Environment Agency

Coarse fishing close season on English rivers

Appendix 3a - Literature review - general

The coarse fishery close season in English rivers: a literature review

Author: Dr Russell Robertson & Dr Graeme Peirson, May 2018

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Executive summary

As part of an evidence gathering exercise, this literature review was commissioned on behalf of the Close Season Working Group to review the evidence in relation to the close season for coarse fish in English rivers. In particular, this review was tasked to look at the evidence base relevant to English coarse fisheries and to identify any evidence gaps.

This review has considered both the direct and indirect impacts of angling practices on coarse fish, focussing on the following topics:

1. Stress
2. Mortality
3. Spawning
4. Physiology
5. Disease
6. Exploitation
7. Migration and behaviour

The review highlights that gaps in the evidence base remain. To confidently assess the impact angling might have on fish and fish populations, a better understanding of the natural variations in these populations and their mortality rates is needed.

There is also a lack of information on the angling exploitation rates of English coarse fish, which limits the ability to extrapolate morality rates to population level effects.

This review also identified a lack of information to help understand what fish losses might be acceptable and how this relates to other non-angling pressures present in catchments.

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Introduction

In 2000, an independent Salmon & Freshwater Fisheries Review took place. It recommended the removal of the close season on rivers, but this proposal was rejected by Government due to concerns around a lack of evidence on the impacts of lifting the close season. In 2004, the Environment Agency commissioned a report to review the evidence base. The findings of that report highlighted a continued lack of conclusive evidence in the literature to support change.

As part of a new evidence gathering exercise, this scientific literature review was commissioned on behalf of the Close Season Working Group to support consideration on the future of the coarse fish close season on rivers. The Close Season Working Group consists of a panel made up from representatives of the Environment Agency, Angling Trust and the Institute of Fisheries Management. The current close season for coarse fish in English rivers runs from March 15th to June 15th inclusive. This law has been in force since 1878; a summary of the history of the close season legislation is included in Annex A.

This report consists of a snap shot of the published scientific literature with regards to the coarse fish close season in English rivers. It is not a definitive literature review, for it is limited to one scientific database (Scopus) search and does not include grey literature such as books, anecdotal evidence (unpublished field observations), government reports or other publications and articles. As such, this report forms part of a planned wider evidence base and so provides no recommendations on the future of the close season.

Methodology

This literature review was conducted using a SCOPUS database search (accessed August 2015). SCOPUS contains tens of thousands of academic peer-reviewed journal publications. SCOPUS was interrogated to search for relevant scientific publications that could help answer the questions around the close season debate. A list of questions and key words used to query the database is included in table 1 of Annex B. Relevant journal references and their abstracts were extracted and stored using reference management software (RefWorks). These extracts were manually scrutinised and used to form the basis of this report. Where appropriate, a full copy of the journal publication was acquired and read in more detail. Over 260 relevant abstracts were extracted and read; of these more than 20 papers warranted further scrutiny, so a full copy of the publication was obtained and read in more detail.

With regard to the most commonly angled coarse species in English rivers, the question around coarse fish spawning times was addressed by reviewing the information stored in the spawning tables held within Fishbase (www.fishbase.org). Only references pertaining to relevant coarse fish species of interest from western European countries with similar climates to the UK were used. References from countries with warmer climates, such as Turkey and Greece were ignored.

Literature review

Angling and stress in fish

Topic overview

Within the science literature, there have been numerous experiments to investigate the physiological stress response of fish to angling or simulated angling (stressed, chased to exhaustion). Most studies have examined the disturbances in blood gas variables, osmotic balance, metabolites, growth and hormonal levels in control fish versus angled fish. Cooke et al., 2013, have highlighted the fact, that over the past 20 years, there has been a dramatic increase in the use of physiological tools and experimental approaches for the study of the biological consequences of catch and release (C&R) angling practices for fishes. They also noted that such studies had been important to the development of strategies for handling fish, such that stress is minimised and survival probability increased.

However, we have to apply caution to any over simplification and liberal interpretation of the stress response in C&R fish, and its subsequent possible effects on the survival of the individual, and even more so when extrapolating to speculate on the overall impacts on the sustainability of angled fish populations. Cooke et al., 2013, argue that even if it is difficult to demonstrate strong links to mortality or other fitness measures, let alone population-level impacts of catch and release, there remains merit in using physiological tools as objective indicators of fish welfare, since this is of increasing interest to fisheries managers.

Catch and release is the dominant practice in UK coarse fisheries, thus harvested fish mortalities by rod and line are regarded as being insignificant. In contrast, in salmonids, the C&R rates (expressed as % of the total reported rod catch) vary from 14% in Norway to as high as 73% in Scotland and 84% in Russia, reflecting varying management practices and angler and stakeholder attitudes among countries (ICES, 2013).

Angling activity-direct impacts

The direct impact of angling on stress physiology of fish has been well documented, across numerous species and from various climates and aqueous environments. From these studies, some rules of thumb can be derived. Bigger fish fight harder and take longer to land, hence more often than not, show a greater stress response, and a higher mortality risk (Arlinghaus et al., 2007, Bartholomew and Bohnsack, 2005). For example, Meka and McCormick (2005) investigated the response of wild rainbow trout (Oncorhynchus mykiss) to C&R angling in the Alagnak River, southwest Alaska and observed that the pattern of increase in plasma cortisol and lactate was due to the amount of time fish were angled, and the upper limit of the response was correlated with higher water temperatures. The results of this study indicate the importance of minimizing the duration of playing the fish in order to reduce the sublethal physiological disturbances in wild fish subjected to C&R angling, particularly during warmer water temperatures. Meka and McCormick (2005) also noted that fish size may influence both the duration of angling and subsequent physiological response.

Furthermore, in general it has been observed that the stress response in angled fish is more pronounced in fish captured at elevated water temperatures (during the warmer, summer months) and when they were also exposed to an extended period of aerial exposure as a result of being handled out of the water during the landing and C&R phase. Water temperature is an important factor in determining survival of Atlantic salmon after release, explaining 72% of the variation in survival from Atlantic salmon (Salmo salar) C&R angling (Dempson et al., 2002). Mortality after C&R angling may increase at high water temperatures, and temperatures above 18–20ºC may have a negative effect on survival (Wilkie et al., 1996, 1997; Anderson et al., 1998; Dempson et al., 2002; Thorstad et al., 2003).

Few studies have assessed C&R mortality of salmonids at water temperatures of 23°C or above. Boyd et al., 2010 investigated the C&R mortality of rainbow trout (Oncorhynchus mykiss), brown trout (Salmo trutta), and mountain whitefish (Prosopium williamsoni) in three water temperature treatments, namely, when daily maximum water temperatures were cool (< 20°C), warm (20-22.9°C), and hot (≥ 23°C). In these studies, all angled fish (fly-fishing only) were confined to in-stream holding cages and monitored for mortality for 72 h. Mortality of rainbow trout peaked at 16% in the Gallatin River and 9% in the Smith River during the hot treatment. Mortality of brown trout was less than 5% in all water temperature treatments in both rivers. Mountain whitefish mortality peaked at 28% in the hot treatment in the Smith River. No mortality for any species occurred in either river when daily maximum water temperatures were less than 20°C. Mortality rates of brown trout and mountain whitefish were not related to time of day of capture. The C&R mortality rates presented here probably represent fishing mortality given that most anglers in south-western Montana practise C&R angling.

Stunz and Mckee, (2006) investigated the mortality associated with C&R in the fishery for spotted sea trout (Cynoscion nebulosus) in south Texas. Specifically, this study investigated the mortality for hook-and-line captured of spotted sea trout as a function of bait type, hook type, angler skill level and fish size. The overall short-term mortality for all treatments was relatively low with the notable exception of the parameter for angler skill level. Angling by novices produced a significantly higher mortality rate than angling by skilled anglers; however, mortality averaged only 18% even for inexperienced anglers. To evaluate long-term mortality, fish were monitored whilst held in a laboratory facility for 30 days; these fish showed no signs of long-term mortality. Although 11% mortality was recorded during the first 48 hour period, no subsequent mortality occurred within the next 28 days. The location of hook-related injuries may be the most important factor in determining C&R mortality. Anatomical hooking location was not a factor in the analyses but was treated as a component of experimental treatment level; however, Stunz and Mckee, (2006) observed that mortality was typically associated with hooking location rather than angling method or bait type.

Reeves and Bruesewitz (2007), conducted studies to estimate hooking mortality in walleyes (Sander vitreus) to determine factors that influence the survival of released fish. Simple hooking mortality rates ranged from 0 to 2% in May, when lake water temperatures were less than 20°C, to between 9 and 16% in the July-August period, when lake water temperatures were at least 20°C. This study and others (Boyd et al., 2010; Wilkie et al., 1996, 1997; Anderson et al., 1998, Dempson et al., 2002; Thorstad et al., 2003) highlight the cumulative risks that elevated water temperatures have on the mortality of angled fish and, as a point of note, the UK close season for coarse fish happens to coincide with the period of highest water temperatures in rivers.

In brook trout (Salvelinus fontinalis) and rainbow trout (Oncorhynchus mykiss), air exposure is also associated with C&R-related physiological disturbance and mortality (Ferguson and Tufts, 1992; Schreer et al.,2005), and there may be interactive effects of air exposure duration and water temperature on survival and physiological disturbances (Gingerich et al., 2007; Gale et al., 2011). Studies have shown that at low to moderate water temperatures, extended air exposure may result in little mortality in bluegill (Lepomis macrochirus), Gingerich et al., 2007. However, at high water temperatures, short-term mortality (within 48 h) can be substantial for bluegill, especially for fish that experience extended air exposure durations. Elevated water temperature combined with aerial exposure has shown adverse effects in sockeye salmon (Oncorhynchus nerka). The inability of all air-exposed sockeye in the warmest temperatures to maintain equilibrium upon return to the water is evidence of the effects of warm temperatures. Fewer than half of the air-exposed fish in the coolest temperature demonstrated this impairment. Further, air exposure resulted in a marked depression of ventilation rates in the warmest temperatures, Gale et al., 2011.

The recovery of fish from the playing stage of the angling event has been shown to be quick. Exhaustive exercise in fish typically led to increased muscle lactate, decreased tissue energy stores and alterations in plasma ionic status. However recovery from physiological disturbance is usually rapid, with most physiological variables returning to baseline levels within a few hours, as shown in the pike, Esox lucius L. (Arlinghaus et al., 2009); and the tench, Tinca tinca (Martín Gallardo et al., 2014). However, it should be noted that, in the context of our UK coarse fisheries close season debate, none of these studies have investigated the stress physiology impacts of angling in spawning fish.

Using a standardized fishing technique, Gallagher et al., (2014), studied sublethal (blood physiology and reflex impairment assessment) and lethal (post-release mortality with satellite tags) outcomes of fishing stress on 5 species of coastal sharks (great hammerhead, bull, blacktip, lemon, and tiger). Species-specific differences were detected in whole blood lactate, partial pressure of carbon dioxide, and pH values, with lactate emerging as the sole parameter to be significantly affected by increasing hooking duration and shark size. Species-specific differences in reflex impairment were also found; although no relationship was found between reflex impairment and hooking duration. The species according to degree of stress response, from most to least disturbed, were as follows: hammerhead shark > blacktip shark > bull shark > lemon shark > tiger shark. The results show that certain species (i.e. hammerhead sharks in this study) are inherently vulnerable to capture stress and mortality resulting from fisheries interactions and should receive additional attention in future conservation strategies.

C&R angling is gaining popularity worldwide and plays an increasingly important role in both fisheries management and conservation. Mortality from C&R angling is well documented across species, but the sublethal effects have not been evaluated in a natural setting. Laboratory studies have yielded mixed results regarding C&R impacts on fish growth. In order to address the fact that such laboratory based experiments fail to factor in the scales of stress and variability of a natural system, in a 27-year mark-recapture study of 1050 individually tagged largemouth bass (Micropterus salmoides), Cline et al., 2012 investigated the effects of C&R angling on growth in a natural setting. Individual bass were angled one to six times per season. Recapture intervals ranged from 1 to 98 days. Largemouth bass exhibited a post-release period (~6 days) of weight loss, but following this weight loss, a period of compensatory growth facilitating recovery to normal weight was observed. Cline et al., 2012 concluded that C&R angling had little impact on the overall seasonal growth patterns of largemouth bass and therefore should have limited adverse effects on growth-dependent ecological functions.

Angling activity-indirect impacts

Of particular interest to the close season debate, are questions probing the indirect effects of angling on the health and welfare of fish retained in some form of confinement prior to catch and release. In coarse fisheries, prior to the weigh-in, match anglers temporarily hold their catch in keeps nets. A significant proportion of recreational anglers may also temporarily retain fish until the end of the day’s fishing. They may also unintentionally keep trophy fish out of the water for extended periods of time for photographic and weighing purposes.

Little is known about the effects of handling stress and fish retention gear commonly used in UK coarse fisheries by anglers. Pottinger (1998), has shown carp (Cyprinus carpio) to be robust to confinement treatment, for it was observed that C&R fish transferred to keepnets did not increase or reduce the magnitude or duration of the stress response (plasma cortisol levels) compared to control groups.

Common carp (Cyprinus carpio L.) captured by specialised carp anglers are often retained in so-called "carp sacks" and released after substantial retention periods of several hours duration. Rapp et al., 2012, studied the effects of capture and retention in carp sacks on the physiological status of small hatchery-reared carp held at two water temperatures (12 °C and 22 °C) under laboratory conditions. A complementary field study (Dow's Lake, Ottawa, Ontario) was also conducted to examine the effects of carp sack retention on physiology, tissue damage, short-term behaviour and long-term fate on C&R fish. During retention for up to 9 hours, decreasing plasma lactate levels suggested recovery from initial capture stress, yet there was evidence of pronounced primary and secondary physiological stress responses resulting from the combined capture and retention in carp sacks in both the laboratory and the field. In addition, there was evidence of tissue damage in carp retained in carp sacks for long periods.

Physiological changes were associated with impaired post-release behaviour reflecting a tertiary stress response, but recovery was rapid within a couple of hours post-release. No mortalities occurred in a two month observation period. The findings of Rapp et al., 2012, indicate that despite being sub-lethally affected by capture and retention, carp are able to recover rapidly with negligible mortality from retention in carp sacks.

It appears from these two previous studies, that common carp are fairly tolerant to the handling and confinement stress faced by being placed in a keepnet. However, there are many other species of fish found in a typical UK coarse fishery and these other species may be less tolerant of such practices. Alas, there is insufficient information in the literature to directly comment further on the impacts of confinement on UK coarse fish.

Although common carp appear robust to confinement treatments, other studies conducted abroad on different species, typically show a prolonged and increased stress response in confined fish, often reported coupled with physical injury. For example, Cooke & Hogle (2000) investigated the injury and short-term mortality of lure-caught adult smallmouth bass (Micropterus dolomieu) in Lake Erie (USA) over a range of water temperatures (10.6-21.8°C) and under different retention practices. Fish were retained for 3-5h using six gear types or methods: metal stringer through lip, metal stringer through gill arch, cord through lip, cord through gill arch, wire fish basket and nylon keep net.

Control fish exhibited very little mortality (3%) and had negligible physical injury across all sampling periods. In general, increased injury and mortality coincided with higher water temperatures, particularly when water temperatures reached 21.8°C. Most retained fish (95%) experienced some form of injury or mortality. Survival and injury varied among retention gears, but gill damage or fungal lesions associated with abrasion, along with the cumulative stress of angling and retention, appeared to be the precursors to most deaths. Cooke and Hogle (2000) found that even at low water temperatures, significant injury can occur from retention gear; at higher temperatures, this injury seems to result in death.

In Australia, Butcher et al., (2011) also noted in angled, luderick (Girella tricuspidata), that compared with immediately sampled angled fish, those confined in keepnets had significantly elevated cortisol, glucose, lactate, chloride, sodium, and aspartate aminotransferase. Most of the variables returned to pre-stress levels within 4 days, but Butcher and co-workers, concluded that the use of keepnets had welfare implications and suggested avoiding their use.

Bettinger et al., (2005) investigated the mortality and physiological responses of adult striped bass (Morone saxatilis) angled from Lake Murray, South Carolina, and held in live-release tubes at different water temperature. Striped bass were caught with angling gear, tagged, and immediately released or held in live-release tubes for 2, 4 or 6 h prior to release. Plasma cortisol, glucose, lactate and osmolality were positively related to tube residence time. Overall mortality during summer was 83%, in contrast no mortality of striped bass was observed during spring. This study concluded that although live-release tubes appear to be useful for keeping striped bass alive when they are angled from cool water, they are not effective for striped bass angled from warm water. The high summer mortality of striped bass suggests a need for restrictive fishing regulations during the summer for the Lake Murray striped bass fishery.

Apart from confinement methods, the type of landing net used in angling may also imposed a risk of damage and mortality in fish. Using bluegill (Lepomis macrochirus) as a model species, Barthel et al., (2003), examined the effects of different net mesh types (rubber, knotless nylon, fine knotted nylon, coarse knotted nylon) on injury and mortality following angling at 26 °C. A control group consisted of individuals that were angled and held out of the water but not netted. Retention in a landing net for 30 s resulted in increased pectoral and caudal fin abrasion relative to control fish. Furthermore, evidence of dermal disturbance (i.e. scale and/or mucous loss) was more prevalent in netted fish than in control individuals. No control fish died during a 168 h holding period, whereas mortality rates ranged from 4 to 14% for fish landed with nets, and the majority of mortality occurred between 48 and 96 h post-treatment. Fish that died exhibited impaired swimming behaviour for approximately 24 h prior to death that was attributable to the extreme caudal fin erosion. Fish that died also had fungal lesions on the caudal peduncle that had begun to progress anteriorly. Barthel et al., (2003), observed that fish captured and landed by hand had lower injury rates than those fish landed using a net and experienced no mortality. Conversely, all net types resulted in raised injury and mortality, with the knotted mesh types being more injurious than the rubber or knotless mesh.

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Angling and mortality rates in fish

Angling mortality can be caused by many factors; in the previous chapter we covered the stress physiology response of fish being played to exhaustion combined with the additional cumulative stress loads associated with post-catch handling methods, variable water temperatures and length of aerial exposure. In this chapter we will concentrate on the risk to fish from capture by various types of angling gear and its subsequent impacts on fish post-release survival.

Little is known about the influence of hook size on fishing success, hooking performance and injury associated with recreational angling for large freshwater fish such as common carp (Cyprinius carpio L.). Rapp et al., (2008) compared two different sizes of conventional carp hooks (small, size 6, and large, size 1) baited with corn and found that small hooks caught more and larger carp at similar landing rates. Moreover, small hooks caused less tissue damage compared to large hooks. However, there was no evidence that small hooks reduced incidences of bleeding. For both hook sizes, most carp were hooked in the lower jaw (size 1: 81%; size 6: 64%) and the side of the mouth (size 1: 16%; size 6: 36%), and not a single fish out of 88 fish landed was hooked deeply in vital organs. These results suggest that more widespread use of small size hooks in carp fisheries might be promoted for conservation, fish welfare and angling quality reasons.

In the literature there is a lack of material investigating the impacts of angling on the mortality of fish species found in UK coarse fisheries. Yet again we must infer potential risks from other studies from species studied in different countries. With proper fish handling and water temperatures below 20ºC, Atlantic salmon mortality after C&R may be low (Dempson et al., 2002; Thorstad et al., 2003). Most studies of the effects of C&R in Atlantic salmon have been performed in North America, and many studies rely on fish being kept in tanks or cages after capture, which may not be representative for fish being released back to the river (Thorstad et al., 2008).

To get around the problems associated with laboratory based or other artificial holding facilities in C&R recovery experiments, Gargana et al., 2015 investigated the success of Atlantic salmon surviving to contribute to the spawning stock following C&R in three Irish rivers by the use of radio transmitter-tagged fish. Survival to spawning was greater for fly caught (98%) than lure caught fish (55%). Hence, survival after C&R was dependent on gear type. Hook location may have influenced C&R mortality in the lure captured fish. All fish bleeding at the hook wound or hooked in the throat died. Simultaneous hooking in the upper and lower mouth may also have contributed to reduced survival. A notable difference between fly and lure captured Atlantic salmon, however, was the larger hooks used for all lure-captured fish.

Meka, 2004 also noted in studies of rainbow trout (Oncorhynchus mykiss), that fish caught by spinning lures were injured more frequently than fish caught by fly. Cowen et al., (2007) noted higher hooking mortality rates of Chinook salmon hooked in critical locations, which were associated with heavy bleeding. However, increased bleeding did not translate into reduced spawning success for those fish that survived. In Chinook salmon, conclusions regarding hook size and its association with hooking mortality rate and spawning success remain unclear.

In another salmonid study, Tsuboi et al., 2002, investigated the effects of C&R angling on growth, survival and catchability of white-spotted charr (Salvelinus leucomaenis) in wild streams. In this species, short term hooking mortality of live bait-angled fish was 6.7%, which agreed well with previous data by studies of C&R mortality. There was no significant difference in standardized growth rate between angled fish and control fish. The recapture rates of angled and control fish were 77.9 and 74.2% respectively, suggesting that the survival rate of angled fish is not lower than that of control fish. No significant difference in catchability was found between angled fish and control fish. The results show no evidence that C&R angling affects growth, survival and catchability of white-spotted charr.

Australian bass, Macquaria novemaculeata, are angled in large numbers from coastal impoundments and rivers throughout south-eastern Australia. Many are released in the belief that most survive with few negative short-term impacts and this assumption was investigated by Hall et al., 2009. Short-term mortalities of angled bass were low (0-6%) and attributed to the effects of bait type, hook location and fish size ($P<0.05$). Specifically, fish that ingested hooks or were caught with natural baits were more likely to die than those that were mouth-hooked or caught on lures. The probability of mortality (relative risk) was 12 times higher for fish caught with natural baits than those caught with artificial lures. In these fish, it was also shown that anatomical hook location significantly influenced mortality. The probability of mortality (relative risk) was 14 times higher for fish that ingested hooks (with hooks subsequently removed) than that for mouth-hooked fish. In the Australian bass, mortality negatively correlated with fish size.

Hall et al., 2009 concluded that their results supported the previous assertions that Australian bass was a resilient, hardy species that could tolerate short-term impacts associated with C&R angling. However, other sublethal physiological impacts that could contribute towards delayed mortalities or reduced reproductive output warrant further investigation, particularly in relation to native populations in coastal rivers that form gauntlet fisheries during their annual spawning season.

Natural baits are typically ingested deeper than artificial lures because of a more aggressive feeding response to what is perceived as normal food (Butcher et al., 2006). In addition, natural baits are often passively fished with a slack line, which allows more time for hook ingestion (Schill 1996; Grixti et al., 2007). In particular, extremely high levels of mortality have been associated with the subsequent removal of ingested hooks (e.g. Schill 1996; Schisler & Bergersen 1996; Broadhurst et al., 2007; Butcher et al., 2007). For most species, significant increases in survival rates have been reported when ingested hooks were left in place and the line was cut a short distance from the mouth (e.g. Schisler & Bergersen 1996, Hall et al., 2009). However, this practice may be not be as good as first thought, for the results of a study in muskellunge pike highlight the dangers of only looking at the short term survival of post-released fish which still have retained hooks in their gut.

The use of live bait for angling of muskellunge (Esox masquinongy) is popular in Wisconsin, USA. A traditional method for catching them utilizes a large hook through the bait fish's snout, which requires the muskellunge to swallow the bait prior to hook set. In a study by Margenau (2007), adult muskellunge were held in lined hatchery ponds and caught while fishing with live bait on 10/0 size single hooks. The leader was cut and the muskellunge was released when hooked in the stomach. Survival was monitored for up to 1 year. No immediate (<24 h) mortality occurred. However, 22% of hooked muskellunge died within 50 days and 83% died within 1 year. Necropsies revealed extensive trauma to the stomach and other organs from hooks, along with systemic bacterial infections. Highest mortality on both hooked and control fish occurred over winter through spring. This peak mortality may be associated with natural stressors that occur during the spring spawning period. Mortality rates observed in this study are considered unacceptable for trophy management of muskellunge. Although use of live bait for muskellunge is traditional in Wisconsin, terminal tackle such as quick-strike rigs that hook fish in the mouth or buccal cavity should enhance the chances that a released muskellunge will survive, Margenau (2007). Arlinghaus et al., (2008) also observed in the northern pike (Esox lucius L) that the use of natural bait can also result in a higher incidence of deep hooking, which in turn increases the likelihood of injury and bleeding.

In striped bass (Morone saxatilis) caught in the Hudson River, Canada, Millard et al., (2005) has shown that C&R mortality averaged 16% for traditional J hooks and 5% for circle hooks. Hook location and the occurrence of bleeding were the most influential variables in determining the probability of death. Mortality rate increased when water temperatures reached 16°C. This mortality rate is significant and should be considered when accounting for Hudson River striped bass removals from their spawning population.

In the walleye (Sander vitreus), Reeves & Staples (2011) investigated the relative mortality of fish caught by means of bobber fishing with leeches on barbed or barbless live-bait octopus hooks or on barbed jigs. In this study, barbed jigs caused less damage than live-bait hooks and damage levels were similar between barbed and barbless live-bait hooks. This study illustrates how gear type can affect hooking mortality based on the amount of damage caused when the fish is caught and adds to the body of literature indicating that the removal of barbs from hooks does not increase fish survival per se.

Recently there has been more research into the effects of hook type, in particular circle hooks, on the mortality and catch rates in fish. High & Meyer 2014, estimated hooking and landing success and relative hooking mortality for stream-dwelling trout caught with baited circle and J hooks, J hook dry flies, and treble hook spinners (all hooks barbed). Trout were caught, individually marked and released for 69 days. Deep-hooking rate was higher for trout captured with baited J hooks (21%) than for spinners (5%), baited circle hooks (4%) and dry flies (1%). Relative mortality rate was higher for trout captured with baited J hooks (25%) and spinners (29%) than for trout captured with baited circle hooks (7%) and dry flies (4%).

High & Meyer (2014) found that deep-hooking was two and six times higher for baited J hooks than baited circle hooks for fish caught actively and passively, respectively. For baited circle hooks, deep-hooking was over three times greater when using an active fishing method (i.e., an active hook-set) compared to passive fishing method (no hook-set), which conflicts with manufacturers recommendations on how circle hooks should be fished. Hooking success (ratio of hook-ups to number of fish strikes) was about one-third lower for baited circle hooks fished both passively and actively compared to other hook types and fishing methods, except for passively-fished baited J hooks. Once hooked, landing success (ratio of fish landed to number of hook-ups) was relatively high for all hook types and fishing methods (range 68-87%). High & Meyer (2014) concluded that when bait fishing for trout in streams, circle hook use may reduce deep-hooking and hooking mortality (but also catch rate) regardless of whether anglers fish passively or actively.

In a similar study, Lennox et al., (2015) evaluated whether hook-set technique can affect hooking and injury in fish, and tested different combinations of hooks (circle hooks and J hooks) and hook-set techniques (e.g., light, moderate, or heavy force, or with a bobber) in an angling study for bluegill (Lepomis macrochirus) in Lake Opinicon, Ontario, Canada. The study found no significant interaction between hook type and hook-set, but overall, J hooks increased the odds of successfully capturing a bluegill and also the odds of deep hooking a bluegill relative to circle hooks. The bobber hook-set technique increased the odds of deep hooking a bluegill relative to the active hook-setting techniques. This study suggests both deep hooking and capture of bluegill are significantly affected by both hook types and hook-set techniques.

Large hooks may be more difficult to swallow than small hooks, but may cause greater tissue damage at the wound site, as shown in cutthroat trout (Oncorhynchus clarkii), Pauley & Thomas, 1993 and pike (Esox lucius L,), DuBois et al., 1994. In Chinook and coho salmon, Gjernes et al., (1993) speculated that the greater depth and gape of larger hooks may lead to deeper hook penetration and greater risk of contact with critical organs. The effects of hook location can be exacerbated by increases in handling time and air exposure, because deeply lodged hooks typically take longer to remove (Aalbers et al., 2004; Pauley and Thomas, 1993). Another factor that can influence the impact of hooking events is the presence or absence of a barb on the hook (Muoneke & Childress, 1994; Cooke & Suski, 2005; Arlinghaus et al., 2007).

Bartholomew & Bohnsack (2005) found that fish captured on barbed hooks had marginally higher mortality than those captured on barbless hooks. Bartholomew & Bohnsack (2005) found in their extensive review that C&R angling mortality varied greatly among and within species, and that anatomical hooking location was the most important mortality factor. Gargana et al., (2015) noted that any interpretation of risks associated with C&R fishing depends upon the characteristics of the fishery in terms of gear used, proportion of fish captured by gear type, angler release practices, and water temperatures when C&R activities occur.

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Coarse fish spawning times

The UK river coarse fishery consists of a mixed fishery dominated with species from the Cyprinidae (carp) family. The most commonly angled species and their spawning times are listed in Table 1 below.

From this table, we can see that the majority of the fish species have their peak spawning times in April and May, which coincides nicely with the close season which runs from March 15th to June 15th. From this table we can see that some species are early season spawners (before April); these include pike, dace and grayling. Late season spawners (beyond May) include some of the carp species and tench, although in most cases, these species' peak spawning period also includes May.

Table 1: Coarse fish spawning times from western European countries (data source FishBase spawning table)

Scientific Name	UK Common Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Anguilla anguilla	**European Eel**					*							
Abramis brama	**Bream**				2	1	1	2					
Alburnus alburnus	**Bleak**					1	1	2					
Barbus barbus	**Barbel**			2	1	1	2	2					
Blicca bjoerkna	**Silver Bream**					1	1	2					
Carassius carassius	**Crucian Carp**				2	1	1	2					
Cyprinus carpio	**Common Carp**					1	1	2					
Esox lucius	**Pike**		2	1	1	2							
Gobio gobio	**Gudgeon**				2	1	1	2					
Gymnocephalus cernua	**Ruffe**			2	1	1	2	3					
Leuciscus leuciscus	**Dace**		2	1	1	2							
Perca fluviatilis	**Perch**		3	2	1	1	2	3					
Rutilus rutilus	**Roach**			2	1	1	2						
Sander lucioperca	**Zander**			2	1	1	2						
Scardinius erythrophthalmus	**Rudd**			2	1	1	2						
Squalius cephalus	**Chub**			2	1	1	1	2					
Tinca tinca	**Tench**				2	1	1	1	2				
Thymallus thymallus	**Grayling**			1	1	1	2						

KEY

1	Peak Spawning	Data source - spawning tables from www.fishbase.org
2	Ocassionally Spawns	****Spawns at Sea***
3	Rarely Spawns	

Angling impacts on spawning fish

Over the past decade, although there has been a plethora of new research in fish looking at the impacts of angling catch and release (C&R) on fish, few papers (none of which studied UK coarse fish) have actually investigated the impacts of angling on spawning or peri-spawning fish, although there have been some studies done in kelts (post-spawned salmonids) and other species.

The effects of exhaustive angling of one-sea-winter Atlantic salmon (Salmo salar) at two different stages of their freshwater migration were investigated by Brobbel et al., (1996). Physiological disturbances in kelts, returning to the ocean after a prolonged period of starvation, were compared with those of bright salmon, which had recently entered freshwater from the ocean. Condition factor was significantly higher in bright salmon than in kelts, and was associated with a greater time required to angle bright salmon to a state of exhaustion. White muscle concentrations of phosphocreatine and glycogen decreased in both kelts and bright salmon immediately after angling, but recovered more quickly in kelts. White muscle lactate peaked after angling at 22.2 mmol·L-1 tissue water in kelts and at 40.6 mmol·L-1 tissue water in bright salmon. Accordingly, the intracellular acidosis that occurred in the white muscle following angling was also greater in bright salmon. Finally, mortality was not observed in any of the 24 angled kelts, but 3 of 25 bright salmon died within 12 h following angling, Brobbel and co-workers concluded that these results demonstrate that the physiological disturbance from angling is smaller in kelts than in bright salmon.

Nelson, et al., (2005) investigated the behaviour and survival of wild and hatchery-origin winter steelhead spawners caught and released in a recreational fishery. Mandatory catch and release of wild fish and supplementation with hatchery-reared fish are commonly used to sustain sport fisheries on low-abundance populations of wild steelhead. However, their effectiveness in limiting angling mortality on wild fish is unclear. Nelson, et al., (2005) radio-tagged wild and hatchery angled adult steelhead (Oncorhynchus mykiss) near the mouth of the Vedder-Chilliwack River, British Columbia and monitored their subsequent movements to determine survival to spawning and overlap in the distributions of inferred holding sites, spawning sites and spawning times. The distributions of pre-spawning holding sites did not differ between wild and hatchery fish in either year of monitoring, but spawning locations differed. Holding and spawning sites used by hatchery fish were restricted to the lower two-thirds of the river, downstream of the hatchery where they were reared but well upstream of their smolt release site. Wild fish spawned throughout the watershed. Spawning times did not differ between wild and hatchery fish, but varied with run timing

The maximum mortality from the initial C&R and radio-tagging was 1.4% in 1999 and 5.8% in 2000; true mortality rates were lower because tag regurgitation was indistinguishable from death. The fishery subsequently killed 2.5% of tagged wild fish and harvested 20% (1999) and 43% (2000) of the hatchery fish. Seventy two tagged fish were recaptured and released in the sport fishery up to three times without any mortality before spawning. Hatchery fish were recaptured at twice the rate of wild fish. At least 92% of unharvested fish spawned, and 75% of successful spawners survived to emigrate from the watershed. The incidence of post-spawning death did not vary with the frequency of capture and release. Nelson, et al., (2005) concluded that C&R angling imposed small costs in terms of survival; however, behavioural differences existed between adult wild fish and the adult F1 progeny of wild fish reared to smolt stage in a hatchery.

Halttunen et al., (2010) investigated the impact of C&R on behaviour and mortality in kelts of Atlantic salmon (Salmo salar L.) by using telemetry in the sub-arctic River Alta, Norway. Recapture rates, behaviour and survival of the angled and tagged kelts were compared to a control group of salmon (n= 17) tagged acoustically 7-10 months earlier, and therefore considered unaffected by recent angling and tagging. The recapture rate of the control group kelts (18%) did not differ from the recapture rate of the kelts tagged in spring (14%), and only a small proportion of the tagged kelts (2%) was recaptured more than once the same season. In total, 4% of the kelts died after C&R in the river and 92% migrated out of the fjord on average 1 month after catch, tagging and release. The C&R fish descended the river slower than the uncaught control group, but no difference in the start of their marine migration, migration progression or survival was observed between the compared groups. Halttunen et al., (2010) concluded that (1) C&R affected the post-release behaviour of kelts only by delaying the river descent, and (2) the delayed post-release mortality rate of C&R kelts was not elevated despite the reduced energy levels and physiological condition of kelts. Hence, releasing angled kelts can be a viable management strategy to enhance the return rate of repeat spawners.

The effectiveness of C&R for Atlantic salmon conservation is reliant on the ability of individuals to recover from angling, resume migration, and reach spawning grounds at appropriate times, and this is what Lennox et al., 2015 studied in caught and released Atlantic salmon in River Gaula, Norway. In this study, 27 C&R salmon were monitored by affixing external radio transmitters to them. These fish were compared with a control group of fish caught and radio-tagged at sea in bag nets before river entry. Whereas none of the control fish died during the study period, there were three mortalities among the C&R fish (11%; significant difference).

The angled and released Atlantic salmon were distributed in similar locations throughout the river during the spawning season compared with control fish, but those caught and released later in the season appeared to migrate shorter total distances than control fish. Among the C&R Atlantic salmon; 17% were recaptured by anglers, which was similar to the rate of recapture of the control fish (21%). Lennox et al., 2015 concluded that individual and population fitness was not likely to be significantly compromised as a result of C&R because individuals were recorded in spawning areas at appropriate times.

Hall et al., (2009), studied the effects of angling treatments on the post-release mortality, gonadal development and somatic condition of Australian bass (Macquaria novemaculeata) in a pond-based experiment. In this study it was shown that the mean per cent of atretic oocytes (degenerated and reabsorbed eggs) was significantly greater in those fish that were harshly angled and it was concluded that the gonadal development of M. novemaculeata could be suppressed or impaired by angling, handling and confinement, and that further research was warranted.

Hanson et al., (2008), investigated the rates of nest abandonment by nesting smallmouth bass (Micropterus dolomieu) subjected to 1) common angling practices (brief angling and no exposure to air 2) air exposure treatment (exhaustive angling and 3 min of air exposure) and 3) tournament practices (simulated tournament condition, consisting of exhaustive angling, 2 h of live-well retention, and 3 min of aerial exposure prior to release) across a latitudinal gradient encompassing virtually the entire south-north range of smallmouth bass (i.e., southern Missouri, southern Ontario, and northern Ontario) and compared these treatment groups with non-angled controls.

Whole-blood lactate and glucose levels were highest in fish subjected to simulated tournament conditions, indicating increased stress; this pattern was conserved across all latitudes. Additionally, the pattern of brood abandonment was similar among fish at all three latitudes; simulated tournament conditions fish exhibited the highest rates of nest abandonment. It was concluded from this study that the reproductive success of individual smallmouth bass can suffer from interaction with anglers, particularly in a tournament context, regardless of the region.

Ostand et al., (2004) examined the reproduction of largemouth bass (Micropterus salmoides) that were subjected to the stress of exhaustive exercise, air exposure, live-well conditions and weigh-in procedures. Age-0 largemouth bass produced from parents subjected to stress were smaller (total length, 31 ± 0.4 mm [mean ± SE]) and weighed less (0.59 ± 0.04 g) than controls that were not stressed (35 ± 0.4 mm; 0.76 ± 0.03 g). Adults that were stressed had offspring with later swim-up dates than did controls. This study provides evidence that angling-induced stress before spawning has the potential to negatively affect largemouth bass reproductive success.

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Seasonal differences in fish physiology - stress, immune response, reproductive state.

Other sections in this review have demonstrated beyond doubt that angling practices can cause a measure of damage and stress to individual fish that have the potential to result in subsequent mortality either directly or due to disease, or impaired reproductive competence. However no evidence has so far been presented that would suggest that these impacts might be more severe or more frequent during the breeding period. The following section explores the likelihood or otherwise that impacts of angling could be more severe during the breeding period – i.e. shortly prior to, during, and after spawning.

Andreou et al., (2011) found that Sunbleak (Leucaspius delineatus) in breeding condition had higher levels of infection by an intracellular parasite (Sphaerothecum destruens) than non-reproductive fish under laboratory conditions. However this was not corroborated by observations in the wild, suggesting that whilst fish in breeding condition may be more prone to infection, the outcome may be not be the same in all situations. Butchtikova et al., (2011) examined indicators of immunological competence in carp and found evidence that the immune response is most weakened in spring, prior to the carp spawning period, and this was more evident in males, these having higher levels of ketotestosterone. Saha et al., (2002) found a positive relationship between reproductive endocrine and immunological parameters, suggesting that carp immune systems work well during the breeding period.

In contrast, Collazos et al., (1994, 1995 & 1996) showed that for tench, some aspects of immunological activity were strong in winter and even stronger in spring, yet others were suppressed in winter. Tolarova et al., (2014) showed that some markers of immunocompetence were still high during the breeding season when sex steroid hormones were high. Ghafoori et al., (2014) studied the Caspian Kutum (Rutilus frisii), an anadromous cyprinid related to roach, and found that the lysozyme activity and protein content of blood and mucus were lowest in winter and spring but rose again in summer and during spawning, suggesting that the immune system was strong during the spawning period but weak in the period leading up to it. Kortet et al., (2003) studied the immunocompetence of roach and found that certain measures of immunological activity decreased immediately before and after spawning but this was not consistent across all markers.

Pottinger et al., (1999) found that levels of 17 β Oestradiol, vital to reproduction in female roach, were depressed after handling and confinement and this was associated with elevated levels of plasma cortisol, a stress indicator. These effects were elevated at higher temperatures (16ºC) than lower (5ºC). Conversely Vainikka et al., (2004) found few significant correlations between sex hormones and immune variables and there was no seasonal pattern to these. Kortet et al., (2002) noted that the incidence of papillomatosis in roach (which manifests itself by large, hard pale grey raised lumps on the back and flanks of the fish) was highest around spawning time and concluded that this was likely to be due to reduced immunocompetence especially in relation to the protective mucus.

Lamkova et al., (2007) looked at immunocompetence in chub and found that this was lowest in spring and early summer and this coincided with high a gonadal somatic index, (proportion of bodyweight as reproductive tissue) and high levels of parasitism. Wang et al., (2003) reported elevated mortality rates for perch during the spawning season. Richard et al., (2012) looked at the effects of catch and release fishing on salmon reproductive success and concluded that it had minimal effect on reproductive success though these effects were slightly higher for larger fish and those exposed to air for longer periods during C&R, and for fish caught at relatively higher temperatures. Richard et al., (2014) did however show that C&R did delay/impair migration.

There is plenty of evidence for changes in immune response physiology and disease susceptibility in relation to reproductive cycle in a number of species. Note that some of the immunological indications do differ for quite closely-related species so we have to be careful in drawing conclusions about one species from observations on another, however for many species there is clear evidence that stress levels are higher and immune response is suppressed and disease/ parasitism is higher in many relevant fish species close to and during the spawning period. As such, this presents good circumstantial evidence to suggest that there may be increased mortality and reduced reproductive success of fish angled during the spawning period; however the degree to which this might be true is unknown.

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Angling and risk of disease in fish

Grant et al., (2005) investigated the effects of practices related to C&R angling on mortality and viral transmission in juvenile largemouth bass (Micropterus salmoides) infected with largemouth bass virus (LMBV; family Iridoviridae). This study examined the separate effects of two angling-related factors on the susceptibility of juvenile largemouth bass to mortality from LMBV infection and on the transmission of LMBV from infected to uninfected fish. The first factor was hook-and-line angling; infected fish that underwent a simulated angling treatment did not experience higher mortality or have higher viral loads in their tissues than those that were not angled. The second factor was direct contact between infected and uninfected fish, as would occur in live wells and holding tanks.

The LMBV was transmitted from infected to uninfected fish through water, even when direct contact was prevented. Transmission of LMBV between infected and uninfected fish separated by a fenestrated barrier was nearly as efficient as LMBV transmission between infected and uninfected fish that were allowed direct contact. Grant et al., (2005) concluded from their results that angling itself may have only minimal effects on the survival of largemouth bass infected with LMBV but that angling-related practices that place infected and uninfected fish together in a limited water volume may facilitate viral transmission.

In a similar study, Schramm & Davis, (2006) investigated the survival of largemouth bass from populations infected with largemouth bass virus and subjected to simulated tournament conditions and held in live wells with or without treatment additives. Treatment fish were held for 8 h in live wells at 23°C with water containing more than 5 mg of dissolved oxygen/L and 0.3% salt (NaCl). Control fish, were confined for 8 h in live wells at 26°C (ambient temperature) with dissolved oxygen fluctuating from 3 to 5 mg/L and no salt, which simulated the live-well management practices used by largemouth bass tournament anglers. Mortality after live-well confinement was 0% for both treatment and control fish, and mortality during the first 24 h after the simulated tournaments was 2.5%. Mortality of fish observed for up to 5 days after the simulated tournaments was high for treatment fish (mean = 75%; SE = 16%) and control fish (mean = 85%; SE = 11%), and it was concluded that the treatment conditions did not reduce post release mortality. Schramm & Davis, (2006) suggested that the unusually high post tournament mortality was related to largemouth bass virus infections.

C&R angling is common in recreational fisheries. During handling and de-hooking, fish are subjected to stress and dermal injuries, which may result in infections by pathogens after the fish is released. Schwabe et al., (2014) designed a study to evaluate the consequences of common handling practices used by anglers on the post release behaviour and fate, particularly the susceptibility to disease, of undersized rainbow trout (Oncorhynchus mykiss). Behaviour immediately following capture and subsequent release of fish was examined in a 40-L container, and long-term fate was studied for 2 weeks in tanks incubated with Saprolegnia parasitica zoospores. Trout were behaviourally impaired as indicated by the ease of being netted following the simulated fight associated with C&R, but there were no further behavioural impacts due to subsequent handling. None of the rainbow trout developed fungal infections nor was any significant mortality observed after 2 weeks; only 1 out of 137 fish died. Schwabe et al., (2014) concluded that juvenile hatchery-reared rainbow trout have a high resilience to Saprolegnia infection associated with handling-induced stress.

In England and Wales, freshwater anglers have shifted their behaviour towards visiting C&R lake fisheries that are intensively stocked, mainly with large common carp, Cyprinus carpio L., to maintain high catch rates. Hewlett et al., (2009) have investigated the role of such management practices in fish kills and found most kills occurred between April and June and were mainly caused by parasitic or bacterial infections. Bacteria were usually associated with ulcerative diseases caused by strains of the bacterium Aeromonas salmonicida and secondary infections of opportunistic bacteria of the genera Aeromonas (excluding salmonicida) and Pseudomonas. Parasites involved in fish kills included Ichthyophthirius multifiliis (Fouquet), Chilodonella sp., Ichthyobodo necator (Henneguy) and Argulus sp. Outbreaks were typically in fisheries with high extant stock densities (>1500 kg ha-1) and sub-optimal habitats, for example of low habitat heterogeneity with few macrophytes in the littoral zone. Recent stocking was also a key factor when only carp was affected. Hewlett et al., (2009) highlighted that certain fisheries management practices that aim to enhance fishery performance may instead trigger fish kills during spring. Again as a point of note in reference to our close season coarse fishery debate, the peak in pathogen-load associated kills coincided with the peak of the spawning season and warmer water temperatures.

Chapter references: Angling and risk of disease in fish

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Angling and exploitation rates

Within the scientific literature, there is a lack of recent data on the angling exploitation rates of UK coarse fish. Those limited papers in the literature that cover this topic are from the pre 1990s or earlier, and thus may not reflect the modern changes to angling practices, in particular today's angling methods or angling pressures on riverine fish. This large evidence gap hinders our prediction of what mortality rates would mean at a population level.

Cooper and Wheatley (1981) estimated exploitation rates in the River Trent, Nottinghamshire, from recapture rates of batch-marked fish. In 18 competitions fished over an 18 week period the overall exploitation rate for the whole population of fish 12 cm long and over was 17%. The rate was 20% and 13% for roach (Rutilus rutilus), and dace (Leuciscus leuciscus), respectively. Cooper and Wheatley estimated, taken into account that the fact that up to 100 competitions are held per annum at this fishery, that the annual exploitation rate could be as high as 94%, i.e. an individual fish was likely to be caught at least once per season.

In the River Derwent, whole season exploitation rates for match and pleasure fishing were combined to estimated annual exploitation rates for coarse fish, Cowx et al., (1986). This study estimated exploitation rates of 17.8% for dace, 15.5% for roach, 61.6% for chub and 26.5% for bream. Furthermore, Cowx and co-workers found that coarse fish exploitation rates in the River Derwent were generally higher in the summer months compared to winter, and that this seasonal variance in exploitation rates was even more pronounced in roach and bream. This suggests that these species continue to feed during the breeding season. In the Willow Brook, a tributary of the River Nene in Northamptonshire, no evidence was found for the cessation of feeding in roach, chub or dace during the closed season, Cragg-Hine (1965).

In single fishing contest held on the River Great Ouse in 1983, Kell (1991) estimated that anglers caught about a third of the total biomass of bream within the river stretch open to competition on that day. In another one off fishing match on the Leeds-Liverpool Canal, O'Hara and Williams (1991) estimated the exploitation rate to be in the order of 9% to 10%. In a canal in Belgium over a 5 month period (June to November), Gerard and Timmermans (1991) estimated exploitation rates to average 55% for all fish caught. Perch, rudd and bream had notable high exploitation rates of >100%, 65% and 40%, respectively.

In studies of C&R Atlantic salmon captured in the Ponoi river, Russia, Whoriskey et al., (2000) estimated angler exploitation rates to range from 10.4% to 19% of the river's salmon population.

Radio-tracked fish caught and released by anglers in 1995 and 1996 had high rates of survival, and anglers recaptured about 11% of them per year a second time. No significant biases were detected in the post-angling movement patterns of these fish. The multiple captures and lack of movement bias suggest that fish behaviour was little altered by the angling experience.

In a multi-lake (21 lakes) study based on angling diaries collected in Germany, Heermann et al., 2013 found that angler-related factors such as fishing experience, species preference and bait/lure type had a large impact on perch catch rates. This study focused on angler-related, biotic and abiotic factors influencing catchability of Eurasian perch, Perca fluviatilis L. It was found that environmental conditions (nutritional status and water transparency) affected either the size or the number of perch caught by anglers. This study also showed that altered food availabilities in the course of the year caused food limitation in perch, which in turn facilitated high catch rates and female biased exploitation in autumn. It is concluded that both angler-related and abiotic factors interact affecting perch catch rates and size of perch captured in recreational angling.

Johnston et al., 2013 used an integrated bio-economic model to study the importance of fish life-history type (LHT) for determining (i) vulnerability to over-exploitation by diverse angler types (generic, consumptive and trophy anglers), who respond dynamically to fishing-quality changes; (ii) regulations [i.e., minimum-size limits and licence densities] that maximize the social welfare of angler populations; and (iii) biological and social conditions resulting under such socially optimal regulations.

Five prototypical freshwater species: European perch (Perca fluviatilis), brown trout (Salmo trutta), pikeperch (Sander lucioperca), pike (Esox lucius) and bull trout (Salvelinus confluentus) were modelled. This study found that life history type is important for determining the vulnerability of fish populations to overfishing, with pike, pikeperch, and bull trout being more vulnerable than perch and brown trout. Angler type influences the magnitude of fishing impacts, because of differences in fishing practices and angler-type-specific effects of life history type on angling effort. Johnston et al., 2013 highlighted the importance of jointly considering fish diversity, angler diversity and regulations when predicting sustainable management strategies for recreational fisheries.

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Angling impacts on fish migration and behaviour

Within the scientific literature, there is a lack of studies investigating the impacts that angling may have on coarse fish migration and behavioural changes which could affect reproductive success, although there are some works on salmonids. Some research work does exist which looks at coarse fish migration patterns in UK rivers, although these studies did not specifically look at angling impacts. For example Lucas and Frear (1997) have shown in the River Nidd that barbel (Barbus barbus) can migrate up to nearly 20km upstream to reach spawning grounds, and that migration over obstacles such as weirs typically occurred around dawn and dusk. The reproductive success of adult barbel was dependant on them completing their migration run, although to what extent angling activity could interrupt this journey is unknown. Other coarse fish species show patterns of in river migration, the occurrences, causes and implications of such activities in England and Wales have been reviewed by Lucas et al., (1998).

Five main movement patterns were defined by Lucas and co-workers and they were as follows: 1) pre & post spawning migration, 2) young-of-the-year movement, 3) feeding migration, 4) refuge migration, and 5) post-displacement movements. In their review paper, Lucas et al., (1998) noted that spawning migrations were the most extensive and most widely reported migration type, for many British freshwater species including several cyprinids (mainly rheophiles such as barbel, chub and dace, but also some limnophiles such as roach and bream).

Electronic tracking studies have recently focused on the potential negative effects of C&R (C&R) angling in Atlantic salmon (Salmo salar L.). Common for these studies is that the fish were tagged between C&R, and the effects of C&R can thus not be separated from the extra handling effects associated with the tagging procedure. To overcome this problem, Jensen et al., (2010) used reference groups (non-angled fish tagged with radio transmitters before entering the fjord). Ten of these salmon were caught and released by anglers in the river. All ten fish survived the angling event, and nine were observed in known spawning areas during the spawning. No difference in migratory behaviour prior to or after C&R was observed between caught and released fish and a reference group. Individuals both among the C&R fish and the reference group showed downstream movements and migratory stops associated with C&R in previous studies. Jensen et al., (2010) concluded that in spite of making studies logistically more challenging and expensive, the use of reference groups is important when assessing natural versus non-natural behaviour and to separate C&R effects from tagging effects. This finding of this study, concurs with the earlier research conducted on this same river by Thorstad et al., (2007) which also found C&R angling resulted in a delays in the upstream migration of salmon.

To reproduce, Atlantic salmon (Salmo salar) return to freshwater rivers and migrate upriver to spawning areas. This migration is the basis for recreational fisheries, which for conservation reasons are increasingly characterized by C&R angling. The effectiveness of C&R for Atlantic salmon conservation is contingent on the ability of individuals to recover from angling, resume migration, and reach spawning grounds at appropriate times (Lennox et al., 2015)

To measure the effectiveness of C&R fish programmes, Lennox et al., (2015), monitored 27 caught and released Atlantic salmon in River Gaula, (Norway) by affixing external radio transmitters to them. Those fish were compared with a control group of 33 individuals caught and radio-tagged at sea in bag nets before river entry. Whereas none of the control fish died during the study period, there were three mortalities among the caught-and-released fish (11%; significant difference). All mortalities were qualitatively associated with poor angler care, emphasizing the responsibility of anglers in practising effective C&R of Atlantic salmon.

Both control and caught and released Atlantic salmon spent similar time resting below and in transiting a large natural barrier to migration, an 80-m gorge. The angled and released Atlantic salmon were distributed in similar locations throughout the river during the spawning season compared with control fish, but those caught and released later in the season appeared to migrate shorter total distances than control fish. Among the caught and released Atlantic salmon, 17%

were recaptured by anglers, which was similar to the rate of recapture of the control fish (21%). Lennox et al., (2015) concluded that ultimately, individual and population fitness was not likely to be significantly compromised as a result of C&R because individuals were recorded in spawning areas at appropriate times.

Using continuous high-resolution positional telemetry, Baktoft et al., (2013) compared the swimming activity of handled and unhandled pike (Esox lucius) in a small lake to stimulate angled and non-angled fish. The results demonstrated that the handling protocol caused temperature-dependent changes in pike activity, with higher temperatures leading to lower activity of the recaptured pike. The effects, however, were transitory and not detectable 48 hours post-release. These findings indicate that pike are relatively resilient to handling and quickly resume pre-handling activity.

In another study, Jacobsen et al., (2014) investigated the combined disturbances of angling and boating activity in lake fish. The effects of disturbances from recreational activities on the swimming speed and habitat use of roach (Rutilus rutilus), perch (Perca fluviatilis) and pike (Esox lucius) were explored. Disturbances were applied for 4h as (1) boating in short intervals with a small outboard internal combustion engine or (2) boating in short intervals combined with angling with artificial lures between engine runs.

The response of the fish species was evaluated by high-resolution tracking using an automatic acoustic telemetry system and transmitters with sub-minute burst rates. Roach swimming speed was significantly higher during disturbances [both (1) and (2)] with an immediate reaction shortly after the engine started. Perch displayed increased swimming activity during the first hour of disturbance but not during the following hours. Swimming activity of pike was not significantly different between disturbance periods and the same periods on days without disturbance (control). Roach increased their use of the central part of the lake during disturbances, whereas no habitat change was observed in perch or pike.

Jacobsen et al., (2014) detected no difference in fish response between the two types of disturbances (boating with and without angling), indicating that boating was the primary source of disturbance. This study highlights species-specific responses to recreational boating and may have implications for management of human recreational activities in lakes.

Chapter references: Angling impacts on fish migration and behaviour

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Summary of literature review

This section briefly summarises the findings of this literature review, within the context of concerns or potential risks associated with changing the current close season for coarse fish in English rivers.

This report is only part of the evidence base to support decisions on the future of the coarse fish close season. Other evidence sources include canvassing the views of an independent expert panel, considering the risks and pressures on fisheries from non-angling sources, looking at the potential impacts of close season reforms on other legislation and learning from the experiences of coarse fisheries management conducted in other European countries.

The chapter on “Angling and stress” highlights the recent wealth of information on the direct and indirect impacts that Catch & Release (C&R) angling practices can have on the health and welfare of individual fish. However, there is a lack of scientific publications that actually extrapolate these individual fish impacts into what they mean at fish population levels.

The direct effects of angling on non-spawning fish are well documented, with numerous references listed in the “Angling & stress” chapter within this report. Although, there are a limited number of studies on UK coarse fish, there are studies on other species to make a general inference. In summary, bigger fish fight harder and thus are more likely to suffer from the symptoms of exhaustive stress and therefore typically have a higher risk of mortality compared to smaller fish. This factor may have ramifications for the targeting of trophy fish. Furthermore, it is evident from the literature review that stress factors tend to have an accumulative impact on fish welfare, and therefore fish exposed to multiple stress factors are intrinsically at a higher risk of mortality.

In addition to angling induced stress, under certain conditions, fish may face additional environmental and physiological stress factors which can raise their overall mortality risk. Within this literature review, numerous papers have shown that the stress levels and mortality rate in fish caused by angling activity are compounded by elevated water temperatures and aerial exposure during the capture and release phase of angling. In the chapter on “Seasonal differences in fish physiology”, it is suggested that fish may be subject to elevated stress levels during the breeding season, as a result of behavioural, hormonal, or other physiological changes.

The type of gear used for angling has been shown to have a significant impact on the mortality rate of fish, with the rule of thumb being that fly fishing is less harmful than spinning and spinning is less harmful compared to bait fishing. However, the size and choice of hook type used, such as J shape, circular, trebles, or barbless can significantly affect mortality rates. Irrespective of the gear used, what can be gleaned from this literature review is that it is the location of the hook when set that has the greatest impact on survival rates, with gullet hooked fish or heavily bleeding fish being most susceptible to death. With reference to earlier comments made in the “Angling and mortality rates” chapter about the study of muskellunge C&R survival rates (Margena, 2007), we must consider the long term impacts of C&R practices, as opposed to an over reliance on short term observations, which may underreport survival rates. There is a lack of scientific publications on English coarse fish survival rates following C&R angling for fish in spawning condition or fish captured during the open fishing season.

This review is inconclusive on whether angled spawning fish have an increased mortality risk compared to non-spawning angled fish, however if the close season window was lifted, it would intrinsically mean an additional mortality cost upon the fishery.

Based on non-coarse fish studies, generally speaking we can state that direct angling mortality rates are comparatively low (<10%) but may vary considerably between species as shown in the study of sharks by Gallagher et al., (2014). While some data exists for UK canal and river coarse fish studied in the mid 1980’s, to evaluate the potential impact at a species specific population level, more information is required to better understand English coarse fish exploitation rates by anglers. Exploitation rates are essential to assess the impact at a local population level.

It is interesting to note in the study by Heermann et al., 2013, that the exploitation rates of perch (Perca fluviatilis L.) in German lakes were reduced in the warmer summer months, which coincided with an increase in natural food availability, which ultimately made these fish harder to catch. The question this raises is, do the exploitation rates (catchability) of coarse fish in English rivers change during the warmer summer months when natural productivity is at its highest and if so, how does this affect the overall angling mortality risk for all species of concern?

Some anecdotal evidence suggests that certain fish species, irrespective of food availability, may feed less during the breeding season. If true, this might mean that certain species of breeding fish may have a reduced exploitation rate, but, as summarised earlier, such spawning fish may already be stressed and thus have an intrinsically higher risk of angling-related mortality compared to non-spawning fish.

The behaviour of fish during the breeding season may make specific species more susceptible to being targeted by anglers. For example, some aggregate spawners, such as dace form large shoals during the breeding season. Other fish like barbel migrate to spawning grounds but during river low flow conditions may get temporarily trapped behind weirs or other obstacles, thus concentrating their numbers and potentially making them easier to capture.

This literature review found a lack of evidence on the effects of angling on the reproductive success of UK coarse fish. Thus, again, we must look abroad to studies on other species to try and draw some inference on how English spawning coarse fish might react to the stress loads associated with angling activities.

Although there is as yet no direct evidence that catch and release angling specifically causes more stress/damage/likelihood of mortality if carried out around/during the reproductive period for coarse fish, the research on other species raises suggests this may be an issue. Some of the literature does indicate potential mortality rates due to catch and release which could be used to model population impacts, however these are almost all in relation to species and situations quite unlike those for coarse fish in England. Furthermore, what data does exists tends to be highly variable, and none distinguish between breeding period and other times of year, temperature is the only factor that appears to be linked to elevated mortality.

Again there is a lack of evidence on the impacts of angling on disease in UK river coarse fish. However, Hewlett et al., (2009) has shown in UK coarse fish stillwaters that angled fish mortality rates are greater in fish with higher pathogen and parasitic loads and that most fish kills occurred between April and June. Again as a point of note, this peak death rate occurred during the spawning season and when the water temperatures were warm. A few American research papers (Grant et al., 2005; Schram and Davies, 2006) working on largemouth bass also suggest that the use of post capture fish confinement methods, such as live-wells on boats, can lead to increased viral transmission rates and fish kills.

This literature review raises some concerns around the use of post capture confinement measures (such as keepnets) on fish mortality risks and we know that such risks are compounded by elevated water temperatures. Although a few studies have shown that common carp appear to be comparatively robust to such post capture handling practices prior to release, other coarse fish species may not and further research is warranted.

Unlike the UK game fishery, where two similar species (salmon and trout) have an overlapping breeding window, the UK coarse fisheries consist of numerous fish species, from several families of fish. On this basis the current close season window is a simple but effective tool in protecting coarse fish. However, early spawners may be protected longer than they need be and conversely late spawners may not be protected enough.

So in summary, this review paper has considered both the direct and indirect impacts of angling practices on coarse fish and what can be concluded from this review paper, is that there are still many evidence gaps. In particular, information is lacking on angling mortality and exploitation rates of specific UK coarse fish. Even with the best intentions, good fish handling skills and 100% C&R, there will always be a residual mortality cost associated with angling and to some unknown extent this would be intrinsically increased with any extension of the open season.

Since the original close season legislation was introduced, much has changed in anglers' attitudes and behaviours to fisheries conservation, with catch & release being commonly applied in most coarse fisheries. In the last 20 years, there has also been a significant change in the angling pressures on rivers. As a whole, less people are now fishing, and those who are, tend to favour stillwaters over rivers. However, it would be too simplistic just to look at fishing pressures and angling impacts in the close season debate. If we are to be successful in protecting and enhancing the coarse fish stocks in our rivers, we must take a holistic and catchment-based approach to sustainable fisheries management.

Annex A: A brief history of the coarse fish close season

We need to go back nearly 140 years to find the origins of the coarse fisheries close season in the UK. Back in those times, match angling was prolific, with much rivalry between local clubs. At the end of a competitive day's fishing, before the advent of keep nets, fish were killed for the weigh-in and, as no close season existed, matches were run all year. This meant that spawning fish were often killed and the overall angling pressure on the fishery was relentless. Recognising that this amount of angling pressure was impacting their sport, some enlightened clubs started lobbying Mr Anthony Mundella, their local Member of Parliament for Sheffield[1,2]. These events eventually led to the creation of the **Freshwater Fisheries Act (Mundella Act) of 1878**.

The act put in place a seasonal window in time in which coarse fishing was closed on rivers, lakes, ponds and drains. The original draft bill had the close from 1st March to the 31st May. Prior to the bill passing through parliament, the close season period was hotly debated between angling clubs from the North, the London Anglers Association and the Piscatorial Society. During these debates, the stakeholders could not reach consensus on which months to close the water, so they opted for a compromise and split the difference. Henceforth, the close season for coarse fish was fixed from the 15th March to the 15th June inclusive. Ever since 1878, various other types of fisheries-related legislation has been amended or newly introduced. However, from a river angler's perspective, the close season law has remained unchanged. A timeline of fisheries legislation is shown in figure 1.

Since 1878, the competent authority in charge of fisheries management has changed on numerous occasions. **The Salmon and Freshwater Fisheries Act (1923)** encompassed all the previous legislation (Mundella Act & its amendments). The 1923 Act also **established the Fishery Boards** whose role it was to enforce the national Salmon and Freshwater Fisheries Act and manage local waters and bylaws.

In 1948, the River Boards Act created a multifunctional catchment-based organisation. The River Boards held responsibilities for land drainage, fisheries and river pollution. The roles and responsibilities of the former Fisheries Boards were combined with those duties of former catchment boards created under the former Land Drainage Act 1930.

The Salmon and Freshwater Fisheries Act 1975 (amended) consolidated the Salmon and Freshwater Fisheries Act of 1923 with certain other enactments relating to salmon and freshwater fisheries, and repealed certain obsolete enactments relating to such fisheries. Within this act, no changes were made to the by now almost 100 year old rule on the coarse fisheries close season.

In 1978 the European Freshwater Fish Directive (78/659/EEC) was transcribed into UK regulations. However, this was not about angling or fisheries populations. This directive set standards of water quality for the protection of coarse and game fisheries, together with monitoring requirements. Waters were split into Salmonids & Cyprinids systems and appropriate water quality standards set to support these fish populations.

In 1995 stillwater fisheries were deregulated with regards to the close season (the close season was retained on stillwater SSSIs where year-round angling could affect designated features). The decision was not based on any specific study, but followed consultation with angling, fisheries and other interests. The rationale was twofold:

- Most stillwaters are discrete water bodies in single ownership; this enables the owner to manage the fish stocks and to impose whatever restrictions are felt to be needed, including non-statutory close seasons.
- The fact that the close season had been dispensed with on many stillwaters without any apparent detriment to those fisheries, presented strong evidence in favour of removing it.

Within many closed systems, the fish populations are artificially supplemented by stocking and therefore do not rely on natural recruitment. Furthermore, these closed systems are less subject to influences from the wider catchment, and, more importantly, management of such systems would have a minimal impact on other stakeholders.

In 2000, an independent Salmon & Freshwater Fisheries Review,[3,4] took place. It recommended the removal of the close season on rivers, but this proposal was rejected by Government due to concerns around a lack of evidence on the impacts of lifting the closed season. As documented in the report, the decision in part was also influenced by lobbyists from other waterway user groups.

In 2000, the close season was lifted on canals. This was based on evidence from a British Trust for Ornithology led study[5] which compared the differences between canal systems that for various historic reasons were either regulated or unregulated with regards to close seasons. The report's recommendations were supported by all eight Regional Fisheries Advisory Committees. Following further consultations, the byelaw was passed in 2000.

In 2003, the Water Framework Directive (England and Wales) Regulations 2003 came into force. They apply to all surface freshwaters including rivers, canals, and lakes (>50 ha). Fish species as indicators of the ecological health of a waterbody are now part of the WFD classification process. This means that if a waterbody does not meet the necessary criteria for fish ecology, it fails the overarching WFD ecological status test for a waterbody. This factor may influence the precautionary approach taken by the Environment Agency in reviewing the close season rule. WFD superseded the Freshwater Fish Directive (repealed 2013). The former Freshwater Fish Directive designated sites were re-designated as WFD Protected Areas (Fish) and new WFD water quality standard were applied to protect fish stocks in these waters.

In 2004, the Environment Agency commissioned a study[6] to scope out the work required to make a decision on the close season. The report concluded that there were significant knowledge gaps which required research funding (>£200k) before any reliable decisions could be made. At the time, on cost grounds, a decision was made not to fund this research. This decision in part was influenced by a limited survey (conducted in 2003) of anglers' attitudes towards revoking the close season.

In 2015, the Close Season Steering Group was formed to review the evidence base on the close season debate. The work is ongoing, but will look at any new evidence since the last review in 2004. The Close Season Working Group consists of a small panel of interested parties made up from representatives of the Environment Agency, Angling Trust, Institute of Fisheries Management, angling industry and fish conservation groups

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Figure 1- Timeline of Close Season Fisheries related legislation

1878

- **Freshwater Fisheries Act (Mundella Act) of 1878,** put in place a close season for all freshwater coarse fish from 15th March till the 15th June.

1923

- **Salmon and Freshwater Fisheries Act (1923)** encompassed all the previous legislation (Mundella Act & its amendments). **Fishery Boards established**.

1948

- **1948** with a legislative change over to the **River Boards Act**. The River boards held responsibilities for land drainage, fisheries and river pollution.

1975

- **Amended SAFFA 1975 -** An Act to consolidate the Salmon and Freshwater Fisheries Act 1923 .

1978

- **EU Freshwater Fish Directive** (78/659/EEC) - **Not about Angling**, It sets standards of **water quality** for the protection of coarse and game fisheries.

1995

- **Stillwater Fisheries- Deregulation of close season -** Decision not based on evidence, arguably driven by lobbyists.

2000

- **Independent Salmon & Freshwater Review** - Recommendations to removed the close season on Rivers rejected by Government due to concerns around a lack of evidence on the impacts

2000

- **Close Season lifted on Canals**- Evidence based decision (based on comparison between canals systems that for various historic reasons had or did not have close seasons).

2003

- **Water Framework Directive.** Fish indicators are now part of the WFD classification process. Former Freshwater Fish Directive designated sites re-designated as WFD Protected Area (Fish).

2004

- **EA commissions survey on scope of evidence base required to review the closed season.** At the time, on cost grounds, a decision was made not to fund this research.

2015

- **Review of the Evidence base** for a closed coarse fisheries on rivers - What has changed since 2004, any new evidence? Close Season Steering Group

Annex B: Key words used in Scopus database search

Table 1: Key questions and words used in the literature search

Topic	Question	Keywords
Fish spawning periods	What are the spawning seasons/dates for the range of coarse fish species?	spawning season date coarse fish (species names)
	How have these varied in recent years in relation to weather/temperature?	As above plus temperature, climate change, flow, weather
Exploitation	What are the typical exploitation rates for coarse fish by anglers in rivers or canals expressed as percentage of population caught per unit effort?	angling, exploitation rate, coarse fish, river canal, CPUE, (species names)
	Is there evidence of likely increased susceptibility to angling at or around spawning time?	angling success, CPUE, season spawning, vulnerability, coarse fish (species names)
	Is there evidence that fish feed more or less at particular stages of reproductive cycle?	feeding, reproductive cycle, maturation, post-spawning, pre-spawning, seasonal, coarse fish (species names), metabolic rate
Damage and mortality	What are the rates of immediate, direct mortality and damage caused by angling?	angling, mortality, injury, damage, morbidity, survival, hooking, handling, retention, scale-loss, mucus, holding, coarse fish (species names)
	What are the rates of post-capture/handling mortality?	Post-capture, mortality, survival injury, damage, angling, handling, stress
	Is there any evidence that these vary with season or temperature?	as above plus season, temperature, reproductive cycle
Disease susceptibility, stress, immune response	What evidence is there that immune response, stress levels, and susceptibility to disease vary with stage in reproductive cycle?	immune response, stress, disease, season, gonadal cycle, breeding, spawning, pre-spawning, post-spawning, coarse fish (species names).
Disruption of spawning behaviour	Is there any evidence that angling/handling/general disturbance can disrupt spawning behaviour (aggregations, courtship)	angling, handling, stress, spawning behaviour, courtship, coarse fish (species names).
	Can physical handling of fish result in loss of gametes or competence of individual fish to spawn?	as above plus reproductive competence, fitness, spawn, eggs, milt, gonads, coarse fish (species names).

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