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Remote monitoring of heart rate as a measure of recovery in angled Atlantic salmon, *Salmo salar* (L.)

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Abstract

The introduction of 'Catch and Release' fishery programs are now widely employed by fisheries managers in most Atlantic Provinces, primarily due to the recent decline of Atlantic salmon stocks on the east coast of Canada. However, there is still considerable debate among special interest groups and regulators as to the effectiveness of the technique. Heart rate telemetry has been utilized as a tool for the assessment of metabolic rate in wild fish by a number of investigators, and was employed in the present study in order to assess recovery following staged angling events in Atlantic salmon. Wild Atlantic salmon were successfully angled at 20 ± 2 °C and 16.5 ± 1 °C at Noel Paul's Brook, Newfoundland. In addition, hatchery reared Atlantic salmon were angled at the Ontario Ministry of Agriculture and Fisheries Research Station, Alma, Ontario, at a temperature of 8 ± 1 °C. Survival rate for the angled salmon was 20% at 20 ± 2 °C; 100% at 16.5 ± 1 °C; and 100% at 8 ± 1 °C. Mean resting heart rate for the fish angled at 16.5 °C and 20 °C was approximately 1.6 and 1.8 times greater than that of fish angled at 8 °C. Heart rate, post angling, was found to increase 1.2 fold in the 8 °C group, 1.3 fold in the 16.5 °C group and approximately 1.15 fold in the 20 °C group. Time to recovery was assessed as a return to observed resting heart rate for each individual fish and was found to be similar for both the 8 °C and 16.5 °C angled groups (approximately 16 h). Although heart rate telemetry in fish is, perhaps, not an ideal measure of metabolic rate, the present study has demonstrated that remote monitoring of heart rate is a good indicator of post exercise physiological activity.

Introduction

Recent declines in the numbers of Atlantic salmon on the east coast of Canada have prompted federal and provincial governments to impose strict regulations on commercial and recreational fishing activities. One measure employed was the introduction of year round 'Catch and Release' fishery programs that are now widely used throughout most Atlantic Provinces. Although many fishery managers now practice catch and release, there is still considerable debate among special interest groups and regulators as to the effectiveness of the technique. Differences in opinion are largely focused on the limited knowledge available regarding post release survival rates and biological effects of angling on Atlantic salmon. As the importance in using catch and release programs as a management tool grows, particularly in Atlantic salmon sports fisheries, there is a greater need to understand how angling and releasing wild fish influences the recovery of the species.

Previous studies involving measurements of acid-base and metabolic disturbances have greatly assisted in our current understanding of the effects of angling on salmon physiology (Booth et al., 1995; Wilkie et al., 1996). These studies have validated laboratory findings concerned with acid-base and metabolic disturbances in exhaustively exercised fish, such as glycogen store depletion and increases in muscular lactate levels (Wood et al., 1983; Milligan & Wood, 1986). However, they have also raised important management questions with regards to optimal times for the implementation of catch and release programs, with temperature appearing to exert a major influence on the survivability of angled and released salmon.

The development of physiological telemetry techniques has enabled researchers to investigate and corroborate results previously reported in laboratory based studies. Using telemetry devices which measure physiological processes such as EMG activity (Kaseloo et al., 1992), and tailbeat frequency (Johnstone et al., 1992) researchers have attempted to correlate these physiological processes with metabolic rate and thus an estimation of energy consumption and fish activity. However, both these processes require the fish to swim and after exhaustive exercise, such as an angling event, the fish will typically remain motionless until such time when oxygen debt is repaid.

Heart rate telemetry has been utilized as a tool for the assessment of metabolic rate in wild fish by a number of investigators (Priede & Tytler, 1977; Armstrong, 1986; Lucas et al., 1991), with the correlation proving to be good in northern pike, *Esox lucius*, (Armstrong, 1986) but not as close in more aerobically active fish such as rainbow trout (Priede & Tytler, 1977). Although Thorarensen et al. (1996) recently demonstrated the drawbacks in using heart rate in fish as the sole indicator of metabolic rate, at the present moment, remote assessment of heart rate is by far the best indicator of physiological activity post exercise.

The present study utilised heart rate telemetry as a means of obtaining *in situ* measurements of activity during angling of Atlantic salmon, *Salmo salar*, and monitoring recovery following release.

Materials and methods

Staged angling events were carried out on wild Atlantic salmon grilse, at Noel Paul's Brook on the Exploits river system in Newfoundland in August of 1996. Ambient water temperature was found to vary greatly during the study period with a maximum temperature of 22 °C at the beginning, dropping to 16 °C towards the end of the study period. A total of 20 fish were used in the study in Newfoundland. Due to the nature of the physiological parameter being measured (see below) not all fish were found to exhibit a constant obtainable signal. However, a total of 10 fish were implanted with heart rate tags (Lotek Eng. Newmarket, Ont.) at Noel Paul's Brook and successfully angled. These fish were grouped into two main categories due to the varying temperature at the time of testing; 5 fish (3 males and 2 females) successfully angled at 20 ± 2 °C (mean weight 1723 ± 282 g, mean fork length 58.8 ± 4.1 cm), and 5 fish (2 females 3 males) successfully angled at 16.5 ± 1 °C (mean weight 1295.6 ± 79.6 g, mean fork length 54.4 ± 1.2 cm). Staged angling events for hatchery reared Atlantic salmon were carried out at the Ontario Ministry of Agriculture and Fisheries Research station in Alma, Ontario in September 1996. Temperature at the fish hatchery during the study period was 8 ± 1 °C. A total of 6 fish (3 females, 3 males) were angled at the hatchery (mean weight 2888 ± 185 g, mean fork length 61.33 ± 1.1 cm).

Due to the nature of the pool where the wild fish were angled, the potential was there for these fish to escape into the Exploits river system. Consequently, an anaesthesia that would produce sufficient calmness for a 10–15 min surgical operation and did not demand an extensive withdrawal period post-release, such as MS-222, was required. The natural anaesthetic Clove oil (Anderson et al., 1997), at a concentration of 40 mg l^{-1}, was used to induce anaesthesia. Once a sufficient depth of anaesthesia was deemed to have been reached the fish were transferred to a foam bed where a fresh solution of well aerated clove oil (30 mg l^{-1}) was irrigated across the gills for the duration of surgery. The heart rate transmitters used in the present study were 18 g in air (8 g in water) and 5×1.6 cm (LOTEK Eng. Newmarket, Ontario). Each tag was cleaned in ethanol prior to insertion, allowed to airdry, and gold tips were attached to the end of each electrode to aid in electrical contact and anchorage within the pericardial cavity.

A small incision was made on the ventral surface of the fish (approx. 2 cm) and the body of the tag was inserted within the abdominal cavity with the trailing antenna brought out through a small puncture wound on the ventro-lateral side of the fish. The electrode wires were brought through the anterior end of the wound, subcutaneously, towards the pectoral fins. The gold tips were placed on specially designed surgical probes and positioned within the pericardial cavity through small holes in the lepidotrichs bone of the pectoral girdle (Harder, 1975). Due to the nature of the physiological process being measured, constant contact with the heart was necessary to ensure a consistent signal from the transmitter. As a consequence, those fish which gave a constant signal during the operating procedure did not always provide a constant signal once recovered, particularly during periods of high activity such as angling. In an effort to reduce this, the electrode wires leading from the pericardial cavity to the abdominal cavity were tightly secured onto the ventral surface of the fish, with enough slack to allow for free movement of the electrode wires with the movement of the fish. An autopsy was also carried out on each individual post experiment to ensure the electrodes were still positioned appropriately. The abdominal incision was closed with 4–6 sutures and a button tag was sutured anterior to the dorsal fin for future identification. The fish was then removed from the operating table and placed in a recovery tank (2 m × 1 m × 0.5 m) filled with fresh aerated river water at ambient temperature. All fish were allowed a minimum of three days in the recovery tank prior to the angling event. Resting heart rate was recorded between 48 and 72 h post surgery.

The angling events in Noel Paul’s Brook were carried out in a controlled channel (25 × 5 × 1 m) at Noel Paul’s Brook adjacent to the station. For each individual angling event, fish were removed from the recovery tank, placed in a cooler of fresh aerated water, transferred to the channel, manually hooked (#8) in the upper jaw and released. The fish were then angled to exhaustion on an 1.8 m graphite fly rod using 7 weight line and a 10 weight tippet. Exhaustion was deemed to have been reached when the fish no longer responded to the angler. Upon exhaustion the fish were released from the hook and immediately released into the angling pool. Heart rate of these fish was recorded as soon as the fish was manually hooked and released into the channel using a SRX_400 telemetry receiver fitted with W20 firmware (LOTEK Eng. Newmarket Ontario). Post angling heart rate was continually recorded for a minimum of 3 h and up to 16 h where possible. Hatchery reared fish at the Alma Research Station were operated on, hooked and angled in a similar fashion as those in Newfoundland except that the hatchery reared fish were angled in a large 10 m diameter by 1.5 m deep circular tank.

Results

Analysis of the heart rate data has concentrated on the angling period and the following recovery period (Figures 1, 2 and 3). Each value presented in figures 1, 2 and 3 is a mean ± 1 SE and represents a minimum sample size of 4. Although the 16.5 °C fish were angled for an average of 5.1 min, sufficient telemetry data was not obtainable due to the intermittency of signal from the heart rate transmitters (particularly during periods of high activity) and also the low angling times in some of the fish. This also applies to the 20 and 8 °C groups, where angling times were an average of 11.8 and 8.1 min, respectively.

The mean resting heart rate of fish angled at 8 ± 1 °C was 40 ± 0.28 beats per minute (bpm), and ranged from 34.2 ± 0.5 bpm to 48.2 ± 0.5 bpm. Mean resting values for the fish angled at 16.5 ± 1 °C was 66.9 ± 0.5 bpm with a minimum of 54.8 ± 0.4 and a maximum of 88.8 ± 1.3 bpm. Mean resting values for the fish angled at 20 ± 2 °C was 72.3 ± 0.4 bpm, and ranged from 53.4 ± 1.81 bpm to 87 ± 1 bpm (Figure 1).

Mean peak heart rate in the 8 °C fish post angling was 48.77 ± 0.7 bpm which occurred 2.5 h after the event (Figure 2). Mean peak heart rate values in the 16.5 ± 1 °C group was 90.68 ± 1.4 bpm 4 hrs after angling (Figure 2). Heart rate in both the 16.5 and 8 °C groups did not return to basal for as much as 16 h (Figure 2). Due to the high mortality rates experienced in the 20 °C group sufficient numbers for the recording of heart rate beyond 3 h was not obtainable. Mean peak heart rate values in the 20 ± 2 °C group was 83.54 ± 0.17 bpm 35 min after angling (Figure 3). Furthermore, heart rate of these fish during the three hour observation period appeared to be very unpredictable.

One of the most striking initial findings of the present study was the mortality rate of fish post angling. Of the five fish angled at 20 ± 2 °C, only one fish survived the following 72 hour post angling period. All the wild and hatchery reared salmon angled at 16.5 ± 1 °C and 8 ± 1 °C respectively survived the event and were in good condition when removed for autopsy following the 72 h observation period. Interestingly, exhaustive states at 20, 16.5 °C, and 8 °C were found to be visually very different. The 20 and 16.5 °C fish at the end of the angling period were found to be extremely docile and in some cases unable to maintain equilibrium immediately post release from the hook. However, the 8 °C fish, although exhausted to the extent that handling was not difficult, were still able to maintain equilibrium and in some cases hold station within the circular tank. These visual observations are reflected in the heart rate telemetry data, whereby the heart rate between 1 and 4 min of angling in the 16.5 °C group decreased from basal by a factor of 1.4 (Figure 1). A similar decrease (factor of

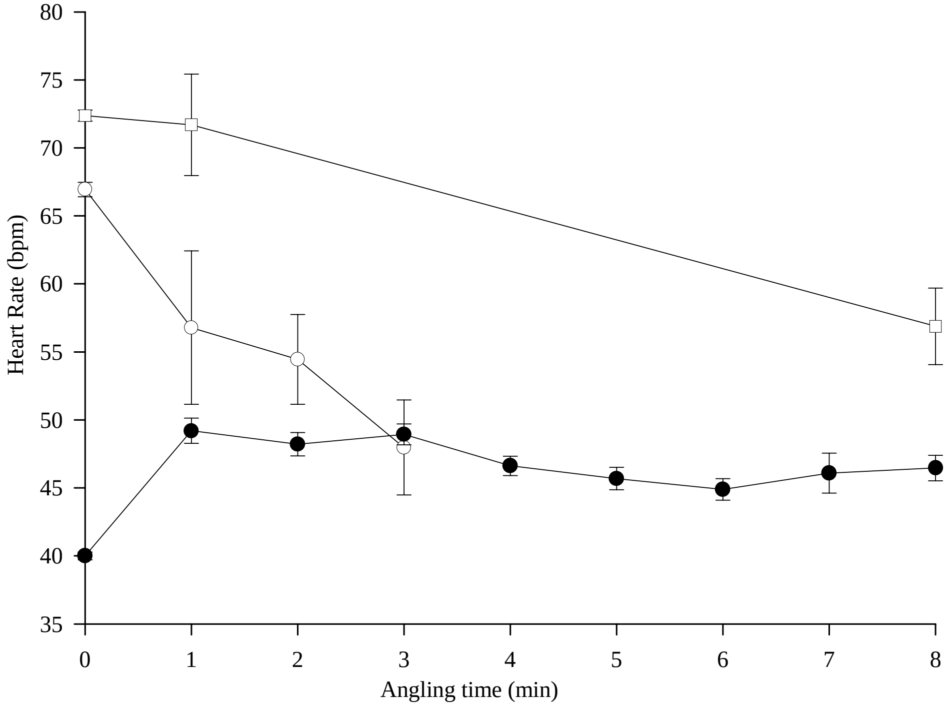

Figure 1. Change in heart rate of adult Atlantic salmon during angling at 3 distinct temperatures. Open circles = 16.5 ± 1 °C; Open squares = 20 ± 2 °C; Closed circles = 8 ± 1 °C. Values are expressed as a mean ± 1 SE.

1.3) from 1–8 min of angling in the 20 °C group was observed. However, heart rate increased by a factor of 1.16 over an 8 minute angling period of the 8 °C group (Figure 1).

Discussion

Results from the present study have demonstrated an increase in resting values with an increase in temperature (Figure 1). Resting values of fish angled at 8 °C and 16.5 °C increased by a factor of approximately 1.6, which increased further to a factor of 1.8 from 8 to 20 °C. This is perhaps not surprising as heart rate in fish has been shown to be closely related to changes in temperature (Farrell & Jones, 1992) with the degree of vagal tone perhaps being a major factor with changes in temperature (Priede, 1974). Although, Gamperl et al., (1994) demonstrated levels of catecholamines and cortisol to remain elevated for up to six days post-operation, the present study used only a 48 h period prior to the collection of basal heart rate data. This was considered to be sufficient as previous studies using heart rate telemetry used a minimum of 24 h post surgery before the onset of experimentation (Claireaux et al., 1995; Lucas, 1994; Nelson et al., 1996). Furthermore, the results reported by Gamperl et al. (1994) were from fish confined in ‘black box’ experiments. The fish in the present study were allowed to recover in an large (2 m × 1 m × 0.5 m) recovery tank.

Examination of heart rate during angling has demonstrated a decrease in heart rate of the wild fish angled at 20 and 16.5 °C but an increase in heart rate of the hatchery reared 8 °C group. Visual observations during angling demonstrated that the wild fish fought very well with the angler and would often use anaerobic bursts in swimming in an effort to escape from the line. The hatchery reared fish on the other hand did not demonstrate a similar willingness to fight to the extent that one fish had to be dragged through the water to encourage it to struggle. Burst exercise in fish has been reported to induce a bradycardia (decrease in heart rate) (Stevens et al., 1972; Farrell, 1982). This depression is considered to be necessary to avoid hypertension as the violent contractions of skeletal muscle close off the peripheral blood vessels (Farrell & Jones, 1992). It is possible, therefore, that the depression in heart rate in the wild fish is due to the intense activity in these fish in comparison to the hatchery reared fish at 8 °C fish. Whether the reduction

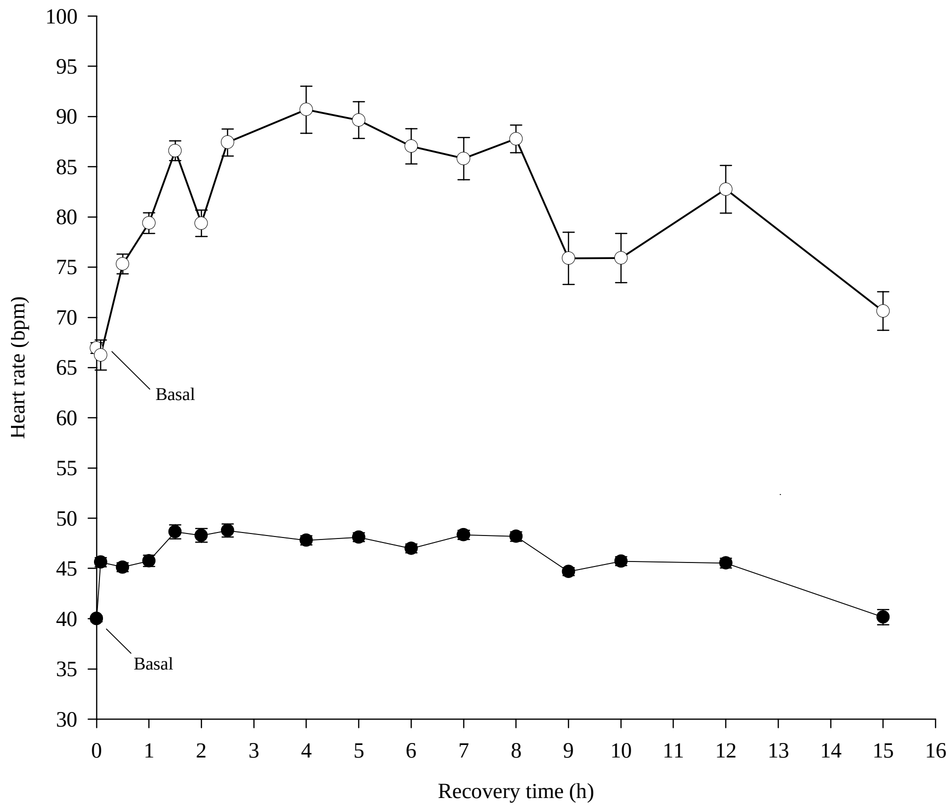

Figure 2. Change in heart rate of adult Atlantic salmon during recovery from angling at two distinct temperatures. Open circles = 16.5 ± 1 °C; Closed circles = 8 ± 1 °C. Values are expressed as a mean ± 1 SE.

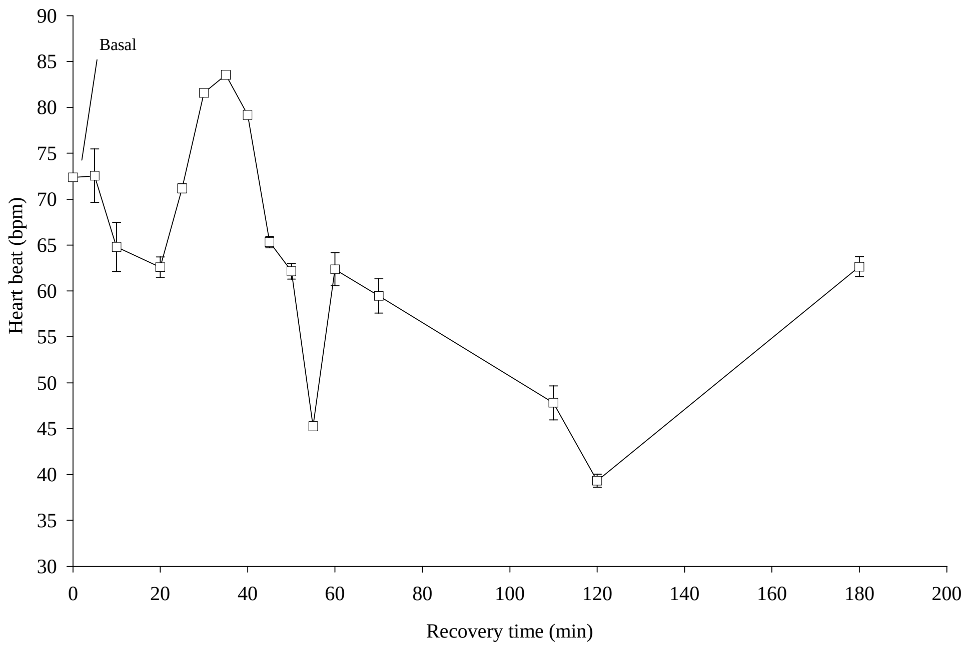

Figure 3. Change in heart rate of adult Atlantic salmon during recovery from angling at 20 ± 2 °. Values are expressed as a mean ± 1 SE.

in activity of the 8 °C fish was a function of temperature or their life history is hard to say. However, studies investigating the swimming performance of wild and hatchery reared Atlantic salmon smolts and parr have produced conflicting results with regards to holding ability and swimming performance, with the hatchery reared fish generally having a lower performance than their wild counterparts (Graham et al., 1996; Moore et al., 1995; Peake & McKinley, 1997; Rimmer et al., 1985).

Although trends in heart rate during angling of the 8 and 16.5 °C groups varied considerably, the trend in heart rate during recovery of these two groups did not. Both groups demonstrated an increase in heart rate post angling for up to 16 h. However, the elevation in heart rate above resting levels was greater in the 16.5 °C group than that observed in the 8 °C group. Maximal increase above basal during recovery in the 8 °C group was by a factor of 1.2 after 2.5 h, whereas heart rate increased by a factor of 1.35 in the 16.5 °C group 4 h after angling. Interestingly heart rate peaked in Atlantic salmon recovering from forced exercise within 30 min of the trial by factors of 1.2 and 1.3 for 8 and 18 °C acclimated fish (Anderson, unpublished data). The reasons for the discrepancies in recovery times between the forced exercised fish and the angled fish is unclear. However, the stressful event of being hooked and angled will certainly have exacerbated any cardiovascular changes associated with exhaustive exercise. This demonstrates the usefulness of the heart rate transmitter in varifying and extending our knowledge of the cardiovascular function in fish post exercise.

Unfortunately extended recording of heart rate in fish angled at 20 °C was not possible due to the mortalities in this group. However, what is evident is that the heart rate of these fish immediately after angling and for the following 3 h followed an unusual trend. Typically following exhaustive exercise, fish heart rate increases (Farrell & Jones, 1992) and this is demonstrated in the present study for the 8 and 16.5 °C fish. However, immediately after angling the heart rate of the 20 °C group dropped below basal and remained lower for up to 30 min. The reasons for this are unclear but what is not known is changes in stroke volume and ultimately cardiac output during this time. To compensate the observed dramatic decrease in heart rate following angling in this group (Figure 3), one would expect an even bigger increase in stroke volume to allow for an anticipated increase in cardiac output following exhaustive exercise.

Success of catch and release obviously depends on the survival rate of released salmon and, therefore, the question of recovery rate and delayed mortality is important. Delayed mortalities have been reported in some exhaustively exercised and angled fish (Bouck & Ball, 1966; Beggs et al., 1980; Graham et al., 1982; Wood et al., 1983; Ferguson & Tufts, 1992), but relatively low mortality has been reported for caught and released wild Atlantic salmon (Booth et al., 1995; Tufts et al., 1991). However, Wilkie et al. (1996) reported a mortality rate of 40% in their angled salmon, a figure which is lower than the present study for fish angled at high temperatures (80%) which may be a function of the increased stress and temperature on the fish implanted with a transmitter. However, zero mortalities in both the 16.5 and 8 °C angled groups would indicate that an increase in temperature is the critical factor regarding increases in the likelihood of delayed post angling mortality. Although all the fish angled at 16.5 ± 1 °C survived the angling event, immediately post angling the fish were very docile and in some cases were unable to maintain equilibrium. As a consequence, if further excessive demand is placed on the heart in response to a repeated stress in warmer waters, these fish could have a reduced ability to adjust cardiovascular parameters accordingly and, therefore, increase the likelihood of mortality.

Heart rate during recovery in the fish angled at 20 °C was very irregular, the reasons for which are unknown but serve to underline the severe physiological imbalance these fish experience post angling. The cardiovascular parameters in conjunction with the reduction in metabolites (Wilkie et al., 1996) of fish angled at higher temperatures could make them more susceptible to disease, although this would occur over the longer term. Furthermore, fish angled at these temperatures experience an energy loss which could ultimately effect their ability to spawn and/or defend nesting sites. Interestingly however, Booth et al. (1995) demonstrated that fish angled in the late fall (6 °C) very close to the spawning season did not have a reduction in spawning capacity when compared to fish not angled and taken at the same time.

Catch and release programmes were employed by fisheries managers in North America as a early as 1964 (Barnhart, 1989) as year round strategies, in an effort to reduce depletion of fish stocks related to overfishing in rivers and lakes. The suite of catch and release studies carried out in New Brunswick, Canada (Bielak, 1996; Booth et al., 1995; Wilkie et al., 1996), in combination with the present study, demonstrate that catch and release may not be an effective management strategy throughout the entire season. Angling during the mid summer months when water temperatures are close to and in excess of 20 °C may well induce a high percentage of delayed post angling mortality. Unfortunately management decisions based solely on changes in temperature would be difficult to implement as prediction of river temperature is not precise. Furthermore, the dynamic range of temperature throughout any given river system could vary considerably. Consequently, a clearer understanding of the environmental changes in individual watersheds is warranted prior to the implementation of catch and release management decisions based on temperature alone.

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