**Biological Implications of "Catch and Release" Angling of Atlantic Salmon**

**Managing Wild Atlantic Salmon**
**New Challenges – New Techniques**

**ABSTRACT**

Catch and release is an integral component of the management strategy for multi-sea-winter Atlantic salmon in Canada. In addition, voluntary catch and release of grilse is promoted. Until recently, however, there had been only minimal published research on the effects of catch and release in Atlantic salmon. Over the course of several years, we have therefore examined the biological effects of catch and release in Atlantic salmon under a wide range of conditions, both in the field and in the laboratory. Taken together, our results show that the vast majority of Atlantic salmon probably do survive to spawn following catch and release. These studies also indicate that certain conditions such as extremely soft water, water temperatures elevated above 22°C, or a recent transition from sea water to fresh water may increase the magnitude of the physiological disturbance and the probability of mortality following catch and release. Thus, while our studies provide biological evidence which generally supports catch and release as a conservation strategy, it is also important to consider the conditions under which the salmon will be angled when evaluating the potential benefits of catch and release for a particular sport fishery.
INTRODUCTION

Human activities, over-exploitation, habitat degradation, species introductions, and a number of other biological and environmental perturbations have led to decreases in the stock abundance of many native fish species and deterioration of the fisheries that they support. In response, fisheries managers have initiated a variety of management and regulatory measures aimed at conserving fish stocks while maximizing the economic and social benefits that can be derived from their fisheries. One such measure that has received widespread acceptance is the use of catch-and-release regulations in recreational fisheries (Barnhart 1989).

In North America, catch-and-release regulations were adopted for trout fisheries in Michigan as early as 1949 (Shetter et al. 1954) and catch-and-release only trout fisheries were in place on some systems by 1954 (Barnhart 1989). Over the past 40 years, catch-and-release philosophy and regulations have expanded in application to include salmonid fisheries throughout North America, and more recently, to fisheries for warm water and marine species (Barnhart 1989).

The premise that caught-and-released fish survive and contribute offspring to their natal population in the same manner as un-angled fish has been challenged since the early days of catch-and-release fishing, and it has been incumbent upon fisheries biologists to quantify the effectiveness of catch-and-release as a management tool. To this end, a great deal of research, particularly on salmonids, has been carried out to determine the survival of caught-and-released fish and the effects of gear types, angling and handling practices, and biological and environmental variables on this survival (Wydoski 1977; Dotson 1982; Schill et al. 1986; Bendock and Alexandersdottir 1993). Other investigators have tried to establish the physiological basis for the delayed mortality observed in some fish following exhaustive exercise or angling (Bouck and Ball 1966; Wood et al. 1983). In addition, the sublethal effects of catch-and-release angling on factors such as migratory behavior and reproductive success have been examined (Marnell and Hunsaker 1970; Reingold 1975; Petit 1977).

The following paper reviews the history and status of catch-and-release regulations and research applicable to Atlantic salmon in eastern North America. It also presents a synthesis of recent research conducted by, or in collaboration with, the authors and discusses the implications of this research for the management of Atlantic salmon.

History of catch-and-release regulations for Atlantic salmon in eastern North America

Although advocated as early as the 1870s (Wydoski 1977), the acceptance of catch-and-release as a conservation measure for Atlantic salmon in eastern North America is a relatively recent phenomenon.

In Atlantic Canada, a selective catch-and-release fishery was initiated on Nova Scotia's Margaree River in 1979 (Bielak and Tufts 1995). The first catch-and-release only fisheries were introduced
by the province of New Brunswick in 1981 on the Big Salmon River and three headwater tributaries of the Miramichi River (W. Hooper, personal communication).

In 1984, maritime-wide concerns for the conservation of declining populations prompted Canada's Department of Fisheries and Oceans (DFO) to introduce catch-and-release regulations to the recreational fishery for Atlantic salmon throughout the Atlantic Provinces. Under these regulations, only salmon less than 63 cm (one-sea-winter, predominantly males) can be retained by anglers. All salmon greater than 63 cm (multi-sea-winter, predominantly females) must be released. The introduction of this "grilse only" regulation resulted in the release of an average of approximately 21,000 angled large salmon annually during the 1984 to 1994 period.

Although the Province of Quebec initially adopted a different management strategy, one not involving mandatory catch-and-release (Bielak and Tufts 1995), with increased public acceptance of its value, the practice has increasingly become part of Quebec's salmon management arsenal.

In the eastern United States, Maine is the only state that still possesses fishable populations of sea-run Atlantic salmon. Since 1995, Maine has restricted the angling of sea-run salmon to catch-and-release only. Further regulations aimed at improving catch-and-release practices and restricting seasons to periods that avoid warm water in order to maximize the survival of caught-and-released fish were introduced in 1997 (E. Baum, personal communication).

**Historical research into the effects of catch-and-release in Atlantic salmon**

Despite an extensive literature on catch-and-release practices in salmonid fisheries (see reviews by Wydoski 1977; Barnhart 1989), prior to 1991 there had been very little published on the effects of catch-and-release fishing on Atlantic salmon.

A series of experiments conducted on landlocked Atlantic salmon (Warner 1976, 1978, 1979; Warner and Johnson 1978) found that angling induced mortality was generally low (~5%) for most gear types but could be considerably higher (35%) for fish caught on worms in nursery areas. Most mortalities occurred within five days and up to 89% occurred within the first 24 hours post-angling. Mortality was significantly less for fish angled in the fall compared to those angled in the spring. Hooking location (particularly hooking in the esophagus or gills) and bleeding were implicated as the major factors affecting post-angling mortality.

Grant (1980, 1983, in Bielak and Tufts 1995) described a tagging study of caught-and-released sea-run Atlantic salmon conducted on the Grimsa River in Iceland from 1977 to 1979. Of the 421 angled salmon that were tagged and released as part of the study in 1978 and 1979, 15% were angled a second time. No mortality of caught-and-released salmon was observed. It was acknowledged, however, that the environmental conditions under which the study was conducted were excellent for salmon (low temperature, well-oxygenated water) and the inference was made that higher water temperatures and lower oxygen levels might result in lower post angling survival.
The only other study prior to 1991 that examined the effects of catch-and-release angling is apparently that of Currie (1985) which monitored the effects of catch-and-release only angling during the 1982-1984 seasons on North Pole Brook, a coldwater tributary of the Little Southwest Miramichi. In the initial year of the study, a 3% mortality rate of caught-and-released salmon was observed. These mortalities had been hooked in the gills or the eye. No mortalities were observed during the subsequent two years. This study concluded that the hook-and-release fishery coupled with an upstream fishery closure was contributing to recovery of the North Pole Brook's previously depleted salmon population.

**Background and rationale for further research**

As noted above, at the time of introduction of the "grilse only" regulation in Canada’s Atlantic Provinces, knowledge of the effects of catch-and-release practices on Atlantic salmon biology was, at best, sparse. The regulatory changes that were made were largely based on the success of catch-and-release regulations in the conservation and management of other salmonid fisheries. There was a need to develop an empirical basis for the application of catch-and-release to the management of Atlantic salmon.

In 1991, proposals to extend salmon angling seasons into mid- to late-October on the Margaree and Miramichi Rivers prompted conservation organizations to request a study of the implications of such season extensions on the survival and spawning success of caught-and-released salmon. In response to this request, in the fall of 1991, the Department of Fisheries and Oceans initiated a study of the survival and spawning success (gamete viability) of late-season angled salmon. During that same period, researchers in the Biology Department at Queen's University had begun physiological studies to examine the influence of specific factors such as brief air exposure on the recovery and survival of salmonids after catch and release (Ferguson et al. 1992). In the subsequent year, a collaboration was developed between these groups, as well as a variety of other parties, to study catch-and-release issues pertaining to Atlantic salmon. As a result, the previous year’s study was expanded to include the physiological effects of late-season angling on Atlantic salmon. In addition, a wide range of further studies was planned to examine the impact of numerous endogenous and exogenous factors on the physiology and survival of angled and/or exhaustively exercised Atlantic salmon.

**OUTLINE OF METHODS AND APPROACH**

**Physiological Analyses**

Numerous laboratory studies have shown that exhaustive exercise results in a marked physiological disturbance in salmonids (reviewed in Wood 1991). Several studies have also reported delayed mortality in fish following exhaustive exercise (Black 1958; Beggs et al. 1980; Graham et al. 1982; Wood et al. 1983). Although the exact cause of mortality after severe exercise is unknown, Wood et al. (1983) suggested that the cause might be related to the magnitude of the physiological disturbance within the muscle. Until recently, determination of the physiological status of the muscle in a fish has been a technically challenging problem. Portner et al. (1990) described a convenient method, however, which can be used to sample
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muscle either in the field or in the lab for later determination of its physiological status. Most of our studies have incorporated this approach. Typically, our physiological analyses have included white muscle energy reserves such as phosphocreatine (PCr), adenosine triphosphate (ATP) and glycogen. Lactate concentrations and acid-base status (pH and in some cases bicarbonate and metabolic proton levels) were also determined to assess the extent of anaerobic metabolism in exhaustively exercised/angled salmon. Changes in these variables during angling or exhaustive exercise, as well as their rate of return to resting levels during recovery, have then been used to gain insight into the magnitude of the physiological disturbance under a given set of conditions. In addition, blood samples obtained from indwelling cannulae (following Smith and Bell 1964) were used in some of our laboratory studies to gain insight into the physiological status of exercised salmon. Measurements of variables such as blood glucose and ion concentrations were also made in some experiments as indirect indicators of the magnitude of the stress response. Parallel experiments were normally carried out to monitor survival, but it was believed that these physiological measures would help to identify conditions that exacerbated the disturbance after angling. More detailed explanations of this methodology and our protocols may be obtained in several recent publications (Booth et al. 1995; Brobbel et al. 1996; Wilkie et al. 1996; Wilkie et al. 1997).

Wild versus Hatchery Salmon

Wild salmon numbers were desperately low, hence hatchery reared salmon were used in several series of experiments within this research program. Since it is well established that numerous behavioural and physiological differences exist between wild and hatchery reared salmonids, the physiological responses of the hatchery fish probably differed quantitatively from those of wild salmon. An important benefit gained from using hatchery fish in some experiments, however, was that factors such as thermal history and nutritional status, which were unknown in wild salmon, could be easily established. Thus, the use of hatchery fish in some studies provided us with a powerful tool to carry out highly controlled experiments and thereby isolate specific factors that might influence the magnitude of the physiological disturbance after exercise or angling.

Tagging and Radio Tracking

In field studies monitoring the survival and migration of wild Atlantic salmon caught and released by the general public, a number of angled or trapped (control) salmon were tagged using commercially available Carlin tags (Floy Tag Co., Seattle WN, USA) and released. Carlin tags were implanted in the dorsal cartilage posterior to the first pterygiophore and secured around the dorsal fin ray. The tagging procedure was conducted with the fish continually submersed in water and the entire process lasted about two minutes.

Additional salmon were also fitted with radio transmitters. The transmitters (60 mm x 20 mm) were custom made by L.L. Electronics (Manhomet, IL, USA) and their total weight was always less than 3% of the salmon's body weight. Using a plastic tube, fitted with a plunger, the transmitters were inserted into the gullet of salmon that had either been trapped or angled. The salmon were then released and their subsequent location was determined at several times during
the following days and weeks using a Suretrack 1000 radio receiver and a portable directional Yagi receiving antenna (Lotek Engineering, Ont. Canada).

**Study Sites**

Experiments were conducted at the DFO's Miramichi, Cardigan, and Margaree Salmonid Enhancement Centres, and through the cooperation of the New Brunswick Department of Natural Resources and Energy's (NBDNRE), at their barrier fences on the North Branch of the Main Southwest Miramichi (Juniper) and the Upsalquitch River (Ten Mile Pool). Additional field studies were also conducted on the Upsalquitch and Restigouche Rivers in New Brunswick and the Lahave River in Nova Scotia.

**RATIONALE AND RESULTS OF SPECIFIC STUDIES**

**Late Fall Angling**

On many rivers in eastern Canada, regulations permit angling of Atlantic salmon into the late fall, close to the spawning season. As mentioned above, late season extensions have also recently been proposed and/or implemented for a number of salmon rivers that do not have extended fall seasons. There is some evidence, however, that stress has negative impacts on reproduction in salmonids. In species such as rainbow trout and brown trout, for example, it has been shown that acute stresses during the reproductive cycle may adversely affect gamete quality (Carragher *et al.* 1989; Campbell *et al.* 1992). Thus, the possibility that angling just prior to spawning may also have a negative effect on reproduction in Atlantic salmon has led to concern and controversy over proposals for late season extensions in Eastern Canada. An initial goal of our research was therefore to examine the effects of angling wild Atlantic salmon during the late season. The specific objectives within this study were to: i) measure the magnitude of the physiological disturbance in wild salmon angled in the late fall, ii) assess survival under these conditions, and iii) determine the effects of angling on gamete viability. The detailed methods employed in these studies have been thoroughly described by Booth *et al.* (1995).

In a qualitative sense, the physiological response of Atlantic salmon to angling in the late season at 6°C (Booth *et al.* 1995) was similar to that associated with other forms of exhaustive exercise in salmonids (Wood 1991). Interestingly, however, the rate of recovery of most physiological variables that were measured within the muscle of wild salmon angled in the late fall was generally more rapid than that observed in other species such as wild rainbow trout following exhaustive exercise. For example, within two and four hours of angling, white muscle pH and lactate in Atlantic salmon caught in the late fall return to levels which are not significantly different from those in control (*i.e.* resting) fish (Fig. 1). In addition, there were no mortalities within the physiological experiments prior to sampling, nor were there any mortalities among 20 salmon that were angled and transported to the hatchery (Table 1). In addition, similar survival of eggs from angled and non-angled salmon occurred (98 and 97%, respectively). Finally, the absence of significant changes in blood glucose levels suggests that the stress response was minimal in wild salmon angled under these conditions. Taken together, our results indicate that the likelihood of delayed mortality is minimal and there are probably no significant
consequences on gamete viability following angling and release of Atlantic salmon in the late fall.

Figure 1. (A) Lactate concentration ($\text{La}^-$) and (B) intracellular pH (pHi) in the white muscle of Atlantic salmon at rest and at various times during recovery from exhaustive angling in the late fall ($6^\circ\text{C}$). An asterisk denotes a significant difference from the resting value. Re-drawn from data of Booth et al. 1995.
Table 1  Survival of Atlantic salmon after exhaustive exercise or angling under various conditions.

<table>
<thead>
<tr>
<th>Study/Conditions</th>
<th>N-number</th>
<th>Survival</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late Fall - 6°C</td>
<td>20 MSW salmon</td>
<td>100%</td>
<td>Wild salmon experimentally angled to exhaustion in their natural environment. Recovery (24h) in holding boxes in the river.</td>
</tr>
<tr>
<td>Mid-Summer - 22°C</td>
<td>10 grilse</td>
<td>60%</td>
<td>Wild grilse experimentally angled to exhaustion in their natural environment. Recovery (24h) in holding boxes in the river.</td>
</tr>
<tr>
<td>Temperature - 12°C</td>
<td>10 grilse</td>
<td>100%</td>
<td>Hatchery-reared grilse exercised to exhaustion and recovered in a holding tank for 3 days.</td>
</tr>
<tr>
<td>Temperature - 18°C</td>
<td>10 grilse</td>
<td>100%</td>
<td>Wild grilse experimentally angled to exhaustion. Recovery (4-12h) in holding boxes.</td>
</tr>
<tr>
<td>Temperature - 23°C</td>
<td>10 grilse</td>
<td>70%</td>
<td></td>
</tr>
<tr>
<td><strong>Different migratory states</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kelts - 4°C</td>
<td>12 grilse</td>
<td>100%</td>
<td>Wild grilse experimentally angled to exhaustion. Recovery (4-12h) in holding boxes.</td>
</tr>
<tr>
<td>Bright salmon - 16°C</td>
<td>12 grilse</td>
<td>75%</td>
<td></td>
</tr>
<tr>
<td><strong>Water Chemistry - 15°C</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard neutral pH water(^1)</td>
<td>16 grilse</td>
<td>100%</td>
<td>Hatchery-reared grilse. Some grilse (roughly half) in each group underwent surgery 24 hours prior to experiments. Exercise to exhaustion and recovery (24h) in holding boxes.</td>
</tr>
<tr>
<td>Soft neutral pH water(^2)</td>
<td>25 grilse</td>
<td>68%</td>
<td></td>
</tr>
<tr>
<td>Soft acidic water(^3)</td>
<td>34 grilse</td>
<td>68%</td>
<td></td>
</tr>
<tr>
<td><strong>Air Exposure - 15°C</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 minute after exercise</td>
<td>14 grilse</td>
<td>100%</td>
<td>Wild grilse. Exercised to exhaustion and then air exposed. Recovered in holding tanks for 24 hours.</td>
</tr>
<tr>
<td><strong>Normal Angling</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upsalquitch R. - 20°C</td>
<td>25 grilse</td>
<td>92%</td>
<td>Wild grilse. Angled normally by the general public. Recovery (24h) in holding tank/boxes or in fenced pool in river.</td>
</tr>
<tr>
<td>Lahave R.(^4)</td>
<td>9 grilse</td>
<td>89%</td>
<td></td>
</tr>
</tbody>
</table>

N-number refers to the number of Atlantic salmon used in each survival experiment. \(^1\)CaCO\(_3\) = 90-100 mg L\(^{-1}\), pH = 6.7-7.2; \(^2\)Ca CO\(_3\) = 30-50 mg L\(^{-1}\), pH = 7.1-7.5; \(^3\)Ca CO\(_3\) = 30-50 mg L\(^{-1}\), pH = 5.3-5.9; \(^4\)Angling at various temperatures.
Grilse versus Multi-Sea-Winter Salmon

In order to minimize potential impacts of our studies on wild salmon populations, experiments such as those described above (section 3.1; Booth et al. 1995) were normally carried out on wild grilse. However, the current catch-and-release management strategy in eastern Canada is mainly oriented towards the release of the larger multi-sea-winter (MSW) salmon. MSW salmon are significantly larger than grilse and they generally require longer periods of time to land when they are angled. Moreover, Ferguson et al. (1993) showed that the magnitude of the physiological disturbance in hatchery rainbow trout following exhaustive exercise is directly related to body size and that larger individuals experience a greater disturbance after a similar period of exercise. Another objective within these studies was therefore to determine whether the post-angling disturbance in MSW salmon was significantly different than that in the smaller grilse.

The weights of the MSW salmon used in this study were about double that of grilse and, as expected, the MSW salmon required approximately twice the amount of time to be angled to exhaustion (landed) as compared to the grilse. Since these experiments required killing the fish for muscle tissue samples, the minimum number of MSW salmon were used to obtain our post-angling sample (N=6). Surprisingly, there were consistently lower levels of energy metabolites in the white muscle of grilse compared to MSW salmon immediately following angling (Fig. 2). In addition, grilse had significantly more lactate in their white muscle, and a lower muscle pH (intracellular muscle pH), than MSW salmon after angling (Fig. 2). Although appropriate resting samples were not available from the MSW salmon for comparison, these results strongly indicate that the magnitude of the post-angling disturbance in MSW salmon is actually lower than that in grilse.

Water Temperature

In Atlantic Canada, many salmon are caught shortly after they return to freshwater during the summer months when water temperatures are highly variable and often exceed 20°C. Angling at warmer temperatures exacerbates the physiological disturbances in the blood of rainbow trout (Wydoski et al. 1976) and largemouth bass (Gustaveson et al. 1991). It has also been suggested that warm water temperature is a major factor in delayed post-angling mortality in walleye (Fielder and Johnson 1994). In view of these results, one might therefore expect that angling of Atlantic salmon in warmer water may also lead to more pronounced physiological disturbances. Moreover, the likelihood of delayed mortality after angling may be increased in warmer water. Thus, two additional series of experiments were designed to evaluate the relative importance of water temperature on the physiological response of Atlantic salmon to angling. In the first set of experiments, wild Atlantic salmon were exhaustively angled in their natural environment in August when water temperatures averaged 20±2°C (Wilkie et al. 1996). In the second set of experiments, groups of hatchery reared Atlantic salmon were exhaustively exercised at 12, 18 and 23°C (Wilkie et al. 1997). In both sets of experiments, as in previous studies, a number of physiological variables were analyzed in control "resting" salmon and in salmon at various time
Figure 2. (A) White muscle concentrations of PCr, ATP and glycogen and (B) white muscle lactate concentration and pH in grilse (N=6) and MSW salmon (N=6) sampled immediately after angling in the late fall (6°C). An asterisk denotes a significant difference between grilse and MSW salmon values. Re-drawn from Booth et al. 1995.
periods following angling or exhaustive exercise. In addition, survival was monitored in subgroups of Atlantic salmon that were exposed to similar treatments, but not subjected to our full sampling regime.

In the first series of these studies, Wilkie et al. (1996) compared white muscle glycogen, pH and lactate levels in resting and angled wild Atlantic salmon at 20°C, with values reported in Booth et al. (1995) for wild salmon at 6°C. Although there were notable differences for each of these variables at the two temperatures both at rest and immediately following angling, the most striking contrast was the slower physiological recovery of the salmon under summer conditions. Considerable delayed mortality (40%) was also observed in a subgroup of Atlantic salmon that were angled at 22°C in the summer experiments (Table 1). By contrast, as explained above, there were no mortalities among the salmon angled under fall conditions at 6°C. The results of these studies suggest that physiological recovery from angling is slower in salmon angled in summer as compared to those angled in fall and that the likelihood of delayed mortality is greater in summer. Since the dissolved oxygen content of warm water is lower than that in cool water, we used measurements of pyruvate, lactate and pH to estimate the NAD⁺/NADH concentration ratio of white muscle to gain insight into whether oxygen availability limited the physiological recovery of Atlantic salmon in warm water. Our results indicated, however, that oxygen delivery was probably not a major factor impeding recovery of the warm water salmon.

Under laboratory conditions (Wilkie et al. 1997), the pattern of recovery for physiological variables in hatchery Atlantic salmon exhaustively exercised at different temperatures was markedly different than that observed during different seasons in the wild (i.e. summer vs. fall). Fig. 3 shows that, in the laboratory, salmon at cooler temperatures (12°C) required longer periods of time for the recovery of white muscle glycogen, lactate and pH after exhaustive exercise as compared to those exercised at higher temperatures (18 and 23°C). Consistent with the observations in the wild, however, significant mortality (30%) was only observed in salmon exhaustively exercised at the highest temperature (23°C) in the laboratory (Table 1).

**Different Stages of Migration**

During their freshwater spawning migration, which typically lasts from six months to a year, Atlantic salmon do not actively feed. Salmon that have spawned and are in the process of migrating back to sea are known as "kelts" or "black salmon" whereas those that have recently entered freshwater from the sea are referred to as "bright salmon". At present, angling for Atlantic salmon in eastern Canada is predominantly directed towards the runs of bright salmon. In sharp contrast to the situation for bright salmon, management policies regarding the angling of kelts are inconsistent. For example, it is currently illegal to intentionally angle for kelts in all Canadian provinces except Quebec and New Brunswick, where there are significant spring kelt fisheries at sites like the Miramichi River. Even the legal angling of kelts has been somewhat controversial since many people believe that angling and release of these starving and spent salmon may lead to their mortality and therefore could eliminate their future potential reproductive contribution.
Figure 3. Changes in white muscle (A) glycogen concentration (B) lactate concentration and (C) pH of Atlantic salmon following exhaustive exercise at 12°C (open bars), 18°C (hatched bars) or 23°C (solid bars). An asterisk denotes a significant difference from the resting value. A plus sign denotes values that are significantly different from the 12°C value at any given sample period. Re-drawn from Wilkie et al. 1997.
It is well known that starvation has a profound impact on the energy reserves of fish. In addition, it has been reported that starvation reduces white muscle glycogen stores in rainbow trout (Scarabello et al. 1991) and northern pike (Ince and Thorpe 1976). Since the anaerobic capacity of fish is largely determined by white muscle glycogen levels, it is likely that significant periods of starvation should also have an important impact on the magnitude of the physiological disturbance following angling. Hence, one would predict that the biological impact of catch-and-release angling may be quite different between kelts and bright salmon. Several other factors may also be important in determining the effects of angling on salmon at these different migratory stages. For example, kelts will have spent many months in freshwater prior to the spring kelt angling season whereas bright salmon may be still experiencing significant osmoregulatory stresses following their recent transition from seawater to freshwater. Finally, water temperatures during the spring when kelts are angled are normally less than 10°C whereas water temperatures during the summer months when many bright salmon are angled may approach 20°C. Thus, in view of the numerous factors that could potentially alter the physiological response to angling in Atlantic salmon at different migratory stages, and the general lack of information on this subject as a basis for management decisions, we carried out another series of experiments which compared the physiological response to angling, and survival, in bright salmon versus kelts. The specific methodology and results of these studies have recently been reported by Brobbel et al. (1996).

As expected, the condition factor of the bright salmon used in these studies was much higher than that for the kelts. In terms of the specific muscle energy reserves, both ATP and glycogen levels were also greater in resting bright salmon as compared to kelts. Predictably, the bright salmon required more time to reach exhaustion during angling. Since energy reserves such as glycogen were relatively low in the kelts, the magnitude of the post-angling physiological disturbance was smaller in these salmon (Fig. 4). There were also striking differences in the amount of time required for recovery in salmon at these different migratory stages. Almost all of the measured physiological variables had returned to resting levels within two hours of angling in kelts whereas a much longer period of time (between 4 and 12 hours) was required for recovery in the bright salmon. Changes in plasma ions indicated that angling also resulted in a greater osmoregulatory disturbance in the bright salmon and this disturbance had not fully recovered by the end of the 12-hour experiment. In terms of survival, there were no mortalities observed among the kelts prior to sampling, but three of the bright salmon died after angling in these experiments. These results are consistent with those of an experiment on Nova Scotia’s Margaree River conducted by the Margaree Salmon Association. During two successive spring seasons, kelts were angled on the Margaree River using a variety of gear types, and post-angling survival was assessed. Mortality was minimal in both years (0 out of 26, 1 out of 83), and the only mortality that did occur resulted from hooking in the gills. Our current results also support our original hypothesis that several factors, including the degree of starvation, osmoregulatory status and environmental temperature have a significant influence on the physiological response to angling in Atlantic salmon at different stages of their freshwater migration. The combined effects of these factors result in smaller physiological disturbances, and better survival, after angling in kelts as compared to bright salmon.
Figure 4. Comparison of (A) Glycogen concentration, (B) lactate concentration and (C) pH in the white muscle of kelts and bright salmon at rest and following exhaustive angling. An asterisk denotes a significant difference from the resting value. A plus sign denotes values that are significantly different from the 12 °C value at any given sample period. Re-drawn from Brobbel et al. 1996.
Soft or Acid Water

The physiology of most fishes, including salmonids, can be largely influenced by the chemical composition of their environment. In recent years, environmental acidification from anthropogenic sources has been identified as a major factor affecting salmonid populations. In Canadian provinces such as Nova Scotia, acidification of certain watersheds has caused a
significant reduction in the potential salmon production (Farmer et al. 1980; Lacroix et al. 1985; Watt 1986).

The potential impact of acid precipitation is largely determined by water hardness. Water hardness refers to the amount of dissolved calcium ($\text{Ca}^{++}$) and magnesium ($\text{Mg}^{++}$), and increases in the concentrations of these ions cause an increase in hardness. Since $\text{Ca}^{++}$ is present more frequently and occurs at higher concentrations, it is the most relevant cation with regard to water hardness (Graham et al. 1982; McDonald et al. 1989). According to Wood and McDonald (1982), acidification problems are essentially restricted to soft water. The significance of water hardness, however, is not confined to acidic environments. Even in neutral environments, hardness can have an impact on the osmoregulatory status of fish due to its influence on gill permeability. In rainbow trout, for example, increased rates of sodium and chloride loss in soft water contribute to significant ionoregulatory disturbances (McDonald et al. 1980).

Most previous studies examining the effects of water hardness and pH on fish have focused on resting animals. Graham et al. (1982) have shown, however, that water hardness and pH can have a profound impact on the recovery of species such as rainbow trout following exhaustive exercise. It is therefore likely that water hardness and pH may also have an important influence on the ability of Atlantic salmon to recover from exhaustive angling. Based on this reasoning, and the fact that several watersheds in eastern Canadian provinces such as Nova Scotia still maintain significant runs of Atlantic salmon in waters that may be relatively soft and/or moderately acidic, we performed experiments to determine the effects of water hardness and acidity on Atlantic salmon recovering from exhaustive exercise.

These experiments were carried out on Atlantic salmon raised in the DFO Salmonid Enhancement Center in Margaree, Nova Scotia. Briefly, our methodology consisted of randomly selecting groups of these hatchery salmon and either maintaining them under control conditions (hard, neutral water) or acclimating them for a short period of time to: i) soft water, or ii) soft and moderately acidic water. Under each of these conditions, physiological variables in blood and muscle, as well as survival, were then monitored at rest and after the salmon were exhaustively exercised in a manner that closely mimicked angling to exhaustion.

The physiological disturbances in the blood of salmon recovering from exhaustive exercise were markedly different between the soft and hard water groups. Significant differences were observed between these groups for plasma pH, plasma osmotic concentration, and the plasma concentrations of lactate, bicarbonate, metabolic protons, sodium, potassium and chloride. In all cases, the magnitude of the disturbances in these variables was greater in the soft water salmon. Interestingly, there were no consistent differences in white muscle variables between salmon in hard water ($\text{Ca}^{++} = 90-100$ ppm) as compared to salmon acclimated briefly (3 days) to soft water ($\text{Ca}^{++} = 30-50$ ppm).

Most importantly, there were also marked differences in the numbers of post-exercise survivors between the soft and hard water groups of salmon (Table 1).
Surprisingly, there were no consistent differences observed during recovery from exercise in any of the blood variables among salmon acclimated in moderately acid (pH 5.3 - 5.5) soft water, as compared to those in neutral (pH 7.0-7.5) hard water. In fact, our results indicated that the moderately acid conditions were associated with an enhanced recovery of the metabolic and acid-base disturbances within the muscle of exhaustively exercised salmon. In addition, rates of post exercise survival in moderately acid soft water were similar to those in soft, neutral pH water (Table 1).

**Air Exposure**

Since catch and release has become an integral component of many recreational fisheries, growing numbers of anglers have turned to photographs and measurements as a means of obtaining a lasting memory of their catch. In order to photograph and measure their fish, anglers who are unfamiliar with appropriate release practices often remove the fish from the water for extended periods prior to its release. While in air, the gill's delicate lamellae (fine filaments) collapse and gas exchange is largely inhibited. Periods of brief air exposure can therefore be an important additional stress that exhaustively angled fish must endure. Ferguson and Tufts (1992) examined the significance of this additional stress in exhaustively exercised rainbow trout. Under laboratory conditions, it was found that even 60 seconds of air exposure caused a marked increase in the magnitude of the physiological disturbance in exhaustively exercised trout. During air exposure, oxygen levels in the arterial blood fell to less than 20% of control levels. In addition, blood lactate levels in trout exposed to air during recovery were about double those in trout that were kept in water after exercise. Most importantly, survival of the exercised trout that were not removed from the water was 88%, whereas survival dropped to 62 and 28% in trout that were exhaustively exercised and then air exposed for 30 and 60 seconds, respectively. Although these experiments clearly demonstrated that even brief periods of air exposure can have an important impact on fish recovering from exhaustive exercise or angling, Ferguson and Tufts (1992) pointed out that numerous factors such as the removal of small blood samples, and the use of hatchery fish in their experiments, meant that the observed rates of mortality in these experiments were not directly extrapolatable to angled-and-released wild fish.

In experiments carried out at DFO's Salmonid Enhancement Center (Cardigan, P.E.I.), we found that brief air exposure (1 minute) increased the magnitude of the observed changes in several physiological variables (white muscle PCr and ATP, plasma lactate and osmotic concentration) in wild salmon recovering from exhaustive exercise (Rossiter, Angus, Davidson and Tufts, unpublished data). As expected, wild Atlantic salmon were more tolerant of brief periods of air exposure, however, than the hatchery rainbow trout used in the experiments of Ferguson and Tufts (1992). By contrast to the previous study on rainbow trout, all of the Atlantic salmon that were air exposed in these experiments, and returned to their holding pen, survived (Table 1).

**Survival and migration of salmon angled by the general public**

In all of the previous studies (sections 3.1-3.6), the protocol that was used to exercise the salmon to exhaustion involved either: i) experimental angling in the field, whereby previously collected
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salmon were removed from holding boxes in the river, artificially hooked, released back into the pool and then angled to exhaustion by volunteer anglers from local clubs, or ii) chasing to exhaustion in a circular tank in the laboratory. These protocols allowed us to carry out enough experiments at any given time to gain insight into the effects of exhaustive exercise or angling under a variety of conditions. Another objective within this project, however, was to examine the impact of normal angling by the general public on the survival and migration of Atlantic salmon.

In 1993, 59 salmon captured by anglers on the Upsalquitch River, N.B. were tagged with Carlin tags prior to release. In addition, another 30 salmon were trapped, tagged and released on their way up the Upsalquitch as a control group. There were no confirmed mortalities among the control group, whereas three tags were returned from angled salmon that were later found dead on the river. The majority of salmon in the Upsalquitch are believed to spawn above the counting fence at the 10 Mile Pool barrier (A. Madden, personal communication), but only five control and eight angled salmon reached this counting fence before it’s removal in October. The number of tagged salmon reaching the 10 Mile Barrier Pool was therefore lower than anticipated. Nonetheless, the percentage of salmon reaching this point after angling (14%) was very similar to that for the control salmon (16%).

In order to further investigate the effects of normal angling by the general public on the survival of Atlantic salmon, another series of experiments was conducted within the 10 mile barrier pool where the fate of angled salmon could be more easily determined. After being angled by local volunteer anglers, 10 grilse were released into a large holding tank within the pool and monitored for the next 24 hours. In addition, 15 angled grilse were Carlin tagged and released back into the barrier pool itself. Any mortalities among this second group of salmon would be easily observed since the water on the Upsalquitch is extremely clear and any dead salmon would be caught on the lower fence in the pool. In these experiments, two of the 10 angled grilse recovering in the holding tank died within 24 hours, but there were no observed mortalities among the 15 grilse that were angled and released into the river itself (Table 1). By contrast to the previous tagging studies, these experiments clearly demonstrated that most Atlantic salmon angled and released on the Upsalquitch probably do survive. Furthermore, these results suggest that additional stress resulting from experimental manipulations such as confinement in holding tanks probably increase the likelihood of delayed mortality in angled salmon.

In the final series of experiments carried out on the Upsalquitch River, 20 salmon were fitted with radio tags and their subsequent survival and migration was monitored. Ten of these fish were caught by anglers prior to being fitted with a radio tag and released. The remaining ten salmon served as controls and were radio tagged and released after being trapped. The initial search, which took place several days after these salmon had been tagged, located nine control salmon and nine angled salmon upstream from the point of that they were initially tagged. These experiments provided further evidence that most Atlantic salmon survive angling. Moreover, this study showed that they continued to migrate upstream following release. In subsequent searches, fewer salmon were located, but the data showed an interesting trend in terms of migration. The total distance traveled by control salmon after tagging was significantly greater than that traveled by salmon that were angled. Since the sample sizes were limited in this study, and several
alternative explanations could also account for these data, no definite conclusions can be drawn
from this information. Nonetheless, these preliminary results suggest that angling may have a
significant impact on the migratory behaviour of Atlantic salmon. Further study in this area is
therefore warranted.

In 1995, another field study was carried out to monitor the survival of Atlantic salmon angled by
the general public on the Lahave River in Nova Scotia. The water in this river is softer and has a
lower pH than that of the Upsalquitch. Due to a limited run of salmon on the Lahave at this time,
only nine salmon were obtained for these experiments. As on the Upsalquitch, the majority (8) of
these salmon survived during the 24 period that they were observed (in holding boxes) following
angling (Table 1). Interestingly, the only salmon that died in this study was angled at 23°C.

DISCUSSION

Several previous studies have shown that exhaustive exercise can result in delayed mortality of a
relatively large fraction of test fish (Black 1958; Beggs et al. 1980; Graham et al. 1982; Wood et
al. 1983). By contrast, other studies have shown that exhaustive exercise is not associated with
significant post exercise mortality (Wydoski et al. 1976; Schwalme and Mackay 1985; Tufts et
al. 1991). The reasons for these apparently conflicting results regarding post exercise/angling
mortality in fish are not entirely clear. Previous studies have shown, however, that specific
endogenous or exogenous factors may affect the magnitude of the physiological disturbance in
an exhausted fish (Pearson et al. 1990; Ferguson and Tufts 1992; Ferguson et al. 1993; Kieffer et
al. 1994) and therefore these factors also likely influence the probability of delayed mortality
(Graham et al. 1982; Ferguson and Tufts 1992). The present studies on Atlantic salmon provide
further evidence that the physiological response to exhaustive exercise and the likelihood of
delayed mortality in any given species are not constant, but rather are largely influenced by
numerous endogenous and exogenous factors.

Our results indicate that most Atlantic salmon do survive being caught and released. Regardless
of the conditions, the majority of the salmon that were exhaustively exercised or angled in each
of our studies survived (Table 1). These findings are probably not surprising since this species is
already highly adapted to cope with periods of exhaustive exercise during its arduous spawning
migrations.

The present studies also identify a variety of factors that influence the responses of Atlantic
salmon to angling. Water temperature, for example, appears to be a critical factor affecting the
probability of delayed mortality. Our studies consistently showed a significant increase in
delayed mortality after angling/exhaustive exercise when water temperatures exceeded about
22°C.

The reason for the marked differences in the apparent effect of temperature on the physiological
recovery of salmon under laboratory conditions, as compared to those in the wild, is unknown
and requires further study. One can speculate, however, that several factors might contribute to
these differences. For example, the laboratory study was carried out on salmon that had been
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In the wild, particularly in the summer experiments, we found that the water temperatures were highly variable over a 24h period. It is therefore conceivable that the physiological adjustments to temperature may be quite different in the laboratory as compared to the wild. In addition, it should be noted that physiological analyses were only carried out on salmon that survived in these experiments, which could lead to an unavoidable experimental bias. Thus, at high temperatures, measured variables from the limited number of salmon that survived to be sampled during the recovery period would have a large influence on the observed trends in the physiological data and these measurements may not be truly representative of all salmon exercised at these temperatures. Finally, additional factors that could influence the salmon's physiological response to exhaustive exercise such as the period of freshwater acclimation and nutritional state can be easily controlled in laboratory studies, but this is not possible in the wild. It is therefore possible that the effect of temperature is indeed clearly described by our laboratory studies and that one or even several of these additional factors may have influenced the physiological responses of Atlantic salmon angled in different seasons in the wild.

Salmon that have recently entered fresh water may also be particularly vulnerable to stress. The magnitude of the post-angling physiological disturbance in these bright salmon is relatively large since they have only recently stopped feeding and therefore have high energy reserves, but their ability to recover from angling is reduced compared to salmon that have spent a longer period of time in fresh water. This lower capacity of bright salmon to recover from angling may reflect the fact that these fish have also undergone significant osmoregulatory and temperature stresses during their recent transition to freshwater.

By contrast to bright salmon, low energy reserves in the white muscle of kelts result in a relatively minor physiological disturbance following angling. The physiological recovery of both kelts and fall salmon is also very rapid and the probability of delayed mortality during both these coldwater periods is minimal. Salmon recently exposed to soft water, however, also exhibit a reduced capacity to recover from exhaustive exercise and experience greater post-exercise mortality.

The results of these studies are most easily explained in terms of the effects of combined stresses in fish (Wedemeyer et al. 1990). Under ideal conditions, Atlantic salmon seem well adapted to cope with the acute period of exhaustive exercise caused by angling. When salmon are simultaneously exposed to other stresses, however, such as extreme or acute changes in water chemistry or temperature, their capacity to recover from angling is reduced and the probability of delayed mortality is increased. A recent study by Eros and Milligan (1996) may provide some insight into the mechanisms behind these findings. These authors showed that elevated levels of cortisol, which are a common feature during a variety of stresses, inhibit the physiological recovery of rainbow trout following exhaustive exercise.

Since other forms of stress will reduce the capacity of Atlantic salmon to recover from exhaustive exercise or angling, it is important to consider that, in many of our studies, confinement of experimental salmon in holding boxes will cause some degree of additional
stress. Thus, although our data provide valuable insights into factors that will increase the relative magnitude of the disturbance after angling, most of these results should not be directly extrapolated to normal angling conditions in the wild. Under normal circumstances, when salmon are not confined before or after angling, rates of survival should be even greater than those observed in these experiments. Evidence supporting this view is provided by the fact that there were no mortalities among the 15 salmon which were angled and released back into the Ten Mile Barrier Pool on the Upsilon River whereas there were two mortalities among the 10 salmon which were angled under identical conditions, but kept in a holding tank in the barrier pool for observation.

Given the significance of combined stresses in determining the survival of Atlantic salmon after angling, it is also important to consider that the practices of individual anglers are important in determining the magnitude of the post-angling disturbance. Minimizing air exposure of fish is very important. Under conditions where the likelihood of delayed mortality is increased (e.g., elevated temperature), the impact of additional stresses such as air exposure may be critical in determining the fate of angled salmon.

Despite the fact that multi-sea-winter (MSW) salmon require longer periods of angling to reach exhaustion, the physiological disturbance in MSW salmon after angling actually seems to be less than that in grilse. These results are initially somewhat surprising given the previously documented positive correlation between body size and anaerobic capacity in other salmonids (Ferguson et al. 1993). It is noteworthy, however, that the study of Ferguson et al. (1993) was carried out on rainbow trout whose maximum size was smaller than the salmon used in our work. Our results indicate that there may be a threshold for the relationship between anaerobic capacity and body size and that extremely large salmonids may be more reliant on aerobic metabolism during strenuous activity. In addition, it should be considered that we measured the concentration of muscle metabolites to quantify the magnitude of the physiological disturbance in these salmon whereas the time required to land them (i.e., playing time) will also be related to their overall mass. Nonetheless, these findings suggest that the probability of delayed mortality in MSW salmon is even less than that in grilse even though MSW salmon typically require longer angling times to reach exhaustion.

As mentioned previously, Wood et al. (1983) proposed that the relative magnitude of the physiological disturbance within the muscle may be an important factor determining the probability of delayed mortality after exhaustive exercise or angling. In most of our studies, a larger physiological disturbance following angling was indeed associated with lower survival. It should be mentioned, however, that we did not find a direct correlation between changes in any specific physiological variable in the muscle and the probability of survival in these studies. In addition, changes in physiological variables within the blood seemed to be more important determinants of survival under some conditions such as during exposure to soft water. Moreover, there was actually an inverse relationship between the rate of recovery within the physiological variables and the probability of survival in the laboratory study examining the effects of temperature on the recovery of exhaustively exercised salmon. Thus, while the probability of mortality following exhaustive exercise or angling may often be correlated with the magnitude of
the disturbance within the muscle, as proposed by Wood *et al.* (1983), the physiological basis of delayed mortality in exhaustively exercised fish remains an enigma. Furthermore, some of our results indicate that the critical events resulting in post exercise mortality may not occur within the white muscle.

Preliminary data within these studies suggests that angling could also have a sublethal impact on the migratory behaviour of Atlantic salmon. It should be considered, however, that the majority of the control salmon used in these tracking experiments were captured, tagged and released during high water episodes when many salmon were moving upstream. By contrast, the angled salmon were typically captured for radio tagging when water levels were dropping. Thus, these findings may also simply reflect the impact of water levels on migratory behaviour.

**MANAGEMENT IMPLICATIONS**

**Background**

The 1984 introduction of the "grilse-only" regulation in much of Canada was widely opposed. Skeptics believed that anglers would give up fishing and that a released fish was effectively a dead fish. Public education has been a major factor in overturning the prevailing view (Bielak 1988; Bielak and Tufts 1995) and in turning attention to the question of optimizing management measures and fishing techniques based on credible science.

In the proceedings of the previous international symposium, Davidson and Bielak (1993) noted that refinement of catch-and-release practices was an important management approach to allow a watershed to be more productive in terms of salmon. Integral to refining practices was the establishment of a broad scientific database on the issue to permit the achievement of the maximum enhancement benefits from catch-and-release. A substantial part of the necessary database is now in place.

In its publication "Atlantic Salmon Issues" (ASF 1996) the Atlantic Salmon Federation (ASF) now refers to the "issue" as being one of how to promote the adoption of catch-and-release "to make the results widely known to assist with the better acceptance in existing areas of skepticism of catch-and-release as an effective conservation-oriented management strategy".
Impacts of the Research

In general terms, the present results are very supportive of the application of catch-and-release as a management measure. The new information gained through these studies has had a significant impact on management decisions which extended and adapted angling seasons in Atlantic Canada. Though unquantifiable, negative effects on salmon stocks have in all likelihood been negligible while economic impacts, in a region where few other employment opportunities exist, have undoubtedly been positive.

In Quebec - historically a province where mandatory catch-and-release was anathema - as a result of increased acceptance of the technique a new class of (cheaper) catch-and-release Atlantic salmon license was introduced in 1997. Furthermore, the imposition of catch-and-release regulations in preference to total closures is now the norm.

In the State of Maine, regulations regarding keeping fish in the water and mandated use of knotless-mesh landing nets are under consideration (E. Baum personal communication). Angling for salmon has also been closed state wide in 1997 for the (warm, low water) summer months, but re-opens to exclusive catch-and-release angling from September 1 - October 15.

The mortality of caught-and-released salmon can be expected to vary depending on a number of factors. There is minimal mortality in kelts angled during the spring, and the mortality that occurs is probably related to direct injury rather than physiological disturbance. Salmon that have recently entered the river and are angled early in the season may experience higher mortality than salmon angled in the fall (which suffer negligible mortality) or fish that have been in fresh water for some time and are caught and released in the course of the season. Fish caught and released during warm water events may well experience higher mortality than fish at other times.

The results of our studies have significance for managers of the Atlantic salmon resource insofar as the 5% catch-and-release mortality "rule-of-thumb" figure used by DFO in salmon stock assessments (Bielak and Tufts 1995) is concerned. More precise estimates of mortality of released salmon under various conditions, (particularly in the light of likely variations in mortality between warm and cool water circumstances) will help fine tune stock assessments for different rivers and situations where accurate temperature record series are available.

Such information will assist managers in deciding whether certain stocks or stock components merit special protection, and if so precisely at what temperatures to consider shutting down angling. For example, until last year DFO protocols in Newfoundland led to complete angling closures of rivers at temperatures exceeding 22°C. In 1997, on some rivers, catch-and-release angling has been permitted in the morning only, providing water temperatures are below 22°C.

Bielak (1996) detailed some of the management considerations raised by our research, particularly regarding water temperature-related river closures. He demonstrated that if the original DFO-Newfoundland rule were to be applied globally in New Brunswick, closures for the major part of the salmon season on certain rivers could be expected in warm water years. He
argued that a variety of factors and inputs should be considered prior to the formulation of a consistent policy related to such closures. He also indicated that innovative suggestions "such as permitting angling only during the cooler (morning) hours of warm or low water episodes" should be considered.

The studies referred to above have relevance for individual anglers as well. One must bear in mind that at one extreme, a fish on the bank is a dead fish, while at the other, a properly released fish has some (variable) chance of survival. In instances where large numbers of fish are being released on a daily basis, and/or individual fish have a high probability of being angled more than once (F. Whoriskey, personal communication), small variations in mortality rate can have a large cumulative effect. Such considerations might be particularly important in the case of the "autumn" (fall) race of Russia's Kola Peninsula Atlantic salmon. These enter the river one year and spawn the next, thus being exposed to angling over the course of two salmon seasons.

In the light of the above, as well as previous studies showing the negative effects of air exposure for caught and released fish (Ferguson and Tufts 1992), and the effects of various terminal gear (bait versus flies or lures) on the subsequent survival of hooked and released Atlantic salmon (Warner and Johnson 1978; Warner 1979), continued education of anglers regarding optimum techniques for catch-and-release angling is an important priority.

It is in this arena that major national and international conservation groups such as the Atlantic Salmon Federation (ASF), the Atlantic Salmon Trust (AST), the Association Internationale de Défense du Saumon Atlantique (AIDSA) and the Federation of Irish Salmon and Sea Trout Anglers (FISSTA), angling clubs and even individual anglers can play a major role by ensuring that information on catch-and-release fishing and proper release techniques continues to be widely disseminated over an extended period.

**Emerging challenges**

Information stemming from these studies may also be useful across the Atlantic where catch-and-release fishing has been less fully embraced than in North America. Despite differences in the fisheries, the present studies should shorten the learning and acceptance curves for anglers and managers alike, so that appropriate and effective measures may be put in place to the benefit of both anglers and salmon stocks.

There are a number of encouraging signs that progress is being made. For example, a catch-and-release policy to protect spring and early summer salmon on parts of Aberdeenshire's River Dee has been developed and others are adopting the practice. Research on behaviour, movements and survival of released fish has also been undertaken by the AST in Scotland and the ASF in Russia, and the results to date are supportive of the practice (John Webb and Fred Whoriskey, personal communication). In addition, an unprecedented debate in Trout and Salmon magazine was engendered during 1996 by a pair of "bookend" articles arguing diametrically opposed views on catch and release (Barr 1996; Ainslie 1996). The animated discussion of catch-and-release was symptomatic of a shift in attitudes to the practice in the U.K.
The international conference (Wild salmon management - the angler's options) organized in Skibbereen by FISSTA in 1996, included a presentation on catch-and-release (Bielak et al. 1997) that was well received. The meeting also featured a speech by the Minister of State of the Department of the Marine (Gilmore 1996) on "A new approach to salmon management", related to the release of the report of the Taskforce on Salmon Management earlier that month. In his speech the Minister stated that he looked "forward to (the audience's) involvement in efforts to adapt the catch-and-release policy of Spring salmon, as is done in other countries".

'Salmometers' used to estimate weight-length relationships of released salmon abound, with versions of the original (developed by the Atlantic Salmon Federation) now widely available throughout the salmon world. Finally the North Atlantic Salmon Conservation Organization's (NASCO) catch-and-release policy was ratified at its 1997 annual meeting, and will be published in an attractive format (P. Hutchinson personal communication).

On the negative side, however, the growth of the "anti-fishing" movement is a real threat to angling generally and catch-and-release specifically. It is exemplified by the campaigns organized by groups such as "People for the Ethical Treatment of Animals" (PETA) that declared the first "National Fish Amnesty Day" in 1995 (McKoy 1995) as well as organizing a "Save our Schools" campaign in 1996. The increased emphasis on catch-and-release fishing is particularly likely to draw the ire and attention of such animal rights groups (Gourlay 1997).

This is a serious threat, as exemplified by a code of practice reported at a 1996 European Inland Fisheries Advisory Committee (EIFAC) Symposium on Social, Economic and Management Aspects of Recreational fisheries (Williamson 1996). Developed in Baden-Wurttemburg, Germany, in conjunction with an official working group on animal welfare, the code makes it effectively illegal to release a fish that is within the legal size limits! Organizations representing sports fishing interests need to be aware of the power of the preservationist movement and actively promote proper catch-and-release practices, with an emphasis on decreasing playing time of fish and mortality.

CONCLUSIONS

The combined results from these studies demonstrate that, under ideal conditions, Atlantic salmon are well adapted for recovery from exhaustive angling. When salmon must also cope with other significant stresses, however, their capacity to cope with the additional challenge of recovery from angling is reduced and the likelihood of delayed mortality is increased.

In terms of management implications, these studies have provided strong evidence that most Atlantic salmon probably do survive following angling by the general public. Thus, catch-and-release is clearly an effective tool for the conservation and enhancement of Atlantic salmon. The present study has also identified several factors that may increase the likelihood of post-angling mortality. These factors include high water temperature (>22°C), a recent transition to freshwater, extremely soft water and air exposure. Since some of our studies involved hatchery salmon and manipulations that might further contribute to stress, such as confinement in the
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laboratory or the field, most of our results should not be directly extrapolated for assessment purposes under natural angling conditions. However, these results should provide the foundation for a valuable database which fisheries managers can use to fine tune estimates of delayed mortality under various conditions. In addition, this information may serve as an important basis for more thorough studies on this topic.

SUGGESTED AREAS FOR FUTURE RESEARCH

Although numerous issues relating to "catch-and-release" in Atlantic salmon have been addressed within these studies, several areas still require further study. For instance, the impact of playing time is a controversial subject among anglers, managers and conservationists, but to our knowledge there is little or no information available on this subject. The significance of other stresses such as furunculosis and sea lice in angled Atlantic salmon may also require study. In addition, more thorough experiments examining the potential sub-lethal effects of angling are necessary. The impact of angling on migratory and spawning behaviour is important issues in this area that must be fully resolved. It is also conceivable that angling could affect gamete development in Atlantic salmon at other migratory stages (eg., bright salmon), but this has yet to be determined. Finally, from a physiological perspective, the exact cause of delayed mortality in exhaustively exercised/angled fish remains a challenging issue. Future physiological studies in this area should therefore seek to incorporate better indicators of sublethal stress in angled salmon.

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