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Symposium Review: Using Electronic Tags to Estimate Vital Rates in Fishes

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Accurate and precise estimates of vital rates, such as natural and fishing mortality, can be challenging to obtain, but are essential for stock assessment, fisheries management, and conservation. Joseph Hightower pioneered a novel approach for estimating mortality rates—assigning fates of electronically tagged fish using telemetry. Herein, we describe a day-long symposium held at the 147th American Fisheries Society Meeting in 2017 dedicated to highlighting and discussing current uses of and recent advancements in electronic tagging to estimate fish vital rates. In this review, we highlight the 18 presentations made in the symposium as well as the discussion that concluded the session. Symposium presentations illustrated the breadth and depth of use of electronic tags to estimate vital rates and the discussion stressed the need for careful study design. As tag technology and analytical approaches continue to improve, we suggest that electronic tagging studies will become even more valuable to help scientists and managers better understand fish biology and manage fisheries.

Joseph Hightower locating acoustically tagged fish.

Accurate and precise estimates of vital rates such as fishing mortality (F) and natural mortality (M) are necessary for stock assessment, fisheries management, and conservation. Over the last two decades, researchers have increasingly used electronic tags to estimate vital rates for fishes. Joseph Hightower (North Carolina State University [NC State]) pioneered this modern approach in his seminal paper Hightower et al. (2001), in which telemetered Striped Bass *Morone saxatilis* were tracked and their fates assigned based on behavior. Specifically, in Hightower et al. (2001), each detected Striped Bass was assigned a fate of "alive" or "non-harvest loss" based on the detection pattern of its electronic tag. Thus, their use of electronic tags allowed them to directly estimate M. This direct estimation was innovative: M is notoriously problematic in stock assessment because it is difficult (or impossible) to observe. As a result, it is estimated indirectly or assumed for many assessments. Using electronic tags also allowed the researchers to determine the seasonal pattern of M (which was linked to low suitability of habitat in summer and fall). Since Hightower et al. (2001), Joseph Hightower has continued to develop new and exciting field and analytical approaches to estimate fish vital rates using electronic tags (e.g., Hightower and Harris 2017). Other researchers have built on the work of Hightower et al. (2001) and as a result, electronic tags have now been used to estimate vital rates for a variety of commercially, recreationally, and ecologically valuable fish species in marine, estuarine, and freshwater environments.

To examine current uses and recent advancements in the use of electronic tags to estimate vital rates for fish, a symposium was convened on August 24, 2017, by Jeffrey Buckel (NC State), Julianne Harris (U.S. Fish and Wildlife Service), Janice Kerns (Ohio Department of Natural Resources), Brendan Runde (NC State), Jacob Krause (NC State), Frederick Scharf (University of North Carolina [UNC]–Wilmington), and Trevor Scheffel (UNC Wilmington) as part of the 147th

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Annual Meeting of the American Fisheries Society. A total of 18 presentations were given regarding 20 species from 14 families of fish, including freshwater, anadromous, estuarine, and marine representatives. The symposium began with a plenary-style talk from expert Joseph Hightower and ended with a discussion period. Hightower introduced the topic of using electronic tags to estimate mortality rates and then described four basic study designs. His talk stressed the importance of carefully considering study design, starting with simulations to maximize the quality of results, and using Bayesian software for flexibility in study design and analysis. His presentation ended with a compilation of *M* estimates from electronic tag studies that were mostly lower than values of *M* predicted from fish body size (Lorenzen 1996). Much of Hightower's presentation, along with JAGS code for simulation and parameter estimation, can be found in Hightower and Harris (2017).

The plenary talk was followed by another presentation in which the need for careful study design was discussed; this talk focused on lessons learned from multiple radio telemetry studies in freshwater, including the possibility of dead fish "moving" and avian predation (Kerns). A subsequent presentation described the use of Bayesian hierarchical models to estimate *M* (Zhou, Virginia Tech). The next talk described the effects of fish condition on survival in two species of anadromous fish (Woodley, U.S. Army Engineer Research and Development Center; Woodley et al. 2013). The impact of winter severity on fish survival was the focus of the next two talks in freshwater (Meyer, South Dakota Game, Fish and Parks) and estuarine (Ellis, NC State; Ellis et al. 2017) habitats. The symposium continued with three talks estimating vital rates of estuarine fishes: one described estimation of apparent survival in Weakfish *Cynoscion regalis* (Krause) while the other two detailed estimation of *F* and *M* using a combined telemetry and conventional tagging approach for Southern Flounder *Paralicthys lethostigma* (Scheffel) and Red Drum *Sciaenops ocellatus* (Nelson, University of South Alabama). The next study used detection arrays on reefs to estimate *F* and *M* for telemetry-tagged Gulf of Mexico Red Snapper *Lutjanus campechanus*, and emphasized the importance of distinguishing false acoustic detections and detections from predation events (Williams-Grove, Auburn; Williams-Grove and Szedlmayer 2016). The following talk described the use of multiple tags and a large-scale receiver array to examine survival of Gulf Sturgeon *Acipenser oxyrinchus desotoi* from multiple Gulf of Mexico rivers; this talk stressed the importance of simulation in study design and the possibility of tag failure in a long-lived fish (Pine, University of Florida; Rudd et al. 2014). Next, acoustic, PIT, and conventional tags were analyzed by an integrated multistate model to estimate *F* from multiple fisheries, *M*, and discard mortality for Striped Bass (Harris; Harris and Hightower 2017).

The symposium then turned to projects that used behavior patterns of telemetry-tagged fish to estimate post-release survival. The first of these talks tracked fates of tournament-angled Walleye *Sander vitreus* in Saskatchewan, Canada (Somers, University of Regina). Two talks described the use of incorporated sensors in transmitters (depth and acceleration) to measure discard mortality in deepwater groupers (Runde; Runde and Buckel 2018) and Red Snapper (Curtis, Texas A and M–Corpus Christi; Curtis et al. 2015).

The final part of the symposium featured tests of habitat quality and estimation of movement and abundance. Apparent survival was modeled for hatchery-reared Common Snook *Centropomus undecimalis* through the use of remotely-detected PIT tags, and more complex habitats were shown to result in higher survival (Schloesser, Mote Marine Laboratory). The next talk examined the use of multiple receiver arrays to track movements of Cobia *Rachycentron canadum* across state and regional boundaries in the ocean (Brenkert, South Carolina Department of Natural Resources). The final presentation in the symposium demonstrated the combined use of acoustic transmitters and side-scan sonar for estimating spawning run size of Atlantic Sturgeon *A. oxyrinchus oxyrinchus* (Kazyak, U.S. Geological Survey).

Several common themes emerged from these presentations and the open discussion that followed the structured session. First, there are drawbacks associated with electronic tags. Ultrasonic and radio tags are typically very costly, resulting in low sample sizes relative to conventional tagging studies usually used to estimate vital rates. However, the consensus was that data obtained through the use of electronic tags were often higher in quality than those from conventional tagging studies (as electronic tagging studies can provide increased understanding of species biology and behavior), but that simulations should be completed prior to study initiation to ensure sample size is adequate to make inferences. Moreover, integrating other data sources (e.g., conventional tags, PIT tags, sonar) with sonic or radio tags can increase precision in vital rate estimates, potentially at minimal additional cost; thus, even with a small number of electronic tags, a study could produce informative results. For example, Hightower and Harris (2017) describe two telemetry study designs that include high-reward conventional tags. An added benefit of combining high-reward and telemetry tags is the ability to estimate population-level estimates of catch-and-release mortality (Kerns et al. 2012, 2016; Harris and Hightower 2017). In addition to high cost, there were concerns regarding tag failure and limited detection range. The failure rate of electronic tags is often assumed to be negligible but may be high enough to cause serious bias. Suggestions were made to attempt to quantify transmitter failure where possible (e.g., Thompson et al. 2016). It was also suggested that implanting an electronic tag in the body cavity of a fish may limit its detection range (see Dance et al. 2016). If the detection range is imperative to the study objectives (e.g., to distinguish emigration from mortality using a receiver gate), researchers should consider conducting range tests using a tagged fish, as opposed to an exposed electronic tag in the water.

After identifying the drawbacks of electronic tags, participants discussed how to assess "fate" (i.e., is the fish alive or dead by either *F* or *M*) using detection patterns of electronic tags. Fate determination is often straightforward, but it is important to consider how fates will be classified before and potentially during the study. A few speakers noted that they learned about behavior and mortality by assessing "normal" vs. "abnormal" detection patterns, by actually observing dead fish, or by discovering tags from consumed fish. Careful consideration of fate assessment may be especially important when working in an unfamiliar system and/or with unfamiliar species. The fate assignment discussion especially focused on determination of *M*. In Hightower et al. (2001), *M* was assumed when a fish was repeatedly detected in the same location; however, concern was raised that differentiating the detection patterns of a dead fish from a live fish may be more difficult in some situations.

One option is to release telemetered dead fish of the target species (Muhametsafina et al. 2014; Havn et al. 2017). Recognizing the signal of a known dead individual may help elucidate otherwise unknown fates. In addition, evaluating detection patterns to identify changes in behavior (Heupel and Simpfendorfer 2002; Khan et al. 2016) or swimming speed (e.g., Bacheler et al. 2009; Friedl et al. 2013) may help differentiate between a live fish and a fish consumed by a predator. It is useful to consider all potential sources of *M* and how they may affect the detection pattern (e.g., detections may be only in one location, detections may cease, detection patterns may change, etc.) during the study design phase as well as during the study.

Another topic of discussion concerned the "probationary period" or the period after release of an electronically tagged fish within which researchers deem mortalities to be induced by tagging and/or handling and when tag shedding may occur. Although many researchers have used a period of 30 days, this duration may be too long or impractical for some studies. Most participants agreed it would be difficult to set such a period a priori, particularly for species that may never have been telemetered before, and taking an ad hoc approach may be the most practical. An alternative may be to separately estimate vital rates in the initial post-tagging period to determine if they differ from later periods.

This symposium illustrated how electronic tags have been successfully used to estimate vital rates for fishes and how this field of study has developed since Hightower et al. (2001). The sheer diversity of presentations in terms of fish species, aquatic systems (e.g., reefs, estuaries, lakes, rivers) and vital rates estimated (e.g., *F*, *M*, discard mortality, abundance) illustrates the incredible value of electronic tags for stock assessment, fisheries management, and ecology. Currently, most studies using electronic tags are aimed at understanding biology, movement patterns, and habitat use, with fewer focused on estimating vital rates to aid stock assessment (Sippel et al. 2015; Crossin et al. 2017). However, with careful study design, an electronic tagging study could improve understanding of biology and movement while simultaneously providing information to estimate vital rates. In addition, it may be possible to perform *post hoc* analyses on already-collected data from electronic tags to estimate vital rates. It is evident that the applications of this technology are broad and that advancements will continue to be made. The advent of sensors within transmitters to record metrics such as acceleration, depth, light, and predation (via pH; Halfyard et al. 2017) are promising developments in this field. As the variety of technological options and statistical methods continue to rise, so does the number of questions that are possible to answer through the use of electronic tagging.

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