Environment Agency

Evidence

Impact of catch and release angling practices on survival of salmon

Report

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Professor Doug Wilson
Director, Research, Analysis and Evaluation

Executive summary

Catch and release (C&R) recreational angling has become a popular conservation strategy and management tool for an array of fish species and fisheries. The main aim of C&R angling is to ensure that the individual fish survive and go on to reproduce successfully. Implicit in C&R angling strategies is the assumption that fish experience low mortality and minimal sub-lethal effects, and swim away unharmed.

Studies on Atlantic salmon have generally demonstrated high survival rates and successful spawning for salmon released after capture, with no difference detected between the gamete viability of caught and control fish. Recent genetic parentage analysis also indicates that C&R fish reproduce and contribute to the next generation as much as uncaught individuals. The information available suggests that C&R angling for salmon is a viable management strategy provided best management and angling practices are followed.

This report provides a review of the factors that can influence the survival of fish during C&R with specific reference to Atlantic salmon, although the findings are also of relevance to brown and sea trout. This includes direct factors associated with the angling event (such as angling methods, bait and handling techniques) and the impact of external factors, especially environmental ones, on the outcome of fish caught and released. Each element of the review is structured to provide evidence to support best practise guidance that will maximise survival rates for salmon (and trout) in C&R angling.

In this report, the effects of C&R angling on fish are broken down into the main phases of the angling event. Typically these are angling methods and gears used, retrieval (playing the fish), landing, handling techniques including unhooking, on bank processing, retention and recovery, and finally release.

Physiological changes were found to result from the intense physical exercise of being played, including depletion of energy reserves, accumulation of lactate and a change of acidity in the blood. It appears that the longer the fight and handling time, the bigger the effect and the greater time needed for recovery. These physiological changes have been linked to mortality in many species of fish.

The main factors found to reduce survival are:

- fishing method
- deep hooking leading to tissue damage and bleeding
- physical damage from poor and excessive handling leading to scale loss abrasions and infection
- being kept out of the water for a prolonged period causing tissue and gill damage
- high water temperatures

Close links have been found between water temperature and survival in C&R salmonid species, with elevated temperatures causing higher rates of delayed mortality. To minimise the impact of high water temperatures on salmonid species, fishing regulations can be implemented on river systems when water temperatures surpass a set threshold. Given that the diel variation in water temperature can be high, it is recommended that C&R fishing is not practised when the water temperatures exceeds 18°C in the mid-morning.

Angling methods and gears can also influence the likelihood and severity of hooking injuries. Methods requiring anglers to ‘strike’ to hook fish (for example, trotting, legering, freelining, wobbling) may allow baits to be ingested and increase the risk of deep hooking, whereas fish captured using lures are generally hooked immediately, as the lure is continuously being retrieved. An important exception is Flying Cs, a brand of spinner with the hook positioned well below the body of the lure, which often results in deep-hooked salmon. The highest incidences of deep hooking are generally associated with relatively small baits (for example, worms) and hooks.

Circle and barbless hooks cause the least damage, while natural baits tend to be swallowed more deeply and cause greater injury. In salmon angling, this is possibly because natural baits (for example, worms, prawns, shrimps, fish) are invariably used with methods that require anglers to strike to hook fish, whereas fish captured using lures (for example, spinners, spoons, plugs) are generally hooked immediately.

In addition, salmon can suffer from scale loss, abrasion and loss of mucus coating, plus damage to the gills caused by pressure on the gills or by removal from the water during the angling event.

The survival rate for salmon is greatly increased if proper angling techniques and gears are used, and best practices for catching, handling and releasing angled fish are adopted. To give the fish the best chance of full recovery from capture and further contributing to the fishery or going on to spawn, a series of measures, which are embedded in numerous guidelines for C&R fishing, are recommended.

- Consider the appropriate angling method and tackle to use where C&R is mandatory or where release is intended.
- Minimise angling duration to avoid fish becoming exhausted. This is particularly important at high water temperatures.
- Avoid angling at high water temperatures.
- Use single barbless hooks to minimise risk of injury.
- Use the least harmful bait/lure type (for example, artificial lures with minimal, appropriately sized, barbless hooks fished actively), even though it may not be the most effective for catching fish.
- Minimise air exposure, ideally not removing the fish from the water during landing, unhooking and photographing.
- Use fish-friendly landing nets with soft knotless mesh to help protect the fish from abrasion injury.
- Handle fish gently with wet hands and do not squeeze as this can damage internal organs. Touching the gills and eyes should be avoided.
- Always support the fish under the belly and keep in an upright / horizontal position, preferably underwater and facing into the current.
- Remove the hook with a long pair of forceps, disgorger or another unhooking device. When it is not be possible to remove the hook, cut the leader as close to the hook as possible as the hook will work its way out. This is less damaging than prolonged handling.

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1 Background

Catch and release (C&R) recreational angling has become popular as a conservation strategy and management tool for an array of fish species and fisheries (Bartholomew and Bohnsack 2005, Cooke and Suski 2005, Arlinghaus et al. 2007, Cooke and Schramm 2007). This is for one of the following reasons.

- Many anglers, by law, have to return fish they have caught to the water to comply with bag and size limits.
- It is normal fishing practice to release fish after the fishing event.
- It is for conservation reasons to protect declining stocks.

It is also common for anglers with a commitment to conservation to release fish they could legally keep because they no longer fish for food, but fish to enjoy the angling experience and release the fish safely to fight another day.

Implicit in C&R angling strategies is the assumption that the fish experience low mortality and minimal sub-lethal effects. This assumption comes from the observation that, when fish are released after being caught, they generally swim away, apparently unharmed. This is supported by numerous angling and radio tracking studies that have demonstrated high survival rates and successful spawning of salmon released after capture (up to 100% in certain conditions) (Webb 1998, Thorstad et al. 2007, Jensen et al. 2010, Havn et al. 2015), with no difference detected between gamete viability of caught and control fish (Booth et al. 1995). Recent genetic parentage analysis also supports that C&R fish reproduce and contribute to the next generation as much as uncaught individuals (Richard et al. 2013, 2014). In some instances, however, fish that appear healthy upon release may later exhibit injuries or distress caused by C&R practices (Muoneke and Childress 1994, Thorstad et al. 2003, Havn et al. 2015). Mortality is not necessarily immediate and can occur later, but is mostly in the first 24 hours after release (Muoneke and Childress 1994). This risk is exacerbated in Atlantic salmon that are fished to exhaustion at higher water temperatures (>16.5°C) as they tend to be less able to maintain equilibrium in the water at the stage of release.

Ensuring high survival of fish post-release is important because C&R angling, which has been embedded in most coarse fishing in western Europe for many years, has become increasingly common in salmon and sea trout fisheries due to the widespread decline in stock abundances in the North Atlantic over the past 2 decades (ICES 2016). For salmon, such trends in C&R angling can be seen from annual rod catch statistics for England and Wales (Figure 1.1). The provisional declared rod caught salmon in 2015 was 12,561, of which 79% were released. This has increased significantly from 10% in 1993, when such information was first recorded. This is due to a mixture of both mandatory (especially of spring multi-sea winter salmon) and voluntary release. In some rivers, such as the Wye and Taff, 100% C&R is mandatory because of poor stock status.

Similar trends in C&R fishing are observed in Scotland, with 84% of rod caught salmon (93% of rod caught spring salmon) being released in 2015 (Figure 1.2). The proportion of rod caught salmon that has been released has increased steadily from <8% in 1994, when such information was first recorded.

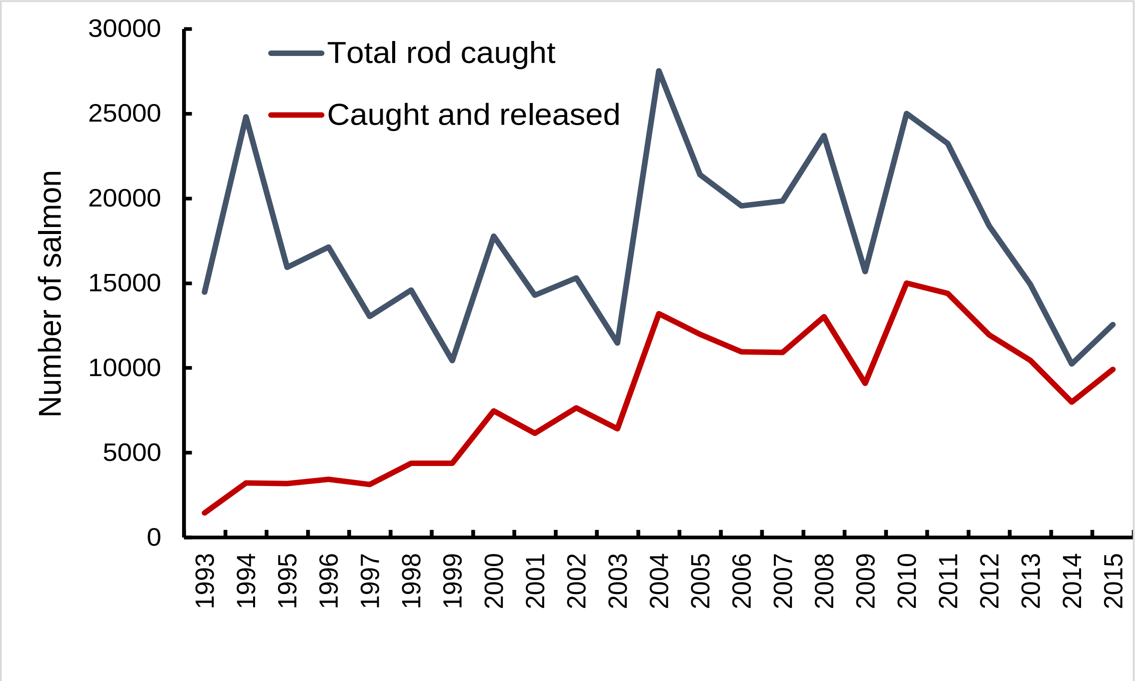

Figure 1.1 Total declared salmon rod catch for England and Wales, 1993–2015 (shaded area indicates fish caught and released)

Source: Environment Agency (2015), ICES (2016)

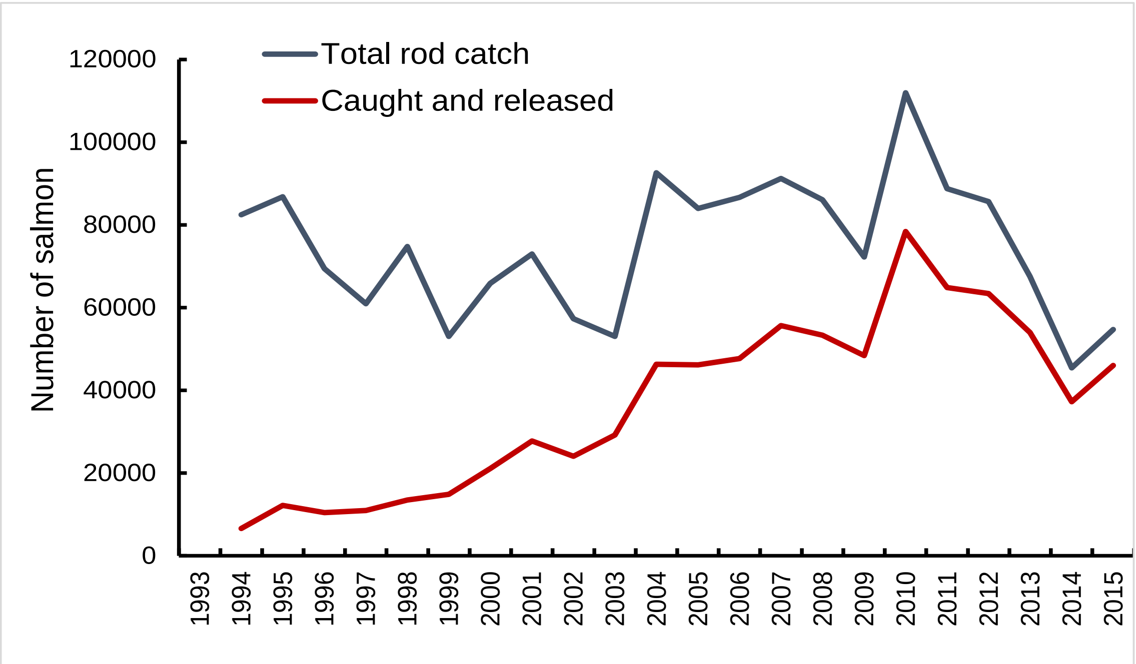

Figure 1.2 Total declared salmon rod catch for Scotland, 1993–2015

Notes: Adapted from Marine Scotland (2016, Figure 1)

Despite the importance of C&R angling, most research has focused on North American sport fishes, including Pacific salmonid species, with less effort directed towards understanding C&R angling effects on other fish species in other regions of the world (Cooke and Schramm 2007). C&R research on injury, mortality and sub-lethal alterations in behaviour and physiology suggests that the survival rate for many species of fish is greatly increased if proper handling practices are used for catching, handling and releasing angled fish (Bartholomew and Bohnsack 2005, Cooke and

Suski 2005, Brownscombe et al. 2017). There is therefore a clear need to explore strategies that maximise survival in C&R angling, especially for salmonids. If integrated with other fish population and fishery characteristics and regulations, it is expected that these strategies can be used by anglers and managers to sustain or enhance salmon stocks and associated fisheries.

1.1 Objectives

The overall objective of this report is to review the impacts of angling methods, baits and handling techniques on the survival of fish associated with C&R with specific reference to Atlantic salmon. In addition, the impact of external factors, especially environmental factors, on the outcome of salmon caught and released is reviewed.

Data from other salmonid species, and where appropriate non-salmonid species, are drawn on to highlight or fill gaps in key issues relevant to the subject area.

Each element of the review is structured to provide evidence to support best practice guidance that will help to maximise survival rates for salmon in C&R angling.

1.2 Review of C&R literature and other information sources

Electronic search engines, including Web of Science, Google Scholar and Scopus, were interrogated for scientific literature and other materials related to C&R fishing, with specific attention to salmonids. These searches used the following keywords (or Boolean derivatives): angling; animal welfare; catch and release; environmental ethics; recreational fish*; philosophy fisheries management; fishing mortality; hooking mortality; sub-lethal stress survival, physiology; fish welfare angler awareness; post-release survival; angler education; salmon salmo-salar; trout; heart-rate; exhaustive exercise; metabolic-rate, air exposure; water temperature; angling tournaments; fish bait; circle hooks; conventional hooks; deep hooking; hooking injury; hooking mortality. The searches also used the snowballing strategy to pick up non-indexed sources of literature, especially grey literature.

The information was consolidated into a review of angling and C&R practices including:

- angling methods (tackle and baits)
- handling practices
- injury
- mortality
- physiological impacts of C&R on individual fish
- population consequences

The following sections summarise the potential issues associated with C&R angling and highlight areas where further research is required.

2 Factors affecting mortality in C&R fishing

2.1 Environmental factors

Fish are ectothermic, and temperature plays an important role in regulating physiological processes (Brett 1971). Consequently, temperature may influence the outcome of C&R angling events in terms of the short- and long-term survival of released fish. In particular, the effects of C&R at high water temperatures (that is, above the thermal optimum for each species) may be more severe than at lower temperatures (Arlinghaus et al. 2007, Gale et al. 2011 and 2013), especially for cold water species such as Atlantic salmon.

Close links have been found between water temperature and survival in C&R salmonid species (Figure 2.1), with elevated temperatures causing higher rates of delayed mortality (Anderson et al. 1998, Dempson et al. 2002, Boyd et al. 2010, Havn, 2013, Havn et al. 2015). For example, mortality rates of C&R Atlantic salmon tend to be less than 12% when water temperatures are <18°C (Brobbel et al. 1996, Dempson et al. 2002, Thorstad et al. 2007, Havn et al. 2015), but can be as high as 80% when the water temperature exceeds 18°C (Figure 2.1) (Wilkie et al. 1996, Wilkie et al. 1997, Anderson et al. 1998, Dempson et al. 2002). Similar results have been reported in cutthroat trout (*Salmo clarki henshawi*) with 1.5% mortality rates at water temperatures <16°C, but rising to 60% mortality at temperatures >20°C (Titus and Vanicek 1988). These effects probably arise because changes in water temperature increase physiological disturbances (Gustaveson et al. 1991, Thompson et al. 2002) and affect fish metabolism (Fry 1971), cellular function (Prosser 1991), protein structure (Somero and Hofmann 1997), enzyme activity (Lehninger 1982) and diffusion.

However, care must be taken when interpreting such information. The high mortality rates recorded for Atlantic salmon caught at temperatures >18°C (Wilkie et al. 1996, Anderson et al. 1998) were fish played to exhaustion – and the sample size was only 5 fish. Mortality rates were considerably lower (10%) where anglers were requested not to extend the playing time intentionally while landing, thus minimising the chances of exhaustion (Dempson et al. 2002). Havn et al. (2015) also found increasing mortality rates in C&R salmon in the River Otra, Norway, with increased water temperatures rising from 7% at temperatures <18°C to 10% at temperatures of 18–20°C and up to 20% at temperatures >20°C; however, they did not record the very high mortality rates reported by Anderson et al. (1998).

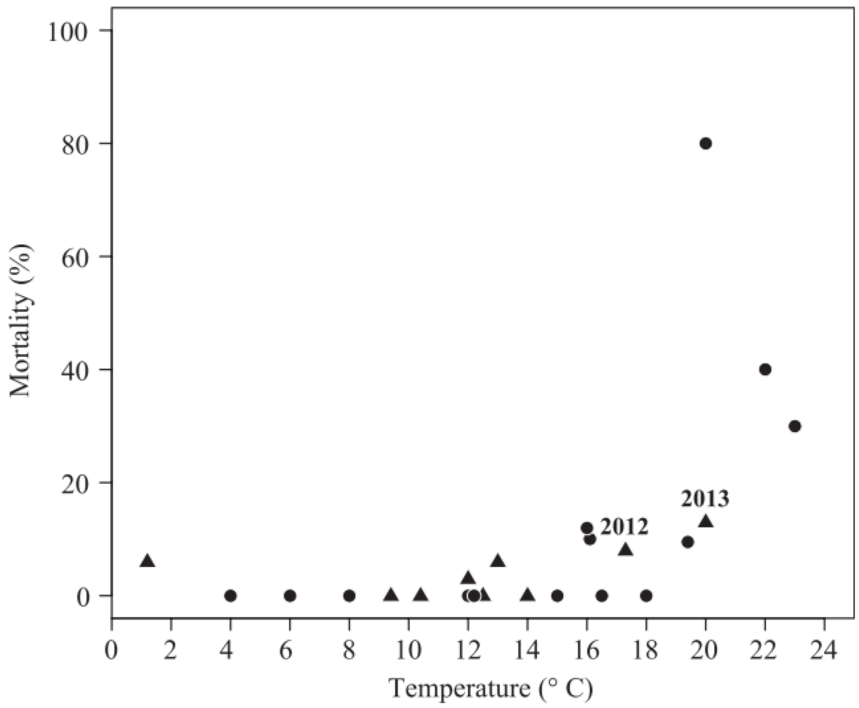

Figure 2.1 Mortality rates after C&R in different studies related to water temperature for *Salmo salar*

Notes: Studies: Tufts et al. (1991), Davidson et al. (1994), Booth et al. (1995), Brobbel et al. (1996), Wilkie et al. (1996, 1997), Anderson et al. (1998), Gowans et al. (1999), Mäkinen et al. (2000), Dempson et al. (2002), Kieffer et al. (2002), Thorstad et al. (2003, 2007), Halttunen et al. (2010), Jensen et al. (2010), Havn et al. (2015)
The values for temperature are given as the average temperature in studies where provided.
If the temperature or mortality is provided as a range, they are presented as the central value.
▲ = studies with radio-tagged *S. salar* released back into the river
● = studies that were laboratory-based or where the *S. salar* were confined in cages in the river after C&R
Source: Havn et al. (2015, Figure 3)

The time taken to retrieve a fish can have a direct influence on survival or mortality at different water temperatures (Table 2.1). This retrieval is referred to as the playing time or fight,[1] during which the longer the period of time a fish spends on the hook resisting the pull of the line, the higher the energy expenditure. Fish become exhausted when they are played for extended periods of time and will eventually stop struggling against the pull of the angler to hold equilibrium in the water column (Booth et al. 1995, Wilkie et al. 1996).

There is also a dearth of information about the effect that time of day, and the intrinsic variation in temperature during the day especially during the summer months, has on C&R survival in salmonid species (Beauregard et al. 2013). For example, rainbow trout caught in the evening in the Smith River, Montana, when daily maximum temperatures reached or exceeded 23°C, had a higher mortality rate than those caught in the morning (Boyd et al. 2010). Conversely, no differentiation in mortality rates was observed in C&R brown trout (*Salmo trutta*) between morning and evening.

[1] The retrieval time between hooking and capture for the purpose of unhooking (Olsen et al. 2010)

Table 2.1 Survival of Atlantic salmon after exhaustive exercise or angling under various conditions

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

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.

Source: Tufts et al. (1997)

Nevertheless, it is generally acknowledged that water temperatures in the early evening are generally warmer than at mid-afternoon (Dempson et al. 1998). It may be that, when temperatures in such rivers are high during the summer, they should be closed to angling for multiple days as temperatures could exceed the threshold for closure if measured in the afternoon and not the morning or early afternoon. This recognises the importance of measuring temperatures critical for enhancing survival in the warmest part of the day rather than the mornings. If temperatures are measured in the morning, consideration should be given to diel variation in temperature, which can be as large as 12°C between day and night in southern UK rivers (Orr et al. 2010).

To minimise the impact of high water temperatures on salmonid species, fishing regulations can be implemented on river systems when water temperatures surpass a set threshold. In eastern Canada, for example, Atlantic salmon rivers are closed to anglers during periods of excessive high water temperature to minimise potential mortality rates (Cooke and Wilde 2007). In the UK, the Hampshire Avon operates a voluntary closure of salmon angling when water temperatures exceed 19°C at 09:00 in recognition of the potential impacts on survival (A. Martin, personal communication).

In addition to the time taken to retrieve the fish, survival at higher temperatures can also be compromised if the fish are not handled carefully and are exposed to the air for prolonged periods of time (Dempson et al. 1998).

2.2 Physiological factors

Extended playing and handling times during C&R angling can significantly influence fish mortality (Bartholomew and Bohnsack 2005). Both the length of time played and the length of time the fish is out the water increased the probability of mortality in rainbow trout, *Oncorhynchus mykiss* (Schisler and Bergersen 1996). A significant increase was also seen in the mortality rate of rainbow trout played to exhaustion with increasing water temperatures (Dotson 1982). The time for Atlantic salmon to be played to exhaustion usually extends from 180 seconds to 480 seconds (Brobbel et al. 1996, Wilkie et al. 1996, Wilkie et al. 1997, Anderson et al. 1998), whereas mean times to retrieve without intentional playing were reported as 144 seconds (Dempson et al. 2002) and 192 seconds (Whoriskey et al. 2000). These times give an indication of the likelihood of a salmon being played to exhaustion during a fishing event.

Prolonged playing times can increase levels of physiological stress, which is particularly true when combined with high water temperatures (Wood et al. 1983, Wilkie et al. 1996). Physiological changes occur in response to the excessive exercise, which result from burst swimming during avoidance of capture (Dauwalter 2004). During these periods, the body responds with increasing levels of lactate in white muscle, decreases in muscle pH and reductions in white muscle concentrations of phosphocreatine, adenosine triphosphate and glycogen (Booth et al. 1995, Brobbel et al. 1996, Arlinghaus et al. 2007). Coupled with these changes is the release of stress hormones, especially adrenaline and noradrenaline.

The changes in these levels of hormones and biochemical alterations shift bodily energy investment from anabolic to catabolic activities (Arlinghaus et al. 2007). Associated with this is an increase on oxygen demand from the body tissues as oxygen consumption from the tissues will increase so to keep up with cardiac output. These cardiac changes have been noted by a variety of studies on C&R angling (Cooke et al. 2002a, Cooke et al. 2003, Cooke et al. 2004, Killen et al. 2006). The oxygen levels in the environment will ultimately restrict the rate at which the body can take up oxygen, with higher temperature waters holding less dissolved oxygen (Bartholomew and Bohnsack 2005). Therefore, at lower water temperatures fish that are exhausted exhibit lower mortality rates, associated with lower metabolic rates and physical activity (Muoneke and Childress 1994) and higher levels of dissolved oxygen in the water (Bartholomew and Bohnsack 2005).

Recovery in terms of C&R is referred to as the complete return to a normal behavioural and physiological functioning after release (Anderson et al. 1998). Despite a number of physiological changes caused by excessive exercise and stress, most fish are able to recover to a pre-fishing physiological state within 2 to 24 hours provided they are not disturbed again, seriously wounded by the fishing (hook or handling) and the water quality is good (Wang et al. 1994, Milligan 1996, Richards et al. 2002, Suski et al. 2006, Arlinghaus et al. 2007). It is important to note that most mortality usually occurs during the first 24 hours after release (Muoneke and Childress 1994).

In higher water temperatures (>16.5°C), Atlantic salmon that are fished to exhaustion are less able to maintain equilibrium in the water at the stage of release. Fish caught (to a state of exhaustion) in cooler waters are usually still able to hold position in the water when released (Anderson et al. 1998).

Water quality can also influence C&R survival rates. Following exhaustion, salmon subjected to pH neutral water may experience greater levels of physiological disturbance compared with fish returned to acid or soft water (Olsen et al. 2010).

2.3 Biological characteristics

The size and sex of salmonids are recognised to impact on mortality rates in C&R angling. Larger Atlantic salmon are generally stronger, thus potentially making it more difficult for anglers to land them before exhaustion (Havn et al. 2015), although the extended playing time does not necessarily affect survival (Gargan et al. 2015). Generally, however, longer playing time would be expected to increase physiological disturbance (Thorstad et al. 2003), as was found in hatchery rainbow trout where hooking stress was less severe in smaller individuals than larger ones (Wydoski et al. 1976).

Such increased stress has been found to lead to higher mortality rates in larger individual resident trout than smaller ones (Nuhfer and Alexander 1992, Taylor and White 1992). Having said this, Bendock and Alexandersdottir (1993) found greater mortality rates of small Atlantic salmon <750mm (mid-eye length) (minimum = 405mm) caught in the Kenai river (9.2–17.6%) than those of large males (>750mm) (0–9.7%) and females (>590mm) (3.3–10.7%). Similarly, a significant inverse relationship was found between size and mortality of Chinook salmon (Figure 2.2) (Wertheimer 1988, Wertheimer et al. 1989). Further to this, when the combined dataset was analysed between legal (>660mm) and sub-legal (<660mm) size classes, only the sub-legal sizes showed a significant inverse mortality with size. Loftus and Taylor (1988) also found smaller sized lake trout (*Salvelinus namaycush*) had a higher mortality rate.

In addition, differences have also been observed in the post-angling physiological disturbance of grilse (one sea winter fish) compared with larger multi-sea-winter Atlantic salmon (Booth et al. 1995). Multi-sea-winter Atlantic salmon show less physiological disturbance than one sea winter fish (Booth et al. 1995). In contrast, a number of studies have not found any relationship between size and mortality, for example, cutthroat trout (Pauley and Thomas 1993), rainbow trout (Schisler and Bergersen 1996) and Atlantic salmon (Havn et al. 2015).

Although there is no definitive conclusion with regard to the relationship between delayed mortality rates in the different size and sex of individual salmon, it may be possible to manage the targeting of different sized salmon (that is, multi-sea winter and grilse) because they tend to migrate at different times of year and thus it may be possible reduce any potential size-related impacts.

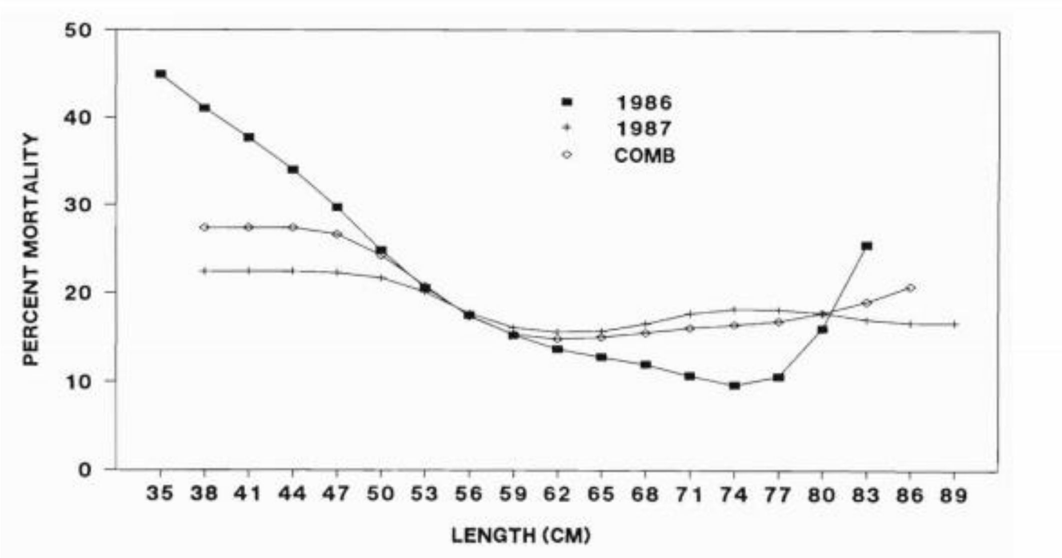

Figure 2.2 Hook and release mortality as a function of fork length for Chinook salmon caught on commercial troll gear in 1986, 1987 and both years combined

Notes: Data were smoothed twice with the 4253H algorithm (Velleman and Hoaglin 1981). End points of the curves incorporated observations outside the range shown. Source: Wertheimer et al. (1989)

Several studies have shown salmon released after capture move downstream (Mäkinen et al. 2000, Thorstad et al. 2007, Jensen et al. 2010, Havn et al. 2015). The reason behind these atypical downstream movements is not known, but may relate to stress caused by the C&R, loss of orientation or avoidance response to escape an unfavourable area (Arlinghaus et al. 2007, Thorstad et al. 2008). Suggestions have been made that this altered behaviour could lead to a shift in the distribution of spawning populations within the river and disadvantage at spawning grounds (Thorstad et al. 2003). However, irrespective of the proportion of downstream movements observed, the majority of individuals were subsequently found on known spawning areas during the spawning period (Webb 1998, Thorstad et al. 2007, Jensen et al. 2010, Havn et al. 2015) with no difference detected between gamete viability of caught and control fish (Booth et al. 1995). Further, genetic parentage analysis also supports that C&R fish reproduce and contribute to the next generation as much as uncaught individuals (Richard et al. 2013, 2014). Also, no differences were found in mortality rates (97% overall survival) or contributions from fresh (<1 week in freshwater) and coloured (>1 month in freshwater) Atlantic salmon on spawning sites that had been caught and released in the River Alta, Norway (Thorstad et al. 2007). It has been suggested that if fresh-run and early summer salmon are treated with care by the angler and returned to the river, they will usually behave normally and survive to spawn (Webb 1998).

2.4 Multiple recaptures

Recaptures of previously released individuals in C&R fisheries could possibly further increase the chance of injury or mortality. The vulnerability of fish to multiple recapture impacts is therefore an important aspect of C&R fisheries that needs exploring (Olsen et al. 2010).

Bartholomew and Bohnsack (2005) produced a cumulative mortality model that implies that mortality rises in response to repeated releases (Figure 2.3). This model is based on the probability of mortality per capture event; thus if a fish had a 10% chance of mortality after one capture event, the total probability of mortality after 5 hooking events would be around 40%.

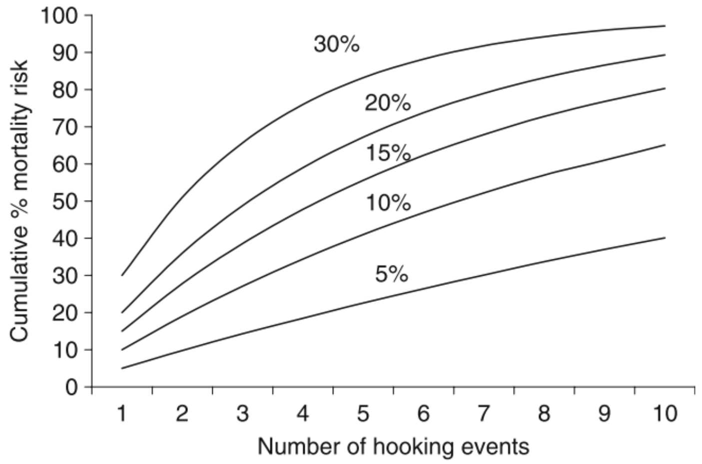

Figure 2.3 Predicted cumulative release mortality as a function of the number of release events and mean mortality per event

Source: Bartholomew and Bohnsack (2005)

As suggested by the cumulative mortality risk model, the recapture of individuals will ultimately increase the probability of mortality. However, recaptures give the opportunity to assess any injury or damage to fish from prior capture, or during periods between capture.

The probability of recapture can vary depending on species or factors linked with life cycle phases and sex (Arlinghaus et al. 2007). Recapture rates of Atlantic salmon are generally low during upstream migration, with few studies recapturing individuals more than once (Webb 1998, Whoriskey et al. 2000, Thorstad *et al*., 2003). One factor that could have an impact on the chances of recapture is the timing when anadromous salmonids enter the river (Olsen et al. 2010). In the River Spey in Scotland, recapture rates of fish caught and tagged in February and March were as high as 25%, but low at only 2% for fish caught and tagged in June/July (Thorley et al. 2007). These recapture rates represent some of the highest and lowest reported across a variety of rivers. In the River Ponoi, Russia, 2 recaptured Atlantic salmon were both reported to be completely healed from the previous angling experience, and one fish was later found in multiple locations in the river after release (Whoriskey et al. 2000) (Table 2.2).

Table 2.2 Rates of recapture among tagged fish released in various rivers

Recaptured once %	Recaptured twice %	Location	No fish tagged	Catch rate %	Author
0	0	River Ewe	25		Cunningham et al. 2002
2	?	River Spey[1]	Ca 55		Thorley et al. 2007
4	0.3	Alta River	353	20 – 50	Thorstad et al. 2003b, Næsje unpubl.
5	0	Aberdeeshire Dee	210		Report cited in Webb 1998
8	0	Aberdeeshire Dee	24		Webb 1998
11	0.5	Ponoi River	2520	10 – 19	Whoriskey et al. 2000
15	0.3	Haffjardara River	379	?	Gudbergsson & Einarsson 2009
18	0	Grimsa River	234	?	Gudbergsson & Einarsson 2009
24	1.7	Hofsa River	592	?	Gudbergsson & Einarsson 2009
25	2.3	Sela River	605	75 – 80	Gudbergsson & Einarsson 2009
25	?	River Spey[2]	Ca 140		Thorley et al. 2007

[1]Tagged (C&R) in early June
[2]Tagged (C&R) in early March

Source: Olsen et al. (2010)

3 Minimising the potential impacts of C&R angling

3.1 Introduction

Fish caught by C&R angling are subject to potential physiological stress and damage at different phases of the angling event (Figure 3.1). Therefore, to explore opportunities to maximise survival of salmonids fully, it is best to assess the likely impacts in a sequential manner of the angling event from hooking to release.

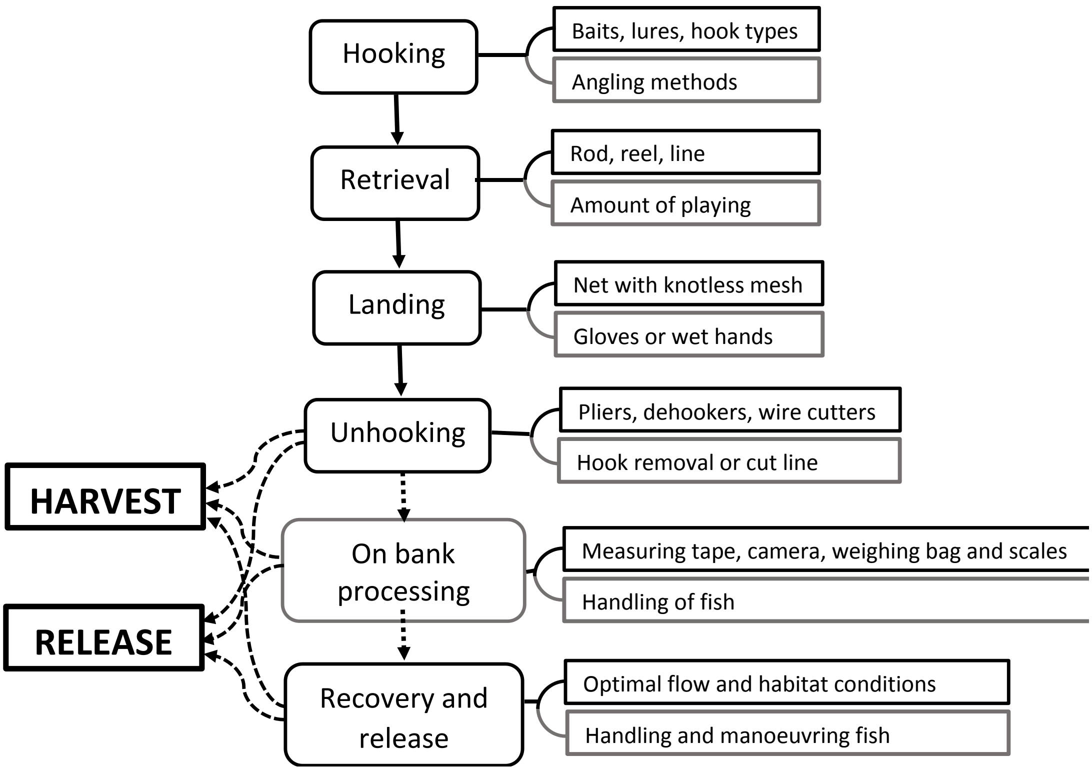

Figure 3.1 Conceptual diagram of potential stages of a salmon angling event (from hooking to recovery) including considerations (angler choices) on angling tools (grey edged boxes) and tactics (black edged boxes), ultimately resulting in either the harvest or release of the captured fish

Notes: Solid connectors represent obligatory steps, while dotted lines indicate potential steps dependent on angler choices
Modified from Brownscombe et al. (2017, Figure 1)

3.2 Angling methods

Angling methods have the potential to differ in their impacts on fish survival following release. Moreover, angling methods, equipment and techniques can be selected to minimise physiological stress and physical injury, and maximise post-release survival; see Arlinghaus et al. (2007), Cooke et al. (2013) and Brownscombe et al. (2017) for comprehensive reviews.

In the UK, salmon are usually captured either by fly fishing, bait fishing or lure fishing (spinning). In 2014, some 47% (4,844) of salmon and 62% (18,211) of sea trout were caught by anglers using a fly, spinning yielded 36% (3,706) of salmon and 26% (7,787) of sea trout, and bait captured 15% (1,496) of salmon and 10% (3,003) of sea trout (Environment Agency 2015).

The general consensus among anglers and fishery managers appears to be that fly fishing causes the fewest injuries and lowest mortality, followed by spinning and then bait fishing (see Schisler and Bergersen 1996, Meka 2004, Cooke and Suski 2005, Arlinghaus et al. 2007, Cooke and Sneddon 2007, Cooke and Wilde 2007, High and Meyer 2014, Gargan et al. 2015). This is probably partly because of the lower incidences of hooking injuries when fly fishing compared with lure and bait fishing, although no studies appear to have made a direct comparison of these 3 methods.

Hooking injury is considered the primary cause of angling-related mortality in fish (Muoneke and Childress 1994, Aalbers et al. 2004, Cox-Rogers 2004, DuBois and Kuklinski 2004, Bartholomew and Bohnsack 2005, Cooke and Suski 2005, Cooke and Wilde 2007, James et al. 2007, Pelletier et al. 2007, Huehn and Arlinghaus 2011). Although hooking in the anterior portion of the mouth typically results in just a small puncture wound, unintentional hooking in more sensitive tissues (for example, oesophagus, stomach, gills, eyes, body) can cause physical damage and bleeding that can lead to mortality (Pelzman 1978, Warner 1978, Warner and Johnson 1978, Loftus and Taylor 1988, Dextrase and Ball 1991, Bendock and Alexandersdottir 1993, Pauley and Thomas 1993, DuBois et al. 1994, Muoneke and Childress 1994, Malchoff and MacNeill 1995, Schisler and Bergersen 1996, Schill and Scarpella 1997, Myers and Poarch 2000, Aalbers et al. 2004, Lindsay et al. 2004, Bartholomew and Bohnsack 2005, Lewin et al. 2006, Lyle et al. 2007).

The degree of hooking-related injury (and unhooking stress) is determined by a complex interaction among many factors including fish size and species, water temperature/dissolved oxygen level, bait or lure type, hook type and configuration, angling method and tactics, and angler experience (Loftus and Taylor 1988, Taylor and White 1992, Muoneke and Childress 1994, Bartholomew and Bohnsack 2005, Arlinghaus et al. 2007, Cooke and Wilde, 2007, Huehn and Arlinghaus 2011).

Hooks are available in a range of types, sizes, shapes, strengths, gape widths, shank lengths, hook points and attachment points. Anglers have traditionally used J-hooks, and these are still very common, including in salmon angling. There is evidence, however, that J-hooks cause more damage than other types such as circle or wide gap hooks, especially when used with organic baits (Siewert and Cave 1990, Lukacovic 2000, Lukacovic 2001, Cooke et al. 2001, Grover et al. 2002, Lukacovic and Uphoff 2002, Prince et al. 2002, Schaeffer and Hoffman 2002, Skomal et al. 2002, Cooke et al. 2003, Aalbers et al. 2004, Cooke and Suski 2004, Bartholomew and Bohnsack 2005, Ostrand et al. 2005, Cooke and Sneddon 2007, Cooke and Wilde 2007, Margenau 2007, Pelletier et al. 2007, Bergmann et al. 2014, High and Meyer 2014, Lennox et al. 2015a, Lennox et al. 2015b).

Circle hooks (where the point of the hook is perpendicular rather than parallel to the shank) can effectively reduce deep hooking and mortality compared with J-hooks as they usually hook in the corner of the mouth (Orsi et al. 1993, Lukacovic 1999, Lukacovic 2000, Caruso 2000, Hand 2001, Cooke and Suski 2004, Casselman 2005, Cooke and Sneddon 2007, Cooke and Wilde 2007). Indeed, even if the bait is swallowed, fish are generally only hooked when the eye of a circle hook clears the mouth (Bartholomew and Bohnsack, 2005). Reduced injury has been reported for salmonids, with coho and Chinook salmon having reduced hooking mortality rates when caught on circle hooks (McNair 1997, Grover et al. 2002); the efficacy of hook types at minimising fish injury and stress has been reviewed by Arlinghaus et al. (2007) and Cooke and Suski (2005).

Generally, using fewer hooks or single hooks, instead of doubles or trebles, reduces potential physical injury and unhooking times (Muoneke 1992, Nuhfer and Alexander 1992, Gjernes et al. 1993, Muoneke and Childress 1994, Ayvazian et al. 2002, Cooke and Wilde 2007, Pelletier et al. 2007, Colotelo and Cooke 2011, Stokesbury et al. 2011). Single hooks are less likely than double or treble hooks to become tangled in landing equipment (for example, nets). Spinners and spoons usually have large treble hooks or, in plugs, 2 or 3 treble hooks, although some salmon lures are available with single hooks or they can be replaced with single hooks.

In contrast, except when using trebles hooks with prawns or fish, bait fishing for salmon invariably involves single hooks. There is therefore an increased risk of hooking injury from lures due to the larger number of hooks compared with bait fishing, but there is not necessarily a statistically significant difference in mortality when using treble and single hooks (Taylor and White 1992, Pauley and Thomas 1993, Bartholomew and Bohnsack 2005). Notwithstanding, in contrast to fly fishing and spinning, there is a greater potential for 'deep hooking' (that is, hooking in the oesophagus or stomach) when bait fishing (see Section 3.3).

Hook size can also have a significant influence on hooking depth and injury, with large hooks causing more damage but small hooks most likely to be hooked in the oesophagus or stomach (Pauley and Thomas 1993, DuBois et al. 1994, Wilde et al. 2003, Cooke et al. 2005, Alós 2008, Rapp et al. 2008, Brownscombe et al. 2017). This could partly explain why fishing with flies can *occasionally* result in deeper hooking than with soft plastic lures (Stålhammar et al. 2014). However, fly fishing technique (for example, passive versus active) will also have an influence and few studies have reported a significant influence of hook size on fish mortality (see Bartholomew and Bohnsack 2005).

Anglers traditionally use barbed hooks to minimise the loss of fish during the retrieval. In many forms of angling (especially C&R based fisheries), barbless hooks are now regarded as preferable to barbed because they are more easily removed from fish, either from mouths and, in the case of foul-hooked individuals, other areas, and should therefore cause less tissue damage (Diggles and Ernst 1997, Cooke et al. 2001, Schaeffer and Hoffman 2002, Meka 2004, Casselman 2005, Cooke and Suski 2005, Pelletier et al. 2007, Huehn and Arlinghaus 2011). Indeed, many fisheries have made barbless hooks compulsory. However, there is a school of thought that barbless hooks penetrate further than barbed hooks and can swivel during the retrieval, causing deeper and more damage than often assumed, especially during long 'fights'. A compromise many anglers now use is hooks that are micro-barbed or semi-barbed (in the case of trebles or doubles). Notwithstanding this, syntheses of hooking mortality studies (Muoneke and Childress 1994, Bartholomew and Bohnsack 2005, Cooke and Suski 2005, Cooke and Sneddon 2007, Arlinghaus et al. 2007) concluded that barbless hooks are consistently less injurious and result in less mortality than barbed hooks, and suggest that barbless hooks should be widely adopted by anglers.

Hook size can also be important in C&R with larger hooks being prohibited to reduce the incidence of 'foul hooking' (Olsen et al. 2010). Local fishery byelaws also prohibit the use of double, treble or multiple hooks that exceed an 8mm gape, except when fishing with an artificial fly not exceeding 15g in weight, after the end of August each fishing season to prevent foul hooking and damage to smaller salmon running at that time.[2]

Angling methods can influence the likelihood and severity of hooking injuries (Brownscombe et al. 2017). For example, methods requiring anglers to 'strike' to hook fish (for example, trotting, legering, freelining, wobbling) may allow baits to be ingested

[2] Environment Agency North West Region Byelaw 24: Size of hooks and weight of lures

and increase the risk of deep hooking (Persons and Hirsch 1994, Schisler and Bergersen 1996, Bartholomew and Bohnsack 2005, Alós 2009, Lennox et al. 2015a, Lennox et al. 2015b), whereas fish captured using lures are generally hooked immediately, as the lure is continuously being retrieved. An important exception is when using flying condoms or 'Flying Cs', a brand of spinner with the hook positioned well below the body of the lure, which often results in deep-hooked salmon. Whether intentional or not, delays in striking could increase the risk of deep hooking fish, which often increases the difficulty of hook removal and air exposure duration during dehooking.

Similarly, angler experience can influence the likelihood and severity of hooking injuries, with novice anglers likely to injure significantly more fish than are experienced anglers, especially during the unhooking process (see Section 3.6) (Diodati and Richards 1996, Meka 2004).

It may be possible to minimise post-release mortality of salmon. For example, avoiding spinning for pike should minimise inadvertent captures of salmon, and adopting best practices (for example, using unhooking mats and minimum line strengths and landing net dimensions) when pike fishing by other methods should minimise fight times and the risk of physical damage during the unhooking process to any salmon captured. Similarly, many salmon fisheries enforce specific regulations (for example, fly fishing only, single barbless hooks only) intended to minimise the impacts of C&R angling.

3.3 Baits

The range of baits available to recreational anglers can be broadly categorised as either 'natural' (organic) baits (for example, live or dead invertebrates or vertebrates), lures (for example, plastic, wooden or metal spinners, spoons and plugs) or 'flies' (natural or artificial fibres tied to a hook) (Brownscombe et al. 2017).

There appears to be no conclusive evidence that bait type as such has an influence on the post-release fate of individual salmonids. Indeed, the theory behind such a phenomenon is unclear. More likely is that the method or technique (see above) associated with the use of particular baits has an influence, especially as the type (and size) of bait will determine the number, size and type of hooks used. It should be noted, however, that some baits are highly effective (for example, worms), can influence behaviour (for example, prawns) or result in the capture of juvenile individuals (for example, worms and maggots) (K. Sumner, personal communication), so there could be cumulative *population* effects.

In general, natural baits appear to be associated more with hooking injuries than artificial bait types (Clapp and Clark 1989, Payer et al. 1989, Siewert and Cave 1990, Taylor and White 1992, Pauley and Thomas 1993, Muoneke and Childress 1994, Schisler and Bergersen 1996, Diggles and Ernst 1997, Wilde et al. 2000, Cooke et al. 2001, Schaeffer and Hoffman 2002, Bartholomew and Bohnsack 2005, Cooke and Suski 2005, Cooke and Sneddon 2007, Cooke and Wilde 2007, Margenau 2007, Pelletier et al. 2007, Arlinghaus et al. 2008, Huehn and Arlinghaus 2011, High and Meyer 2014, Stålhammar et al. 2014).

In salmon angling, this is possibly because natural baits (for example, worms, prawns, shrimps, fish) are invariably used with methods that require anglers to strike to hook fish, whereas fish captured using lures (for example, spinners, spoons, plugs) are generally hooked immediately. However, fish may occasionally be deep-hooked even with an immediate strike, especially when feeding voraciously or if 'bite' indication is poor. The orientation of bait on hooks may also affect fish survival, as observed in Chinook salmon, for which mortality was highest when baits were presented head down (Grover and Palmer-Zwahlen 1996, Grover et al. 2002).

In general, lures incorporating soft plastic or rubber appear to be more associated with hooking injuries than harder lures (Schisler and Bergersen 1996). A well-known example is the Flying C, a brand of spinner with a soft rubber sheath, which often results in deep-hooked salmon. However, lure (and hook) size may mask any effects of lure type, with the highest incidences of deep hooking generally associated with small lures and hooks (see Section 3.2) (Wilde et al. 2003, Alós, 2008). Indeed, lure size (or hook size; see Section 3.2) may be the primary factor influencing hooking injury in recreational fisheries (Brownscombe et al. 2017) and may explain the comparatively high incidence of deep hooking when using Flying Cs. This is also likely to be the case when using natural baits for salmon, with the highest incidences of deep hooking generally associated with relatively small baits (for example, worms) and hooks (Warner 1976, Warner and Johnson 1978). Lure size could also explain why single hooks are sometimes more likely than treble hooks to deep-hook fish (Muoneke and Childress 1994).

Many authorities and fisheries regulate the types of bait that can be used for salmon angling, especially those that are highly effective (for example, worms), can influence behaviour (for example, prawns) or result in the capture of juvenile individuals (for example, worms and maggots) (K. Sumner, personal communication). Some, for example, only allow fly fishing, restrict the use of worms, maggots, shrimps and prawns (for example, to certain times of year or certain stretches of river), or have banned C&R when using worms because of the high incidences of deep hooking. Although the latter avoids the possibility of post-release impacts, it cannot be an effective conservation tool because captured fish are removed from the fishery.

Ideally, anglers should use the least harmful bait/lure type (for example, artificial lures with minimal, appropriately sized, barbless hooks fished actively), although in many cases, the ideal lure or bait type for fish welfare is not the most effective for catching fish (Brownscombe et al. 2017).

3.4 Retrieval

There is often a positive correlation between retrieval ('fight') duration and fish physiological stress (see Section 2.2) (Beggs et al. 1980, Wood et al. 1983, Gustaveson et al.1991, Tufts et al. 1991, Booth et al. 1995, Kieffer et al. 1995, Brobbel et al. 1996, Milligan 1996, Tomasso et al. 1996, Wilkie et al. 1996, Gallman et al. 1999, Kieffer 2000, Schreer et al. 2001, Thompson et al. 2002, Cooke et al. 2003, Thorstad et al. 2003, Bartholomew and Bohnsack 2005, Cooke and Suski 2005, Meka and McCormick 2005, Cooke and Wilde 2007, Skomal 2007, Suski et al. 2007, Arlinghaus et al. 2009, O'Toole et al. 2010, Sepulchro et al. 2012, Cooke et al. 2013). For example, Thorstad et al. (2003) found a correlation between haematological disturbances (increases in plasma lactate and decreases in blood pH) in Atlantic salmon and retrieval duration.

It would therefore be best practice for anglers to use gear of sufficient strength (for example, lines greater than a particular breaking strain, rods greater than a particular test curve) to minimise fight duration (Cooke and Suski 2005, Cooke and Sneddon 2007, Pelletier et al. 2007, Brownscombe et al. 2017). There is often a trade-off, however, between gear strength and fish catches. Fish that are captured on light gear invariably take longer to 'land' (see Section 3.5), which is likely to increase physiological stress. This is particularly important because anglers are most likely to fine down when water clarity is high, as is often the case during periods of high water temperatures and low dissolved oxygen concentrations. There is therefore a risk that salmon captured on light gear may be at an increased risk of mortality, especially following long fights during periods of high water temperatures and low dissolved oxygen concentrations.

In addition, there is a possibility that salmon could be captured inadvertently by anglers targeting other species. For example, anglers targeting perch, grayling or chub with small lures or large worms could potentially hook salmon, although most medium-sized or large individuals would likely escape if hooked on light gear. The gear used by most pike anglers should be sufficient to land large salmon, but trout anglers generally use lighter gear, and salmon could take a considerable length of time to subdue.

There is, thus, an opportunity to enhance salmon C&R survival through best practice recommendations specifying gear requirements (for example, minimum line, rod strengths, hook size and shape) that should minimise retrieval times.

3.5 Landing

In salmon C&R, ‘landing’ can involve bring the fish to the river bank for unhooking in the water, although fish are also removed from the river using a landing net. Landing is a critical aspect of C&R angling because it often involves air exposure and potential physical injury from contact with:

- equipment such as nets (note gaffs and tailers are banned in the UK)
- angler’s hands
- abrasive surfaces (for example, shore, boat) (Brownscombe et al. 2017)

To minimise stress and maximise survival, use of a landing net is recommended used to bring the fish to the bank. Landing nets are a simple and effective way for anglers to gain control of hooked fish and to return them to the water with minimum stress or injury (Arlinghaus et al. 2007).

It is therefore best practice for anglers to carry a landing net both to speed up the landing process and to hold the fish in the water prior to handling and hook removal. Numerous types of nets are available, all of which cause differing amounts of injury, epithelial damage and fin abrasion, depending on mesh size and material (Cooke and Sneddon 2007).

Knotted mesh types are known to be the most injurious leading to higher mortality (Pottinger 1997, Cooke and Hogle 2000, Barthel et al. 2003). For this reason it is illegal to use landing nets with knotted or metallic meshes and to retain salmonids in keep nets in the UK. Nets with large mesh size can increase the likelihood of damage to fins (Olsen et al. 2010), while net material can be abrasive (Barthel et al. 2003) and remove the layer of mucus that contains both non-specific and specific defence factors, such as immunoglobulins, lysozymes and proteases (Pickering and Pottinger 1995, Wendelaar Bonga 1997).

To reduce susceptibility to disease, injury or mortality from net trauma, landing nets with rubberised or knotless nylon mesh – particularly with a mesh size large enough to retain the fish but small enough to ensure pasts of the body do not protrude through the mesh (Barthel et al. 2003, Casselman 2005, Colotelo and Cooke 2011) – should be selected for C&R angling (Arlinghaus et al. 2007).

Depending on the situation and angler experience, it may be possible to unhook fish in the water with minimal handling. Intuitively, experienced anglers using good handling techniques should reduce air exposure and potentially improve post-release survival, but many studies found no influence of handling technique on mortality (Bartholomew and Bohnsack 2005). Notwithstanding this, other studies have found a negative correlation between air exposure and fish survival.

Air exposure should be minimised, ideally to <10 seconds and a maximum of 15–20 seconds (Cooke and Suski 2005) during the landing (and unhooking and documentation) process to facilitate recovery and maximise survival (Ferguson and Tufts 1992, Schisler and Bergersen 1996, Cooke et al. 2001, Bartholomew and Bohnsack 2005, Cooke and Suski 2005, Arlinghaus and Hallermann 2007, Cooke and Sneddon 2007, Pelletier et al. 2007, Wedemeyer and Wydoski 2008, Arlinghaus et al. 2009, Gale et al. 2011, Cooke et al 2013, Lennox et al. 2015c).

For salmon, this can sometimes be achieved by unhooking the fish in the water (Olsen et al. 2010). When this is not possible (for example, if it would be dangerous for the angler to enter the water), fish should be unhooked and released (see below) as quickly as possible. However, even when experienced salmon anglers are accompanied by professional guides, the time from landing to release of the fish can be on average 180 seconds (Thorstad et al. 2003). If necessary, fish can be allowed to partially recover (for example, in a landing net in clean, oxygenated water) prior to unhooking (and documentation), thereby reducing the duration of air exposure.

3.6 Handling of fish

Best practice handling techniques are important for the effective management of fish during C&R events such as landing, handling and on bank processing. All of this can improve the health and welfare of captured fish, thus increasing their survival chances after release.

C&R typically involves handling the fish – unhooking, recording body measurements, photographing, all of which can have considerable impact on the angled fish (Arlinghaus et al. 2007). Angler experience is critical to reducing injury and stress to fish during the catch, handling and release stages of C&R angling. Fish mortality was found to be lower when captured by more experienced anglers (Diodati and Richards 1996, Meka 2004); novice anglers take significantly longer to play and unhook fish (Newman et al. 1986) and can injure fish in the process (Meka 2004). Regardless of their experiences, anglers are encouraged to reduce handling and eliminate air exposure (Arlinghaus et al. 2007).

Prolonged air exposure and handling can increase physiological impairment and mortality levels of fish during C&R angling events (Ferguson and Tufts 1992). Exposure to air impedes a fish's ability to uptake oxygen, reducing the amount carried by the blood and resulting in increased anaerobic metabolism (Ferguson and Tufts, 1992). About 120 seconds of air exposure was found to impair the swimming performance of brook trout (Schreer et al. 2005), while increased mortality to 38% and 72% was found in rainbow trout exposed for 30 or 60 seconds following exhaustive exercise, respectively (Ferguson and Tufts 1992).

Handling of fish also results in the production of stress hormones (Rice and Arkoosh 2002) and cortisol secretions, which cause suppression of the immune system, reduced immune cell function and a concomitant increase in susceptibility to disease and pathogens (Anderson 1990, Rice and Arkoosh 2002).

Handling also removes the layer of mucus that contains defence factors and thus increases susceptibility to infection (see Section 3.8). Minimising handling will remove less mucus membrane and reduce the chances of fungal infections and mortality (Steeger et al. 1994, Barthel et al. 2003, Colotelo and Cooke 2011). Clean, wet hands or non-abrasive gloves are suitable options for handling (Brownscombe et al. 2017); slime loss has been found to be similar between bare and gloved hands (Murchie et al. 2009). Reducing handling time will not only decrease fish stress but limit the time the fish is exposed to air.

When unhooking a fish, a suitable removal tool and appropriate technique are essential to reduce hooking and handling-related injuries (Barthel et al. 2003, Cooke and

Sneddon 2007). Where possible, fish should be retained in water during unhooking to avoid air exposure, which can cause physiological stress (Brownscombe et al. 2017). Long-nosed pliers are recommended, especially where fish are hooked deep in the mouth.

If fish are hooked in sensitive tissues (most commonly the oesophagus), cutting the hook or line and leaving the hook in the tissue (assuming the hook will eventually be regurgitated (Bartholomew and Bohnsack 2005, Cooke and Wilde 2007) often results in less injury, physiological disturbance, and greater survival than hook removal (Mason and Hunt 1967, Warner 1979, Fobert et al. 2009). For example, Schill (1996) found that 60% of rainbow trout managed to expel hooks. Although not tested for salmon, fish are capable of expelling embedded hooks (Schill 1996, Diggles and Ernst 1997, Aalbers et al. 2004, Tsuboi et al. 2006). Fobert et al. (2009) found that removing the hook from the oesophagus of bluegill (*Lepomis macrochirus*) resulted in 40% mortality (corrected for controls) after 48 hours, whereas cutting the line resulted in only 9% mortality and 46% of deeply hooked fish were able to expel the hook within 48 hours. However, there is concern that recent advances in hook materials (for example, tungsten and high carbon steel) to delay corrosion times may make this ability to shed embedded material less effective (Brownscombe et al. 2017).

3.7 On bank processing

On bank processing after landing and hook removal could include weighing and/or length measurement and photographing prior to its release. During this sequence of events fish are retained, handled and exposed to air (Brownscombe et al. 2017). Physical injuries can occur at each of these stages.

For example, gill lamellae can collapse while the fish is out of water (Boutilier 1990), inhibiting gas exchange and in the case of rainbow trout, blood oxygen tension. The amount of oxygen bound to haemoglobin have been found to fall by over 80% during brief air exposure (Ferguson and Tufts 1992), causing severe anoxia (Cooke and Suski 2005). Long air exposure can result in physiological impacts, longer recovery periods (leading to reduced ability to avoid predators) (Schreer et al. 2005, Klefoth et al. 2008) or mortality (Ferguson and Tufts 1992, Mitton and McDonald 1994, Cooke et al. 2001, Cooke et al. 2002a, Cooke et al. 2002b, Davis and Parker 2004, Schreer et al. 2005).

It is recommended that anglers endeavour to eliminate air exposure by handling and processing fish in the water, but when fish must be exposed to air, being prepared can reduce the time a fish is out of water by, for example:

- using a large landing net to ensure fish remain in the water for as long as possible
- taking length measurements while the fish is submerged in water

Use of a measuring stick or material tape measure should be considered.

Under some circumstances, anglers may wish to photograph or weigh their catch. Although this is not recommended, if this is the case anglers can weigh fish in the landing net (or proper weighing sling); the time taken for pictures should be kept to a minimum to reduce air exposure and minimise handling (Shiffman et al. 2014, Brownscombe et al. 2017), or ideally taken with the fish remaining in the water.

To avoid weighing fish altogether, it is recommended that length–weight relationships are used to determine weight from length measurements.

All these measures will work towards improved post-release survival.

3.8 Recovery and release

The release method, where fish are transferred from an angler's possession back into the water, represents a crucial transitional period (Brownscombe et al. 2017). The physiological disturbances that occur during exhaustive exercise, stress caused by handling and on bank processes take approximately 8–12 hours for full recovery for most fish species (Kieffer 2000). Consequently, care must be taken when returning fish to the river.

Assessment of the condition of the fish is crucial to determining if it should be released immediately, especially as fish can become disoriented when returned to their environment (Brownscombe et al. 2017). Assessment of the physical condition of fish caught in recreational fisheries has largely developed separately as physical injury scores (for example, deep hooking) and reflex (for example, equilibrium) impairment tests (Davis and Ottmar 2006, Davis 2010).

Physical injuries are common predictors of mortality in all types of fisheries (Muoneke and Childress 1994, Chopin and Arimoto 1995, Cooke and Suski 2005). Deep hooking (where the hook(s) enter deeply into the fish's mouth, hooking the oesophagus, stomach or gills) is recognised as the main cause of mortality for many species (Muoneke and Childress 1994, Cooke and Suski 2005). Injuries that result in blood loss to the point that gills become pale and the fish loses perfusion of gill tissues most commonly arise from damage to the cardiorespiratory structures such as the gills or heart (see for example: Pelzman 1978, Savitz et al. 1995, Prince et al. 2002, Lindsay et al. 2004). Epithelial damage can be caused by line rolling while on the hook, contact with abrasive surfaces such as landing nets, rolling on the bank, abrasion against bed substrate, or handling during unhooking. This can lead to fungal, bacterial or viral infections, and mortality (Plumb et al. 1988, Steeger et al. 1994, Barthel et al. 2003, Colotelo and Cooke 2011). Despite the obvious welfare consequences of injury and stress associated with physical injuries, fish behaviour may be impaired and this could increase susceptibility to predation (Cooke and Philipp 2004) and passive displacement from behavioural territories (Thorstad et al. 2003).

Reflex impairment indicators assess the internal physiological stress that can occur independent of injury (for example, long fight or air exposure times). Although measuring physiological condition of a fish is impractical for salmon anglers, fish reflexes (involuntary motor responses to external stimuli) are a suitable alternative for assessing impairment (Davis 2010). These include equilibrium responses such as (Davis 2010, Lennox et al. 2015c):

- the time taken to self-right when inverted
- moving its eyes to track level when rotated
- tail grab for escape response from predators

Equilibrium loss was found to be a good predictor of behavioural impairment in coho salmon (*Oncorhynchus kisutch*) (Raby et al. 2012). Head complex (consistent, active opercular ventilation) and vestibular ocular response (eye movement when body moved) impairment are also good indicators of physiological impairment and are often the last to become impaired in angled fish (Brownscombe et al. 2017), indicating extreme physiological stress, neurological and behavioural impairment, and higher mortality risk (Davis 2007, Raby et al. 2012, Brownscombe et al. 2013).

If a fish has lost its ability to maintain upright / horizontal orientation or does not respond to handling, this reflects underlying physiological condition that may lead to post-release mortality (Davis and Ottmar 2006, Davis, 2007, Davis 2010) if it is not allowed to recover fully before release. These basic indicators should be used to assess whether the fish is in a suitable condition for release or should be allowed a longer recovery time.

Anglers should plan locations suitable for releasing fish back into the water body in advance. The location should be a similar environment to where the fish was caught, but should also take into account the condition of the fish post capture to avoid it being washed downstream.

A fish that responds well to stimuli and is energetic will do better if released as soon as possible with minimal handling and air exposure.

- When returned to the water, fish should be supported gently under the belly, kept in an upright / horizontal position under the water and head facing upstream to aid breathing until it swims off (Marine Scotland 2010).
- If there is a current, the fish should be held so it is facing into the flow as it recovers.
- If possible, release the fish into deeper water where there is more oxygen present.
- If the fish looks like it is in difficulty and unable to maintain an upright / horizontal orientation, cradle it in the water by holding it by the tail and gently moving it left to right until it regains strength. Gently hold the fish in the water current so that it obtains a good flow of well-oxygenated water over its gills (Brownscombe et al. 2017).

The fish will attempt to swim off when it is ready to go; depending on how tired the fish is, this may take several minutes.

4 Guidance on minimising the impacts of C&R

The main aim of C&R salmon angling is to ensure that the individual fish survive to grow on and contribute to the fishery and/ or to spawn. Numerous angling and radio tracking studies have demonstrated high survival rates and successful spawning for salmon released after capture (up to 100% in certain conditions).

As discussed in Section 3, the main factors found to reduce survival are:

- angling method
- deep hooking
- poor and excessive handling
- being kept out of the water for a prolonged period
- high water temperatures

To give the fish the best chance of full recovery from capture and further contributing to the fishery or going on to spawn, the simple measures detailed below should be followed. These measures are embedded in numerous guidelines for C&R fishing such as:

- 'Guidelines on Catch and Release' (NASCO 2009)
- 'STFA Guidelines for Catch and Release' (STFA 2017)
- 'Catch and Release for Atlantic Salmon (Inland Fisheries Ireland, undated)

4.1 Check the rules

Always check the fishery rules before beginning angling and ask for advice from the fishery manager if unsure about the protocols.

Some fisheries that encourage C&R angling may not allow angling during hot weather because of the significantly reduced likelihood of survival. There is clear evidence that the survival of caught and released Atlantic salmon considerably reduces at temperatures above 18–20°C. Given the diel variation in water temperature can be high, it is recommended that C&R fishing is not practised when water temperatures exceed 18°C in the mid-morning.

4.2 Planning ahead

One of the main ways to maximise the survival of C&R salmon is to plan the fishing event/experience before starting to fish. The following tactics should be considered

- Always identify where a fish can be landed safely without risk of damage on rocks or stones. The location should preferably be in slack water where the angler can safely keep the fish in the water.
- Carry a net. A net can greatly reduce damage to the fish when landing and can help minimise the time the fish is out of the water.

- Have long-nosed pliers or forceps, a commercial dehooker or a similar tool close to hand so the hook can be removed quickly and easily with minimal handling and stress. Such tools can greatly reduce damage to the fish and can help minimise the time the fish is out of the water.
- Although not recommended, if the catch is to be photographed before release, do so preferably under water. The camera should be readily accessible, for example, on a neck lanyard.

4.3 Fishing tackle

Anglers or fishery managers should take care when choosing the angling method and tackle they are going to use where C&R is mandatory or where they intend to release fish. The angling method and tackle used can have a significant bearing on the survival of released fish.

- Use strong, well-balanced tackle to play fish quickly, rather than tiring them to exhaustion. Fighting a fish too long unduly stresses the fish, and over-exhaustion can increase the chances of predation when released.
- A leader tip should be heavy enough to bring in large fish quickly, or light enough to allow large fish to break off.
- C&R is more effective if using single barbless hooks. They do less damage and, if anything, penetrate better on the strike. Provided tension is kept on the line there should not be any significant increase in lost fish. These types of hooks can be released quickly with the minimum of trauma to the fish.
- Circle hooks are the ideal choice for C&R fishing, though they are not necessarily suitable for fly fishing or spinning. They are designed so that the point is turned away from the shank to form a circular shape. This allows the hook to pass back through the fish's stomach, should it be swallowed, and hook in the corner of the lip once line pressure is applied by the angler.
- Fly fishing and the use of artificial lures (except Flying Cs) are the best choice when practising C&R with salmon. Adult salmon are more likely to swallow the hook if using live baits, so using artificial lures when possible will increase the chances of survival when releasing the fish.
- Worm fishing is not recommended for C&R angling because it often results in fish dying. Similarly, shrimp/prawn fishing can result in deep hooking and higher mortality rates. Where worm and/or shrimp/prawn fishing is allowed, using a circle hook will reduce the chances of deep hooking and enhance survival.

4.4 Playing the fish

Angling has the potential to impact on the physiology of the fish – the bigger the event (such as the duration of fight time), the bigger the effect. Physiological changes resulting from the intense physical exercise of being played include depletion of energy reserves, accumulation of lactate and a change of acidity in the blood. Fish should therefore be played quickly and as firmly as possible so that they can be landed and released before becoming too exhausted.

Use tackle that has an appropriate strength for the size of fish that is likely to be caught, as this avoids having to play the fish for a long time before landing. Long fights in warm weather are especially damaging.

In a river, move the salmon out of the fast current into quieter water for dehooking and recovery.

If fishing from a boat, bring the fish to the boat as quickly as possible to avoid extreme exhaustion.

4.5 Landing the fish

When landing the fish, it is best to identify the landing location before starting to fish.

If fishing from the bank and it is easy to wade or reach into the water, there should be no need to remove the fish from the water or to handle it at all.

Landing on the bank or on gravel should be avoided as this causes abrasion and removes the surface mucus and scales, and leaves the fish vulnerable to fungal infections.

If the fish needs to be landed, it is essential to use fish-friendly landing nets with soft knotless, fine mesh.

Fish should never be lifted from the water by its tail or gill cover.

When a fish needs to be landed, it should be laid on a flat, wet surface for unhooking. A soaking wet towel or unhooking mat is ideal for this purpose. Laying the fish upside down will often calm it for unhooking. Holding down the tail on a flat surface will keep a fish still.

4.6 Handling the fish

If possible the salmon should not be landed, and the entire salmon should be kept underwater as much as possible. Exposing a salmon to air for even a short period, for example to take a photograph, can significantly reduce its chances of survival.

If the fish has to be taken out of water, it is essential to use wet hands when handling the fish. Dry hands are much more likely to cause abrasion, which increases the risk of infection from fungus, bacteria and parasites.

It is best to work quickly to minimise the time the fish is out of the water. The fish should be handled gently and not squeezed as this can damage internal organs; touching the gills and eyes should be avoided. Loss of scales and damage to the gills caused by pressure on the gills or by the removal from the water can affect survival.

The fish should be supported under the belly and kept in an upright / horizontal position, preferably underwater and facing into the current.

4.7 Removing the hook

Removing the hook can be stressful and a damaging aspect of the fishing activity, but if the angler is careful, the detrimental effects can be minimised.

- When the fish is quiet, use a long pair of pliers or forceps, disgorger or another unhooking device to gently – but quickly – unhook the fish, taking care not to squeeze it. Fish should be retained in the net on the surface of the water while the hook is removed.

- If the fish is deeply hooked, it may not be possible to remove the hook. In this case, cut the leader as close to the hook as possible. The hook will potentially work its way out and this will cause less damage than prolonged handling.
- Fish that have suffered serious damage (bleeding heavily) should still be returned as they may still survive.

4.8 Recording the catch

If the fish needs to be measured, which is not recommended as best practise, use a measuring stick or tape and measure underwater.

Weighing should be avoided for C&R because of the increased handling time and increased chance of damage to the fish, for example, fins, mucus and body, when weighing. Weight can be estimated from the length of the fish using conversion charts. A proper weighing sling should be used if the fish needs to be weighed.

Photographs should be taken with the fish remaining in the water to minimise handling and air exposure. The fish should be held with one hand around the tail wrist and the other hand supporting the fish behind the gill area.

Always wet hands before handling the fish.

4.9 Releasing the fish

Fish intended for release should be kept in the water. Exposing a fish to the air for even a short period, for example to take a photograph, can significantly reduce survival.

If possible, the fish should be slipped out of the net without touching it and be allowed to swim away on its own. If the fight was strong, the fish may well need time to recover.

Care should be taken to revive fish before release if they appear exhausted (struggling to hold themselves upright and/or unable to swim away).

- The fish should be held upright / horizontal and stable in the water until it is ready to swim off strongly. This could take quite a few minutes in some cases.
- If there is a current, the fish should be held facing into the flow to obtain a good flow of water over its gills as it recovers.
- If possible release the fish into deeper water where there is more oxygen present.
- If the fish looks in difficulty, cradle it in the water by holding it by the tail and gently moving it left to right until it regains strength.
- Do not drag the fish back through the water in an attempt to pass water through the gills. Instead hold the fish upright / horizontal facing towards the current until it starts to show signs of recovery.

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