Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2020/029

Newfoundland and Labrador Region

Influence of water temperature on mortality of Atlantic Salmon after catch and release angling

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June 2020

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Van Leeuwen, T.E., Dempson, J.B., Burke, C.M., Kelly, N.I., Robertson, M.J., Lennox, R.J., Havn, T.B., Svenning, M-A., Hinks, R., Guzzo, M.M., Thorstad, E.B., Purchase, C.F., Bates, A.E. 2020. Influence of water temperature on mortality of Atlantic Salmon after catch and release angling. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/029. vi + 51 p.

Aussi disponible en français :

Van Leeuwen, T.E., Dempson, J.B., Burke, C.M., Kelly, N.I., Robertson, M.J., Lennox, R.J., Havn, T.B., Svenning, M-A., Hinks, R., Guzzo, M.M., Thorstad, E.B., Purchase, C.F., Bates, A.E. 2020. Influence de la température de l'eau sur la mortalité du saumon de l'Atlantique remis à l'eau après avoir été pêché à la ligne Secr. can. de consult. sci. du MPO. Doc. de rech. 2020/029. vi + 58 p.

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ABSTRACT

Average global air temperature has increased in recent decades resulting in accompanying changes in river temperatures. Poikilotherms, like Atlantic Salmon (*Salmo salar L*.), are vulnerable to temperature fluctuations. At the same time, many Atlantic Salmon populations are subject to catch and release angling. Catch and release mortality is influenced by angler practices and water temperature. Because Atlantic Salmon are commonly caught by anglers during the warmest months, angled fish can be exposed to physiologically stressful and potentially lethal water temperatures. Here we test interactions between river warming and mortality in recreational Atlantic Salmon fisheries. We first quantify the range of mortality rates observed at a given water temperature for caught and released Atlantic Salmon by compiling and analyzing published and unpublished data on catch and release mortality. We then focus on the region of Newfoundland and Labrador, Canada, and provide mortality estimates for caught and released Atlantic Salmon on an individual river basis by combining estimates for number of caught and released salmon from angler survey data with river temperature data. Lastly we update and compare regional and temporal trends (~1978 to 2018) for river temperatures and river closures due to high water temperatures and/or low water levels. Catch and release mortality for Atlantic Salmon was variable across studies with the majority of published data (~75%) having mortalities of <0.10. Mean mortality among control fish was 0.004. Probability of mortality increased with water temperature and depended on life history and gear type. At mean water temperatures between 0 and 12°C, catch and release mortalities (±95% confidence interval [CI]) ranged from 0.01 to 0.05 and at temperatures between 12 and 18°C from 0.04 to 0.14. Furthermore, at mean water temperatures between 18 and 20°C, mortalities ranged from 0.07 to 0.33 and at 20 to 25°C from 0.14 to 0.65. Average monthly river temperatures in July and August for Newfoundland showed a significant increase over time with a simultaneous increase in percent of days closed to angling due to high water temperatures and/or low water levels in more recent years. River temperatures for Labrador in August showed a slight increase over time and had only one documented river closure due to high water temperatures and/or low water levels. On a local scale, monitored rivers on the East and Southeast Coasts of Newfoundland increased in river temperatures in both July and August, whereas rivers on the South, West and North Coasts did not change through time, or cooled. Results of this study highlight the need for adaptive management considerations in recreational catch and release Atlantic Salmon fisheries in response to climate change.

INTRODUCTION

Average global air temperature has increased 0.74°C since 1906 with 17 of the 18 warmest years on record occurring since 2001 (IPCC 2018) and predictions of further increases to reach 1.8 to 4.0°C by year 2100 (Hein et al. 2012; Taylor et al. 2018). A well-documented consequence of climate change is increased frequency of extreme events including the duration of intense heat waves (Stillman 2019) and drought (Lennox et al. 2019). Because global temperature patterns vary spatially, weather and species distributions are not uniform, such that the effects of climate change will be significantly higher or lower in some areas than those predicted globally (Stillman 2019). High latitude environments have changed proportionally much more than lower latitudes (Prowse et al. 2006), emphasizing the need to evaluate potential consequences of climate change on a regional scale. Poikilotherms, such as most fishes, cannot regulate their body temperature and are therefore directly influenced by environmental temperature fluctuations (Brett 1971).

Indigenous to the Eastern coast of North America and Western Europe, Atlantic Salmon (*Salmo salar L.*) is an important species for commercial, recreational, and subsistence purposes (MacCrimmon and Gots 1979). Juveniles spend one to eight years in fresh water (approximately two to five years in Newfoundland and three to seven in Labrador) before undergoing a physiological and morphological transformation in preparation for seaward migration in the spring (i.e. smolting; Thorpe 1994). Atlantic Salmon can spend one to five winters at sea before returning as adults to their natal freshwater stream to spawn in the fall (Klemetsen et al. 2003). Newfoundland stocks are comprised primarily of one sea-winter (1SW) salmon while both 1SW and multi sea-winter (MSW) salmon are common in Labrador (O'Connell et al. 2006). Multi-sea winter salmon often migrate to West Greenland whereas post-smolt and 1SW salmon overwinter on the Grand Bank or the Labrador Sea (Reddin and Shearer 1987; Reddin and Short 1991). Once spawning has taken place, some surviving fish will emigrate (kelt; a salmon that spawned the previous fall) to again complete the seaward migration (Klemetsen et al. 2003). Additionally, some Atlantic Salmon never migrate to sea but instead spend their entire lives in fresh water as resident ouananiche (typically associated with lakes; Hutchings et al. 2019), or as precocious male parr (Dalley et al. 1983).

Over the past decades, Atlantic Salmon abundance has declined across the North Atlantic (Chaput 2012; Friedland et al. 2014; Soto et al. 2018; Lehnert et al. 2019). The total reported nominal catch has declined from 10,000 tons in 1970 to 1,000 tons in recent years (Nicola et al. 2018; ICES 2019). In NL, declines have occurred despite various management measures to reduce exploitation in recreational fisheries (Table 1) and a commercial fishing closure for Atlantic Salmon since the 1990s (Dempson et al. 2004). While some stocks increased by the commercial fishery closure, populations on the south coast of Newfoundland have continued to decline and are currently designated as 'threatened' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Dempson et al. 2004; COSEWIC 2010). In 2017, 15 of 19 monitored rivers in NL showed a decline in numbers of anadromous adults, with 12 rivers declining by >30% compared to the previous generation mean (previous five and six years for NL, respectively; DFO 2018).

While retention harvests still occur in recreational Atlantic Salmon fisheries, the voluntary release of caught salmon is sometimes promoted. Among fisheries managers and conservation organizations, catch and release has been accepted as a management tool (Brownscombe et al. 2017), as it allows for the recreational fishery and associated social and economic benefits (tackle shops, lodge owners, license fees, guiding fees) to continue, even when stocks are low, based on past evidence of little or minimal mortality associated with the practice (Tufts et al. 1991; Booth et al. 1995; Brobbel et al. 1996; Wilkie et al. 1996,1997; Lennox et al. 2017a).

The proportion of caught and released Atlantic Salmon in recreational fisheries is estimated to range from 22% of the total catch in Norway, 54% in NL, to as high as 90% in Scotland. This translates into an estimated total of 57,357 Atlantic Salmon caught and released across Eastern Canada in 2017, 20,000 in Iceland, 26,000 in Norway, and over 44,000 released in Scotland. Given the reduced retention limits in many Atlantic Salmon fisheries, the resultant high numbers of caught and released fish and the declining abundance of Atlantic Salmon, the use of catch and release as a management tool for the species is sometimes challenged and re-evaluated (ICES 2019).

Whereas much of the mortality following catch and release can be attributed to angler practices (e.g. gear type, bait type) and experience (e.g. handling and air exposure; Cooke and Wilde 2007; Lennox et al. 2017a), it has been shown that water temperature at time of capture also influences survival following catch and release (Wilkie et al. 1996; Havn et al. 2015; Lennox et al. 2017a).

Because many Atlantic Salmon are caught by anglers during the warmest months of the year (July and August), angled salmon can be exposed to physiologically stressful and potentially lethal water temperatures (Huntsman 1942; Breau 2013). Mortality rates of Atlantic Salmon following catch and release have been reported between 0% and 12% at water temperatures ≤18°C (Dempson et al. 2002; Thorstad et al. 2007). At water temperatures >18°C significant increases in mortality are likely (Gale et al. 2011; Havn et al. 2015; Lennox et al. 2017a), because the synergistic effects of high water temperature and resultant lower dissolved oxygen, with exhaustive exercise (associated with the hook and capture process) can impede the fish’s aerobic and anaerobic recovery (Wilkie et al. 1996, 1997; Arlinghaus et al. 2007; Breau 2013).

To ensure effective catch and release management, predicted increases in river temperatures should be considered in management decisions to ensure conservation. Indeed, to some extent this does occur; fisheries managers implement river closures to angling when water temperature exceeds a pre-determined threshold, however, the threshold value is often variable and subjective (Table 1).

While discrepancies over an appropriate threshold temperature for river closures is based on biological evidence, and can be attributed to pre-determined differences in thermal sensitivity of locally adapted populations (Beitinger et al. 2000; Finstad et al. 2004), limited studies have historically been available to estimate catch and release mortality at water temperatures ≥18°C (Havn et al. 2015; Lennox et al. 2015, 2016, 2017b).

Given the predicted increases in the frequency and intensity of high water temperature events (Stillman 2019), coupled with documented declines in Atlantic Salmon abundance, and continued debate associated with the use of catch and release angling as an effective management tool, we review the role of water temperature and other stressors in the management of recreational Atlantic Salmon angling. The overall objective is to provide more informed advice to managers responsible for the conservation of Atlantic Salmon. Published and available unpublished data were examined, including relevant information on landlocked salmon (ouananiche) to provide a complete synthesis of the potential for catch and release mortality. We first quantify the range of mortality rates observed at a given water temperature for caught and released Atlantic Salmon by compiling and analyzing published and unpublished data on catch and release mortality. We then focus on the region of Newfoundland and Labrador, Canada, and provide mortality estimates for caught and released Atlantic Salmon on an individual river basis by combining estimates for number of caught and released salmon from angler survey data with river temperature data. Lastly, we update and compare regional and temporal trends (~1978 to 2018) for river temperatures and river closures due to high water temperatures and/or low water levels.

METHODS

PREDICTING THE PROBABILITY OF MORTALITY AT A GIVEN WATER TEMPERATURE FOR CAUGHT AND RELEASED ATLANTIC SALMON

Building on previous work by Dempson et al. (2002), Havn et al. (2015) and Lennox et al. (2017a), several variations of models, to predict the probability of mortality at a given water temperature for a caught and released Atlantic Salmon, are presented. Initial data were collected from published studies investigating the effects of recreational catch and release angling on the survival, physiology and behavior of Atlantic Salmon (Table 2). However upon discussion with authors of these studies, it was revealed that unpublished data for rod-caught Atlantic Salmon at a known water temperature and fate following release were also available (Table 3). Therefore, researchers were contacted and these additional data were provided. Notably, some of the published catch and release studies have excluded salmon from experimental results that were critically injured during capture. This is because of regional regulations that prevent the release of wounded fish. Where this occurs, it is outlined in the methods section in each of the published papers, and in Table 2 noted with an asterisk.

For each study the following information was recorded: sampling date, country, river, minimum water temperature for the study, mean water temperature for the study, maximum water temperature for the study, site (field or laboratory), life history (1SW, MSW, 1SW/MSW [if both were used in a study], kelt, ouananiche), gear type (fly, lure, chase), hook type (single, double, treble), presence of barbs, duration animals were followed to assess fate (~3 days to spawning) and methodology used in both the capture process and to assess the fate of a fish following release (Tables 2 and 3). Chase protocols, whereby an individual fish is chased in a circular arena until exhaustion, are sometimes used to simulate the exhaustive nature of an angling event (Wilkie et al. 1997; Lennox et al. 2019). Studies took place in various countries (Canada, Norway, USA, Finland, United Kingdom, Ireland) that incorporates much of the natural distribution of wild Atlantic Salmon. Although, catch and release studies have also been carried out in other countries (e.g. Russia – Whoriskey et al. 2000) water temperature data were not readily available.

In cases where 1SW and MSW salmon were not specified in the study, length of fish was used to infer this (salmon ≤63cm in North America and ≤70cm in Norway were considered 1SW and fish larger, were considered MSW; O'Connell et al. 1992; Norwegian Institute for Nature Research, personal communication). Life history type was chosen instead of fish length because most studies reported life history type. Additionally, given that fish length may be related to life history type (i.e., ouananiche are generally smaller than their anadromous counterparts: 1SW, MSW), and may have a lower probability of mortality at an equivalent water temperature because of greater thermal acclimation potential associated with often fluctuating freshwater rearing environments.

Most data were collected from studies that used salmon anglers familiar with proper angling and handling procedures. Field studies often involved cooperation between researchers and recreational anglers fishing from riverbanks and researchers tagging salmon with either an internal or external, acoustic, radio or gastric tag prior to release or placing fish in cages to monitor their fate (Tables 2 and 3). Laboratory studies primarily involved simulations of the catch and release process in tanks either by chasing the fish to exhaustion (chase) or manually hooking the fish in the jaw and retrieving fish with standard fishing gear. To reflect the variation in minimum and maximum water temperatures recorded for each study and the potential for these fish to be caught and released at the lower and upper thresholds of these water temperatures, values for mortality were analyzed separately in statistical models using the minimum, mean and maximum water temperature recorded for each study as a single measure of water temperature at time of capture. To investigate the effects of methodologies among studies not generally associated with catch and release (e.g. substantial handling associated with experimental procedures, tagging, anesthetic or confinement) we also recorded whether studies included a control group (Table 4; Figure 1). Additional data recorded for each of these studies included: capture method (seine, bag nets, angling but seven months prior), holding environment and procedure (confinement, internal/external/gastric tag; Table 4).

Models 1 and 2 (Synthesis Temperature Models)

Models 1 and 2 included data from a synthesis of published studies only (Table 2) and are presented with (Model 1; Tables 2 and 5; Figures 2 and 3; Supp. Figure 1 and 2) and without ouananiche (Model 2; Table 2; Figures 4 and 5 respectively; Supp. Figures 3 and 4). While all studies reported water temperature, other factors reported differed across studies, preventing inclusion of all parameters of possible interest. Therefore, models with and without ouananiche are presented for comparison. Models 1 and 2 were analyzed using a general linear mixed effects model with a binomial distribution (number of dead versus number of live fish; Table 5; Figures 2, 3, 4, 5; Supp. Figures 1, 2, 3, 4) using the function "glmmadmb" in the package glmmADMB (Skaug et al. 2014) in R (R Core Team 2017). A binomial distribution allowed studies to be weighted based on sample size of fish (larger sample sizes equals greater effect in the model). Temperature (modelled separately as minimum, mean and maximum water temperature of the study and used as a measure of temperature at time of capture) was modeled as a polynomial term, to allow curvature in the relationship between probability of mortality and water temperature. We further included reference (the literature source) as a random effect to control for differences in methodology among studies and control for multiple estimates of mortality at various water temperatures from a single study (non-independence of measures).

Models 3 and 4 (Raw Data Models)

Models 3 and 4 included data from published (Table 2) and unpublished studies (Table 3), investigating the effects of recreational catch and release angling on the survival, physiology and behavior of Atlantic Salmon. When possible, raw data for individual caught and released Atlantic Salmon at a known water temperature were used. When this was not possible, data were entered as individual fish, but with minimum, mean and maximum water temperature of the study used as a measure of water temperature at time of capture. Therefore, data for individual fish will have an equivalent temperature for minimum, mean and maximum water temperature at time of capture whereas individuals for which raw data were unavailable will have different values to reflect the range of temperatures fish may have experienced during the study.

Models 3 and 4 were analyzed using a general linear model with a binomial distribution (live or dead for an individual fish). To allow for a comparison of results between those that used a synthesis of published data (Models 1 and 2), and published and unpublished data for individual fish we first modelled water temperature as a single factor (Model 3; Table 6; Figure 6; Supp. Figure 5). However, given the addition of unpublished and published data for individual fish (n=2,700 individual fish) we attempted to evaluate the effect of life history type, gear type, hook type and presence of barbs, in addition to water temperature, in predicting the probability of mortality for a caught and released Atlantic Salmon. Factors in Model 4 included: water temperature, gear type, presence of barbs, life history and hook type. Model selection, using Akaike information criterion (AIC), suggested the best fit model included: water temperature, gear type and life history (Table 6). To avoid any potential bias associated with using minimum, mean and maximum water temperatures of the study, as a measure of water temperature at time of capture, each were included separately in the final models (Tables 6 and 7; Supp. Table 1; Figures 6 and 7; Supp. Figures 5 and 6).

ESTIMATES OF MORTALITY FOR CAUGHT AND RELEASED ATLANTIC SALMON ON AN INDIVIDUAL RIVER BASIS

The number of retained and the number of caught and released Atlantic Salmon in NL was estimated using data from the Department of Fisheries and Oceans (DFO) license stub program (O'Connell et al. 1998; Veinott et al. 2018). Anglers are provided with a logbook upon purchase of a license to record information regarding their fishing activities. When completed in full, logbook information included: date, river name, number of fish retained and/or released and number of hours fished. Angler records are submitted voluntarily through the mail, telephone or online. Corrections for accuracy (i.e. the number of licenses returned to DFO as a proportion of the total number of licenses sold) followed procedures outlined in Veinott et al. (2018).

We estimated the total number of fish expected to have died following catch and release in select rivers in NL for a given fishing season (2016) on a daily basis, using data for daily number of fish released from anglers' log book data, daily water temperatures and results from the synthesis Model 2 on expected mortality at different water temperatures. The 2016 rod-catch data were used because of the uncertainty associated with angler participation resulting from an unprecedented decline in salmon abundance in 2017 (DFO 2018) and changes in the cost of licenses and management measures (e.g. warm water protocols, reduction in number of fish retained) in 2018. Therefore, 2016 was the most recent year that the management measures in the recreational fishery and salmon abundance was comparable to recent decades. Model 2, with mean water temperature recorded for the study as a measure of water temperature at time of capture, was used because this model contained published data from studies that had been previously peer-reviewed and excluded ouananiche, which are often not targeted during Atlantic Salmon fisheries. Only log-book data that contained entries for river, date, and number of fish released were included (Table 8). The number of fish estimated to have died as a result of catch and release were summed to give monthly estimates of mortality (Table 9). To scale the data (i.e. adjust for stub returns that were not completed in full and were missing dates of capture and release) and provide rough estimates of mortality for the entire fishing season, we used the total number of fish released from the 2016 salmon season and multiplied it by the proportion of fish released per month in 2016 (calculated in Table 8). Estimates were compared to the DFO NL Region established protocol assuming 10% mortality for caught and released Atlantic Salmon (Table 9).

REGIONAL AND TEMPORAL TRENDS FOR RIVER TEMPERATURES

Water temperature data for select rivers were obtained from archived DFO records from the NL Atlantic Salmon abundance monitoring program used to determine the number of Atlantic Salmon returning each year (Moores and Ash 1984). As part of this program, counting facilities are checked several times daily for migrating salmon and water temperature along with other abiotic variables recorded. Water temperatures taken in the morning (~08:00) and afternoon (~16:00) were used here, which usually corresponded to daily minimum and maximum values.

River temperature trends in July and August across years for select rivers of Newfoundland (Figure 8) and Labrador (Figure 9) were modelled using a general additive mixed effects model in the package mcgv and the function "gamm" (Wood 2011) in R (R Core Team 2017). River was included as a random effect (because rivers were repeatedly sampled through time) with a temporal autocorrelation term across years. We included time of day (morning or afternoon) as a covariate, modelled as a spline fit with a k=4. In addition, we analyzed data excluding years ≤2010 to test for a significant recent trend in river temperature using a general least squares regression which included time of day as a covariate (the slopes are presented in the bottom left corner of each panel in Figures 8 and 9).

REGIONAL AND TEMPORAL TRENDS FOR ENVIRONMENTAL RIVER CLOSURES

For more than 40 years Atlantic Salmon rivers in NL have been periodically closed to angling by fishery managers due to high water temperatures and low water levels. River closure data, prior to 1982, were obtained from archived DFO management records. Closure data from 1982 to 2018 were obtained from DFO Anglers' notices and respective annual stock status reports, which often included detailed reasons for, and dates of, river closures. The potential number of days salmon rivers were open to angling each year (1975-2018) for each salmon fishing area (SFA), were calculated by multiplying the number of scheduled salmon rivers open to angling for a given SFA by the number of days in the season, including those rivers that were open for catch and release only (as described in Dempson et al. 2001). The percent of days closed to angling was determined by dividing the number of days salmon rivers were closed by the potential number of angling days for an entire season and multiplying by 100. River closure, for our purpose, relates to a river closed due to high water temperature and/or low water level, i.e. for environmental reasons, and not for reasons associated with stock conservation measures. To date we are only aware of one river closure in Labrador (Shinney's River- SFA 2 in 1999) for environmental reasons.

Trends in environmental closures (% of fishing days closed) for the salmon season across rivers of Newfoundland are modeled using a general additive mixed effects model (Figure 10). To identify if the trend across SFAs has been significant since 2010, we used a general linear mixed effects model (GLMM) in the package MASS (Venables and Ripley 2002) in R (R Core Team 2017) with a poisson distribution (for counts), and SFA modeled as a random intercept. Models were run for both the entire time series of data and for years ≥2010 to compare overall and more recent trends in environmental closures.

RESULTS

PREDICTING THE PROBABILITY OF MORTALITY AT A GIVEN WATER TEMPERATURE FOR CAUGHT AND RELEASED ATLANTIC SALMON

Catch and release mortality for Atlantic Salmon was highly variable across studies ranging from 0 to 0.80 for mean water temperatures between 1.2 and 23.0°C (Tables 2 and 3) albeit with the majority of published data (~75%) having mortalities of <0.10 (Table 2). Mean mortality among controls was 0.004 (Table 4; Figure 1). Results among our catch and release mortality models were consistent (Supp. Table 2) and indicate that the probability of mortality following catch and release increases significantly with increasing water temperature (Model 1, GLMMADMB, z=5.50, n=53, p<0.001, Table 5, Figures 2 and 3; Model 2, GLMMADMB, z=5.07, n=32, p<0.001, Table 5, Figure 4 and 5; Model 3, GLM, z=9.26, n=2,700, p<0.001, Table 6, Figure 6; Model 4, GLM, z=6.58, n=2,700, p<0.001, Table 6 and 7, Figure 7).

In addition to water temperature, model results, which included both published and unpublished data (Tables 2 and 4), also suggest that the probability of mortality for a caught and released Atlantic Salmon depends on life history and gear type (Table 6; Figure 7). Ouananiche, and studies using the chase protocol to simulate catch and release angling, had the lowest probability of mortality, and 1SW salmon captured on lures had the highest probability of mortality (Table 6).

ESTIMATES OF MORTALITY FOR CAUGHT AND RELEASED ATLANTIC SALMON ON AN INDIVIDUAL RIVER BASIS

The 10% estimate for catch and release mortality currently used by DFO Science in NL Region, was for the most part representative of lower (95% CI), and mean estimates predicted by our synthesis temperature Models 1 and 2 for select rivers during the 2016 NL angling season (Table 9). However, when examined for specific rivers, the level of mortality (number of fish) using the 10% estimate was likely an overestimate for Torrent River (SFA 14A) in June 2016 and an underestimate for Middle Brook (SFA 5) in July 2016. This suggests that catch and release mortality is highly variable (even on a regional scale) among rivers and when (i.e. which month) fish were caught and released during the angling season.

REGIONAL AND TEMPORAL TRENDS FOR RIVER TEMPERATURES

Average monthly river temperatures during the Atlantic Salmon angling season across the 13 monitored rivers in NL, with sufficient time series of data to support an analysis, were highest in July and August and showed a warming trend when moving southward. Rivers in Newfoundland on average were warmer than rivers in Labrador. Average daily river temperatures in the morning and late afternoon varied considerably (Figures 8 and 9) by geographic location and month. Daily river temperatures in July and August for NL generally increased between 08:00 and 16:00 with some rivers on the East Coast of Newfoundland (e.g. Rocky River) increasing in excess of 5°C throughout the day (Figure 8), although the difference between minimum and maximum water temperatures could be even greater when using hourly thermograph data.

Average monthly river temperatures in July and August for the nine monitored rivers in Newfoundland, with sufficient time series for analyses, showed a significant increase over time (July, GAMM, t=30.07, n=29,861, p<0.001; August, GAMM, t=34.79, n=25,124, p<0.001). When restricting the data to years ≥2010, river temperatures in July, did not show a significant increase or decrease (GAMM, t=0.65, n=5,084, p=0.51) whereas river temperatures in August showed a significant increasing trend (GAMM, t=9.62, n=3,971, p<0.01). All monitored rivers (three of three) on the East (SFA 5) and (one of one) Southeast (SFA 9) Coasts of Newfoundland showed a significant increase in river temperatures in both July and August for years ≥2010 (Figure 8), whereas monitored rivers on the South (SFA 11), West (SFA 13) and North Coasts (SFA 14A) showed either no significant trend (SFA 11) or a significant cooling trend (SFA 13 and 14A; Figure 8).

Overall, river temperatures in July for the four monitored rivers in Labrador, showed no significant increase or decrease over time (GAMM, t=0.92, n=5,090, p=0.36) whereas river temperatures in August showed a slight increase over time (GAMM, t=7.97, n=5,012, p<0.001). When restricting the data to years ≥ 2010, river temperatures in July (GAMM, t=-6.50, n=1,640, p<0.001) and August (GAMM, t=-13.02, n=1,442, p<0.001) both showed a significant cooling trend with half (two of four) of the rivers significantly cooler (SFA 2; Figure 9) in July and all rivers (four of four) significantly cooler in August (SFA 1 and 2; Figure 9).

REGIONAL AND TEMPORAL TRENDS FOR ENVIRONMENTAL RIVER CLOSURES

The percent of days closed to angling for environmental reasons in Newfoundland varied annually with over 30% of all angling days affected in some years, while individual SFAs could have 40% to 60% or more days closed to angling due to low water levels and high water temperatures. Overall, there was no significant trend over time (Figure 10; GLMM, t=0.69, df=512, p=0.49). When restricting the data to years ≥2010 there was a significant increase in the percent of days closed to angling (GLMM, t=5.68, df=83, p<0.01) with rivers on the East Coast of the island (SFA 4, 5 and 6) showing the greatest increase in number of days closed

(Figure 10). Closures across all SFAs in 2017 and 2018 were the highest recorded since 1987. This result seems consistent with regional patterns in river temperatures described above in July and August for Newfoundland (Figure 11).

Consistent with the cooling trend for monitored rivers and years described above in July and August for Labrador, we are only aware of one river closure in Labrador (Shinney's River- SFA 2 in 1999) for environmental reasons.

DISCUSSION

Average mortality rates of Atlantic Salmon following catch and release have been reported between 0 and 12% at water temperatures ≤18°C (Dempson et al. 2002; Thorstad et al. 2007). However, at water temperatures >18°C increases in mortality are likely (Gale et al. 2011; Lennox et al. 2017a). Consistent with published literature, results from our catch and release mortality models show that as water temperature increases so does the probability of mortality for a caught and released Atlantic Salmon. As the fight time of a fish increases, so do levels of extracellular acidosis and blood and muscle lactate. These physiological responses cause a decrease in extracellular pH, plasma bicarbonate, adenosine triphosphate and glycogen that all significantly decrease likelihood of recovery following capture (Tufts et al. 1991; Booth et al. 1995; Brobbel et al. 1996; Wilkie et al. 1996; Wilkie et al. 1997). When the catch and release process is paired with high water temperatures and resultant lower dissolved oxygen the combination becomes synergistic and the complete exhaustion of aerobic and anaerobic muscular fuels, scope and cardiac function are possible (Wood et al. 1983; Wilkie et al. 1996; Anderson et al. 1998; Breau 2013). Following release, the exhaustion of aerobic and anaerobic muscular fuels and scope can lead to increased vulnerability to predation (Raby et al. 2014), onset of disease (Breau 2013) and an overall higher probability of mortality (Muoneke and Childress 1994; Bartholomew and Bohnsack 2005; Arlinghaus et al. 2007).

River closures to angling are sometimes implemented when water temperature exceeds a pre-determined threshold. Rivers in NL that permit retention are closed to angling during the day when water temperature is >20.0ºC across two to three days (Table 1). Catch and release only rivers are closed to angling during the day when water temperature is >18ºC across two to three days (Table 1). Rivers in New Brunswick are closed to angling when water temperature is ≥20°C on two consecutive days (DFO 2012; Breau 2013). While retention fishing for Atlantic Salmon remains open for rivers in Ireland when water temperature is above 18°C, the practice of catch and release is discouraged, although this remains on a river by river basis. In Norway, rivers are sometimes closed to angling when water temperature increases and water levels decrease, or catch and release is discouraged, but like Ireland, this is decided subjectively case by case.

The practice of river closures due to high water temperatures and/or low water levels remains a debated topic. Some argue that salmon are reluctant to take a fly or lure at water temperatures above 20°C, suggesting that river closures do little for conservation and causes unnecessary economic disruption. Results from the literature have been mixed, with some studies suggesting that substantial numbers of fish are caught at river temperatures above 20°C (Mowbray and Locke 1999) and others not (Breau 2013). Determining the causes of variation in catch success at varying water temperatures can be difficult. In NL, periods when river temperatures are highest often coincide with the end of the fishing season and correlate negatively with the proportion of migrating fish available to anglers. Decreases in fishing effort are also common near the end of the season and during high water temperature events, making it difficult to compare catch statistics between cooler and warmer months. Alternatively, it has also been argued that environmental closures are necessary, as increased numbers of fish concentrate around cold-water refuges and in pools during high water temperatures and low flow events (Huntsman 1942), making them more susceptible to capture.

While the debate on the effectiveness of environmental closures will continue, mortality estimates predicted by our synthesis temperature Model 2, that used a variety of information from published studies and excluded ouananiche, suggest that at mean water temperatures between 0 and 12°C (± 95% CI), catch and release mortalities range from 0.01 to 0.05, and at temperatures between 12 and 18°C from 0.04 to 0.14. At temperatures between 18 and 20°C, mortalities ranged from 0.07 to 0.33, and at 20 to 25°C from 0.14 to 0.65. Model 4, which incorporates both published and unpublished data, suggests that mortality of 1SW Atlantic Salmon in particular may be greater, especially at higher water temperatures. Interestingly, 1SW salmon had the highest probability of mortality following catch and release, compared to ouananiche and MSW life histories. However, due to relatively large variation in mortality among studies ≥19°C, specific predictions at these high temperatures should be interpreted within the context of a wide error margin due to inherent variability (e.g. differences in run-timing between countries) in the processes driving relatively higher mortality (see below discussion [pg.11,12] on inferring results to specific locations).

Variation among studies ≥19°C suggests that some experimental procedures may themselves have a synergistic relationship with water temperature (Wilkie et al. 1996, 1997; Anderson et al. 1998) as considerably higher mortalities occurred at higher temperatures compared to equivalent procedures (e.g. insertion of heart rate tags) at lower temperatures. Anderson et al. (1998) observed 0% mortality at mean water temperatures of 8.0°C (Point # 7) and 16.5°C (Point # 35) but 80% mortality at 20.0°C (Point # 39), similar to Wilkie et al. (1996; 1997) who found 0% mortality at 12.0°C (Point # 18) and 18.0°C (Point # 37) but 40% mortality at 20.0°C (Point # 40) and 30% at 23°C (Point # 44). Other sources of variation may be explained by differential susceptibility of populations to catch and release mortality (Gargan et al. 2015; Point #'s 16,19 and 20) or simply a result of low sample sizes at higher water temperatures. For example Dempson et al. (2002) found 0% mortality at mean water temperature of 11.7°C (Point # 14) with a sample size of eight, 10% mortality at 16.0°C (Point # 30) and 20.0°C (Point # 38) with sample sizes of 20 but 0% mortality at 22.0°C (Point # 43) with a sample size of one.

While debate over which studies are most representative of catch and release angling will remain, two anticipated points of debate in our study include:

1. the inclusion of results from the Anderson et al. (1998) study; and,
2. the increased mortality associated with the addition of critically wounded fish, intended for release, but euthanized after capture due to regional legislation (Point #'s 10, 23, 36).

However, model predictions with and/or without the Anderson et al. (1998) study, and the critically wounded fish, revealed minimal differences (see Supp. Table 2 for comparisons). This suggests that these values have little effect on model predictions and the addition of unpublished raw data and, life history and gear type as factors, are the most important in explaining variation among models.

While a considerable amount of variation was found among studies and across temperature ranges within a single study there are also several caveats among our model predictions. For example, the use of minimum, mean and maximum water temperatures recorded for each study as a measure of water temperature at time of capture. Although most studies had minimum and maximum water temperatures within ± 2°C, some had a greater range (Richard et al. 2014; Lennox et al. 2015; Gargan et al. 2015) which could be problematic when inferring mortality estimates across narrow water temperature ranges. Mortality estimates predicted by our models were similar when minimum or mean water temperatures were used. However, using maximum water temperature reported by studies to predict mortality led to estimates that were considerably lower than when minimum or mean temperatures were used, or temperatures that were time and location specific to a sampling event. Because few fish were angled when water temperatures were at the maximum for a study, the mortality recorded is mismatched from maximum temperature. We thus selected mean water temperature as being the most representative predictor, but also present estimates using minimum and maximum water temperatures for transparency. Nevertheless our predicted estimates serve as the most comprehensive assessment of catch and release mortality for Atlantic Salmon available to date. Future experimental studies should focus less on the effects of handling and air exposure (which should be obsolete assuming best practices are followed) and more on understanding water temperature profiles of study rivers, the precision and accuracy of how fine scale water temperature data is collected and could be incorporated into models, thermal tolerances of adult Atlantic Salmon, and how water temperatures leading up to the time of capture, at time of capture and following release (which may be more important than water temperature at time of capture), especially for water temperatures ≥19°C, influences catchability of fish and mortality following release.

While an acceptable level of catch and release mortality for any fishery is debatable (ethical vs economical), DFO in the NL Region currently uses a 10% estimate of mortality whereas 3% and 6% are applied to the annual catch and release estimates for the Miramichi and Restigouche Rivers by DFO Gulf Region (Breau 2013). For ethical animal welfare reasons, legislation in some parts of the world (e.g. Norway), only allows for release of uninjured and viable fish, and for wounded fish to be euthanized. Mandatory catch and release is used less in fishing regulations in Norway than in Canada, and there are no rivers or periods where salmon angling is solely mandatory catch and release. However, in many rivers where there is mandatory release of groups of salmon (e.g. large females), a wounded fish that is euthanized by the angler for animal welfare reasons have to be given to the proprietor of the river location and often donated. Because there is no benefit to the angler (i.e. no fish) the sometimes-subjective assessment of a critically wounded fish remains representative.

According to estimates predicted by our synthesis temperature models, the level of catch and release mortality currently used by DFO would remain representative, on average, if river temperatures for the salmon season remain ≤17°C. The 10% estimate used by NL Region is representative of low to mean estimates of mortality predicted using the catch and release model. However, when examined for specific rivers, the level of mortality (number of fish) using the 10% estimate was likely an overestimate for Torrent River (SFA 14A) in June 2016 but an underestimate for Middle Brook (SFA 5) in July 2016. Nevertheless, the modelling exercise highlights the variation in retention harvest among rivers, the considerable variation that can exist in predicting catch and release mortality on an individual river basis and the need for improved angler records and river temperature data to refine catch and release mortality estimates. The high variability (even on a regional scale) in predicted mortality among rivers is expected and will be dependent on differences in geography, seasonal air temperatures, timing and duration of snow melt, hydrology, period and duration of high river temperatures, run timing, angling pressure, type of anglers (consumptive vs. non consumptive), angler experience, discharge, density of fish and availability of cold-water refuges and pools (e.g. Frechette et al. 2018). For example if water discharge is low, and river temperature is uniformly high, the mortality risk is likely larger than when there are colder deeper pools available for fish to escape. Also, mortality risk may be higher in rivers with partial or complete barriers to fish passage, or a higher density of fish because competition for space in deeper pools and cold water refuges may be higher.

Another aspect that undoubtedly occurs but for which our modelling exercise does not address, pertains to situations when a salmon is hooked and played, but escapes or is broken off with or without an embedded hook. In cases like this it is doubtful that anglers record the event as a caught and released salmon. If escapes happen frequently, then it is possible that the overall impact of angling, particularly at higher temperatures (≥18°C) could be greater than commonly assumed. However, these fish, if intended for release, would not be subjected to the stresses of physical handling and possible air exposure and are likely to have much higher survival than caught and manually released fish with or without an embedded hook, and of course substantially higher survival than a retained fish.

Even after accounting for temperature effects, a considerable amount of variation in catch and release mortality can still exist. For example, in a study by Warner and Johnson (1978) mortality estimates for ouananiche ranged from 0 and 8.3% across years, despite similar mean water temperatures and gear types used. Therefore, it is important to recognize that a certain level of uncertainty around predicting catch and release mortality will always remain and that models are updated as further research becomes available. To illustrate this uncertainty, predicted values of mortality are presented as range estimates in this study to account for the uncertainty in different methodology, life stage 'bright salmon' that recently entered the river compared to kelts (Brobbel et al. 1996), body size (Lennox et al. 2017a), angler experience and playing time (Booth et al. 1995; Lennox et al. 2017a). Lower bounds of the 95% CI, presented here, may be reflective of angling events in which best practices are followed, whereas upper 95% CI estimates may be reflective of when poor practices are followed, essentially a 'worst case scenario' (e.g. deep hooking, fish are landed on the riverbank, tailing gloves are used, air exposed for pictures or roughly handled).

Because most experimental studies of catch and release use anglers considered 'above average' to 'experienced' it is possible that results reported in the literature may be an underestimation of 'true' mortality for the fishery. On the contrary, fish in the wild would not be exposed to substantial handling, potential effects of tagging, anesthetic or confinement used to estimate catch and release mortality in experimental studies, which likely inflate levels of mortality beyond what is observed in recreational fisheries. However, for studies that have attempted to remove such effects, by using a range of skill levels (Dempson et al. 2002) or a control (for tagging, confinement or anesthetic) results of our study synthesis suggest that mean probability of mortality among controls was 0.004 for water temperatures ranging from 1.2 to 23.0°C.

Consistent with previous studies and in support of the fly-fishing only legislation in NL, we found that fly caught Atlantic Salmon on average had a lower probability of mortality compared to fish angled with lures. Interestingly, however, modelling results suggested salmon that endured the chase protocol, used in some studies to simulate catch and release angling (Wilkie et al .1997; Lennox et al. 2019) and released, had a lower probability of mortality than those caught using flies or lures. This suggests that values obtained in these studies may be an underestimate of the actual catch and release process and factors beyond the exhaustive period of the angling event (hook set, tension kept on the line etc.) may also be important in predicting the survival of fish following catch and release. Furthermore, we found that ouananiche had the lowest probability of mortality, whereas 1SW salmon had the highest probability of mortality. This result may be due to a greater thermal acclimation in ouananiche, which are likely to experience greater temperature shifts in their environment than their anadromous counterparts, a result of a disproportionate amount of laboratory studies using only 1SW salmon in experiments, or perhaps because 1SW salmon in parts of Europe enter rivers later in the season (Reed et al. 2017) when water temperatures are highest and consequently, may experience a more abrupt acclimation prior to being caught and released. Therefore, until these effects can be accounted for, this model specifically, should be interpreted with caution especially when inferring results to specific locations (ie: Newfoundland and Labrador).

Physical injury by hooking can be significant in some fisheries (Muoneke and Childress 1994). For example, the number of critical hooking events (eyes, esophagus, gills and tongue) for ouananiche in Moosehead Lake, USA were reported to be nine times higher when anglers used bait compared to anglers who used flies (Warner and Johnson 1978). Contrary to expectation, we did not find a significant difference in probability of mortality between Atlantic Salmon caught and released using single, double and treble hooks and barbed vs. barbless hooks, suggesting that the use of artificial lures and flies may lead to shallower hooking whereas the use of bait may promote swallowing of the hook and lead to greater mortality due to greater difficulty in hook removal, regardless of hook type and whether barbs are present or absent. Although we did not find a significant effect of hook type and barbs it would be expected that fish hooked with barbless single hooks should have a greater probability of survival because of the added ease of hook removal during these situations. Because the recreational catch and release fishery for Atlantic Salmon in NL requires the legislated use of barbless hooks and artificial flies, the effect of critical hooking on the fishery should be minimal, although the actual number of critical hooking events that occur in a given fishing season remains unknown and would be an interesting area to investigate.

The length of time gills are exposed to air has been shown to influence survival rate (Ferguson and Tufts 1992) following catch and release. However, Dempson et al. (2002) found no significant difference in survival for Atlantic Salmon that were exposed to air when kept to a minimum <30 sec. Nevertheless, air exposure should be minimized in all catch and release fisheries (Cook et al. 2015). Assuming a high level of angler care, the effect of air exposure on the mortality of Atlantic Salmon in NL would also be expectantly minimal, although here again average air exposure duration for fish released in the NL fishery and elsewhere remains unknown.

Lastly, the level of angler responsibility should not be underestimated (Lennox et al. 2015). It is accepted that the use of a suitably matched rod, reel and line for the size of the target species, is important to minimize fight time and prevent fish exhaustion. Keeping fish in the water and use of a rubber net, cradle (i.e. no tailing gloves and no dry hands) or de-hooker tool can help prevent air exposure, minimize handling and prevent mucous and scale loss (Cooke and Suski 2005). Without the adoption of ‘best practice’ among anglers, the use of catch and release as a management strategy is unlikely to meet conservation objectives, as the level of mortality would be uncertain and not sustainable, thus costs would exceed any social and economic benefits to the fishery. Therefore it is imperative that best practices are used and current methodologies adopted by individual anglers are self-evaluated to reflect advances in the field of catch and release science (Brownscombe et al. 2017).

While it is clear that there are a number of factors that can contribute to catch and release mortality, it is important to recognize that mortalities that arise following release may not be apparent to anglers, especially when rivers are in remote areas (fewer anglers) or of limited accessibility. Some fish may initially swim off and soon after float to the surface but then sink and drift downstream or end up in the bottom of deep pools. Experiments with Atlantic Salmon smolts found some dead fish drifted several kilometers down river, with most found within several hundred meters, although results were variable (Havn et al. 2017). Salmon carcasses are also readily consumed by a variety of vertebrate scavengers including river otters, foxes and birds (Hewson 1995), and may therefore be removed from the system and undetected by anglers. However, given that DFO in NL, receive relatively few reports of mortalities through the angling season, further suggests that estimates of catch and release mortality are more likely reflective of the lower 95% CI estimates predicted by our models.

While the success of a catch and release program depends a great deal on angler care (Lennox et al. 2015), and not practicing catch and release when water temperatures are high, the level of engagement regulatory agencies have with anglers is also important. Communication between scientists, anglers and management can ensure the most comprehensive catch statistics are used in analyses and the latest developments in catch and release science are available. Too often, however, there is a common misconception that improved engagement (eg. increased participation in angler stub return programs, or 'truthful' or complete records of the fishery) leads to an increase in restrictive management measures. Because most legislative bodies, including DFO, often adopt the 'precautionary approach' to management, more data available to support the science of catch and release may have the opposite effect. Improved certainty in models can improve the understanding of how stressors are likely to affect spawning recruitment (e.g. the number of fish retained and dates for the capture and release of fish can refine estimates of mortality) and perhaps lead to higher or more consistent retention limits legislated by management.

The influence of water temperature on the survival of Atlantic Salmon following catch and release angling in combinations with increases in global air temperature over the last several decades highlights the importance of understanding the effect of climate change on river temperatures when evaluating the conservation of catch and release. In our study we found significant differences in the response of rivers to climate-mediated temperature change at both regional and local scales. Regionally we found that average monthly river temperatures in July and August for Newfoundland increased over time, whereas river temperatures in Labrador only showed a slight increase over time, for August only. On a local scale, we found that rivers on the East and Southeast Coasts of Newfoundland (SFA 5 and 9) warmed in both July and August, whereas monitored rivers on the South (SFA 11), West (SFA 13) and North Coasts (SFA 14A) did not change significantly (SFA 11) or even cooled (SFA 13 and 14A) in recent years. Because majority of the salmon season coincides with the warmest months of the year, with the highest fishing pressure in July (Veinott et al. 2018), slight increases in water temperature in the summer suggests that an increase in mortality due to the catch and release fishery is probable (assuming that catchability of fish remains the same) given a scenario of future increase in temperature. A corresponding increase in economic disruption as a result of increased environmental closures (perhaps in frequency and duration) would also be anticipated. To some extent, this seems to be occurring as evidenced by the increase in percent of days closed to angling in Newfoundland in recent years, while Labrador, as far as we are aware, has only experienced one river closure for environmental reasons despite having the same environmental protocol. While some of the increase in environmental closures for Newfoundland can likely be explained by recent changes in the water temperature threshold for closure from ≥22°C to >18°C in 2018 and slight differences in angling season duration across years, the clear increase in river temperature for the island overall, and most notably for rivers on the East and Southeast Coasts in recent years, suggest an increase in closures would likely have occurred, regardless of changes to the environmental protocol.

Although there remains a level of uncertainty around the predicted global temperature increase as a result of climate change, it is certain that climate change is occurring. Increases and decreases in precipitation and extreme hot and cold days are likely to occur in greater frequency, duration and intensity. Together, changes in these two variables will likely have an impact on recreational catch and release fisheries. The present analyses highlights:

1. changes in river temperatures across NL have restricted recreational Atlantic Salmon fishing opportunities,
2. the increasing need for adaptive management considerations in recreational catch and release fisheries in response to climate change; and,

3. increased need to educate anglers in ‘best practice’ during catch and release angling in response to climate change.

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APPENDIX I: TABLES

Table 1. *List of legislated management measures and year from which they were implemented for the recreational Atlantic Salmon fishery in Newfoundland and Labrador (NL), Canada.*

Year	Management Measures
1984	Salmon anglers in NL and the Maritime provinces were legislated to release all large salmon (≥ 63 cm in fork length; Randall 1990; O'Connell et al. 1992).
1986	A limit of four fish was placed on the number of salmon an angler could catch and release in a single day (O'Connell et al. 1992).
1988	A formal criterion for closing rivers to angling when water temperatures were ≥22°C was established.
1999	A barbless single hook only restriction was legislated.
2018	Criterion for closing rivers was lowered from ≥22°C to >18°C. A reduction in seasonal harvest limits from two, four, or six fish (consistent with the River Classification System; Veinott et al. 2013) to one fish per angler. A catch and release daily limit changed from four to three fish per angler (DFO 2019).
2019	A retention limit of one fish was placed on Class 2 rivers and a limit of two fish retention on Class 4, Class 6 and unclassified rivers (River Classification System; Veinott et al. 2013). Criterion for closing rivers changed to rivers that permit retention being closed to angling from 10:01 a.m. each day to one hour before sunrise the following day when water temperature is >20.0ºC across two to three days. Catch and release only rivers were closed to angling from 10:01 a.m. each day to one hour before sunrise the following day when water temperature is >18ºC across two to three days.

Table 2. *List of published studies investigating the effect of catch and release angling for Atlantic Salmon and associated data used in synthesis temperature models (Models 1 and 2) to predict the probability of catch and release mortality at a given water temperature (Table 5; Figures 2,3,4,5). Data recorded from each study included: probability of mortality, life history type (1 Sea-winter [1SW], Multi-sea-winter [MSW],MSW/1SW [if both were used], ouananiche and kelt), Technique (presence of a barb [barbed/barbless] - hook type [single/double/treble] - capture method [fly, lure, none] – [angling or chase ie: simulated angling] – [assessing fate of fish following release: internal tag, external tag, cage, genetics of offspring]), minimum water temperature of the study, mean water temperature of the study, maximum water temperature of the study, sample size and reference. Point # refers to the data point reference on Figures 1,2,3,4,5 and Supp. Figures 1,2,3,4. Note: overlapping data points from Figures 2,3,4,5 and Supp. Figures 1, 2, 3, 4 were given the same point # but in some cases may refer to multiple studies.* **** denotes studies that excluded critically injured fish in previous analyses given that regional legislation prevented the release of critically wounded fish. Two mortalities were added to Point 10, one mortality to Point 23 and 8 mortalities to Point 36 as mentioned in the methods sections of these papers.***

Point #	Temp °C (min)	Temp °C (avg)	Temp °C (max)	Sample Size	Prob. Mort	Type	Technique	Reference
1	0.40	1.2	2.60	11	0.00	Kelt	barbless-treble-lure-angling-internal tag	Halttunen et al. 2010
2	0.40	1.20	2.60	13	0.08	Kelt	barbless-treble-lure-angling-external tag	Halttunen et al. 2010
3	3.00	4.00	5.00	89	0.01	Kelt	barbed-single-fly-angling-cage	Bielak et al. 1996
4	3.00	4.00	5.00	24	0.00	Kelt	barbed-single- fly-angling-cage	Brobbel et al. 1996
6	5.00	5.50	6.00	20	0.00	MSW/1SW	barbed-single-fly-angling-cage	Davidson et al. 1994
5	4.00	6.00	5.00	20	0.00	MSW/1SW	barbed-single-fly-angling-cage	Booth et al. 1995

Point #	Temp °C (min)	Temp °C (avg)	Temp °C (max)	Sample Size	Prob. Mort	Type	Technique	Reference
7	7.00	8.00	9.00	6	0.00	1SW	barbed-single-fly-angling-internal heart tag	Anderson et al. 1998
9	8.40	9.40	10.40	5	0.00	1SW	barbed-treble-lure-angling-external tag	Mäkinen et al. 2000
10*	8.40	9.60	10.70	38	0.05	MSW/1SW	barbed-treble-fly/lure-angling-external tag	Lennox et al. 2017b
11	9.00	10.00	12.00	8	0.50	1SW	barbed-treble-lure-angling-external tag	Gargan et al. 2015
12	9.00	10.00	11.00	100	0.01	Ouananiche	barbed-single-fly-angling-cage	Warner 1976
12	9.00	10.00	11.00	100	0.00	Ouananiche	barbed-single-lure-angling-cage	Warner 1976
13	9.00	10.00	11.00	100	0.00	Ouananiche	barbed-treble-lure-angling-cage	Warner 1976
14	9.50	11.70	13.90	8	0.00	1SW	barbless-single-fly-angling-cage	Dempson et al. 2002
18	12.00	12.00	12.00	10	0.00	1SW	none-none-chase-cage	Wilkie et al. 1997
15	10.00	12.25	14.50	30	0.00	MSW/1SW	barbed-treble-fly/lure-angling-external tag	Thorstad et al. 2003b
16	11.00	13.00	16.00	48	0.02	1SW	barbed-double/treble-fly-angling-external tag	Gargan et al. 2015
19	13.00	13.00	14.00	3	0.33	MSW/1SW	barbed-single-lure-angling-external tag	Gargan et al. 2015
20	13.00	13.00	14.00	12	0.00	MSW/1SW	barbed-single/double/treble-fly-angling-external tag	Gargan et al. 2015
8	8.00	13.00	18.00	27	0.11	MSW/1SW	barbed-treble-fly/lure-angling-external tag	Lennox et al. 2015
21	13.00	13.90	15.00	100	0.04	Ouananiche	barbed-single-fly-angling-cage	Warner 1976
22	13.00	13.90	15.00	100	0.03	Ouananiche	barbed-single-lure-angling-cage	Warner 1976
20	13.00	13.90	15.00	100	0.01	Ouananiche	barbed-treble-lure-angling-cage	Warner 1976
23*	13.00	14.00	15.00	40	0.05	MSW/1SW	barbed-treble-fly/lure-angling-external tag	Lennox et al. 2016
24	13.00	14.40	16.00	100	0.09	Ouananiche	barbed-single-fly-angling-cage	Warner 1976
23	13.00	14.40	16.00	100	0.05	Ouananiche	barbed-single-lure-angling-cage	Warner 1976
20	13.00	14.40	16.00	100	0.00	Ouananiche	barbed-treble-lure-angling-cage	Warner 1976
17	11.60	14.50	16.40	20	0.00	MSW	unknown-unknown-fly-angling-internal gastric tag	Richard et al. 2014
30	14.00	15.95	17.90	20	0.10	1SW	barbless-single-fly-angling-cage	Dempson et al. 2002
34	15.00	16.00	17.00	25	0.12	1SW	barbed-single-fly-angling-cage	Brobbel et al. 1996
25	13.90	16.10	18.90	100	0.01	Ouananiche	barbed-single-fly-angling-cage	Warner 1979
25	13.90	16.10	18.90	102	0.02	Ouananiche	barbed-single-lure-angling-cage	Warner 1979
26	13.90	16.10	18.90	100	0.03	Ouananiche	barbed-treble-lure-angling-cage	Warner 1979

Point #	Temp °C (min)	Temp °C (avg)	Temp °C (max)	Sample Size	Prob. Mort	Type	Technique	Reference
27	13.90	16.10	18.90	119	0.08	Ouananiche	barbed-single-fly-angling-cage	Warner 1979
28	13.90	16.10	18.90	100	0.06	Ouananiche	barbed-single-lure-angling-cage	Warner 1979
29	13.90	16.10	18.90	100	0.11	Ouananiche	barbed-treble-lure-angling-cage	Warner 1979
25	13.90	16.10	18.90	100	0.02	Ouananiche	barbed-single-fly-angling-cage	Warner 1979
28	13.90	16.10	18.90	100	0.06	Ouananiche	barbed-single-lure-angling-cage	Warner 1979
26	13.90	16.10	18.90	100	0.04	Ouananiche	barbed-treble-lure-angling-cage	Warner 1979
35	15.50	16.50	17.50	5	0.00	1SW	barbed-single-fly-angling-internal heart tag	Anderson et al. 1998
31	14.00	16.50	19.00	37	0.00	Ouananiche	barbed-single-fly-angling-cage	Warner and Johnson 1978
32	14.00	16.50	19.00	28	0.07	Ouananiche	barbed-single-fly-angling-cage	Warner and Johnson 1978
33	14.00	16.50	19.00	12	0.08	Ouananiche	barbed-single-fly-angling-cage	Warner and Johnson 1978
36*****	16.30	17.30	19.70	60	0.20	MSW/1SW	barbed-double/treble-fly/lure-angling-external tag	Havn et al. 2015
41	18.90	17.60	20.20	19	0.11	1SW	none-none-chase-gastric tag	Lennox et al. 2019
37	18.00	18.00	18.00	16	0.00	1SW	none-none-chase-cage	Tufts et al. 1991
37	18.00	18.00	18.00	10	0.00	1SW	none-none-chase-cage	Wilkie et al. 1997
38	18.00	19.95	21.90	20	0.10	1SW	barbless-single-fly-angling-cage	Dempson et al. 2002
39	18.00	20.00	22.00	5	0.80	1SW	barbed-single-fly-angling-internal heart tag	Anderson et al. 1998
42	19.40	20.00	21.10	23	0.13	1SW	barbed-double/treble-fly/lure-angling-external tag	Havn et al. 2015
40	18.00	20.00	22.00	10	0.40	1SW	barbed-single-fly-angling-cage	Wilkie et al. 1996
43	22.00	22.00	22.10	1	0.00	1SW	barbless-single-fly-angling-cage	Dempson et al. 2002
44	23.00	23.00	23.00	10	0.30	1SW	none-none-chase-cage	Wilkie et al. 1997

Table 3. *List of unpublished studies investigating the effect of recreational catch and release angling for Atlantic Salmon and associated summarized data combined with published data (Table 2) used in raw data models (Models 3 and 4) to predict the probability of catch and release mortality for a given water temperature (Table 6; Figures 6 and 7). Data recorded from each study included: probability of mortality, life history type (1 Sea-winter [1SW], Multi-sea-winter [MSW], MSW/1SW [if both were used], ouananiche and kelt), technique (presence of a barb [barbed/barbless, unknown] - hook type [single/double/treble, unknown] - capture method [fly, lure, none] – [angling or chase ie: simulated angling] – [assessing fate of fish following release: internal tag, external tag]), minimum water temperature of the study, mean water temperature of the study, maximum water temperature of the study, sample size and researcher and year.*

Temp °C (min)	Temp °C (avg)	Temp °C (max)	Sample Size	Prob. Mort	Type	Technique	Researcher and Year
8.2	10.9	13.3	30	0	MSW/1SW	barbed-treble-fly-angling-external tag	Svenning et al. 2007, pers. comm.
11	11.7	14	6	0	MSW/1SW	barbed-treble-fly-angling-external tag	Johansen et al. 2013, pers. comm.
16	19.8	22	6	0.33	1SW	unknown-unknown-fly-angling-internal tag	Kennedy et al. 2013, pers. comm.
13.4	17.1	21.4	40	0.43	1SW	barbless-single-fly-angling-internal tag	Miawpukek First Nation et al. 2009, pers. comm.

Table 4. *List of controls from published and unpublished studies investigating the effect of recreational catch and release angling for Atlantic Salmon. Data recorded from each study included: probability of mortality, life history type (1 Sea-winter [1SW], Multi-sea-winter [MSW], MSW/1SW [if both were used], ouananiche and kelt), technique, minimum water temperature of the study, mean water temperature of the study, maximum water temperature of the study, sample size, reference (for published studies) and researcher and year (for unpublished studies). Point # refers to the data point reference on Figures 1, 2, 3, 4, 5 and Supp. Figures 1, 2, 3, 4.*

Point #	Temp °C (min)	Temp °C (avg)	Temp °C (max)	Sample Size	Prob. Mort	Type	Technique	Reference
1,2	0.40	1.20	2.60	17	0.00	Kelt	angled-internal tag but 7-10 month earlier-released	Halttunen et al. 2010
6	5.00	5.50	6.00	20	0.00	MSW/1SW	seine-cage-undisturbed	Davidson et al. 1994
12	9.00	10.00	11.00	100	0.00	Ouananiche	seine-cage-undisturbed	Warner 1976
14	9.50	11.70	13.90	5	0.00	1SW	box trap-cage-undisturbed	Dempson et al. 2002
18	12.00	12.00	12.00	16	0.00	1SW	hatchery-cage-undisturbed	Wilkie et al. 1997
8	8.00	13.00	18.00	33	0.00	MSW/1SW	bag nets at sea-external tag-released	Lennox et al. 2015
21	13.00	13.90	15.00	100	0.00	Ouananiche	seine-cage-undisturbed	Warner 1976
24	13.00	14.40	16.00	100	0.01	Ouananiche	seine-cage-undisturbed	Warner 1976
17	11.60	14.50	16.40	20	0.00	MSW	box trap-anaesthetic-internal tag-release	Richard et al. 2014
30	14.00	15.95	17.90	8	0.00	1SW	box trap-cage-undisturbed	Dempson et al. 2002
25	13.90	16.10	18.90	100	0.00	Ouananiche	seine-cage-undisturbed	Warner 1979

Point #	Temp °C (min)	Temp °C (avg)	Temp °C (max)	Sample Size	Prob. Mort	Type	Technique	Reference
27	13.90	16.10	18.90	100	0.01	Ouananiche	seine-cage-undisturbed	Warner 1979
25	13.90	16.10	18.90	100	0.00	Ouananiche	seine-cage-undisturbed	Warner 1979
31	14.00	16.50	19.00	16	0.00	Ouananiche	trap-cage-undisturbed	Warner and Johnson 1978
32	14.00	16.50	19.00	35	0.00	Ouananiche	trap-cage-undisturbed	Warner and Johnson 1978
33	14.00	16.50	19.00	23	0.00	Ouananiche	trap-cage-undisturbed	Warner and Johnson 1978
41	18.90	17.60	20.20	18	0.06	1SW	box trap-internal/external tags-released	Lennox et al. 2019
37	18.00	18.00	18.00	16	0.00	1SW	hatchery-cage-undisturbed	Wilkie et al. 1997
38	18.00	19.95	21.90	7	0.00	1SW	box trap-cage-undisturbed	Dempson et al. 2002
44	23.00	23.00	23.00	16	0.00	1SW	hatchery-cage-undisturbed	Wilkie et al. 1997
Unpublished								
Point #	**Temp °C (min)**	**Temp °C (avg)**	**Temp °C (max)**	**Sample size**	**Prob. Mort**	**Type**	**Technique**	**Researcher and Year**
45	13.4	17.10	21.40	32	0.03	1SW	box trap-anaesthetic-internal tag-release	Miawpukek First Nation et al. 2009

Table 5. *Coefficient estimates returned using a general linear mixed effects model to test for the relationship between probability of mortality and minimum water temperature of the study as a measure of temperature at time of capture, mean water temperature of the study as a measure of temperature at time of capture and maximum water temperature of the study as a measure of temperature at time of capture for an angled and released Atlantic Salmon. Water temperature was modeled as a polynomial term to allow curvature in the relationship between probability of mortality and water temperature. A binomial distribution allowed studies to be weighted based on sample size of fish (elevated sample sizes of fish equals greater effect in the model). We further included reference (the literature source) as a random effect to control for differences in methodology among studies and control for multiple estimates of mortality at various water temperatures from a single study (non-independence of measures).* **** denotes significance of factors.***

Synthesis temperature model 1 (published data only)					
Fixed-effects	**Estimate**	**SE**	**z-value**	**p-value**	**AIC**
Intercept	-4.12	0.33	-12.33	< 0.01 *	221.70
Minimum water temperature^2	0.01	0.00	5.15	< 0.01 *	-
Intercept	-4.57	0.39	-11.60	< 0.01 *	216.50
Mean water temperature^2	0.01	0.00	5.50	< 0.01 *	-
Intercept	-5.01	0.47	-10.56	< 0.01 *	212.50
Maximum water temperature^2	0.01	0.00	5.49	< 0.01 *	-
Synthesis temperature model 2 (published data only excluding Ouananiche)					
Fixed-effects	**Estimate**	**SE**	**z-value**	**p-value**	**AIC**
Intercept	-3.72	0.38	-9.70	< 0.01 *	115.10
Minimum water temperature^2	0.01	0.00	4.32	< 0.01 *	-
Intercept	-4.00	0.40	-10.05	< 0.01 *	110.20
Mean water temperature^2	0.01	0.00	5.07	< 0.01 *	-
Intercept	-4.38	0.43	-10.21	< 0.01 *	104.60
Maximum water temperature^2	0.01	0.00	5.58	< 0.01 *	-

Table 6. *Coefficient estimates returned using a general linear modelling approach to test for the relationships between probability of mortality and minimum water temperature of the study as a measure of temperature at time of capture, mean water temperature of the study as a measure of temperature at time of capture, and maximum water temperature of the study as a measure of temperature at time of capture, for an angled and released Atlantic Salmon (n=2,700 individuals). To allow for a comparison of results between the data synthesis models (Models 1 and 2 which used published data only) and the raw data models we first modelled water temperature as a single factor (Model 3). To identify additional factors important in estimating the probability of mortality for a caught and released Atlantic Salmon at varying water temperatures we used a general linear model with a binomial distribution (but alive or dead for a single fish; Model 4). Factors included: water temperature, gear type, presence of barbs, life history and hook type. Model selection, using AIC criterion, suggested the best fit model included: water temperature, gear type and life history. To avoid any potential bias associated with using a minimum, maximum or mean water temperature of the study as a measure of temperature at time of capture each were included separately.* **** denotes significance of factors.***

Raw temperature model 3 (published and unpublished raw data)						
Model	**Fixed-effects**	**Estimate**	**SE**	**z-value**	**p-value**	**AIC**
Minimum water temperature	Intercept	-6.60	0.45	-14.66	< 0.01*	1091.03
-	Minimum water temperature	0.28	0.03	9.11	< 0.01*	-
Mean water temperature	Intercept	-7.21	0.51	-14.07	< 0.01*	1083.12
-	Mean water temperature	0.30	0.03	9.23	< 0.01*	-
Maximum water temperature	Intercept	-5.94	0.56	-10.67	< 0.01*	1131.05
-	Maximum water temperature	0.19	0.03	5.96	< 0.01*	-

Table 6 continued

Raw temperature model 4 (published and unpublished raw data)						
Model	**Fixed-effects**	**Estimate**	**SE**	**z-value**	**p-value**	**AIC**
Mean water temperature+life history+gear type+hook type+barbs	-	-	-	-	-	1027.59
Mean water temperature+life history+gear type+hook type	-	-	-	-	-	1025.96
Mean water temperature+life history+gear type	Intercept	-7.56	0.94	-8.08	< 0.01*	1025.14
-	Mean water temperature	0.27	0.04	6.56	< 0.01*	-
-	*Salmon.type 1SW*	-	-	-	-	-
-	*Salmon.type Kelt*	0.84	0.92	0.91	0.36	-
-	*Salmon.type MSW*	-0.43	0.30	-1.42	0.16	-
-	*Salmon.type Ouananiche*	-1.12	0.25	-4.48	< 0.01*	-
-	*Gear.type chase*	-	-	-	-	-
-	*Gear.type fly*	1.52	0.51	2.95	< 0.01*	-
-	*Gear.type lure*	1.77	0.55	3.19	< 0.01*	-
-	-	-	-	-	-	-
Minimum water temperature+life history+gear type	Intercept	-6.66	0.89	-7.50	< 0.01*	1037.90

Raw temperature model 4 (published and unpublished raw data)						
Model	**Fixed-effects**	**Estimate**	**SE**	**z-value**	**p-value**	**AIC**
-	Minimum water temperature	0.22	0.04	5.79	< 0.01*	-
-	*Salmon.type 1SW*	-	-	-	-	-
-	*Salmon.type Kelt*	0.28	0.89	0.31	0.76	-
-	*Salmon.type MSW*	-0.36	0.31	-1.18	0.24	-
-	*Salmon.type Ouananiche*	-0.97	0.27	-3.65	< 0.01*	-
-	*Gear.type chase*	-	-	-	-	-
-	*Gear.type fly*	1.41	0.51	2.75	< 0.01*	-
-	*Gear.type lure*	1.43	0.54	2.63	< 0.01*	-
-	-	-	-	-	-	-
Maximum water temperature+life history+gear type	Intercept	-6.75	0.84	-8.08	< 0.01*	1027.10
-	Maximum water temperature	0.22	0.03	6.41	< 0.01*	-
-	*Salmon.type 1SW*	-	-	-	-	-
-	*Salmon.type Kelt*	0.19	0.86	0.22	0.82	-
-	*Salmon.type MSW*	-0.66	0.30	-2.22	0.03*	-
-	*Salmon.type Ouananiche*	-1.84	0.23	-7.83	< 0.01*	-
-	*Gear.type chase*	-	-	-	-	-
-	*Gear.type fly*	1.45	0.51	2.86	< 0.01*	-
-	*Gear.type lure*	1.55	0.54	2.85	< 0.01*	-

Table 7. *The probability of mortality and mean water temperature of the study as a measure of temperature at time of capture, partitioned by life history and gear type, for a caught and released 1SW and MSW Atlantic Salmon caught on flies and lures (n=2,700 individuals). Predictions are from Table 6 and Figure 7 which used a general linear model with a binomial distribution and included water temperature, life history type, gear type, hook type and presence of barbs as factors (Model 4). Data were collected using published (Table 2) and unpublished (Table 3) data provided by various authors from across North America and Europe. Note: after model selection the best fit model contained water temperature, life history type and gear type which were all shown to be significant predictors for probability of mortality following catch and release. Due to large variation among studies ≥19°C predictions above and approaching this temperature should be interpreted over a wide error and revised as new data become available.* ****See discussion for limitations and interpretation of the model.***

Mean water temperature °C					
-	-	Lure		Fly	
Water Temperature °C	Life history	lower 95% CI	upper 95% CI	lower 95% CI	upper 95% CI
15.0	1SW	0.09	0.21	0.08	0.16
16.0	1SW	0.12	0.26	0.11	0.19
17.0	1SW	0.15	0.31	0.14	0.24
18.0	1SW	0.18	0.38	0.17	0.29
19.0*	1SW	0.22	0.45	0.21	0.35
20.0*	1SW	0.26	0.52	0.25	0.42
21.0*	1SW	0.31	0.60	0.29	0.50
22.0*	1SW	0.36	0.67	0.34	0.58
15.0	MSW	0.06	0.16	0.05	0.12
16.0	MSW	0.07	0.20	0.06	0.15
17.0	MSW	0.09	0.25	0.08	0.19
18.0	MSW	0.11	0.32	0.10	0.24
19.0*	MSW	0.14	0.38	0.12	0.30
20.0*	MSW	0.16	0.46	0.15	0.37
21.0*	MSW	0.20	0.54	0.18	0.44
22.0*	MSW	0.23	0.62	0.21	0.52

Table 8. *The proportion of Atlantic Salmon released per month and mean water temperature for select rivers across Newfoundland and Labrador in 2016. Note: the proportion of fish released are only for those angler records that contained a date for the catch and release event. No record refers to missing data (ie: incomplete temperature record or no record of a fish being released).*

Newfoundland 2016 Angling Season			
Month	**River**	**Prop. of fish released**	**Mean water temperature (°C)**
June	Campbellton	0.30	15.7
July	Campbellton	0.48	20.1
August	Campbellton	0.13	20.8
September	Campbellton	0.09	15.4
Season Total	**Campbellton**	**-**	**18.0**
June	Exploits	0.23	16.0
July	Exploits	0.58	18.8
August	Exploits	0.15	21.1
September	Exploits	0.04	no record
Season Total	**Exploits**	**-**	**18.6**
June	Harry's	0.26	13.8
July	Harry's	0.54	18.5
August	Harry's	0.19	19.5
September	Harry's	0.01	no record
Season Total	**Harry's**	**-**	**17.3**
June	Middle Brook	0.02	16.7
July	Middle Brook	0.81	21.3
August	Middle Brook	0.08	23.2
September	Middle Brook	0.08	20.1
Season Total	**Middle Brook**	**-**	**20.3**
June	Terra Nova	0.03	15.6
July	Terra Nova	0.58	19.2
August	Terra Nova	0.32	20.5
September	Terra Nova	0.07	16.7
Season Total	**Terra Nova**	**-**	**18.0**
June	Torrent	0.14	11.4
July	Torrent	0.79	14.9
August	Torrent	0.06	16.9
September	Torrent	no record	13.9
Season Total	**Torrent**	**-**	**14.3**

Table 8 continued

Labrador 2016 Angling Season			
Month	**River**	**Prop. of fish released**	**Mean water temperature (°C)**
June	Paradise River	0.22	15.2
July	Paradise River	0.67	15.0
August	Paradise River	0.11	15.6
September	Paradise River	no record	no record
Season Total	**Paradise River**	**-**	**15.3**
June	Sand Hill River	0.10	12.4
July	Sand Hill River	0.90	12.9
August	Sand Hill River	no record	13.5
September	Sand Hill River	no record	no record
Season Total	**Sand Hill River**	**-**	**12.9**

Table 9. *The number of Atlantic Salmon estimated to have died (retention mortality and catch and release mortality) in select rivers across Newfoundland and Labrador in 2016. The number of released fish per month was calculated by multiplying the proportion of fish released per month (Table 8) by the total number of fish reported in the 2016 salmon assessment. Values for the number of fish estimated to have died following catch and release were generated using the monthly average temperature between 08:00 and 20:00 and the equation from Figures 4 and 5 (synthesis temperature Model 2) which included published studies and anadromous Atlantic Salmon only. No record refers to missing data (ie: incomplete temperature record or no record of a fish being retained or released). 'Morts (10%)' refers to the current estimate used to calculate catch and release mortality in the Newfoundland and Labrador recreational fishery. Lower 95% CI estimates of mortality, presented here, may be reflective of angling events in which best practices are followed, whereas upper 95% CI estimates may be reflective of when best practices are not followed, essentially a 'worst case scenario' (eg. fish are landed on the riverbank, tailing glove used, air exposed for pictures or roughly handled).*

Newfoundland 2016 Angling Season							
Month	**River**	**# retained (scaled)**	**# released (scaled)**	**Temperature °C (Avg.)**	**Predicted # of C+R morts (lower 95% CI)**	**Predicted # of C+R morts (upper 95% CI)**	**Assumed # of C+R Morts (10%)**
June	Campbellton	82	75	15.7	3	14	7
July	Campbellton	246	117	20.1	10	52	12
August	Campbellton	57	32	20.8	3	16	3
September	Campbellton	4	21	15.4	1	4	2
Season Total	**Campbellton**	**389**	**245**	**18.0**	**17**	**85**	**25**
June	Exploits	867	937	16.0	39	185	94
July	Exploits	2853	2322	18.8	157	822	232
August	Exploits	455	607	21.1	62	312	61
September	Exploits	44	149	no record	no record	no record	15
Season Total	**Exploits**	**4219**	**4015**	no record	**no record**	**no record**	**402**

Newfoundland 2016 Angling Season							
Month	**River**	**# retained (scaled)**	**# released (scaled)**	**Temperature °C (Avg.)**	**Predicted # of C+R morts (lower 95% CI)**	**Predicted # of C+R morts (upper 95% CI)**	**Assumed # of C+R Morts (10%)**
June	Harry's	108	288	13.8	8	33	29
July	Harry's	449	605	18.5	39	203	61
August	Harry's	150	208	19.5	16	83	21
September	Harry's	21	10	no record	no record	no record	1
Season Total	**Harry's**	**728**	**1111**	no record	**no record**	**no record**	**111**
June	Middle Brook	33	2	16.7	0	0	0
July	Middle Brook	183	63	21.3	7	34	6
August	Middle Brook	8	7	23.2	1	4	1
September	Middle Brook	8	7	20.1	1	3	1
Season Total	**Middle Brook**	**233**	**78**	**20.3**	**9**	**41**	**8**
June	Terra Nova	35	7	15.6	0	1	1
July	Terra Nova	138	125	19.2	9	47	12
August	Terra Nova	62	68	20.5	6	32	7
September	Terra Nova	7	14	16.7	1	3	1
Season Total	**Terra Nova**	**242**	**214**	**18.0**	**16**	**84**	**21**
June	Torrent	111	1	11.4	0	0	7
July	Torrent	629	13	14.9	0	2	36
August	Torrent	131	1	16.9	0	0	3
September	Torrent	no record	no record	13.9	no record	no record	no record
Season Total	**Torrent**	**872**	**15**	**14.3**	**no record**	**no record**	**45**

Table 9 continued

Labrador 2016 Angling Season							
Month	**River**	**# retained (scaled)**	**# released (scaled)**	**Temperature °C (Avg.)**	**Predicted # of C+R morts (lower 95% CI)**	**Predicted # of C+R morts (upper 95% CI)**	**Assumed # of C+R Morts (10%)**
June	Paradise	10	11	15.2	0	2	1
July	Paradise	1	34	15.0	1	5	3
August	Paradise	0	6	15.6	0	1	1
September	Paradise	no record	no record	no record	no record	no record	no record
Season Total	**Paradise**	**11**	**51**	no record	**no record**	**no record**	**5**
June	Sand Hill	0	18	12.4	0	1	2
July	Sand Hill	27	164	12.9	4	15	16
August	Sand Hill	no record	no record	13.5	no record	no record	no record
September	Sand Hill	no record	no record	no record	no record	no record	no record
Season Total	**Sand Hill**	**27**	**182**	no record	**no record**	**no record**	**18**

APPENDIX II: FIGURES

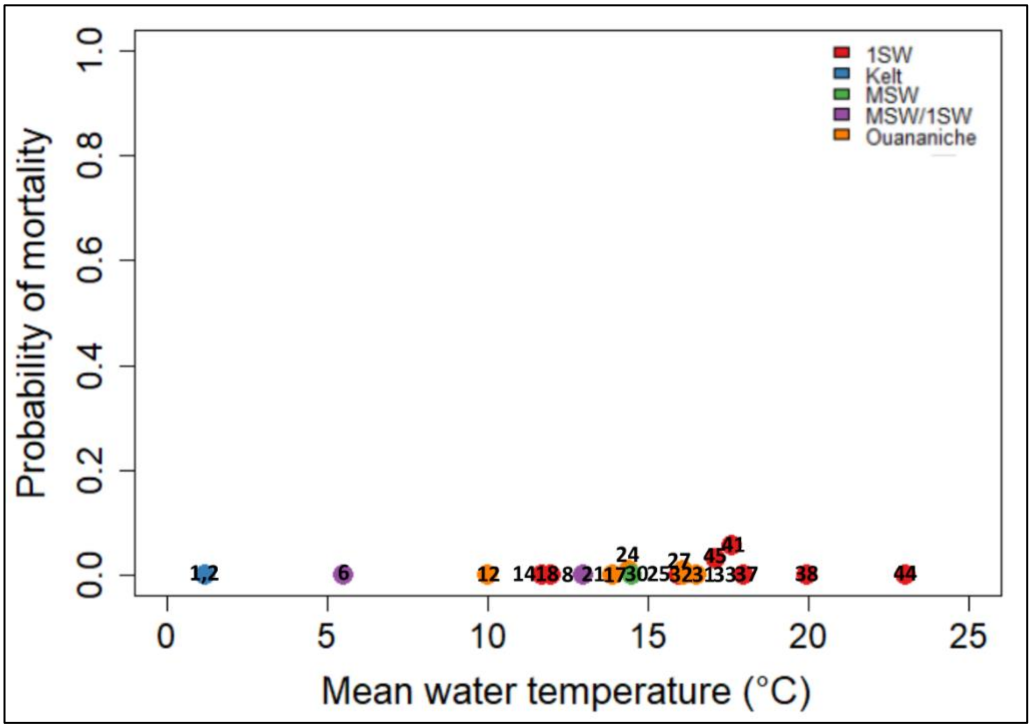


Figure 1. *The relationship between probability of mortality and mean water temperature of the study as a measure of temperature at time of capture for control groups from studies investigating the effects of catch and release angling on the survival, behavior and physiology of Atlantic Salmon. Data were collected using published and unpublished studies from across North America and Europe and caught using various gear types and techniques to assess fate of fish following release. Numbered data points refer to the study reference with additional information for each study presented in Tables 2,3,4. Coloured data points refer to life history of the salmon (1 Sea-winter [1SW], kelt, Multi-sea-winter [MSW], MSW/1SW [if both were used], ouananiche and kelt). Note: overlapping coloured data points may be hidden and may have multiple data point numbers.*

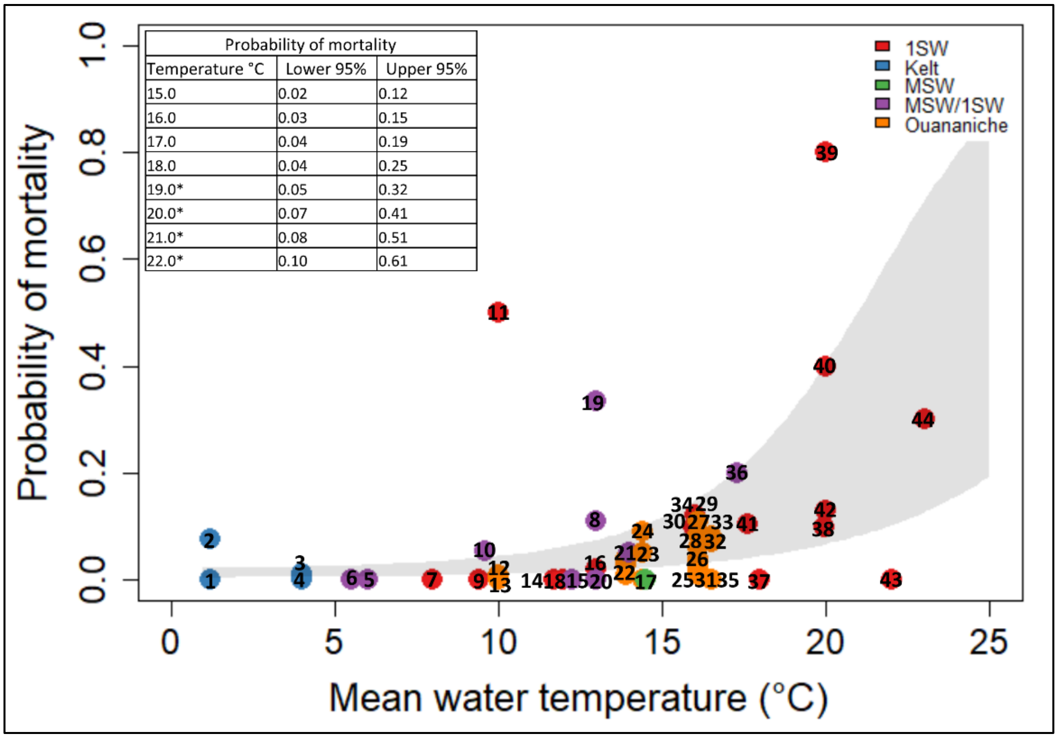


Figure 2. *The relationship between probability of mortality and mean water temperature of the study as a measure of temperature at time of capture, partitioned by life history type, for a caught and released Atlantic Salmon using a general linear mixed effects model with a binomial distribution (Model 1). Data were collected using published studies from across North America and Europe (Table 2) and included four life history types (Ouananiche, Kelt, 1SW, MSW, MSW/1SW [if both were used]) caught using various gear types and techniques to assess fate of fish following release. Numbered data points refer to the study reference with additional information for each study presented in Table 2. Shaded curved area represents upper and lower 95% CI. Relationships between probability of mortality and minimum water temperature of the study as a measure of temperature at time of capture and maximum water temperature of the study as a measure of temperature at time of capture for a caught and released Atlantic Salmon can be found in Supplementary Figures 1 and 2.* ***Note the relatively large variation in mortality estimates among studies ≥19°C, therefore, predictions above and approaching this temperature are bounded by a wide error margin, represented in the figure table with an asterisk. Models should be revised as new data becomes available.***

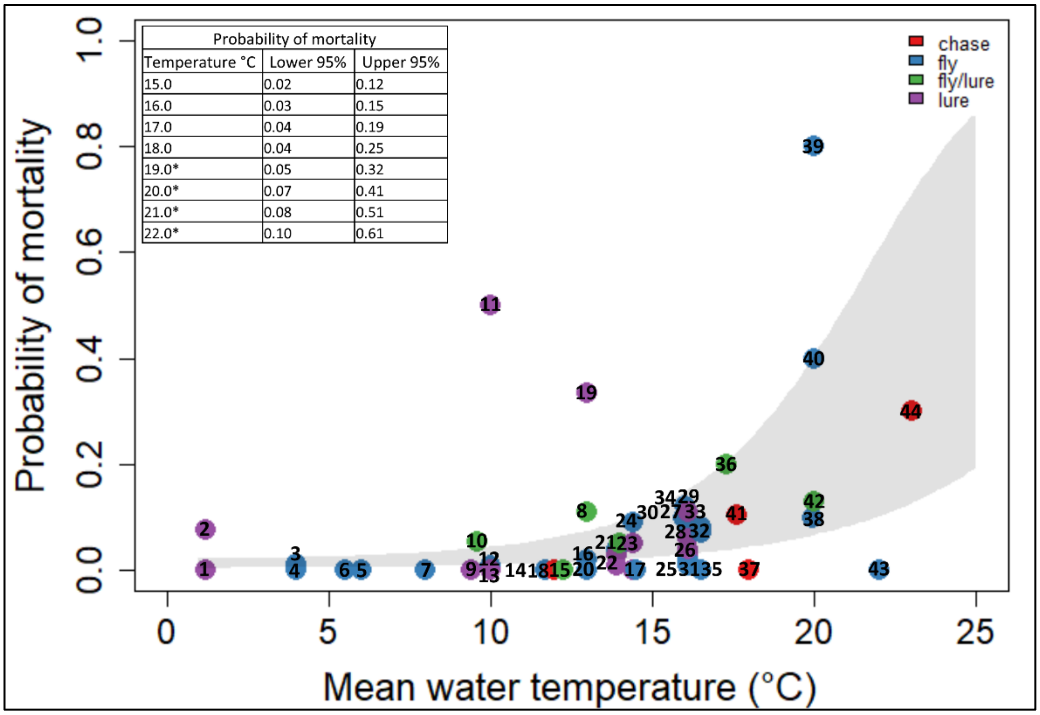
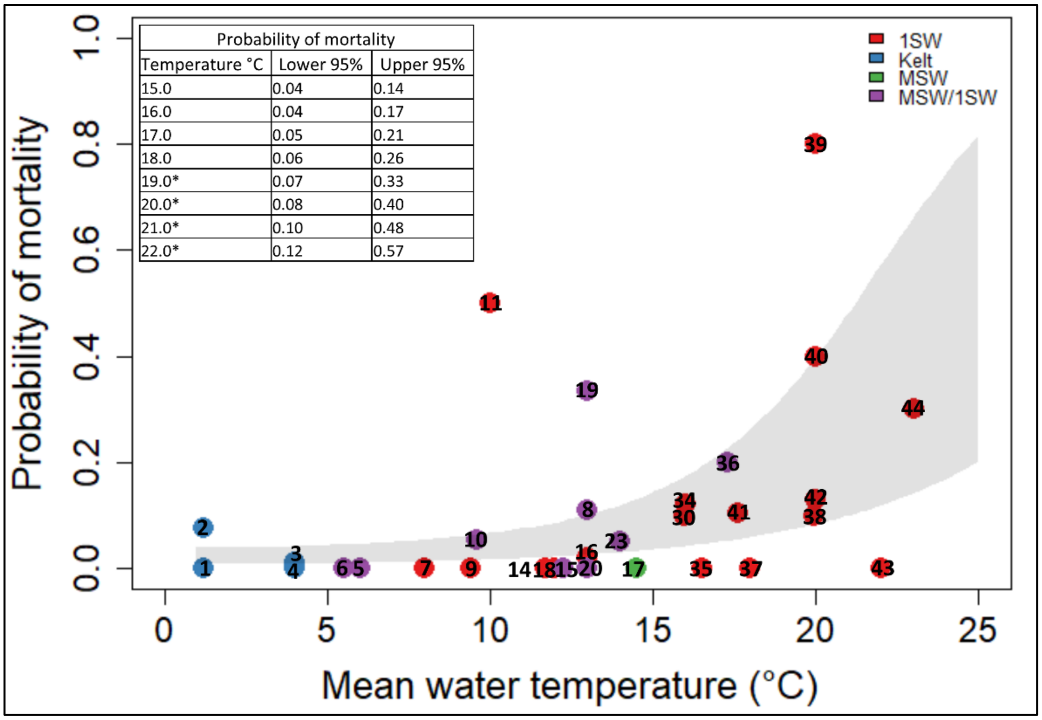


Figure 3. *The relationship between probability of mortality and mean water temperature of the study as a measure of temperature at time of capture, partitioned by gear type, for a caught and released Atlantic Salmon using a general linear mixed effects model with a binomial distribution (Model 1). Data were collected using published studies from across North America and Europe (Table 2) and included four life history types (Ouananiche, Kelt, 1SW, MSW, MSW/1SW [if both were used]), caught using various gear types (fly, lure, fly/lure, if both were used), techniques (chase) and protocols to assess fate of fish following release. Chase protocols, whereby an individual fish is chased in a circular arena until exhaustion, are sometimes used to simulate the exhaustive nature of an angling event. Numbered data points refer to the study reference with additional information for each study presented in Table 2. Shaded curved area represents upper and lower 95% CI. Relationships between probability of mortality and minimum water temperature of the study as a measure of temperature at time of capture and maximum water temperature of the study as a measure of temperature at time of capture for a caught and released Atlantic Salmon can be found in Supplementary Figures 1 and 2.* ***Note the relatively large variation in mortality estimates among studies ≥19°C, therefore, predictions above and approaching this temperature are bounded by a wide error margin, represented in the figure table with an asterisk. Models should be revised as new data becomes available.***



Probability of mortality		
Temperature °C	Lower 95%	Upper 95%
15.0	0.04	0.14
16.0	0.04	0.17
17.0	0.05	0.21
18.0	0.06	0.26
19.0*	0.07	0.33
20.0*	0.08	0.40
21.0*	0.10	0.48
22.0*	0.12	0.57

Figure 4. *The relationship between probability of mortality and mean water temperature of the study as a measure of temperature at time of capture, partitioned by life history type, for a caught and released anadromous Atlantic Salmon using a general linear mixed effects model with a binomial distribution (Model 2). Data were collected using published studies from across North America and Europe and included only the anadromous life histories of Atlantic Salmon (1SW, MSW, Kelt, MSW/1SW, if both were used) caught using various gear types and techniques to assess fate of fish following release. Numbered data points refer to the study reference with additional information for each study presented in Table 2. Shaded curved area represents upper and lower 95% CI. Relationships between probability of mortality and minimum water temperature of the study as a measure of temperature at time of capture and maximum water temperature of the study as a measure of temperature at time of capture for a caught and released anadromous Atlantic Salmon can be found in Supplementary Figures 3 and 4.* ***Note the relatively large variation in mortality estimates among studies ≥19°C, therefore, predictions above and approaching this temperature are bounded by a wide error margin, represented in the figure table with an asterisk. Models should be revised as new data becomes available.***

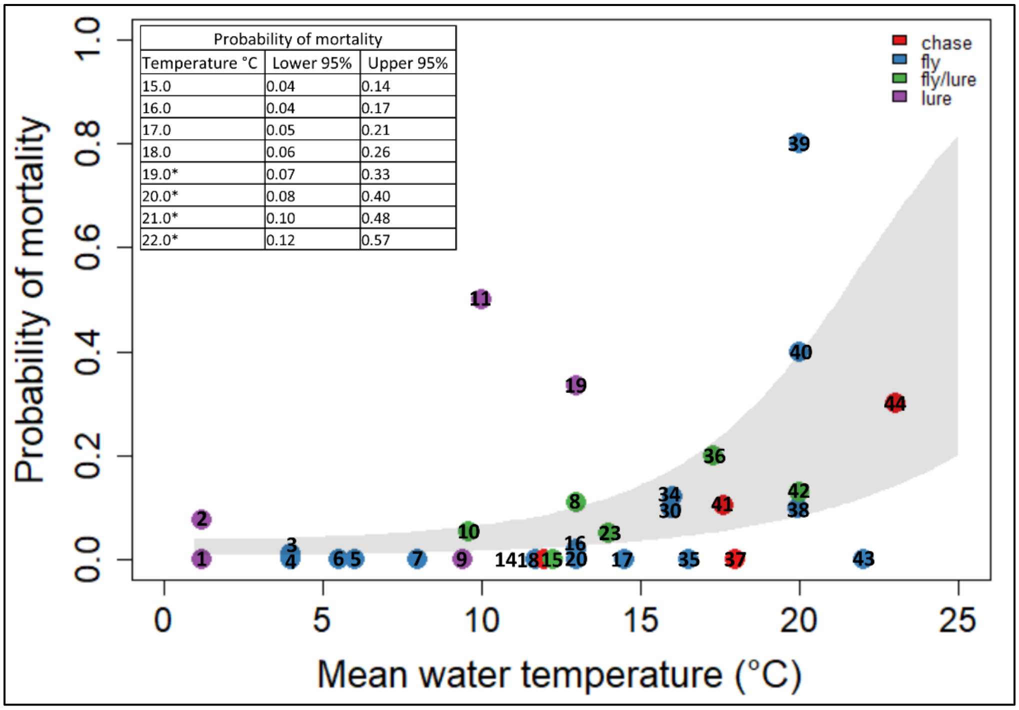
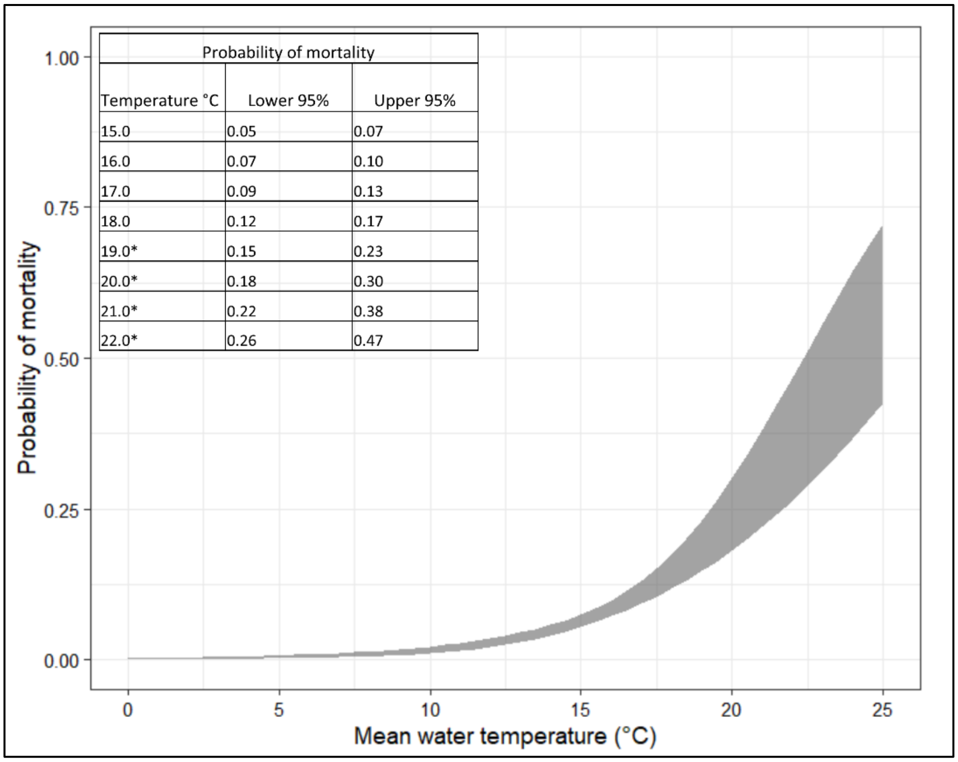


Figure 5. *The relationship between probability of mortality and mean water temperature of the study as a measure of temperature at time of capture, partitioned by gear type, for a caught and released anadromous Atlantic Salmon using a general linear mixed effects model with a binomial distribution (Model 2). Data were collected using published studies from across North America and Europe and included only the anadromous life histories of Atlantic Salmon (1SW, MSW, Kelt, MSW/1SW, if both were used) caught using various gear types (fly, lure, fly/lure, if both were used), techniques (chase) and protocols to assess fate of fish following release. Chase protocols, whereby an individual fish is chased in a circular arena until exhaustion, are sometimes used to simulate the exhaustive nature of an angling event. Numbered data points refer to the study reference with additional information for each study presented in Table 2. Shaded curved area represents upper and lower 95% CI. Relationships between probability of mortality and minimum water temperature of the study as a measure of temperature at time of capture and maximum water temperature of the study as a measure of temperature at time of capture, for a caught and released anadromous Atlantic Salmon can be found in Supplementary Figures 3 and 4.* ***Note the relatively large variation in mortality estimates among studies ≥19°C, therefore, predictions above and approaching this temperature are bounded by a wide error margin, represented in the figure table with an asterisk. Models should be revised as new data becomes available.***



Probability of mortality		
Temperature °C	Lower 95%	Upper 95%
15.0	0.05	0.07
16.0	0.07	0.10
17.0	0.09	0.13
18.0	0.12	0.17
19.0*	0.15	0.23
20.0*	0.18	0.30
21.0*	0.22	0.38
22.0*	0.26	0.47

Figure 6. *The relationship between probability of mortality and mean water temperature of the study as a measure of temperature at time of capture, for a caught and released Atlantic Salmon using a general linear model with a binomial distribution (Model 3). Data were collected using raw published (Table 2) and unpublished (Table 3) data from studies across North America and Europe and included four life history types (Ouananiche, Kelt, 1SW, MSW) caught using various gear types and techniques to assess fate of fish following release (n=2,700 individuals). Shaded curved area represent upper and lower 95% CI. Relationships between probability of mortality and minimum water temperature and maximum water temperature of the study as a measure of temperature at time of capture can be found in Supplementary Figure 5.* ***Note: due to large variation among studies ≥19°C predictions above and approaching this temperature should be interpreted within the context of a wide error margin represented in the figure table with an asterisk. Narrower confidence intervals compared to Figures 1 and 2 are because of a greater sample size provided by the addition of unpublished raw data. Models should be revised as new data becomes available.***

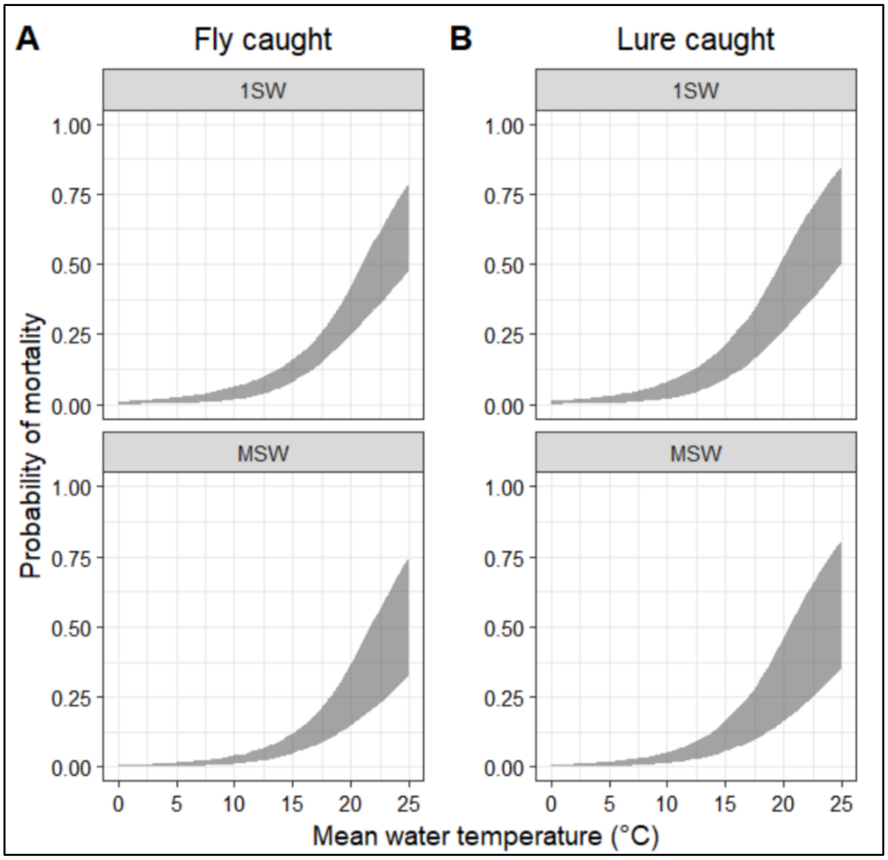


Figure 7. *The relationship between probability of mortality and mean water temperature of the study as a measure of temperature at time of capture, partitioned by life history and gear type, for a caught and released 1SW and MSW Atlantic Salmon caught on flies (A) and lures (B). Data were collected using published (Table 2) and unpublished (Table 3) data provided by various authors from across North America and Europe (n=2,700 individuals). Data were modelled using a general linear model with a binomial distribution that initially included water temperature, life history type, gear type, hook type and presence of barbs as factors (Model 4; Table 6). Shaded areas represent upper and lower 95% CI. Relationships between probability of mortality and minimum water temperature and maximum water temperature of the study as a measure of temperature at time of capture can be found in Supplementary Figure 6.* ***Note: after model selection the best fit model contained water temperature, life history and gear type which were all shown to be significant predictors for determining probability of mortality following catch and release. Due to large variation among studies ≥19°C predictions above and approaching this temperature should be interpreted over a wide error margin and revised as new data becomes available. See discussion for limitations and interpretation of the model.***

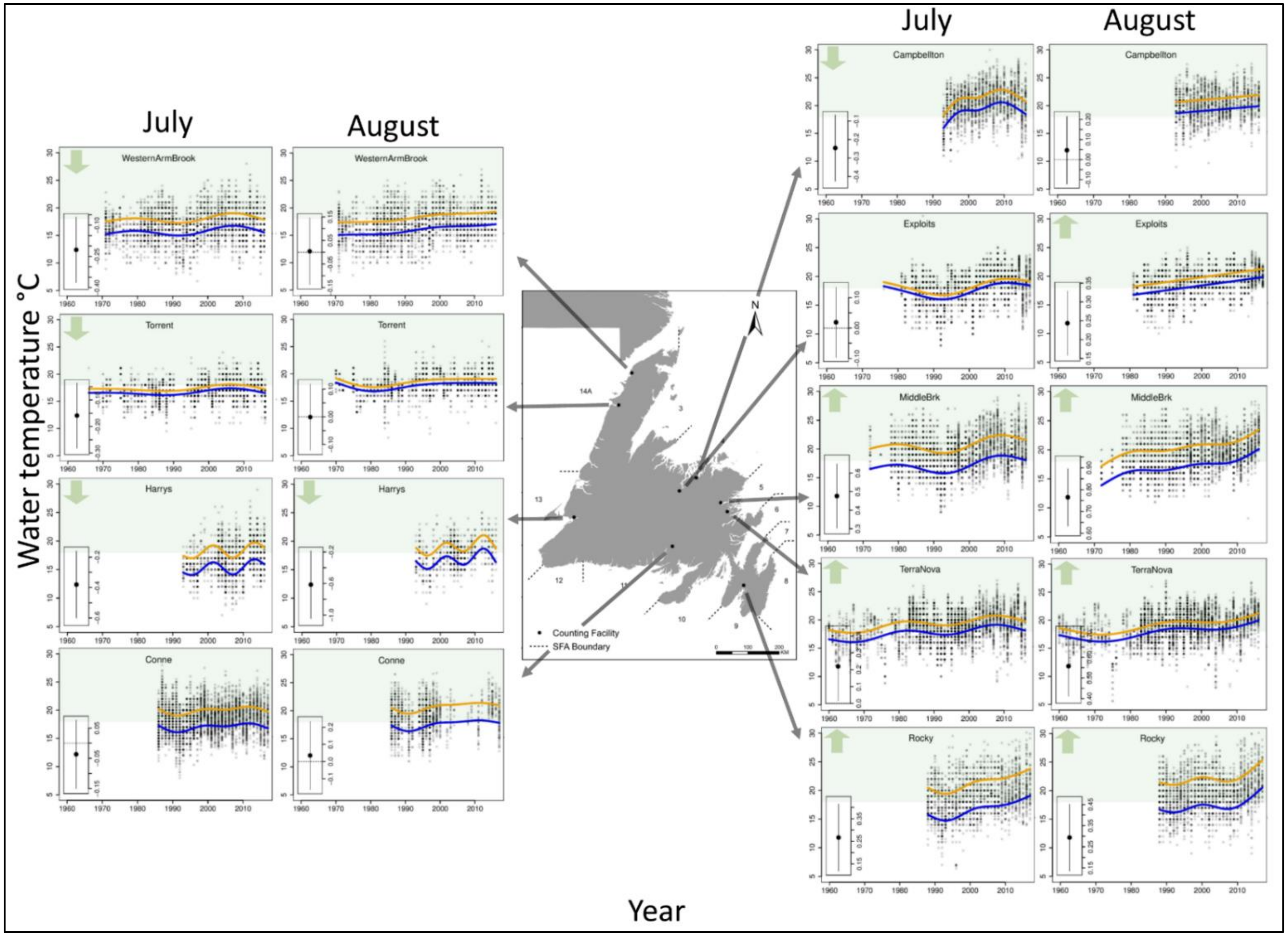


***Figure 8**. The relationship between July and August river temperature and year for nine monitored rivers in Salmon Fishing Areas 3, 4, 5, 9, 11, 13 and 14A in Newfoundland, Canada. Data points represent river temperatures taken at 08:00 and 16:00. The blue line represents river temperatures at 08:00 across years and the orange line represents river temperatures at 16:00 across years. The shaded green area represents daily river temperatures above 18°C. The window in the left bottom corner of each panel refers to the 95% CI's generated using a liner mixed effects model on data ≥2010. Windows that contain 95% CI's that do not cross zero represent a statistically significant trend in river temperature for years ≥2010. Green arrows in the upper left corner of the panel refer to the direction of the significant trend in river temperature if found. See text for results of the statistical analyses.*

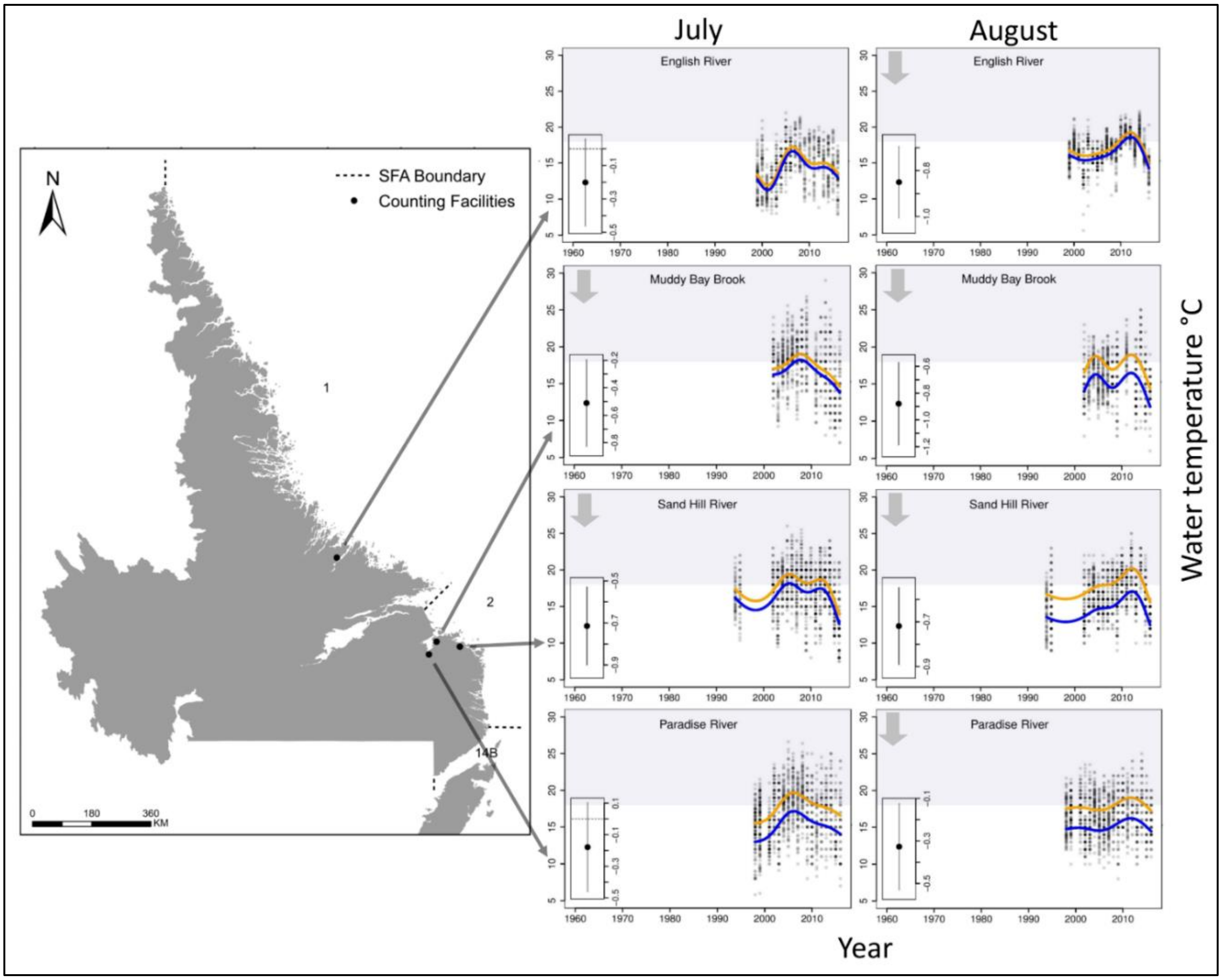


***Figure 9**. The relationship between July and August river temperature and year for four monitored rivers in Salmon Fishing Areas 1 and 2 in Labrador, Canada. Data points represent daily river temperatures taken at 08:00 and 16:00. The blue line represents river temperatures at 08:00 across years and the orange line represents river temperatures at 16:00 across years. The shaded grey area represents daily river temperatures above 18°C. The window in the left bottom corner of each panel refers to 95% confidence intervals (CI's) generated using a liner mixed effects model on data ≥2010. Windows that contain 95% CI's that do not cross zero represent a statistically significant trend in river temperature for years ≥2010. Grey arrows in the upper left corner of the panel refer to the direction of the significant trend in river temperature if found. See text for results of the statistical analyses.*

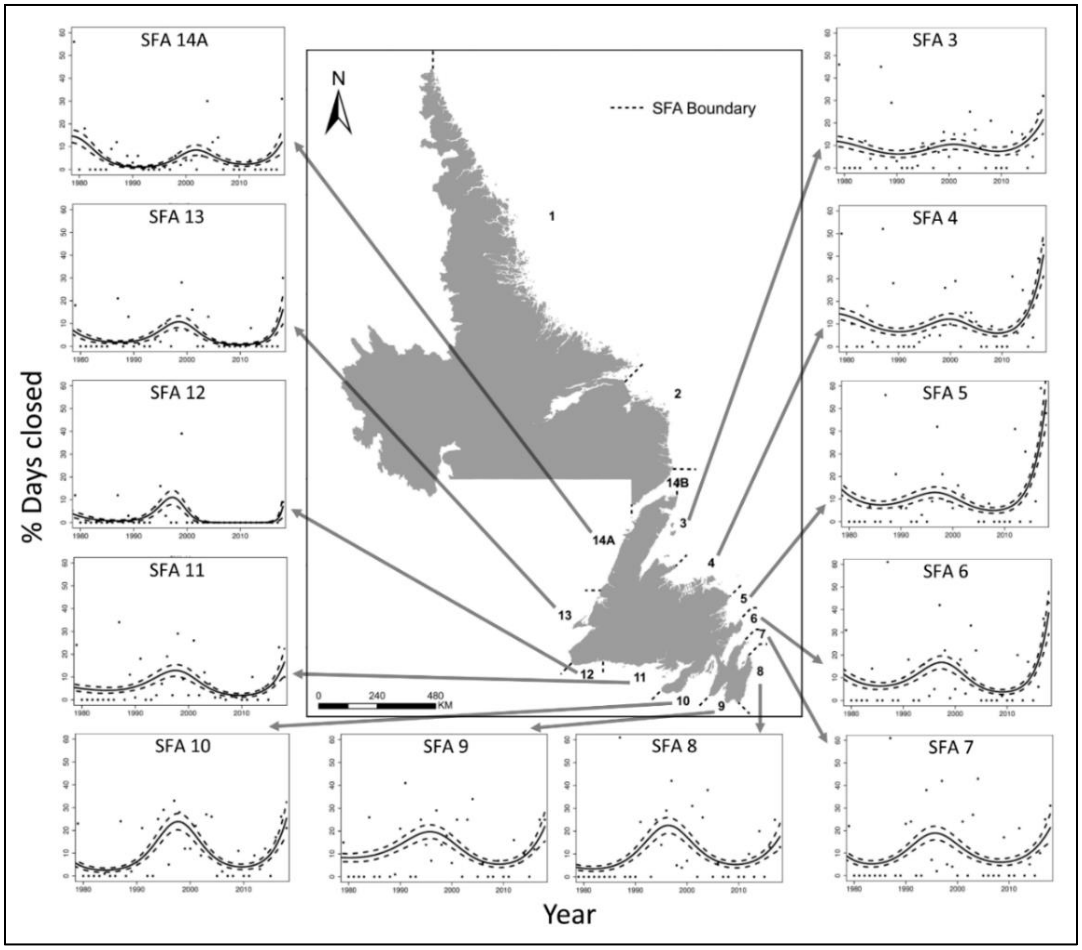


Figure 10*. The relationship between environmental closures (percent of days rivers were closed to angling) and year (1975-2018) for each Salmon Fishing Area in Newfoundland, Canada (SFA 3-14A). The solid black line represents the average trend in percent days closed across years. The dotted black line represents 95% confidence intervals for the model. To date we are only aware one river closure in Labrador, Canada (Shinney's River-SFA 2 in 1999) for environmental reasons. See text for results of the statistical analyses.*

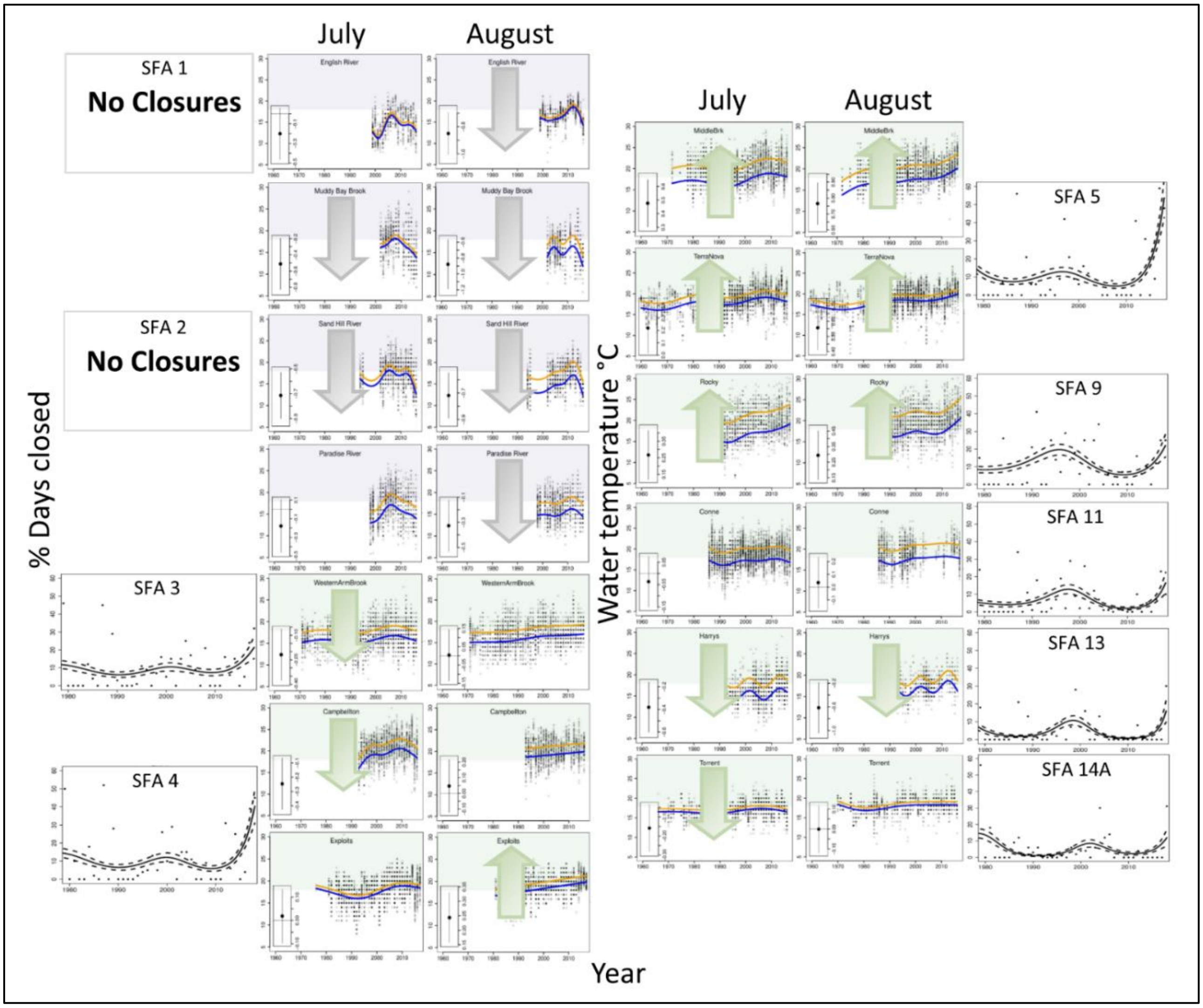
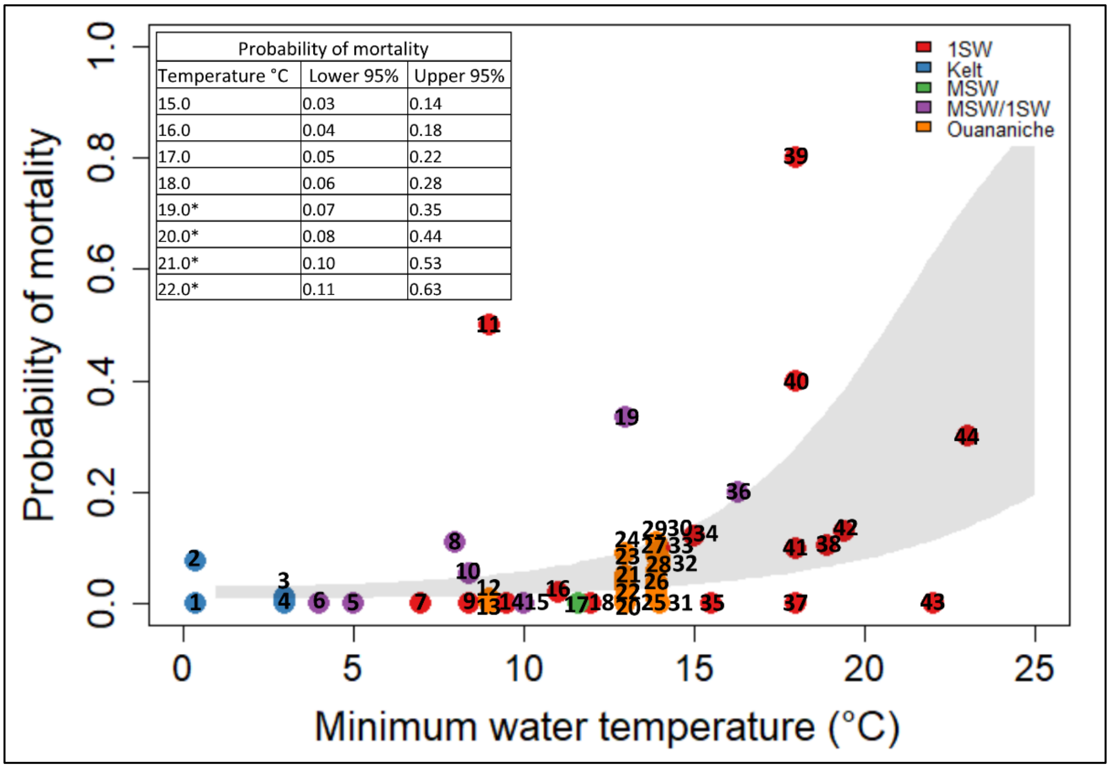
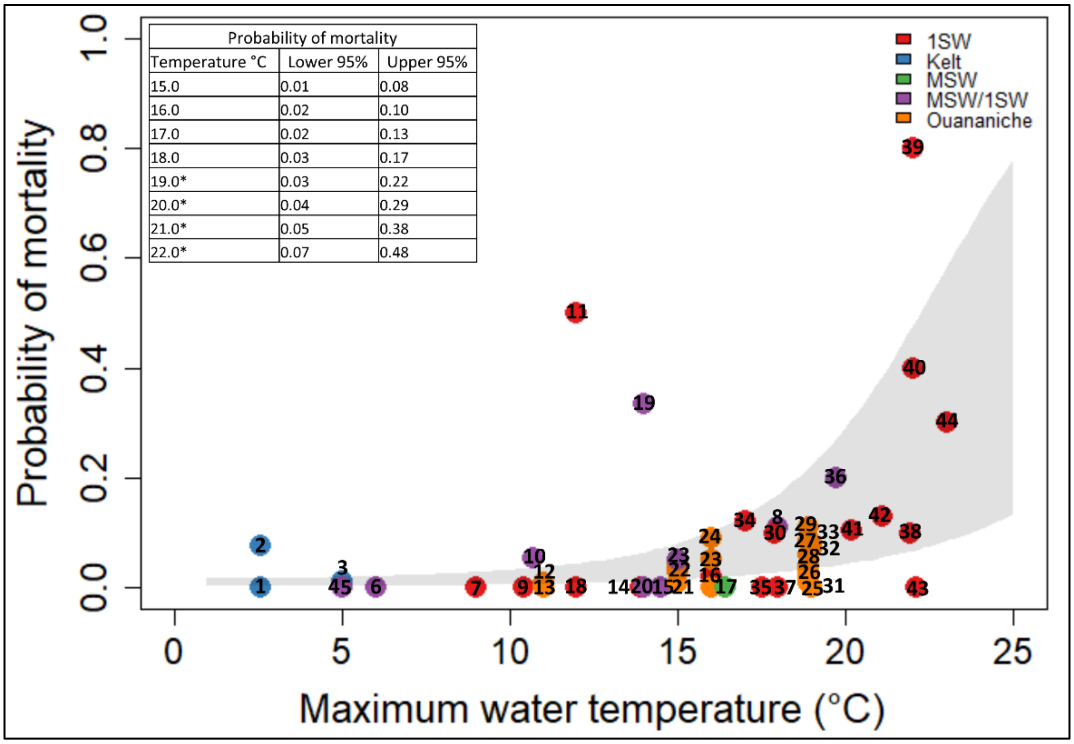


***Figure 11**. River temperatures (July and August) and environmental closures (percent of days closed) by year for different Salmon Fishing Areas (SFA 1, 2, 3, 4, 5, 9, 11, 13 and 14A) in Newfoundland (panels with a green background) and Labrador (panels with a grey background), Canada. Arrows represent the direction of the statistically significant trend in river temperature for years ≥2010 generated using a liner mixed effects model. See text for results of the statistical analyses.*

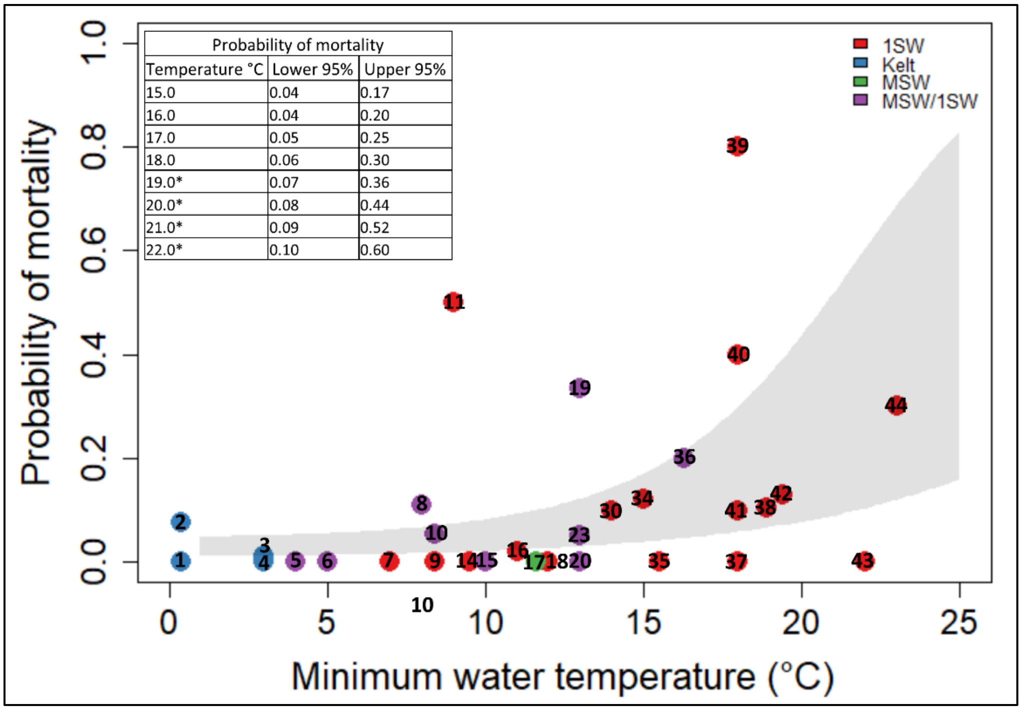
APPENDIX III: SUPPLEMENTARY INFORMATION



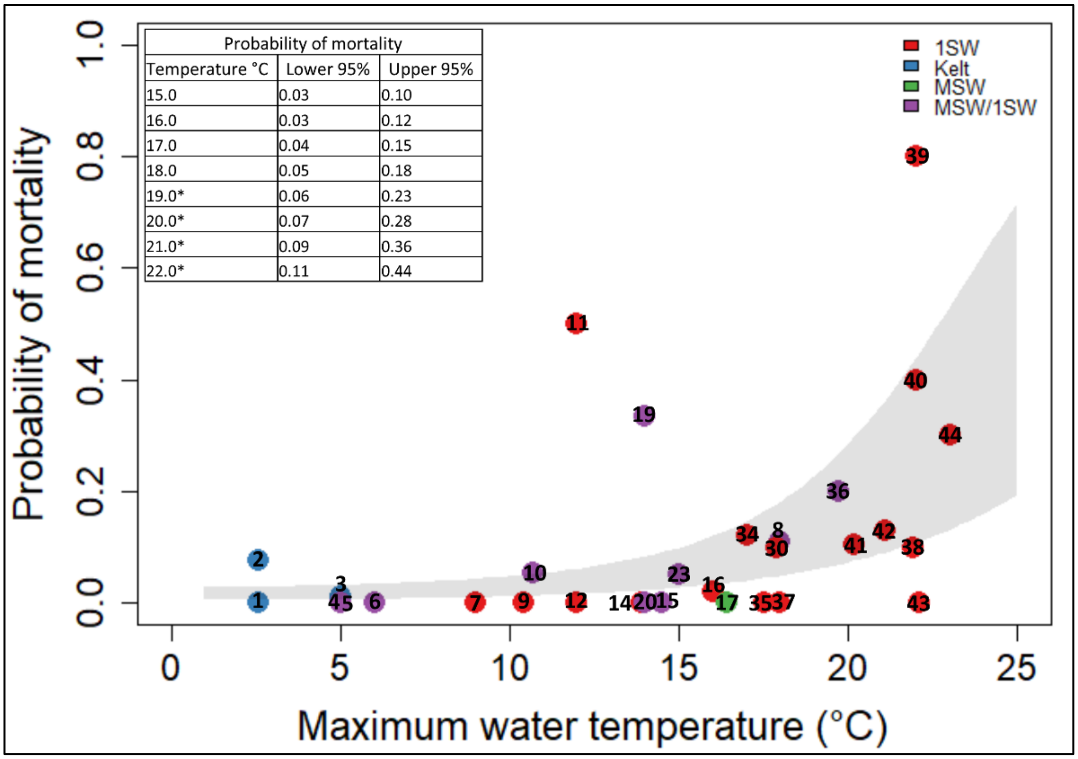
Supp. Figure 1. *The relationship between probability of mortality and minimum water temperature of the study as a measure of temperature at time of capture, partitioned by life history type, for a caught and released Atlantic Salmon using a general linear mixed effects model with a binomial distribution. Data were collected using published studies from across North America and Europe (Table 2) and included four life history types (Ouananiche, Kelt, 1SW, MSW, MSW/1SW, if both were used) caught using various gear types and techniques to assess fate of fish following release. Numbered data points refer to the study reference with additional information for each study presented in Table 2. Shaded curved area represents upper and lower 95% CI.* ***Note the relatively large variation in mortality estimates among studies ≥19°C, therefore, predictions above and approaching this temperature are bounded by a wide error margin, represented in the figure table with an asterisk. Models should be revised as new data becomes available.***



Supp. Figure 2. *The relationship between probability of mortality and maximum water temperature of the study as a measure of temperature at time of capture, partitioned by life history type, for a caught and released Atlantic Salmon using a general linear mixed effects model with a binomial distribution. Data were collected using published studies from across North America and Europe (Table 2) and included four life history types (Ouananiche, Kelt, 1SW, MSW, MSW/1SW, if both were used) caught using various gear types and techniques to assess fate of fish following release. Numbered data points refer to the study reference with additional information for each study presented in Table 2. Shaded curved area represents upper and lower 95% CI.* ***Note the relatively large variation in mortality estimates among studies ≥19°C, therefore, predictions above and approaching this temperature are bounded by a wide error margin, represented in the figure table with an asterisk. Models should be revised as new data becomes available.***

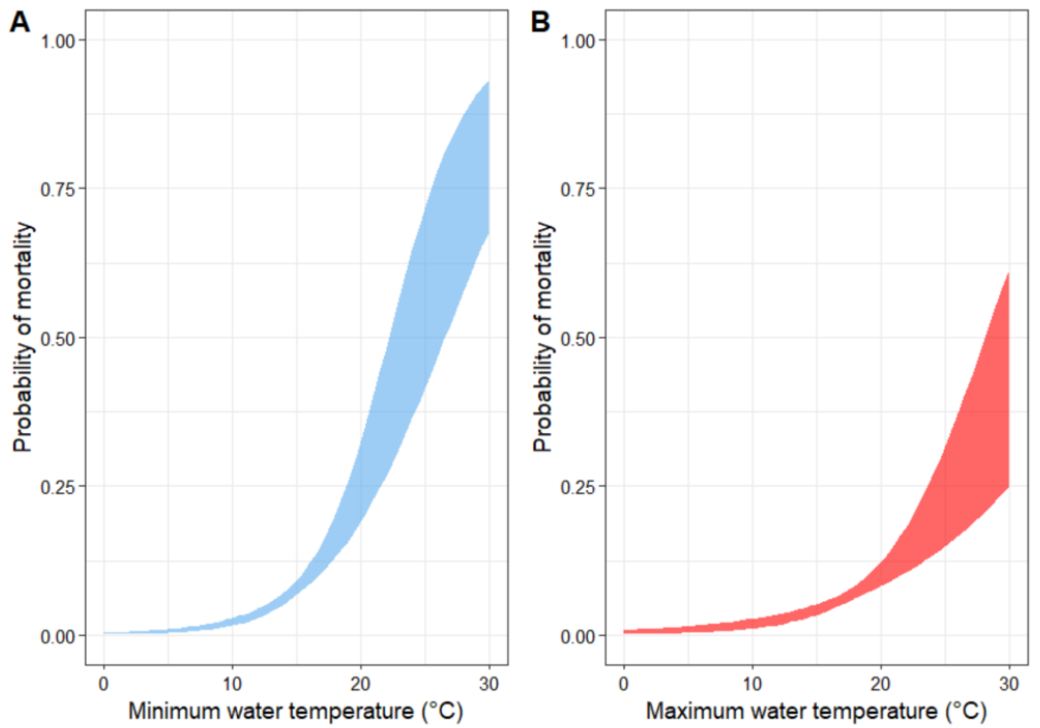


Supp. Figure 3. *The relationship between probability of mortality and minimum water temperature of the study as a measure of temperature at time of capture, partitioned by life history type, for a caught and released anadromous Atlantic Salmon using a general linear mixed effects model with a binomial distribution. Data were collected using published studies from across North America and Europe and included only the anadromous life histories of Atlantic Salmon (1SW, MSW, Kelt, MSW/1SW, if both were used) caught using various gear types and techniques to assess fate of fish following release. Numbered data points refer to the study reference with additional information for each study presented in Table 2. Shaded curved area represents upper and lower 95% CI.* ***Note the relatively large variation in mortality estimates among studies ≥19°C, therefore, predictions above and approaching this temperature are bounded by a wide error margin, represented in the figure table with an asterisk. Models should be revised as new data becomes available.***



Probability of mortality		
Temperature °C	Lower 95%	Upper 95%
15.0	0.03	0.10
16.0	0.03	0.12
17.0	0.04	0.15
18.0	0.05	0.18
19.0*	0.06	0.23
20.0*	0.07	0.28
21.0*	0.09	0.36
22.0*	0.11	0.44

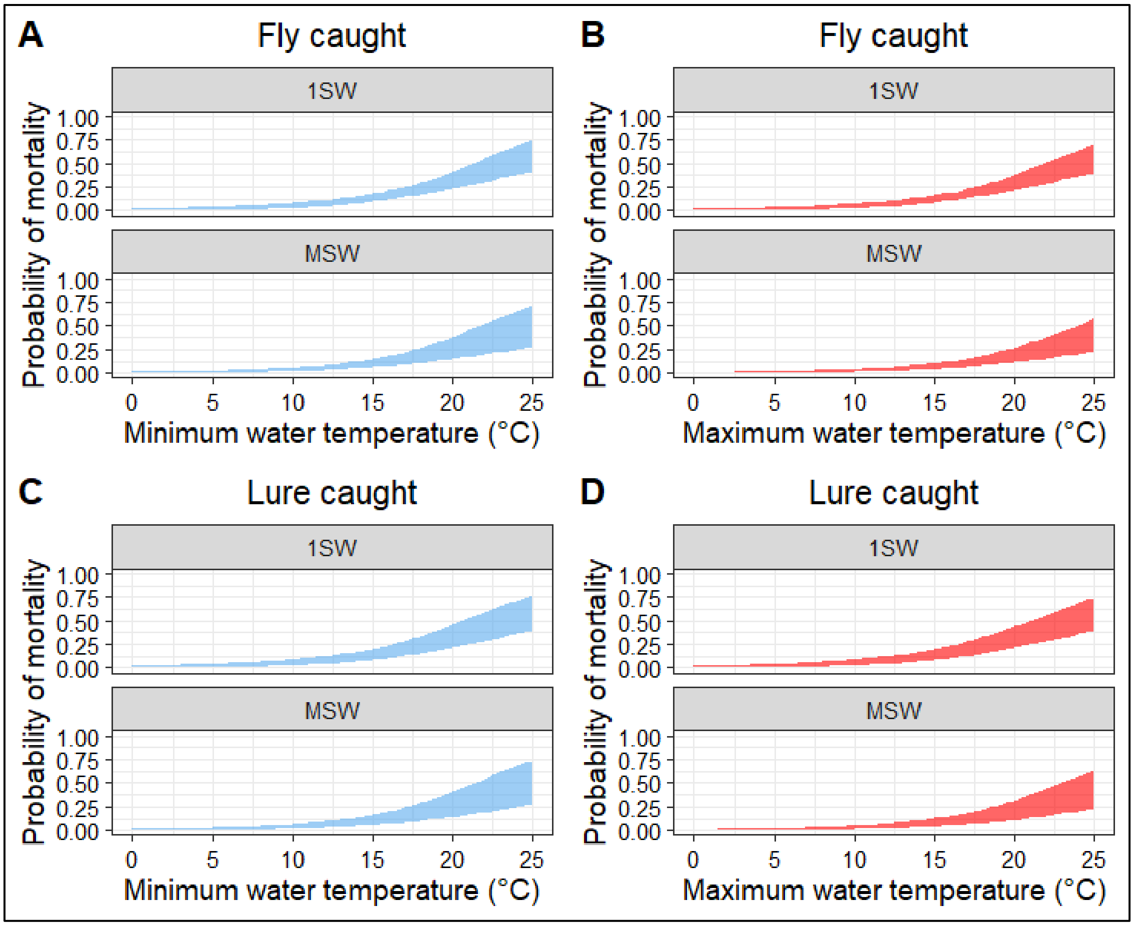
Supp. Figure 4. *The relationship between probability of mortality and maximum water temperature of the study as a measure of temperature at time of capture, partitioned by life history type, for a caught and released anadromous Atlantic Salmon using a general linear mixed effects model with a binomial distribution. Data were collected using published studies from across North America and Europe and included only the anadromous life histories of Atlantic Salmon (1SW, MSW, Kelt, MSW/1SW, if both were used) caught using various gear types and techniques to assess fate of fish following release. Numbered data points refer to the study reference with additional information for each study presented in Table 2. Shaded curved area represents upper and lower 95% CI.* ***Note the relatively large variation in mortality estimates among studies ≥19°C, therefore, predictions above and approaching this temperature are bounded by a wide error margin, represented in the figure table with an asterisk. Models should be revised as new data becomes available.***



Probability of mortality		
Temperature °C	Lower 95%	Upper 95%
15.0	0.07	0.09
16.0	0.09	0.12
17.0	0.11	0.16
18.0	0.13	0.20
19.0*	0.16	0.26
20.0*	0.19	0.33
21.0*	0.23	0.40
22.0*	0.27	0.48

Probability of mortality		
Temperature °C	Lower 95%	Upper 95%
15.0	0.03	0.05
16.0	0.04	0.06
17.0	0.05	0.07
18.0	0.06	0.08
19.0*	0.07	0.10
20.0*	0.08	0.12
21.0*	0.09	0.15
22.0*	0.11	0.18

Supp. Figure 5. *The relationship between probability of mortality and minimum (A) and maximum water temperature (B) for a caught and released Atlantic Salmon using a general linear model with a binomial distribution and minimum and maximum water temperature, separately as a single factor. Data were collected using raw published (Table 1) and unpublished (Table 2) data from studies across North America and Europe and included four life history types (Ouananiche, Kelt, 1SW, MSW) caught using various gear types and techniques to assess fate of fish following release (n=2,700) . Shaded blue and red curved area represent upper and lower 95% CI for minimum and maximum water temperatures, respectively.* ***Note: due to large variation among studies ≥19°C predictions above and approaching this temperature should be interpreted within the context of a wide error margin represented in the figure table with an asterisk. Narrower confidence intervals compared to Figures 1 and 2 are because of a greater sample size provided by the addition of unpublished raw data. Models should be revised as new data becomes available.***



Supp. Figure 6. *The relationship between probability of mortality and minimum (A,C) and maximum (B,D) water temperature as a measure of temperature at time of capture, partitioned by life history and gear type, for a caught and released 1SW and MSW Atlantic Salmon caught on flies (A,B) and lures (C,D). Data were collected using published (Table 2) and unpublished (Table 3) data provided by various authors from across North America and Europe (n=2,700 individuals) and modelled using a general linear model with a binomial distribution. Models initially included water temperature, life history type, gear type, hook type and presence of barbs as factors (Table 4). Shaded blue and red curved areas represent upper and lower 95% CI for minimum, and maximum water temperatures recorded for each study and used as a single measure of water temperature at time of capture, respectively. Lower bound of the 95% CI estimates of mortality may be reflective of angling events in which best practices are followed (e.g. shallow hooked fish, minimal playing time and handling) whereas upper 95% CI estimates may be reflective of when poor practices are followed, essentially a 'worst case scenario' (eg. deeply hooked fish, landed on the riverbank, tailing gloves used, air exposed for pictures or roughly handled).* ***Note: after model selection the best fit model contained water temperature, life history type and gear type which were all shown to be significant predictors for probability of mortality following catch and release. Due to large variation among studies ≥19°C predictions above and approaching this temperature should be interpreted over a wide error margin and revised as new data become available. See discussion for limitations and interpretation of the model.***

Supp. Table 1. *The probability of mortality and minimum and maximum water temperature recorded for each study and used as a single measure of water temperature at time of capture, partitioned by life history and gear type, for a caught and released 1SW and (MSW Atlantic Salmon caught on flies and lures (n=2,700 individuals). Data were collected using published (Table 2) and unpublished (Table 3) data provided by various authors from across North America and Europe. Predictions are from Table 6 and Figure 7 which used a general linear model with a binomial distribution and included water temperature, life history type, gear type, hook type and presence of barbs as factors. Lower bound of the 95% CI estimates of mortality may be reflective of angling events in which best practices are followed (e.g. shallow hooked fish, minimal playing time and handling) whereas upper 95% CI estimates may be reflective of when poor practices are followed, essentially a 'worst case scenario' (eg. deeply hooked fish, landed on the riverbank, tailing gloves used, air exposed for pictures or roughly handled).* ***Note: after model selection the best fit model contained water temperature, life history type and gear type which were all shown to be significant predictors for probability of mortality following catch and release. Due to large variation among studies ≥19°C predictions above and approaching this temperature should be interpreted over a wide error represented in the table with an asterisk and revised as new data become available. *See discussion for limitations and interpretation of the model.***

-	-	Minimum water temperature °C				Maximum water temperature °C			
-	-	Lure		Fly		Lure		Fly	
Water temperature °C	Life history	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI
15.0	1SW	0.09	0.21	0.10	0.18	0.08	0.20	0.09	0.16
16.0	1SW	0.11	0.24	0.12	0.21	0.10	0.24	0.11	0.19
17.0	1SW	0.13	0.29	0.15	0.25	0.13	0.28	0.13	0.23
18.0	1SW	0.16	0.34	0.18	0.30	0.15	0.33	0.16	0.27
19.0*	1SW	0.19	0.39	0.21	0.35	0.18	0.38	0.19	0.32
20.0*	1SW	0.22	0.45	0.24	0.41	0.21	0.44	0.22	0.38
21.0*	1SW	0.25	0.52	0.27	0.48	0.24	0.50	0.25	0.44
22.0*	1SW	0.29	0.59	0.30	0.55	0.28	0.56	0.29	0.50
15.0	MSW	0.06	0.17	0.06	0.15	0.04	0.13	0.04	0.10
16.0	MSW	0.07	0.20	0.08	0.18	0.05	0.15	0.05	0.13
17.0	MSW	0.08	0.24	0.09	0.22	0.06	0.18	0.06	0.15
18.0	MSW	0.10	0.29	0.11	0.27	0.08	0.22	0.08	0.18
19.0*	MSW	0.12	0.35	0.13	0.32	0.09	0.26	0.09	0.22
20.0*	MSW	0.14	0.41	0.15	0.38	0.11	0.32	0.11	0.27
21.0*	MSW	0.16	0.48	0.17	0.45	0.13	0.37	0.13	0.32
22.0*	MSW	0.19	0.55	0.20	0.52	0.15	0.43	0.15	0.38

Supp. Table 2. *A sensitivity type analysis showing how the inclusion (yes) / exclusion (no) of Anderson et al. (1998) and/or critically wounded fish, not included previously in published studies, affects the probability of mortality for a caught and released Atlantic Salmon. Models 1 and 2 used a general linear mixed effects model with a binomial distribution. Data were collected using published studies from across North America and Europe (Table 2). Model 1 included four life history types (Ouananiche, Kelt, 1SW, MSW, MSW/1SW (if both were used)) whereas Model 2 included only the anadromous life histories of Atlantic Salmon (1SW, MSW, Kelt, MSW/1SW, if both were used) caught using various gear types and techniques to assess fate of fish following release. Models 3 and 4 used a general linear model with a binomial distribution. Data were collected using raw published (Table 1) and unpublished (Table 2) data from studies across North America and Europe and included four life history types (Ouananiche, Kelt, 1SW, MSW) caught using various gear types and techniques to assess fate of fish following release (n=2,700). Model 3 included water temperature only, whereas Model 4 included water temperature, life history type, gear type, hook type and presence of barbs as factors. All models used mean water temperature recorded as a single measure of water temperature at time of capture. Lower bound of the 95% CI estimates of mortality may be reflective of angling events in which best practices are followed (e.g. shallow hooked fish, minimal playing time and handling) whereas upper 95% CI estimates may be reflective of when poor practices are followed, essentially a 'worst case scenario' (eg. deeply hooked fish, landed on the riverbank, tailing gloves used, air exposed for pictures or roughly handled).*

Probability of Mortality (lower 95% CI – upper 95% CI)				
Temp. (°C)	**yes/yes**	**no/yes**	**yes/no**	**no/no**
Model 1				
15	0.02-0.12	0.02-0.11	0.02-0.07	0.02-0.08
16	0.03-0.15	0.03-0.14	0.03-0.10	0.03-0.10
17	0.04-0.19	0.03-0.18	0.03-0.10	0.03-0.12
18	0.04-0.25	0.04-0.22	0.04-0.17	0.04-0.16
19	0.05-0.32	0.05-0.28	0.06-0.23	0.05-0.22
20	0.07-0.41	0.06-0.36	0.07-0.31	0.06-0.28
21	0.08-0.51	0.07-0.45	0.09-0.40	0.07-0.37
22	0.10-0.61	0.08-0.54	0.11-0.51	0.09-0.47
Model 2				
15	0.04-0.14	0.03-0.14	0.02-0.13	0.03-0.11
16	0.04-0.17	0.04-0.17	0.03-0.16	0.03-0.13
17	0.05-0.21	0.04-0.21	0.03-0.21	0.04-0.17
18	0.06-0.26	0.05-0.25	0.04-0.26	0.04-0.20
19	0.07-0.33	0.06-0.31	0.05-0.34	0.05-0.25
20	0.08-0.40	0.07-0.37	0.06-0.43	0.06-0.32
21	0.10-0.48	0.08-0.45	0.07-0.53	0.07-0.39
22	0.12-0.57	0.09-0.53	0.09-0.63	0.08-0.47
Model 3				
15	0.05-0.07	0.05-0.07	0.05-0.07	0.05-0.06
16	0.07-0.10	0.07-0.10	0.07-0.09	0.06-0.09
17	0.09-0.13	0.09-0.13	0.09-0.12	0.08-0.12
18	0.12-0.17	0.11-0.17	0.11-0.16	0.10-0.16
19	0.15-0.23	0.14-0.22	0.13-0.22	0.13-0.21
20	0.18-0.30	0.17-0.29	0.16-0.28	0.15-0.27
21	0.22-0.38	0.20-0.36	0.20-0.36	0.18-0.34
22	0.26-0.47	0.24-0.44	0.24-0.44	0.22-0.42

Supp. Table 2 continued.

Model 4																
Temp. (°C)	**yes/yes**				**no/yes**				**yes/no**				**no/no**			
-	1SW/fly	MSW /fly	1SW/ lure	MSW/ lure	1SW/fly	MSW/ fly	1SW /lure	MSW/ lure	1SW/fly	MSW/fly	1SW /lure	MSW/ lure	1SW/fly	MSW/fly	1SW /lure	MSW/ lure
15	0.08-0.16	0.05-0.12	0.09-0.21	0.06-0.16	0.08-0.15	0.05-0.12	0.09-0.21	0.06-0.16	0.08-0.16	0.04-0.11	0.09-0.21	0.05-0.14	0.07-0.15	0.04-0.11	0.08-0.20	0.05-0.14
16	0.11-0.19	0.06-0.15	0.12-0.26	0.07-0.20	0.10-0.18	0.10-0.18	0.11-0.25	0.07-0.20	0.10-0.19	0.05-0.13	0.11-0.26	0.06-0.18	0.10-0.18	0.05-0.13	0.11-0.25	0.06-0.18
17	0.14-0.24	0.08-0.19	0.15-0.31	0.09-0.25	0.13-0.22	0.13-0.22	0.14-0.30	0.09-0.25	0.14-0.24	0.07-0.17	0.15-0.32	0.08-0.23	0.13-0.22	0.07-0.17	0.14-0.30	0.07-0.23
18	0.17-0.29	0.10-0.24	0.18-0.38	0.11-0.32	0.16-0.27	0.16-0.27	0.17-0.36	0.11-0.31	0.17-0.29	0.09-0.22	0.18-0.38	0.09-0.29	0.16-0.28	0.08-0.22	0.17-0.37	0.09-0.29
19	0.21-0.35	0.12-0.30	0.22-0.45	0.14-0.38	0.19-0.33	0.19-0.33	0.21-0.43	0.13-0.38	0.21-0.36	0.11-0.28	0.22-0.46	0.12-0.36	0.20-0.34	0.10-0.27	0.21-0.44	0.12-0.36
20	0.25-0.42	0.15-0.37	0.26-0.52	0.16-0.46	0.23-0.40	0.23-0.40	0.24-0.50	0.16-0.45	0.26-0.43	0.13-0.35	0.27-0.54	0.15-0.44	0.24-0.41	0.13-0.34	0.25-0.52	0.14-0.43
21	0.29-0.50	0.18-0.44	0.31-0.60	0.20-0.54	0..27-0.47	0.27-0.47	0.28-0.58	0.19-0.53	0.30-0.52	0.16-0.43	0.32-0.62	0.18-0.52	0.28-0.49	0.15-0.42	0.30-0.60	0.17-0.51
22	0.34-0.58	0.21-0.52	0.36-0.67	0.23-0.62	0.31-0.55	0.31-0.55	0.33-0.65	0.22-0.61	0.35-0.60	0.20-0.52	0.37-0.69	0.21-0.61	0.33-0.58	0.19-0.50	0.30-0.67	0.20-0.60