<1 year, we estimated 3% of males lost both ear tags (95% CI = 2-4%); however, for an interval of 4.5-<5.5 years, we estimated 56% lost both ear tags (95% CI = 42-75%). We selected the same type of model for females, but ear tag loss rates were much lower. We estimated 2% of females lost both ear tags for tagging-recovery intervals of 0.5-<1 year (95% CI = 1-4%), and 5% of females lost both ear tags for intervals of 4-<5 years (95% CI = 1-18%). Comparison of survival estimates with and without a correction for ear tag loss suggests uncorrected annual survival estimates may be biased -6% for males and -1% for females. Black bears are a long-lived species with high loss rates of ear tags for males. Estimates of survival rates or population size that use mark-recapture type models should either incorporate ear tag loss in the model, especially for males, or use data from short time intervals (less than or equal to 1 yr) to minimize bias from ear tag loss. In addition to ear tagging to identify individuals for mark-recapture studies, we recommend researchers tattoo bears on both inner sides of the upper lip.

Fabrizio, M. C., J. D. Nichols, et al. (1999). "Modeling data from double-tagging experiments to estimate heterogeneous rates of tag shedding in lake trout (Salvelinus namaycush)." Canadian Journal of Fisheries and Aquatic Sciences **56**(8): 1409-1419.

Data from mark-recapture studies are used to estimate population rates such as exploitation, survival, and growth. Many of these applications assume negligible tag loss, so tag shedding can be a significant problem. Various tag shedding models have been developed for use with data from double-tagging experiments, including models to estimate constant instantaneous rates, time-dependent rates, and type I and II shedding rates. In this study, we used conditional (on recaptures) multinomial models implemented using the program SURVIV (G.C. White. 1983. J. Wildl. Manage. 47: 716-728) to estimate tag shedding rates of lake trout (Salvelinus namaycush) and explore various potential sources of variation in these rates. We applied the models to data from several long-term double-tagging experiments with Lake Superior lake trout and estimated shedding rates for anchor tags in hatchery-reared and wild fish and for various tag types applied in these experiments. Estimates of annual tag retention rates for lake trout were fairly high (80-90%), but we found evidence (among wild fish only) that retention rates may be significantly lower in the first year due to type I losses. Annual retention rates for some tag types varied between male and female fish, but there was no consistent pattern across years. Our estimates of annual tag retention rates will be used in future studies of survival rates for these fish.

Lenarz, W. H. and F. R. Shaw (1997). "Estimates of tag loss from double-tagged sablefish, Anoplopoma fimbria." Fishery Bulletin **95**(2): 293-299.

Between 1986 and 1988, 10,545 double-tagged sablefish were released off California, Oregon, and Washington. Tags recovered from these fish have provided one of the best sets of data available for estimating tag-shedding rates. We developed a new model and a maximum-likelihood procedure to estimate the rates. Both initial and long-term shedding rates were low, but posteriorly placed tags were shed at about twice the rate of anteriorly placed tags. Bootstrapping indicated that the estimates were precise and accurate. Shedding rates for sablefish were considerably lower than most published estimates for other species. Although the rates were low, the extra tag increased recoveries by nine percent over a six-year period.

Pistorius, P. A., M. N. Bester, et al. (2000). "Evaluation of age- and sex-dependent rates of tag loss in southern elephant seals." Journal of Wildlife Management **64**(2): 373-380.

Rates of tag loss were estimated in a long-term tagging study of southern elephant seals (Mirounga leonina) to assess the potential for bias in estimates of survival rates. Dalton Jumbo Rototags(R) were applied to each hind flipper of 5,743 recently weaned elephant seal pups on Marion Island from 1983 to 1993. We adapted and developed a Method based on the resighting times of seals retaining 1 or 2 tags to estimate tag loss and test for effects of age and sex of the seals. Tag loss by young seals was low but there was a strong increase in tag loss with seal age, especially for males. Annual single tag loss at age 14 was 10% for males and 5.6% for females. Although these are relatively modest rates of tag loss, substantial fractions of seals (35% of males and 17% of females) would lose both tags by age 15, requiring corrections to avoid bias in demographic studies based on these tagging data. The method we used to estimate tag loss has significant advantages over a ratio estimator that has been used for most previous studies of tag loss in pinnipeds.

Xiao, Y. S., L. P. Brown, et al. (1999). "Estimation of instantaneous rates of tag shedding for school shark, Galeorhinus galeus, and gummy shark, Mustelus antarcticus, by conditional likelihood." Fishery Bulletin **97**(1): 170-184.

Fish and other animals are often tagged to estimate their abundance as well as rates of growth, fishing mortality, natural mortality, and movement. Results of these studies are biased if tags are not retained permanently and if tag loss is not taken into account. In this paper, we develop a simple tag shedding model to account for the effects of time at liberty, sex, and other factors and use one of its special cases to estimate the instantaneous tag shedding rate from data based on two double-tagging experiments on the school shark, Galeorhinus galeus, and gummy shark, Mustelus antarcticus, off southern Australia. For either species, tag shedding rate could vary with tag type, position of tag on fish, and sex of fish, but not with length at release or time at liberty. The shedding rate of Petersen disc fin tags was well above 50%/yr. Dart tags were shed at a higher rate (41%/yr for school shark; 63%/yr for gummy shark) than either "Roto" or "Jumbo" fin tags (8%/yr for school shark; 6%/yr for gummy shark). For either species of shark, the shedding rate of dart tags anchored in the basal cartilage of the dorsal fin was about half that of dart tags anchored in the dorsal musculature.

**Incorporating tag loss into models for survival/abundance**

Cowen, L. and C. J. Schwarz (2006). "The Jolly-Seber Model with Tag Loss." Biometrics **62**(3): 699-705.

Summary. Tag loss in mark-recapture experiments is a violation of one of the Jolly-Seber model assumptions. It causes bias in parameter estimates and has only been dealt with in an ad hoc manner. We develop methodology to estimate tag retention and abundance in double-tagging mark-recapture experiments. We apply this methodology to walleyes (Stizostedion vitreum) in Mille Lacs, Minnesota.

Kremers, W. K. (1988). "Estimation of Survival Rates from a Mark-Recapture Study with Tag Loss." Biometrics **44**(1): 117-130.

**Examples of tag loss estimates**

Bradshaw, C. J. A., R. J. Barker, et al. (2003). "Estimating survival and capture probability of fur seal pups using multistate mark-recapture models." Journal of Mammalogy **84**(1): 65-80.

We use a multistate mark-recapture model incorporating information on body mass, sex, time of capture, and natal colony to estimate the probabilities of survival, capture, and mass-state transition of New Zealand fur seal (Arctocephalus forsteri) pups from 3 sites (colonies) on Otago Peninsula, South Island, New Zealand. Apparent survival for a mean sampling interval of 47 days was high (greater than or equal to0.850) after correcting for tag loss, and there was evidence that there were differences between sexes and among sites even after controlling for mass at capture. Survival did not differ among body-mass classes. Heavier pups had lower capture probabilities; however, differences in mass adequately explained any potential differences in capture probability due to sex. State-transition probabilities among mass classes also differed with time of capture, and between sexes and among sites. Although bias in estimates of survival probability is minimal when survival is high, heterogeneity in capture probabilities among different classes of individuals can bias estimates of pup growth rate and sex ratio. We recommend measuring mass of individuals and incorporating this and perhaps other pertinent information into multistate mark-recapture models when attempting to estimate survival and to determine the effect of capture probability on estimates of other life-history parameters.

Hall, A. J., B. J. McConnell, et al. (2001). "Factors affecting first-year survival in grey seals and their implications for life history strategy." Journal of Animal Ecology **70**(1): 138-149.

1. In order to estimate the effect of weaning mass and body condition on the post-weaning survival of grey seal pups from the Isle of May, Scotland in 1998 during their first year of life, a simultaneous analysis of live resighting and dead recovery mark-recapture data was used. A new type of tag was employed which allowed individuals to be identified when resighted alive (Hall, Moss & McConnell 2000) as well as when found dead. 2, The probability of post-weaning survival to age 1 increased with body condition at weaning and differed between the sexes. Regardless of pup condition and time of year, the odds of survival for female pups over a 2-month interval was estimated to be 3.37 (SE = 1.30) times higher than for males. Regardless of sex, a 1 standard deviation increase in pup condition was estimated to increase the odds of survival by a factor of 1.422 (SE = 0.226). For a male pup in average condition (0.41 kg cm(-1)) the estimated annual survival after adjusting for tag-loss was 0.193 (SE = 0.084); for a female pup in average condition (0.39 kg cm(-1)) it was 0.617 (SE = 0.155). 3, The effect of condition at weaning on survival was significantly greater for male pups than for females. This implies that high quality females should invest more heavily in their male pups because the marginal return, in terms of increased reproductive value, from any additional expenditure is twice that for females. Male pups in our sample were significantly heavier at weaning and in better condition than female pups. However, this does not provide conclusive support for our predictions, because we could not control for the effects of maternal size on weaned mass.

Limpus, C. J. (1992). "Estimation of Tag Loss in Marine Turtle Research." Wildlife Research **19**(4): 457-469.

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.

Wilkinson, I. S. and M. N. Bester (1997). "Tag-loss in southern elephant seals, Mirounga leonina, at Marion Island." Antarctic Science **9**(2): 162-167.

Rates of tag-loss are determined for Dalton Jumbo Rototags applied to the hind flippers of 4343 (2208 males, 2135 females) southern elephant seal (Mirounga leonina) pups at Marion Island over an eight year period from 1983-1990 as part of a demographic study of the species. Loss rates were the lowest recorded to date for this species (range 0.0-9.1%). No significant relationship existed between age and rate of tag-loss, neither was there any sex or year related differences in age-specific tag-loss rates. The low rates of loss highlight the value of tagging as a marking technique, and allow for high levels of confidence in the reliability of the population parameters that are derived from the tagging data collected for the Marion Island population.

**Influence of tag loss on survival/abundance**

Arnason, A. N. and K. H. Mills (1981). "Bias and Loss of Precision Due to Tag Loss in Jolly-Seber Estimates for Mark-Recapture Experiments." Canadian Journal of Fisheries and Aquatic Sciences **38**(9): 1077-1095.

McDonald, T. L., S. C. Amstrup, et al. (2003). "Tag loss can bias Jolly-Seber capture-recapture estimates." Wildlife Society Bulletin **31**(3): 814-822.

We identified cases where the Jolly-Seber estimator of population size is biased under tag loss and tag-induced mortality by examining the mathematical arguments and performing computer simulations. We found that, except under certain tag-loss models and high sample sizes, the population size estimators (uncorrected for tag loss) are severely biased high when tag loss or tag-induced mortality occurs. Our findings verify that this misconception about effects of tag loss and tag-induced mortality could have serious consequences for field biologists interested in population size. Reiterating common sense, we encourage those engaged in capture-recapture studies to be careful and humane when handling animals during tagging, to use tags with high retention rates, to double-tag animals when possible, and to strive for the highest capture probabilities possible.

Rotella, J. J. and J. E. Hines (2005). "Effects of tag loss on direct estimates of population growth rate." Ecology **86**(4): 821-827.

The temporal symmetry approach of R. Pradel can be used with capture-recapture data to produce retrospective estimates of a population's growth rate, lambda(i), and the relative contributions to lambda(i) from different components of the population. Direct estimation of lambda(i) provides an afternative to using population projection matrices to estimate asymptotic lambda and is seeing increased use. However, the robustness of direct estimates of lambda(1) to violations of several key assumptions has not yet been investigated. Here, we consider tag loss as a possible source of bias for scenarios in which the rate of tag loss is (1) the same for all marked animals in the population and (2) a function of tag age. We computed analytic approximations of the expected values for each of the parameter estimators involved in direct estimation and used those values to calculate bias and precision for each parameter estimator. Estimates of lambda(i) were robust to homogeneous rates of tag loss. 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 lambda(i) were not robust to tag loss. Tag loss reduced the precision of all estimates because tag loss results in fewer marked animals remaining available for estimation. Clearly tag loss should be prevented if possible, and should be considered in analyses of lambda(i), but tag loss does not necessarily preclude unbiased estimation of lambda(i).

Stobo, W. T. and J. K. Horne (1994). "Tag Loss in Grey Seals (Halichoerus-Grypus) and Potential Effects on Population Estimates." Canadian Journal of Zoology-Revue Canadienne De Zoologie **72**(3): 555-561.

Cumulative tag loss among 4064 grey seal (Halichoerus grypus) pups observed on Sable Island was less than 1% during the first 5 months of life, 13% by the end of the first year, and continued to increase with age. Cumulative tag loss among grey seals aged 6 and older was over 40.0%. A double-tagging study indicated that pre-punching of flippers, the colour of tags applied, and application to the left or right flipper significantly affected tag loss. The addition of a flag to the tag had no significant effect. A comparison of scientific observations of tag loss with commercial bounty return data indicated that casual observers probably missed tags on double-tagged animals. Overlooked tags in single-tagging experiments result in population overestimates. In double-tagging experiments, overlooked tags result in correction factor overestimates and population underestimates. Age-specific tag loss correction factors should be used if population estimates include more than one age group.