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Pan-Holarctic assessment of post-release mortality of angled Atlantic salmon *Salmo salar*

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ABSTRACT

Recreational Atlantic salmon *Salmo salar* fisheries are culturally and economically important, but confronted with global population declines, catch-and-release has frequently replaced harvest in these fisheries. Many studies have evaluated the effects of catch-and-release angling on Atlantic salmon; however, studies typically focused on a single system and had small sample sizes. Using data from Atlantic salmon catch-and-release studies conducted in 12 rivers throughout the pan-Holarctic range of wild Atlantic salmon, we modeled delayed mortality data using logistic regression. The model was based on 512 salmon (75 ± 15 cm TL) captured and released with electronic tags (i.e. radio or acoustic transmitters), which permitted the determination of fish fate after release (delayed mortality). The percentage of salmon categorized as survivors after release was high (93%). Salmon with longer body length tended to be played for longer durations ($R^2 = 0.60$) but there was no significant effect of fish length or playing time on mortality. Water temperature at capture emerged as a significant predictor of delayed mortality of salmon. Individuals captured by flies had significantly higher survival (96%) compared to lure (86%) and natural bait (85%) caught salmon. Data from throughout the range of Atlantic salmon confirm that fish captured by anglers adhering to best practices have high probability of surviving catch-and-release angling.

1. Introduction

Fisheries can have substantial and diverse impacts on ecosystems and on the environment (Chuenpagdee et al., 2003; Dayton et al., 1995; Large et al., 2015). For some fish that escape fisheries (Chopin and Arimoto, 1995) or are released (Arlinghaus et al., 2007), interactions with fishing gear can cause physical damage, physiological stress and/or cognitive impairment that contribute to decreased fitness (Raby et al., 2014; Wilson et al., 2014). Encounters can be also be lethal. Some fish die upon capture but more may experience delayed mortality after release arising from physical injuries, or prolonged physiological responses (Arlinghaus et al., 2007; Bartholomew and Bohnsack, 2005; Muoneke and Childress, 1994). For these reasons, increased adoption of catch-and-release in recreational fisheries has been confronted by concerns arising from doubts that the practice provides the anticipated population conservation benefits (Barnhart, 1989; Spitler, 1998). Therefore, substantial efforts have been made to document the effects of recreational angling on individual fish as well as fish populations to determine the sustainability of recreational catch-and-release fisheries and to manage their risk against the conservation, economic, and cultural benefits (Arlinghaus et al., 2007; Cooke and Suski, 2005; Muoneke and Childress, 1994).

The Atlantic salmon has a pan-Holarctic distribution and has been targeted by fisheries for millennia (Hindar et al., 2007, 2010; Turrero et al., 2014), with recreational fisheries increasing in popularity during the 1800s and spreading from the British Isles to other nations by the end of that century (Verspoor et al., 2008). Conservation concerns resulted in catch-and-release being advocated as early as the mid-1800s (Nettle, 1857). During the 20th century, declining salmon stocks

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resulted in the closure of many commercial fisheries (Dempson et al., 2004) as well as implementation of catch-and-release as a regulatory strategy for recreational Atlantic salmon fisheries (Barnhart, 1989), which was believed to maximize the socioeconomic value society derived from each salmon while concurrently minimizing fishery impacts on populations (Policansky, 2002). However, Atlantic salmon catch-and-release has received specific criticism from stakeholders (e.g. Wydoski, 1976; Barnhart, 1989) arising from concerns that released fish may frequently show delayed mortality post-release as a consequence of the capture event.

A number of investigators have examined the effects of recreational angling on individual Atlantic salmon behaviour, wounding, or survival. These include studies of captive fish on the impacts of various hook types (Warner and Johnson, 1978; Warner, 1979), the short and long-term physiological effects of angling (Tufts et al., 1991; Wilkie et al., 1996, 1997), and short-term survival in cages or pens (Booth et al., 1995; Dempson et al., 2002). Most recently, there has been an interest in documenting the fate of fish after release (i.e. delayed mortality) by integrating electronic tagging fish and then releasing them back to the wild (Donaldson et al., 2008). Electronic tagging and tracking have permitted intensive remote monitoring of behaviour and survival of released wild salmon (Dee River Trust, 2010; Gargan et al., 2015; Havn et al., 2015; Lennox et al., 2015, 2016; Richard et al., 2013; Thorstad et al., 2003; Webb, 1998). Most of these studies have reported that survival of salmon after release can be relatively high (>90%). However, individual studies have suffered from an inability to collect and tag sufficient numbers of salmon in order to meet a key study objective: identify factors that can be used to explain mortality of salmon released by anglers and potentially predict the outcome of salmon catch-and-release events.

By compiling the data available from a variety of published and unpublished studies on Atlantic salmon released from recreational angling gear, we overcame the small sample size problem to explain causes of delayed mortality in sport fisheries throughout the Atlantic salmon's geographic range. Data sharing is an important part of contemporary science and integral to broad analyses (Kowalczyk and Shankar, 2011; Parr and Cummings, 2005; Tenopir et al., 2011). We focused on data from telemetry studies in which the post-release fate of free-swimming fish could be quantified over the long-term from detection data. The data used were collated from studies conducted throughout the distribution of wild Atlantic salmon, generally with the common goal of calculating the post-release delayed mortality of adult salmon prior to spawning in order to identify the factors contributing to mortality.

2. Methods

2.1. Data collection

Data from telemetry studies in which wild Atlantic salmon were tagged after being captured on recreational angling gear were shared among the authors. Data were collected from rivers throughout the range of Atlantic salmon (Fig. 1; graphics created with the maptools package in R [Bivand and Lewin-Koh, 2015] and ggplot2 [Wickham, 2009]). All available metadata about salmon that were tagged, including fish size, the year and location of the study, and the date and water temperature when the fish were captured, were collated (Table 1).

Most data were collected from studies in which a biologist worked alongside recreational anglers fishing from riverbanks, with biologists tagging the salmon prior to release. In the Escoumins River, fish released by anglers were marked by adipose fin punch, verified by genetic analysis, and were then recaptured in an upstream fish ladder and tagged then (see Richard et al., 2014). Although the anglers had a range of experience, they were generally described as being experienced in salmon fishing and handling. Both radio and acoustic tags were used to monitor the movement and survival of salmon after release. In studies on Norwegian salmon, individuals that were assessed as having life-threatening wounds were not tagged, therefore the information necessary for modelling was not available. Fish were anaesthetized with clove oil in the Escoumins River and in tricaine methanesulfonate in Rivers Dee and Bann. No anaesthetic was used for tagging in the other studies. For the analysis, fishing gear types were reduced to three categories: fly (e.g. dry fly, wet fly, tube fly, bead head nymph, fly suspended under a float indicator), natural bait (e.g. worms, shrimp), and lures (e.g. spoons, spinners, wobblers). Reported fork lengths of salmon were converted to total length by multiplying fork length by 1.046; fish weight in Webb (1998) was converted to length from a standard length-weight conversion chart developed for the River Dee (Hawkins, unpublished data). Hooking locations were classified in two categories: superficial (e.g. jaw/mouth/foul) and deep (e.g. gills, eyes, throat/esophagus, roof of mouth, tongue). When a multi-pronged hook was lodged in both a superficial and a deep location, the fish was considered to be deep hooked.

Because studies were conducted independently, not all datasets were fully complete and we encountered an analytical problem with missing data. Instead of deleting entries with missing data, we opted to impute missing values. Completing data sets with imputation is useful for preserving relationships between predictor and outcome

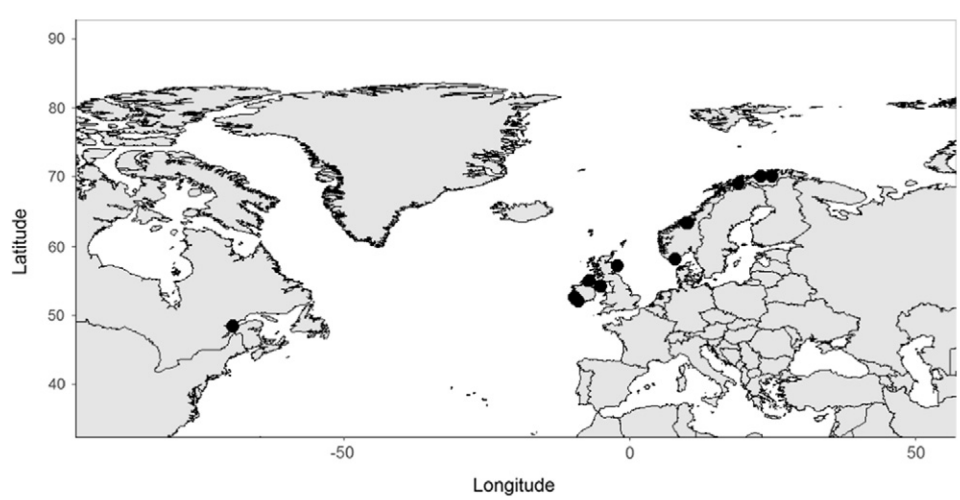

Fig. 1. Geographic distribution in North America and Europe of 12 Atlantic salmon rivers with catch-and-release data included in this study.