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ARTICLE

Effects of Simulated Angler Capture and Live-Release Tournaments on Walleye Survival

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Abstract

We examined the effects of acclimation water temperature, live-well (LW) water temperature, and LW dissolved oxygen (DO) concentration on survival of adult Walleyes *Sander vitreus* subjected to simulated tournament conditions (angling, LW confinement, and weigh-in procedures) under controlled laboratory conditions. We tested three acclimation temperatures (12, 18, and 24°C), and three LW temperature differentials ($\Delta T = -4$, 0, and $+4$°C) were tested at each acclimation temperature. Survival was monitored after 8 h of LW confinement and during a 5-d retention period in 1,700-L tanks. None of the Walleyes that were acclimated to 24°C and subjected to simulated tournament procedures survived the 5-d retention period; for fish subjected only to simulated angling at 24°C, survival during the 5-d retention period was 29%. Five-day survival was generally over 70% at acclimation temperatures of 12°C and 18°C, and we observed a significant interaction between acclimation temperature and ΔT; survival was greatest in LWs at -4°C ΔT for fish acclimated to 18°C and in LWs at $+4$°C ΔT for fish acclimated to 12°C. Best survival of Walleyes subjected to the stress of angling and tournament procedures was obtained at temperatures 6–8°C below the optimum temperature for adult Walleyes (i.e., optimum = 20–22°C). Five-day survival exceeded 70% when LW DO was 5 or 12–15 mg/L (at an acclimation and LW temperature of 18°C), but survival was 0% when DO was 2 mg/L. Anglers may increase survival of Walleyes through careful manipulation of LW temperature and DO when ambient temperature is at or below 18°C, but high mortality of angled and LW-retained Walleyes should be expected when ambient water temperatures are 24°C or greater.

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Organized tournaments in which anglers fish for Walleyes *Sander vitreus* and Saugers *Sander canadensis* (hereafter, Walleye tournaments) began in the late 1970s (Schramm et al. 1991). Recent trends in Walleye tournaments have not been measured, but paralleling the expansion of inland fishing tournaments (Schramm and Hunt 2007), Walleye tournaments appear to have rapidly grown in number and participation. Due to public interest in preventing excessive exploitation and conserving Walleye populations in waters where tournaments are conducted, tournament organizers have made efforts to release alive as many tournament-caught fish as possible. To this end, tournament organizers have (1) required boats to be equipped with functional aerated live wells (LWs), (2) imposed penalties for dead fish, and (3) implemented weigh-in procedures that are expected to improve survival (Tufts and Morlock 2004). Furthermore, size limit regulations that require release of Walleyes are being implemented on many waters, and voluntary use of catch-and-release practices appears to be increasing. Knowledge of factors affecting the postrelease mortality of Walleyes, whether the fish are released immediately after capture or after LW retention and tournament weigh-in procedures, is important for management of this popular sport fish.

Several factors, including rough-water conditions (Goeman 1991; Suski et al. 2005), capture depth (Schramm et al. 2010; Talmage and Staples 2011), and hook wounding (Reeves and Bruesewitz 2007), have been suggested or found to influence health or mortality of angler- and tournament-caught Walleyes; however, water temperature appears to be the most pervasive factor. Mortality of angler-caught Walleyes increases with water temperature, but of potentially greater significance is the consistent finding that the probability of mortality increases sharply as water temperature increases from 14°C to 20°C (Hoffman et al. 1996; Graeb et al. 2005; Reeves and Bruesewitz 2007; Schramm et al. 2010). The rapid increase in mortality over this relatively narrow temperature range centered around 18°C has been observed for Walleyes caught in tournaments, caught and immediately released by recreational anglers, and captured by electrofishing. Although providing consistent results, these evaluations were conducted under varying environmental conditions and did not allow assessment of the independent effects of water temperature.

Except for lethal wounding and severe trauma sustained during capture and handling, most of the mortality of angler-caught fish, including those caught in tournaments, is attributed to stress. Stress occurs when environmental conditions alter routine physiological processes and is characterized by a complex series of primary, secondary, and tertiary responses (Wedemeyer et al. 1990). Mortality is a tertiary response. In-water weigh-in procedures (Tufts and Morlock 2004) have been developed to reduce handling and air exposure of tournament-caught fish, thereby reducing the stress associated with the weigh-in process. Although supported only by measures of secondary stress in Largemouth Bass *Micropterus salmoides* (Suski et al. 2004), these in-water weigh-in procedures are probably also beneficial for Walleyes and may reduce mortality. However, tournament-caught fish are held in LWs for up to 8–9 h postcapture, during which they may be subjected to additional stress (Hartley and Moring 1993; Kwak and Henry 1995). Because the effects of sequential stressors tend to be cumulative (Carmichael et al. 1984; Barton et al. 1986), LW conditions to which fish are confined after being stressed by capture are also likely to affect survival.

Schramm et al. (2010) found that the survival of Walleyes caught during 14 tournaments spanning the entire open-water Walleye tournament season was correlated with LW temperature and dissolved oxygen (DO) concentration. Although LW conditions can increase stress, angled fish can also recover from stress in LWs. Based on measures of secondary stress response variables, studies have demonstrated that Atlantic Salmon *Salmo salar* (Wilkie et al. 1996), Walleyes (Killen et al. 2006), and Largemouth Bass (Suski et al. 2004, 2006) can recover from angling stress while being held in LWs, but recovery can be impaired by temperature changes and unsuitable DO conditions (Suski et al. 2006). An understanding of how LW temperature and DO affect Walleyes may benefit survival of tournament-caught fish because these conditions can easily be manipulated by anglers. For example, modern fishing boats have LWs that aerate water, but the LW must be operated properly to ensure sufficient aeration throughout a range of water temperatures, numbers of fish, and weights of fish, as all of these variables will affect LW DO concentrations (Hartley and Moring 1993). In addition, simple procedures, such as the use of ice (Gilliland et al. 2002), can be implemented to change LW water temperature and are effective for increasing the survival of Largemouth Bass that are caught during summer tournaments (Schramm et al. 2006).

The purpose of this study was to examine the independent effects of ambient water temperature, LW water temperature, and LW DO concentration on the survival of Walleyes subjected to simulated angler capture and live-release tournament procedures under controlled conditions. Specifically, our objectives were to use laboratory experiments to evaluate (1) the effects of LW temperature on survival of Walleyes acclimated to different water temperatures representing the temperature range frequently encountered in Walleye tournaments and (2) the effects of LW DO concentration on Walleye survival.

METHODS

Experimental conditions for this study were designed to accurately simulate the fish handling procedures that are implemented during modern, live-release Walleye tournaments (described by Schramm et al. 2010). Walleyes for the laboratory experiments were collected by electrofishing from rivers throughout Minnesota and were held in 0.34-ha ponds at several Minnesota Department of Natural Resources (MNDNR) hatcheries for 2 weeks to 5 months. Fathead Minnow *Pimephales promelas* were provided as forage in the ponds. Groups of 50–85 Walleyes were collected by electrofishing from the ponds and were transported to the laboratory at the University of Minnesota, St. Paul, by MNDNR personnel using the same equipment and procedures that are used to transport hatchery fish. Walleyes were transported when temperatures in the hatchery ponds approximated the acclimation temperatures used in the laboratory trials. In total, 495 similar-size Walleyes with a mean TL of 44 cm (SE = 0.13) and a mean weight of 0.75 kg (SE = 0.01) were used in laboratory trials.

Walleyes were acclimated to a water temperature of 12, 18, or 24°C for 14–21 d in square, rounded-corner fiberglass tanks (2.4 × 2.4 × 0.75 m) containing approximately 3,600 L of water. These temperatures were selected to correspond to temperatures associated with near-zero mortality (12°C), a rapid increase in mortality (18°C), and high mortality (24°C) as observed during the 14 live-release Walleye tournaments assessed by Schramm et al. (2010). Fathead Minnow were provided as forage during acclimation. The tanks were covered with foam insulation to maintain water temperature and to exclude light; the tank covers were only removed when DO was measured, when Fathead Minnow were added, or when Walleyes were removed for experimental trials. None of the individual Walleyes was used in more than one trial.

Well water (15–16°C) was filtered to remove iron and was mixed with water supplied from a laboratory recirculation system (24°C) to achieve the 18°C and 24°C acclimation temperatures. Chillers were used to cool treated well water to achieve the 12°C acclimation temperature. The recirculation system was equipped with biological filtration to oxidize ammonia and mineralize nitrate. Dissolved oxygen in the acclimation tanks was maintained at over 6.0 mg/L by aeration with compressed air.

Live-well conditions were simulated in actual 100-L LWs from Ranger multispecies boats (Ranger Boats, Flippin, Arkansas), representing a type of boat that is commonly used in Walleye tournaments. Water was supplied to each LW from a 208-L reservoir, where treatment temperatures were achieved as for the acclimation tanks. Water in the reservoir was replaced approximately every 2 h to remove ammonia and carbon dioxide. Water from the reservoir was pumped through a 4.5-m column in which compressed air or nitrogen gas was bubbled through the water to achieve treatment DO concentrations. The DO concentrations were measured with a YSI Model 55 DO meter (YSI, Inc., Yellow Springs, Ohio). Water turnover rate for individual LWs was 16 min.

For all experiments, survival after the simulated angling or tournament procedures (i.e., postrelease survival) was assessed by retaining Walleyes in 1.8-m-diameter, 1,700-L tanks for 5 d at the acclimation temperature. During the 5-d retention period, the tanks were covered with foam insulation to exclude light except when DO was measured and during twice-daily observations for mortality. The tanks were supplied with water from a common reservoir that was maintained at acclimation temperatures by mixing treated well water and recirculated water or by using a chiller unit as necessary. The water turnover rate for each tank was approximately 85 min, and the turnover rate for the entire system was 12.5 h. Dissolved oxygen concentrations were maintained at or above 6 mg/L by aeration with compressed air.

Experiment 1: effects of acclimation and live-well temperature change on survival.—The first experiment evaluated survival of Walleyes that were subjected to simulated tournament conditions at three acclimation temperatures (12, 18, and 24°C) and three LW temperature differentials (ΔT; no change from acclimation temperature [0°C ΔT]; 4°C below acclimation temperature [−4°C ΔT]; and 4°C above acclimation temperature [+4°C ΔT]). The acclimation temperature represents the water temperature at which the tournament is conducted (i.e., ambient temperature). The −4°C ΔT simulates cooling of the water in LWs with ice, a practice that is recommended for black bass *Micropterus* spp. tournaments (Gilliland et al. 2002; Siepker et al. 2007) and that is used by some Walleye tournament anglers (B. Vondracek, personal observation). The +4°C ΔT simulates the temperature change that occurs when anglers operate their LW systems in "automatic mode" (i.e., near-surface ambient water is pumped into the LW) or simulates the conditions that are experienced by fish caught in deeper, cooler water and then held in LWs at warmer, surface water temperatures. Dissolved oxygen was maintained above 5 mg/L in all LWs.

Each trial was initiated by manually chasing the fish with a dip net in an acclimation tank for 60 s to simulate activity related to angling; this is an accepted procedure for exhausting fish and replicating the physiological disturbances associated with angling (e.g., Wood 1991; Suski et al. 2004). Five exercised Walleyes were then randomly captured via dip net and were transferred into each of two LWs (hereafter, treatment fish; total of 10 fish). Five additional exercised Walleyes (reference fish) were randomly captured by dipnetting from the same acclimation tank; these fish were marked by clipping approximately 12 mm from the upper lobe of the caudal fin and were immediately transferred to a postrelease tank that was maintained at the acclimation temperature. Although perfect controls for evaluating the effects of angler capture and tournament handling on survival are not possible (Pollock and Pine 2007), high mortality of reference fish would suggest adverse environmental conditions in the postrelease tanks. In the absence of mortality levels that suggest adverse conditions, the mortality of reference fish in the postrelease tanks would provide an estimate of mortality resulting from angler capture and immediate release. As such, differences in mortality between reference fish and treatment fish provide estimates of mortality resulting from tournament conditions (i.e., LW retention and the additional handling associated with weigh-in).

Treatment fish were held in covered LWs for 8 h to simulate LW confinement during a tournament and then were transferred by hand from each LW into a fish transport bag that contained 20 L of LW water. Fish were held in the bag for 2 min to simulate transport from the tournament boats to the weigh-in area. Fish were poured from the carrying bags into acrylic boxes suspended in a postrelease tank at the acclimation temperature. The acrylic boxes were 68 × 39 × 26 cm, with 2.5-cm-diameter holes in the bottom and sides to allow water circulation and drainage. Fish were held in the boxes for 10 min to simulate the waiting period that occurs immediately prior to fish judging and weigh-in. The fish transport bags, acrylic boxes, and sequence of fish handling procedures in this study were the same as those used in the live-release Walleye tournaments studied during 2006 and 2007 (Schramm et al. 2010).

Air exposure (when fish are not submersed in water) occurs during four periods of the water weigh-in procedure simulated in this experiment: when fish are removed from a LW and placed into carrying bags (~5–10 s); and when fish are transferred from the aerated trough to the judging tank (≤5 s), from the judging tank to the weigh-in tank (≤10 s), and from the weigh-in tank to the release boat (usually < 60 s). Walleyes were subjected to the first three air exposures as we processed the fish through the simulated weigh-in. The acrylic box containing five treatment fish was lifted from the water for 60 s prior to releasing the fish into the postrelease tank to simulate the air exposure during transport from weigh-in to the release boat. After air exposure, all treatment fish were released into the same postrelease tank maintained at the acclimation temperature, which also contained the reference fish for that trial. Survival was monitored twice daily; fish that were unable to swim, that could not maintain a dorsal-up position in the water, or that lacked opercular movement were considered to be mortalities and were removed from the tank.

Three trials, each consisting of 5 reference fish and 10 treatment fish, were used to evaluate the effects of acclimation temperature and LW ΔT on survival. The reference and treatment fish in each trial were held for 5 d in a postrelease tank; fish from individual trials were held in separate postrelease tanks. We expected treatment fish to have greater mortality than reference fish; thus, 10 treatment fish were used for each trial to increase the precision of estimating mortality, and five reference fish were used for each trial to minimize the density of fish in the postrelease tanks and to minimize the number of Walleyes that were needed to complete the research. Trials were initiated at 2-d intervals after the initial temperature acclimation period.

Experiment 2: effects of dissolved oxygen concentration on survival.—The experimental procedure used to determine survival in relation to LW DO concentration was the same as that described for the temperature experiment. Dissolved oxygen treatments in the LWs were 2, 5, and 12–15 mg/L; these concentrations were within the range of DO observed during the 14 live-release Walleye tournaments assessed by Schramm et al. (2010). Oxygen treatments were applied to fish that were acclimated at 18°C and held in LWs at 18°C; mortality of tournament-caught Walleyes rapidly increases at 18°C (Schramm et al. 2010), and thus variation in mortality was expected to occur at this temperature. Trials with five treatment fish in each of two LWs and five reference fish (i.e., a total of 15 fish/trial) were replicated three times at each DO concentration.

Statistical analysis.—Differences in weight between treatment and reference fish were tested with mixed-model ANOVA (MIXED procedure in the Statistical Analysis System; SAS 2010). For temperature experiments, fixed-effect factors in the model included acclimation temperature and a factor describing postacclimation handling, which included the LW ΔT of −4, 0, and +4°C as well as reference handling (i.e., no temperature change, with fish being moved immediately to the postrelease tank). The interaction between trial and postacclimation handling was included as a random effect. For DO experiments, the studied DO concentration and the reference handling of fish after acclimation were fixed-effect factors, and the interaction between trial and treatment was included as a random effect.

The effects of acclimation temperature, ΔT, and DO treatments on survival were tested with models analogous to those used for the analysis of weight. However, arcsine–square root transformations, which are typically used to stabilize the variance of proportions (i.e., survival rate), could not be used due to the unequal sample sizes for treatment fish ($n = 10$) and reference fish ($n = 5$) in each trial. Therefore, fish survival (the response variable) was taken to be binomial, and the probability of fish surviving was tested with generalized linear mixed models (GLIMMIX procedure; SAS 2010). An additional model with acclimation temperature as a fixed-effect factor and the interaction between trial and acclimation temperature as a random effect was used to compare survival of reference fish at different acclimation temperatures. Because of the small sample size, statistical significance was set at an α of 0.10 to increase the likelihood of detecting a difference if one existed. Differences among treatment levels were assessed with least-squares means when significant treatment effects on survival were detected.

RESULTS

Experiment 1: Effects of Acclimation and Live-Well Temperature Change on Survival

Weights of Walleyes assigned to the combinations of acclimation temperature and postacclimation treatment did not vary significantly ($F_{11,24} = 1.65$, $P = 0.15$). Thus, fish weight did not differ among acclimation temperatures, among ΔTs, or between treatment and reference fish. Survival of reference fish differed among acclimation temperatures ($F_{2,6} = 10.12$, $P = 0.01$); survival at 24°C (mean survival ± SE = 0.29 ± 0.06) was lower than survival at 12°C (1.00 ± 0.00) or at 18°C (0.87 ± 0.06; Figure 1).

No treatment fish died during the tournament simulation portion (i.e., all stages from capture through simulated weigh-in) of the temperature experiment at 12°C and 18°C; all mortality of fish that were acclimated at these two temperatures occurred during the 5-d postrelease period. Conversely, 11 of 90 treatment fish that were acclimated at 24°C died during LW confinement, and none of the ΔT treatment fish from the 24°C acclimation survived the 5-d postrelease period. All 11 fish that died while in the LWs were in the +4°C ΔT trials. Further analyses of ΔT considered only the 12°C and 18°C acclimation temperatures.

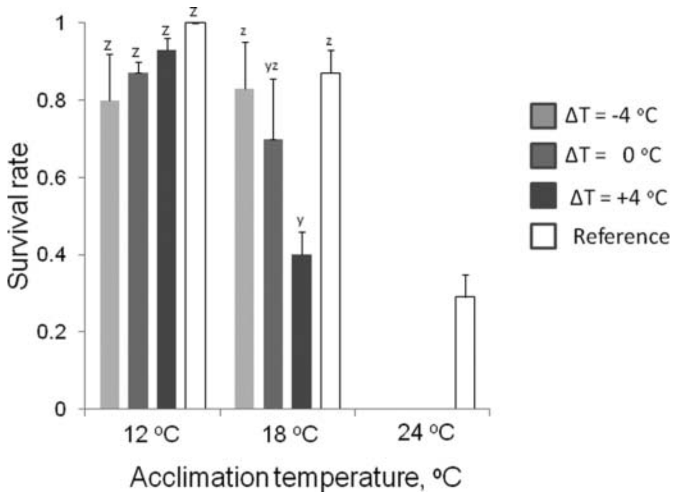

FIGURE 1. Mean (+SE) survival rate of Walleyes that were acclimated to 12, 18, or 24°C and subjected to simulated tournament conditions with a live-well temperature adjustment (ΔT) of −4, 0, or + 4°C from each acclimation temperature or subjected only to simulated angler capture (reference fish). Lowercase letters indicate significant differences in survival rate within acclimation temperatures (least-squares means, $P < 0.10$).

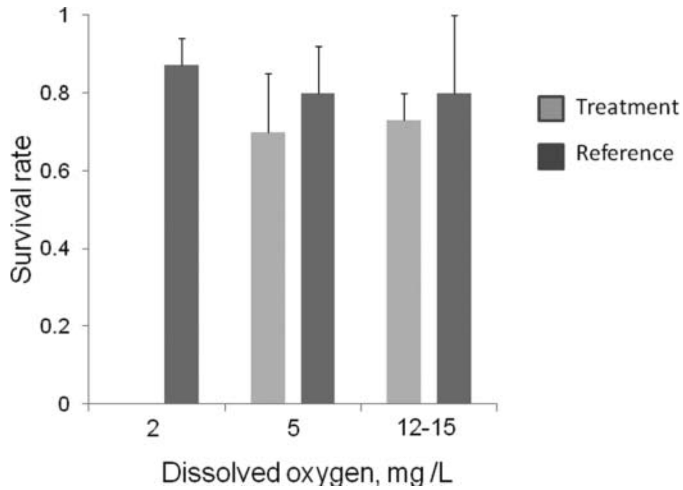

FIGURE 2. Mean (+SE) survival rate of Walleyes that were acclimated to 18°C and subjected to simulated tournament conditions with a live-well dissolved oxygen concentration of 2, 5, or 12–15 mg/L (treatment fish) or subjected only to simulated angler capture (reference fish).

Analysis of survival rates at 12°C and 18°C indicated a significant interaction between ΔT and acclimation temperature ($F_{2,12} = 3.31$, $P = 0.07$). Survival increased with LW temperature for Walleyes that were acclimated to 12°C, but survival decreased with LW temperature for Walleyes that were acclimated to 18°C (Figure 1). High survival of reference fish at 12°C and 18°C suggested that the 5-d retention conditions did not adversely affect Walleye survival. Survival differed among reference fish and LW ΔT treatment fish at the 18°C acclimation temperature ($F_{3,16} = 2.72$, $P = 0.08$) but not at the 12°C acclimation temperature ($F_{3,16} = 1.44$, $P = 0.27$). For fish that were acclimated to 18°C, survival of treatment fish in LWs at + 4°C ΔT was lower than the survival of reference fish or the survival of treatment fish in LWs at −4°C ΔT.

Experiment 2: Effects of Dissolved Oxygen Concentration on Survival

Weights did not vary significantly for the reference fish and the fish that were assigned to the DO treatments ($F_{3,8} = 1.87$, $P = 0.21$). Thus, weight did not differ among DO treatments or between treatment and reference fish.

All Walleyes survived the tournament simulation portion of the DO trials. All but one fish that were held in LWs at 2 mg/L died within 24 h of LW confinement, whereas the mortalities in the 5- or 12–15-mg/L treatment occurred after 2–5 d of post-treatment observation. High survival of reference fish (mean ≥ 0.80) for all DO treatments suggested that 5-d retention conditions did not adversely affect Walleye survival. Due to 100% mortality of fish in the 2-mg/L DO treatment, further analysis considered only the 5- and 12–15-mg/L treatments. Survival did not differ among fish in the 5-mg/L treatment, fish in the 12–15-mg/L treatment, and reference fish ($F_{2,4} = 0.41$, $P = 0.69$; Figure 2).

DISCUSSION

Water temperature significantly affects survival of tournament-caught Walleyes. The results of these laboratory experiments evaluating the independent effect of water temperature closely paralleled the results of field studies of live-release Walleye tournaments; those studies found relatively high survival at temperatures less than 14°C, rapid decreases in survival rate at temperatures of 14–20°C, and generally low survival rates at temperatures greater than 20°C (Hoffman et al. 1996; Graeb et al. 2005; Schramm et al. 2010). Our experiments also indicated that the effects of exercise associated with angling, as measured by the survival of reference fish, produced a large decrease in survival at 24°C (mean survival = 29%) compared with 100% mean survival at 12°C and 87% survival at 18°C. Similarly, Reeves and Bruesewitz (2007) found that for Walleyes captured by conventional angling and immediately released, survival decreased sharply at water temperatures near 20°C. Low survival of reference fish (Walleyes) collected by electrofishing and held in net pens with tournament-caught fish in actual tournaments at temperatures above 18°C (Schramm et al. 2010) suggests that capture by electrofishing and the associated handling and transport affect long-term survival in a manner similar to angling-induced exercise. The results of both the laboratory and field assessments consistently indicate that survival of Walleyes is low at temperatures above 18°C, whether the fish are immediately released after being stressed by capture or are retained in LWs and subjected to tournament weigh-in procedures.

Survival of Walleyes that were subjected to simulated tournament conditions was significantly affected by acclimation temperature but was modulated by changing LW temperature.

Warming and cooling of the LW water had opposite effects at acclimation temperatures of 12°C and 18°C such that survival for fish acclimated at 12°C increased when water was warmed, whereas survival for fish acclimated at 18°C increased when water was cooled. Although the survival of Walleyes subjected to simulated tournament procedures was relatively high for fish that were acclimated to 12°C and 18°C and then held in LWs at these same temperatures (i.e., 0°C ΔT), the best survival of Walleyes acclimated to 12°C was at 16°C (+ 4°C ΔT), and the best survival of Walleyes acclimated to 18°C was at 14°C (−4°C ΔT). This convergence of temperatures suggests that 14–16°C may be the best temperature range for survival of tournament-caught Walleyes.

Of interest is the fact that the temperature range of greater survival in our study was below the 20–23°C optimum and preferred temperatures of adult Walleyes (Coutant 1977; Christie and Regier 1988; Rose et al. 1999). The significantly lower survival of fish that were acclimated to 18°C and held in LWs at + 4°C ΔT (i.e., 22°C) compared with 0°C ΔT (i.e., 18°C) further supports our contention that adult Walleyes survive stress better at temperatures below their optimum. In a review of field and laboratory studies evaluating the effects of temperature on the survival and physiological impairment of captured and released fish, Gale et al. (2013) found evidence that mortality began increasing at temperatures within the optimal or preferred temperatures for 10 of the 15 species for which data were sufficient to permit evaluation. The zero survival of Walleyes that were exercised at 24°C and held in LWs at −4°C ΔT (i.e., 20°C) compared with the survival of Walleyes that were acclimated to 18°C and held in LWs at 0°C ΔT (survival = 0.70) or at + 4°C ΔT (i.e., 22°C; survival = 0.40) raises the possibility that the thermal conditions under which the stress (exercise) is incurred also may affect survival; thus, the effect of the stressor may not be reversed at a temperature near or slightly below the optimum temperature. Alternatively, as suggested by Gale et al. (2013), thermal and capture stressors may be additive. Application of this hypothesis to our work would imply that the optimal temperature is not necessarily a temperature of minimal thermal stress. Nevertheless, survival of exercised Walleyes—whether retained in LWs and subjected to tournament procedures or released immediately—is greater at temperatures below the 20–22°C optimum temperature of adult Walleyes.

Adequate oxygen is essential for Walleye survival. Hoff and Chittenden (1969) reported that adult Walleyes exhibited behavioral distress at a DO concentration of about 2.0 mg/L, and mortality occurred when DO was less than 1.6 mg/L for over 160 min. The mortality of all Walleyes held in LWs at 2 mg/L in the present study indicates that DO must be maintained above this level when LW temperature is 18°C. Conversely, the high and similar survival at 5 and 12–15 mg/L and the lack of a difference between LW-held and reference fish indicate that 5 mg/L is sufficient to sustain high survival of exercised Walleyes at 18°C. Because metabolism slows and oxygen demand declines at cooler temperatures, 5 mg/L can also be considered sufficient for high survival at cooler temperatures. The 12–15-mg/L DO treatment equates to 130–162% saturation (at 18°C and 200 m above sea level). Supersaturation of oxygen does not impair survival, at least up to 163% saturation.

Numerous studies have measured changes in secondary stress responses of fish that are subjected to both simulated and actual angler capture and tournament procedures (Cooke et al. 2013). Changes in secondary stress measures (e.g., blood glucose, plasma chloride, plasma and tissue lactate, and plasma osmolality) are informative for assessing sublethal effects of angling or tournament processes on fish and may provide insight into mechanisms for mortality; however, for fisheries managers, anglers, and tournament organizations, the foremost concern is fish survival (Cooke and Schramm 2007). Our study, which measured survival directly, used almost 500 adult Walleyes to assess the effects of only three variables on Walleye survival. Measurement of secondary stress responses offers a relatively economical (i.e., fewer fish and less observation time) and scientifically sound (no reference fish are needed for postrelease survival evaluation; Pollock and Pine 2007) alternative for assessing the effects of angling and tournament procedures on fish. Unfortunately, relationships that allow prediction of mortality based on secondary stress measures have not been established (Cooke and Schramm 2007).

Interfacing our measures of survival with similarly designed studies that have measured secondary stress responses supports the conclusion by Cooke et al. (2013) that the linkage between physiological stress measures and mortality is not straightforward. For example, our finding that Walleyes survived the stress of capture and tournament procedures better at temperatures below optimum—in particular, that fish acclimated to 18°C and held in a LW at 22°C (+ 4°C ΔT) had lower survival than fish held in a LW at 18°C (0°C ΔT) or at 14°C (−4°C ΔT)—is not supported by a similar laboratory study (Killen et al. 2006) that measured secondary stress responses. In the Killen et al. (2006) study, Walleyes that were acclimated to and exercised at 11°C and then retained in LWs at 22°C exhibited recovery within 6 h for most secondary stress measures, despite their exposure to a + 11°C ΔT when placed in the LWs. Although acclimation temperature differed between the two studies, we found elevated mortality of Walleyes that were held in LWs at 22°C. Further, the 11°C temperature change applied in the study by Killen et al. (2006) would be expected to cause mortality of adult Walleyes in a hatchery environment (Jay Rudacille, Iowa Department of Natural Resources, personal communication) and was greater than the + 7°C temperature shock that was found to impair the recovery of secondary stress responses in Largemouth Bass (Suski et al. 2006). In addition, we found that LW DO concentrations ranging from 5 mg/L (54% saturation) to 15 mg/L (162% saturation) resulted in similarly high survival of Walleyes at 18°C, whereas Suski et al. (2006) found that recovery was impaired for Largemouth Bass when subjected to simulated angling and held in LWs at 25°C with a DO concentration of 4 mg/L (49% saturation) or 20 mg/L (222% saturation). These comparisons are constrained by different temperature conditions and by the use of different species (i.e., Largemouth Bass in the Suski et al. [2006] study versus Walleyes in the Killen et al. [2006] study and the present study). Wilkie et al. (1996) observed recovery of secondary stress measures after exhaustive exercise of Atlantic Salmon, but they also observed 40% mortality of these fish; Wilkie et al. (1996) concluded that few of the physiological parameters measured in their study were predictive of mortality.

A primary purpose for evaluating mortality of tournament-caught fish or any caught-and-released fish is to identify conditions that cause mortality and ameliorate those conditions (to the extent possible) to reduce mortality. A conservative application of our results is to retain Walleyes in LWs at temperatures below 18°C and to release tournament-caught Walleyes at a location where the fish can readily access good-quality water with temperatures below 18°C. Lowering the temperature in LWs by the addition of ice or by using commercially available LW chillers is easily accomplished. Our laboratory results suggest that slight increases in survival can be achieved by warming the LW temperature for Walleyes that have been acclimated to 12°C. In light of the high survival of tournament-caught Walleyes at ambient water temperatures less than 15°C (Schramm et al. 2010), we see no benefit in managing LW water temperatures at levels lower than 15°C.

This study also established that DO independently affected the survival of tournament-caught Walleyes. We recommend that 5 mg/L be considered a minimum DO concentration for Walleyes that are subjected to tournament conditions. Given that most anglers in Walleye tournaments maintain DO concentrations greater than 5 mg/L in their LWs (Schramm et al. 2010), modern fishing boats with functional aerated LWs can maintain sufficient DO when operated properly. Our results also indicate that oxygen saturation levels of 130–162% do not impair survival; therefore, continual operation of LW aeration systems that rely on pumping water and exposing the water to the atmosphere to prevent excessive supersaturation will not impair Walleye survival. Walleyes should be released at locations where they will have access to water that is cooler than 18°C and that has a DO concentration of at least 5 mg/L.

Our results also have implications for live-release fishing by recreational anglers. The high mortality of reference fish that were acclimated to 24°C mirrors the substantial increase in mortality of angled Walleyes at water temperature greater than 20°C, as reported by Reeves and Bruesewitz (2007). Thus, voluntary live release and regulations that are implemented to reduce mortality will have less of an effect on the conservation of Walleye stocks during warm seasons. In addition, regulations that mandate the release of fish, such as minimum or protected length limits, may actually increase fishing mortality at high water temperatures if the anglers release fish as they attempt to catch a daily possession limit of legal-length Walleyes.

Given the significant effect of water temperature on Walleye survival and that LW temperature can be manipulated by conscientious anglers, further evaluation of the effects of LW temperature may be warranted. For example, it would be beneficial to determine whether LW temperature reductions greater than 4°C could be used to increase survival of Walleyes that are caught from 24°C or warmer waters. Gale et al. (2013) found that only 42% of 83 studies relating the effects of fish capture to temperature provided any information about the ecological context of the temperature challenge (i.e., related the temperature of capture to the species' optimal temperature) and encouraged consideration of thermal optima in the design and interpretation of future studies. Our results underscore the importance of considering thermal optima when designing and interpreting assessments of water temperature effects on the survival of Walleyes and other species for which high postcapture survival is important.

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