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Sensitivity of tag-recovery mortality estimates to inaccuracies in tag shedding, handling mortality, and tag reporting

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ABSTRACT

We used Monte Carlo simulations to evaluate the sensitivity of tag-recovery mortality estimates to inaccuracies in tag shedding, handling mortality, and tag reporting. The data-generating model used in the simulations assumed that tagging was conducted annually for 4 years with tag recoveries occurring over a 4-year period. Several different combinations of instantaneous fishing (*F*) and natural (*M*) mortality were evaluated in the simulations. The data-generating model additionally assumed that immediate-shedding and handling-mortality rates equaled 2.5% and 0%, respectively, and that chronic shedding was a sigmoidal function of months since tagging. Two spatial patterns of reporting rates were considered—one where reporting was a function of distance from the tagging site and one where reporting was a random generation across the study area. Maximum likelihood estimates of *F* and *M* were calculated from the recovery of tags from the data-generating model under different assumed rates of tag shedding, handling mortality, and tag reporting. We found that assumptions about reporting rates resulted in the most variability in mortality estimates regardless of which combination of *F* and *M* was evaluated, with assumptions about chronic shedding also contributing substantially to overall variability in mortality estimates for most mortality combinations. Assumptions about immediate tag shedding and handling mortality had relatively minor effects on mortality estimates compared to reporting rate. When planning a tag-recovery study, care should be taken to ensure that chronic shedding and tag-reporting rates are accurately measured, as inaccurate measurements in these factors can result in significant errors in mortality estimates.

Introduction

Tag-recovery models (Brownie et al., 1985) are widely used to estimate mortality of both marine and freshwater fish stocks. Several factors, including tag shedding, handling mortality, and tag reporting, can affect the numbers of recovered tags and, as a consequence, mortality estimates. While it is possible to estimate at least some of these rates when fitting a tag-recovery model, accurate estimation can be difficult (Hoenig et al., 1998; Denson et al., 2002). As a result, accurate mortality estimation using a tag-recovery approach at least partly depends on the collection of auxiliary data pertaining to tag shedding (hereafter referred to as shedding), handling mortality, and tag reporting (hereafter referred to as reporting). Each of these factors can be measured in a variety of ways: shedding can be estimated by double tagging or supplemental marking of fish (Pierce and Tomcko, 1993; Fabrizio et al., 1999; Latour et al., 2001; Miranda et al., 2002, Livings et al., 2007); handling mortality can be estimated by withholding samples of tagged fish in tanks, pens, or cages (Pierce and Tomcko, 1993; Latour et al., 2001; Miranda et al., 2002; Taylor et al., 2006); reporting rates can be estimated through the use of high-reward tags (Pollock et al., 2001; Pollock et al., 2002; Taylor et al., 2006), planted tags (Hearn et al., 2003), or creel or port surveys (Hearn et al., 1999; Pollock et al., 2002).

Even when data concerning shedding, handling-mortality, and reporting rates are collected as part of a tagging study, biased mortality estimates may still result if measurements of these rates are not accurate (Miranda et al., 2002). For example, handling mortality may be overestimated if fish held in nets or pens become stressed as a result of biofouling (Ahlgren, 1998; Udomkusonsri and Noga, 2005; Isermann and Carlson, 2008). Alternatively, handling mortality may be underestimated if favorable conditions in tanks promote the recovery of tagged specimens. In either case, biased mortality estimates would result because of the inaccuracies in handling-mortality data. Knowing how such inaccuracies can influence mortality estimates can be beneficial when planning a tagging study as more resources can be devoted to measuring those factors that can result in the largest biases in the estimates.

Our interest in how inaccuracies in shedding, handling-mortality, and reporting rates can affect estimation of fishing and natural mortality stemmed from our involvement in a project meant to clarify the

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relationship between indicators of fish health and natural mortality rates in four lake whitefish (*Coregonus clupeaformis* Mitchill) stocks in northern lakes Huron and Michigan (Wagner et al., 2010). For that study, lake whitefish were tagged with anchor tags, and the recovery and reporting of tags by commercial fishers was used to estimate fishing and natural mortality rates for the stocks (Ebener et al., 2010a). Data pertaining to shedding, handling mortality, and reporting were collected as part of the study; however, there was concern that measurements of some of these factors were inaccurate. For example, one way that handling mortality was monitored was by holding a subsample of tagged fish at an onshore facility. While at this facility, though, many tagged fish developed fungal infections and died. The cause of these infections was believed to be the transport and holding of fish at the onshore facility rather than the tagging process. As a result, we did not use this information when calculating handling-mortality rates. Even though we ultimately did not to use this information, it still caused us to question whether our estimates of handling mortality were accurate, and, if not, how our estimates of fishing and natural mortality might be affected by the inaccuracy.

Another factor that concerned us with the lake whitefish study was how possible spatial differences in reporting rates might affect mortality estimation. For the lake whitefish study, reporting rates by commercial fishermen were measured through onboard observers. Reporting rates were not calculated as part of the tag-recovery model; rather, reporting rates for the stocks were calculated separately and were used as constants when specifying the tag recovery probabilities for the estimation model (e.g., Latour et al., 2001). Given the sizes of the systems that we were studying, we believed it was possible, if not likely, that reporting rates varied depending on where tags were recovered from the lakes regardless of whether exploitation was constant across the study area or not. Reporting rates are likely affected by many factors, such as publicity of the tagging program, prior acquaintanceship between fishers and study investigators, perceptions of fishers as to how the tagging information will be used, and general fisher indifference to the tagging program. It is widely recognized that changes in factors such as these can lead to reporting rates that vary with time (Pollock et al., 2002; Polacheck et al., 2006; Taylor et al., 2006). However, spatial differences in tag reporting rates also are likely to occur (Jenkins et al., 2000; Denson et al., 2002), which may be a significant source of error when estimating mortality.

The purpose of this research was to evaluate the sensitivity of tag-recovery mortality estimates to inaccuracies in shedding, handling-mortality, and reporting rates. This analysis should provide useful information regarding the sensitivity of mortality estimates to possible inaccuracies of these factors, and thereby guide planning of tagging studies to ensure that mortality estimates are as accurate as possible.

Methods

We used Monte Carlo simulations to explore the sensitivity of tag-recovery mortality estimates to errors in assumed rates of shedding, handling mortality and reporting. Our simulations consisted of a data-generating model that generated tag recoveries, and an estimation model that used the number of recovered and reported tags to estimate instantaneous fishing and natural mortality rates. We based our simulations on the tagging protocol and spatial framework of the aforementioned lake whitefish study. For our data-generating model, tagged fish were released annually for 4 years, with tag recoveries occurring over a 4-year period that began with the initial tagging event. Fish were assumed to be tagged at a single site in northern Lake Michigan, with recovery of tags occurring at locations throughout the lake (Fig. 1). A target tagging level of 2,000 fish per year was used for the data-generating model, although the actual number of tagged fish in a year was determined by random draw from a normal distribution with a mean equal to the target tagging effort and a standard deviation equal to 5% of the mean. The resulting value was then rounded to the nearest integer. Immediately after tagging, fish dispersed to various parts of the lake, with dispersal being a function of distance from the tagging site. The fraction of tagged fish dispersing to areas within 25 km, from 25 to 50 km, from 50 to 100 km, from 100 to 200 km, and beyond 200 km of the tagging site was a random draw from a multinomial distribution with expected cell probabilities of 70%, 15%, 10%, 4%, and 1%, respectively, which was similar to the observed dispersal of lake whitefish from the tagging study (Ebener et al., 2010b). Dispersal of fish to individual 10-min grids within these distances of the tagging site was random. After dispersal, it was assumed that fish remained within their occupied grid cells throughout the duration of the study, which we assumed primarily for the sake of simplicity. Conceptually, the tagging site represented a spawning area for the lake whitefish population, while the dispersal locations represented feeding areas occupied by the lake whitefish during other times of the year.

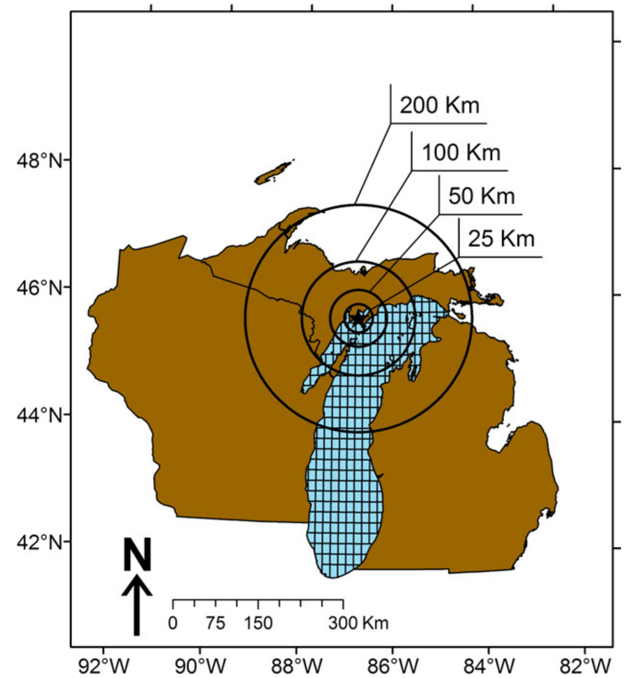

Fig. 1. The assumed spatial framework used in our simulations to evaluate the sensitivity of tag-recovery mortality estimates to shedding, handling mortality, and reporting rate inaccuracies. Fish were assumed to be tagged at a single site in northern Lake Michigan (&), whereupon fish dispersed to various Lake Michigan 10-min grids. The concentric circles around the tagging site indicate various distances from the tagging site.

Recovery of tags for the data-generating model were determined using the Hoenig et al. (1998) instantaneous mortality formulation of a tag-recovery model for an assumed Type-II (continuous fishing throughout the year) fishery. Several different combinations of instantaneous fishing (F) and natural mortality (M) were incorporated in the data-generating model and evaluated in our simulations: high F and high M ($F=0.40$ and $M=0.40$), high F and low M ($F=0.40$ and $M=0.15$), low F and high M ($F=0.15$ and $M=0.40$), and low F and low M ($F=0.15$ and $M=0.15$). To mimic our lake whitefish study, we divided the year into three seasons that differed in both length of year and amount of harvest. The fraction of the year for the seasons was 0.417 (season 1), 0.333 (season 2), and 0.25 (season 3). The fraction of the harvest for the seasons was 0.19 (season 1), 0.40 (season 2), and 0.41 (season 3). For simplicity, we assumed that fishing and natural mortality were constant throughout the lake and for each