PERSPECTIVE

The Need for Reporting Rationale and Detailed Methods in Studies that Surgically Implant Fish with Electronic Tracking Devices

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Each year, thousands of fishes are tagged with electronic devices to study their biology and inform fisheries management. Such research assumes that the process of capturing, tagging, and then holding fish to allow them to recover before release (i.e., the "tagging process") does not alter the physiology, behavior, and survival of these fish. However, the fish can experience physiological challenges during the tagging process that may affect their behavior and survival. We have observed that the rationale used to establish protocols for holding durations and conditions of fish before and following surgery has received little attention. Here, we provide a perspective that: (1) provides an overview of the tagging process and its effects on the physiology, behavior, and survival of fish; (2) highlights the diverse holding conditions and durations used by researchers (that are often inadequately described and seem arbitrary); and (3) identifies key research needs. We conclude that decisions of whether, how, and for how long to hold tagged fish before release depend on diverse circumstances that need to be evaluated by researchers. We recommend that researchers explicitly report the details of how, when, where, and why tagged fish are held to facilitate protocols that benefit fish welfare, science, and management.

INTRODUCTION

Fishes are the most common taxon of aquatic animals that are tagged with electronic devices such as acoustic tags, radio tags, GPS-enabled and light-based geolocators, passive-integrated transponder (PIT) tags, and biologging sensor tags (e.g., Cooke et al. 2012, 2013; Matley et al. 2022). Electronic tagging and tracking studies generally seek to provide insight into the physiology, behavior, and survival (PBS) of fishes. The tracking of tagged individuals provides researchers with a wealth of spatial and temporal data not usually possible with other methods. Thus, electronic tags present a unique opportunity to observe and assess the ecology of fishes in their environments (e.g., Caudill et al. 2013; Matley et al. 2022). Knowledge gained from electronic tagging and tracking studies has a pivotal role in managing the aquatic ecosystems that humans rely on for social, cultural, and economic fulfillment. Thus, specific goals of telemetry studies are broad, as exemplified by the following metrics: evaluating effectiveness of aquatic protected areas (e.g., Dwyer et al. 2020); quantifying mortality rates (e.g., Faust et al. 2019) and survival estimates (e.g., Rechisky et al. 2013; Skalski and Whitlock 2020; Lees et al. 2021); identifying fish spawning migratory routes (e.g., Erisman et al. 2017) and spatial ecology (e.g., Cooke et al. 2016); determining ecosystem implications of escaped aquaculture species (e.g., Skilbrei and Jørgensen 2010); and characterizing behavioral impacts of hydropower (e.g., Trancart et al. 2020) and time-to-event passage efficiency at barriers (e.g., Castro-Santos and Perry 2012). Many of these studies identify relevant metrics or tools that guide fisheries policy and management decisions (Haraldstad et al. 2018; Brooks et al. 2019; Matley et al. 2022).

General aspects of simple tagging or marking fish—i.e., nonsurgically invasive applications of unique marks or non-electronic tags—are reviewed in Pine et al. (2012). The "tagging process" for surgically implanting electronic tags into fish is comparatively more invasive. This process includes the capture, handling, holding, anesthesia or physical restraint, tagging, holding for recovery, and then release of the fish to generate data. Each of these steps can provoke stress responses (Barton and Iwama 1991; Portz et al. 2006), cause physical injuries, alter physiology and behavior, increase the chances for disease, and thus affect post-release PBS in tagged fish (Skomal 2007; Donaldson et al. 2011; Wargo Rub et al. 2014; Figure 1). For example, when holding fish before or after tagging, they can experience stress and injury from aggressive behaviors of other fish, high fish density, poor container design, poor water quality, high light levels, and prolonged holding duration (reviewed in Portz et al. 2006; Oldenburg et al. 2011). In our collective experience, we have observed that little attention has been paid towards holding methods,

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Step	Description	Concerns (examples)
1. Capture	The act of catching the fish (e.g., netting, angling, trapping or other)	• Physical injuries and associated infections • Barotrauma • Stress response
2. Handling	Direct interaction with the fish (e.g., unhooking, removing from net, time out of water)	• Physical injuries and associated infections • Elevated plasma cortisol • Hypercapnia • Anaerobiosis • Lactate accumulation • Stress response
3. Initial holding	Placement of fish within a controlled or semi-controlled environment to recover from effects of capture and handling	• Physical injuries and associated infections • Accelerated respiration • Increased blood flow • Oxygen debt • Barotrauma
4. Anaesthesia or Restraint	Application of chemical anaesthesia, electrical stimuli, or physical restriction to reduce stress or injury during tagging	• Physical injuries and associated infections • Over-exposure • Gill (or other) irritant • Recovery time • Stress response
5. Tagging	The procedure to attach or insert an electronic device onto or into a fish	• Physical injuries and associated infections • Mortality • Internal injury • Stress response
6. Holding (post-surgery)	Placement of fish within a controlled or semi-controlled environment to recover from tagging	• Physical injuries and associated infections • Oxygen debt • Aggressive behavior • Stress response • Tag burden
7. Release	The act of releasing the tagged fish back into the wild. May occur at any previous stage depending on perceived condition of fish	• Physical injuries and associated infections • Stress response during transport and release
8. Post-Release	The period following fish release which incorporates acute or chronic impacts of the tagging process when in its natural environment	• Reduced motor control • Increased energy use • Tag burden • Altered behavior • Indirect mortality • Predation • Other direct mortality • Disease exposure

Figure 1. Summary of the tagging process, including examples of common health concerns associated with each step. Many concerns such as injuries, stress, and infections may be cumulative throughout the process if appropriate steps are not taken.

including whether, when, and how to hold tagged fish in ways that encourage PBS to be like that of untagged fish (Brown et al. 2011).

We reviewed the reported methods of holding conditions for fish during the tagging process. Briefly, to identify relevant research articles, we used the following search term in Matley et al. (2022) for acoustic telemetry studies via the Web of Science search engine: "Acoustic telemetry" OR "Acoustic tracking" OR "Passive telemetry" OR "Acoustic transmit*" OR "Acoustic receiver*" OR "Acoustic tag*" OR "Ultrasonic tracking" OR "Ultrasonic telemetry" OR "Fish track*". Additionally, the repository for the journal *Animal Biotelemetry* was searched for articles that met the above search criteria, because this publication regularly publishes animal tracking studies, but is not affiliated with Web of Science. Searches were done for the years 1969–2019. These searches yielded 118 papers that investigated the various effects that tagging imposes on animals (hereafter, tagging effects) and 1,419 papers affiliated with broad ecological questions (e.g., behavior, movement patterns, survival, etc.; hereafter, ecological papers). As part of our scoping, we randomly chose 20 papers of the more recent (i.e., between the years 2000 and 2020) out of the 1,537 available (118 + 1,419) from our searches, which equates to 1.3% of the papers available, partitioned as 10 randomly chosen tagging effects papers (8.5% of 118) and 10 randomly chosen ecological papers (0.7% of 1,419) to review. For each article, we identified and evaluated categories associated with fish holding. None of these 20 papers provided rationale or support for the holding durations and holding conditions (Table S1). In addition, few studies empirically contrasted different capture and holding methods for tagged fish (but see exceptions in Donaldson et al. 2011; Oldenburg et al. 2011), which makes it difficult to determine whether, when, and how holding fish for various durations and in different conditions has merit. Given the low rate of holding information found, we concluded that insufficient information existed to warrant a comprehensive, quantitative review of all cited fish holding practices and reporting during the tagging process. We instead decided to focus on a more qualitative approach incorporating useful findings from the literature. We acknowledge that we specifically reviewed few papers relative to the amount available in our search, and that the papers we reviewed focused only on acoustic telemetry. Nevertheless, we deemed that our accumulated decades of experience implanting fish with electronic tracking devices of different kinds (not just acoustic) and knowledge of the relevant literature were sufficient.

Here, we provide our perspective, which draws from our collective research experiences. Our three goals are to (1) provide an overview of the tagging process, including goals, assumptions, and the effects of this process on the PBS of fish, (2) highlight the diverse holding conditions and durations used by researchers (that are often inadequately described and seem arbitrary), and (3) identify key research needs. Establishing and communicating defensible guidelines for holding (and other capture and tagging methods; Thiem et al. 2011) across fish species is a major gap in fish tracking research that will improve the comparability of results across studies, and the welfare of study fishes.

THE TAGGING PROCESS AND ITS EFFECTS ON FISH

Fishes live in largely inaccessible and invisible environments and generally must be captured to be instrumented with electronic tags (but see Winger et al. 2002 for an alternative tagging method). Traps, nets, hooks, electrofishing, and other gear may be used to capture fishes passively or actively as individuals or in groups so that they can be tagged (Brownscombe et al. 2019). All fish captures are stressful to some degree for the fish, with the potential to cause injuries and affect their PBS (Davis 2002; Wilson et al. 2014; Holder et al. 2022). Capturing fish with conventional fishing gear using hooks causes some level of injury (Cooke and Sneddon 2007), and gear such as nets that might not otherwise cause overt injury can cause torn fins and dermal abrasions that may lead to delayed infections (Cooke et al. 1998; Baker and Schindler 2009; Twardek et al. 2019).

In addition to injuries, fish capture can induce exhaustive exercise and air exposure that result in anaerobiosis, yielding lactate accumulation, blood acidosis, and hypercapnia (Barton and Iwama 1991), electronarcosis (for fish captured via electrofishing; Snyder 2003), and barotrauma (in fishes with swim bladders; Wegner et al. 2021). Fish capture can also cause other challenges to fish homeostasis that take time for the fish to recover (Wood et al. 1983; Kieffer 2000; Milligan et al. 2000). During recovery, fish may exhibit accelerated respiration, heart rate, and blood flow along with dilation of the arteries and release of red blood cells from the spleen (Wood 1991). If a fish is in a perturbed physiological state prior to tagging (e.g., anesthesia), then its ability to recover may be impaired, given the potential for oxygen debt (Scarabello et al. 1991) and other forms of allostatic load (McEwen 1998; Schreck 2010) that remain from capture and handling. This is highly relevant in the context of tagging, because the condition of fish prior to tagging has the potential to influence their PBS post-release due to the cumulative stress response (Barton et al. 1986; Barton and Iwama 1991; Barton 2002). Fortunately, research focused on improving fish welfare in the context of bycatch (e.g., Davis 2002) and catch and release (Brownscombe et al. 2017) has led to improved understanding of factors that contribute to capture injury and stress, and how to use that information to mitigate stress.

After the initial holding, fish are anesthetized or restrained for tag attachment or implantation. Anesthesia is a physiological challenge that takes time and energy for fish to overcome (Ross and Ross 2008; Priborsky and Velisek 2018). Chemical anesthesia requires the fish to respire treated water, and the active ingredient is subsequently metabolized, which creates a clearance period in which fish may be vulnerable to sublethal perturbations to their physiology and behavior and lethality (including from predation; see review on capture stress by Raby et al. 2014). Anesthesia is typically induced with a chemical sedative such as tricaine methanesulfonate (MS-222) or eugenol (Iversen et al. 2003). However, MS-222 should not be used on fish that may be harvested for food within 21 days of use (FDA 2022a), and eugenol is not approved for use by the United States' Federal Drug Administration as a fish anesthetic in the USA (FDA 2022b). Hence, there is a need for anesthetics in fisheries research that are federally approved for immediate release (Trushenski et al. 2013). Mechanical anesthesia, using electric stimulation of the nerve cells, can be an alternative to chemical treatment in some situations, but methods are subject to regional animal welfare laws (Reid et al. 2019). For elasmobranchs, tonic immobility may be induced by orienting the animal supine (Kessel and Hussey 2015). For the largest fish species that cannot be safely brought onto land or onboard a research vessel and placed into a container, the fish may need to be physically restrained in some manner rather than anaesthesized.

Once a fish has reached an acceptable level of anesthesia (see Summerfelt and Smith 1990), surgery is performed either to internally implant a tag into the intracoelomic cavity or to attach the tag through the musculature using wire or cord to anchor the tag, commonly through the pterygiophore bones of bony fishes or below a dorsal fin or through the dorsal fin of elasmobranchs (Jepsen et al. 2015). Open wound sites are typically closed with sutures (Wargo Rub et al. 2014). If the tag burden (frequently reported as tag mass to body mass ratio) or volume is too high, it can increase energy expenditure of the fish to maintain station in the water column and to swim (Campbell et al. 2005; Darcy et al. 2019), thus causing stress. Standard thresholds for tag burden are based on only a small subset of aquarium-based trials (Brown et al. 1999; Jepsen et al. 2005; Cooke et al. 2011). However, tag volume and shape may be as or more important burdens to fish than tag mass (Jepsen et al. 2002; Cooke et al. 2011). Consequently, many studies assume minimal tag burden without species-specific baseline information or following guidelines based on controlled settings.

DIVERSE HOLDING CONDITIONS

Although holding wild fish in tanks or nets post-surgery can be stressful for them, it may be necessary to ensure that tagged individuals have resumed normal behavior before release (Brownscombe et al. 2019). Every effort should be made to hold tagged fish, pre- and post-surgery, under the best possible conditions relative to stressors on them (i.e., appropriate fish density, high water quality, and refuge from direct sunlight). Because the goals, objectives, circumstances, life stages, species, and context of telemetry studies vary widely, we emphasize that a particular recommendation for optimum holding conditions across all studies is not possible. And indeed, optimum holding conditions for fish of the same species and life stage may differ based on contextual circumstances. Therefore, it seems prudent to recognize that identification of optimal ranges of conditions for particular life stages and species may be an eventual goal, but we cannot achieve this goal without wide reporting by scientists about their holding conditions and studies on the effects of holding conditions.

Understanding the effects of the tagging process (Figure 1) on fishes is important for deciding whether to initially hold them before surgical tag implantation or to tag immediately upon capture (Oldenburg et al. 2011). Holding post-tagging provides an opportunity for fish to recover; thus, *how* fish are held matters (e.g., Oldenburg et al. 2011; Wargo Rub et al. 2014). Holding fish close to capture, tagging, and release sites can improve successful tagging and post-release PBS by minimizing air exposure and handling time (Brownscombe et al. 2019). Fish can be held in net cages in rivers with appropriate flow of oxygenated water, in net pens in lakes or coastal seas, or ex situ in tanks with flow to support water quality (Wilson et al. 2017; Brownscombe et al. 2019; Figure 2). Large animals may have to be supported by hand or alongside a boat for short periods. For example, holding Arapaima *Arapaima gigas*, *A*. cf. *arapaima* close to the surface following fishing was crucial to facilitate recovery of this air-breathing fish (Lennox et al. 2018; e.g., Figure 2). For fish species small enough to be temporarily held in containers, the water temperature of the containers should be kept as close as possible to the temperature of the water body from which the fish were collected to reduce recovery time and to mitigate the stress of large temperature differences (Iwama et al. 1999; Suski et al. 2006; Aslanidi et al. 2008; Donaldson et al. 2008). Slow swimming helped accelerate recovery of Rainbow Trout *Oncorhynchus mykiss* from anaerobiosis, so providing a gentle current may be helpful (Milligan et al. 2000). Specialized devices for holding fish and facilitating recovery have been developed for Pacific salmon *Oncorhynchus* spp. that consider their specific physiological needs (Farrell et al. 2001; Donaldson et al. 2013). Holding time post-surgery should be evaluated based on species and on-site recovery; however, holding fish too long can be detrimental to their PBS, and decisions for when and how to hold them should be made carefully. For example, adult migratory Sockeye Salmon *O. nerka* kept in net-pens for 24 h following capture exhibited higher levels of physiological stress and post-release mortality compared to fish released immediately after capture (Donaldson et al. 2011). The exact approaches for the tagging process (Figure 1) must be tailored to meet the needs of each fish species, life stage, and study objectives; thus, the specific details of holding fish pre- and post-surgery will vary.

Holding fish that are acclimated to captivity tends to contribute minimal additional stress (beyond the other stressors of the tagging process; Figure 1), provided that environmental conditions such as water quality are adequate (Svobodová 1993) and negative intraspecific interactions are mitigated (Arechavala-Lopez et al. 2022). However, wild fish that are captured and temporarily held in containment ranging from net-pens to coolers, tanks, or enclosures, may exhibit stress associated with being introduced into a new, artificial environment. Efforts to reduce negative effects associated with holding fish pre-tagging include using appropriate mesh sizes and types of nets to minimize skin abrasion and tearing of fins or water-to-water transfers; minimizing air exposure during handling; maintaining oxygen near saturation in holding containers; maintaining water temperatures as close as possible to temperatures at which the fish are acclimated (exceptions may

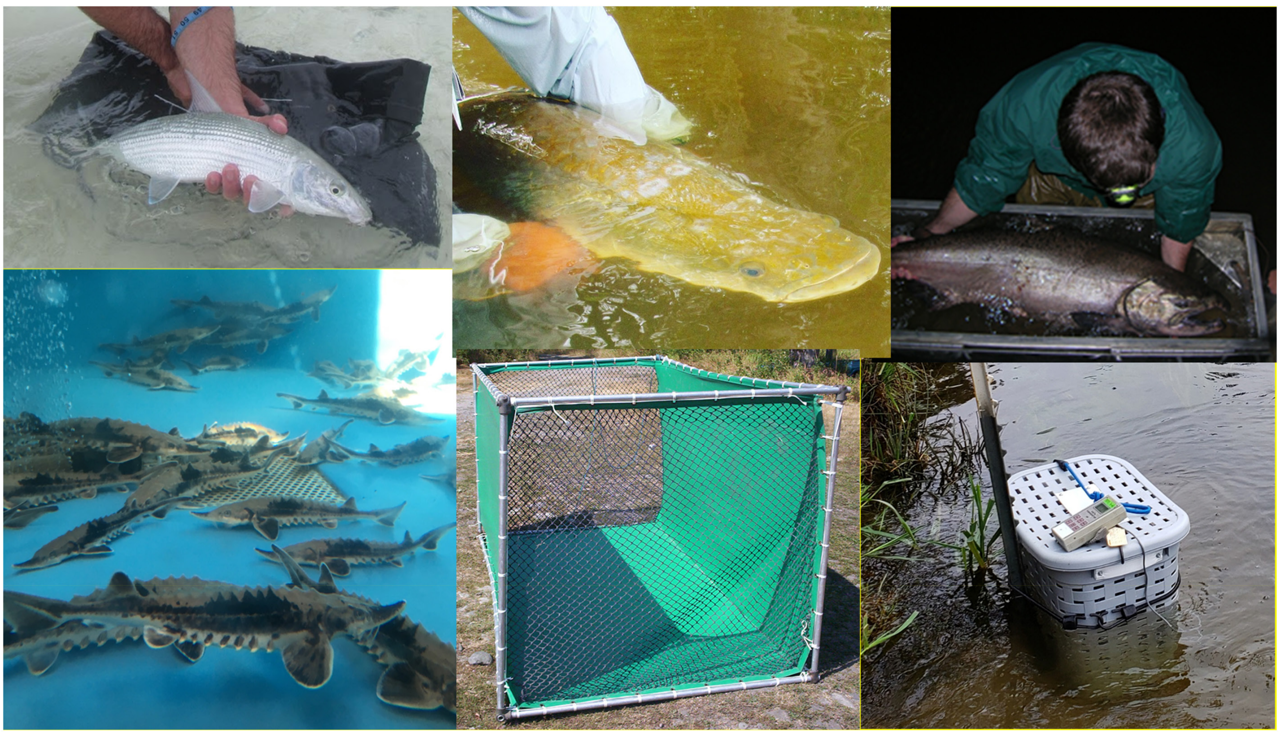

Figure 2. Some examples of the diverse scenarios in which tagged fish are held and released. Clockwise, from top left: adult Bonefish *Albula glossodonta* being released from a black holding–recovery bag following angling and tagging; Arapaima *Arapaima* cf. *arapaima*, an obligate air-breather, being held near the surface following angling and tagging; adult Chinook Salmon *Oncorhynchus tshawytscha* being recovered in an aerated live well following tagging; adult Pacific Lamprey *Entosphenus tridentatus* being held prior to tagging in plastic, ventilated containers (repurposed laundry hampers) placed within the stream; a net pen used for holding tagged salmonids *Oncorhynchus* spp.; and juvenile, hatchery-reared Lake Sturgeon *Acipenser fulvescens* being held in tanks following tagging. Photo credits (in order presented): Robert Lennox, Robert Lennox, Oregon Department of Fish and Wildlife, John Schaefer, Steve Cooke, and Natalie Klinard.

be needed in excessively warm water temperatures, including foregoing tagging); maintaining holding containers in shade or natural ambient light; and withholding feed before and after surgery (Oldenburg et al. 2011).

KEY RESEARCH NEEDS

Similar to advice from others who have called for more detailed reporting on tag implantation (Thiem et al. 2011; i.e., steps 4–5 in Figure 1), we recommend that researchers report the explicit details of how, when, where, and why tagged fish are handled and held in line with other steps of the tagging process. We envision a series of questions that researchers can address to promote the standardization of electronic tag studies, which can advance meta-analyses, literature reviews, and understanding of tagging methodology. The first two questions are: Were the tagged fish held before and after tagging? And, if so, why? If held, we recommend a series of other questions be described when reporting the study results (Table 1).

Much of the research on fish tagging has focused on anesthesia/restraint and tagging, steps 4 and 5, respectively, of the tagging process (Figure 1). However, holding fish pre- and post-tagging is an important component of the tagging process that can have critical bearing on the short- and long-term PBS of fish following release. Conditions of recovery across species, life stages, capture methods, and environmental factors should be reported to inform the designs of future studies. The goal of these efforts should be progression towards metrics or tools that characterize the benefits and risks of different holding procedures to answer the questions in Table 1 for each species, life stage, and the suite of environmental conditions. Furthermore, standardized methods and guidelines should be developed for commonly studied fishes (e.g., for juvenile salmonids; see Liedtke et al. 2012), where appropriate, to encourage the consistent use of tested or established approaches. Doing so, in combination with applying best practices for the tagging process (Figure 1), will improve the ability of biologists to integrate findings across studies while enhancing fish welfare. A potential step to encourage more integrated procedures is the use of an open-source database where holding (and other) steps, affiliated parameters, and decision-making processes are compiled across species and geographic areas. In addition, we recommend field studies designed to inform standardized methods for the duration of pre- and post-tagging holding and holding conditions (water quality, volume, container shape, holding density and location) that optimize fish PBS.

Table 1. Questions for how tagged fish are held. We recommend that questions 3–11 be accompanied with "Why."

	Questions
(1)	Animal biology (body size, proximity to holding and release sites)?
(2)	Amount of handling required during capture and the need to transport the fish to holding and/or release sites?
(3)	Holding container submerged in natural environment or artificial tank?
(4)	Shape and volume of containers?
(5)	Fish density in containers?
(6)	Water recirculated, filtered, flow-through?
(7)	Aeration provided?
(8)	Water temperature and other water quality parameters?
(9)	Fish held in darkness, ambient conditions (sun or shade)?
(10)	Duration of pre-tag holding and post-tag holding?
(11)	What measures were used to assess fish condition before, during, and after holding?

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SUPPORTING INFORMATION

Additional supplemental material may be found online in the Supporting Information section at the end of the article.

Table S1.