7 The Fate of Fish Released by Recreational Anglers

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7.1 Introduction

Discussions of by-catch are usually restricted to the commercial fishing sector. Several papers and reviews (Dayton et al. 1995; Hall 1996; Greenstreet and Rogers 2000; Bache 2003; Cheunpagdee et al. 2003; Lewison et al. 2004) and even entire books have been devoted to this topic. Due to the well-documented role of commercial fishing practices in generating by-catch, by-catch reduction has arguably become one of the most pressing conservation issues today (Hall et al. 2000; Cheunpagdee et al. 2003). Indeed, commercial by-catch has been implicated in the global decline of marine fish resources (Hilborn et al. 2003). The realisation that the fishing mortality of large numbers of non-target organisms is a problem in the marine commercial fishing sector has led to much research and innovation into ways of mitigating by-catches (Hall et al. 2000; Bache 2003). New approaches, techniques and gear modifications are needed to reduce the mortality and sublethal disturbances that can arise from by-catch. However, efforts focusing on reducing by-catch in the commercial sector alone fail to recognise the potential contribution that the recreational fishing sector may have on by-catch-related issues and global fish declines. Before discussing the latter, however, it is useful to provide a summary of the terminology relevant to a discussion of recreational by-catch and discard issues (see Box 1).

Only recently has the recreational fisheries sector been considered as a potential threat to fisheries stocks, especially on a global scale (e.g., for freshwater, see Post et al. 2002, Arlinghaus and Cooke 2005; for marine, see McPhee et al. 2002, Coleman et al. 2004). For example, Cooke and Cowx (2004) argued that commercial and recreational fisheries share much in common, including the potential to degrade environments, alter ecosystems,

S. J. Kennelly (ed.), By-catch Reduction in the World's Fisheries, 181–234.

Box 1: Terminology. Definitions of terms associated with by-catch and discards originally proposed by McCaughran (1992). We have modified and expanded the terminology to place it in a more recreational context

Recreational fishing – Conducted by individuals for sport and leisure, with a possible secondary objective of catching fish for personal consumption (FAO 1997; Pitcher and Hollingworth 2002). Sometimes this definition is expanded to include selling surplus catch to offset costs (Cowx 2002).

Commercial fishing – The act of fishing with the intent to make a profit from selling the harvested fish to consumers.

Angler – One who fishes for recreation, generally with a rod and line.

Catch-and-release – The act of releasing fish that were caught by a recreational angler. The phrase "catch-and-release" was believed to develop from the various conservation organisations in the United States (e.g., Trout Unlimited) reflecting a strong conservation ethic (See Policansky 2002 for detailed discussion of the history of catch-and-release).

Discarded catch – The proportion of the total catch that is returned to the water – may be either target species or non-target species.

Fishing mortality – Death of fishes that can be directly or indirectly attributed to fishing activities.

Incidental catch – Catch of non-target species.

Target catch – Individuals that are primarily sought by the fishery. In recreational fisheries, many anglers fish opportunistically and thus it is sometimes difficult to determine the target catch.

By-catch – Discarded catch plus the incidental catch.

Hooking mortality – Death of fishes attributable to capture with standard fishing gears (baited hooks, artificial baits with various hook types and arrays). Mortality may result from fatal wounds or the accumulation of sublethal wounds and physiological disturbances.

Sublethal disturbances – The suite of non-lethal effects imparted by recreational angling to fish that are released. These can include physiological, behavioural and fitness impacts as well as physical injuries. In this context, fitness includes all metrics that can affect life-time reproductive success including factors that reduce growth (and thus fecundity or ability to compete for mates) or directly affect reproductive success or the quality or quantity of progeny (See Cooke et al. 2002a for a more detailed discussion of sublethal disturbances in catch-and-release).

Unaccounted fishing mortality – Death resulting from fishing that cannot be easily quantified. In commercial fishing this would result from fish passing through net webbing, freeing themselves from hooks, ghost fishing, etc. In recreational fishing, unaccounted fishing mortality has never been considered to our knowledge but may include fish that are snagged or hooked legally, but either break the line or get off the hook(s). Another example would include fish that are preyed on during the angling event.

Box 1. (cont.)

Immediate mortality – Immediate (or initial) mortality is defined as capture-related death that occurs during and following capture, up to the time the fish is released.

Post-release (delayed) mortality – Represents death from catch-and-release angling at some point after the released fish swims away. This mortality is usually determined by holding fish in cages, pens or hatchery ponds, or by affixing transmitters or tags to them prior to release in the wild.

impart evolutionary effects through selective fishing, collapse stocks and generate by-catch. But, as noted above, the current debate on by-catch has largely failed to include the recreational fishing sector. Because impacts from recreational fisheries are believed to be diffuse, there is the perception that any impacts on global fish capture are negligible. However, recent estimates suggest that the annual contribution of recreational fisheries to the global fish harvest may be quite high. Specifically, Cooke and Cowx (2004) estimated that recreational harvest may exceed 10 million t, compared to over 80 million t in the commercial sector. Furthermore, nearly 12% of the world's population engages in recreational fishing on a regular basis. With recreational discard/release rates believed to be at or near 60%, more than 30 billion angler-caught fish may be released annually (Cooke and Cowx 2004). This level of release warrants examination as a potential conservation concern (Box 2).

In this chapter, we discuss by-catch in the recreational fishing sector, alongside other contributions in this book on by-catch in commercial fisheries. We begin by providing an overview of recreational fishing, including the main reasons why large numbers of fish are released following their capture. We then review the developments in fishing gears and practices that have the potential to mitigate by-catch and provide several relevant species-specific case-studies. We outline a conceptual model of release and by-catch in recreational fisheries and synthesise existing knowledge to assess recreational fishing by-catch in a conservation and management context. Overall, we contend that this synthesis will help to evaluate and illuminate the issue of by-catch in recreational fishing. Furthermore, this will promote future developments in both gear and angling practices and ultimately minimise the injury, mortality or sublethal disturbances to fish released by recreational anglers. However, unlike commercial fishing, it is less likely that widescale reductions in by-catch or actual discards can be achieved in recreational fishing because in many cases, anglers have not targeted their effort solely on one species and because discards are really those fish that have been subject to catch-and-release angling. Thus, our

Box 2: Why has recreational by-catch been largely ignored by scientists, managers and conservationists? Modified from Hall et al. (2000).

Lack of visibility – Any discard mortality arising from recreational fishing will tend to be diffuse (both temporally and spatially) compared to that which occurs to commercial by-catch. Furthermore, mortality in recreational fishing can be delayed rather than immediate as is often seen in fish that are captured in commercial gears. An exception would be the visibility of moribund fish after mass release at competitive angling events. Such events have helped to drive change in this sector (e.g., Wilde et al. 2002).

Disbelief that there was a problem – Many anglers, product manufacturers and special interest groups do not want to publicise the negative aspects of recreational fishing. The onus has been placed on governments to document problems. The limited number of examples of recreational fisheries collapses (due in part to complex angler behaviour and stock supplementation) add to this problem.

Assumption that mortality following release is negligible – There are relatively few mortality studies for recreational fisheries, although this field is rapidly expanding. Earlier work tended to be short-term and failed to consider delayed mortality (which can be significant). Further, there is a significant difference between a dead fish and a fish that has negligible effects arising from the angling experience. Many fish experience sublethal disturbances that could affect fitness.

Assumption that the overall magnitude is small – There is a tendency to consider the effects of recreational fishing in the context of individual anglers as compared to a large commercial fishing fleet. Recent estimates place global angling participation rates and capture rates much higher than that which was previously thought.

Fisheries management versus fisheries conservation – There is a pervasive belief that recreational fishing is simply a resource management problem. By elevating recreational fisheries to a conservation issue through recognition that angling can affect fish populations (e.g., Coleman et al. 2004; Cooke and Cowx 2006), it will help to generate public interest and drive future improvements in angling gear and practices.

objective is to discuss efforts to ensure that released fish are minimally impacted by capture and handling processes.

7.1.1 What is Recreational Fishing?

Commercial and recreational fishing are both important sources of protein, and contribute substantially to local and national economies (e.g., Arlinghaus et al. 2002; Cowx 2002; Hilborn et al. 2003; Pitcher and Hollingworth 2002). Whilst commercial fishing is conducted specifically to catch fish for sale, recreational fisheries usually involve participants that fish for sport and leisure, with a secondary objective of catching fish for personal consumption (FAO 1997; Pitcher and Hollingworth 2002; note that in some jurisdictions, catch-and-release is dissuaded or illegal, with the primary purpose being for food consumption). Sometimes this definition is expanded to include the sale of surplus catch to offset costs (Cowx 2002). Cowx (2002) refined the FAO (1997) definition to categorise anglers into four main types: those who participate in leisure, competitive, game, and specimen or specialist fishing (when anglers focus all of their efforts on a specific type of fish and fishing activity). It must be noted, however, that many anglers participate in more than one type of recreational fishing activity. Although recreational fishing is most often perceived as involving anglers using hook-and-line fishing, recreational fishers also employ other gears and techniques. For example, in some countries, recreational fishers use spears (e.g., Nevill 2005), bows and arrows (i.e., bowfishing), rifles and even explosives (Cowx 2002). For these fisheries, few if any fish are released. Sometimes conventional hooks are used to snag fish in locations other than the mouth. Gillnets, cast nets, trawls and traps also are considered appropriate gear for recreational fishing in some places, but the delineation between artisanal, commercial and recreational fisheries can become difficult (See Cowx 2002 for discussion). In addition to these techniques, there are a number of regionally-specific gears and tactics (e.g., 'noodling' for large Ictalurids – this involves placing ones fist and forearm into underwater cavities that contain these fish and when they bite down the 'angler' attempts to pull the fish aboard the boat). Nonetheless, despite all the above variations, this chapter is restricted to recreational fisheries that use hook and line, generally with a rod, because these recreational fisheries are by far the largest and are most often characterised as having potentially problematic by-catch.

7.1.2 Why are Fish Released in Recreational Fisheries?

Although there are many fish released each year under the classification of discarded by-catch, the reasons for releasing fish vary significantly among different fishing sectors. In the commercial sector, most highly-regulated fisheries are managed using total allowable catch, quota systems and, for net-based gears, minimum mesh sizes. These strategies result in excessive catch with under-sized individuals, many of which do not survive, being dumped. In other instances, non-target species or undesirable-sized fish of target species are also discarded. In the recreational sector, while some anglers do harvest a portion of the fish they catch, many fish are immediately released. Among the reasons why anglers release fish is that they are undesirable (wrong gender, questionable food value), not the targeted species, or of an illegal size. In an attempt to conserve fisheries resources in some countries, regulations mandate release of some or all fish (Quinn 1996).

However, compared to commercial fisheries, recreational fisheries also include a significant voluntary catch-and-release component, in which anglers release fish for ethical, conservation or sporting reasons (e.g., the assumption that the released fish will survive to be caught again in the future; Quinn 1996; Aas et al. 2002; Policansky 2002). There is a growing debate concerning the ethics of recreational fishing, and in particular catch-and-release fishing (e.g., de Leeuw 1996; Balon 2000) although thorough discussion is beyond the scope of this paper. Irrespective of the reasons for releasing fish, however, mortality and sublethal effects can arise from capture and handling, which can lead to uncertainty in estimating fishing mortality.

7.1.3 How Many Fish are Released?

Alverson et al., (1994) estimated that between 17.9 and 39.5 million tonnes of fish are discarded each year in commercial fisheries. This compares with an estimated 19 million tonnes of fish, representing over 30 billion individuals, released globally in recreational fisheries (Cooke and Cowx 2004). Although there is some uncertainty in these estimates, it is clear that many fish in the recreational fishery are discarded, with discard rates varying considerably among species and countries. In some specialised recreational fisheries, such as in the coarse (i.e., a terminology used to describe 'non-game' fish that typically are benthivorous) fisheries of Western Europe or in elitist fisheries such as that for bonefish (*Albula* spp), voluntary release rates approach 100% (Policansky 2002). In other fisheries few, if any, fish are released (e.g., 8% of dorado [*Coryphaena hippurus*] and 9% of king mackerel [*Scomberomorous cavalla*] along the US Atlantic coast; United States Department of Commerce 2002). Overall in North America, it is estimated that approximately 60% of fish caught by recreational anglers are released (e.g., United States Department of Commerce 2002; Department of Fisheries and Oceans Canada 2003).

7.1.4 What do we Know About the Fate of Released Fish in Recreational Fisheries?

Since the mid 1970's, fisheries scientists and managers have made great advances towards understanding which angling practices contribute to the injury, stress and mortality of released fish. In addition to numerous articles in the primary literature and government technical reports, proceedings from three catch-and-release symposia have also been published (Barnhart and Roelofs 1977, 1989; Lucy and Studholme 2002). By identifying and understanding the key factors associated with hooking injury and mortality of particular species (Muoneke and Childress 1994; Bartholomew and Bohnsack 2005; Cooke and Suski 2005), fisheries managers, media, competitive angling groups and conservation organisations have been able to alter angling practices to increase the probability of fish surviving catch-and-release.

The widespread involvement of people in catch-and-release fishing is predicated on the general assumption that most released fish will survive (Wydoski 1977). Since most fish that die from catch-and-release angling do so some time after release (Muoneke and Childress 1994), there is the false perception that fish which swim away after release, apparently unharmed, always survive. Although this may be the case for some species, other species experience very high, often unnoticed, rates of mortality. In a review of hooking mortality studies, Muoneke and Childress (1994) reported that the mortality rates for released fish ranged from 0 to 89% across a variety of marine and freshwater species.

Hooking mortality is usually divided into immediate (or initial) mortality and delayed mortality. Immediate (or initial) mortality is defined as capture-related death that occurs during and following capture, up to the time when the fish is released. Delayed mortality represents death at some point after the released fish swims away; this mortality is usually determined by holding released fish in cages, pens or ponds, or by acoustic telemetry. Total hooking mortality is the sum of initial and delayed mortality minus the cross-product of initial and delayed mortality (Wilde et al. 2001). There have been several major papers that have aided our understanding of hooking mortality. Muoneke and Childress' (1994) review on hooking mortality in marine and freshwater fish and suggested that total hooking mortality rates above 20% generally should be considered unacceptably high. A more contemporary review (Bartholomew and Bohnsack 2005) found that mortality rates were sufficiently high that catch-and-release angling should not be permitted in marine protected areas. The magnitude of mortalities for catch-and-release can be extensive when viewed in actual numbers. For example, in striped bass (*Morone saxatilis*) fisheries on the eastern seaboard of North America, it is believed that in excess of 12.5 million fish are landed, of which over 90% are released (Millard et al. 2003). Estimates of catch-and-release mortality are around 28% (95% confidence interval 17–44%) or approximately 3.2 million striped bass per year (Millard et al. 2003).

Another key synthesis of hooking mortality (Cooke et al. 2002a) noted that there also may be a suite of sublethal physiological, behavioural, and fitness impairments that can arise from catch-and-release angling, and these sublethal stressors are rarely considered by managers who are focused primarily on the presence, abundance and distribution of fish populations (Wydoski 1977). Although some information exists on how angling-related stress may induce mortality (Wood et al. 1983), few studies have focused on what sublethal stress means to the organism, especially in relation to long-term individual fitness (Maltby 1999; Cooke et al. 2002a). To date, most efforts have concentrated on population-level effects, but individual effects can also be important (Maltby 1999). The body of literature evaluating the impacts of catch-and-release angling is rapidly expanding, however, this research has typically focused on species or groups of fish that are economically important, readily caught by the majority of anglers, and the subject of attention by media (see Muoneke and Childress 1994). In addition, the majority of these studies have been focused on freshwater fisheries in North America (Barnhart 1989; Muoneke and Childress 1994, Cooke and Suski 2005; but see several more global examples e.g., white-spotted charr (*Salvelinus leucomaenis*) in Japan, Tsuboi et al. 2002, and cichlids in Africa, Thorstad et al. 2004).

Also potentially important is the mortality of fish that escape from the hook before being brought to the boat or fish that are removed from the hook by predators – so-called 'drop offs' (Lawson and Sampson 1996). Lawson and Sampson (1996) developed a model that suggests that drop-off mortality could be as important as hook-and-release mortality. This type of mortality is poorly understood and has not been researched in detail. Efforts in this chapter are restricted to those fish that are caught, landed and then released by recreational anglers.

7.1.5 Why is it Important to Reduce Discard Mortality in Recreational Fisheries?

Beyond obvious conservation- and ethics-based considerations, there are a number of reasons why fisheries managers must strive towards reducing the discard mortality from recreational fisheries. Many of the current management strategies employed depend on the regulated release of certain individuals with the notion that fish will be able to be captured multiple times and will attain greater sizes and have greater fitness (i.e., more opportunity to produce viable offspring) because they live longer (Wydoski 1977). Regulations are also imposed in response to overfishing and a need to increase spawner-per-recruit (i.e., spawner biomass) levels (Waters and Huntsman 1986).

Target species are often protected using input controls such as minimum and maximum size and slot limits (when a range of fish lengths is designated for either harvest or protection). Legal size regulations often are based on known relationships between reproductive maturity and size, and are typically set at a size that allows fish to reproduce at least once before removal by fishing (Martell and Walters 2004). However, undersize fish (i.e., by-catch) are caught by anglers and thus the effectiveness of length-based limits as a management tool depends on the fishes' survival after release (e.g., Shetter and Allison 1955; Mason and Hunt 1967). Similar problems exist for slot limits where both undersize and trophy size fish must be released. Success of harvest regulations depends on low discard mortality within mandated size ranges (Waters and Huntsman 1986; Muoneke and Childress 1994). Indeed, often catch-and-release research is conducted in support of this premise (St John and Moran 2001).

Similarly, creel limits (i.e., possession limits) may also be ineffective if discarded fish die, thus inflating the number of fishery removals indirectly resulting in exploitation. This also includes fisheries where it is assumed that all individuals are released and few die. Management of such fisheries requires that mortality rates be maintained at low levels. Ultimately, high levels of discard mortality could lead to a reduction in the size and abundance of fish (Wydoski 1977), resulting in lower catch rates, alterations to populations, community structures and potentially the value of the fishery. In productive waters, even moderate levels of discard mortality may not affect population structures (Wydoski 1977). However, even very low levels of discard mortality (i.e., 1 to 5%) could have devastating effects on populations of long-lived species with low rates of population increase, such as giant sea bass (*Stereolepis gigas*; see Schroeder and Love (2002) for case study).

The increasing use of aquatic protected areas as a management tool has further prompted interest in understanding and reducing discard mortality from recreational fisheries. The premise of a 'no-take' protected area is that fish are not harvested. However, some have suggested that this may not preclude activities such as catch-and-release angling if there are negligible discard mortalities. At present, there is controversy regarding the compatibility of catch-and-release angling with the premise of closed areas and this will likely continue to be a contentious topic as the creation of aquatic protected areas increases around the world (Cooke et al. 2006).

7.2 Factors Influencing the Fate of Released Fish

When a fish is hooked and released by an angler, there are many factors that can affect its fate. Ideally, the released individual will survive, recover quickly and experience no long-term sublethal impairments. Although many anglers strive for such a positive outcome, it is often more probable that there will be at least some negative impacts. Some of the factors that may affect the fate of released fish are intrinsic such as gender, age, previous exposure to stressors, maturity, condition, size and the degree of satiation. Often these intrinsic factors cannot be controlled or altered by the angler to benefit the fish and, indeed, few of these factors have been studied with sufficient rigor to provide any conclusive recommendations for any species.

The environment in which the fish is caught and released can also affect its ultimate fate. Pertinent environmental conditions include abiotic factors such as water temperature, hypoxia, depth, or habitat complexity, as well as biotic factors such as predator burden (i.e., number of predators at a site that could potentially injure or kill a released fish). Although these factors cannot be controlled by anglers, most can be readily assessed and, if deemed to be detrimental, the angler could release captured fish at alternative locations. The remaining factors that typically influence the outcome of an angling event can be controlled by the angler, including the choice of fishing gear and angling practices.

The above factors rarely act independently to cause mortalities, and will most likely manifest as a series of cumulative stressors (Wood et al. 1983; Cooke et al. 2002a). As an example, angling mortality in salmonids has been suggested to be a two-stage process, which emphasises the interrelated and cumulative nature of fishing impacts. Gjernes and Kronlund (1993) observed that injury location was affected by hook and barb type at the first stage, and mortality was affected by injury location and species at the second stage.

Below, we review the issue of discarded by-catch in the context of recreational fishing. We focus our efforts on reducing discard mortality and sublethal disturbances by discussing both angling gear and practices (including factors such as environmental conditions). In our opinion, many of the issues associated with angling gear and practices are unique and require separate treatments. For our review, we focus on the literature that was published since the review by Muoneke and Childress (1994) with reference to historical examples.

7.3 Gear

A growing interest in catch-and-release angling has led to gear developments intended to reduce the injury and mortality of released fish. These gear developments are discussed below in the context of reducing discard injury, mortality and sublethal effects.

7.3.1 Hook Types

Mortality in catch-and-release angling can arise from a number of factors including cumulative sublethal physiological disturbance, physical injury and bleeding (Muoneke and Childress 1994). Hooks play little role in physiological disturbances other than when the hook type influences the difficulty of removal, leading to increased air exposure (e.g., Cooke et al. 2001), and this factor is discussed elsewhere. Hook type, however, does play a major role in mortality arising from direct hooking injury, and almost all of the studies we examined considered mortality as an important endpoint. Indeed, the review by Muoneke and Childress (1994) focuses on hooking-related mortalities. The different types of hooks discussed in this paper are presented in Fig. 7.1.

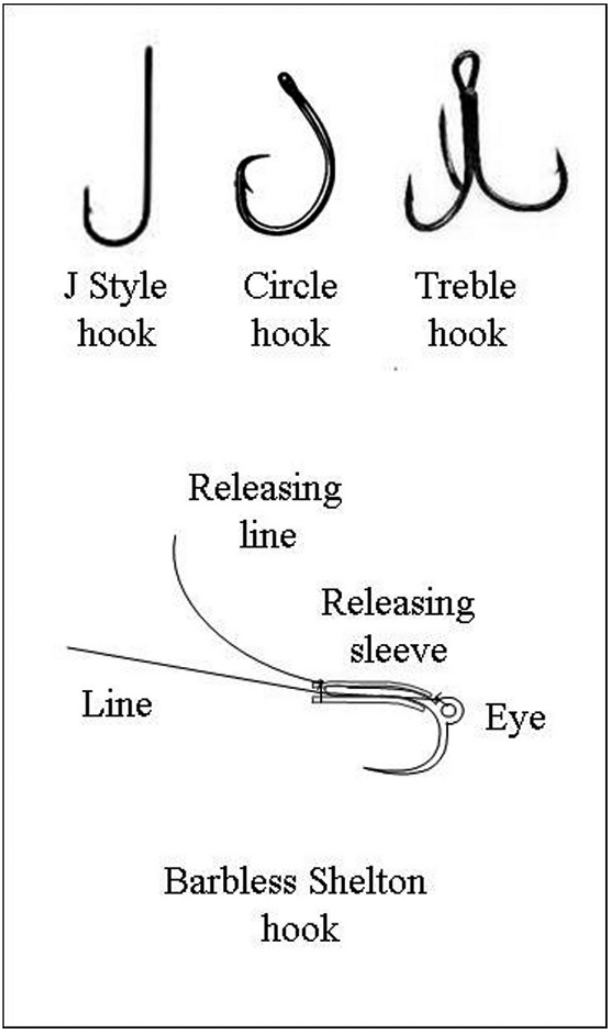

Fig. 7.1. Schematic of different hook types discussed in this chapter. The Shelton self-releasing hook (bottom) enables the angler to grip the releasing line without touching the fish (See Jenkins 2003)

7.3.1.1 Circle versus J Style Hooks

Circle hooks have become popular among recreational anglers in a number of fisheries based largely on the assumption that they reduce hook ingestion and, therefore, mortality of released fish. Owing to their geometry, circle hooks are intended to penetrate and lodge in the jaw, which typically results in fewer mortalities than when hooks are ingested. Unfortunately, the assumption that the widespread use of circle hooks reduces capture mortality has been perpetuated by anecdotal reports with few supporting scientific data. The most obvious difference between circle and conventional 'J-style' hooks is that, with a circle book, the point of the hook is oriented perpendicular to the shank, while in J-style hooks, the point is generally parallel to the shank (Fig. 7.1). In some circle hooks, the point is actually oriented towards the bend.

Some researchers have argued that the configuration of the 'circle' hook design promoted hooking as fish tried to expel bait they could not swallow (Stewart 1977). However, Johannes (1981) proposed an alternative mechanism based on simple physics. As fish attempt to consume a baited circle hook, the fish moves away, or a gentle pressure from the angler pulls the hook to the side of the mouth – thus hooking the fish superficially rather than in the gut. For circle hooks to function effectively, fishers must therefore modify their angling technique. Because circle hooks are used mostly with live bait, the premise is that an angler allows fish to ingest the bait including the hook, and then applies gentle but steady pressure as the hook and fish are reeled in. If the hook is set with the normal vigour used for conventional hooks, the hook either will not capture the fish at all, or is more likely to hook fish at locations that are injurious (such as the roof of the mouth or the eye). Usually, the species that are targeted for circle hook research are those that are commonly captured on live or dead bait and those that exhibited high rates of hooking mortality using conventional hooks (Muoneke and Childress 1994).

Cooke and Suski (2004) recently reviewed existing research on circle hooks in more than 40 studies. Here, we provide a brief summary of the main findings. Mortality, arising both from direct assessment and from projections/estimations, ranged between 0 and 34% for fish caught with circle hooks, and 0 and 46% for fish caught with J-style hooks. Although there was considerable variation among studies, overall mortality rates were consistently lower (approximately 50% lower overall) for circle hooks than J-style hooks (Cooke and Suski 2004). For example, in the United States, striped bass have consistently shown reduced mortality rates when caught on circle hooks compared to other hook types (Caruso 2000; 3% circle, 16% J), Maryland (Lukacovic 1999; 1% circle, 9% J; Lukacovic 2000; 2% circle, 9% J), and North Carolina (Hand 2001; 6% circle, 18% J).

Salmonids exhibited similar patterns with coho salmon (*Oncorhynchus kisutch*; McNair 1997; 3% circle, 24% J) and chinook salmon (*O. tshawytscha*; McNair 1997; 0% circle, 15% J; Grover et al. 2002; 31% circle, 46% J) having reduced hooking mortality rates when caught on circle hooks.

There were also instances, however, in which there were no differences in mortalities between circle hooks and J-style hooks. For example, in Canada, Cooke et al. (2003a) noted no mortality among rock bass (*Ambloplites rupestris*) caught using circle hooks or any of three other conventional hook designs (aberdeen, widegap, baitholder). Cooke *et al.* (2003c) also assessed mortality in bluegill (*Lepomis macrochirus*) and pumpkinseed (*L. gibbosus*) and found that mortality was negligible for all hook types (circle, aberdeen, widegap, baitholder). No mortality was observed for pumpkinseed, and only 1% of captured bluegill died, evenly among the circle hooks and the three other hooks types. Mortality rates were also similar for a study of largemouth bass (*Micropterus salmoides*) in the United States between fish caught on circle and conventional octopus hooks (Cooke et al. 2003b). In a study of summer flounder (*Paralichthys dentatus*), Malchoff et al. (2002) reported that mortality was similar between circle, widegap and sproat hooks.

There is no doubt that in some marine fisheries such as those for tuna, billfish and striped bass, catching efficiency remains high and injury and mortality rates are drastically reduced when circle hooks are used. However, in other freshwater species (e.g., bluegill), injury can actually be more severe from circle hooks compared with other hook types (Cooke et al. 2003c). In species such as largemouth bass, circle hooks have minimal conservation benefit, but have reduced catching efficiencies compared to conventional hook designs. Factors such as hook size, fishing style, fish feeding mode and mouth morphology all appear to affect the effectiveness of circle hooks. For these reasons, it is difficult to promote the adoption of circle hooks as a solution for all fish and fisheries. Instead, we recommend that, as is the case for most gear modifications, management agencies should focus on recommending circle hooks only where appropriate scientific data exist.

7.3.1.2 Shelton Releasing Hooks

A new hook design that shows promise for reducing or eliminating handling is the ‘self-releasing’ Shelton hook (Jenkins 2003; See Fig. 7.1). These hooks can be removed without handling the fish when the angler pulls on a tag line that activates a release mechanism. In a study of rainbow trout (*Oncorhynchus mykiss*), mortality rates of fish caught on barbless circle hooks that were removed were four times greater than fish caught on Shelton self-releasing hooks (Jenkins 2003).

7.3.1.3 Single versus Treble Hooks

Muoneke and Childress (1994) reported that single hooks tend to be more deeply ingested than treble hooks. However, if treble hooks are ingested, they almost certainly result in massive injury or mortality. In a meta-analysis of salmonids, Taylor and White (1992) failed to demonstrate a difference in mortality between these two hook types. Diodati and Richards (1996) also determined that treble hooks were associated with lower mortality rates than single hooks for striped bass because the latter were more likely to be swallowed, resulting in a greater occurrence of gut hooking. DuBois and Dubielzig (2004) reported that treble hooks hooked and held more brown trout (*Salmo trutta*), rainbow trout, and brook charr (*Salvelinus fontinalis*) than single hooks, but that there were no differences in the frequencies of severe injuries (i.e., in the eye or gullet) or mortalities. Similarly, Jenkins (2003) reported that treble hooks and single baited hooks lodged in the esophagus of rainbow trout at similar frequencies. Conversely, Ayvazian et al. (2002) investigated the effects of different hook designs on hooking injury and mortality of tailor (*Pomatomus saltatrix*) in Western Australia. The authors reported that treble hooks resulted in a significantly greater mortality rate than did other hook types. The authors concluded that their current management strategies, including discouraging the use of treble hooks, should be effective in ensuring the survival of a high proportion of discarded tailor.

7.3.1.4 Barbed versus Barbless Hooks

Using barbless hooks is one of the most common strategies employed to minimise discard injuries and mortalities. They are easier to remove from fish and so reduce the time required to remove hooks (Diggles and Ernst 1997; Schaeffer and Hoffman 2002; Cooke et al. 2001; Meka 2004) and tissue damage at the point of hooking (e.g., Cooke et al. 2001; Meka 2004). Cooke et al. (2001) also evaluated the effects of different handling periods (i.e., short for barbless and long for barbed) on the cardiovascular disturbance of rock bass and revealed that subtle differences in hook removal time translated to significant differences in physiological disturbance. Similar findings have been reported in a marine fishery in the Gulf of Mexico where unhooking times were shorter and injuries were reduced with barbless hooks (Schaeffer and Hoffman 2002). DuBois and Dubielzig (2004) studied stream-caught trout (rainbow, brown and brook trout) and showed that barbless single hooks were quicker to remove than other hook types (treble barbless, treble barbed and single barbed), but the difference was insufficient to reduce mortality.

One perceived concern among anglers associated with using barbless hooks is a reduced hooking efficiency. Schaeffer and Hoffman (2002) compared barbed and barbless hooks in a nearshore marine fishery in the Gulf of Mexico. Bait loss, catch-per-unit effort, and mean length of captured fish did not differ between hook types. However, anglers landed 22% more fish with barbed hooks. DuBois and Dubielzig (2004) and Meka (2004) also noted that anglers using barbed hooks hooked and retained more trout than those using barbless hooks.

Schill and Scarpella (1997) summarised the results of past studies that directly compared the hooking mortality of salmonids caught and released with barbed or barbless hooks. The authors determined that barbed hooks caused less hooking mortality in 2 of 4 comparisons with flies and in 3 of 5 comparisons with lures, however, only 1 of 11 comparisons resulted in statistically significant differences in hooking mortality. The authors concluded that the use of barbed or barbless flies or lures played no role in the mortality of trout caught and released by anglers. In fact, the authors concluded that, because natural mortality rates for wild trout in streams commonly range from 30 to 65% annually, a 0.3% mean difference in hooking mortality for the two hook types was irrelevant at the population level, even when fish were subjected to repeated capture. Others have also suggested that barbless hooks provide little benefit and are really just a ‘social issue’, generating substantial controversy (e.g., Taylor and White 1992; Schill and Scarpella 1997; Turek and Brett 1997). However, sublethal injuries and physiological disturbance (due to longer handling times) are more extensive with barbed hooks and, for these reasons, barbless hooks can be considered an effective conservation and management tool (Cooke and Suski 2005).

7.3.3.5 Hook Size

Among conventional hook types, the relationship between hook size, fish size and hook performance has varied widely among studies (Muoneke and Childress 1994). Taylor and White (1992) conducted a meta-analysis on factors associated with hooking mortality in salmonids and concluded that hook size did not influence mortality rate. Similarly, Savitz et al. (1995) found no effect of hook size on the mortality of coho or chinook salmon in the Laurentian Great Lakes. However, Carbines (1999) studied the relationship between mortality and hook size in blue cod (*Parapercis colias*) and observed no deaths among fish caught with 6/0 hooks, but noted significant mortality (25%) among those captured with smaller, 1/0 hooks.

Cooke et al. (2005) reported that size may be more important for circle hooks than other hook types. To function properly, the entire circle hook needs to be ingested by a fish prior to 'setting the hook'. This could pose some challenges if the optimal hook size for the targeted fish causes substantial injury in individuals that are released as by-catch. Cooke et al. (2005) caught bluegill on each of five different-sized circle hooks (1/0, 2, 6, 10, and 14). Jaw hooking rates generally increased with decreasing hook size, whereas hooking rates in the roof of the mouth decreased. Gullet hooking was restricted to the three smallest hook sizes. Beckwith and Rand (2005) found similar results for red drum (*Sciaenops ocellatus*) with fewer injuries associated with intermediate- to large-sized circle hooks. Circle hooks function most effectively when the entire hook can fit in the mouth of the fish and when the shank-to-point distance (gape) is large enough to permit jaw hooking (Beckwith and Rand 2005; Cooke et al. 2005).

7.3.3.6 Offset versus Non-offset Hooks

An important consideration with respect to hooks is the degree to which the point is offset from the shank. This is particularly important for circle hooks. Offset hooks would superficially appear to increase the potential for deep hooking and injury due to the exposed point. However, there is contradictory evidence regarding the importance of non-offset hooks for minimising injury and mortality. For example, in a study of striped bass, Hand (2001) compared offset and non-offset circle hooks and determined that offset hooks were more damaging than non-offset hooks. Bleeding and deep-hooking rates were 7 and 13%, respectively, for offset circle hooks compared to 0 and 6% for non-offset circle hooks. In contrast, Lukacovic (2001) concluded that there was no difference in the rate of deep hooking for striped bass between offset (3% all fish and 2% sublegal) and non-offset (2% all fish and 2% sublegal) hooks. Projected mortality rates (based on the degree of injury to vital tissues) for striped bass were also similar for all fish and sublegal fish between offset (1% all fish and 0.4% sublegal) and non-offset (0.6% all fish and 0.6% sublegal) circle hooks. Malchoff et al. (2002) reported that severe offset circle hooks (i.e., 15°), used in their study of summer flounder, may have affected high jaw hooking rates. Due to the inconclusive data regarding the importance of offset versus non-offset hooks, it is difficult to provide any clear management direction on these hook types at this time but, in general, severely offset hooks (i.e., $> 5^{\circ}$) tend to cause more injuries than non-offset hooks.

7.4 Bait

Another important factor is the choice of bait. Artificial lures or flies are highly regarded for superficially hooking fish, with minimal damage to the vital organs or tissues of the fish (Muoneke and Childress 1994). Organic baits, including live bait (but excluding artificial flies), are typically ingested deeper than artificial lures – resulting in more time required to remove hooks and a greater potential for mortality (Siewert and Cave 1990; Cooke et al. 2001).

Since the review by Muoneke and Childress (1994), there have been several comparisons of bait types. For example, Diggles and Ernst (1997) evaluated the effects of different lure and bait types on the hooking mortality of the yellow stripey (*Lutjanus carponotatus*) and the wire netting cod (*Epinephelus quoyanus*). Baitfishing with single hooks caused a significantly greater post-release mortality rate (5%) than did lure fishing with treble or single hooks (0.4%), and was the method most likely to cause bleeding and damage to vital organs. Similarly, Pauley and Thomas (1993) revealed that mortality rates of cutthroat trout were generally greater for fish caught on worm-baited hooks (40 to 58%) compared to those captured on lures (11 to 24%). Conversely, studies of both ling cod (*Ophiodon elongates*; Albin and Karpov 1998) and weakfish (*Cynoscion regalis*; Malchoff and Heins 1997) did not find any differences in mortality between those fish caught on natural baits or those caught on artificial lures.

Studies of flies versus lures and baits have been consistent in that flies tend to be less injurious and have a lower chance of causing mortality. For example, Schisler et al. (1996) compared the hooking mortality of fish caught on flies and lures and determined that mortalities were lowest by several fold for fly-caught fish. Meka (2004) also determined that rainbow trout caught on spinning gear tended to be injured more frequently than fish caught by fly fishing.

7.4.1 Fishing Techniques and Rigging

Although not well studied, angler experience and technique have been shown to be important predictors of catch-and-release mortality for some species. Diodati and Richards (1996) and Meka (2004) reported that mortality among fish caught by more experienced anglers was less than that observed among fish caught by less experienced anglers. Dunmall et al. (2001) found a greater incidence of deeply-hooked smallmouth bass (*Micropterus dolomieu*) among those caught by experienced anglers, which would lead one to expect greater mortality among fish released by experienced anglers.

The manner in which specific baits or lures are rigged and used also affects the mortality of hooked fish. Schisler et al. (1996) observed greater mortality among rainbow trout caught on artificial baits (slip-rigged artificial eggs) that were actively fished than among fish caught with the same bait fished passively. Similarly, Schill (1996) found that the frequency of deep hooking was greater among rainbow trout caught on a ‘slack line’ than a ‘tight line’. The orientation of bait on hooks affected the survival of drift-caught chinook salmon (Grover and Palmer-Zwalhlen 1996), with greater mortalities observed when the bait was hooked with the head down as opposed to upwards. Persons and Hirsch (1994) evaluated hooking mortality for lake trout (*Salvelinus namaycush*) caught through the ice by jigging and by set-lining with dead baits. Seventy percent of the lake trout caught by set-lining were hooked in the gills or gut, compared with 9% of fish caught by jigging. These differences in hooking location were reflected in mortality: 32% for fish captured by set-lining and 9% for jig-caught fish.

Dedual (1996) examined the effects of four different trolling techniques on injury and mortality of rainbow trout. The author reported cumulative mortalities of 15% for fish caught on downriggers, 14% for those caught using wire line, 8% for those captured on lead line, and 2% for fish caught by harling (fly fishing gear trolled near the surface). The differences in mortality were related to the depth of capture and fishing gear: fish caught on downriggers generally were played with lighter lines than were fish caught on lead and wire lines.

7.4.2 Gear Summary

Although we have a reviewed a number of specific gear types and styles, there is a growing body of literature across a variety of species that indicates hooking location is perhaps the single greatest gear-related factor in determining the outcome of an angling event for a fish. For example, anatomical hooking location has been identified as the primary factor determining the mortality of striped marlin (*Tetrapturus audax*; Domeier et al. 2003), yellow stripey (*Lutjanus carponotatus*; Diggles and Ernst 1997), wire netting cod (*Epinephelus quoyanus*; Diggles and Ernst 1997), largemouth bass (Pelzman 1978), rainbow trout (Schisler et al. 1996) and snook (*Centropomus unidecimalis*; Taylor et al. 2001). In fact, because hooking mortality varies with anatomical hooking location, some researchers have developed models to estimate the mortality of spring adult chinook salmon in Oregon (Lindsay et al. 2004). The authors modelled hooking mortality rates for each of five anatomical locations (jaw, 2%; tongue, 18%; eye, 0.0%; gills, 82%; and esophagus-stomach, 67%) using recaptures of tagged fish and from the frequency of these anatomical locations in the sport fishery determined by creel surveys (jaw, 82%; tongue, 5%; eye, 0.4%; gills, 5%; and esophagus-stomach, 8%). This work also estimated total hooking mortality rates of 12% for wild chinook salmon caught-and-released in the sport fishery and 3% for the entire run of wild chinook salmon based on a mean encounter rate of 26%. The question remains as to how different gear types influence hooking location.

Of all current gear developments, only circle hooks have consistently had a demonstrable positive effect on anatomical hooking location (Cooke and Suski 2004; McEachron et al. 1985; Woll et al. 2001). The recent interest in circle hooks has been beneficial for stimulating interest and research on the role of hook designs in reducing hooking related injury and mortality. The challenge is to develop additional hook designs or configurations that reduce or eliminate hooking of vital tissues or deep regions. There is no doubt that other gear-related factors can also be important – such as barbless hooks (in reducing handling and air exposure time), but these do little to alter the location where fish are hooked. To date there have been few novel gear developments that have revolutionised the recreational fishing industry with respect to reducing discard injuries or mortality. This contrasts strongly with the commercial sector where considerable effort has been devoted towards developing gear that reduces by-catch and discard mortality. We encourage tackle manufacturers to continue to develop new hook designs that have the potential to provide conservation benefits to caught-and-released fish.

7.5 Practices

Fishing practices refer to events that are largely under the control of the angler and do not include gear-related decisions. For example, on a seasonal basis, anglers must make decisions regarding if and when they will fish, knowing that water temperature or life-history stages of the targeted species are potentially important factors. In theory, angling practices should be easy to change since they depend on an individual making a change in their behaviour. However, change by anyone, including anglers, takes time and is never as straightforward as one may hope, even when scientific data are compelling.

7.5.1 Fighting Time

There is a general consensus among the current body of catch-and-release research that the duration of an actual angling event experienced by a fish correlates positively with the magnitude of physiological disturbance and the time required for recovery (Kieffer 2000). Angling is essentially a combination of aerobic and anaerobic exercise for fish that results in a series of physiological changes, including a depletion of energy stores and an accumulation of lactate, as well as acid/base changes and osmoregulatory disturbances (Wood 1991).

Evidence supporting the concept that the duration of angling influences the degree of sublethal disturbances can be found for several fish species, and the general physiological processes that result in this response should be consistent for most fishes. Gustaveson et al. (1991) determined that the length of angling duration for largemouth bass (varying between 1 and 5 minutes) was correlated with the degree of physiological disturbance measured by variables such as blood cortisol and plasma lactate. Similar haematological disturbances (increases in plasma lactate and decreases in blood pH) were observed to be correlated with the duration of angling in Atlantic salmon (*Salmo salar*; Thorstad et al. 2003). In a study of smallmouth bass, Kieffer et al. (1995) determined that white muscle disturbance, including increases in metabolites and decreases in energy stores, were more severe in fish angled for 2 minutes than those angled for only 20 seconds. Similar patterns were observed in a marine fish, red drum, where plasma glucose, cortisol, lactate and osmolality all increasing according to the duration of angling (varying between 10 seconds and 6 minutes; Gallman et al. 1999). In addition, striped bass angled for long durations in Maryland also had more severe physiological disturbances (in terms of plasma pH, O_2, and CO_2) compared to briefly-angled individuals (Thompson et al. 2002).

Beyond the magnitude of disturbance, the time needed for recovery can also be prolonged with longer angling durations. For example, Schreer et al. (2001) reported that smallmouth bass exposed to brief simulated angling in a swim tunnel recovered more rapidly than those fish exercised until exhaustion. The heart rate and cardiac output returned to resting values twice as rapidly for briefly-angled smallmouth bass compared to exhaustively-angled individuals. Extended angling duration can also result in death through mechanisms outlined in Black (1958) and Wood et al. (1983). Indeed, Thompson et al. (2002) noted that the mortality of striped bass increased 3-fold when angling duration increased from 1 to 3 minutes at 26°C. Interestingly, at 8°C no mortality was observed when fish were angled for similar durations, highlighting the important role of water temperature and the concept that stressors rarely act alone.

The duration of the angling event primarily depends on the type of tackle used and size of fish caught, but can also be affected by water temperature and habitat (especially depth). Larger individuals within a species may require longer periods of time to land – as observed for Atlantic salmon (Thorstad et al. 2003). In this study, the duration of the angling events ranged from 1 to 49 minutes with fish undertaking between 0 and 10 runs (mean of 3.7 runs). Plasma lactate increased and plasma pH decreased with increased angling duration. A recent study by Meka and McCormick (2005) revealed that plasma cortisol and lactate were greater in large fish that took longer than 2 minutes to land compared to smaller fish that were landed in shorter periods (Thorstad et al. 2003). In addition, Meka (2004) determined that experienced anglers took longer to land fish than novices because they tended to capture larger individuals. Thus, factors such as fish size and angler experience can affect the duration of angling and subsequent physiological responses (Meka and McCormick 2005). In some cases, fish landed rapidly (< 20 seconds) have even been used as 'unangled controls' in physiological studies (Kieffer et al. 1995). Collectively, the trends in the literature point towards increased physiological disturbance and risk of mortality as fish are fought for longer durations. These effects appear to be pronounced when combined with multiple stressors such as high water temperatures. Based on this evidence, we conclude that anglers should attempt to land fish as rapidly as possible to minimise the duration of exercise and the concomitant physiological disturbances.

7.5.2 Landing

The processes of landing a fish and removing the hook present several opportunities for fish to experience injury and sublethal physiological disturbances. Landing the fish is usually accomplished by hand or with the aid of a device (e.g., a landing net, a gaff or a Boca Grip for holding fish by the lower jaw). All of these techniques have the potential to injure fish. Landing fish by hand can result in disruption or removal of the external mucous covering, which may increase the risk of pathogenic infections, especially those associated with fungi. However, some fish such as the centrarchids can be landed safely by gripping the fish by the lower jaw. Commercially-available gripping devices such as the Boca Grip may also be effective for safely restraining large (or toothy) fish.

Although landing nets are widely used, they can be detrimental to fish. A recent study (Barthel et al. 2003) involving freshwater fish determined that the use of landing nets can result in physical injury and increased risk of mortality compared with to that observed in fish landed by hand. In addition, the degree of injury (including dermal disturbance and fin fraying) varies with the type of mesh in the landing net, with knotless nylon and rubber being the least injurious and knotted, large/coarse mesh being the most damaging (Barthel et al. 2003). We are unaware of any studies that explicitly evaluated the effects of gaffing on released fish, presumably because this practice is generally viewed as incompatible with live release.

Decisions regarding how to land fish will be influenced by the species, environment, fishing gear used, etc., but should also include consideration of what will be best for the fish. The key is to restrain the fish sufficiently to enable hook removal and then release it safely without excessive injury.

7.5.3 Air Exposure and General Handling

Among all species of recreational fishes examined thus far, exposure to air is harmful. In recreational fisheries, air exposure occurs after capture when anglers remove hooks, weigh and measure fish, and/or hold fish for photographs and causes hypoxia to the fish. During hypoxia, gill lamellae collapse leading to adhesion of the gill filaments (Boutilier 1990) which cause several major physiological changes. For example, in rainbow trout, blood oxygen tension and the amount of oxygen bound to haemoglobin were lowered by over 80% during brief air exposure, causing severe anoxia (Ferguson and Tufts 1992). Furthermore, those fish exposed to air typically experienced greater acid/base disturbance than those fish that were exercised but not exposed to air (Ferguson and Tufts 1992). Several researchers have also monitored cardiovascular variables for fish exposed to air. Cooke et al. (2001) subjected rock bass to either 30 seconds or 3 minutes of air exposure. When fish were exposed to air for longer periods, all cardiac variables measured (cardiac output, stroke volume, heart rate) took significantly longer to return to base levels. Similar studies on smallmouth bass (Cooke et al. 2002b) determined that the duration of air exposure was correlated with the time required for cardiovascular variables to recover. Extended exposure to air eventually results in permanent tissue damage beyond some threshold. Mortality rates can also be increased by exposing fish to air. Short-term mortality (12 hours) was negligible for control rainbow trout, and low for trout that were exercised to exhaustion but not exposed to air (12%; Ferguson and Tufts 1992). When trout were exposed to air for either 30 or 60 seconds following exhaustive exercise, mortality increased to 38 and 72%, respectively. In a recent study, the swimming performance of brook trout was not impaired following short duration air exposure (e.g., less than 60 sec; Schreer et al. 2005). However, exposure to air for 2 minutes led to swimming performance being reduced by 75%.

Based on these studies, it appears that air exposure, especially in fish that have experienced physiological disturbances associated with angling, can be extremely harmful. Although different fish species will vary in their sensitivity to air exposure, we recommend that whenever possible, anglers attempt to eliminate air exposure by handling fish that are to be released in the water. When fish must be exposed to air, we urge that anglers do everything possible to minimise the duration of air exposure.

The manner in which fish are held, particularly for photographs or other displays, has implications for post-release survival and well-being. Although undocumented in the literature, there are numerous anecdotal accounts of large largemouth bass and other fish, when held by their lower jaws without additional support, sustaining debilitating injuries including broken jaws.

7.5.4 Hook Removal

As discussed above, fish hooked deep in the esophagus or stomach have an increased chance of mortality. This increased mortality has been attributed to the nature and severity of hooking wounds and to the difficulty of, and increased handling time attributed to, removing ingested hooks. Consequently, there has been some discussion as to whether it is better to remove, or leave in place, ingested hooks. Diggles and Ernst (1997) left hooks in one specimen each of two Australian reef fishes, captured on bait, and hooked in the gut or esophagus. In both instances, the fish survived and subsequently regurgitated the hook during the observation period. Removing hooks was found to result in increased mortality among brown trout (Hulbert and Engstrom-Heg 1980) and red drum (Jordan and Woodward 1994). In the latter study, there was little difference in mortality due to hook removal, among fish hooked in the esophagus (41% if hook was removed and 50% if hook was left in); however, among fish hooked in the gills, mortality was greater if hooks were removed (79%), than if they were left in place (54%).

A number of studies have presented evidence that leaving hooks in place increases the survival of deeply-hooked fish. Schill (1996) determined that cutting the line on deep-hooked rainbow trout, rather than removing the hook, reduced post-release mortality by 36% in a hatchery setting and 58% among wild-caught fish. Among surviving fish in which the line was cut, hooks were shed by 74% of the hatchery fish and 60% of wild-caught rainbow trout during the two-month study period. Similarly, Schisler and Bergersen (1996) reported 55% mortality among rainbow trout when the hook was removed by hand and only 21% when the hook was not removed. Among surviving fish in which the hook was not removed, 25% of fish shed their hooks during the 3-week observation period. Taylor et al. (2001) removed hooks from 12 deeply-hooked common snook and left hooks in place in another 12 fish. Mortality was 25% among fish from which hooks were removed and 0% among those in which the line was cut. This difference was not statistically significant, however, which Taylor et al. (2001) attributed to low statistical power.

The above studies have a common limitation. They were not specifically designed to examine the mortality associated with hook removal and, consequently, suffer from small sample sizes and little power. Wilde and Sawynok (unpublished manuscript) examined capture and recapture records (n = 248,010) for 27 species of Australian fishes collected as part of a large cooperative angler-tagging program. Anglers left hooks in 1% of released fish and the overall recapture rate, across species, was 9%. Wilde and Sawynok (unpublished manuscript) used relative risk, the probability of an event (recapture) in one group (fish with hooks not removed) divided by the probability of an event in a second group (fish with the hook removed), to assess the potential effects of leaving hooks in released fish. Relative risk did not differ significantly from 1.0 for any species; thus there was no evidence that hook removal affected recapture probability. Pooling results across all species and habitats yielded an overall relative risk of 1.18 (with a 95% confidence interval of 1.02 to 1.36), which suggests that survival was 18% greater, on average, among fish in which hooks were not removed. Wilde and Sawynok (unpublished manuscript) concluded there was no clear benefit to removing hooks from deeply-hooked fish and recommended that anglers use their best judgment in when deciding whether to remove hooks.

If hooks are removed, using de-hooking tools may help to reduce mortality. Survival of fish from which anglers remove hooks also can be increased by educating anglers in best practices. Meka (2004) noted that training was required to promote proper hook removal techniques to minimise injury and that even barbless hooks can injure fish if not removed properly.

7.5.5 Short-Term Retention (Fish Baskets and Keep Nets)

Catch-and-release angling sometimes involves the retention of fish for a period of time (usually hours) prior to release as anglers assess whether they will harvest individuals, or in competitive events when fish are retained for later enumeration at a weigh-in. Professional anglers often hold fish in aerated live-wells, whereas recreational anglers commonly use more affordable, readily available and convenient methods, including fish baskets and keep nets. Research has investigated the effects of keeping fish in keep nets on the growth, survival (Raat et al. 1997), stress response and recovery (Pottinger 1997 1998) of various cyprinid species. Additional research has focused on changes in water quality in keep nets during retention (Pottinger 1997). Collectively, these studies suggest that retention is stressful to fish, but if provided with adequate water quality, mortality and sublethal disturbances are minimised. Cooke and Hogle (2000) compared 6 retention methods on smallmouth bass for 3–5 hour periods: metal stringer through the lip, metal stringer through the gill arch, cord through the lip, cord through gill arch, wire fish basket and nylon keep net. Control fish exhibited very little mortality (3%) and had negligible physical injury in all sampling periods. Most (95%) fish retained experienced some form of injury or mortality. In general, injury and mortality increased with high water temperatures. Survival and injury varied among retention methods, but gill damage or fungal lesions associated with abrasion, and the cumulative stress of angling and retention appeared to be the precursor to most deaths. Details on live-wells (vessels for holding fish in water aboard a boat) are provided in the case study on black bass below.

7.5.6 Fishing Locations and Environment

The habitat where fish reside, and the environmental conditions faced by fish at the time of angling, can also affect the outcome of angling events. Here, we briefly discuss the role of these factors (i.e., water temperature, oxygen, water hardness, depth, salinity, other habitat features and predation).

7.5.6.1 Water Temperature

In species for which data exist across a gradient of water temperatures, angling at extreme water temperatures (especially high) is correlated with increased physiological disturbances and the probability of mortality. This is not surprising considering that beyond some thermal optima, fish performance is constrained (e.g., Farrell et al. 1996; Schreer et al. 2001; Farrell 2002). Since fish are poikilothermic, changes in ambient water temperatures are realised throughout the animal, and can have pronounced impacts on cellular function (Prosser 1991), protein structure (Somero and Hoffman 1996), enzyme activity, diffusion rates and metabolism (Fry 1971).

There are many examples in temperate recreational fisheries where temperature has been identified as an important determinant of the degree of sublethal disturbance and mortality (See Muoneke and Childress 1994). For example, mortality among Atlantic salmon was reduced when fish were caught in water temperatures between approximately 8 and 18°C, but as water temperatures increase above 18°C, the risk of angling-induced mortality increased exponentially (Thorstad et al. 2003). Similar patterns were observed for largemouth bass captured in fishing tournaments, for which there was a strong positive correlation between water temperature and mortality (Wilde 1998). Underlying the mortality of Atlantic salmon at high temperatures are limitations in maximal cardiovascular performance as fish approach their maximal metabolic rate (Anderson et al. 1998) and extreme biochemical alterations (Wilkie et al. 1996). Wilkie et al. (1997)

determined that whereas warmer water may facilitate post-exercise recovery of white muscle metabolism and acid-base status in Atlantic salmon, extremely high temperatures increased their vulnerability to mortality. Greater oxygen debt may also be correlated with higher water temperatures (McKenzie et al. 1996). In tropical marine fish, most studies have been conducted at moderate temperatures and thermal relationships are not as obvious (e.g., there was no effect of minor changes in water temperature on hooking mortality of snook, Taylor et al. 2001).

Catch-and-release angling at extremely cold water temperatures has also been suggested as potentially challenging to fish. However, Persons and Hirsch (1994) concluded that the lack of mortality for lip-hooked lake trout captured under ice suggested that catching and handling fish in cold (i.e., sub-zero) temperatures had little effect on mortality.

Individual species exhibit different thermal tolerances (Beitinger et al. 2000) and this must be considered for each species, population and location. However, there is a period of the year where water temperatures are at their highest, and it is during this period that catch-and-release angling has the potential to be particularly harmful. Under these scenarios, if anglers do continue to fish, both the duration of the fight and handling time should be minimised. Because water temperature influences most physiological processes in fish (Fry 1971), extreme water temperatures lead to fish being particularly susceptible to mortality. Ideally, fishing should be restricted during such periods of extreme water temperature.

7.5.6.2 Oxygen

Temperature is also negatively correlated with oxygen availability. At present, we are unaware of any studies that evaluate the role of low dissolved oxygen in the natural environment on caught-and-released fish. However, there are several studies that have revealed the importance of providing fish with adequate water quality during live well retention to minimise the lethal effects of hypoxia (e.g., Hartley and Moring 1995; Furimsky et al. 2003).

7.5.6.3 Water Hardness

A recent study examined the influence of environmental water hardness (40 mg/L versus 100 mg/L $CaCO_3$) on the physiology and survival of exhaustively-exercised Atlantic salmon (Kieffer et al. 2002). In softer water, exhaustive exercise caused a significantly greater elevation in post-exercise blood lactate concentrations and a larger acid-base disturbance compared with fish caught in hard water. Post-exercise survival of Atlantic salmon in softer water was directly related to environmental water hardness, and those that succumbed failed to exhibit any post-exercise correction of their extra-cellular acid-base disturbance. In contrast, all fish captured in hard water survived.

7.5.6.4 Depth

When brought to the surface rapidly, the gasses in swimbladders of physoclistous fish rapidly expand to the point that the fish are unable to achieve neutral buoyancy, maintain equilibrium, and may even have their stomachs protruding from their mouths or anus (because of the expanded swimbladder pushing out the viscera; Burns and Restrepo 2002). The fish may also experience embolisms and blood-gas disturbances (Morrissey et al. 2005). Different species respond to capture at depth differently and each also has their own threshold regarding which depths are problematic. For example, depth of capture was the major source of mortality in a study of pink snapper in Australia (St John and Moran 2001). Mortality after 3 days increased with depth, but not linearly. Mortality was drastically lower at the shallow sites (4% at 15 m and 7% at 30 m) than at the deeper sites (71% at 45 and 84% at 65 m).

One obvious, but draconian, option for anglers to avoid these problems is to not fish in deep waters. However, an alternative solution can involve anglers venting the swimbladder with a needle to release the gas and enable the fish to swim back to depth (Keniry et al. 1996; Collins et al. 1999; Kerr 2001, Burns and Restrepo 2002). However, St John and Moran (2001) found that such venting failed to reduce mortality. This research topic requires more work before definitive answers can be provided.

7.5.6.5 Salinity

There are few studies, and none that have been done in a quantitative manner, that have evaluated how salinity affects either fish mortality or sublethal impairments. For example, Gallman et al. (1999) evaluated responses to exercise across salinity values of 17 to 33‰ but did not include salinity as a factor in analyses. However, research with striped bass (Diodati and Richards 1996) and red drum (Jordan and Woodward 1994) suggests that for marine species, survival is related to salinity, presumably because fish that were caught, handled and maintained in isotonic environments were under less stress than those similarly handled in less dilute environments.

7.5.6.6 Habitat Features and Predation

The habitats where fish are caught and released may also affect their ability to survive a catch-and-release angling event. For example, Schill (1996) concluded that stream locations where bait anglers catch fish and the general habitat characteristics of a stream could influence bait-related hooking mortality based on empirical data on rainbow trout. Similar data do not exist for other systems or fisheries.

The habitat where fish are released can influence exposure to predators. For example, mortality rates of bonefish in the Bahamas exceeded 40% due to post-release predation by sharks (Cooke and Philipp 2004). However, mortality was related to the density of sharks. Survival was greater in areas with few sharks and in complex, shallow mangrove habitats. Whilst shark predation was greatest in areas with significant densities of predators, these also tended to be areas near deep water and with little cover. Edwards (1998) observed limited predation on caught-and-released tarpon (*Megalops cyprinoides*) but suggested that the predation was associated with the use of light tackle that resulted in severe exhaustion, which thus made fish more susceptible to predation. In a study of cichlids in the Zambezi River, Africa, Thorstad et al. (2004) reported that catch-and-release angling may increase the risk of predation before recovery: they located a telemetry transmitter from a tagged threespot tilapia (*Tilapia andersoni*) under a tree used as a roost by an African fish eagle (*Haliaeetus vocifer*).

7.5.7 Seasonality, Sensitivity and Biologically-Intrinsic Factors

There are a number of factors other than those discussed above, that can affect the fate of discarded fish. For example, in addition to temperature, different seasons may also affect the sensitivity of fish due to their reproductive status. Lowerre-Barbieri et al. (2003) determined that common snook subjected to catch-and-release angling did not immediately leave a spawning aggregation and there was no obvious negative consequences of angling during this period. Brobbel et al. (1995) compared the physiological response to angling in Atlantic salmon at two different stages of migration (kelts and bright salmon). This demonstrated large differences in the degree of physiological disturbance that derived from angling in these two migratory stages, as well as differences in angling-induced mortality.

Mortality (Meals and Miranda 1994; Thorstad et al. 2003) and physiological disturbance (Kieffer 2000) can also vary with the size of individuals of the same species – larger individuals generally experience more substantial physiological disturbance. In addition, the gender of individual fish may also play an important role, but there are few tests of that supposition. In fact, there has been insufficient research on all of these topics and work needs to continue on these (i.e., sex, life-stage, reproductive status, etc.) and other factors that are not typically considered.

7.5.8 Expediting Recovery

Recent research, primarily focused on salmonids, indicates that, after capture and exposure to air, slow speed swimming can expedite recovery (Milligan et al. 2000). This knowledge is being applied to reduce by-catch mortality of fishes captured in the commercial troll-fishery for salmonids and to facilitate the recovery of tournament-caught largemouth bass (Cory Suski, unpublished data). Live-wells used in freshwater fishing tournaments were once regarded as stressful but, if provided with adequate water quality and if fish are kept at low densities, some fish can actually recover tissue energy stores and reduce cardiac output (Cooke et al. 2002b; Suski et al. 2004).

7.6 Case Studies

In addition to the above review of the many factors associated with by-catch in recreational fisheries, we felt that it would be useful to present three brief relevant case studies. The species covered in these case studies are very different (Atlantic salmon, marine pelagics and black bass) and provide an opportunity to explore specific issues further (e.g., predation, hook technology, stress, fitness impacts) using these well-studied species.

7.6.1 Atlantic Salmon Case Study

Atlantic salmon (Fig. 7.2A) are a highly-valued recreational species in North America and Europe that has experienced population declines that have been partially attributed to recreational fishing mortality. Recognising the importance of Atlantic salmon and its sensitivity to fishing-induced mortality, much effort has been devoted to catch-and-release research for this species. This species is an appropriate model for a case-study due to the high levels of mortality that are believed to occur after angling. Indeed, there are many jurisdictions where strict management regulations have been applied that require the release of some or all of these fish (e.g., O'Connell et al. 1992). Here we present a brief case-study on the catch-and-release of Atlantic salmon focusing on the effects of two issues on post-release survival: migratory disruptions and thermal effects. Although there are a number of other issues such as handling, air exposure, use of barbless hooks and type of bait, migratory disruptions and thermal effects are particularly important for Atlantic salmon. More detailed evaluation of all catch-and-release issues facing Atlantic salmon may be found in DFO (1998) and Tufts et al. (2000).

Like many other species, Atlantic salmon tend to be targeted during their migration. As such, research efforts have focused on the consequences of angling these fish during migration, particularly en route to spawning grounds. For example, Whorisky et al. (2000) studied the effects of catch-and-release fishing on Atlantic salmon in Russia's Ponoi River. This highly-developed salmon sport fishery has estimated angler exploitation rates of between 10 and 19%, resulting in concern for the sustainability of this activity. The authors determined that released salmon had high rates of survival, and anglers recaptured about 11% of released fish per year. The authors also held 62 angled fish for 24 hours in a cage to evaluate rates of delayed mortality. Only one of the 62 fish died, and it was heavily scarred with gillnet marks. Approximately 10% of released fish were angled and released twice, and about 0.5% were angled and released three times. No significant biases were detected in the post-angling movement patterns of these fish. The multiple captures and lack of differences in movement patterns suggest that fish behaviour was altered little by the angling experience.

Conversely, in Finland, when subjected to catch-and-release, Atlantic salmon migrating upriver actually moved downstream after release causing delays in their net upstream migration (Makinen et al. 2000). Thorstad et al. (2003) conducted a study on catch-and-release of adult Atlantic salmon in a Norwegian river. At intermediate water temperatures (10–14.5°C), a high proportion of the radio-tagged salmon (97%) survived hook-and-release and stayed in known spawning areas during the spawning period. However, behaviour after release was altered by the angling event. The authors attributed increased playing time, increased number of runs during the angling event, hooking in the throat, bleeding at the hook wound, increased handling time, air exposure and water temperature to contributing to a cumulative negative effect. Dempson et al. (2002) evaluated the effects of catch-and-release angling on survival of Atlantic salmon at Conne River, Newfoundland. The authors determined that, overall, 8% of salmon caught-and-released died, and mortality rates increased to 12% at water temperatures greater than, or equal to, 17.9°C. Interestingly, there were no significant differences between salmon that survived or those that died due to the time associated with angling, exposure to air, tagging, transfer to holding cages, nor total handling time.

Wilkie et al. (1997) determined that while warmer water may facilitate post-exercise recovery of white muscle metabolism and acid-base status in Atlantic salmon, extremely high temperatures increased their vulnerability to mortality. More recently, Anderson et al. (1998) used heart rate telemetry to evaluate the response of Atlantic salmon in Newfoundland. Heart rate, after angling, was found to increase but not vary with temperature, but the magnitude of the increase was similar among temperatures. Time to recovery was assessed as the return to the observed resting heart rate for each individual fish and was found to be similar for both the 8°C and 16.5°C angled groups (approximately 16 hours). However, approximately 80% of the fish died at the higher water temperature.

Collectively, data for Atlantic salmon indicated that they tend to be sensitive to angling during their spawning migration. In part, this is due to the stress associated with migration and reproduction. However, the more pervasive factor appears to be water temperature which can be lethal when combined with exercise and the stress associated with recreational angling. In eastern Canada, Atlantic salmon rivers are temporarily closed to recreational angling during excessive water temperatures (Department of Fisheries and Oceans 1998).

7.6.2 Marine Pelagics

Marine pelagic recreational fish (Fig. 7.2B) include some of the most iconic, yet imperiled, marine ichthyofauna, owing in part to their large size and value, but also to their low reproductive output. Examples of important recreational marine pelagic species include marlin, sailfish, tuna and sharks. Despite their diffuse distribution throughout the world, these fish have become the frequent target of certain recreational fisheries. Here, we explore several catch-and-release issues that are particularly relevant to marine pelagics. Specifically, we discuss developments in hook technology (i.e., circle hooks) and issues associated with stress and predation.

For years, hooking mortality rates in marine pelagics were assumed to be high due to frequent deep hooking (Muoneke and Childress 1994). Recent developments in gear technology have resulted in efforts to assess the role of circle hooks in potentially reducing injury and mortality. For example, Prince et al. (2002) determined that Pacific sailfish caught on J style hooks were 21 times more likely to experience bleeding than those hooked with circle hooks. Atlantic bluefin tuna (*Thunnus thynnus*) also had reduced mortality rates when circle hooks (4%) were used instead of conventional J hooks (28%; Skomal et al. 2002). A similar study on white marlin (*Tetrapturus albidus*) revealed that circle hooks resulted in no mortality, but J hooks resulted in 35% mortality (Horodysky and Graves 2005). Domeier et al. (2003) used satellite archival tags to assess the effects of catch-and-release angling on striped marlin (*Tetrapturus audax*) using live bait. The authors compared circle hooks and J hooks and determined that circle hooks were equally effective in hooking and landing striped marlin and far less likely to cause bleeding or deep hooking. Also, non-offset and 5° offset circle hooks had very similar performances (unlike the findings of

Prince et al. 2002). Depth and temperature records allowed the authors to assess the fate of individual marlin following release. All mortality (26%) occurred within 5 days of release with injury being the best predictor of mortality; all of the fish that were bleeding from the gill cavity died, and 63% of deeply-hooked fish died. Data generated by these studies on circle hooks are currently being used to develop angling guidelines and legislation.

When targeting powerful and toothy marine pelagics, it is common for fish to escape capture by biting off the line. Borucinska et al. (2001) found that a retained fish hook in a single blue shark (*Prionace glauca*) led to peritonitis and pericarditis. This was the first documentation of a pathogenic affect of a retained fish hook. In a more exhaustive survey, Borucinska et al. (2002) found retained fishing hooks from previous capture events in 6 of 211 blue sharks off Long Island New York. The hooks were embedded within the esophagus or perforated the gastric wall and lacerated the liver. Collectively, tissue damage led to lesions including esophagitis, gastritis, hepatitis and proliferative peritonitis. Because circle hooks tend to be hooked more superficially (e.g., in jaw tissue), they may help to reduce the chance of internal damage.

The capture of large marine pelagics is stressful to the fish as the duration of the fight can be more than an hour. Wild kahawai (*Arripis trutta*) exhibited immediate increases in muscle and plasma lactate after angling while cortisol peaked about 1 to 2 hours later (Davidson et al. 1997). Lowe and Wells (1996) studied both primary and secondary stress responses to line capture in blue mao mao (*Scorpis violaceus*). They also noted increases in lactate and cortisol that correlated to the increase in time after angling and intensity of the exercise intensity. Marine pelagic fish including bluefin tuna, yellowfin tuna (*Thunnus albacares*), blue shark and white marlin are angled for long durations (up to 1 hour) and usually experience pronounced acedemia and high plasma lactate that increase with the duration of angling (Skomal and Chase 2002).

When marine pelagics are in poor condition, they tend to become targets of predators. Jolley and Irby (1979) noted that an Atlantic sailfish (*Istiophorus albicans*) released after angling, and which had an eye injury from the hook, was attacked by a shark within 6 hours after release. Horodysky and Graves (2005) determined that the mortality of white marlin in the western north Atlantic occurred between 10 minute and 64 hours after release. Pepperell and Davis (1999) evaluated the post-release behaviour of black marlin (*Makaira indica*) off the Great Barrier Reef in Australia using acoustic telemetry and observed that 5 of 6 tagged fish survived, but one was attacked and killed by a shark. Graves et al. (2002) found that at least 8 of 9 blue marlin tagged off Bermuda survived the monitoring period (assessed with satellite tags), but provided no information on whether or not the dead animal was eaten.

A

B

C

Fig. 7.2. Photographs illustrating key fishes discussed in the three case-studies including (a) a trophy Atlantic salmon being released by a fly angler in Norway (photo credit, Eva Thorstad), (b) a white marlin jumping during the angling event in the Atlantic Ocean (photo credit, Greg Skomal), and (c) largemouth bass tournament in Ontario, Canada

7.6.3 Black Bass

Black bass (*Micropterus* spp.), including the largemouth and smallmouth bass, represent some of the most popular recreational fish in North America. Black bass are also the frequent focus of competitive angling events, most of which are catch-and-release. Since the inception of catch-and-release angling in 1954, regulations mandating the release of black bass and numerous other fish species have increased (Barnhart 1989). Even voluntary catch-and-release angling has increased substantially (Quinn 1996). Due to their popularity and the frequency with which they are released, black bass are among the most well-studied species with respect to post-release survival. Here, we present a brief case-study on black bass, emphasising several unique characteristics of their fishery including competitive angling events and the consequences of catch-and-release.

The first unique characteristic of the black bass is that they are extremely popular targets of many competitive angling events in North America (Fig. 7.2C). A survey done by the American Fisheries Society's Competitive Fishing Committee over a decade ago estimated the number of inland and marine events to be 31,000 annually, of which 73% targeted black bass (Schramm et al. 1991a). Most of these events are catch-and-release but require that fish be held in live-wells for extended periods of time until the fish are brought to the weigh-in prior to being released (Holbrook 1975). Recently, Wilde (1998) conducted a meta-analysis of tournament-associated mortality of black bass and found that it was important to measure both initial and delayed mortality to determine total mortality accurately. Delayed (hours to weeks) mortality rates were highly variable within and among black bass species, 0–77% for largemouth bass and 0–47% for smallmouth bass.

The increasing popularity of competitive angling and concerns for its effects on released fish (Schramm et al. 1991b) have spurred recent research into improving competitive angling events to reduce post-release mortality fish and other sublethal effects. Suski et al. (2003) revealed that black bass were stressed (e.g., blood and white muscle disturbances) when sampled at tournament weigh-ins, suggesting an opportunity to improve such effects. Cooke et al. (2002b) and Suski et al. (2004) determined those components of a competitive angling event which are most stressful to the fish. When angled, fish exhibited alterations in blood and muscle biochemistry, but after confinement in a live-well, the fish had actually recovered. However, when these fish were exposed to weigh-in procedures, stress indicators again became elevated and in tournaments, fish are generally released immediately after the weigh-in. The authors showed that maintaining good live-well conditions are essential to enhance the survival of released fish.

As mentioned, the effects of retaining black bass in live-wells (Plumb et al. 1988; Hartley and Moring 1993; Steeger et al. 1994), as well as other tournament procedures may alter survival (Weathers and Newman 1997) or invoke sublethal stress (Cooke et al. 2002b; Suski et al. 2004). Water quality parameters like temperature and dissolved oxygen in live-wells have been consistently deemed as important influences on mortality (Carmichael et al. 1984). Meals and Miranda (1994) studied pre-release mortality at major fishing tournaments on Sardis Reservoir, Mississippi, and found that mortality increased with water temperature and the mean number of fish per boat. In contrast, Schramm et al. (1985) concluded that largemouth bass mortality during tournaments depended more on poor live-well management practices (e.g., not aerating frequently) by some anglers than on the density of fish in live-wells. Cooke et al. (2002b) found that the cardiac and locomotory activity of smallmouth bass was elevated when fish were first put into live-wells after angling. When only one fish was in the live-well, cardiac activity slowly decreased. However, when fish were held at greater densities (i.e., 2, 4 or 6 fish), cardiac variables remained high. Clearly, not only does high fish biomass and density lead to greater demands on available oxygen (as evidenced by increased cardiac output and heart rate), but it may also affect the activity levels of fish as they interact with each other. Interestingly, Furimsky et al. (2004) determined that smallmouth and largemouth bass had different hypoxia sensitivity providing an explanation for the greater tournament mortality rates observed for smallmouth bass.

Water conditioners and antibacterial treatments have been added to live-wells in an attempt to reduce the mortality and stress of fish during confinement. Research has provided contradictory conclusions as to the effects of water conditioners on black bass. Plumb et al. (1988) reported that adding a commercially-available water conditioner to live-wells enhanced survival, but Cooke et al. (2002b) determined that commercial live-well conditioner and salt delayed the recovery of smallmouth bass compared to fish that were held in unmodified water. Most research has suggested that antibiotics do not improve survival (Plumb et al. 1975; Seidensticker 1975; Schramm et al. 1987), although Welborn and Barkley (1974) and Archer and Loyacano (1975) reported improved survival rates when antibiotics were used. Hartley and Moring (1993) recommended continuous aeration in live-wells and this is consistent with the findings from other physiological analyses (e.g., Cooke et al. 2002b; Suski et al. 2004).

Since the reproductive period of a species is essential for generating offspring for subsequent populations, it is logical to do everything possible to minimise sublethal stress during this phase. Black bass are perhaps the best studied species with respect to the sublethal effects of catch-and-release angling. Black bass provide sole male parental care and evidence suggests that when nesting males are angled from the nest, even for a short period, the unprotected offspring are quickly consumed by predators (Philipp et al.

1997). Further, even if fish are released after angling, Cooke et al. (2001) determined that when nesting males return to the nest, they exhibit impairments in locomotory activity for over 24 hours. Suski et al. (2003) also found that angling reduced the level of care provided to offspring by the attending male. Ostrand et al. (2004) determined that largemouth bass exposed to a simulated fishing tournament immediately prior to the spawning period produced fewer and smaller offspring than control fish. In the aquaculture-based literature, there is overwhelming data suggesting that salmonids exposed to acute and chronic stressors exhibit endocrine alterations that depress fitness (Campbell et al. 1992). Similar hormonal changes have been shown to occur in largemouth bass and walleye following bouts of angling (Suski et al. 2003), but the extent to which these hormonal changes can affect fitness have yet to be explored. At other times of the year, it is less clear if such effects on fitness occur. Pope and Wilde (2004) used growth as an indicator of fitness and found no differences among angled fish and controls. Conversely, Siepker (2004) found that simulated tournaments led to reduced food intake by black bass. Bioenergetic simulations suggest that this would result in long-term reductions in growth which would be contrary to most fisheries management objectives.

In some states in the north of the United States and several Canadian provinces, seasonal closures are used to restrict angling and/or the harvest of black bass during their reproductive period (Quinn 1993). However, in some jurisdictions, catch-and-release angling for nesting bass is permitted. Compliance with such regulations has been observed to be minimal in many areas (Schneider et al. 1991; Kubacki 1992; Philipp et al. 1997), probably because anglers often assume that as long as the fish are released, they will return to the nest and raise a successful brood.

7.7 Summary and Synthesis

Recreational fisheries share four important characteristics with commercial fisheries: (i) fish are harvested and removed from the population; (ii) non-targeted species and sizes of fishes are captured and subsequently discarded, of which varying proportions of fish survive; (iii) the gears and fishing practices used by fishers have a substantial influence on the nature and magnitude of such survival; and (iv) the interests of all stakeholders are best served by a high survival rate among released fishes, although this must be considered within the context of the economic and social costs of various release practices and/or regulations. Simply put, both commercial and recreational fisheries seek to maximise economic, social and biological goals. There are, however, fundamental differences between recreational and commercial fisheries. In particular, the most important goal of commercial fisheries is to maximise economic returns, whereas in recreational fisheries, the most important goal generally is to maximise social, or psychological, returns. This simple difference has profound implications for how these fisheries are managed and how they are scientifically investigated.

Given the value of commercial fishes and the economic gains derived from their harvest, it is relatively easy for management agencies to determine fees and regulations governing the harvest of commercially-important species. In the case of recreational fisheries, however, managers are reluctant to disaffect anglers, because there is no latent source of participants. Therefore, recreational fishery managers, particularly in fresh waters, historically have been hesitant to restrict angling gears and behaviours. Instead, they have relied on the slow, voluntary adoption of improved gears and techniques among anglers.

In the extreme, this approach can fail as is best illustrated by competitive fishing events for black bass in the United States. Wilde (1998) reviewed studies of the mortality of fishes caught and released in black bass tournaments over the 30-year period between 1965–1995. Few estimates of mortality were available prior to 1975, but he found no change in the initial (or total) mortality of released fishes from the 1980s and the 1990s. However, in a subsequent study, Wilde et al. (2002) reported that in tournaments conducted by the Bass Anglers Sportsman Society (B.A.S.S.), initial mortality had shown a dramatic decrease. In the case of B.A.S.S. tournaments, where a direct economic value is derived from the recreational fishery and where there is a real desire to minimise effects of by-catch, adoption of various handling improvements was rapid and effective. In contrast, in the case of the general recreational fishery, in which fishery managers have suggested the possibility for improvement, none was observed. Recent efforts have attempted to develop a general understanding of catch-and-release that can be broadly applied to most species (Cooke and Suski 2005; Box 3).

The second obvious difference between commercial and recreational fisheries is that, in the latter, there is an incentive for, and indeed often a high incidence of, voluntary release of harvestable fish. This difference may not alter how we regulate fisheries, or how we minimise effects of a fishery, but it does affect the need for leadership by management agencies. In many recreational fisheries, anglers have often assumed the leadership role, by default, and directly affect fisheries by their individual decisions to keep or release fish. Management agencies have often adopted a role of setting fishery regulations that have been shown to have little direct effect on fishery characteristics (e.g., Wilde 1997).

Box 3: Proposed general strategies for minimising the effects of catch-and-release angling

In a recent paper, Cooke and Suski (2005) explored the need for developing species-specific guidelines for catch-and-release angling. They reasoned that there were some generalities that could be derived from existing studies that could be broadly applied to most species. However, they also cautioned that the diversity in the function and form of fish, and the techniques used by anglers for different species, requires some level of specialised guidelines. In the coming years, we suggest that there will be a greater need for species-specific guidelines to reduce mortality and sublethal disturbances further. Until then, Cooke and Suski (2005) provided five generalisations based on research conducted to date on catch-and-release that should be applicable to virtually any catch-and-release fishery. These generalisations should reduce the application of inappropriate data from one species to another and include: (i) the duration of the angling event increases the physiological disturbance; (ii) air exposure is harmful to fish and should be minimised; (iii) excessive water temperatures magnify the level of disturbance and angling should be avoided at those temperatures; (iv) barbless hooks and artificial lures or flies can greatly reduce handling time, hooking injuries, and the likelihood of mortality; and (v) angling immediately prior to, or during the fish's reproductive period can affect fitness and should be avoided.

Beyond these five generalisations, there are few others that can be broadly applied to catch-and-release fisheries. Data in support of each of these generalisations is presented in this review and in Cooke and Suski (2005).

Despite some fundamental differences (e.g., in why fish were released), Cooke and Cowx (2006) concluded that by-catch/discard mortality issues were similar in both the recreational and commercial fisheries sectors. Our synthesis reveals that there are a number of changes that can be made with respect to gear and practices that could benefit recreational fishes and these same opportunities also exist in the commercial sector. Indeed, many of the stresses affecting fish that are associated with recreational and commercial fisheries are identical, such as handling and air exposure (Alverson 1998; Davis 2002; Cooke and Suski 2005). Because both sectors have the common goal of returning more unwanted fish alive after capture and handling (Hall et al. 2000; Cooke and Suski 2005), Cooke and Cowx (2004) suggest that it is intuitively apparent that progress could be gained from common research programs. Indeed, efforts to solve by-catch problems in the recreational fisheries may be best served by pursuing catch-and-release research in a systematic fashion using the framework developed for commercial by-catch reduction by Kennelly and Broadhurst (2002; See Box 4 for a modified framework specific to recreational fisheries). The framework that we have modified for catch-and-release recognises the important role of the angler and the angling industry to ensure that the research is relevant to the recreational angling community.

Box 4: Framework for solving by-catch problems in the recreational fishery. Modified from Kennelly and Broadhurst (2002)

Identify and quantify the problem

- catch, harvest, by-catch, discard, effort and angler behaviour studies done in the field using creel surveys, angler diary programs, log books, etc.
- empirical mortality studies done via observation and experimentation

Identify species/fisheries of concern

- link fishing mortality with other population/community parameters to identify critical issues of concern
- determine required rates of reduction to ensure sustainability using modeling approaches

Develop modifications (in gear or practices) to reduce injury, mortality, and sublethal disturbances

- ideas based on scientists' input, the literature, etc.
- angler (or related stakeholders, e.g., tournament organisers, guides) ideas and experiences, knowledge of gear
- gear technology in recreational fisheries tends to be driven by consumer demand and potential profit rather than by government or non-industry scientists so industry, social/environmental conscience, marketing, sales and new product development are critical
- N.B. can bypass point 1 and 2 if issues are led by industry or anglers

Test modifications (in gear or practices) to reduce injury, mortality and sublethal disturbances

- scientists conducting field experiments
- industry-based experiments (field testing, including outdoor media opportunities)
- angler experiences involved in experiments to ensure their practical application

Implementation of appropriate modifications

- scientists and managers disseminating information (delivering presentations, writing scientific papers, outreach, internet postings)
- angler communication (sharing experiences, peer pressure, voluntary adoption)
- outdoor media, government outreach efforts, regulations, brochures, product marketing (note that sometimes gear or practices are broadly or inappropriately implemented and which can be driven by misinformation)

Catch-and-release recreational angling has become very popular as a conservation strategy among anglers and as a tool for fishery management in a diverse array of fisheries. Implicit in catch-and-release angling strategies, is however, the assumption that released fish experience low mortality and minimal sublethal effects. Despite the importance of these premises, research on this topic has mostly focused on a relatively small number of popular North American sportfish species, with negligible efforts directed towards understanding catch-and-release angling effects on other species, especially in developing countries. Clearly, there is a need to conduct additional research on several key topics in this field as outlined in Box 5. The sustainability of recreational fisheries in the future will largely depend on effective catch-and-release angling and it is our hope that catch-and-release research will focus not only on minimising sublethal and fitness-related disturbances, but also on facilitating or enhancing recovery (See Box 5). Only when constituents are provided with access to reliable information on how to properly execute catch-and-release angling while minimising lethal and sublethal effects, can we hope to manage sustainable recreational fisheries in the long-term.

The studies reviewed in this chapter demonstrate that a diversity of factors influence survival and the subsequent well-being and performance of fish caught and released by recreational anglers. These factors are well known, having been rather conclusively documented in a general form by Muoneke and Childress (1994) and in subsequent efforts. It is apparent, however, that except among highly-specialised or invested anglers, adoption of these improvements by the general angling public has been poor. In the short term, this affects fishing quality and, in the long term, it may affect whether or not we fish. It is time for all scientists, managers, and participants in these fisheries, to come together and face an unpopular challenge – we have the knowledge and technology necessary to reduce the effects of discarding, but it is yet to be determined whether we will use them to alter the way recreational fisheries are conducted.

Box 5: Research Agenda for Recreational Fisheries Release Issues

Although there is now a substantial background of research associated with catch-and-release angling and the reduction of release mortality and sublethal effects, most of this research tends to focus on a few popular species. In fact, Cooke and Suski (2005) suggested that there are only five species of fish for which we have a reasonable understanding of catch-and-release angling effects, all of which are freshwater (largemouth bass, *Micropterus salmoides*; walleye, *Stizostedion vitreum*) or anadromous (rainbow trout, *Oncorhynchus mykiss*; striped bass, *Morone saxatilis*; Atlantic salmon, *Salmo salar*). Indeed, these species are some of the most popular and heavily managed fish in the world. However, we contend that there is still much research to be done as the data from these species are obviously not representative of the vast diversity of morphologies, life-histories, physiologies, habitats, etc. associated with fish that are subjected to recreational capture and release. Below we briefly outline the key research questions that we believe need to be addressed if we are to understand and minimize the effects of recreational angling on released fish.

Construct baseline information on blood and muscle biochemistry and determine how these parameters are affected by angling for a variety of marine and freshwater species

There are few studies (see Thorstad et al. 2003; Suski et al. 2003) that evaluate the baseline and post-angling blood and muscle biochemistry profiles of recreationally important fish. Factors worthy of initial investigation include the effects of gear type, duration of angling event and water temperature.

Conduct controlled experiments to document the disturbance and recovery trends of blood and muscle biochemistry, hormones and the cardio-respiratory system

Controlled laboratory experiments can be used to manipulate factors such as the duration of air exposure, degree of exhaustion and water temperature to determine how these factors may contribute to sublethal disturbances or mortality, and how they alter recovery duration. Such experiments would most likely involve cannulation to collect serial plasma samples or cardiovascular monitoring devices to record cardio-respiratory activity. Such research is essential if we are to establish time-course recovery profiles for angled fish.

Evaluate the fate and behaviour of released fish at multiple temporal and spatial scales

When a fish is captured and released, its behaviour is almost certainly affected. What does this mean to short- and long-term survival? Some species are susceptible to post-release predation and mortality, whereas others survive with negligible negative effects. Researchers must apply techniques that enable them to evaluate the mechanisms associated with different outcomes (i.e., what are the physiological and behavioural correlates of those fish species that tend to die after release).

Box 5. (cont.)

Assess the effects of different strategies for facilitating the recovery of angled fish

There has been recent interest in trying to develop strategies that actually facilitate the recovery of commercial by-catch and caught-and-released fish. It would be useful to know if short-term retention in live-well devices could provide captured fish adequate time to recover such that they would be able to evade predators upon release.

Evaluate the performance of novel hook types and fishing techniques in the context of their potential to reduce mortality or injury and other sublethal effects

Recent advances in terminal tackle show promise for reducing injury and mortality of released fish. New tackle developed by anglers, industry and scientists will need to be evaluated for their potential conservation benefits.

Consider catch-and-release angling from an animal welfare perspective

Much research in aquaculture has recently focused on an assessment of welfare correlates. There is a need for similar research activities in the recreational fishing sector. In reality, the concepts associated with considering the welfare of angled fish are identical to those associated with ensuring that fish are released in the best possible condition (See Cooke and Sneddon – in press).

Assess the sublethal effects of angling-related behaviour on growth and other fitness-related variables

Growth and other fitness-related indices can be affected by catch-and-release angling either directly through reduced food intake or indirectly through sublethal acute or chronic stress (See Cooke et al. 2002a). There is an important need for research that evaluates how different angling-related stressors affect factors such as the quality and quantity of gametes, reproductive behaviour, viability of offspring, etc. (See Cooke et al. 2002a for comprehensive list of possible fitness alterations).

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