AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS

Aquatic Conserv: Mar. Freshw. Ecosyst. **14**: 299–326 (2004)

DOI: 10.1002/aqc.614

CASE STUDIES AND REVIEWS

Are circle hooks an effective tool for conserving marine and freshwater recreational catch-and-release fisheries?

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ABSTRACT

1. Circle hooks have rapidly become popular among recreational anglers, based largely on the assumption that their use aids in the conservation of fisheries resources by reducing gut hooking, and hence mortality. In addition, circle hooks are intended to facilitate jaw hooking. Unfortunately, these assumptions have been perpetuated by anecdotal reports with very little rigorous scientific information to support these assertions.

2. A number of recently published, forthcoming, and grey literature reports provide an opportunity to review briefly and synthesize research conducted on circle hooks. We surveyed literature databases and also used questionnaires to solicit information from unpublished or in-progress circle hook research.

3. Although among studies the results have been quite disparate, overall the mortality rates were consistently lower for circle hooks than J-style hooks. In addition, circle hooks were more frequently hooked in the jaw, and less frequently hooked in the gut than conventional hook types. There is no doubt that in some marine fisheries, such as tuna, billfish, and striped bass, capture efficiency remains high and injury and mortality rates are drastically reduced. However, in other species (e.g. bluegill), injury can actually be more severe from circle hooks relative to some other hook types. In other species, such as largemouth bass, circle hooks have minimal conservation benefit, but have reduced capture efficiency relative to conventional hook designs.

4. 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 the use of circle hooks as a panacea for all fish and fisheries. Instead, we recommend that management agencies focus on recommending circle hooks only for instances for which appropriate scientific data exist.

5. 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. We encourage tackle manufacturers to continue to develop new hook designs that have the potential to provide conservation benefit to caught and released fish. This paper provides direction to management

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Received 14 April 2003
Accepted 12 October 2003

agencies and outdoor media for disseminating responsible information to anglers regarding the application of circle hooks for conserving fisheries resources.

KEY WORDS: circle hooks; gear type; gear efficiency; hooking mortality; conservation; catch and release; recreational fisheries

INTRODUCTION

A growing interest in catch-and-release recreational angling has lead to gear developments intended to reduce injury and mortality of fish that are released (Muoneke and Childress, 1994). Circle hooks have gained notoriety in recent years for their apparent conservation benefits relative to conventional J-style hooks (e.g. Montrey, 1999), and the use of circle hooks is now encouraged by outdoor media, tackle manufacturers, resource management agencies, and conservation organizations. In addition, circle hooks are legislatively mandated for some specialized fisheries. However, there have been few scientific studies that provide data to justify the widespread adoption of this terminal tackle. The research that does exist seems to draw disparate conclusions regarding the effectiveness of circle hooks at both hooking and capturing fish, and reducing injury and mortality.

This paper endeavours to define circle hooks, describe how they function, and to assess their role objectively in conservation and fisheries management. The focus of this paper is on recreational catch-and-release angling but will include information from commercial fisheries where pertinent. This synthesis of existing, forthcoming and grey literature is provided to determine whether circle hooks are effective tools for the conservation of marine and freshwater fish. Furthermore, an integration of this information with management recommendations and key research areas is provided. The conclusions from the synthesis are distilled down to a series of key points that require dissemination to fisheries managers, anglers, guides, outdoor media, and tackle manufacturers.

What is a circle hook?

The most obvious difference between circle hooks (Figure 1(a) and (b)) and a conventional 'J'-style hook (Figure 1(c)) is that, with a circle hook, the point of the hook is generally oriented to be perpendicular to the shank, whereas in J-style hooks the point is generally parallel to the shank (Figure 1(c)). In some circle hooks, the point is actually pointed down towards the bend. Furthermore, the entire hook is rounded and the shank is shortened lending to the name circle hook. This generic description of circle hooks does not account for the large variation in actual design among and within different manufacturers' product lines. Circle hooks are available from most major hook manufacturers and have been created in many different sizes and design specifications (i.e. degree of point off-set, gauge of wire). Although most major hook

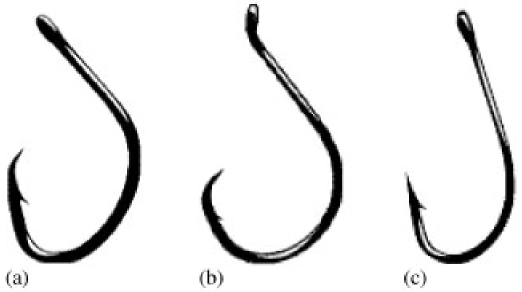

Figure 1. Schematic of two circle hook designs (a,b) and a conventional J-style hook (c).

manufacturers are now producing circle hooks for retail, some anglers fashion their own circle hooks by bending conventional hooks in an effort to mimic commercially available hooks. This lack of consistent terminology and design has led to legislative and enforcement challenges, as discussed later.

This hook style is not new, but actually has been in existence for hundreds of years. Excavations of graves from pre-Columbian native peoples in Latin America uncovered hooks that resemble modern circle hooks made from seashells. Similar designs using shell and bone have also been traced back to Polynesians (Johannes, 1981). Early Japanese fishers tied pieces of reindeer horn together in the shape of a circle hook, and a similar design has been found from Easter Island (Moore, 2001). North Pacific indigenous people have also used hooks that fished similarly to modern circle hooks (Stewart, 1977).

Some have argued that the configuration of the circle hook type design promoted hooking as fish tried to expel bait they could not swallow (Stewart, 1977). Johannes (1981), however, proposed a mechanical explanation for circle hook effectiveness based upon 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 (Figure 2). The point of the hook then catches on flesh at the jaw and pivots outwards as the amount of applied pressure steadily increases. Once tension exceeds a threshold, the hook pulls over the jaw and rotates as the fish moves or angler sets the hook. The design of the hook prevents the hook from backing out on its own and should hold a fish even under slack line conditions (Johannes, 1981; Figure 2).

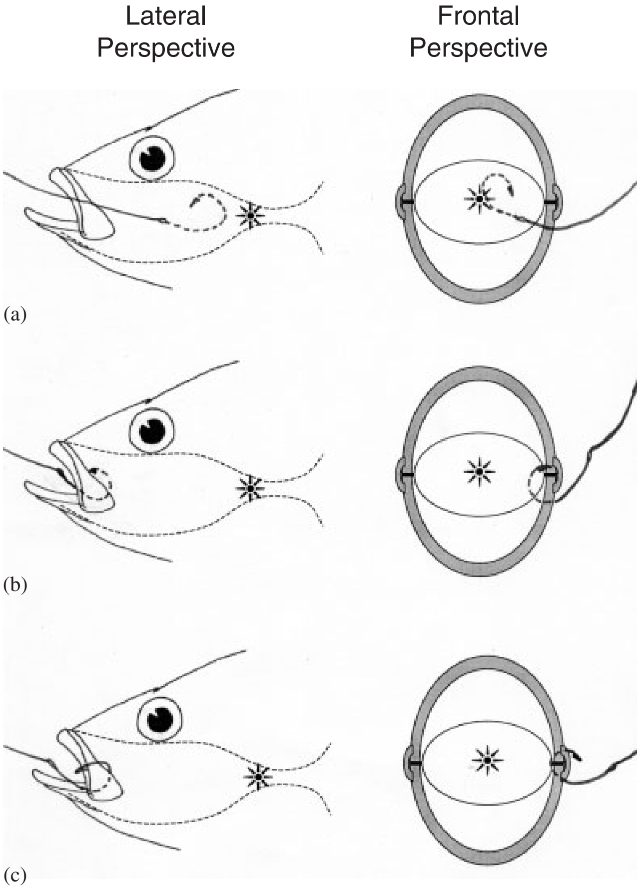

Figure 2. Schematic of circle hook function when pressure is applied to the line (both lateral and frontal views).

For circle hooks to function effectively, fishers must modify their angling technique. Since circle hooks are used almost exclusively 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 then the hook either will not capture the fish at all or it is more likely to hook fish in locations that are injurious.

Prior to becoming popular with recreational anglers (in the 1990s), circle hooks were used extensively in commercial marine longline and freshwater trotline fisheries (e.g. McEachron *et al.*, 1985; Woll *et al.*, 2001). Their popularity in these commercial fisheries is due to the higher retention rate of fish upon hookup (Bjordal, 1988) and, secondarily, reduced bycatch mortality (Trumble *et al.*, 2002).

The increase in attention to circle hooks in recreational fisheries is evidenced by the recent increased wide coverage in the outdoor media and the scientific community. At the American Fisheries Society Catch-and-Release in Marine Fisheries Conference (December of 1999 in Virginia Beach), circle hooks were a focal point of research interest for hook manufacturers and some marine fisheries scientists. But, despite the strong consensus that circle hooks likely would play an important role in future fisheries conservation, there was a surprising paucity of literature supporting this notion. The largest body of circle hook research has appeared in a recently published symposium proceedings (Lucy and Studholme, 2002). There have also been many articles published by outdoor media touting circle hooks as effective tools for conserving fish. These articles have indicated the benefits of circle hooks in locations that include North America (Stange, 1999; Manns, 2002), Central/South America (Fogt, 1999), Africa (Bursik, 1999; Van Biljon, 1999), and Australia (Bowermann, 1984). In addition, numerous government natural resource agencies have produced educational material on catch-and-release angling that encourages the use of circle hooks in jurisdictions around the world (e.g. New South Wales Fisheries Unit, Australia; Maryland Department of Natural Resources, USA; Florida Sea Grant, USA (Sea Grant, 2002); Fisheries and Oceans, Canada). Conservation and sportfishing advocacy organizations have also developed resource materials that encourage circle hook use (e.g. American Sportfishing Association (Montrey, 1999), International Game Fish Association (Choate, 1999), the Billfish Foundation), and both national and international fisheries management organizations dealing with trans-jurisdictional issues for migratory fish species have been involved in promoting the use of circle hooks (e.g. Atlantic States Marine Fisheries Commission; International Commission for the Conservation of Atlantic Tunas).

Supposed benefits

As with any product that is marketed by commercial businesses, there are a number of positive claims that are associated with circle hooks. Some of these benefits have also been proposed by anglers, outdoor media, and management agencies. Here, we briefly highlight the apparent benefits of these hooks derived from collective anecdotal reports before examining the scientific literature to evaluate these claims. The most frequent claims include:

1. Fish are frequently hooked in the jaw, facilitating hook removal.
2. Reduced gut hooking, resulting in reduced mortality.
3. Higher catch rates.
4. The hook sets itself, and thus is good for inexperienced anglers and deeper waters.
5. Fewer snags on debris.
6. Safer for anglers.

Of these six claims, this review will focus on those that are relevant to fish conservation, specifically numbers 1, 2 and 3. The first claim deals with jaw hooking rates. Circle hooks are intended to hook on the exposed edge of a fish's mouth, such as the jaw or maxillary. This superficial hooking location should lead to a reduction in handling time, less physical injury, and a concomitant decrease in sublethal physiological disturbances that result from fish being caught and released. The second claim is related and deals with reduced gut hooking. Although bait is often ingested deeply by fish, when a circle hook is set, the hook moves towards the anterior portion of the fish, avoiding the oesophagus and gut, and instead catching the jaw region. Gut and oesophageal hooking are known to increase greatly the risk of bleeding and damage to vital tissues (e.g. heart), and thus increased mortality (Pelzman, 1978; Muoneke and Childress, 1994). The final claim of relevance to fisheries conservation concerns point 3 — hooking and landing rates. To gain acceptance among anglers, and in particular guides and charter captains that depend on the capture of fish for their livelihood, there must be some indication that circle hooks will perform at least as well as conventional hook types (Jordan, 1999). Thus, although not directly related to conservation, knowledge of hooking and catch rates is essential for supporting management actions and recommendations.

METHODS

To evaluate these claims, we conducted a meta-analysis of existing and forthcoming literature that involved the use of circle hooks. We located published research using the library article databases *Fish and Fisheries Worldwide* (coverage 1974–March 2003), *Aquatic Sciences and Fisheries Abstracts A* (1978–Jan 2003), and *Web of Science* (1990–Jan 2003). We also searched *Dissertation Abstracts* (1990–Nov 2002) and *Conference Abstracts* (1990–Dec 2002). We used the common search string term ‘circle hook*’ to locate articles. We also searched the *International Game Fish Association* database of outdoor media (1988–Jan 2003) for popular press articles on circle hooks. Web-based searches were also conducted using the search engine *Google*. When we located a published paper, we obtained the source and contacted authors to determine whether they were involved in any additional circle hook research. We also used these contacts to locate other individuals working in the field. Individuals who were engaged in circle hook research were sent an electronic questionnaire asking for basic information such as the species of interest, objectives of the study, types of hook, and summary information regarding the findings. Because of the rapidly expanding research base, this method of contact was important for incorporating data that are currently not available to researchers, managers, or anglers.

Since the focus of this research was on catch-and-release angling, we excluded studies dealing with commercial bycatch reduction. However, where appropriate, we comment on commercial bycatch issues later in the discussion. By combining both published research and questionnaires, we generated a tabular database from which we extracted summary information. For this synthesis, we considered each individual species examined with regard to circle hook performance as an individual study. For example, if a single researcher examined two species within a single published study (e.g. Cooke *et al*., 2003c) then, for this synthesis, that study would we considered as two studies with independent findings. This approach is common for meta-analysis research (Wolf, 1986). In several instances, researchers included clearly different methodologies within the same study (e.g. empirical assessment of hooking mortality versus logbook records). These distinct components were also treated independently (Wolf, 1986). For summarization purposes, it was not sensible to present grouped results for multiple species together. Given that fisheries management plans dealing with catch-and-release angling are usually focused on the species level, this was considered to be the appropriate means of determining what constituted an individual study. This approach has also been used elsewhere for catch-and-release syntheses (Muoneke and Childress, 1994; Cooke *et al*., 2002b) and meta-analyses (Taylor and White, 1992). For analyses, we compared circle hooks with J-style hooks, and we tested the null hypothesis that the performance of circle hooks and J-style hooks was equal. The variables that we examined included hooking mortality, hooking depth and capture efficiency. Statistical analyses focused on assessing categorical trends in circle hook performance using contingency table analyses. To assess trends in hooking mortality, we used a paired *t*-test. These statistical analyses are specifically recommended for syntheses and meta-analyses (Hedges and Olkin, 1985).

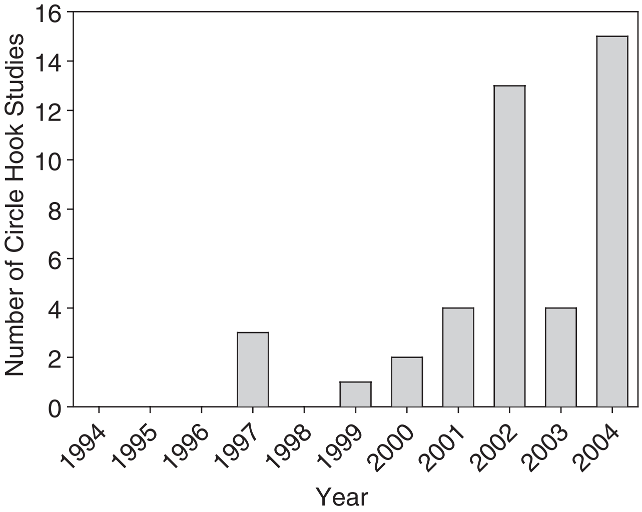

Figure 3. Progression of circle hook research evidenced by publication rate. Publications indicated as 2004 are those that are currently in various stages of collection, preparation, and review.

ANALYSIS AND DISCUSSION

Overview

An earlier review on the topic of hooking mortality in recreational fisheries (i.e. Muoneke and Childress, 1994) did not assess the role of hook design beyond barbed versus barbless and single versus treble hooks. The only comments on circle hooks dealt with comparative efficiency of circle hooks on trotlines (e.g. McEachron *et al.*, 1985). One of the main reasons for the poor treatment of circle hooks in this earlier review was that there were no circle hook studies on catch-and-release recreational fisheries at the time of publication. The first catch-and-release circle hook study was published in 1997 (McNair, 1997). Since that time, there has been a rapid increase in circle hook research (Figure 3). Much of this research is novel and the results are not yet published. It is expected that the number of circle hook studies will continue to expand rapidly over the next several years as their effectiveness is assessed for different fish and fisheries.

Within the 43 circle hook studies in this review (Table 1), 25 different species were examined. At present, there has been a greater focus on marine recreational fisheries (65.1%, $N = 28$), but freshwater examples are becoming more common (34.9%, $N = 15$). This is somewhat atypical of catch-and-release studies, which tend to focus on freshwater fisheries (Cooke *et al.*, 2002a), and is likely a reflection of the strong connection between marine recreational fisheries and marine commercial fisheries. Striped bass[1] are the most studied species with respect to the efficacy of circle hooks. This is likely attributed to the large fishery off the eastern USA and the high rates of discard of sublegal-sized fish due to harvest regulations. For example, annual catch-and-release mortality estimates for striped bass in 2000 was 1.3 million fish, more than the number of fish landed in the commercial fishery that year (Moran, 2003). Investigators have attempted to use circle hooks as a means of reducing bycatch mortality for this species. Other research has been driven by smaller, diffuse fisheries of local or regional importance. 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 levels of hooking mortality using conventional hook types (See Muoneke and Childress (1994)).

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[1] Latin binomials for all species in this paper are listed in Appendix 1.

Table 1. Summary of circle hook performance relative to conventional hook types. Latin binomial terms for common names can be found in Appendix 1. Fish capture method describes the type of recreational angling. The response variables differed among studies and have been coded to permit inter-study comparisons: (SM) short-term mortality; (DM) delayed mortality; (MP) mortality estimates; (HL) anatomical hooking location; (HD) hooking depth; (TD) tissue and organ damage; (BL) degree of bleeding; (CE) capture efficiency; (SS) size selectivity; (ER) ease of hook removal; (gut) gut hooking; (jaw) jaw hooking; (RR) recapture rate; (RS) reproductive success; (GR) growth. The hook types are coded: (C) circle, (J) J style; (S) sproat; (W) widegap; (B) bait holder; (A) aberdeen; (O) octopus. Mortality rates are a composite of SM, DM, and MP. The performance of circle hooks is assessed relative to the conventional hook type for each response variable and assigned equal (=), reduced or lower (<), or increased or higher (>)

Species	Fish capture method	Response variables	Hook types	Performance of circle hooks	Mortality	Reference
White seabass	Casting	HL, G, DM	C, J	>jaw, <gut, <G, <HD	9.7% C, 10.2% J	Aalbers *et al.* (2003)
Red drum	Jigging/bottom	HD, SS, BL, SM, HL, ER, CE	C, J	<HD, =SS, <BL, >jaw, <gut, <CE, <ER	9% C, 3% J	Aguilar *et al.* (2002)
Smallmouth bass	Casting/bottom	RS, HD, ER, CE, SS, HL	C, J	<HD, =RS, =SS, >jaw	3% C, 6% J	Barthel and Cooke (unpublished data)
Red snapper	Jigging	RR	C, J	>RR		Burns (unpublished data)
Red grouper	Jigging	RR	C, J	>RR		Burns (unpublished data)
Gag	Jigging	RR	C, J	<RR		Burns (unpublished data)
Striped bass	Casting/bottom	HL, TD, CE, SM	C, J	<TD, >jaw, <gut, = CE	3% C, 15.5% J	Caruso (2000)
Pumpkinseed[a]	Bobber	CE, HD, HL, BL, SS, ER, SM	C, B, A, W	=HD, <CE, <gut, <BL, <ER	0% C, 0% J	Cooke *et al.* (2003c)
Rock bass[a]	Bobber	MP, HD, HE, SS, HL, BL	C, B, A, W	=SS, <HD, <CE, =BL, <gut, >jaw, >ER	0% C, 0% J	Cooke *et al.* (2003a)
Bluegill[a]	Bobber	CE, HD, HL, BL, SS, ER, SM	C, B, A, W	=SS, <jaw, =HD, =BL, <CE, <ER	0.2% C, 1.2% J	Cooke *et al.* (2003c)
Largemouth bass	Casting	CE, MP, HL, BL, TD, SS, ER, HD	C, O	<BL, <HD, <CE, =SS, =HL, <ER	5.1% C, 6.6% J	Cooke *et al.* (2003b)
Rainbow trout	Ice fishing	HD, HL	C, O	<HD, >jaw, <gut		Eisler (unpublished data)
Coho salmon	Trolling	HL, HD, ME	C, J	>jaw, <HD	14% C, 14% J	Grover (unpublished data)
Chinook salmon	Mooching	HD, SM	C, J	<HD,	31% C, 46% J	Grover *et al.* (2002)
Striped bass	Casting/bottom	HD, HL, BL, SS, HE	C, J	=HL, =SS, <HD, =BL, <HE		Hand (2001)
Rainbow trout[b]	Casting/bobber	HL, HD, SS, GR, BL	C, J	<gut, =BL, >GR, >jaw, =SS	0% C, 0% J	Jenkins (2003)
Walleye	Casting/bobber	SS, CE, HL	C, O	=SS, =CE, =gut, >jaw		Jones (unpublished data)
Striped bass	Casting/bottom	HD	C, J	<HD		Lockwood (unpublished data)
Striped bass	Casting/bottom	HD, SS, SM	C, J	<HD, =SS	0.8% C, 9.1% J	Lukacovic (1999)

(*continued over*)

Table 1. *continued*

Species	Fish capture method	Response variables	Hook types	Performance of circle hooks	Mortality	Reference
Striped bass	Casting/bottom	HD, SS, SM	C, J	<HD, =SS	1.9% C, 8.7% J	Lukacovic (2000)
Striped bass	Casting/bottom	HL, HD, CE	C, J	<HD, <CE, <gut		Lukacovic (2001)
Striped bass	Casting/bottom	HD, CE	C, J	<CE, <HD		Lukacovic (2002)
Bluefish	Bottom	CE	C, J	=CE		Lukacovic (2002)
Summer flounder	Bottom	CE	C, J	=CE		Lukacovic (2002)
Croakers	Bottom	CE	C, J	>CE		Lukacovic (2002)
Striped bass	Casting	HD, SS	C, J	=SS, <HD		Lukacovic and Uphoff (2002)
Summer flounder[a]	Casting	HL, SM, BL, HD	C, S, W	= gut, =BL, = HD	14% C, 14% J	Malchoff *et al.* (2002)
Coho salmon	Mooching/ trolling	SM	C, J		3% C, 24% J	McNair (1997)
Chinook salmon	Mooching/ trolling	SM	C, J		0% C, 15% J	McNair (1997)
Rainbow Trout	Fly	BL, HL, ER, CE, SS	C, J	<ER, =BL, <gut, >jaw, <CE, =SS		Meka (unpublished data)
Rainbow trout	Casting	HL, HD, TD, DM, CE	C, J	=TD, =gut, =jaw, HD, =CE	10.4% C, 19.0% J	Parmenter (2001)
Rainbow trout	Casting/bobber	HL, DM	C, J	<gut, >jaw	10.1% C, 15.9% J	Pecora (unpublished data)
Brown trout	Casting/bobber	HL, DM	C, J	<gut, >jaw	6.1% C, 10.0% J	Pecora (unpublished data)
Brook charr	Casting/bobber	HL, DM	C, J	<gut, >jaw	25.0% C, 23.8% J	Pecora (unpublished data)
Pacific sailfish	Trolling	CE, HL, BL, HD, CE	C, J	<BL, =CE, =CE, >jaw, <gut, <HD		Prince *et al.* (2002)
Pacific sailfish	Trolling	CE	C, J	>CE		Prince *et al.* (2002)
Blue marlin	Trolling	CE	C, J	=CE		Prince *et al.* (2002)
Atlantic bonito	Rod and reel	HL	C, J	>jaw		Skomal *et al.* (2002)
Atlantic bluefin tuna	Rod and reel	HL,TD, CE, ME	C, J	<TD, >jaw, =CE	4% C, 28% J	Skomal *et al.* (2002)
Bluegill	Fly fishing	CE, HD, SS	C, J	=BL, <CE, =SS	0% C, 0% J	Suski and Cooke (unpublished data)
Red drum	Casting	CE, HD, HL, ER, SM, BL, TD, SM	C, J	=CE, <HD, <gut, >jaw, <BL, <TD, >ER	3% C, 7% J	Thomas *et al.* (1997)
Silver perch	Casting	SS, CE, HD, SM	C, J	=SS, =CE, <HD	33.8% C, 35.3% J	Van der Walt and Faragher (in preparation)
Summer flounder	Bottom	HL, BL, TD, ER,	C, J	=HL, =BL, =TD, =ER, <gut		Zimmerman and Bochenek (2002)

[a] All non-circle hook data are combined for comparison with circle hooks.

[b] Hooks were all barbless, J-hooks were all left in when deep hooked, circle hooks removed, so mortality and bleeding based on author-provided estimates if hooks were not removed from circle hooks.

Incidence of hooking mortality

From a fisheries management perspective, one of the most important considerations in hook design is mortality level. 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). Hook type plays little role in physiological disturbance, other than when hook type influences the difficulty of hook removal, leading to increased air exposure (e.g. Cooke *et al.*, 2001), and this factor is discussed in a different section. 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. Exceptions were generally restricted to those species for which it was logistically and/or biologically impossible to hold individuals for prolonged periods to monitor mortality (e.g. billfish).

Mortality, arising both from direct assessment and from projections/estimations, ranged between 0 and 33.8% of fish caught for circle hooks, and 0 and 46% for J-style hooks. Our results, however, indicated that the use of circle hooks resulted in lower hooking mortality than with other hook types (paired t, $t = -3.58$, d.f. = 23, $P = 0.002$; Figure 4). Mortality was consistently higher for J-hook-caught fish in the majority of the studies that we examined. For example, in studies on red drum in Louisiana, hooking mortality rates were 3% for circle hooks and 7% for conventional hooks (Thomas *et al.*, 1997). Striped bass have also consistently shown reduced mortality rates when captured on circle hooks relative to other hook types in studies from Massachusetts (Caruso, 2000: 3% circle, 15.5% J), Maryland (Lukacovic, 1999: 0.8% circle, 9.1% J; Lukacovic, 2000: 1.9% circle, 8.7% J), and North Carolina (Hand, 2001: 5.9% circle, 18.2% J). Salmonids exhibited similar patterns, with coho salmon (McNair, 1997: 3% circle, 24% J) and chinook salmon (McNair, 1997: 0% circle, 15% J; Grover *et al.*, 2002: 31% circle, 46% J) having reduced hooking mortality rates when captured on circle hooks. Atlantic bluefin tuna also had reduced mortality rates when circle hooks (4%) were used instead of conventional J-hooks (28%; Skomal *et al.*, 2002).

There were also instances, however, where circle hooks had equal or higher mortality than other hooks. Cooke *et al.* (2003a) noted no mortality for rock bass captured using circle hooks or any of three other conventional hook designs (aberdeen, widegap, baitholder). Cooke *et al.* (2003c) also assessed mortality in bluegill and pumpkinseed and found that mortality was negligible for all hook types (circle, aberdeen, widegap, baitholder). No mortality was observed for pumpkinseed, and only 1.3% of captured bluegill died, spread evenly among the circle hooks and three other hooks types. Mortality rates were also similar for a study of largemouth bass in Illinois between fish captured on circle (5.1%) and conventional octopus

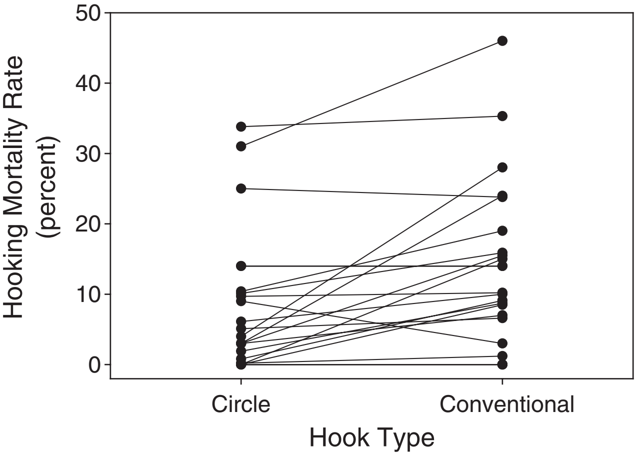

Figure 4. Comparative hooking mortality rates of circle-hook-and J-style-hook-captured fish from 24 different studies.

hooks (6.6%; Cooke *et al*., 2003b). In a study of summer flounder, Malchoff *et al*. (2002) reported that mortality was similar between circle (14%), widegap (16%), and sproat (12%) hooks.

A mark–recapture study is currently under way in Florida to estimate the mortality of gag, red grouper, and red snapper captured on circle hooks and J-hooks under field conditions (Burns, unpublished data). Although it is not possible to calculate estimates of mortality directly from these data, they can be used to infer mortality trends. Recapture rates were higher for J-hooked gag (7.7%) than circle-hooked gag (5.6%). Conversely, for red grouper (5.0% circle, 3.6% J) and red snapper (7.2% circle, 6.9% J), circle hook recapture rates were higher than J-hooks. In this instance, high recapture rates imply greater survival rates.

Collectively, the available data indicate that mortality rates of fish caught using circle hooks are generally lower than or equal to mortality rates of fish caught on other hook types. However, mortality rate estimates are often based upon initial or short-term mortality and may not be indicative of delayed and total mortality (Wilde, 1998). For that reason, it is also informative to examine other indicators of physical injury and well-being that could affect longer term survival and fitness.

Factors affecting mortality

There is no question that mortality rates of caught and released fish can vary widely, but what are the factors that contribute to mortality? To address this issue, studies must incorporate measures associated with, at minimum, injury and mortality, but ideally with other variables such as environmental conditions, ease of hook removal, and size of fish. Several of the studies conducted on circle hooks have drawn direct correlations between mortality and other factors.

Cooke *et al*. (2003b), for example, highlighted the importance of hook removal time and hooking location on mortality, as hooking location and ease of hook removal both influenced mortality in largemouth bass. Similarly, post-mortems conducted on striped bass indicated that mortalities from conventional hooks were often the result of damage to the heart, liver, gill arch, nephros, and intestines inflicted by the hook (Caruso, 2000). All of these anatomical sites require deep hooking, and the likelihood of similar injuries is reduced because of the frequent jaw hooking when circle hooks are used (Caruso, 2000). The depth of hooking was the only variable found to affect hooking mortality in a study of red drum (Aguilar *et al*., 2002). Those individuals that died had gross internal haemorrhaging; however, individual descriptions of post-mortems did not differentiate between fish captured on circle and J-hooks. Malchoff *et al*. (2002) determined that, for the summer flounder recreational fishery, wound location, bleeding, and environmental conditions (water temperature) were all significant predictors of mortality for all hook types, including circle hooks.

Collectively, these results illustrate the wide range of factors that may contribute to the mortality of angled fish. Hooking depth, anatomical hooking location, amount of bleeding, and ease of hook removal, were all identified as major contributors to mortality in different fisheries, and these factors may differ for circle and conventional-style hooks. Within the body of circle hook research, almost all studies have monitored some proxy for injury. Based on the premise that circle hooks are intended to minimize deep hooking and result in high rates of jaw hooking, these assessments are particularly critical. Each of these factors is discussed in detail below.

Hooking depth

Hooking depth has been identified as an important factor influencing mortality of angled fish. Hooking depth can be measured precisely and expressed as a relative hooking depth (RHD) (i.e. length corrected; see Dunmall *et al*. (2001)), or expressed more qualitatively using categorizations like ‘shallow’ or ‘deep’. In the current review, we determined that circle hooks were more likely to result in shallow hooking than J-style hooks ($X^2 = 66.91$, d.f. $= 2$, $P < 0.001$; Figure 5).

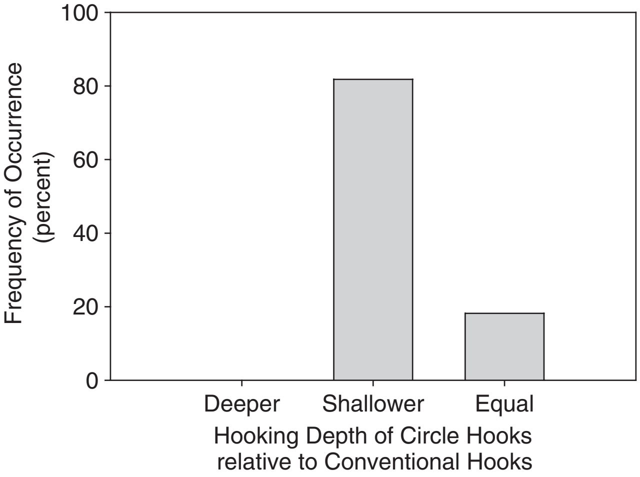

Figure 5. Distribution of hooking depths for circle hooks relative to J-style hooks from 22 studies.

Largemouth bass hooked on conventional octopus hooks were hooked more deeply than those captured on circle hooks (~ 0.09 RHD circle, ~ 0.11 RHD octopus; Cooke *et al.*, 2003b). For rock bass, circle hooks were less deeply hooked (0.04 RHD) than baitholder hooks (0.08 RHD), but similar to aberdeen (~ 0.05 RHD) and widegap hooks (~ 0.06 RHD; Cooke *et al.*, 2003a).

Skomal *et al.* (2002) collapsed anatomical hooking locations into two categorical depths (shallow or deep) and determined that hooking locations were significantly different for hook types. Circle hooks (96%) were routinely classified as 'shallow' whereas J-hooks were less likely to be classified as 'shallow' (66%; Skomal *et al.*, 2002). Similar to Skomal *et al.* (2002), Aguilar *et al.* (2002) pooled their hooking locations into 'shallow' and 'deep' and determined that J-hooks were far more likely to deep-hook fish than circle hooks (52.3% for J, 4.2% for circle). Lukacovic and Uphoff (2002) reported that fewer striped bass were deeply hooked on circle hooks (10.6%) than on J-style hooks (45.6%).

Anatomical hooking location

One common theme for much of the circle hook literature is the high rate of jaw hooking for circle hooks and the high variability of hooking locations for other hook types. Indeed, in our analysis, circle hooks were more likely to result in jaw hooking than J-style hooks ($X^2 = 100.00$, d.f. = 2, $P < 0.001$; Figure 6(a)). For example, in rock bass, jaw hooking rates were 76% for circle hooks; which was higher than the three other hook types examined in that study (Cooke *et al.*, 2003a). For largemouth bass, 56.8% of fish captured on circle hooks were hooked in the jaw, whereas only 40.3% were hooked in the jaw using conventional octopus hooks (Cooke *et al.*, 2003b). Aalbers *et al.* (2003) reported that white seabass caught using circle hooks were more frequently hooked in the jaw region (73%) than fish captured on J-hooks (41%). Aguilar *et al.* (2002) determined that red drum captured on circle hooks were hooked in the jaw more frequently (95.8%) than those fish captured on J-style hooks (45.6%). High rates of jaw hooking have also been observed for circle-hook-caught striped bass (Lukacovic, 1999; Caruso, 2000), summer flounder (Zimmerman and Bochenek, 2002), Atlantic bluefin tuna (Skomal *et al.*, 2002), and Pacific sailfish (Prince *et al.*, 2002).

Furthermore, the results of our meta-analysis revealed that circle hooks were less likely to gut hook fish than were J-style hooks ($X^2 = 69.41$, d.f. = 2, $P < 0.001$; Figure 6(b)). For example, in striped bass, only 1.6% of angled fish were hooked in the gut when using circle hooks, but 27.5% of fish were hooked in potentially lethal locations (gills, pharynx, and gut) when using J-hooks (Caruso, 2000). In a study of

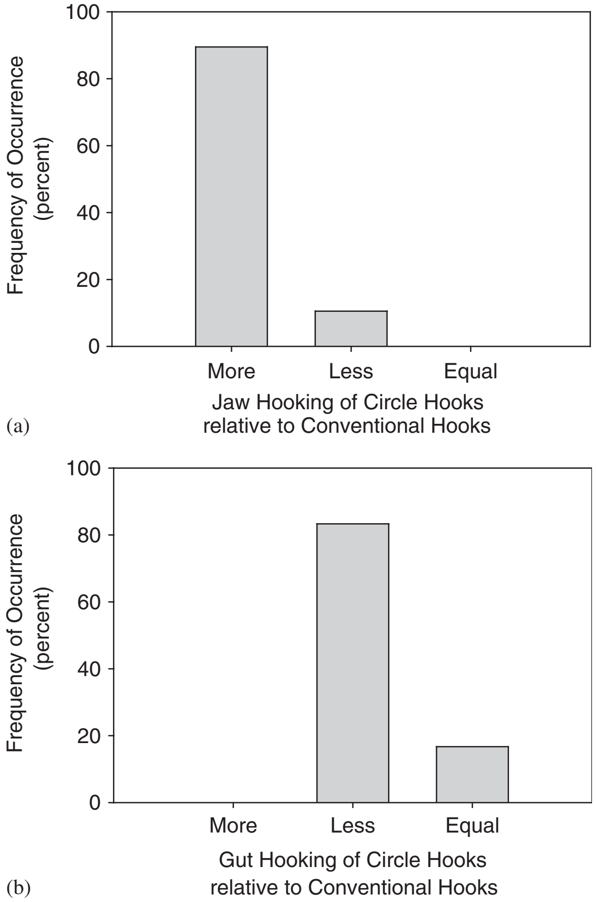

Figure 6. Frequency of jaw hooking (a) and gut hooking (b) for circle hooks relative to J-style hooks from 19 and 18 studies respectively.

largemouth bass, Cooke *et al.* (2003b) determined that conventional hooks (9.7%) resulted in nearly twice as many gullet-hooked fish as circle hooks (4.8%). Aguilar *et al.* (2002) found that few red drum (4.2%) captured using circle hooks were hooked in the gut, whereas almost half of all fish captured on J-hooks were hooked in the gut (48.9%).

The issue of eye damage associated with the use of circle hooks has been raised by several researchers (Grover *et al.*, 2002; Skomal *et al.*, 2002; Cooke *et al.*, 2003b,c), and this seems to be one of the largest drawbacks to using circle hooks for several reasons. Skomal *et al.* (2002), for example, noted that, when jaw hooked, the point and barb of circle hooks larger than 10/0 sometimes (36%) caused external tissue damage to Atlantic bluefin tuna, and in 8% of cases caused major damage to the eye socket, whereas only 2% of J-hooked fish had eye damage resulting from the hook. This eye damage can occur due to the hook piercing the eye orbit from inside the mouth, or from the hook piercing tissue adjacent to the eye but having the point of the hook end up being bent back toward the eye region. Additionally, when removing a circle hook that has violated the eye orbit, the short shank can limit the rotation of the hook, resulting in additional trauma (Grover *et al.*, 2002). Damage to the eye can result in bleeding and tissue damage, and may act as an entry point for bacteria. Furthermore, injury to the eye of a fish can result in immediate mortality or impaired vision, which could lead to reduction in foraging ability, predator avoidance, and hence reduced fitness and increased risk of delayed mortality. Finally, Cooke *et al.* (2003c) noted that circle hooks resulted in bluegill eye hooking rates of 22.8%, nearly twice as high as other hook designs, and concluded that the size of the hook relative to the size of the fish may be an important consideration for optimal circle hook performance (i.e. high capture efficiency, low rates of injury and mortality). The influence of size is discussed below.

Bleeding

Bleeding rates are generally evaluated by categorical analyses (e.g. none, little, severe). Several studies have determined that the degree of bleeding does not vary among hook types for a variety of species, including rock bass (Cooke *et al.*, 2003a) and striped bass (Hand, 2001). However, when the results of our meta-analysis were examined, overall bleeding rates did differ among hook types, with circle hooks being less likely to result in bleeding than J-style hooks ($X^2 = 10.89$, d.f. $= 2$, $P = 0.004$; Figure 7). In one such study, Cooke *et al.* (2003b) determined that largemouth bass caught using circle hooks had lower bleeding rates (15.2%) than conventional octopus hooks (25.4%). Prince *et al.* (2002) determined that Pacific sailfish captured on J-hooks were 21 times more likely to experience bleeding than those hooked with circle hooks. Conversely, however, summer flounder captured on circle hooks bled more (12.5%) than those captured on J-hooks (9.4%; Malchoff *et al.*, 2002).

For those studies that did observe bleeding, it was generally related to the anatomical location of the hook (e.g. striped bass; Hand, 2001). Deeply hooked fish frequently have higher rates of bleeding, and bleeding can also occur from hooking in the eye and gills. Skomal *et al.* (2002) noted that hook wounds to the palate, jaw, and body produced minor bleeding, compared with hook wounds in the pharynx or oesophagus, which resulted in severe bleeding. Oesophageal and pharyngeal hook wounds were more common for J-hooked fish than for circle-hooked fish resulting in excessive bleeding. Gut-hooked fish may bleed from damage to the cardiovascular system or organs, such as the liver.

Ease of hook removal

Only a few researchers have examined the role that hook type has on the ease of removal from angled fish. Overall, circle hooks were likely to be classified as more difficult to remove than were J-hooks ($X^2 = 73.96$, d.f. $= 2$, $P < 0.001$; Figure 8). In a study that did not use circle hooks, Cooke *et al.* (2001) compared barbed

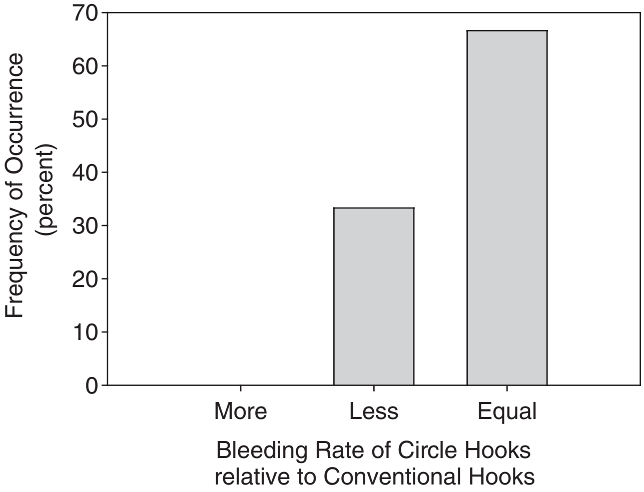

Figure 7. Distribution of bleeding fates for circle hooks relative to J-style hooks from 12 studies.

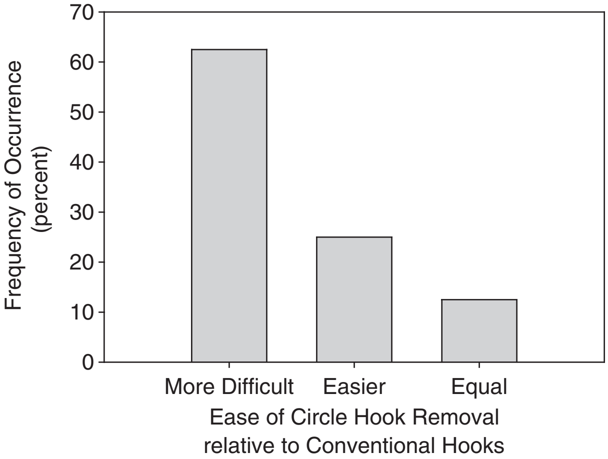

Figure 8. Distribution of ease of hook removal categories for circle hooks relative to J-style hooks from eight studies.

and barbless jigs baited with either an artificial lure or a minnow. These authors determined that the type of terminal tackle influenced both hooking location and hooking depth, and thus the ease of hook removal. The variation in hook removal time translated to longer air exposure and increased physiological disturbance (Cooke *et al.*, 2001), highlighting the importance of ease of hook removal. In a circle hook study, Cooke *et al.* (2003a) determined that the ease of hook removal did vary for rock bass, depending upon hook type. In that study, it was reported that circle hooks were the easiest to remove and were only categorized as 'difficult' for one fish. Other hook types resulted in between 14 and 29% of fish being categorized as difficult to remove. Similarly, for largemouth bass (Cooke *et al.*, 2003b), conventional hooks were determined to be 'difficult' to remove twice as frequently as circle hooks (19.4% conventional, 8.9% circle) and were determined to be 'not possible' to remove three times as frequently as circle hooks (9.7% conventional, 3.2% circle). Malchoff *et al.* (2002) indicated that mates on party boats found that severely offset circle hooks (15°) were more difficult to remove than sproat or wide-gap hooks. In one instance, ease of hook removal was similar between hook types (i.e. summer flounder; Zimmerman and Bochenek, 2002).

Circle hooks and other metrics

In addition to the standard assessments of how circle hooks affect injury and mortality, several authors have examined sublethal consequences of circle hooks on growth (Aalbers *et al.*, 2003) and reproduction (Barthel and Cooke, unpublished data). Aalbers *et al.* (2003) determined that 90-day growth rates differed between white seabass captured on different hook types and controls. Specifically, the growth rate of circle-hooked fish was higher than J-type hooks and controls. The reasons for these results were unclear, but do not represent a causal relationship between capture on circle hooks and enhanced growth. In a preliminary study, Barthel and Cooke (unpublished data) determined that reproductive success (measured by the successful production of free-swimming fry) of smallmouth bass did not differ between fish captured on circle hooks and J-style hooks. Additional studies on these factors (i.e. growth and reproduction) will be useful in assessing the influence of hook design on fitness. At present, there are insufficient data on growth and fitness implications of catch-and-release in general, let alone for circle hooks.

Hooking, landing, and capture efficiency

As indicated earlier, to gain acceptance among anglers, guides, and charter captains, the performance of circle hooks must at least match that of conventional hooks. The two elements of performance that must be

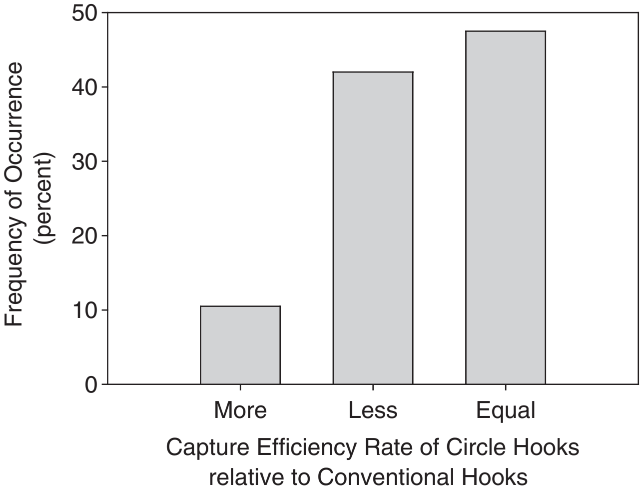

Figure 9. Distribution of capture efficiencies for circle hooks relative to J-style hooks from 18 studies.

assessed are the number of fish hooked (hooking efficiency) and the number of hooked fish that are landed (landing efficiency). Collectively, these two measures contribute to overall capture efficiency. Measures of hooking and landing efficiency lack standardization and, as such, have been estimated as ratios, proportions, and catch-effort statistics. Overall, the results of our meta-analysis revealed that circle hooks were considered to have significantly lower capture efficiency than J-style hooks ($X^2 = 27.56$, d.f. = 2, $P < 0.001$; Figure 9). For example, Cooke *et al.* (2003b) noted that for largemouth bass the capture efficiency for circle hooks was half that of conventional octopus hooks. Similarly, Aguilar *et al.* (2002) noted that significantly fewer red drum were captured by circle hooks than J-hooks when corrected for effort. There are also documented instances of improved capture efficiency with circle hooks relative to J-hooks. Using logbook data from charter captains, Prince *et al.* (2002) compared capture rates for Pacific sailfish and blue marlin hooked using circle and J-hooks. Catch per unit effort (CPUE) rates were equal among hook types for blue marlin (circle: 0.174 CPUE; J: 0.167 CPUE), but they were significantly higher for Pacific sailfish captured on circle hooks (10.25 CPUE) than those captured on J-hooks (6.34 CPUE).

There is substantial inter-study variation in hooking, landing, and capture efficiency, and, in some cases, a particular hook type may have low hooking efficiency but may not have low capture efficiency. For example, Prince *et al.* (2002) reported that the hooking percentages (fish hooked/fish bite) of Pacific sailfish doubled when circle hooks were used rather than J-hooks. Once hooked, however, there were no differences in the capture rate (fish landed/fish hooked) of sailfish when the two hook types were compared. For bluefin tuna, 13 fish (out of 69) were missed using circle hooks, whereas only eight (out of 73) were not hooked by J-hooks (Skomal *et al.*, 2002). Conversely, five fish hooked were lost on circle hooks, and 15 were lost on J-hooks. J-style hooks tended to hook fish more readily, but, when hooked, circle-hooked fish were less likely to escape. Despite these differences, overall, Skomal *et al.* (2002) noted that 68% of Atlantic bluefish tuna fish captured on J-hooks were landed compared with 74% on circle hooks.

Size selectivity and circle hook size

Among conventional hook types, the relationship between hook size, fish size, and hook performance varies widely among studies (Muoneke and Childress, 1994), perhaps due to interspecific variation, prompting Muoneke and Childress (1994) to conclude that further research into the relationships between different hook types, sizes of hook, and sizes of fish was warranted. However, it appears that hook size may be more

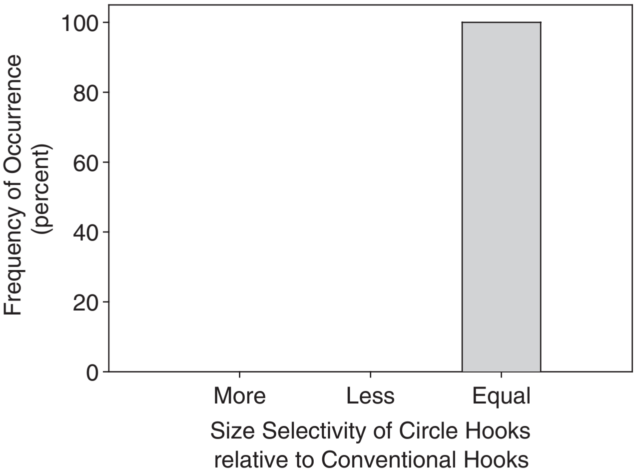

Figure 10. Distribution of size selectivity categories for circle hooks relative to J-style hooks from 14 studies.

important for anglers fishing with circle hooks than with 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 when one considers that the optimal hook size for the targeted species and size of fish may cause substantial injury in smaller or larger fish that are being captured and released as bycatch. There have been many studies that have documented no difference in the size of fish captured using circle hooks and conventional J-type hooks. In all, 14 studies that assessed the size of fish captured with circle and J-type hooks determined that there were no differences in size of fish across different hook types ($X^2 = 0$, d.f. = 2, $P = 1$; Figure 10). Examples included largemouth bass (Cooke *et al.*, 2003b), striped bass (Caruso, 2000; Hand, 2001; Lukacovic and Uphoff, 2002), rock bass (Cooke *et al.*, 2003a), red drum (Aguilar *et al.*, 2002), and white seabass (Aalbers *et al.*, 2003).

There are also clear examples where the relationship between the size of the hook and the size of the angled fish are important. Cooke *et al.* (2003c) noted that smaller bluegill and pumpkinseed (<145 mm) captured on circle hooks were hooked more deeply than larger specimens (>145 mm), but the same trend was not observed in the other three hook types they examined. In a different study, Cooke *et al.* (in press) angled bluegill on each of five different-sized circle hooks (1/0, 2, 6, 10, and 14). The largest hook size (1/0) had low hooking and capture efficiency but captured larger individuals. The smallest hook size also had low hooking efficiency and resulted in the capture of smaller individuals. Intermediate hook sizes captured fish of intermediate size. Jaw hooking rates generally increased with decreasing hook size, whereas roof hooking rates decreased. Gullet hooking was restricted to the three smallest hook sizes. Relative hooking depth, ease of hook removal, and incidences of bleeding were uniformly low for all hook sizes. Mortality projections in that study revealed no trends associated with hook size, with overall mortality rate being $<1\%$. These data indicate that 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 (Cooke *et al.*, in press). There are some practical difficulties in applying this information, because anglers will typically use larger hooks to target larger fish, some of which may be harvested, but the larger hooks may cause more damage to smaller fish that will inevitably be released (e.g. eye hooking; Cooke *et al.*, 2003c). Conversely, if anglers used smaller hooks to target smaller fish, then larger fish would likely ingest the smaller hooks more deeply (e.g. gullet hooking), or they would function less efficiently. The results of Cooke *et al.* (in press) suggest that it may not be possible to eliminate the capture of small fish by using larger hooks. Large hooks do result in some size selectivity towards larger fish; however, they do hook smaller fish as well. Thus, intermediate-sized hooks may be most appropriate for minimizing injury and mortality risk while maintaining high capture efficiencies and facilitating the capture of fish across a range of sizes, including trophy fish. The challenge lies in choosing hooks that are appropriate for minimizing bycatch injury and mortality while maximizing capture efficiency of target fish when the size of the potential fish to be angled is unknown (Cooke *et al.*, in press). The choice of proper hook size seems to be especially important for the proper function of circle hooks if they are to provide reasonable conservation benefits. This is a key issue in circle hook effectiveness for conservation, and additional research is clearly required in this area.

Offset versus non-offset hook design

An important consideration in the use of circle hooks is the degree to which the point is offset. Offset hooks refer to the amount of deviation (in degrees) in the plane of the hook point relative to that of the shank (Figure 11). Offset hooks would superficially appear to increase the potential for deep hooking and injury due to the exposed point. However, at present, there is contradictory evidence regarding the importance of non-offset hooks for minimizing injury and mortality.

Evidence supporting the notion of increased tissue damage from the use of offset hooks can be derived from studies on sailfish and striped bass. 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 7.8% and 12.5% respectively, for offset circle hooks, compared with 0% and 5.9% respectively for non-offset circle hooks. Although that study compared baited circle hooks on striped bass, another study on the same species (Lukacovic, 2001) concluded that there was no difference in rate of deep hooking for all fish and sublegal-sized fish between offset (2.8% all fish, 1.6% sublegal) and non-offset hooks (2.4% all fish, 2.4% sublegal). Projected mortality rates (based upon degree of injury to vital tissues) for striped bass were also similar for all fish and sublegal fish between offset (0.7% all fish, 0.4% sublegal) and non-offset circle hooks (0.6% all fish, 0.6% sublegal). In addition, anglers landed more fish per strike when using non-offset hooks than when using offset hooks. Malchoff *et al.* (2002) reported that the severe offset circle hooks (i.e. 15°; Figure 11) used in their study of summer flounder may have negated the predicted high jaw hooking rates. Preliminary data on walleye also indicated no difference in deep hooking between offset and non-offset circle hooks (Tom Jones, personal communication).

One of the clearest examples of the use of circle hooks to reduce injury was for Pacific sailfish captured using minor offset circle hooks (Prince *et al.*, 2002). In that study, the authors contrasted the offset circle hook with a J hook and found that the offset circle hook was less injurious than the J hook. Recognizing the need for comparison of non-offset and offset circle hooks, Prince *et al.* (2002) conducted a parallel study

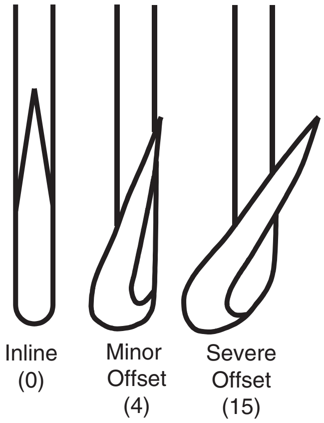

Figure 11. Schematic of inline (non-offset), minor offset, and major offset hooks. Numbers in parentheses below each drawing represent the degrees at which the point deviates from the orientation of the hook shank.

where they compared non-offset hooks with minor offset (~4°) and severe offset (15°) for Atlantic sailfish (see Figure 11). Severely offset hooks were associated with deep hooking, whereas minor and non-offset hooks were typically associated with jaw hooking. Overall, deep hooking was almost three times more common for severely offset hooks. There was no difference in bleeding or in the hooking rate between hook types. The authors of that study also determined that the deep-hooking rates of Atlantic sailfish (44%) captured on severely offset circle hooks were similar to the deep-hooking rates of Pacific sailfish (46%) captured on J-hooks.

Owing to the inconclusive data regarding the importance of offset versus non-offset hooks, it is difficult to provide any clear management direction at this time. Using available data and a conservative approach, we suggest that, until additional data are generated, anglers should avoid circle hooks offset > 5° whenever possible.

Fishing methods and the hook set

For circle hooks to perform as designed, anglers must alter the method by which they set the hook. Typically, the J-hook set would involve a rapid and forceful sweeping motion of the rod intended to sink the hook into the mouth of a fish. Conversely, a circle hook is most likely to perform properly when the angler applies gentle pressure to the hook with their rod. The angler must also provide the fish with sufficient time to actually ingest the entire hook into the oral cavity. Although these modified hook-set guidelines are provided by hook manufacturers, management agencies, and outdoor media, there are no empirical studies that have compared circle hook performance with different types of hook set.

In commercial longline fisheries, the fish themselves create the necessary hooking pressure as they swim away with ingested bait (e.g. Trumble *et al.*, 2002). Some recreational circle hook studies have indicated that the method of fishing and type of hook set can alter catch rates rather than the performance of circle hooks. For example, Zimmerman and Bochenek (2002), reported that, for a summer flounder fishery, drift speed influenced the performance of circle hooks, and anglers reported that circle hooks were more prone to deep hooking when the rig was drifted slowly. This result, however, may be related to the experience of the angler and their ability to detect a strike rapidly. There has been some suggestion that circle hooks work best for species of fish that turn after taking the bait, which increases corner jaw hooking. Some anecdotal reports have suggested that circle hooks work poorly for species that nibble the bait while maintaining a stationary position. Below, we briefly discuss the role of circle hooks for fly-fishing, lure fishing, and other specialized fisheries.

Fly-fishing

One type of angling in which the use circle hooks is growing in popularity is fly-fishing. Circle hooks are currently being used by fly-anglers targeting popular sportfish, including largemouth bass and bonefish (Cooke, personal observation), and the list of species targeted with circle hooks will likely grow in the future. Hook manufacturers have developed circle hooks with longer shanks designed specifically for fly tiers, and, similarly, fly tiers have designed patterns that can be effectively tied on circle hooks (Pfeiffer, 2000; Moore, 2001). Though there are currently no published studies that report on the use of circle hooks by fly-anglers, there are several studies that are in progress that are evaluating circle hooks in fly-fishing scenarios.

A forthcoming study (Julie Meka, unpublished data) assessed the efficacy of circle hooks for a rainbow trout catch-and-release fly-fishery in Alaska. Using different fly patterns (streamer, egg, flesh), circle hooks and J-style hooks had similar levels of bleeding, tissue damage, and captured fish of similar sizes, but circle hooks were less likely to deep-hook fish. Additionally, both novice and experienced fly-anglers landed fewer fish with circle hooks than with J-hooks, despite exhibiting similar effort, and hook removal time was greater for circle hooks but did not differ significantly from J-style hooks. The researchers concluded that there were minimal conservation benefits when using circle hooks to fly-fish for rainbow trout, as the longer air exposure associated with hook removal likely outweighed the slight benefits of reduced deep hooking (Julie Meka, unpublished data). An ongoing study in eastern Ontario (Suski and Cooke, unpublished data) is comparing the injury, mortality, and capture efficiency of bluegill captured on both dry and wet flies tied on circle and conventional hook types. Preliminary data from that study suggest that although injury and mortality rates do not differ between hook and fly types, circle hooks have reduced capture efficiency relative to conventional hooks. Thus, the limited preliminary data suggest that circle hooks may not be effective for fly-fishing. We suggest further research on this topic.

Ice fishing

A recent study in Alberta compared the hooking injury and mortality of rainbow trout captured on circle hooks and J-style hooks fished through the ice. The researchers determined that fish captured on J-hooks were hooked deeper than those hooked on circle hooks (Greg Eisler, unpublished data). Although this study is the first to assess circle hooks in this type of fishery, they may be particularly well suited to ice fishing. Ice fishing is often conducted in a manner similar to commercial trotlines, with bait left suspended or on the bottom with little intervention from the angler, and the fish usually sets the hook itself as it swims away after ingesting the bait.

Lures

Although most commonly used with organic bait (live, dead, cut), circle hooks have also been combined with lures. The ‘coon-pop’ is a modified lead head jig that places the circle hook through the eye of the jig, with no hook protruding behind the lure. In Texas and Louisiana, the ‘coon-pop’ has been associated with a major reduction in mortality of tarpon arising from catch-and-release angling (Andre Landry, personal communication). Circle hooks may also work with soft plastic baits when fished with Carolina rigs for largemouth bass (Cooke, personal observation).

Specialized fisheries

An example of a specialized freshwater fishery that may benefit from circle hooks is muskellunge. A disturbing trend has seen anglers using live bait rigs that are designed to be swallowed by trophy fish. In this fishery, the angler actually waits for a prolonged period of time until the bait is within the fish’s stomach before setting the hook. Although mortality resulting from this technique has not been quantified, the use of circle hooks may have the potential to reduce injury and mortality in this situation. Several Websites (e.g. www.muskies101.com), for example, have been cautiously advocating the use of circle hooks for swallow rigs over J-hook swallow rigs, although no scientific data are available. This site reports that informal studies by club members determined that some 33% of muskellunge caught on octopus-style circle hooks have died, and that using ‘true’ circle hooks may reduce mortality. Data to support or refute this hypothesis, however, are non-existent. Muskellunge anglers surveyed (see Margenau and Petchanik, in press) in the Midwestern USA in 1999 reported that 93% had no experience of using circle hooks, but 51% would support their use if they provided a conservation benefit. Some 40% of the respondents were uncertain about using circle hooks until they had tried them. Thus, at this time, the onus is on the management agency to respond quickly to situations where circle hooks are being used and conduct appropriate studies to provide anglers with justifiable data.

As a result of the apparent conservation benefits associated with circle hooks, they have rapidly been incorporated into competitive angling events. For example, although there are no published data on the benefits of circle hooks for tarpon, bonefish, redfish, permit, snook, or sea trout, in charity angling events, bonus points are awarded for fish captured using circle hooks (Boy Scout Backbone Celebrity Classic, Official Rules, 2002). Furthermore, several recent tournaments that target billfish have mandated the use of circle hooks for participants based upon the strong benefits identified by Prince *et al.* (2002) when trolling for billfish with bait (e.g. Yamaha Contender Miami Billfish Tournament 2002; see Cocking, 2002). Controversy arose, however, when some anglers used fishing techniques other than trolling (i.e. suspending live bait from kites) that may actually lead to greater injury than J-style hooks (Cocking, 2002). Thus, even for perhaps the most compelling study on the benefits of circle hooks (i.e. Prince *et al.*, 2002), subtle differences in techniques may actually result in reduced circle hook performance (both injury/mortality reduction and catch rates) and lower angler acceptance. Collectively, these examples highlight how specialized fisheries and fishing techniques possess unique challenges that may often require specialized, focused research to provide meaningful answers.

CIRCLE HOOK INSIGHTS FROM COMMERCIAL FISHERIES

Although the focus of this review is on catch and release in recreational fisheries, there are some lessons that can be learned from commercial longline and trotline fisheries that operate with circle hooks. In addition, sometimes these techniques are also used by fisheries management agencies to sample fish (e.g. Arterburn and Berry, 2002). This is particularly useful for obtaining information on the possible performance of circle hooks in recreational fisheries for which data exist in commercial fisheries; however, because most commercial fisheries involving circle hooks are passive, the performance of circle hooks may not be directly applicable to recreational fisheries. Nonetheless, it is a starting point that should be considered by the recreational angling community. Several groups of fish that have been targeted extensively by commercial fishers using circle hooks are freshwater catfish, sharks, pelagic marine fisheries (tuna), and benthic marine fisheries (e.g. flatfish).

The data for channel catfish and flathead catfish from trotlines suggest that circle hooks have reduced catch rates relative to J-style hooks; but, when modified (i.e. bend opened slightly to increase space between point and shank), the capture rates were improved (Arterburn and Berry, 2002). In another study on channel catfish, Ott and Storey (1991) found that circle hooks on trotlines resulted in a two-to-three-fold reduction in mortality relative to other hook types. In a study of chinook salmon bycatch from commercial trolling, Orsi *et al.* (1993) determined that circle hooks resulted in greater jaw hooking rates, but they had reduced capture efficiency and similar mortality rates to other hook designs. Conversely, both McEachron *et al.* (1985), studying mixed marine trotline fisheries off Texas, and Woll *et al.* (2001), studying Greenland halibut captured on benthic longlines in the North Atlantic, demonstrated that circle hooks had substantially higher catch rates than conventional hooks. These two studies also reported high levels of jaw hooking for circle hooks relative to J-hooks. Trumble *et al.* (2002) summarized the role of circle hooks in bycatch mortality reduction programs in the Pacific halibut commercial longline fishery. Between 1982 and 1983, the entire commercial Pacific halibut fleet converted to circle hooks (Trumble *et al.*, 2002), which increased catch rates as well as targeted fish closer to the legal size (Sullivan *et al.*, 1999). Kaimmer and Trumble (1997, 1998) later documented high rates of jaw hooking with circle hooks (95%) relative to J-hooks (80%) in Pacific halibut.

A recent study contrasted circle hook and J hook mortality and hooking efficiency in the pelagic longline industry (Falterman and Graves, 2002). CPUEs were higher using circle hooks, both for target fish (yellowfin tuna) and bycatch (15 other species). Mortality rates were lower for circle-hook-captured fish, both for the target and bycatch species. Overall, more than 95% of circle-hooked fish were hooked in the jaw and had lower rates of gut hooking relative to J-hooked fish. Recent research activities that rely on longlines for capture of red drum off North Carolina and Georgia (Nicholson and Jordan, 1994; Spud Woodward, unpublished data) and sharks in the Gulf of Mexico (Mark Grace, unpublished data) have switched to circle hooks to increase retention and decrease bycatch mortality.

Collectively, the clearest message from marine fisheries is that slight differences in circle hook design and size can greatly influence circle hook performance. The same levels of interspecific variation in mouth morphology, feeding mode, and behaviour (Huse and Fernö, 1990) associated with circle hook performance in recreational fisheries are also observed in commercial fisheries.

In addition to possible conservation benefits to fish bycatch, other organisms may also benefit from the use of circle hooks. A recent focus of circle hook use in marine environments has been sea turtle bycatch reduction in the Atlantic (NOAA, 2001) and Pacific pelagic longline fisheries (Laurs *et al.*, 2003). Preliminary data from Laurs *et al.* (2003) suggest that circle hooks appear to reduce the injury rate of sea turtles relative to conventional hook types. There is currently little known about whether circle hooks could reduce bycatch of seabirds, waterfowl, or marine mammals.

CIRCLE HOOK REGULATORY ISSUES

Currently, a problem for regulatory agencies is the lack of a clear definition as to what is a circle hook. Because there is no industry standard for circle hooks, there is substantial variation in design and size. This issue is of particular concern to several jurisdictions that have mandated the use of circle hooks for some specialized commercial and recreational fisheries. Currently, Canada requires commercial fishers targeting white hake in some regions to use circle hooks (Kulka and Simpson, 2002), and Maine is currently the only US state with requirements for circle hooks in some groundfish fisheries (*sensu* Moran, 2003). The only recreational fisheries that we are aware of that require circle hooks are for specialized salmonid bait fisheries off the California coast and for a section of the Delaware River in New Jersey for a striped bass bait fishery. A California statute (i.e. Section 27.80, Title 14, CCR) defines a circle hook as a ‘hook with a generally circular shape and a point that turns inwards, pointing directly back at the shank at a 90 degree angle’. However, even the California statute contains ambiguity. Circle hooks were considered as a conservation tool for winter chinook salmon in Sacramento in accordance with the Endangered Species Act (USA; Allen Grover, personal communication). Winter chinook salmon have early age at maturity, and these small fish experience over 70% of their adult mortality from the recreational fishery. Although circle hooks were identified as an important conservation measure for reducing catch-and-release mortality of small winter chinook (Grover *et al.*, 2002), the legislation was not enforceable by the district attorneys. The statute did not include reference prohibiting offset circle hooks that were deemed to be harmful.

There is clearly need for consensus to standardize fishing tackle terminology and products in order for consistent implementation of legislation and enforcement to occur. Indeed, owing to the current lack of standardization, a proposal to require circle hooks for all striped bass bait fisheries prosecuted in waters under the purview of the Atlantic States Marine Fisheries Commission’s (ASMFC) member states was recently defeated (Anon., 2002). To remedy this problem, the ASMFC formed a multi-stakeholder committee (enforcement and technical personnel, managers, hook manufacturers, and researchers) to develop recommendations on a circle hooks definition and related issues. For additional details on the ASMFC work and additional description of statutes in other jurisdictions, readers are directed to a recent ASMFC ‘white paper’ on this topic (Moran, 2003). In the interim, the ASMFC will continue to develop educational materials to encourage the use of circle hooks.

In an angler-driven example of how to deal with lack of a clear definition, some of the tournaments for billfish have identified specific circle hook models that are either acceptable or prohibited. Apparently, the circle hooks with wide gaps between the hook point and shaft lead to increased gut hooking in billfish (Joan Vernon, personal observation) and tournament organizers have selected hooks based upon research findings (e.g. Prince *et al.*, 2002). In 2003, the Costa Rican government established a law (Ordinary Act AJDI/09-2003, Agreement AJDIP/063-2003) that mandated the use of circle hooks when billfishing, except if using fly tackle (INCOPESC, 2003).

RESEARCH AGENDA

There is a need for additional research on circle hooks and their utility for minimizing injury and mortality in recreational fisheries. Advances in hook design clearly have the potential to result in significant reductions in injury and mortality of fish that are to be released. Circle hooks represent the first major effort to alter hook design for conservation purposes. Of particular interest are studies that vary the degree to which the hook forms a circle, the gap between the point of the hook and the shank, and the size of the hook relative to the size of the fish. Subtle differences in hook size could have profound differences on hook performance and utility as a tool for conservation. In addition, since offset circle hooks appear to perform differently than non-offset circle hooks, this would also be a productive research topic and would provide clear direction to legislators. Circle hooks are also being used in fly-fishing for species ranging from bonefish to salmonids with no information on how these hooks perform in terms of injury, mortality or hooking efficiency. Tests of circle hook performance for fly-fishing would also, therefore, be useful and could clarify whether circle hooks can further be considered for these specialized fisheries. The use of circle hooks also apparently requires a change in angler hook-set behaviour. Studies that compare the performance of circle hooks in relation to the relative efficiency of a swift and forceful hook set versus a slow and steady hook set would also help to provide information on the function of circle hooks and the importance of emphasizing different hook-sets to anglers. Since the media and fisheries management agencies have embraced the use of circle hooks so broadly, there may also be some interesting human-dimension questions that could arise from this topic, such as how anglers respond to new gear technologies with conservation benefits. Many of the issues identified in this review were also identified during a facilitated, interactive consensus building process (Group-Solutions Inc., 1999) at the Marine Catch and Release Symposium in 1999. Overall, circle hook research and hook design were identified as two of the top six research issues in marine catch and release angling. The consensus-building process also identified that undertaking species-specific studies will be essential for understanding circle hook effectiveness.

We agree that owing to the apparent influence of mouth morphology, feeding mode and, therefore, performance of circle hooks, species-specific studies will be required to determine in what cases circle hooks are truly effective as conservation tools for reducing injury and mortality of caught-and-released fish. A recent set of general catch-and-release guidelines developed to deal with the application of information from one fish species to another concluded that gear type was important; but, at this point, only the use of barbless hooks should be encouraged for all recreational fisheries, and not the use of circle hooks (Cooke and Suski, in press). Perhaps, as additional research becomes available, there may be more opportunity to provide more general guidelines on the use of circle hooks in other fisheries and for other species.

Circle hooks have clearly drawn attention to issues of catch-and-release mortality. If this energy can be channelled into research on circle hooks and, indeed, other novel hook designs, then we could see more advances in gear-based conservation in the next few years. For example, recent developments in terminal tackle, such as the Shelton self-releasing hook, may also represent new opportunities for increasing survival (Jenkins, 2003).

CONCLUSIONS

Circle hooks have generally been accepted by anglers as conservation tools. Though much of the current literature shows the benefits from using circle hooks, the data are somewhat limited, and, in many cases, are somewhat conflicting. Are circle hooks an effective tool for conserving marine and freshwater recreational catch-and-release fisheries? Based upon this review, the answer is yes, but not in all situations. Our meta-analysis revealed that, in general, hooking mortality rates were reduced by $\sim 50\%$ by using circle hooks relative to J-style hooks. The reduction in mortality associated with use of circle hooks resulted primarily from the tendency of circle hooks to jaw-hook fish, resulting in shallow hooking depths. Gut hooking, and hence deep hooking, was generally rare for fish captured on circle hooks, minimizing the opportunity for damage to vital organs and excessive bleeding. Reduction of injury and mortality in recreational fisheries is essential as recreational fishing continues to expand rapidly, placing increased pressure on limited resources. Our meta-analysis consistently resulted in us rejecting the null hypothesis of equal performance of circle hooks and J-style hooks. However, there were instances where fish exhibited increased tissue damage, especially to the eye region, from the use of circle hooks. Based upon our synthesis, we strongly support management strategies that incorporate the use of circle hooks when species-specific data or compelling evidence from other species with similar mouth morphology suggest that circle hooks result in less injury and mortality than other hook designs. Several management agencies currently encourage the use of circle hooks for specialized fisheries supported by specific studies (e.g. Maryland DNR for striped bass bait fisheries; Florida FWCC and Guatemala Federal Government for billfish fisheries). However, we must dissuade management agencies, conservation organizations, outdoor media and tackle manufacturers from encouraging anglers to adopt circle hooks for use with all species. Although the general consensus of our synthesis was that circle hooks do provide conservation benefits to some species, these benefits are not cosmopolitan. This is particularly important for management agencies that may lose credibility if circle hooks do not perform as hoped.

Several management agencies currently broadly encourage circle hook use for all bait fisheries. Anglers will certainly begin to view circle hooks with caution for instances when hooking efficiency is reduced relative to other hook types. Only if research supports strong conservation benefits for a given species or group of fishes can we expect anglers voluntarily to adopt the use of circle hooks in light of possible reduced hooking and capture success. In addition, in instances when circle hooks actually result in increased injury or mortality, how do we dissuade anglers from using circle hooks? Based upon the considerable conservation benefits derived from using circle hooks to target valuable yet vulnerable marine stocks such as billfish, it is quite likely that circle hooks should also be effective for many other species. However, the use of circle hooks for different species may require fine-tuning of the hook properties as well as a fundamental change in the way anglers set the hook. Until species-specific data exist, we encourage management agencies to restrict the encouragement of circle hooks unless there are compelling data (ideally scientific, but anecdotal in specialized cases) supporting that action.

The widespread adoption of circle hooks is an example of how a conservation-oriented change in angler behaviour can be developed and adopted in many jurisdictions. However, responsibility lies with management agencies to determine whether or not the use of circle hooks is indeed an appropriate conservation action, and a number of key questions need to be considered:

- How do management agencies and researchers stay at the forefront of changes in gear technology for catch-and-release recreational fisheries?
- What kind of evidence is required before new gear is embraced?
- At what point do we advocate the use of new gear?
- What conservation results can we realistically expect from fisheries gear improvements for recreational catch-and-release fisheries?

These are all questions that present themselves after reviewing the status of circle hooks in recreational fisheries. Circle hooks differ from other regulatory changes in that, in many previous cases, management agencies have had to work hard to acquire the support of anglers when conservation-oriented changes have been proposed. In this instance, however, most management agencies have not provided adequate science to justify the actual use of these hooks to the extent that they are being used. Circle hooks undoubtedly will play an important role in reducing injury and mortality in some fisheries. However, at this time, there is insufficient evidence to suggest that circle hooks should be used for all recreational fish and fisheries. Rather, we support continued research in the field of developing novel terminal tackle that reduces injury and mortality of recreational fish. Conservation of aquatic resources will require fisheries managers to incorporate more conservation-oriented gear restrictions, such as circle hooks, into modern fisheries management and conservation strategies.

ACKNOWLEDGEMENTS

We are grateful to the numerous individuals that have contributed to the development of the ideas presented here. We are particularly grateful to those that provided access to unpublished data or other leads that ensured that this synthesis was comprehensive. They include Rudy Lukacovic, Tom Jones, Karen Burns, Mark Malchoff, Spud Woodward, Bob Beal, Jim Moran, Julie Meka, Nicholas Parnell, Robert Aguilar, Peter Rand, Darren Pecoric, Steve Parmenter, Jon Lucy, Bob Faragher, Scott Aalbers, Tom Jenkins, Mark Drawbridge, Allen Grover, Terry Margenau, Jim Franks, Greg Eisler, and Joan Vernon. The work presented here was supported by the University of Illinois, the Illinois Department of Natural Resources, the Illinois Natural History Survey, Queen's University, and the University of British Columbia. However, the authors acknowledge that the views presented here are theirs and do not necessarily reflect those of their agencies. We also acknowledge the continued support provided by Scott Hinch, David Philipp, David Wahl, and Bruce Tufts. Additional assistance was provided by the Natural Sciences and Engineering Research Council of Canada and the Izaak Walton Killam Foundation.

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APPENDIX 1

Common names and Latin binomials for fish species named in the paper and associated table.

Common name	Latin binomial
Atlantic bluefin tuna	*Thunnus thynnus*
Atlantic sailfish	*Istiophorus albicans*
Blue marlin	*Makaira nigricans*
Bluefish	*Pomatomus saltatrix*
Bluegill	*Lepomis macrochirus*
Bonefish	*Albula* spp.
Bonito	*Sarda sarda*
Brook charr	*Salvelinus fontinalis*
Brown trout	*Salmo trutta*
Channel catfish	*Letalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscha*
Coho salmon	*Oncorhynchus kisutch*
Croakers	*Micropogonias undulatus*
Flathead catfish	*Pylodictis olivaris*
Gag	*Mycteroperca microlepis*
Greenland halibut	*Reinheardtius hipposglossoides*
Largemouth bass	*Micropterus salmoides*
Muskellunge	*Esox masquinongy*
Pacific halibut	*Hippoglossus stenolepis*
Pacific sailfish	*Istiophorus platypterus*
Permit	*Trachinotus falcatus*
Pumpkinseed	*Lepomis gibbosus*
Rainbow trout	*Oncorhynchus mykiss*
Red drum	*Sciaenops ocellatus*
Red grouper	*Epinephelus morio*
Red snapper	*Lutjanus jordani*
Redfish	*Sebastes* spp.
Rock bass	*Ambloplites rupestris*
Seatrout	*Cynoscion* spp.
Silver perch	*Bidyanus bidyanus*

Common name	Latin binomial
Smallmouth bass	*Micropterus dolomieu*
Snook	*Centropomus undecimalis*
Striped bass	*Morone saxatilis*
Summer flounder	*Paralichthys dentatus*
Tarpon	*Megalops atlanticus*
Walleye	*Sander vitreus*
White hake	*Urophysis tenuis*
White seabass	*Atractoscion nobilis*
Yellowfin tuna	*Thunnus albacares*

APPENDIX 2

Personal communications and unpublished data

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