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A review of catch-and-release angling mortality with implications for no-take reserves

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Abstract

Management agencies have increasingly relied on size limits, daily bag or trip limits, quotas, and seasonal closures to manage fishing in recreational and commercial fisheries. Another trend is to establish aquatic protected areas, including no-take reserves (NTRs), to promote sustainable fisheries and protect aquatic ecosystems. Some anglers, assuming that no serious harm befalls the fish, advocate allowing catch-and-release (C&R) angling in aquatic protected areas. The ultimate success of these regulations and C&R angling depends on ensuring high release survival rates by minimizing injury and mortality. To evaluate the potential effectiveness of these practices, we review trends in C&R fishing and factors that influence release mortality. Analysis of Marine Recreational Fishery Statistic Survey (MRFSS) data for 1981–1999 showed no statistically significant U.S. trends for total number of anglers (mean 7.7×10^6), total catch in numbers (mean 362×10^6), or total annual catch/angler (mean 42.6 fish). However, mean total annual landings declined 28% (188.5 to 135.7 × 10^6), mean total catch/angler/trip declined 22.1% (0.95 to 0.74 fish), and mean landings/angler/trip declined 27% (0.42 to 0.31 fish). The total number of recreational releases or discards increased 97.1% (98.0 to 193.2 × 10^6) and as a proportion of total catch from 34.2% in 1981 to 58.0% in 1999. Evidence indicates that the increased releases and discards are primarily in response to mandatory regulations and to a lesser extent, voluntary releases. Total annual catch and mean annual catch/angler were maintained despite declines in catch per trip because anglers took 30.8% more fishing trips (43.5 to 56.9 × 10^6), perhaps to compensate for greater use of bag and size limits. We reviewed 53 release mortality studies, doubling the number of estimates since Muoneke and Childress (1994) reviewed catch and release fishing. A meta-analysis of combined data ($n = 274$) showed a skewed distribution of release mortality (median 11%, mean 18%, range 0–95%). Mortality distributions were similar for salmonids, marine, and freshwater species. Mean mortality varied greatly by species and within species, anatomical hooking location was the most important mortality factor. Other significant mortality factors were: use of natural bait, removing hooks from deeply hooked fish, use of J-hooks (vs. circle hooks), deeper depth of capture, warm water temperatures, and extended playing and handling times. Barbed hooks had marginally higher mortality than barbless hooks. Based on numbers of estimates, no statistically significant overall effects were found for fish size, hook size, venting to deflate fish caught at depth, or use of treble vs. single hooks. Catch and release fishing is a growing and an increasingly important activity. The common occurrence of release mortality, however, requires careful evaluation for achieving fishery management goals and in some cases, disturbance, injury, or mortality may conflict with some goals of NTRs. Research is needed to develop better technology and techniques to reduce release mortality, to assess mortality from predation during capture and after release, to determine cumulative mortality from multiple hooking and release events, and to measure sub-lethal effects on behavior, physical condition, growth, and reproduction.

Introduction

Catch-and-release (C&R) fishing is growing as a proportion of total fishing in the United States. The sport fishing industry encourages anglers to voluntarily release fish as a way to expand recreational fishing (RecFish Proceedings, 2000; Lucy and Studholme, 2002) and many new regulations require more fish to be released in both recreational and commercial fisheries.

Another trend to promote sustainable fisheries and protect aquatic ecosystems is to establish aquatic protected areas, including no-take reserves (NTRs) where extractive activities are banned, except for scientific and educational purposes (Bohnsack, 1998ab; Murray et al., 1999; National Research Council, 1999; Horwood, 2000; Lindeboom, 2000; Fogarty et al., 2000; Roberts and Hawkins, 2000; Roberts et al., 2001; Halpern and Warner, 2002; Halpern 2003, Shipley, 2004). Some anglers argue that if non-extractive activities, such as SCUBA diving and snorkeling are allowed within NTRs, then C&R angling should be permitted because it is not extractive per se, assuming that no serious harm befalls the fish. In response to these arguments, four of 23 "no-take" Sanctuary Preservation Areas established in the Florida Keys National Marine Sanctuary (FKNMS) in 1997 allowed C&R trolling but not other fishing (Department of Commerce, 1996). Similar proposals to allow C&R angling in marine reserves established in the Tortugas region of Florida, however, were rejected because C&R angling potentially interferes with other objectives, such as ecosystem protection and fishery enhancement, particularly if release mortality is high (Department of Commerce, 2000).

Muoneke and Childress (1994) previously reviewed recreational C&R mortality, but since then many additional studies have been reported. Also, fishery management agencies have put more reliance on measures that require releasing fish, including use of minimum and maximum size limits, bag limits, quotas, and seasonal closures. The ultimate success of these measures requires sufficient survival and successful reproduction of released organisms. Coleman et al. (2004) showed that recreational angling is an important source of total mortality for many marine species, but were unable to evaluate C&R mortality. Here we review C&R angling trends, release mortality factors, and potential impacts of C&R angling on stocks and aquatic reserves.

Methods

We analyzed trends in U.S. marine recreational C&R angling using Marine Recreational Fisheries Statistics Survey (MRFSS) data[1]. MRFSS estimates total catch (the number of fish caught but not necessarily brought ashore), total landings, and the combined total of releases and discards by state based on phone interviews and creel surveys (Department of Commerce, 2001). Phone surveys determine marine recreational angler participation while creel surveys document landings and collect information about how many fish were caught and their disposition as landed (brought to shore), released (caught and released alive), discarded (if dead), or consumed as food or bait at sea. We queried the MRFSS database by year for all states and all fishing modes (e.g. shore, private/rental boat, or party/charter boat) which participated in the survey. Impacts of size and bag limits on the proportion of fish released were evaluated based on landings and release data from studies conducted before and after fishing regulations were implemented.

Muoneke and Childress (1994) reported 132 release injury or mortality estimates from 76 studies involving 32 fish taxa. In 2002, we compiled an additional 142 mean estimates from 53 studies of 32 taxa. Each mean mortality estimate represented all reported trials conducted under a specified set of experimental conditions. We focused on recreational angling, but included studies of commercial hook-and-line fisheries if the results could potentially apply to recreational angling. We included two studies on the effects of vigorous exercise since it was a potentially important mortality factor in C&R angling. We excluded control data in which fish were not angled and C&R studies of commercial fishing not involving hook and line.

We conducted meta-analyses on the combined 274 total mortality estimates based on 142 from our survey and 132 reported by Muoneke and Childress (1994). First, we statistically described pooled mortality data, assuming independence of estimates. Next, we divided all mortality estimates into three groups: salmonids and either freshwater or saltwater species, according to their primary adult habitat, and compared their mortality distributions. Finally, we examined 15 injury and mortality factors based on paired comparisons of specific factors (e.g. barbed vs. barbless hooks) from individual studies using the Sign test. Paired comparisons minimized possible confounding from multiple factors by eliminating multiple comparisons (e.g. different bait types, hook types, and depth differences) from consideration. The analysis gave equal weight to each mean mortality estimate although individual studies varied considerably in quality, size, and in the precision and accuracy of estimates. When only ranges were reported, we used the midpoint value in lieu of the mean. Fish sex and salinity were not examined as mortality factors.

For consistency and to avoid confusion, we refer to percent mortality throughout this paper. For studies that only reported survival, we converted their numbers to percent mortality as the mathematical complement of survival. We define "catch" as all organisms caught while fishing. For commercial fisheries, catch is composed of "landings" and "bycatch." Landings are the portions of catch retained by being brought to shore, used as bait, or consumed at sea. Bycatch is unwanted catch composed of organisms either not targeted or required to be released by regulations. Bycatch is disposed at sea as either discards (if dead) or releases (if alive). Recreational catch and release fisheries differ in that the category "bycatch" includes organisms deliberately targeted for capture and release. However, the disposition of recreational catch remains the same (i.e. landed, released alive or discarded dead).

We modeled potential cumulative mortality from multiple C&R events assuming different constant, event-specific mortality rates and no interactions between events. Annual trends were analyzed by regression after applying an arcsine transform to percentage data. Slopes were compared by *t*-test, non-parametric data by Mann–Whitney U-test, and individual potential mortality factors with the Sign test (Sokal and Rholf, 1981).

Results

Recreational fishing trends

MRFSS data show the magnitude of marine recreational C&R fishing in the U.S. In 2000 an estimated 10.65×10^6 recreational anglers

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[1] available at: recreational/index.html/recreational/index.html

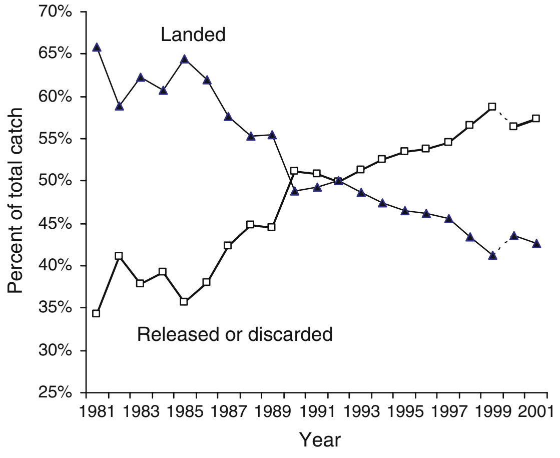

Figure 1. Trends in the percent of total marine recreational catch retained vs. discarded or released from 1981 to 2001 (MRFSS data query at http://www.st.nmfs.gov/recreational/index.html. Data reported from 2000 and later are not directly comparable to earlier years because a new method for estimating effort and catch began in 2000.

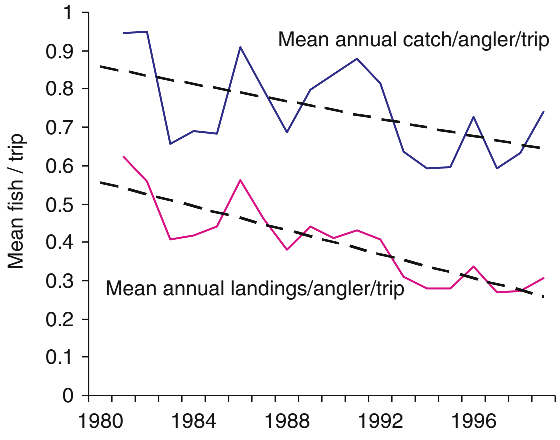

Figure 2. Trends in U.S. recreational fishery catch and landings (per angler per trip) from Marine Recreational Fishing Statistic Survey data (1981–1999).

participated in 77.8 × 10^6 marine fishing trips, caught 444.7 × 10^6 fish, of which 252.8 × 10^6 (57%) were released or discarded (Department of Commerce, 2002). Recreational landings exceeded commercial landings in weight for eight of the 10 species principally targeted by recreational fishing in 2000: red drum (100% of total landings) spotted seatrout (97%), dolphin (94%), striped bass (74%), king mackerel (64%), yellowfin tuna (63%), summer flounder (59%), and bluefish (57%) (Dept. of Commerce, 2001).

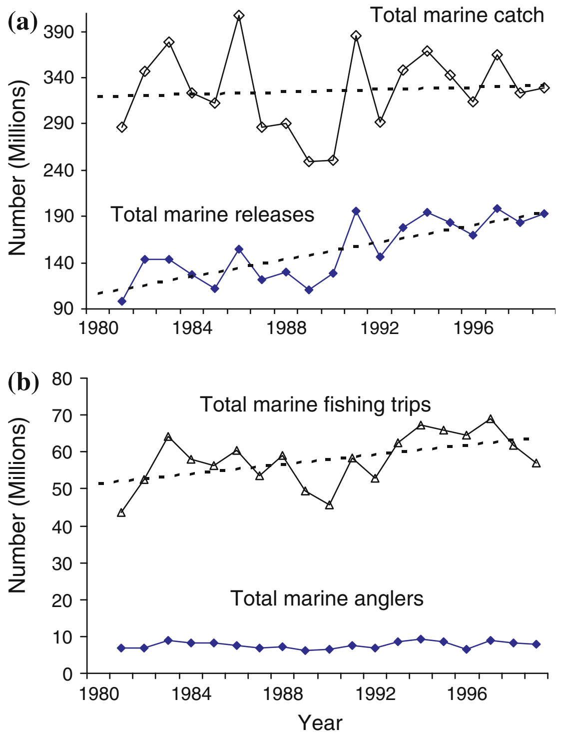

Figure 3. Trends in U.S. (a) total marine catch and releases; and (b) total fishing trips and anglers, 1981–1999. Source: Marine Recreational Fishing Statistic Survey.

Trend analysis[2] for 1981–1999 MRFSS data show that the proportion of fish released or discarded increased from 34.2% of the total catch in 1981 to 58.7% in 1999, while total landings decreased from 65.8% of total catch in 1981 to 41.3% in 1999 (Figure 1). In numbers, the mean total annual releases and discards increased 97.1% (98.0 to 193.2 × 10^6 fish; $p < 0.01$, F-test) while mean total annual landings decreased 28.0% (188.5 to 135.7 × 10^6 fish; $p < 0.01$, F-test). Also, mean total catch/angler/trip declined 22.1% (0.95 to 0.74 fish; $p < 0.05$, F-test) and mean landings/angler/trip declined 27.1% (0.42 to 0.31 fish; $p < 0.01$, F-test) (Figure 2). Although not statistically significant, the total number of marine anglers increased 12.3% (mean = 7.7 × 10^6, range 6.6–9.3 × 10^6, $p = 0.255$, F-test), total catch/angler increased 2.2% (mean = 42.6 fish, range 38.5–54.8, $p = 0.426$, F-test), and total catch increased 14.8%

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[2] Data from 2000 and 2001 were excluded from this analysis because different methods were used by MRFSS to calculate estimates starting in 2000.

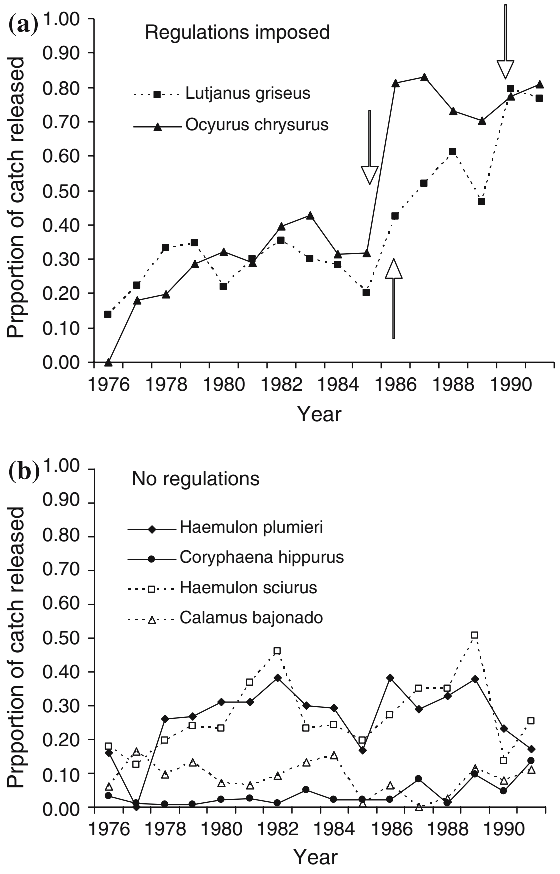

Figure 4. Changes in the proportion of total catch released in Biscayne National Park. (a) species regulated by Florida minimum size and daily bag limits. Arrows show years when legislation started requiring releases: 1985, 12 in. minimum size for yellowtail snapper, *Ocyurus chrysurus*; 1986, daily bag limit of 10 total snapper per angler; 1990, 10 in. minimum size and five fish bag limit for gray snapper, Lutjanus griseus. (b) unregulated species: white grunt, *Haemulon plumieri*; bluestriped grunt, *Haemulon sciurus*; jolthead porgy *Calamus bajonado*; and dolphinfish, *Coryphaena hippurus*. Data from Harper et al. (2000).

(mean = 326.2 × 10^6 fish, $p = 0.425$) (Figure 3). The total number of fishing trips increased 30.8% from 43.5 × 10^6 in 1981 to 56.9 × 10^6 in 1999 ($p < 0.01$, F-test; Figure 3).

Impact of regulations

Minimum size limits have been shown to have a greater impact on the total proportion of releases in numbers of fish than by weight (Bohnsack, 2000). Harper et al. (2000) examined impacts of minimum size regulations on recreational releases in Biscayne National Park, Florida and showed that releases increased significantly for regulated species after new state-wide minimum size and bag limit regulations were implemented, as intended, while no changes were detected for unregulated species (Figure 4). The total percentage of releases for the two regulated species, yellowtail snapper *Ocyurus chrysurus* and gray snapper *L. griseus*, jumped from the 20–30% to 80% after regulations went into effect.

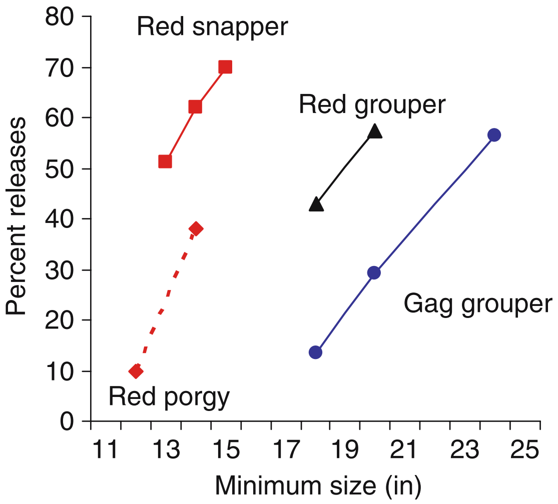

Figure 5. Projected short term percentage of catch required to be released by commercial reef fish line fisheries in response minimum size (TL) limits in federal waters of the southeastern U.S. Data were landed size distributions collected before implementing minimum size regulations (Bohnsack 2000). Data do not take into account possible changes in yield per recruit over time.

Regulations also require releases by commercial fisheries. In a hook-and-line, reef fish fishery in the southeastern U.S. (Figure 5), the projected releases as a proportion of the total numerical catch under existing minimum size limits reached 70% for 38.1 cm (15″) TL red snapper *L. campechanus*, 57.5% for 50.8 cm (20″) TL red grouper *Epinephelus morio*, and 56.6% for 61.0 cm (24″) TL gag grouper *Mycteroperca microlepis* in the Gulf of Mexico and 37.5% for 35.6 cm (14″) TL red porgy *Pagrus pagrus* in the Atlantic (Bohnsack, 2000).

Review of mortality factors

Appendix A provides data from our review of recent studies in a similar format as used by

Muoneke and Childress (1994). Below we describe results for individual factors in categories as intrinsic factors, terminal gear, handling techniques, environmental conditions, and other considerations.

Intrinsic factors

Anatomical Hook location

Eleven studies concluded or experimentally demonstrated that fish hooked in critical body areas suffered higher mortality. Hooking location was shown to be important for common snook (Taylor et al., 2001), spotted seatrout (Murphy et al., 1995), Atlantic bluefin tuna (Skomal et al., 2002), sailfish (Prince et al., 2002), summer flounder (Zimmerman and Bocheneck, 2002), striped bass (Diodati and Richards, 1996; Nelson, 1998; Lukacovic, 2000; Lukacovic, 2001; Lukacovic and Uphoff, 2002) and cutthroat trout (Pauley and Thomas, 1993).

Fish size

For nonanadromous trout (Taylor and White, 1992) and striped bass (Malchoff and MacNeill, 1995), morality was higher for larger than smaller individuals (Appendix A). In contrast, mortality was higher for smaller than larger individuals for lake trout (Loftus, 1986) and Chinook salmon (Bendock and Alexandersdottir, 1993). Nine studies reported no mortality differences due to fish size, including striped bass (Bettoli and Osborne, 1998; Nelson, 1998; Wilde et al. 2000, in a review), blue cod (Carbines, 1999), common snook (Taylor et al., 2001), spotted seatrout (Murphy et al., 1995), cutthroat trout (Pauley and Thomas, 1993), rainbow trout (Schisler and Bergersen, 1996), black sea bass and vermilion snapper (Collins et al., 1999).

Terminal fishing gear

Artificial lures vs. natural bait

Six studies demonstrated higher mortality with natural bait than with artificial lures and flies and five studies found no difference. Natural bait led to higher mortalities than artificial bait for cutthroat trout (Pauley and Thomas, 1993) and rainbow trout (Schisler and Bergersen, 1996). Higher mortalities were associated with natural bait compared to lures or flies for nonanadromous trout (Taylor and White, 1992), wire netting cod and yellow stripey (Diggles and Ernst, 1997). Striped bass caught with live bait were more likely to be hooked deeper, leading to greater mortality (Diodati and Richards, 1996; Wilde et al., 2000). In contrast, no mortality differences were found between artificial and natural baits for striped bass (Nelson, 1998; Bettoli and Osborne, 1998); common snook (Taylor et al., 2001) and weakfish (Malchoff and Heins, 1997). Lee and Bergersen (1996) found no difference in the tag recovery rates of lake trout hooked on lures and natural bait.

Treble vs. single hooks

One study found lower mortality of fish caught on treble hooks vs. single hooks, while three studies found no difference. Treble hooks caused less mortality than a single, large hook for northern pike (DuBois et al., 1994). No differences in mortality from single vs. treble hooks were reported for nonanadromous trout (Taylor and White, 1992), cutthroat trout (Pauley and Thomas, 1993) and common snook (Taylor et al., 2001). Gjernes et al. (1993) reported that treble hooks were less likely to hook "critical" locations for Chinook and coho salmon, but there was no difference in mortalities, possibly because treble hooks took longer to remove.

Hook size

Carbines (1999) found 25% mortality of blue cod using small hooks compared to 0% for larger hooks. No effect of hook size was found for striped bass (Diodati and Richards, 1996), cutthroat trout (Pauley and Thomas, 1993), and nonanadromous trout (Taylor and White, 1992).

Hook type

Five studies reported reduced fish mortality using circle hooks compared to J-hooks. Two studies reported no significant difference in the percentage of fish critically hooked by circle vs. J-hooks. A comparison of hooking locations in Atlantic and Pacific sailfish showed that fish caught on circle hooks were hooked in the mouth 85% of the time and only 2% were deeply hooked compared to J-hooks in which 27% of fish were hooked in the corner of the mouth and deeply hooked 46% of the time (Prince et al., 2002). Circle hooks also had higher hooking rates (number of fish hooked / bite) than "J" hooks (Prince et al., 2002). Atlantic bluefin tuna (Skomal et al., 2002) and Chinook salmon (Grover et al., 2002) suffered less mortality when caught with circle hooks than J-hooks. Summer flounder (Zimmerman and Bochenek, 2002) and yellowfin tuna (Falterman and Graves, 2002) had no significant difference in the incidence of critical hooking or mortality when caught on circle vs. J-hooks, although on average critical hooking was lower in fish caught with circle hooks for both species. Three studies reported greater mortality of striped bass using J-hooks compared to circle hooks because J hooks resulted in more frequent deep hooking (Lukacovic, 2000; Luckacovic, 2001; Luckacovic and Uphoff, 2002). Prince et al. (2002) reported for circle hooks, that the degree to which the tip of the hook is "offset" to the side of the shaft influenced mortality; the greater degree of offsetting lead to higher mortality.

Modified hooks

Willis and Millar (2001) showed a higher incidence of gut hooking for sparid snapper *Pagrus auratus* fished by longline using standard hooks compared with hooks modified by the addition of either a 20 mm or 40 mm wire appendage attached roughly perpendicular to the shank. Gut hooking with normal hooks was 17% in January and 30% in June compared to 7 and 12%, respectively, for 20 mm appendage hooks, and 2% in both months for 40 mm appendage hooks.

Barbed vs. barbless hooks

Fish mortality was lower with barbless hooks for nonanadromous trout (Taylor and White, 1992) and for coho salmon with barbless treble hooks (Gjernes et al., 1993) than with barbed hooks. Cooke et al. (2001) reported that barbless jigs were easier to remove than barbed jigs, and significantly reduced air exposure for rock bass.

Fishing, handling, and release techniques

Active vs. passive fishing

Two studies reported that active fishing and setting the hook quickly may reduce fish mortality compared to passive fishing by preventing the fish from swallowing hooks. Passive fishing using set lines had higher mortality for lake trout (Persons and Hirsch, 1994) and rainbow trout (Schisler and Bergersen, 1996) than actively fished lines. For lake trout caught on set lines, 70% were caught in the gills or gut (Persons and Hirsch, 1994).

Playing time, handling time, and angler experience

Researchers have examined playing time (time between hooking and removal from the water), air exposure time, handling time, and angler experience as possible factors contributing to fish mortality. Five studies found that one or more of the above factors affected fish survivorship or recovery time, while five studies found no effect of any of these factors. Diodati and Richards (1996) found a tendency for higher mortality in striped bass among fish caught by inexperienced anglers, although handling technique, release technique, and total time from hooking to release did not affect mortality. Length of air exposure and handling technique affected rainbow trout mortality (Ferguson and Tufts, 1992; Schisler and Bergersen, 1996). Longer recovery times were required for rock bass with increased air exposure (Cooke et al., 2001) and for smallmouth bass with longer exercise duration (Schreer et al., 2001). Mortality was not influenced by playing time nor handling time for striped bass (Tomasso et al., 1996; Bettoli and Osborne, 1998; Nelson, 1998), playing time for rainbow trout (Schisler and Bergersen, 1996), or handling technique for blue cod (Carbines, 1999).

Deep hook removal

Five studies found that cutting the line on critically hooked fish increased survivorship compared to removing the hook and several studies demonstrated that fish can shed hooks themselves. Hook removal led to higher mortality for red drum (Jordan and Woodward, 1994) and brown trout *Salmo trutta* (Hulbert and Engstrom-Heg, 1980). Deeply hooked rainbow trout suffered 74% mortality when the hook was removed compared to only 47% when the hook was not removed (Schill, 1996). Among the surviving deeply hooked trout with the hook left in, 74% shed the hook within two months. Schisler and Bergersen (1996) found similar results with rainbow trout: mortality was 55% when the hook was removed by hand and only 21% when the hook was not removed. Among surviving deeply hooked fish in which the hook was not removed, 25% managed to shed it within 3 weeks. Taylor et al. (2001) also suggest that leaving the hook in critically hooked common snook increases survivorship. If hooks are removed, using dehooking tools is a recommended way to reduce mortality (Malchoff and MacNeill, 1995).

Venting

Four studies found that venting by puncturing inflated swim bladders reduced fish mortality. Two studies found no effect on survivorship. Deflation had no detrimental effect on burbot *Lota lota* (Bruesewitz et al., 1993) and increased survival of largemouth bass (Feathers and Knable, 1983), black sea bass (Collins et al., 1999), and yellow perch (Keniry et al., 1996). Survival of vermilion snapper increased in one study (Fable, 1994), but not significantly in another (Collins et al., 1999).

Environmental conditions

Capture depth

In six studies, increased fish mortality or trauma with increased depth of capture occurred for red snapper (Gitschlag and Renaud, 1994; Dorf, 2000), black sea bass (Rogers et al., 1986; Collins et al., 1999), vermilion snapper (Collins et al., 1999) and red grouper (Wilson and Burns, 1996). No mortality effect with water depth was reported in two studies: lake trout, a physostomous species, (Loftus, 1986) and yellow perch, *P. flavescens* (Keniry et al., 1996). In the latter study, however, there was only a 5 m difference in the experimental capture depths. Three studies showed that susceptibility to mortality when captured from a given depth varied by species (Rogers et al., 1986; Wilson and Burns, 1996; Collins et al., 1999).

Water temperature

Warm water temperatures contributed to increased mortality in 10 studies while three studies found no effect of temperature. Greater mortality with higher water temperatures was observed for walleye (Fielder and Johnson, 1994), striped bass (Tomasso et al., 1996; Nelson, 1998; Bettoli and Osborne, 1998; Wilde et al., 2000), rainbow trout (Klein, 1966; Schisler and Bergersen, 1996), cutthroat trout (Benson and Bulkley, 1963) and Atlantic salmon (Brobbel et al., 1996, and compare the results of Booth et al., 1995; Wilkie et al., 1996). Temperature was not a mortality factor for spotted seatrout (Murphy et al., 1995) or common snook (Taylor et al., 2001) and did not effect recovery time of smallmouth bass after exercise (Shreer et al., 2001).

Other considerations

We found few or no studies of indirect mortality from predation, cumulative mortality from multiple capture and release events, or sub-lethal impacts of C&R fishing. Fish are vulnerable to predation during capture and after release. Parker (1985) reported 20% mortality, mostly due to predation, for red snapper caught and released in 20–30 m of water. C&R angling may increase nest abandonment by male smallmouth bass (Philipp et al., 1997) and decrease nest-guarding activity in largemouth bass (Cooke et al., 2000). Diodati and Richards (1996) found that surviving hooked-and-released striped bass were in worse physical condition than control fish. Clapp and Clark (1989) found evidence that the growth rates of surviving smallmouth bass were inversely related to the number of times that the fish were caught-and-released. In contrast, Horak and Klein (1967) found similar stamina levels for caught-and-released and non-exercised rainbow trout suggesting no sub-lethal effects of angling.

Meta-analyses of combined data

Mean mortality for the 274 estimates was 18%, the median 11%, and range 0–95%. The mortality distribution was highly skewed with 46% of estimates below 10% mortality, 23% between 10 and 20% mortality, 9% between 20 and 30%, and 22% of estimates above 30% mortality. Salmonidae comprised 38% of the 274 estimates, followed by Centrachidae (14%), Perichthyidae (12%), reef fishes (11%, Labridae, Lutjanididae, and Serranidae), Sciaenidae (8%), other freshwater fishes (10%, Ictaluridae, Esocidae), and other saltwater fishes (7%, i.e. Centropomidae, Hexagrammidae, Istiophoridae, Pinquipedidae, Pleuronectiformes, and Scrombidae).

Mortality distributions were similar for species grouped as salmonids, marine, or freshwater species, despite taxonomic and environmental differences for these groups (Figure 6). When mean mortality estimates were ordered for all 48 species by increasing values (Figure 7), results

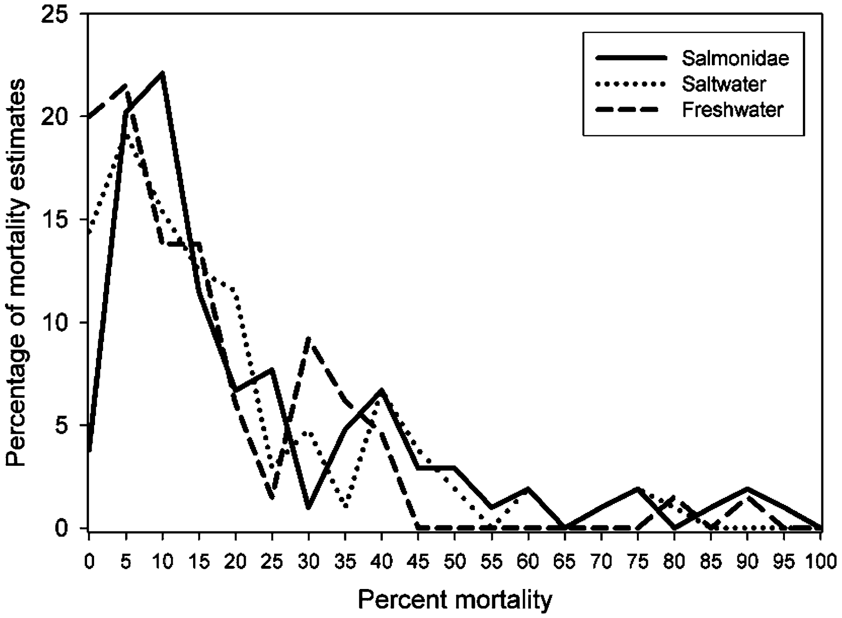

Figure 6. The distribution of reported mortality estimates for salmonids ($n = 106$), freshwater ($n = 65$) and saltwater ($n = 102$) species based on adult stages. Percent of estimates with 0 mortality is shown followed by plots in 5% increments: >0–5.0%, >5.0–10%. etc.

showed a wide range of mortality (0–60%) and individual species widely dispersed over the range for all three groups.

In addition to species differences, 14 other C&R mortality factors were examined (Table 1). In some cases results from combined data differ from the smaller pool of data reported from the more recent studies. Five mortality factors were highly significant ($p < 0.01$, Sign test): hooking in vital organs ($n = 33$ vs. 0 studies), use of natural

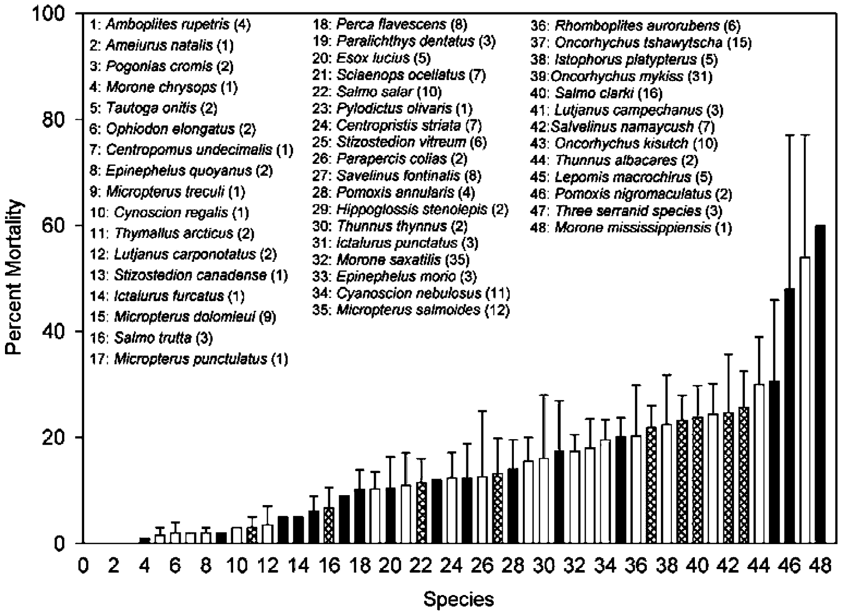

Figure 7. Mean percent mortality (+1 SE) by species in increasing order. Species were classified as freshwater (black bars), saltwater (white bars), or salmonids (hatched bars). Numbers show the number of estimates used for each species.

Table 1. Meta-analysis showing number of paired comparisons of mortality factors associated with catch and release fishing

Total Mortality Comparison		Factor 1 > Factor 2			No difference			Factor 2 > Factor 1			Factor #2	p
		Data source			Data source			Data source				
Variable	Factor #1	Total	M&C 1994	B&B	Total	M&C 1994	B&B	Total	M&C 1994	B&B		
Intrinsic factors												
Hook location	Non-critical tissue	**0**			**0**			**33**	22	11	Critical organ	$p < 0.01$
Fish size	Larger	**7**	5	2	**28**	19	9	**8**	6	2	Smaller	n.s.
Terminal fishing gear												
Bait	Artificial lure	**0**			**11**	6	5	**19**	13	6	Natural bait	$p < 0.01$
Hook size	Large hook	**2**	2		**3**		3	**3**	2	1	Small hook	n.s.
Hook type	Treble hook	**1**	1		**5**	2	3	**5**	4	1	Single hook	n.s.
Hook type	Circle hook	**0**			**2**		2	**5**		5	J-hook	$p < 0.05$
Hook type	Barbless	**0**			**5**	5		**4**	2	2	Barbed	$p < 0.10$
Hook appendage	Present	**0**			**0**			**2**		2	Absent	n.s.
Fishing/release technique												
Deep hook removal	Cut line	**1**	1		**0**			**10**	5	5	Removed hook	$p < 0.01$
Venting	Deflated	**1**	1		**3**	1	2	**4**		4	Not deflated	n.s.
Technique	Active fishing	**0**			**0**			**2**		2	Passive fishing	n.s.
Play/handling time	Less	**0**			**8**	3	5	**6**	1	5	More	$p < 0.05$
Environmental conditions												
Capture depth	Shallow	**0**			**3**	1	2	**12**	6	6	Deep	$p < 0.01$
Water temperature	Cool	**0**			**6**	3	3	**26**	16	10	Warm	$p < 0.01$

Significant mortality factors are in bold.

bait (19 vs. 0, 11 no difference), removing hooks from deeply hooked fish (10 vs. 1), depth of capture (12 vs. 0, 3 no difference), and warm water temperatures (26 vs. 0, 6 no difference). Two factors were significant at $p < 0.05$: J-hooks (vs. circle hooks) (5 vs. 0, 2 no difference), longer playing and handling times (6 vs. 0, 8 no difference).

Barbed hooks were marginally significant ($p < 0.1$) compared to barbless hooks (4 vs. 0, 5 no difference). Factors not statistically significant overall ($p > 0.1$) were fish size (7 large vs. 8 small, 28 no difference), hook size (3 small vs. 2 large, 3 no difference) , venting inflated fish (4 vs. 1, 3 no difference), and treble hooks vs. single hooks (5 vs. 1, 5 no difference). Further analyses of data, however, showed significantly reduced mortality by venting for four species ($p < 0.05$, Figure 8) and significantly higher mortality with J-hooks ($p < 0.05$) than circle hooks (Figure 9). Sufficient data were not available to meaningfully analyze hook appendages ($n = 2$) or active vs. passive fishing ($n = 2$).

Discussion

Fishing trends

In this paper we update previous reviews of catch and release fishing to evaluate and quantify the importance of various mortality factors. This release mortality issue has become more important in the U.S. because state and federal regulatory agencies

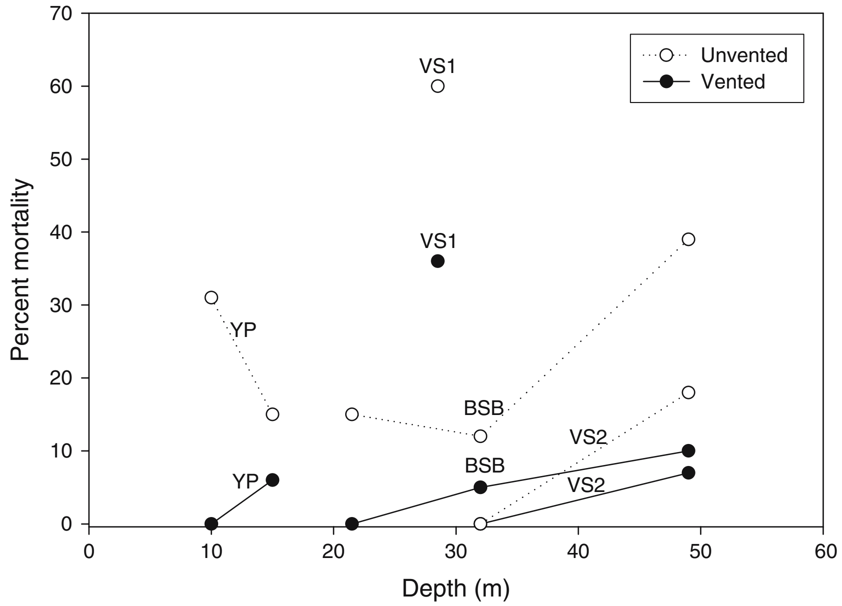

Figure 8. A comparison of mortality for vented and unvented fish by capture depth. Depth is the mid-range of the reported fishing depths. Abbreviations: BSB, black sea bass (Collins et al., 1999); VS1, vermillion snapper (Fable, 1994); VS2,vermillion snapper data (Collins et al., 1999); YP, yellow perch (Keniry et al., 1996).

have increasingly relied on size limits, daily bag or trip limits, quotas, and closed seasons to regulate recreational and commercial fisheries. Also, there is increasing interest and promotion of C&R fishing for its own sake. All these actions have the effect of increasing the number of releases and many enjoy strong support from some fishing sectors (e.g. Nussman, 2005). The ultimate success of all these

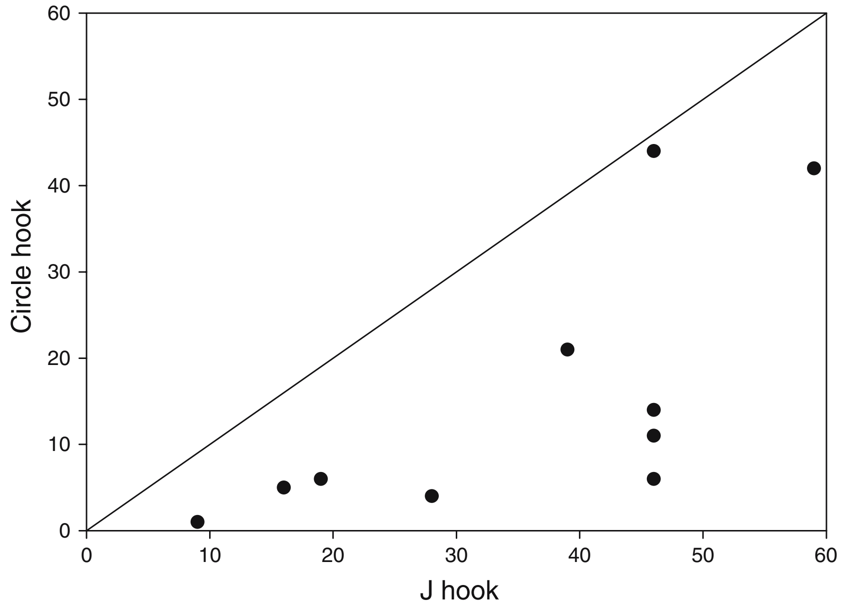

Figure 9. Percent mortality of fish caught on J-hooks compared to circle hooks tested under the same conditions. The solid line through the origin (slope = 1.0) shows expected values if the two hook types had equal mortality. Circle hooks had significantly less mortality than J-hooks ($p < 0.05$, *t*-test). The three stacked points compare three types of circle hooks to a single reference J-hook.

actions depends on ensuring adequate survival rates by minimizing release injury and mortality.

Previous studies have shown that recreational fishing accounts for a major proportion of the total marine landings for many species targeted by recreational and commercial anglers (Department of Commerce 2002, Coleman et al., 2004). MRFSS data show (Figures 1–3) that the proportion of fish caught and released by marine recreational anglers almost doubled in two decades and now exceeds total landings. From 1981 to 1999, no statistically significant changes were detected in total number of marine anglers, total catch, and total catch/angler. However, mean total annual landings, catch/angler/trip, and mean landings/angler/trip all declined significantly. The total annual catch/angler was maintained (+2.2%), despite a 22.1% decline in mean total catch/angler/trip, because anglers compensated by taking 30.8% more total fishing trips. A possibility consistent with the data is that anglers took more fishing trips in response to reduced trip limits. Because our trend analysis was restricted to U.S. marine recreational fishing, these results may not apply to recreational freshwater fisheries or commercial fisheries. Also, the results may not apply to all marine areas because the MRFSS database excludes Texas and a few other areas.

We showed for a recreational fishery in Biscayne National Park that total percentage of releases increased substantially from ~20 to 30% of catch to ~80% for regulated species after new size and bag limits took effect, while percentages of unregulated species did not change (Figure 4). This result, if extrapolated, suggests that the observed increase in the total proportion of releases in MRFSS data is most likely due to mandatory fishing regulations and that voluntary (non-regulatory) actions played a lesser role. Because Biscayne National Park may or may not be representative of other areas, this extrapolation should be considered with caution. Gentner (2002) concluded that 89% of striped bass caught by anglers during 1998 in the Northeast region ($n = 5789$) were released because they could not be legally retained while only 4% were released voluntarily. A possible alternative explanation for the increased proportion of releases is that increasing stock sizes resulted in more younger and smaller fish being caught and released by anglers. If true, then total catch should eventually increase. The fact that total catch did not increase significantly in MRFSS data, discounts the generality of this alternative explanation.

We also showed that a predicted short-term response to larger minimum size regulations in a commercial reef fish fishery was an increase in the total number of required releases from 10 to 38% for red porgy, 14 to 57% for gag, 43 to 58% for red grouper, and 51 to 70% for red snapper (Figure 5). These projected short-term responses, may not necessarily reflect long-term responses due to changes in the fishery or population recruitment, but emphasize the shared concern about release survival for recreational and commercial fisheries even though the two fisheries may differ in motivation, gear, or release practices.

Release mortality factors

The expansion of C&R fishing increases the importance of understanding and minimizing C&R mortality. This study has more than doubled the total number of estimates used to evaluate mortality since the Muoneke and Childress (1994) review and gives statistical support for many of their conclusions. Average mortality was 18% ($n = 274$), but was highly skewed (median = 11%) and varied greatly by species. The fact that mortality distributions were similar for salmonids, marine, and freshwater species was surprising considering the different taxa and their environments.

In the meta-analysis, seven of 14 mortality factors were significant: hook location, natural bait, removing hooks from deeply hooked fish, J-hooks, depth of capture, warm water temperatures, and extended playing and handling times. Some of these factors, such as depth and temperature, likely influence observed mortality differences among species. Within species, hooking location was the most important mortality factor. Fish hooked in critical locations (esophagus, gills, brain, stomach and in some cases the eyes) invariably had increased mortality (Taylor and White, 1992; Malchoff and MacNeill, 1995). Factors shown in the literature to influence hooking location include type of bait, terminal gear, and fishing technique.

Natural bait appears to increase the risk of deep hooking because fish are more likely to ingest natural bait and reject artificial lures or flies (May, 1973; Warner and Johnson, 1978; Diggles and Ernst, 1997). Cutting the line on deeply hooked fish significantly increased survivorship because attempting to retrieve deeply ingested hooks may cause further internal injuries. Many deeply hooked fish have been shown to eventually shed the hooks themselves.

Circle hooks can effectively reduce deep hooking and mortality compared to J-hooks for many species, although some species suffer greater injury with circle hooks (Cooke and Suski, 2004). Circle hooks are more likely to lodge in the corner of a fish's mouth and do less damage than J-hooks, which are more likely to hook in the gut. Even if the bait is swallowed, fish generally do not get hooked with circle hooks until the eye of the hook clears the mouth. Since circle hooks usually lodge in the corner of the mouth, they are usually easy to remove, reducing handling time and stress.

Capture depth was important. Internal injuries from swim bladder expansion include protrusion of the intestines through the anus and the stomach through the mouth, and "popeye" in which the eyes are forced outward. Species vary in susceptibility to injury based upon their anatomy. Physostomous fish, which have a pneumatic duct connecting the gas bladder and the digestive tract, have higher survivorship than physoclistous fish which lack this duct (Hogan, 1940). Lingcod, which do not have a gas bladder, do not suffer expansion-related injuries (Albin and Karpov, 1998). Evidence suggests that puncturing fish with expanded swim bladders or releasing the trapped gasses with a hypodermic needle can be effective in reducing release mortality if properly performed (Figure 8), but more research is needed to support this idea. Venting relieves pressure on the internal organs and allows fish to return to depth or sink to the bottom after release, rather than floating on the surface where they are extremely vulnerable to fish and bird predators.

Mortality increased with warmer water temperatures. At higher temperatures dissolved oxygen concentration decreases while fish respiratory demands increase. This combination can increase physiological stress from C&R fishing (Muoneke and Childress, 1994; Lee and Bergersen, 1996). Higher temperatures were associated with hypochloremia and hyperglycemia in rainbow trout (Wydoski et al., 1976) and increased levels of plasma cortisol and lactate in striped bass (Tomasso et al., 1996). Also, injuries may be more susceptible to infection in warmer water (Muoneke, 1992a).

Long handling and playing times increase physiological stress (Wood et al., 1983) and are particularly detrimental when combined with high water temperatures (Tomasso et al., 1996; Wilkie et al., 1996). Handling out of the water stresses fish by depriving them of oxygen during the critical period immediately after heavy exertion (Ferguson and Tufts, 1992) and can lead to longer recovery times (Cooke et al., 2001). Experienced anglers using good handling techniques may potentially reduce air exposure and improve survivorship, but in many cases handling did not make a difference in mortality. Based on our analyses, angler education on proper handling and release techniques could potentially reduce C&R mortality. Handling practices to encourage include: (1) fishing actively and setting the hook as soon as possible, (2) avoid playing the fish for long periods of time, (3) use de-hooking tools (4) leave fish in the water when removing hooks, (4) avoid touching gills and handling the soft underbelly of the fish, and (5) leaving the hook in deeply hooked fish (Malchoff and MacNeill, 1995; Schisler and Bergersen, 1996; Wilde et al., 2000).

Barbless hooks had marginally less mortality than barbed hooks perhaps because they are easier to remove which reduces handling, air exposure, and injury (Cooke et al., 2001). Fish size and hook size were not significant in the meta-analyses. Large hooks may be harder to swallow than small hooks, but may cause greater tissue damage at the wound site (Pauley and Thomas, 1993; DuBois et al., 1994). Gjernes et al. (1993) speculated that the greater depth and gape of larger hooks may lead to deeper hook penetration and greater risk of contact with critical organs.

Too few studies were available to assess mortality associated with treble hooks, passive fishing, hook appendages and venting inflated fish. Treble hooks may cause less mortality than single hooks because they are more difficult to swallow (Klein, 1965; Muoneke, 1992b), but may cause more tissue damage at the hooking location (Muoneke, 1992b; Nuhfer and Alexander, 1992). Treble hooks also may be more difficult for anglers to remove,

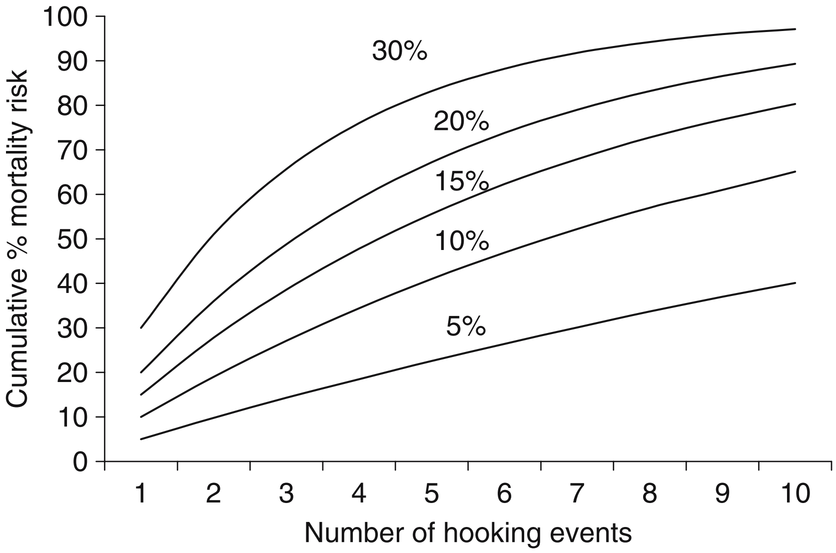

Figure 10. Predicted cumulative release mortality as a function of the number of release events and mean mortality per event.

resulting in detrimental increases in handling time and air exposure (Nuhfer and Alexander, 1992; Gjernes et al., 1993).

We found almost no data on sub-lethal effects of C&R fishing which can increase fish susceptibility to injury or mortality from predation, disease, and parasites (Wydoski, 1977). After release and heavy exertion, fish may require a substantial recovery period during which they exhibit reduced fitness or altered behavior that makes them more susceptible to predation and disease (Cooke et al., 2001). Also, we found that many studies estimated release mortality by releasing fish into pens immediately after capture. Such studies underestimate actual mortality by excluding predators during this vulnerable recovery period (Diggles and Ernst, 1997; Carbines, 1999). Although predation by birds, fish, and marine mammals is commonly reported during capture or after release, this source of mortality has rarely been quantified.

A necessary consequence of greater use and more restrictive bag, trip, and size limits, and seasonal closures is an increased total number of C&R encounters and the risk of cumulative mortality. We found no studies of cumulative mortality from multiple C&R events for individual fish. This risk is an especially important for long-lived species and populations subject to intense fishing pressure (Musick, 1999). Our cumulative mortality model (Figure 10) shows that total mortality rises rapidly in response to repeated releases based on the mortality probability per event. For example, a red grouper with a 12% chance of mortality per release has a 72% cumulative probability of dying after 10 events. At high angling encounter rates, release mortality could approach certainty, especially for species with life spans lasting decades (Plan Development Team, 1990; Coleman et al., 1999). Evidence that multiple C&R events are common in some fisheries comes from tagging studies that report high recapture rates and short recapture intervals. A tagging study of sub-legal sized reef fish in Florida, for example, reported an average recapture period of only 39 days for red grouper, 56 days for gag, and 50 days for gray snapper (Burns, 2002). Also, multiple recaptures represented 13% of red grouper recaptures (maximum seven for one individual), 13% for gag grouper, (maximum four recaptures), and 6% for red snapper (maximum three recaptures).

Implications for NTRs

'No-take' marine reserves are defined as "areas of the sea in which all fishing and extractive activities are banned, other human interference is minimized, but where people are welcome to view, study and enjoy the area." (Ballantine, 1994). Their primary goal is to maintain in full the natural life and processes in the sea. In practice, marine reserves are permanently closed to fishing and other extractive uses with limited exceptions for scientific research and education by permit (Ballantine, 1997; Bohnsack et al., 2004). Reserves function by protecting specific sites from all directed fishery and bycatch removals, and habitat damage from fishing (Tasker et al., 2000).

Over 30 potential benefits of NTRs have been described in four primary categories: protection of ecosystem structure, function and integrity; increased scientific and public knowledge and understanding of marine systems; enhancement of non-consumptive opportunities; and providing fishery benefits (Plan Development Team, 1990; Bohnsack 1998; Bohnsack et al. 2004). Allowing exploited species to accumulate and grow in reserves can benefit fisheries by creating refuges that make overfishing more difficult and allow rare and vulnerable species to persist in multi-species fisheries (Yoklavich, 1998). They also insure against catastrophic stock collapse from recruitment failure (Bohnsack, 1999) and potentially protect the genetic diversity of exploited populations from the selective effects of fishing (Plan Development Team, 1990; Bohnsack, 1999; Trexler and Travis, 2000; Conover and Munch, 2002). Reserves also act as control areas for scientific study of natural processes and for evaluating the effectiveness of fishery management. In overfished fisheries, NTRs can potentially increase yield by supplying more recruits to fishing grounds from increased reproduction within reserves and by exporting biomass from reserves into adjacent fished areas (Bohnsack, 1992; Russ and Alcala, 1996; McClanahan and Manoi, 2000; Roberts et al., 2001).

C&R fishing is an important activity, but does cause some disturbance, injury, and mortality which may conflict with some goals of NTRs. The common occurrence of release mortality for some species, for example, can jeopardize goals of promoting the survival of large individuals which provide a disproportionate contribution to overall egg production (Roberts and Hawkins, 2000; Berkley et al. 2004) and protecting population genetic structure (Trexler and Travis, 2000; Conover and Munch, 2002). Even if mortality is low for individual hooking events, cumulative mortality from C&R angling in NTRs could be damaging, particularly for long-lived species (Figure 10). Increased popularity of C&R angling could attract enough anglers to effectively negate the population benefits of reduced mortality from C&R angling compared to extractive fishing. Allowing C&R fishing in NTRs makes surveillance and enforcement more difficult because simply detecting the act of fishing is no longer sufficient evidence of a violation (Plan Development Team, 1990). Concerns about total fishing effort, enforcement, and cumulative mortality suggest using caution and a precautionary management approach until a better understanding of C&R fishing is obtained (Dayton et al., 1995; Dayton, 1998; Bohnsack, 1999).

Zones allowing C&R fishing could be created for allocation purposes in addition to, but not instead of, NTRs because the two are not equivalent. C&R zones could potentially reduce conflicts between commercial and sport fishing, expand recreational fishing opportunities, and provide some protection for exploited fish if fishing mortality is reduced within their boundaries compared to areas with extractive fishing. Support for this possibility comes from Anderson and Nehring (1984) who compared the length–frequency distributions of rainbow trout in three sections of the South Platte River, where one section was open to traditional fishing, one was open to C&R fishing only, and one was closed to fishing. They found that fish sizes in the C&R section were intermediate between the fully exploited and unexploited sections.

Implications for fisheries

Fisheries are often compared or evaluated in terms of total landings (Coleman et al., 2004; Nussman, 2005). However, direct comparisons can be problematic because commercial landings are measured in weight and recreational landing are measured in numbers and then converted to weight (Department of Commerce, 2000). Weight comparisons alone can obscure the importance of size and age structure, total numbers, or reproductive potential. Landings also do not accurately reflect total mortality or fishing impacts in some fisheries because they do not directly reflect release mortality. Our results indicate that release mortality represents a considerable portion of total fishing mortality in some fisheries. Assuming the mean 18% mortality reported in this study, for the example, the 80% release rate for gray and yellowtail snapper in Biscayne National Park (Harper et al., 2000) is equivalent to 72% of landings in numbers. Our results also indicate that many reported mortality estimates probably underestimate actual mortality, at least for marine species, because they rarely include predation during capture and after release, or consider cumulative mortality from multiple releases.

We have shown that C&R fishing has grown substantially as a total proportion of marine fishing over the last two decades. C&R fishery strategies are based on the principle that short-term lost yield from releasing fishes is compensated for in the long-term by increased yield from growth of released fish; increased numbers of recruits from greater spawning per recruit; or in the case of C&R fisheries, increased total numbers of C&R encounters. The effectiveness of C&R strategies depends on achieving adequate release survival. Increased regulatory use of more restrictive minimum sizes, slot limits, bag limits, quotas, and seasonal closures at some point can be expected to face reduced effectiveness because all these measures require more releases and risk higher total mortality.

Research needs

Further research is needed to better understand the impacts of C&R fishing. General needs are to: (1) provide more accurate mortality estimates for different species, conditions, and fishing practices, including predation during capture and after release; (2) improve technology to avoid injury and capture of unwanted individuals; (3) develop better techniques to increase release survival; (4) determine cryptic mortality from predation during capture and after release; (5) assess angling encounter probabilities and the cumulative effects of multiple hookings; and (6) evaluate sub-lethal effects on behavior, physical condition, growth, reproduction, and vulnerability to disease and parasites after release.

A need exists to develop and evaluate innovations in hook design to reduce deep hooking mortality. This includes further exploration of whether treble hooks reduce mortality relative to single hooks. A promising recent innovation is the use of wire appendages extending outward from the shank to make hooks harder to swallow, especially for smaller fish. Willis and Millar (2001) showed that hook appendages reduced the incidence of critical hooking in a commercial

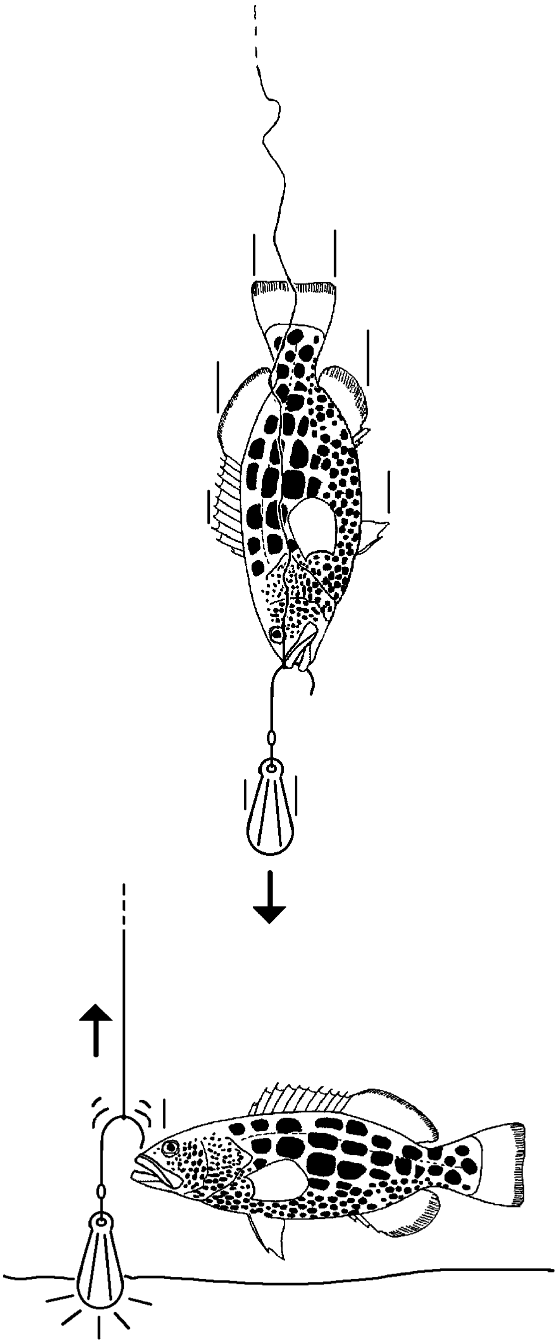

Figure 11. A weighted release device to release fish at depth. Rapid descent reduces risk of predation, repressurizes a fish without puncturing internal organs, and reduces exposure to warmer surface water.

line fishery for sparid snapper without significantly changing the landed weight of exportable sized fish. They concluded that using hook appendages could greatly reduce discard mortality.

Although we found no studies of their effectiveness, another potential way to release fish with expanded air bladders is the use of "release sinkers" (Anonymous, 1993; Bohnsack, 1996). One device consists of a line attached to a weighted, barbless hook passed through the upper jaw of a fish to be released. The weight rapidly takes the fish to depth where it is re-pressurized, reducing the volume of the air bladder. A sharp tug on the line releases the fish, and the weighted rig is retrieved for future use (Figure 11). Potential advantages of this device are that fish do not need to be punctured, risking further injury, and the rapid return to depth reduces their risk of predation and exposure to thermal stress at the surface.

Although we are optimistic that research may develop better techniques and tools to reduce C&R mortality, some factors will be difficult or impossible to overcome, including differences among species, vulnerability to predation, and environmental conditions, such as depth and warm water temperatures.

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Appendix A. Percent release mortality (% M) reported in 142 trials involving 32 taxa in 53 catch-and-release mortality related studies since Muoneke and Childress (1994)

Family/species	% M	Depth (m)	Temp. (°C)	Length (cm) mean/range	Gear	Experimental conditions	Reference
Esocidae							
Esox lucius							
Northern pike	1	25 max	–	46 (33–76)	Treble hook		DuBois et al. (1994)
	33				Single hook	Large hook	
Salmonidae							
Oncorhynchus kisutch							
Coho salmon	14	–	10–14	–	Barbed single lure	Trolling	Gjernes et al. (1993)
	16				Barbed treble lure		
	17				Barbless single lure		
	6				Barbless treble lure		
Oncorhynchus mykiss							
Rainbow trout	87	1 max	6–10	20	Lure	Played to exhaustion	Bouck and Ball (1966)
Rainbow trout	10	–	Cool	25	Lures and artificial flies	May–June	Klein (1966)
	11					July	
	16		Warm			August	
	22					September	
Rainbow trout	8	–	19–20	–	Artificial flies	Played to exhaustion	Horak and Klein (1967)
Rainbow trout	0	–	8	25	Artificial flies	Played to exhaustion	Dotson (1982)
	3		9	22			
	3		11	25			
	5		15	24			
	6		15	17			
	9		16	24			
Rainbow trout	12	–	15	300–500 (grams)	Not hooked, just exercised	Exercised	Ferguson and Tufts (1992)
	38					Exercised + 30 s in air	
	72					Exercised + 60 s in air	
Rainbow trout	0	–	–	53	–		Pankhurst and Dedual (1994)
Rainbow trout	16	3 max	12 (10–14)	> 10	Single hook		Schill (1996)
Rainbow trout	4	–	4–17	20–40	Flies	Line attended	Schisler and Bergersen (1996)
	22				Single hook	Line unattended	
	32				Single hook	Line unattended	
Oncorhynchus tshawytscha							
Chinook salmon	35	–	10–14	–	Barbed single lure	Trolling	Gjernes et al. (1993)
	40				Barbed treble lure		
	23				Barbless single lure		
	23				Barbless treble lure		
Chinook salmon	12	–	–	41–75	Single hook and lure	Male	Bendock and Alexandersdottir (1993)
	3			75–121		Male	
	6			59–116		Female	

Appendix A. Continued.

Family/species	% M	Depth (m)	Temp. (°C)	Length (cm) mean/range	Gear	Experimental conditions	Reference
Chinook salmon	42	–	–	< 66	Barbless circle hook		Grover et al. (2002)
	59				J hook		
Oncorhynchus clarki							
Cutthroat trout	40	–	9–21	–	Single hook	#10	Pauley and Thomas (1993)
	47				Single hook	#6	
	58				Single hook	#2	
	41				Single hook	#1	
	24				Lure, treble hook	No bait	
	11				Lure, treble hook	Baited	
	16				Lure, single hook	No bait	
Salvelinus namaycush							
Lake trout	9	8–15	–	46 (8–62)	Single and treble hook	Active jigging	Persons and Hirsch (1994)
	32				Single hook	Passive set line	
Lake trout	12	–	Lower	56–89	Lures and hooks	Higher DO_2	Lee and Bergersen (1996)
	88		Higher	64–84		Lower DO_2	
Salmo salar							
Atlantic salmon	0	2 max	5–7	–	Fly, played to exhaustion	Hook manually inserted in jaw	Booth et al. (1995)
Atlantic salmon	40	–	22	< 63	Fly, played to exhaustion	Hook manually inserted in jaw	Wilkie et al. (1996)
Hexagrammidae							
Ophiodon elongates							
Lingcod	4	6–47	–	28–69	Single hook, lure	Rod and reel	Albin and Karpov (1998)
	0	40–64		46–61	Lure	Trolling	
Centropomidae							
Centropomus undecimalis							
Common snook	2	–	22–30	60 (20–110)	Various		Taylor et al. (2001)
Percichthyidae							
Morone saxatilis							
Striped bass	14	–	12	67 (51–84)	Single hook		Bettoli and Osborne (1998)
	44				Artificial lure		
Striped bass	12	–	26–32	10–15	Treble hook	Critically hooked fish not used in mortality estimate	Tomasso et al. (1996)
	5–7		16–19				
Striped bass	0		–	< 51	Various		Malchoff and MacNeill (1995)
	3			51–71			
	33			> 71			
Striped bass	9	3	15–28	27–55	Lures and single hook		Diodati and Richards (1996)

Appendix A. Continued.

Family/species	% M	Depth (m)	Temp. (°C)	Length (cm) mean/range	Gear	Experimental conditions	Reference
Striped bass	0	–	16	–	Single hook		Nelson (1998)
	0		18		Single hook		
	7		20		Single hook		
	20		22		Single hook		
	27		24		Single hook		
	0		16		Lures		
	19		18		Lures		
	7		20		Lures		
	18		22		Lures		
	13		24		Lures		
Striped bass	1	–	–	42 (27–93)	Circle hook		Lukacovic (2000)
	9				J-hook		
Striped bass	6	–	–	–	Circle hook		Lukacovic (2001)
	19				J-hook		
Striped bass	11	–	–	54	Circle hook	Deep hooked	Lukacovic and Uphoff (2002)
	46			56	J hook		
Serranidae							
Centropristis striata							
Black sea bass	15	20–23	–	–	Single hook	Not deflated	Collins et al. (1999)
	0	20–23				Deflated	
	12	29–35				Not deflated	
	5	29–35				Deflated	
	39	43–55				Not deflated	
	10	43–55				Deflated	
Epinephelus morio							
Red grouper	12	87	–	< 51	Circle hooks	Longline	NMFS (1995)
	13			> 51			
Red grouper	29	44	–	28–66	"Hook and line"	Fish repressurized on-deck	Wilson and Burns (1996)
Epinephelus quoyanus							
Wire netting cod	1	1–2	23	30 (23–37)	Lure		Diggles and Ernst (1997)
	3				Single hook		
Red grouper scamp	8	44	–	–	"Hook and line"	Fish lowered to bottom in cages	Wilson and Burns (1996)
Myctoperca phenax and gag	75	54					
Myctoperca microlepis	79	75					
Centrachidae							
Micropterus dolomieui							
Smallmouth bass	0	7 max	4–16	31	Lure	Unscented	Dunmall et al. (2001)
	0				Lure	Scented	
	0				Single hook		
Amboplites rupestris							
Rockbass	0	–	–	–	Lure	Barbed	Cooke et al. (2001)
	0				Single hook	Barbed	
	0				Lure	Barbless	
	0				Single hook	Barbless	

Appendix A. Continued.

Family/species	% M	Depth (m)	Temp. (°C)	Length (cm) mean/range	Gear	Experimental conditions		Reference
Pericidae								
Perca flavescens								
Yellow perch			18–20	–	Not hooked, caught with nets	Decomp.	Punct.	Keniry et al. (1996)
	31	10				No	No	
	15	15				No	No	
	12	10				Yes	No	
	14	15				Yes	No	
	0	10				No	Yes	
	6	15				No	Yes	
	2	10				Yes	Yes	
	2	15				Yes	Yes	
Stizostedion canadense								
Sauger	5	9 (5–18)	10 (7–12)	35 (22–48)	Single hook and lure			Bettoli et al. (2000)
Lutjanide								
Rhomboplites aurorubens								
Vermilion snapper	0	29–35	–	–	Single hook	Not deflated		Collins et al. (1999)
	0	29–35				Deflated		
	18	43–55				Not deflated		
	7	43–55				Deflated		
Vermilion snapper	60	27–30	–	–	“Rod and reel”	Not deflated		Fable (1994)
	36					Deflated		
Lutjanuscar ponotus								
Yellow stripey	0	1–2	23	26 (16–37)	Lure			Diggles and Ernst (1997)
	7				Single hook			
Lutjanus campechanus								
Red snapper	17	43 (13–96)	–	10–91	–	23% of “survivors” swam erratically and may have died soon after release		Dorf (2000)
Red snapper	20	21	–	–	–			Render and Wilson (1993)
Red snapper	36	50	–	25–43	–	Repressurized by lowering in cages		Gitschlag and Renaud (1994)
Sciaenidae								
Cyanoscion nebulosus								
Spotted seatrout	5	–	18–31	19–47	Single hook			Murphy et al. (1995)
Spotted seatrout	16	–	21–37	< 35.5	Single hook	Culture ponds		Duffy (2002)
	14				Treble hook			
	15				Single hook			
	9				Treble hook			
Cynoscion regalis								
Weakfish	3	–	24 (22–27)	30–45	Single hook or lure			Malchoff and Heins(1997)

Appendix A. Continued.

Family/species	% M	Depth (m)	Temp. (°C)	Length (cm) mean/range	Gear	Experimental conditions	Reference
Sciaenops ocellatus							
Red drum	2	–	23–38	< 40.6	Single hook	Culture ponds	Duffy (2002)
	10				Treble hook		
Labridae							
Tautoga onitis							
Tautog	0	< 10	–	37	Various hooks		Lucy and
	3	11–17					Arendt (2002)
Scombridae							
Thunnus thynnus							
Yellowfin tuna	21	–	–	–	Circle hook	Pelagic longline	Falterman and
	39				J hook		Graves (2002)
Thunnus thynnus							
Atlantic bluefin tuna	4	–	–	–	Circle hook	Assumed mortality	Skomal et al.
	28				J hook	based on hook location	(2002)
Istiophoridae							
Istiophorus Platypterus							
Sailfish (Pacific)	2	–	–	–	Circle hook	Mortality based upon % deep hooked	Prince et al. (2002)
Sailfish (Atlantic)	46				J hook		
	44				Circle hook, 15° offset		
	14				Circle hook, 4° offset		
	6				Circle hook, no offset		
Pleuronectiformes							
Hippoglossus stenolepis							
Pacific halibut	20	–	–	–	Small cod-style hook	Groundfish longline	Trumble et al.
	11				Large halibut hook		(2002)
Paralichthys dentatus							
Summer flounder	10		17–21	20–65	J and circle hooks		Malchoff et al. (2002)
Summer flounder	5	–	–	–	Circle hook	Mortality based upon	Zimmerman and
	16				J hook	% critically hooked	Bochenek (2002)
Pinquipedidae							
Parapercis colias							
Blue cod	25	–	–	29 (23–33)	Single hook	Small	Carbines (1999)
	0					Large	

Experimental conditions are factors that could have influenced mortality results. Release mortality rounded to nearest one percent; lengths rounded to nearest cm. “Depth” is capture depth unless indicated as “max”, which is the reported maximum water body depth in which angling occurred. Data exclude “control” trials from individual studies.