An Annotated Bibliography of the Science on Catch and Release Angling of Salmonids

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Summary

Note: hyperlinks within this Summary connect to the annotated distillation of the individual paper. Hyperlinks in the title of the article connect to the publisher's website.

1. Catch-and-release angling is the voluntary and/or obligatory practice of releasing fish after capture (Ferguson and Tufts 1992; Pope et al. 2007; Roth et al. 2019).

2. Catch-and-release angling can result in exhaustive exercise and air exposure for fish, both of which can elicit a stress response, as illustrated by blood physiology (Barton et al. 1986; Ferguson and Tufts 1992; Gale et al. 2011), reflex impairment (Raby et al. 2013; Brownscombe et al. 2022), and loss of equilibrium (Gale et al. 2011; Brownscombe et al. 2022). Such responses may or may not be associated with greater and lasting consequences (e.g., see Cook et al. 2014 vs. Raby et al. 2013).

3. Estimates of post-release survival range from 20% to 100% (Booth et al. 1995; Schisler and Bergersen 1996; Pope et al. 2007; Boyd et al. 2010; Lindsay et al. 2014; Smukall et al. 2019). However, because survival estimates vary with temperature, species, method of investigation, and a myriad of other factors, results should be carefully considered within the specific context of each study before generalizations or comparisons are made across studies.

4. Research offers conflicting interpretations regarding the effects of catch and release on reproductive success in fish (as measured directly or via indicators)(Booth et al. 1995; Raby et al. 2013; Roth et al. 2019; Smukall et al. 2019; Bouchard et al. 2022). For example, whereas Bouchard et al. (2022) found that caught-and-released Atlantic Salmon produced 26% fewer progeny than their non-caught counterparts, Roth et al. (2019) found that Yellowstone Cutthroat Trout exposed to a simulated catch-and-release event produced comparable numbers of offspring as conspecifics in a control group.

5. Multiple lines of evidence suggest that risk of post-release mortality increases with water temperature (e.g., Schisler and Bergersen 1996; Wilkie et al. 1997; Anderson et al. 1998; Boyd et al. 2010; Van Leeuwen et al. 2020; Meyer et al. 2022).

6. Findings to date are inconsistent with respect to effects of water temperature on fish catchability. Anglers in eastern Canada and eastern Idaho caught progressively fewer Atlantic Salmon and Cutthroat Trout, respectively, as water temperature increased (Van Leeuwen et al. 2020; Meyer et al. 2022). Conversely, anglers at one Montana study site caught greater numbers of trout during a hot temperature regime (maximum daily temperature ≥ 23°C) than during a warm temperature regime (maximum daily temperature = 20.0-22.9°C), and catch rates were comparable between the two regimes (Boyd 2008; Boyd et al. 2010).

7. Although some have posited that an inverse relationship between stream temperature and fish catchability serves as a self-regulating mechanism on angler impacts, few studies have accounted for temperature effects on both fish catchability and post-release mortality. Myer et al. (2022) concluded that water temperature had a negative effect on both catchability and

post-release survival of Cutthroat Trout, suggesting lower survival is offset by lower catchability at higher temperatures. Van Leeuwen et al. (2020) observed similar effects of water temperature on Atlantic Salmon but concluded that reduced catchability only partially mitigated increased risk of post-release mortality.

8. Observations of angler practices suggest that, on average, fish are exposed to air for < 30 seconds during the course of catch and release event (Boyd et al. 2010; Lamansky and Meyer 2016; Chiramonte et al. 2018; Whitney et al. 2019).

9. Findings are inconsistent with respect to how commonly-observed durations of air exposure affect fish. Whereas Richard et al. (2013) concluded that as little as 10 seconds of air exposure could reduce reproductive success in Atlantic Salmon (temperature < 17°C), a number of authors failed to detect effects in salmonids exposed to air for as much as 60 seconds (e.g., Roth et al. 2018; McCarrick et al. 2019; Roth et al. 2019). Cook et al. (2015) noted that the effect of air exposure on fish can be influenced by a number of other factors (e.g., water temperature, body size).

10. Although fight (hook set to landing) time is often referenced or recorded during the course of a catch and release study, formal examinations of its effects have been rare if not somewhat contradictory. Schisler and Bergerson (1996) found that the best supported model for predicting post-release mortality of Rainbow Trout included fight time as a predictor. Whitney et al. (2019) included fight time as a predictor of reproductive success among steelhead and found no evidence of its significance.

11. Several lines of evidence suggest that stressors associated with catch-and-release, such as exhaustive exercise and air exposure, can have additive or cumulative effects (Barton et al. 1986; Ferguson and Tufts 1992; Schisler and Bergerson 1996; Gale et al. 2011; but see Roth et al. 2018; McCarrick et al. 2019). Ferguson and Tufts (1992) found, for example, that fish both exercised and exposed to air exhibited greater signs of stress than fish that were only exercised, and Barton et al. (1986) found that the stress response among juvenile Chinook Salmon increased cumulatively with each of three 30-second rounds of air exposure, despite a 3-hour break between each round of exposure. Because researchers typically have neither knowledge of nor control over the capture of study fish prior to or during their investigation, at least in the context of real angling events (but see Smukall et al. 2019), effects of multiple captures remain unclear.

Editor’s Note

The following pages include an annotated bibliography of 26 sources on Catch-and-Release Angling. Papers included herein were selected to represent a variety of species, topics, and study designs from across a span of years and authors. Because the peer review process sets a standard for, and improves the quality of, scientific communication, only articles from peer-reviewed journals are included (one thesis was cross-referenced with the subsequent peer-reviewed paper). To avoid biasing author’s interpretations, author’s conclusions were taken at face value. As noted above, individual summaries can be accessed by following the hyperlink within the above summary and/or by navigating through the alphabetical list of references below. The hyperlink in the title of each paper will connect to the publisher’s website.

Conversion factors

°C	°F
0	32
5	41
10	50
15	59
20	68
25	77
30	86

1 inch = 2.54 cm = 25.4 mm

1 mile = 1.61 km

References

Anderson, W.G., R. Booth, T. A. Beddow, R. S. McKinley, B/ Finstad, F. Økland, and D. Scruton. 1998. Remote monitoring of heart rate as a measure of recovery in angled Atlantic Salmon, *Salmo salar* (L.). Hydrobiologia 371:233-240.

Anderson et al. (1998) surgically implanted pulse-monitoring radio tags into wild and hatchery-reared Atlantic Salmon before catching the fish in three staged angling events (one event each at 8.0, 16.5, and 20.0°C). During each event fish were manually hooked, released into a pool (or tank), and then angled to exhaustion. Mean angling or fight times were 8.1, 5.1, and 11.8 minutes for salmon in the 8.0, 16.5, and 20.0°C temperature treatments, respectively. Following capture, fish were re-released into the pool (tank) and their heart rate monitored via telemetry for 3-16 hours post angling. Whereas 6 of 6 hatchery-bred Atlantic Salmon survived angling at the 8.0° treatment and 5 of 5 wild salmon survived at the 16.5°C treatment, 1 of 5 wild salmon survived angling at the 20.0°C treatment. Heart rate data revealed that time to recovery among surviving salmon from the 8.0°C and 16.5°C treatment groups was approximately 16 hours.

Barton, B. A., C. B. Schreck, and L. A. Sigismondi. 1986. Multiple Acute Disturbances Evoke Cumulative Physiological Stress Responses in Juvenile Chinook Salmon. Transactions of the American Fisheries Society 115(2):245-251.

Although Barton and others (1986) were not necessarily investigating catch and release angling in particular, the methods and findings of their lab-based investigation offered some insight into the matter. To test for a cumulative stress response, the authors subjected juvenile Chinook Salmon from three different Oregon stocks to one of three stress treatments consisting of one, two, or three 30-second rounds of air exposure (water temperature = 12 ± 1°C). In the case of the latter two groups, each stress or air exposure event was separated by 3 hours. Control groups of unstressed fish were also maintained for point of comparison. Blood samples were collected from each fish immediately prior to a stress event and over a course of hours following the final event (control fish were generally sampled at the same times). Blood cortisol and glucose levels were higher among treatment groups than among control groups and increased cumulatively with each subsequent air exposure event (increases in plasma cortisol and plasma glucose indicate stress). Moreover, juvenile Chinook Salmon displayed stepwise increases in stress with each round of air exposure.

Booth, R. K., J. D. Keiffer, K. Davidson, A. T. Bielak, and B. L. Tufts. 1995. Effects of late-season catch and release angling on anaerobic metabolism, acid-base status, survival, and gamete viability in wild Atlantic salmon (*Salmo sal*ar). Canadian Journal of Fisheries and Aquatic Sciences 52:283-290.

Booth et al. (1995) obtained wild Atlantic Salmon from the Miramichi River in New Brunswick (Canada) during the fall spawning run and conducted a number of experiments to simulate and evaluate the effects of catch-and-release angling on physiology, survival, and gamete production. All wild fish were transported to a holding pool before being assigned to a control or treatment (angled) group, and all angling events were completed according to the same fight-to-exhaustion methodology (water temperature 6 ± 1°C). In the end, 20 of 20 angled salmon survived and egg survival was comparable between treatment (angled) and control groups.

Bouchard, R., K., Wellband, L. Lecomte, L. Benatchez, and J. April. 2022. Effect of catch-and-release and temperature at release on reproductive success of Atlantic salmon (*Salmo salar* L.) in the Rimouski River, Québec, Canada. Fisheries Management and Ecology 29(6):888-896.

Bouchard et al. (2022) used molecular parentage analysis to evaluate whether catch and release, air exposure time, and/or water temperature at time of release affected the relative reproductive success of Atlantic Salmon. The Rimouski River in Québec (Canada) offered a favorable setting for the study because adult Atlantic Salmon cannot reach spawning grounds above the dam at river kilometer 4 without being trapped below and transported above the dam. In 2018, anglers fishing below the dam were enlisted to take notes about each catch and release event and collect a small tissue sample (fin punch) from each salmon captured and released. Anglers recorded date, time, capture location, and duration of air exposure for each event. Date, time, and location were later used to determine water temperature from data loggers in the river. In 2019, young-of-year Atlantic Salmon (fry) were captured between the dam and an impassable waterfall upstream; a small tissue sample was collected from each fry. Molecular methods were then used to assign fry to parents. Finally, statistical methods were used to evaluate 1) if reproductive success (number of offspring) differed between caught-and-released and uncaught salmon and 2) if water temperature, air exposure, or body length at time of capture influenced reproductive success. Overall, caught-and-released Atlantic Salmon produced approximately 26% fewer offspring than non-caught Atlantic Salmon. Reproductive success of caught-and-released salmon was unaffected by water temperature (range ≈ 13.5-24.5°C), air exposure, and body length. However, water temperature at time of catch and release had a significant effect on whether or not salmon were transported upstream of the dam: as a group, fish that failed to enter the trap were caught and released at warmer temperatures than fish that reached and entered the trap. The authors suggested that their findings can help inform the tradeoffs of catch-and-release angling.

Boyd, J. W., C. S. Guy, T. B. Horton, and S. A. Leathe. 2010. Effects of Catch-and-Release Angling on Salmonids at Elevated Water Temperatures. North American Journal of Fisheries Management 30(4):898-907.

Boyd, J. W. 2008. Effects of water temperature and angling on mortality of salmonids in Montana streams. Master's thesis. Montana State University, Bozeman, Montana.

In contrast with studies that simulated catch-and-release events in a laboratory (e.g., by manually placing a hook in a fish's mouth), the study by Boyd et al. (2010) was based around real captures by volunteer anglers. In brief, Boyd et al. (2010) enlisted anglers to fish for salmonids on the Gallatin and Smith rivers (Montana) during three different naturally-occurring temperature regimes: maximum daily temperature < 20°C (cool), 20.0-22.9°C (warm), and ≥ 23.0°C (hot).

Each day was divided into a morning session (centered around the lowest daily temperature) and evening session (centered around the highest daily temperature). Following a catch, fish were "released" back into in-situ cages and monitored for survival over the next 72 hours. Both fight time (hook set to landing) and air exposure time were recorded. Post-catch survival did not differ between session of capture (i.e., morning vs. evening) but for the case of Rainbow Trout in the Smith River, where morning-caught fish exhibited greater survivorship than evening-caught fish. Survival differed significantly with temperature regime at capture among all species in the Smith River and among Rainbow Trout in the Gallatin River (see Table). Multiple regression models yielded inconsistent interpretations with respect to the relative importance of fight time (mean = 58 s), air exposure time (mean = 12 s), and maximum daily temperature on post-catch mortality of fishes.

Table production using data from Boyd et al. (2010) and Boyd (2008). Comparison of post-catch salmonid survival rates among thermal regime at capture. Superscript letters (e.g., ^{a}) denote statistically significant differences or lack thereof at $\alpha = 0.10$ (same letter = no difference).

Species	Percent post-catch survival (n)		
		Gallatin River	
	Cool	Warm	Hot
Rainbow Trout	100^{a} (48)	91^{b} (35)	84^{b} (25)
Brown Trout	100^{a} (142)	99^{a} (109)	98^{a} (52)
Mountain Whitefish	100^{a} (45)	97^{a} (36)	97^{a} (29)
		Smith River	
Rainbow Trout	100^{a} (57)	92^{b} (53)	91^{b} (161)
Brown Trout	100^{a} (78)	100^{a} (37)	96^{b} (101)
Mountain Whitefish	100^{a} (131)	80^{b} (5)	72^{c} (64)

<u>Brownscombe, J. W., T. D. Ward, L. Nowell, R. J. Lennox, J. M. Chapman, A. J. Danylchuk, and S. J. Cooke. 2022. Identifying thresholds in air exposure, water temperature and fish size that determine reflex impairment in brook trout exposed to catch-and-release angling. Conservation Physiology 10(1): coac070.</u>

To inform development of catch-and-release angling practices, Brownscombe et al. (2022) conducted experiments wherein they evaluated effects of air exposure, water temperature, and fish size on reflex impairment in, and mortality of, Brook Trout (n = 337). Both of two experiments were conducted on hatchery-origin Brook Trout occupying four natural lakes in Quebec, Canada. During the first experiment, 141 fish were captured by rod and reel, randomly assigned to one of five air exposure treatments (0, 10, 30, 60, or 90 seconds), and then evaluated for reflex impairment before being measured, tagged, and released into an in-situ pen for monitoring. Water temperature (range = 12.0-23.3°C) was measured at each sampling event, and fight and handling time were recorded but ultimately ignored for lack of difference. In a second experiment, 196 previously captured (i.e., already captive) Brook Trout were subjected to a 20-second swimming challenge, exposed to one of the five air exposure treatments, and then evaluated for reflex impairment before being released back into a lake. Results revealed that greater levels of reflex impairment were associated with warm (> 19.5°C) water temperatures and relatively long (≥ 60 second) air exposure times; large (> 328 mm) Brook Trout experienced loss of equilibrium with ≥ 30 seconds of air exposure. Loss of equilibrium and time to regain equilibrium were, in turn, strongly and moderately related to mortality of Brook Trout (6% overall). The authors concluded that their methods could be replicated to identify thresholds and guidelines for other catch-and-release fisheries.

Chiramonte, L. V., K. A. Meyer, D. W. Whitney, and J. L. McCormick. 2018. Air Exposure, Fight Times, and Deep-Hooking Rates of Steelhead Caught in Idaho Fisheries. North American Journal of Fisheries Management 38(5):1114-1121.

Chiramonte et al. (2018) studied the catch-and-release behavior of anglers participating in a popular steelhead fishery in Idaho. The research team examined how gear type (fly or non-fly), picture taking, landing method, and deep hooking influenced fight time and air exposure time. From September of 2016 to April of 2017 the team observed the catch of 432 steelhead and the release of 293 steelhead. Fight time varied from 5 to 900 seconds (mean = 130 s, n = 395) and was significantly (1.54X) longer among fly than non-fly anglers. Air exposure time for any one exposure ranged from 0 to 185 seconds (mean = 28 s, n = 251) and was significantly (1.69X) longer among anglers photographing their catch than those skipping the photo. Approximately 17% of anglers exposed fish to air more than once, and fly anglers were more likely to photograph their catch than non-fly anglers. Compared to anglers who were overtly observed, those who were covertly observed exhibited 39% shorter fight times and 57% longer air exposure times; the majority of observations during the study were overt. Deep hooking rates were less than 1% for bait, lure, and fly fisherman. The authors concluded that the observed fight times, air exposure times, and deep hooking rates are unlikely to have a detectable effect on steelhead fisheries in Idaho.

Cook, K. V., G. T. Crossin, D. A. Patterson, S. G. Hinch, K. M. Gilmour, and S. J. Cooke. 2014. The stress response predicts migration failure but not migration rate in a semelparous fish. General and Comparative Endocrinology 202:44-49.

Cook et al. (2014) intercepted 54 Sockeye Salmon in route to spawning grounds in the Fraser River (British Columbia, Canada), exposed them to a stressor (2 minutes of air exposure), and then evaluated the effects of the stress response on migration rate and success. First, all of the salmon were captured at a fish wheel on the Fraser River and immediately sampled for a baseline blood cortisol concentration. Next, fish were exposed to air for 2 minutes and then held in the river in a sensory deprivation bag. At the end of a 25-minute holding period, a second stress-induced blood cortisol sample was collected and each fish implanted with a gastric radio transmitter prior to release. Finally, fish movements were monitored based on detection, or lack thereof, at a number of stationary receivers located along the 150 river km between point of release and ultimate destination. Of the 54 fish fitted with radio transmitters, 10 failed and 15 succeeded in reaching the spawning grounds (the other 29 fish were excluded from analyses for various reasons). Whereas the difference between pre- and post-stress cortisol concentrations failed to predict swim speed, the stress response was a significant predictor of migratory success.

Specifically, the probability of a successful migration decreased as the stress response increased. Conversely, baseline cortisol levels were neither a predictor of swim speed nor a predictor migratory success. Cook et al. (2015) were among the first to evaluate effects of catch-and-release on survival of a semelparous (obligatory single-spawn) species.

Cook, K. V., R. J. Lennox, S. G. Hinch, and S. J. Cooke. 2015. FISH Out of WATER: How Much Air is Too Much? Fisheries 40(9):452.461.

In a review-style paper, Cook et al. (2015) synthesized findings and issued recommendations regarding effects of air exposure on fish. The authors noted that the methods employed during a study can influence interpretation of results from that study. Moreover, results from a lab-based experiment on air exposure may or may not translate to a "real world" scenario. The authors further noted that findings around effects of air exposure on fish can be influenced by a suite of other factors or covariates, including temperature, species, and size and state of maturity. Cook et al. (2015) recommended that, in light of literature available in 2015, fish not be exposed to air for more than a cumulative 10 seconds. They also recommended that further research be conducted so as to inform species-specific regulations around exposure of fish to air.

Ferguson, R. A., and B. L. Tufts. 1992. Physiological Effects of Brief Air Exposure in Exhaustively Exercised Rainbow Trout (*Oncorhynchus mykiss*): Implications for "Catch and Release" Fisheries. Canadian Journal of Fisheries and Aquatic Sciences 49(6):1157-1162.

To explore the implications of catch and release policies, Ferguson et al. (1992) tested for the effects of air exposure on the physiology of exhaustively-exercised Rainbow Trout. Experiments were conducted at 15°C. Compared to fish that had been only exercised (n = 8), fish that were both exercised and exposed to air for 60 seconds (n = 7) exhibited certain signs of elevated stress. For example, four hours post experiment, trout from the exercise + air exposure group had higher levels of blood lactate, than trout from the exercise group. Survival 12 hours post experiment varied from 100% in control fish to 88% and 28% in fish exercised and both exercised and exposed to air for 60 seconds, respectively. The authors concluded that exposing angled fish to air prior to release increases stress and potentially influences survival post release. The authors cautioned, however, that their experiment was not designed to evaluate post-release survival.

Gale, M. K., S. G. Hinch, E. J. Eliason, S. J. Cooke, and D. A. Patterson. 2011. Physiological impairment of adult sockeye salmon in fresh water after simulated capture-and-release across a range of temperatures. Fisheries Research 112(1-2):85-95.

Gale et al. (2011) intercepted 101 wild Sockeye Salmon during the summer run on the Fraser River (British Columbia, Canada) and transported the fish to a nearby laboratory. Salmon were allocated to one of nine tanks, each one representing a different combination of water temperature (13, 19, and 21 °C, ± 0.2°C) and capture (none, capture, and capture + air exposure) treatment. Capture was simulated by three minutes of manual chasing and air exposure by suspending a fish out of water for 60 seconds immediately following capture. Blood samples were collected from all fish immediately, 30 minutes, and 72 hours post “trial”. Compared to salmon that were only handled (no capture stress), salmon that were “captured” exhibited a number of physiological indicators of stress (e.g., elevated plasma lactate, chloride, sodium, and osmolality). Air exposure following capture further increased blood lactate levels (indicative of anerobic metabolism) and blood glucose levels (indicative of stress; females only). Whereas 100% of captured and air-exposed fish failed to maintain equilibrium at the 19°C and 21°C treatments, 42% of captured and air-exposed fish failed to maintain equilibrium at the 13°C treatment. Similarly, time to regain equilibrium was longer in the 19° and 21° groups than in the 13° group. Short-term mortality was comparable among capture treatments at all temperatures. The authors concluded that their findings had important implications for catch-and-release of migratory fish, particularly Sockeye Salmon. They noted, for example, that exhaustive exercise during capture could cause physiological stress and that air exposure during release could further exacerbate the situation. Gale et al. (2011) offered that, if catch and release is intended to conserve fishes, managers might consider increased risk of post-release mortality.

Lamansky, J. A., and K. A. Meyer. 2016. Air Exposure Time of Trout Released by Anglers during Catch and Release. North American Journal of Fisheries Management 36(5):1018-1023.

Lamansky and Meyer (2016) covertly observed 280 catch-and-release trout anglers at two streams and three lakes in Idaho and Oregon. The authors recorded fight times and air exposure times and evaluated the latter as a function of gear (fly, lure, bait), handling method (hand or net), access (from the bank or from a boat) and fish size (small, medium, large). Fight times varied from 7 to 128 seconds (mean = 53.0 seconds), continuous air exposure times from 0 to 160 seconds (mean = 26.1 seconds), and total air exposure times from 0 to 165 seconds (mean = 29.4 seconds). Approximately 22% of anglers exposed a fish to air more than once and 4% exposed a fish to air for more than a continuous 60 seconds. Anglers using flies and handling fish by hand exposed trout to air for shorter durations than anglers using lures or bait and handling fish by net. Air exposure time was comparable between wade and boat anglers and generally protracted by 18-20 seconds when pictures were taken. Large trout (estimated length > 45 cm) were exposed to air for greater durations than small or medium-sized trout (estimated length ≤ 45 cm). The authors concluded that few of the trout in their study were exposed to air for a period sufficient to cause lethal or sub-lethal effects.

Lindsay, R. B., R. K. Schroeder, K. R. Kenaston, R. N. Toman, and M. A. Buckman. 2004. Hooking Mortality by Anatomical Location and Its Use in Estimating Mortality of Spring Chinook Salmon Caught and Released in a River Sport Fishery. North American Journal of Fisheries Management 24(2):367-378.

Using the Willamette River in Oregon as their test case, Lindsay et al. (2004) completed a two-part study on catch-and-release mortality rates among Chinook salmon (range in water temperature = 9-18°C). During the first part of the study, the research team captured 869 salmon via hook and line, tagged the fish with a unique identifier, and then released them back into the river. Gear type, hook location, and a number of other factors were recoded. For point of comparison, another 825 salmon were trapped, tagged, and released at a nearby fishway. From subsequent recaptures, primarily at hatchery facilities, the authors were able to estimate relative rates of survival between control and treatment groups. During the second part of the study, the research team coupled their survival data with creel survey data on hook location and wild Chinook encounter rates to estimate hooking mortality rates. All factors considered, Lindsay et al. (2004) estimated that 12.2% of the wild Chinook Salmon caught and released in the lower Willamette River failed to survive the experience, and that this mortality rate extrapolated out to a 3.2% reduction in the total run of wild Chinook salmon.

McCarrick, D. K., C. J. Roth, D. J. Schill, B. High, and M. C. Quist. 2019. Effects of Air Exposure on Survival of Yellowstone Cutthroat Trout Angled from a Stream with Warm Water Temperatures. Journal of Fish and Wildlife Management 10(2):509-516.

McCarrick et al. (2019) used a mark-recapture study to evaluate effects of air exposure on the short-term survival of Yellowstone Cutthroat Trout (YCT) in a relatively warm Idaho stream. In August of 2018, 161 YCT were captured via hook and line (mean fight time = 11.3-12.2 s), tagged, and assigned to one of three air exposure treatments: 0 seconds, 30 seconds, or 60 seconds. Following the prescribed air treatment, angled fish were released back into the 2.3-km study reach from which they had been caught. Water temperature ranged from 10.0 to 19.7°C (mean = 14.9°C) during the study period. Ten days after the last fish was caught and released, the research team used backpack electrofishing units to recapture YCT within the study reach. Relative survival, as inferred from recapture rates of tagged fish, was comparable among treatment groups. The authors concluded that YCT fisheries are unlikely to be affected by exposure of fish to ≤ 60 seconds of air, but that additional research is warranted.

Meka, J. M., and F. J. Margraf. 2007. Using a bioenergetic model to assess growth reduction from catch-and-release fishing and hooking injury in rainbow trout, *Oncorhynchus mykiss*. Fisheries Management and Ecology 14:131-139.

Meka and Margraf (2007) used a bioenergetics model to explore how a hooking injury that results in reduced foraging efficiency or a break in feeding might influence growth (Δ weight) of Rainbow Trout. Specifically, the authors used an existing model (Hanson et al. 1997) but parameterized the model to account for, among other factors, temperature regime, diet composition, and caloric density of prey items in the Alagnak River in Alaska. Results of the first simulation suggested that, depending upon timing, a one-day break in feeding could result in a 3-13% reduction in growth and two one-day breaks in feeding could result in an 11-15% reduction in growth. Results of the second simulation suggested that, depending on timing, 5% and 50% reductions in foraging efficiency could reduce growth by 9-20% and 83-164%, respectively. Although the results of Meka and Margraf (2007) were founded on model predictions with respect to a specific river and species, they elucidated a potential growth-related penalty of catch-and-release fishing.

Meyer, K. A., J. L. McCormick, J. R. Kozfkay, and J. C. Dillon. 2022. Effects of elevated water temperature on cutthroat trout angler catch rates and catch-and-release mortality in Idaho streams. Fisheries Management and Ecology 30(2):134-141.

Meyer et al. (2022) tested for effects of water temperature on catchability and post-release mortality of Cutthroat Trout. All Cutthroat Trout (n = 100) were captured during July-August of 2020 by one of four fly anglers at one of four streams in Eastern Idaho. Once landed, a fish was measured underwater and marked with an anchor tag and adipose fin clip; water temperature at capture was also recorded (range = 13.5-25.7°C). Fish were then released back into the reach of origin. Several weeks later, backpack electrofishers were used to capture fish throughout each of the study reaches. The authors used a mixed effects logistic regression model to test for a temperature effect on post-release relative survival (as determined by presence or absence during the electrofishing survey), and a mixed effects generalized linear model to test for a temperature effect on catch rate or catchability (fish/hour). A number of covariates were also considered during the model fitting and selection processes (e.g., total length, angler). Meyer et al. (2022) concluded that stream temperature at time of capture had a significant negative effect on both relative survival and catchability of Cutthroat Trout. The authors also noted that fishing restrictions might be no more helpful at relatively warm water temperatures than at relatively cool water temperatures.

Pope, K. L., G. R. Wilde, and D. W. Knabe. 2007. Effect of catch-and-release angling on growth and survival of rainbow trout, *Oncorhynchus mykiss*. Fisheries Management and Ecology 14(2):115-121.

Pope et al. (2007) used a lab-based experiment to simulate and then evaluate the effects of catch-and-release angling on Rainbow Trout. In brief, hatchery-bred trout were randomly assigned to one of four aquaria: one aquarium with a control group (no handling or hooking) and three aquaria representing three different treatment groups (one, two, and four handling events). All aquaria were maintained at 15-16°C. Each treatment group was further divided into subsets of fish that were either hooked and played on a fishing rod (0 – 295 s) or simply handled (9 to 128 s) and then returned to the aquarium. Neither change in length nor change in weight differed with treatment (control vs. hooked) or number of times handled. Approximately 97% of Rainbow Trout hooked in the mouth survived and 100% of the fish in the control group survived. The authors concluded that catch-and-release angling appeared to have little effect on growth and survival.

Raby, G. D., S. J. Cooke, K. V. Cook, S. H. McConnachie, M. R. Donaldson, S. G. Hinch, C. K. Whitney, S. M. Drenner, D. A. Patterson, T. D. Clark, and A. P. Farrell. 2013. Resilience of Pink Salmon and Chum Salmon to Simulated Fisheries Capture Stress Incurred upon Arrival at Spawning Grounds. Transactions of the American Fisheries Society 142(2):524-539.

To explore the effects of catch and release on pre-spawn survival and egg retention in salmon, Raby et al. (2013) exposed pre-spawn Pink Salmon and Chum Salmon to different combinations of exhaustive exercise, air exposure, and injury. A total of 294 salmon were netted from an artificial spawning channel in the Fraser River system in British Columbia (Canada; mean water temperature = 11.8-13.2°C) and randomly assigned to one of the six different experimental treatments that varied with respect to stress (from none to 180 seconds) and air exposure (from 0 to 60 seconds). Following treatment, fish were tagged, examined for injury, and measured. A blood sample was collected from each fish and the condition of each fish evaluated based on a series of brief reflex tests. Fish were then released back into the spawning channel and the channel monitored twice daily for mortalities. For each tagged fish, two additional metrics were calculated: longevity (days survived post catch and release) and egg retention (number of eggs remaining relative to expected total number of eggs). Salmon exposed to 3 minutes of stress and 1 min of air exhibited greater signs of reflex impairment than salmon exposed to ≤ 10 s of stress and 0 s of air. Although increased stress and air exposure were linked to some signs of physiological disturbance (e.g., elevated plasma lactate), the authors did not observe a treatment effect across all blood tests. Neither longevity of female salmon nor egg retention among female salmon differed among the six treatment groups. Moreover, 92% of Pink Salmon and 96% of Chum Salmon spawned successfully following treatment and irrespective of treatment. The authors concluded that Pink and Chum salmon might be resilient to the stress of catch and release because of low water temperatures and a shift from aerobic to anaerobic pathways. The authors noted that post-release survival rates should be interpreted with caution, pending further research in real fisheries and natural systems.

Richard, A., M. Dionne, J. Wang, and L. Bernatchez. 2013. Does catch and release affect the mating system and individual reproductive success of wild Atlantic salmon (*Salmo salar* L.)? Molecular Ecology 22:187-200.

Richard et al. (2013) used the Atlantic Salmon population from the Escoumins River in Québec (Canada) to evaluate the effects of catch and release angling on reproductive success. During the first year of their study, genetic samples were collected from all Atlantic Salmon returning to the Escoumins River via a fishway near the river's mouth (n = 268). Meanwhile, anglers were asked to collect genetic samples and basic information at each catch and release of an Atlantic Salmon in the river (n = 42). Specifically, anglers were asked to record the date, time, hook type, hooking location, fight time, air exposure time, severity of bleeding, and condition of fish upon release. Date and time were used to extract water temperature from data loggers in the river (mean = 16.0°C; range = 10.5-19.1°C). During the second year of the study, Atlantic Salmon fry were captured by electrofishing and assigned to year-one parents via genetic parentage analysis (n = 2,548). Regression modeling and multi-model inference were then used to evaluate relationships and effects of different variables. One of the findings was that, among caught-and-released salmon, the number of fry decreased with parent length, whereas the opposite was true of uncaught fish. The authors interpreted this to suggest that catch and release angling might have a greater effect on relatively large fish. Another finding was that air exposure decreased reproductive success when water temperature was < 17°C but increased reproductive success when water temperature was > 17°C. For example, relative to fish that had been exposed to air for ≤ 10 seconds, fish exposed to air for > 10 seconds were estimated to produce fewer offspring at low (< 17°C) temperatures and more offspring at high (> 17°C) temperatures; the authors expected the former but were surprised by the latter.

Roth, C. J., D. J. Schill, M. C. Quist, and B. High. 2018. Effects of Air Exposure in Summer on the Survival of Caught-and-Released Salmonids. North American Journal of Fisheries Management 38(4):886-895.

To test for effects of air exposure on fish during catch-and-release events, Roth et al. (2018) enlisted anglers to systematically expose wild, angler-caught Bull Trout (n = 278), Rainbow Trout (n = 322), and Yellowstone Cutthroat Trout (n = 328) to one of three air exposure treatments. All of the trout were caught at one of three Idaho streams using hook and line and an artificial fly or lure; water temperature at time of capture ranged from 8.7 to 13.8°C (means = 10.8-11.6°C). Fight time, tackle type, and hooking location were recorded. Once landed, fish were held under water, measured, marked with a T-bar anchor tag (and secondary clip), and randomly assigned and subjected to 0, 30 or 60 seconds of air exposure. Fish were then released back into the specific reach from which they came. Two weeks later backpack electrofishers were used to capture fish from throughout the three study reaches and recapture rates compared to infer relative rates of survival. Overall, recapture rates were comparable among air exposure treatments. Fight times (means = 14.6 -16. 9 s) and fish lengths (means = 192-241 mm) were comparable among treatments groups and recaptures. Roth et al. (2018) concluded, in light of their findings and those from other field studies, that ≤ 60 seconds of air exposure is unlikely to have a population-level effect in catch-and-release fisheries for Bull, Rainbow, and Yellowstone Cutthroat trout.

Roth, C. J., D. J. Schill, M. C. Quist, B. High, M. R. Campbell, and N. V. Vu. 2019. Effects of Air Exposure During Simulated Catch-and-Release Angling on Survival and Fitness of Yellowstone Cutthroat Trout. North American Journal of Fisheries Management 39(1):191-204.

During a two-year study in Idaho, Roth et al. (2019) tested for effects of angling and air exposure on survival and fitness of Yellowstone Cutthroat Trout (YCT). In total, 2,200-2,300 adult YCT were intercepted during spawning runs, PIT tagged, manually hooked, and then randomly assigned to one of three treatment groups. Fish in the first group were played on a fishing rod for 102 seconds and then returned to the river, whereas fish from the second and third groups were played for 102 seconds and then exposed to air for 30 or 60 seconds, respectively, before being returned to the river. During the second year of the study a control group was included; these YCT were neither played nor exposed to air. Water temperature ranged from 5.7°C to 16.8°C during the sampling periods (mean = 10.4-11.8°C). Short- and long-term survival were evaluated based on adult recaptures at the weir immediately and one year after initial capture. Fitness was evaluated based on numbers of progeny, as informed by captures of young-of-year YCT and parentage analysis. Relative rates of survival and fitness were compared among groups to test for angling and air exposure effects. In short, the authors found no evidence that capture or air exposure influenced survival and fitness of adult YCT. They subsequently concluded that exposing salmonids to air for < 60 seconds is unlikely to have negative, population-level effects.

Schisler, G. J., and E. P. Bergersen. 1996. Postrelease Hooking Mortality of Rainbow Trout Caught on Scented Artificial Baits. North American Journal of Fisheries Management 16(3):570-578.

Schisler and Bergersen (1996) conducted five replicate experiments to evaluate how terminal tackle (fly, artificial bait fished passively, artificial bait fish actively) and a number of other factors—including water temperature, fight time, and air exposure—influenced survival of caught and released Rainbow Trout. To set the stage for summer-fall experiments in 1993 and spring-summer experiments in 1994, 2,100 hatchery-bred Rainbow Trout were tagged and stocked into a ¼-acre pond in Colorado. Trout were captured by anglers who agreed to rotate fishing methods and record details of each catch (e.g., tag number, hook location, bleeding intensity). The research team recorded fight time, air exposure time, and surface water temperature with each catch. After being captured, fish were relocated to a large net pen, where they were fed and monitored for survival over a three-week period. Probability of mortality varied with tackle and hooking location and generally increased with bleeding intensity, water temperature at capture, fight time, and air exposure time. Odds of post-release mortality decreased with length at capture. Average post-release mortality was 3.9, 32.1, and 21.6% for fish caught on fly, passively-fished artificial bait, and actively-fished artificial bait, respectively. Hooking location (critical vs. not critical) was the single most important predictor of mortality. Schisler and Bergersen (1996) fitted a logistic regression model that allows for exploration of *what-if* scenarios (see Figure below).

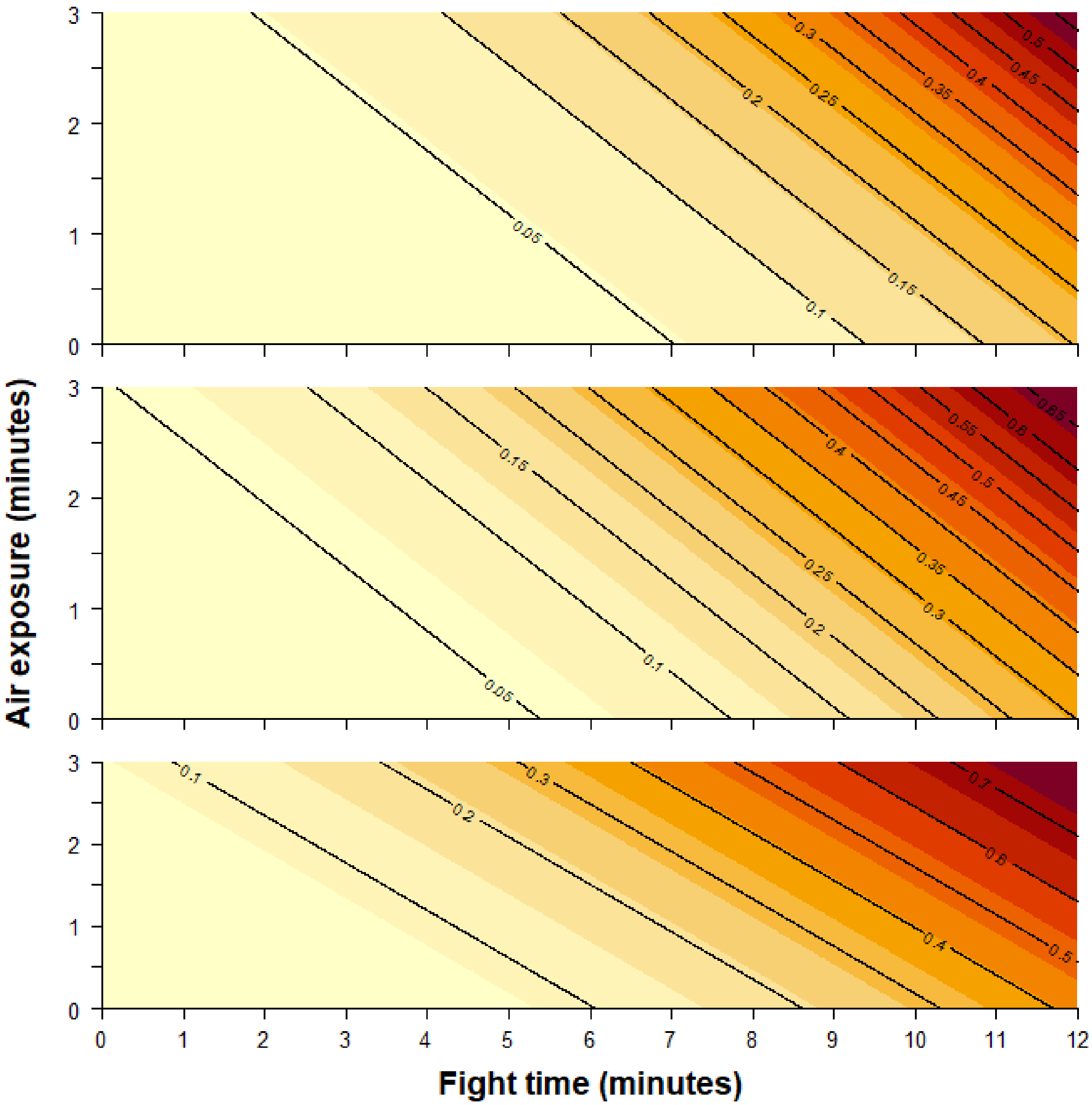

Figure production from Equation 3 in Schisler and Bergerson 1996. Probability of post catch-and-release mortality as a function of fight and air exposure time. All of the panels were constructed on assumptions that method of capture was fly, fish length 400 mm, hooking location superficial, and bleeding intensity *none.* Probabilities were estimated at assumed water temperatures of 10°C (top), 15°C (middle), and 20°C (bottom). Axes were selected to include plausible fight and air exposure times, as derived from other sources in this document (Anderson et al. 1998; Pope et al. 2007; Chiramonte et al. 2018; Whitney et al. 2019).

<u>Smukall, M. J., A. Shaw, and D. C. Behringer. 2019. Effect of simulated catch-and-release angling on postrelease mortality and egg viability in sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 76(12):2390-2395.</u>

Smukall et al. (2019) conducted a field experiment to evaluate effects of simulated catch and release angling on a Sockeye Salmon run in southeast Alaska. Because the watershed was closed to salmon fishing the authors were able to make a reasonable assumption that subjects had not been captured prior to the onset of their investigation. As Sockeye Salmon entered a weir in June, 405 of them were randomly assigned to one of three groups and handled accordingly. Fish from a control group were tagged and returned immediately to the stream. Fish from a "chased" group were, after being weighed and tagged and before being released back into the stream, transferred to a large tank and chased to exhaustion (or for three minutes). Fish from a "chased + air" group were subjected to the same treatment but were additionally removed from water for 60 seconds following the chase. All fish were monitored following release upstream of the weir. In July and August of the same year, salmon were collected from the spawning grounds, females stripped of eggs, and eggs labeled by source female. Eggs were subsequently fertilized and monitored for viability in a hatchery. Water temperature ranged from 11.1°C to 14.0°C during the study period (mean = 12.6 ± 0.8°C). Whereas egg viability did not differ among groups of Sockeye Salmon, post-release survival of adults differed among treatments, with 0, 1, and 4% mortality in control, chased, and chased + air groups.

<u>Van Leeuwen, T. E., B. Dempson, D. Cote, N. I. Kelly, and A. E. Bates. 2020. Catchability of Atlantic salmon at high water temperatures: Implications for river closure temperature threshold to catch and release angling. Fisheries Management and Ecology 28(2):147-157.</u>

Van Leeuwen et al. (2020) evaluated the effects of stream temperature on catchability of Atlantic Salmon in the Northwest River of Newfoundland (Canada). Stream temperature was measured twice each day (once in the morning, once in the afternoon) at a location near to, and deemed representative of, angling locations (mean = 19.5 ± 1.9°C; range = 12.6-25.8°C). Numbers of available salmon were derived from counts at a fish weir and numbers of angler-caught salmon from mandated reporting of captures upstream of the weir. A generalized additive mixed model was fitted to data from 2003-2011 and 2017-2018 to evaluate daily catch of Atlantic salmon as a function of mean daily stream temperature, counts of available salmon, and a number of other covariates. The authors then calculated for a given temperature the absolute probability of catch-and-release mortality: the product of probability of catch and probability of post-release mortality. They found that as water temperature increased, odds of catching an Atlantic Salmon decreased and odds of post-release mortality increased; the former only partially offset the latter. Moreover, as water temperature increased, the absolute probability of catch, release, and mortality increased.

Whitney, D. W., K. A. Meyer, J. L. McCormick, and B. J. Bowersox. 2019. Effects of Fishery-Related Fight Time and Air Exposure on Prespawn Survival and Reproductive Success of Adult Hatchery Steelhead. North American Journal of Fisheries Management 39(2):372-378.

Whitney et al. (2019) tested for effects of catch and air exposure on the pre-spawn survival and reproductive success of hatchery steelhead in Idaho. During three consecutive February-March timeframes, one group of hatchery steelhead was captured by anglers on the South Fork Clearwater River and then transported downstream to the hatchery on the Clearwater River, while another group of hatchery steelhead swam into the Clearwater facility by their own volition. Observers recorded both the fight (hook to landing) time and air exposure time for all angler-caught fish, and each angler-caught fish was marked such that these times could be followed with individuals (water temperature = 2.4-4.4°C). Both groups of fish were spawned at the hatchery, albeit separately, and eggs from each spawn cross and treatment group were individually identified. Mixed effects models were used to test for predictors of egg survival. At the end of the three-year study, pre-spawn survival was comparable between angler-caught and swim-in steelhead (97% vs 92%). The authors found little to no evidence that fight time (mean = 164 s; range = 2-668 s) or air exposure time (mean = 23s; range = 2-178 s) influenced survival among progeny of angler-caught steelhead (confidence intervals for odds ratios included 1).

Wilkie, M. P., M. A. Brobbel, K. Davidson, L. Forsyth, and B. L. Tufts. 1997. Influences of temperature upon the postexercise physiology of Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 54(3):503-511.

In a two-part experiment, Wilkie et al. (1997) examined the effects of exercise and water temperature on the physiology and survival of adult Atlantic Salmon. All salmon were held, acclimated, and subjected to one of two experiments at one of three temperatures (12, 18, or 23°C). During the first experiment, salmon were exercised to exhaustion (manually chased for 6 minutes) and their blood sampled for physiological attributes. During the second experiment, salmon were exercised to exhaustion (manually chased for 6 minutes) and monitored for post-exercise survival. Overall, salmon exercised at 12°C were slower to recover from the trial, as indicated by blood indices, than salmon exercised at 18°C or 23°C. However, whereas 100% of salmon from the 12°C and 18°C groups survived the exercise experiment, only 70% of salmon from the 23°C group survived. Accordingly, the authors concluded that, although warm water can facilitate recovery from exercise, extremely warm water can increase risk of delayed mortality following exercise.