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Angling-induced cardiac disturbance of free-swimming largemouth bass (*Micropterus salmoides*) monitored with heart rate telemetry

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Summary

The sub-lethal effects of catch-and-release angling have been poorly studied because of the difficulties in monitoring physiological parameters in free-swimming fish. Laboratory studies provide the opportunity to examine sub-lethal effects in controlled environments, but do not incorporate site-specific characteristics. In this study we angled free-swimming largemouth bass (*Micropterus salmoides*) equipped with heart rate transmitters to exhaustion using rod and reel, and exposed fish to air for 30 s. Experiments were repeated at four water temperatures (13, 17, 21, and 25°C). These field data were compared with published findings from largemouth bass collected at the same water temperatures in a controlled laboratory setting using Doppler flow probes. Field collected heart rate data increased with increasing water temperatures (Q_{10} values 1.30–1.37). Pre-disturbance heart rates were ~30% higher for free-swimming fish in the field than previously collected laboratory data at the same water temperatures. Fish angled in the field exhausted ~40% more rapidly than fish chased in the laboratory. Maximal heart rate was ~15% higher for free-swimming fish in the field than for data collected from laboratory restrained fish, but scope for heart rate was reduced by up to 20% in the field, especially at higher water temperatures. Heart rate in free-swimming fish was highly variable at all times, obscuring clear recovery patterns. Conversely, laboratory cardiac parameters exhibited less variable patterns, peaking clearly following disturbances and recovering in about 135 min, independent of water temperature. Based upon these findings, we suggest that comprehensive studies incorporating both laboratory and field experiments are needed for truly understanding the effect of catch-and-release angling on fish.

Introduction

The most common methods for quantifying the sub-lethal effects of catch-and-release angling are laboratory studies, in which different blood and white muscle (Booth et al., 1995; Wilkie et al., 1997; Kieffer, 2000) or cardiovascular (e.g. Cooke et al., 2001, in press; Schreer et al., 2001) variables are monitored. Collectively, these studies have provided substantial insight into the sub-lethal physiological consequences of different catch-and-release angling related disturbances. Laboratory studies benefit from the controls that can be imparted on the experiments to minimize unwanted variation, however, concerns exist regarding the applicability of laboratory collected data to natural field environments. In laboratory environments, fish are sheltered from a series of stressors that they typically face in their natural environments, such as predation attempts, variation in food availability, excessive movement, rapid temperature change, and variations in water quality. The laboratory environment, however, introduces a variety of other stressors that the fish do not face in the natural environment, including confinement stress, restricted mobility, and interruption of circadian rhythms. It is reasonable to assume that examinations of the sub-lethal effects of catch-and-release angling in laboratory environments may not reflect the suite of scenarios that present themselves in natural environments.

To circumvent these problems, researchers have turned to remote monitoring using different telemetry techniques (Cooke et al., 2002b). Researchers have monitored locomotory activity (Cooke et al., 2000) and heart rate (Anderson et al., 1998) post-angling. These techniques also provide the opportunity to integrate behavioral and energetics perspectives (Cooke et al., 2002b). There is no doubt that remote measures of other physiological parameters will be possible in the future, but currently, there are no technologies that permit the remote determination of any blood or white muscle biochemical parameters (Lucas et al., 1993). As a result the telemetric recording of heart rate is perhaps the best means to remotely monitor the sub-lethal effects of catch-and-release angling on fish in their natural environment (Anderson et al., 1998). Differences between laboratory- and field-derived data may exist, but to date, there are no published studies that compare the effects of catch-and-release angling in these two environments. Furthermore, studies in laboratory environments typically use manual chasing to simulate exercise experienced during angling, whereas in the field, test fish can be angled using rod and reel. Although studies have suggested that these methods of exhausting a fish result in different levels of disturbance (Reidy et al., 1995), there is currently no assessment that compares the results obtained using actual angling versus manual chasing.

The purpose of this study was to address several of the shortcomings mentioned above. Across a range of water temperatures we angled heart rate transmitter equipped, free-swimming, adult largemouth bass (*Micropterus salmoides*) and assessed their cardiac response and recovery. Largemouth bass were chosen for this study due to their importance as a recreational sport-fish and because heart rate telemetry devices have been previously deployed on them (Cooke et al., 2002a). In addition, an existing parallel laboratory study of catch-and-release angling effects on largemouth bass using cardiac output

has been published (Cooke et al., in press), providing opportunities to contrast and compare results.

Materials and Methods

Study animals

Fish used for this study were captured from two geographic areas. Fish used for experiments at 13 and 17°C, were collected from reservoirs in central Illinois and held at the Illinois Natural History Survey Aquatic Research Laboratory in Champaign, Illinois. Fish used for experiments at 21 and 25°C, were collected from Lake Opinicon, Ontario. All fish were held for at least 48 h prior to surgery in flow-through tanks (~200 L volume, 10 L/min flow rate) provided with lake water in Ontario and pond water in Illinois. Food was withheld for 48 h prior to surgery so that fish were in a post-absorptive state. Water temperatures at time of capture were within 2°C of the experimental temperature. Minor natural variation in temperature was consistent with ambient conditions.

Heart rate telemetry apparatus and attachment

We used an acoustic heart rate transmitter (V16H-4HR; Vemco Inc., Shad Bay, Nova Scotia) that was triggered by the QRS pulse of the ECG. Description of the functioning of the transmitters (Claireaux et al., 1995; Vemco, 1995) as well as of their customization and attachment (Cooke et al., 2002a) may be found elsewhere.

Prior to surgery, fish were anaesthetized with 60 p.p.m. clove oil (emulsified with ethanol, 9 : 1 ethanol : clove oil) until they were non-responsive. Water containing a maintenance concentration of anesthetic (30 p.p.m. clove oil) was pumped over the gills during the surgery. Transmitter and battery packages were attached externally to the dorsal surface of the fish using a surgical stainless steel harness. Two gold-plated electrodes insulated to within 3 mm of the distal end were implanted ventral to the pericardial cavity that touched but did not violate the pericardial membrane. Cyanoacrylate glue and braided silk sutures were used to secure the electrodes. The electrode wires were sutured to the body of the fish using six to eight mattress sutures each. The surgical procedure took between 10 and 15 min to complete.

After surgery, fish were released into large outdoor raceways in Illinois (2 m × 8 m × 1 m, ~16.0 m^3) or enclosures (3 m × 9 m × 0.6 m, ~16.2 m^3) in Lake Opinicon, Ontario. Fish were provided with a moderate amount of complex cover including aquatic macrophytes (floating and submerged), overhead cover (~20% surface area), and woody debris. Fish in these systems were provided with forage [small bluegill (*Lepomis macrochirus*) in Ontario and fathead minnows (*Pimephales promelas*) in Illinois] and had to avoid predators (primarily avian). Fish were angled when mid-water column temperatures were within 0.3°C of the desired test temperatures. During experiments, we measured micro-scale differences in water temperature within the enclosures and raceways that were as much as 2°C different from the mid-water (and the temperature treatment). We assume that this variation is inherent in natural systems and provided test fish with an opportunity to behaviorally thermoregulate.

We used a VR-60 acoustic receiver (Vemco Inc.) with an omnidirectional hydrophone to record telemetric signals. Data were relayed via an RS – 232 port to a laptop computer. Software provided with the transmitters (VSCAN – GPS, V4.06; Vemco Inc.) was used to log and manage the data-set. Individual largemouth bass were captured on rod and reel 2–4 days post-transmitter attachment between 10:00 and 14:00 hours. All fish were angled using medium action bait casting equipment with 10 lb (*ca.* 4.5 kg) test by the same angler. Fish were fought until they were exhausted (cessation of active swimming, beginning to lose equilibrium) and could be easily landed (grasped by the lower mandible). The hook was removed, and the fish were held out of the water for a 30 s period. Because ultrasonic signals are not transmitted effectively through air, the posterior two-third of the fish's body remained submerged during air exposure. The opercular and buccal cavity was not in contact with water during the air exposure. Fish were then released after the prescribed period and heart rate was monitored for 5 h.

Analysis

Data were collected in real-time for each fish and imported into a spread-sheet. A macro in Excel (Microsoft Inc., Seattle, WA) was used to generate 60-s mean heart rates that were then plotted in Sigma Plot (Jandel Scientific) for visual analysis. Resting (pre-angling) heart rates were recorded for one hour prior to angling and represent a mean for that period. Maximal (post-angling) heart rate was the maximal value during the monitoring period. Scope for heart rate was calculated by subtracting resting heart rate from maximal heart rate. Q_{10} values were calculated using the approach provided by Schmidt-Nielsen (1997). To compare our field data with the laboratory data of Cooke et al. (in press) collected using Doppler flow probes, we first tested normality and homogeneity of variance as described above. Because data were normally distributed, and variances were homogeneous, data were not transformed, and we used parametric analyses (i.e. analysis of variance). To test slopes, the interaction term was used. Fishers least significant difference (LSD) test was used to identify LSDs and mean separation. Values reported are means (± SE) and significance was evaluated at $\propto = 0.05$.

Results

Field data

Basal heart rates in the field varied with water temperature, increasing steadily with increasing temperature (Table 1, Fig. 1). Basal values were highly variable during the 60 min basal value collection period. Q_{10} values for all temperature intervals ranged from 1.30 to 1.37 (Table 2). Time required to exhaust fish in the field using rod and reel did not vary among water temperatures and generally required about 120 s (Table 1). The maximal disturbance during recovery increased with higher water temperatures (Fig. 1). The scope for HR increased with increasing water temperature and differed significantly among these temperature groups (Fig. 1). Recovery patterns of fish angled in the field were highly variable (Figs 2–5). No clear trends were observed limiting our ability to quantify the time required for fish to recover.

Comparison

Basal heart rates differed among the method used to exhaust the fish (i.e. chasing in Cooke et al. (in press) and angling in this study) and by temperature ($F = 33.36$, $P < 0.001$).

Table 1
Meristic and cardiac parameters for largemouth bass affixed with heart rate transmitters (HR) compared with mean summary data for laboratory derived data (lab). Field values represent individual fish and are not mean values. In total, two fish in the field were monitored at every temperature (13, 17, and 25°C), except 21°C at which only one fish was monitored. Lab values are mean values (based upon 11, 10, 8, and 8 fish at 13, 17, 21, and 25°C, respectively; Cooke et al., in press). Standard errors are presented below mean values in brackets. Basal heart rate is based upon the 60 min period prior to angling. Maximum HR is based upon the maximal HR value recorded during the angling recovery period

Fish	Temperature (°C)	TL (mm)	WT (g)	Basal HR (beats/min)	Maximum HR (beats/min)	Time until exhaustion (s)
HR1	13	468	1940	46	64	108
HR2	13	463	1910	44	68	116
Lab	13	390	917	32	57	179
		(6)	(29)	(1)	(2)	(10)
HR3	17	480	1860	53	85	147
HR4	17	470	1640	47	84	174
Lab	17	397	953	41	77	187
		(6)	(52)	(1)	(2)	(7)
HR5	21	515	1950	56	96	121
Lab	21	348	592	43	87	158
		(11)	(67)	(1)	(3)	(8)
HR6	25	440	1250	64	113	126
HR7	25	412	1120	63	110	118
Lab	25	370	748	49	107	167
		(4)	(24)	(1)	(4)	(9)

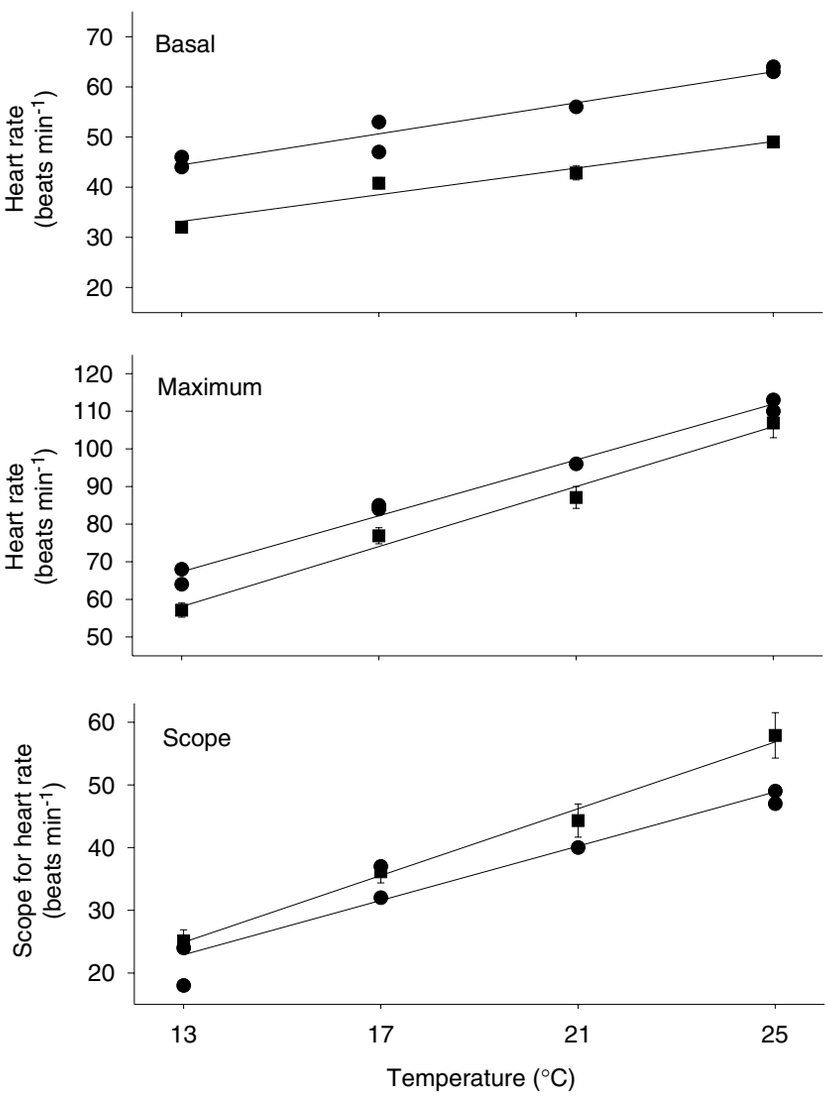

Fig. 1. Comparison of cardiac parameters of largemouth bass in the laboratory (squares) and field (circles) across four water temperatures. Laboratory data was collected after manual chasing at 13 (n = 11), 17 (n = 10), 21 (n = 8), and 25°C (n = 8) and represent mean values (±SE). Values for rod and reel angled fish in the field (n = 7 total) are plotted individually. Lines represent the line of best fit for linear regressions. Basal values were recorded during a 60 min period prior to experimentation. Maximum values represent the maximum heart rate after exhaustive angling (field) or chasing (lab) followed by brief air exposure. Scope is the difference between basal and maximum values

Although basal values for heart rate were consistently lower in the laboratory than in the field (Table 1, Fig. 1), the effect of temperature on basal heart rate was not influenced by the method of exhaustion based on similarity of slopes ($P = 0.550$); basal heart values increased with water temperature for both exhaustion methods. The basal heart rates during

Table 2
Q_{10} values for largemouth bass heart rate between 13 and 25°C. All values are based upon resting values 1 h prior to angling. Sample sizes are as in Table 1

	Q_{10} values	
Temperature ranges (°C)	Heart rate (lab); Cooke et al., in press	Heart rate (field); this study
13 ⇒ 17	1.84	1.30
13 ⇒ 21	1.44	1.31
13 ⇒ 25	1.42	1.33
17 ⇒ 21	1.13	1.32
17 ⇒ 25	1.26	1.35
21 ⇒ 25	1.40	1.37

the 60 min pre-treatment period were substantially more variable in the field than in the laboratory. Q_{10} values for HR of fish in the field were less variable (range of 0.07) compared with laboratory Q_{10} values (range of 0.71) (Table 2).

Times required to exhaust fish were consistently longer in the laboratory than in the field ($F = 3.94$, $P = 0.003$) and were independent of water temperature (Table 1). Maximal heart rates differed among the laboratory and the field ($F = 34.78$, $P < 0.001$), with field values being consistently higher (Fig. 1). These differences were consistent across temperatures as evidenced by similarity of slopes ($P = 0.960$). Overall, although differences in scope for heart rate were observed ($F = 17.62$, $P < 0.001$), no differences were observed in slopes ($P = 0.761$) or in the method of exhaustion ($P = 0.100$) across all temperatures. No direct quantitative comparisons in recovery time were possible because of the extreme variation in heart rate, lack of consistent trends, and failure of fish angled in the field to return to pre-angling levels (Figs 2–5). Some fish exhibited peak heart rates within minutes of release, whereas other fish experienced equally heightened and variable heart rates throughout the entire 300 min monitoring period. Overall, laboratory fish had less variable and more consistent recovery patterns, eventually returning to pre-disturbance levels.

Discussion

Telemetric approaches facilitate our ability to monitor the response of free-swimming fish to catch-and-release angling

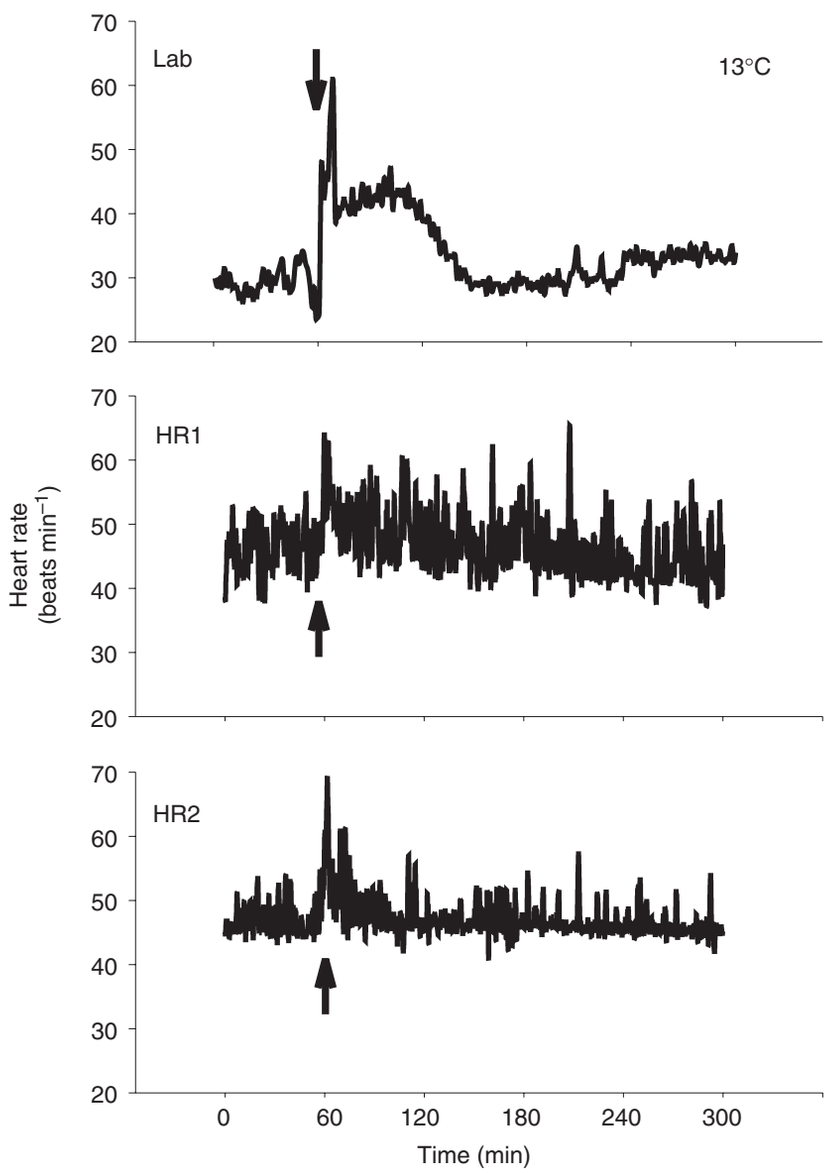

Fig. 2. Trace of largemouth bass heart rate measured using two techniques at 13°C. The first 60 min of data are basal heart rate values, the arrow indicates the exhaustive manual chasing (laboratory) or angling (field) and 30 s air exposure, and the remaining 240 min represent the recovery period. The uppermost panel is a representative largemouth bass heart rate trace (lab) measured with Doppler flow probes in the laboratory. The two bottom panels represent data collected from largemouth bass in the field using heart rate transmitters (HR1,2) (See Table 1). All data are plotted at the same resolution (60 s mean values)

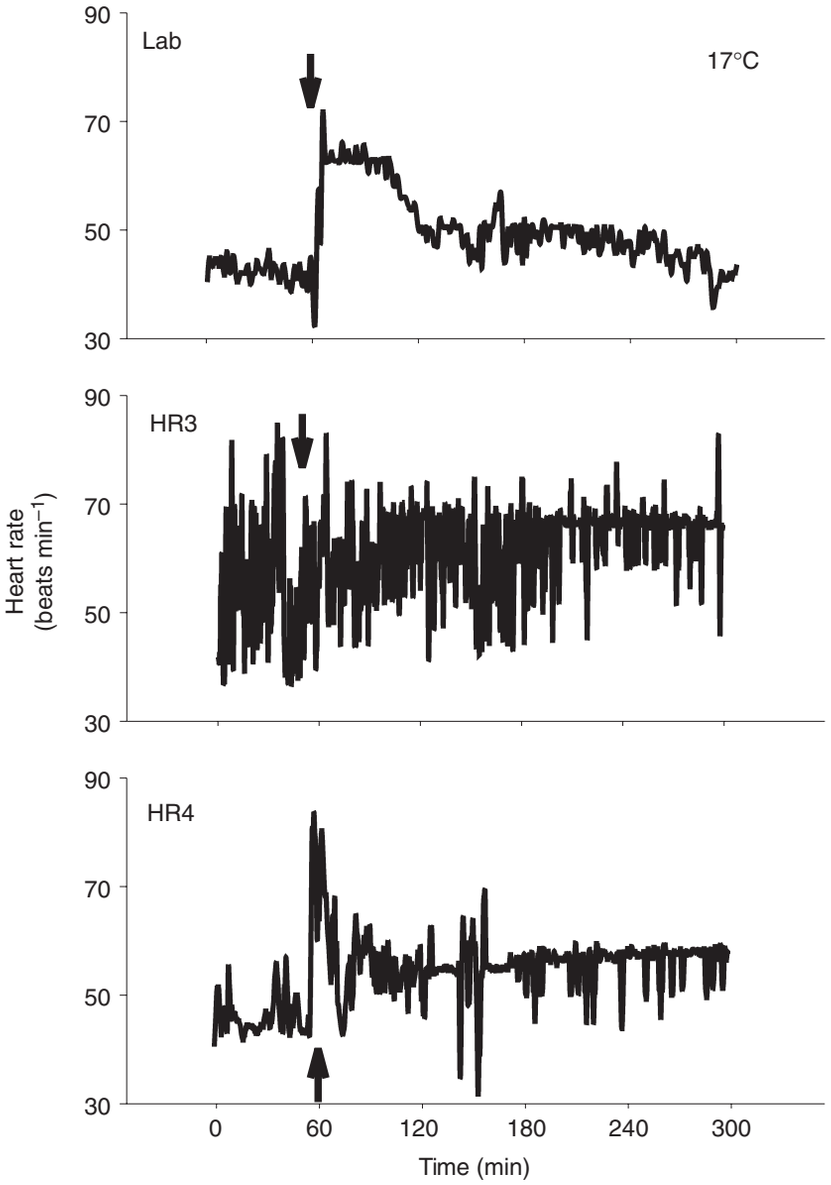

Fig. 3. Trace of largemouth bass heart rate measured using two techniques at 17°C. The first 60 min of data are basal heart rate values, the arrow indicates exhaustive manual chasing (laboratory) or angling (field) and 30 s air exposure, and the remaining 240 min represent the recovery period. The uppermost panel is a representative largemouth bass heart rate trace (lab) measured with Doppler flow probes in the laboratory. The bottom two panels represent data collected from largemouth bass in the field using heart rate transmitters (HR3,4) (see Table 1). All data are plotted at the same resolution (60 s mean values)

(Cooke et al., 2002b). Our study uses measurements of cardiac activity to contrast and compare the effects of simulated angling in the laboratory and the effects of actual rod-and-reel angling on free-swimming fish in the field. The results that we present have implications for understanding catch-and-release angling effects and for conducting future studies of sub-lethal stress arising from catch-and-release angling.

Basal heart rate was much higher and more variable at a given water temperature in our field-collected data than in the laboratory data reported by Cooke et al. (in press). We do not believe that this difference suggests fish in the field are more stressed than fish in the laboratory. Instead, we feel that this variation in resting heart rate reflects the higher activity levels in the field, and the interaction of several other biological and environmental factors. Fish in the laboratory were restricted to a 70 L volume of water and often sat on or near the bottom, resulting in a reduction in metabolic rate. It is also possible that the fish in the laboratory may experience confinement stress that may increase heart rate. However, in our study the basal heart rate values from the laboratory were consistently lower than those from the field. As such, we believe that the basal cardiac values that we present from the laboratory are likely close to those that would be recorded at standard metabolic rates. In the field, fish were mobile and could move about as they wished. Locomotory activity in some species of fish is strongly coupled with heart rate (Sureau and Lagardère, 1991). Variation in activity levels experienced during locomotion (e.g. slow swimming, acceleration, turns) would also contribute to the variation in heart rate. A suite of possible biological and environmental factors could also contribute to the higher and more variable values. In laboratory environments, water temperatures are usually quite stable, but in natural environments, substantial thermal variation may result from currents, thermoclines, and patchy regions. Fish have been shown to detect temperature changes as small as 0.03°C (Bull, 1936) and may quickly respond both behaviorally to attempt thermoregulation (Crawshaw, 1977; Schreer and Cooke, 2002) and physiologically to compensate for thermal changes (Schreer and Cooke, 2002). Other factors such as social interactions (Cooke et al., 2002a), diurnal rhythms (Priede, 1983; Cooke et al., 2002a), wave action (Cooke et al., 2002c), and

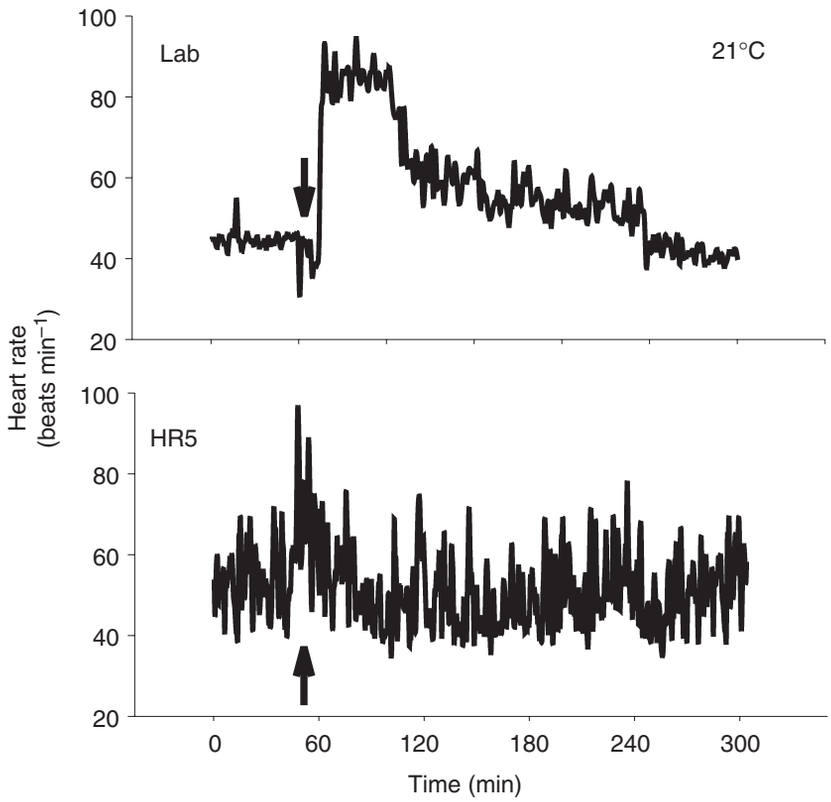

Fig. 4. Trace of largemouth bass heart rate measured using two techniques at 21°C. The first 60 min of data are basal heart rate values, the arrow indicates the exhaustive manual chasing (laboratory) or angling (field) and 30 s air exposure, and the remaining 240 min represent the recovery period. The uppermost panel is a representative largemouth bass heart rate trace (lab) measured with Doppler flow probes in the laboratory. The bottom two panel represents data collected from a largemouth bass in the field using a heart rate transmitter (HR5) (See Table 1). All data are plotted at the same resolution (60 s mean values)

meteorological changes may also contribute to heart rate variation.

Field values of scope for heart rate were consistently lower than laboratory determined values at all four temperatures that we studied, although they had higher maximal heart rates. Furthermore, the disparity between laboratory and field scope values increased with increasing water temperatures, likely as a result of several factors. Maximum heart rates for most teleost fishes appears to be about 120 beats per minute (Farrell, 1991; Lillywhite et al., 1999). In our study, values approached, but did not exceed this value at our highest temperature (25°C). The maximum heart rate determined from fish angled in the field was consistently higher by 4–20% than mean values determined in the laboratory. In addition, our resting heart rate values increased with temperature. As the resting rates of laboratory-derived data are more representative of standard metabolic rate than our field-derived data that included an activity component, less scope for heart rate was available in field fish. For this reason, field studies are more realistic because the fish are operating at basal levels and cardiac scopes that are reflections of routine metabolic rate, not standard metabolic rate as in the laboratory. Indeed, resting heart rates from fish in the field were consistently higher than laboratory values, with the disparity as high as 44%. Based upon these results, we predict (similar to Schreer et al., 2001) that the scope for heart rate would decrease at higher temperatures; basal heart rates would continue to conform to temperature increases, while the maximum heart rate plateaued (likely at ~120 beats per minute). Also of note is the fact that the transmitters are not capable of triggering at intervals that would be consistent with higher (i.e. ~130 beats/min) rates of cardiac contraction.

Four additional factors may have accounted for some of the variation in results between field and laboratory (Cooke et al., in press) data. First, it is possible that the differences in maximum heart rate that we observed reflect the different protocols used to exhaust the fish. Fish angled in the field became exhausted more rapidly than those chased until exhaustion in the laboratory. Laboratory chased fish were somewhat restricted in the intensity of their burst activity due to the size of the tank, whereas angled fish in the field had the opportunity to swim in numerous directions and to do so for longer durations. Secondly, to maintain a low transmitter to body-weight ratio, the fish angled in the field were larger than those chased in the laboratory. Body size has been shown to influence both aerobic and anaerobic metabolism in fish, although the relationships appear to vary with life history (Goolish, 1991). For largemouth bass, however, across the ranges of ~8–10 and 29–36 cm there was no relationship between anaerobic metabolism and body size (Kieffer et al., 1996). Thirdly, it is possible that the transmitter itself impaired the swimming ability of the fish in the field, leading to rapid exhaustion and variation in heart rate. We feel that this is unlikely, based upon our extensive observations of fish of this species equipped with heart rate transmitters; in these observations, all fish appeared to behave normally (Cooke et al., 2002a). Our transmitter packages generally weighed less than 2% of the body weight of fish, the widely accepted guideline for fish telemetry (Brown et al., 1999). Recent research suggests that transmitter weights approaching 4% can substantially elevate metabolic rates, whereas values close to 1% do not (Lefrancois et al., 2001). Our transmitter weights were closer to the lower value, suggesting that it is unlikely that the transmitter caused an appreciable increase in metabolic rate. Finally, in the laboratory, all fish were fasted for 48 h prior to surgery and experimentation. Although similar fasting occurred before surgery in the fish equipped with transmitters, these fish were released into enclosures that had numerous prey

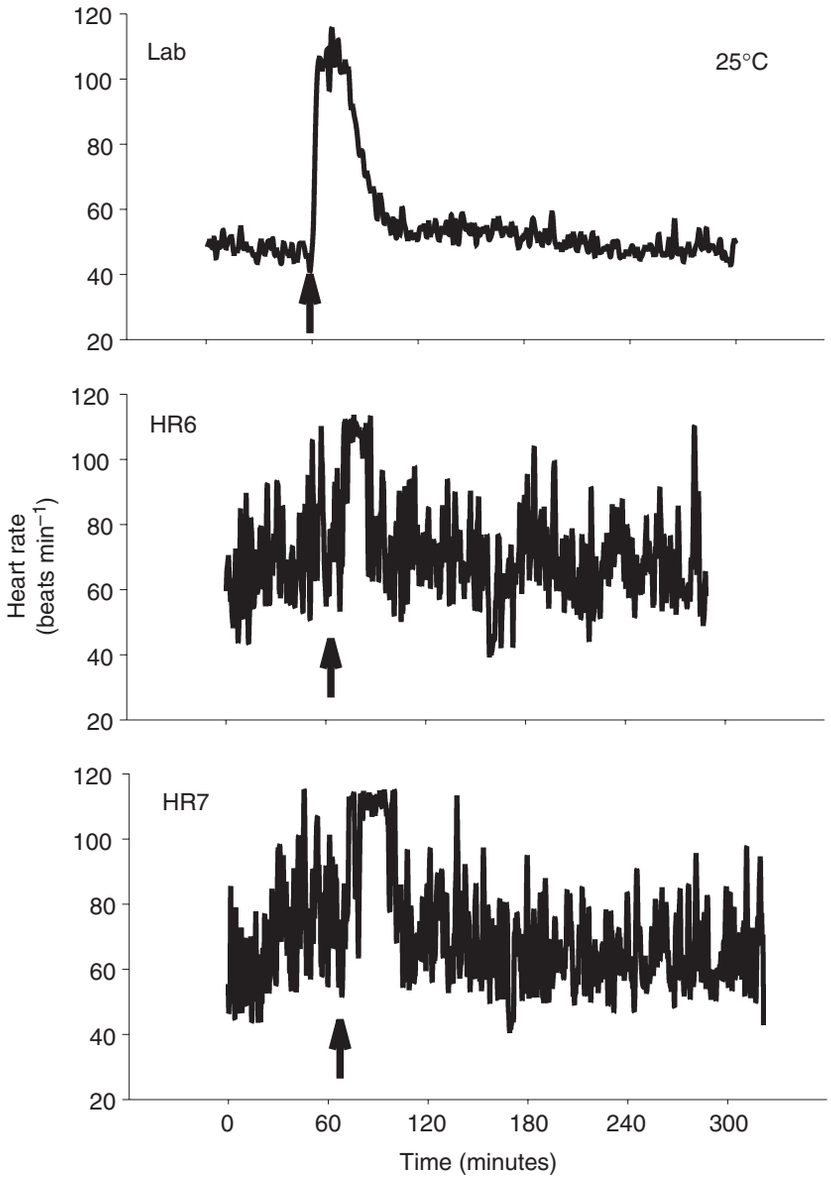

Fig. 5. Trace of largemouth bass heart rate measured using two techniques at 25°C. The first 60 min of data are basal heart rate values, the arrow indicates the exhaustive manual chasing (laboratory) or angling (field) and 30 s air exposure, and the remaining 240 min represent the recovery period. The uppermost panel is a representative largemouth bass heart rate trace (lab) measured with Doppler flow probes in the laboratory. The bottom two panels represent data collected from largemouth bass in the field using heart rate transmitters (HR6,7) (See Table 1). All data are plotted at the same resolution (60 s mean values)

sources. Using underwater videography we have observed transmitter-equipped fish chasing and ingesting prey as soon as 1 day following surgery. As a result, field angled fish may have had food in their digestive tracts that also influenced their basal metabolic rates (Armstrong, 1986), time until exhaustion, and recovery patterns. Indeed, the contribution of specific dynamic action (SDA) and digestive processes can elevate metabolic rate substantially (Schmidt-Nielsen, 1997). The field data collected are more reflective of fish angled in normal field situations, with varying levels of food quantity and quality in their stomachs. Overall, these potential sources of variation discussed here all likely contribute to the variation that were observed between the laboratory and field collected data.

In the previous laboratory study (i.e. Cooke et al., in press), the time required for largemouth bass cardiac parameters to return to pre-exercise levels in the laboratory was approximately 135 min across the range of water temperatures that we examined (13–25°C). Conversely, in our field collected data, it was not possible to clearly identify when fish had recovered, due to the large amount of variation that is attributable to numerous different sources (as discussed above). Of importance, however, is the finding that controlled laboratory studies may yield results that are not directly applicable to field scenarios. Studies monitoring the recovery of fish angled or exercised using remote cardiac parameters are rare. To date, the only other published study of this nature has been conducted on Atlantic salmon (*Salmo salar*) using wild fish in an enclosure in Newfoundland and hatchery-reared Atlantic salmon at a research station in Ontario. Using heart rate transmitters, Anderson et al. (1998) reported an increase in post-angling heart rate in wild Atlantic salmon that remained elevated for a period of up to 16 h; the authors describe a series of unpublished data in which heart rate following forced exercise peaked after 30 min of the recovery period, as monitored with cardiac output. Anderson et al. (1998) state that the reason for this discrepancy in recovery patterns between laboratory and field derived data is unclear, but may be attributed to the stresses of hooking and angling. Data for largemouth bass exhibit a similar pattern, in that fish chased in the laboratory for ~150 s and then held out of the water for 30 s exhibited a peak in heart rate within several minutes after being returned to the water (Cooke et al., in press). The heart

rates then slowed down over a 2-h period as they approached basal (pre-disturbance) levels. In the free-swimming fish, the pattern of recovery was not as predictable or distinct. Substantial variation in heart rate was exhibited for most fish throughout the 300 min during which we monitored cardiac parameters. We believe that these elevated periods reflect other stressors or activities that may or may not be influenced by the angling event, many of which were discussed earlier. Overall, the catch-and-release angling event resulted in some level of cardiac disturbance, but as a result of variation in heart rate (both before and after angling) it was not possible to precisely determine the magnitude of the disturbance and the time required for recovery.

Our results on the effects of catch-and-release angling on largemouth bass provide several conclusions for management and future research. Field and laboratory approaches such as those described here and in Cooke et al. (in press) proved to be useful for quantifying the sub-lethal effects of catch-and-release angling, however, each approach possesses several inherent properties that make them more effective for achieving different objectives. Laboratory studies are best suited for testing specific hypotheses in controlled environments. This type of study is essential for determining what aspects of the catch-and-release angling event and associated handling are most stressful. It also provides an opportunity to determine resting metabolic rate. Conversely, field studies are best suited for evaluating how fish respond to catch-and-release angling in natural conditions that include predation threat, opportunity for movement and foraging, and fine scale environmental variation (e.g. temperature, dissolved oxygen). Field studies will be more realistic, but often preclude large-scale manipulative experiments and the collection of baseline values. We advocate a comprehensive approach to the assessment of sub-lethal catch-and-release angling effects that incorporates both controlled laboratory studies and natural field studies. Furthermore, this comprehensive and integrated approach will facilitate an understanding of the suite of behavioral, energetic, and fitness related effects, not just physiological effects. We are confident that this approach will provide researchers with a better understanding of the mechanisms that magnify disturbances and expedite recovery and will also provide managers with a clearer and scientifically defensible strategy for minimizing sub-lethal effects resulting from catch-and release angling in recreational fisheries.

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