15 Recreational Fishing

Chapter Summary
The definitions of recreation fishing and the numbers involved are discussed in this chapter. The direct impacts on fish stocks, on endangered fish species through trophy fishing, on size selection and fish community structure, including truncation of age and size structure, are reviewed. There is a loss of genetic diversity and evolutionary changes. Discards and catch-and-release impacts and the effects of invasive, non-native species are discussed. There are a series of indirect impacts such as habitat disturbance, walking tracks, off-road vehicles, effects on wildlife, loss of fishing gear, boat strikes, nutrient impact, pollution, plastics and pathogen transmission. The management of recreation fishing impacts such as the use of marine protection areas, best practice guidelines and codes of conduct, and the education of practitioners, including mandatory programmes, are reviewed.

15.1 Introduction

Overfishing throughout the world is a major ecological problem with much reduced fish stocks and individual fish species threatened with extinction. There is no doubt that commercial fishing has played a major role in this problem and it is clear there have been dramatic effects from commercial fisheries on marine fish stocks and marine ecosystems, but what seems to have been ignored to some extent is the potential role of the other major fishery sector to contribute to this crisis: recreational fishing. Furthermore, previous analyses have focused exclusively on marine environments, with little consideration of the role of freshwater fisheries. However, Cooke and Cowx (2004) outline the reasons why this has happened and suggest that failure to recognise the contribution of recreational fishing to fishery declines, environmental degradation, and ecosystem alterations places ecologically and economically important resources at risk. So we will see that the same issues that have led to commercial fisheries concerns have the equivalent and sometimes magnified impacts in recreation fisheries. The over-exploitation of fish stocks has also affected traditional activities such as small-scale artisanal fishing in some parts of the world by reducing the availability of catches. Artisanal fishing is usually operated by relatively small vessels typically fishing three nautical miles from the coast in, for example, the Mediterranean, with considerable cultural and historical significance, but is now declining in many areas with a downward trend in the number of vessels, licences, catches, and net revenues. The interacting impacts of artisanal and recreation fisheries have been described by Prato et al. (2016).

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In this chapter it is a hope to outline aspects of these ecological problems by considering the environmental impacts of recreational fishing, some of the management techniques and solutions and approaches to educating the recreational fishing community about related topics.

15.2 Definition of Recreational Fishing

Recreational fishing is where aquatic animals that do not constitute the individual's primary resource to meet nutritional needs and are not generally sold or otherwise traded on export, domestic, or black markets are caught. This definition is sufficiently broad to include other animals beyond fish (e.g. invertebrates such as lobster and crabs); it avoids pointing to individual motivations (fun, sport, enjoyment, thrill of the catch, social bonding), does not discriminate against particular methods of fish capture (e.g. recreation rod and line angling vs. recreation gill netting, which is an important recreational fishing activity in some countries), does not preclude the catch being taken for personal consumption (as long as the catch does not become the primary resource to meet essential physiological needs), does not discriminate against non-Western cultures, but does discriminate commercial and purely subsistence fishing (artisanal) from recreational fishing. It is acknowledged that the unambiguous demarcation between pure recreation fisheries and pure subsistence fisheries is impossible because many recreation fishers have strong subsistence-like incentives to harvest fish. However, using fishing activity to generate resources for livelihoods marks a clear differentiation between recreation fisheries and pure subsistence fisheries, and, as a rule, recreation fishers have the capacity to substitute the products of their fishing experience by other products to meet nutritional needs. Globally, angling is by far the most common recreational fishing technique, which is why recreational fishing is often used synonymously with (recreation) angling.

Hence recreation or sportfishing is defined as fishing for pleasure, as opposed to commercial fishing for income or subsistence fishing for survival. Angling is typically conducted with a rod, reel, and line with a baited hook, lure, or fly attached. Some recreational fishing is conducted with a spear, net, or bow and arrows. In addition to finfish, recreation fishers collect crustaceans by net or trap; molluscs by hand, rake, or shovel; and frogs and turtles by net. Fishing may occur from the shore of the water body, by wading in shallow waters (Fig. 15.1), or from watercraft ranging in size from large multi-passenger, live-aboard ocean-going ships, to single-passenger kayaks and other small boats.

15.2.1 Types of Recreational Fishing

The main forms of recreational fishing according to the National Survey of Fishing (2011) are shoreline (49.9%), boat (48.3%), riverbank (43.0%), and kayak fishing (3.9%). However, the terminology can be confusing. For example, coarse fishing is a term used in the UK and Ireland for fishing for game fish (like barbel, carp, pike, perch, roach, bream) which are not salmonids whilst game fishing is angling for freshwater salmonids (particularly salmon, trout, and char) using a fly-fishing technique (Fig. 15.1). However, there is no taxonomic basis for the distinction between coarse and game fish. Sportfishing includes fly fishing (Fig. 15.1), coarse and game fishing, and if it takes place offshore, for fish like marlin, tuna, sailfish, and shark, it might be called big-game fishing (Fig. 15.2). Tailrace fishing is angling immediately below natural, or man-made dams, or where there are restrictions in water flow on rivers and canals. There are other types of fishing like ice fishing which are carried out by very low numbers of recreation fishers.

15.3 Numbers of Recreation Fishers

Estimates for recreation fishers worldwide vary between 220 and 700 million (FAO212, World Bank 2012), but accurate figures are not easy to collect and different ages are used in different surveys which make comparisons difficult. In Australia there were 3.36 million in 2001 or

Fig. 15.1 Fly fishing on River Sava, Bohinjka, Slovenia. Photo by Ziga

Fig. 15.2 Trophy fishing for striped blue marlin, caught off Cabo San Lucas, Baja California. Photo by Kate Crandell

19.5% of the population, although in Western Australia this figure was estimated to be one third of the population, whilst in Canada in 2005 over 3.2 million adults bought licences which was about one in every ten adults. This number though was as high as one third of the population in Newfoundland and Labrador. The trends show that the numbers had decreased by 2% during the period 1995–2005 whilst the total days fishing declined, but the number of days fished per angler stayed the same (Hoffman 2009). In the USA Cordell (2012) suggested that the numbers had fallen 15% from 1996 to 2006, although 30 million of the 229 million citizens over 16 years of age (i.e. one in every eight) went fishing in the latter year. This was made up of 25.4 million freshwater and 7.7 million saltwater anglers.

In the Topline Survey (2017) for the USA, fishing was the second most popular activity with 14.6% of the over 25 year olds participating (31.5 million), whilst in terms of frequency of participation, fishing was third overall with 40.1 average outings and a total of 628 million. Figures were also gathered for 6–24 year olds where fishing was the third most popular activity with 19.5% participating (15.6 million), a total of 16.1 average outings per person and a total of 252.4 million. The two types of fishing which showed growth were kayak fishing up to 38% in the period 2013–2016 to 2.371 million participants and fly fishing which had a 6% growth 2015–2016. The figures for both saltwater and freshwater had declined slightly from 2006 to 2016. In 2013 almost 46 million Americans fished, or 15.8% of the population aged 6+ (Outdoor Foundation 2014) and for the first time since 2010 this was a loss of 1.2 million. However in 2017 there was a net gain of 1.5 million, with a total for freshwater 38.1 million, saltwater 12.3 million, and fly fishing 6.5 million. There are regional variations too in the USA with figures declining for the Great Lakes and increasing for Colorado where there was a 36.4% participation rate in 2011, with over 26 million activity days. In the estimates to 2060 produced by Bowker and Askew (2012), the fishing participation rate is expected to fall from 30.9% to around 28% of the population, although in total numbers the estimates are a growth between 27% and 56% because of population growth, depending on a series of factors, including climate change. The projected increase in fishing days/year is likely to exceed 200 million.

Overall on a global basis, rates for recreational fishing are variable and can exceed 45% of the population for some Scandinavian countries, like Finland, and every tenth European Union citizen goes fishing, with the global average about 11% (Arlinghaus and Cooke 2009). In Australia 20% of residents aged 5+ in 2015 took part in recreational fishing at least once within the last year, 20% in freshwater, and 35% in estuarine ecosystems.

In the UK it is estimated that the figure for recreational fishing is 4.2 million, about 9% of the population in England and Wales (Simpson and Mawle 2010), although in Wales the figure was between 10% and 12% between 2008 and 2014 (Wales Outdoor Recreation Survey 2015). Arkenford (2014) though put the total at 1.135 million (2.1%) for 16+ for the UK whilst according to the Environment Agency there were 1.4 million rod licences sold to freshwater anglers in England and Wales (2010–2011). This figure is rather less than the 2.3 million estimate for freshwater anglers during 2009 (Simpson and Mawle 2010). For 2012 Armstrong et al. (2013) estimated over 1.08 million sea anglers for the UK, a figure much less than the 1.9 million of sea anglers estimated by Simpson and Mawle (2010).

15.4 Direct Impacts of Recreational Fishing

Due to this large population of recreation fishers, it is no real surprise that there are a whole raft of direct and indirect impacts of this fishing on the fish populations, on the ecosystems in which they live, and on the overall environment. These range from effects on fish stocks, through evolutionary changes, disease and pathogen transmission to pollution. However, each mode of fishing, such as shore or boat fishing, is implicated in a variety of ecological impacts that are specific to each one.

15.4.1 Effects on Fish Stocks

In terms of biomass, recreational fishing has been estimated to take up to 12% of global fish catches (Cooke and Cowx 2004) which does not seem a large figure, and there seem to be few documented declines to fish stocks in recreation fisheries. However, Post et al. (2002) documented four in Canada that showed evidence of dramatic declines which were attributed to recreational fishing: lake trout, walleye, northern pike, and rainbow trout. These were largely unnoticed by the fisheries managers and it seems

Table 15.1 Comparative catches of species shared by recreation and commercial fishers in various Australian studies

Location	Species	Recreational catch (tons/year)	Commercial catch
SE Queensland	Snapper	148	50
Metropolitan Adelaide waters	King George whiting	48.5	15.4
Fraser Island (Queensland)	Tailor	180	25–55
Richmond and Clarence Rivers (New South Wales)	Yellowfin bream, dusky flathead	70	54
Pumicestone Passage (Queensland)	Yellowfin bream, dusky flathead, and sand whiting	43.1	0
Leschenault Estuary (Western Australia)	Blue swimmer crab	45.7	2.8
Eastern Gulf of Shark Bay (Western Australia)	Snapper	100	3
Greater Metropolitan Perth	Tailor	651	7
Port Phillip Bay (Victoria)	Mixed inshore species including snapper and King George whiting	469	482

that this may well be widespread in recreation fisheries, and it was concluded that recreation and commercial fisheries were not inherently different, with both having the potential to affect fisheries negatively. In Australia in the eastern Gulf of Shark Bay (Western Australia), the biomass of snapper was estimated to be only 2–10% of the original virgin stock and that recreational fishing was thought to be the main cause. This can be seen from Table 15.1 where the comparative catches of species shared by recreation and commercial fishers are shown. In North America the NOAA (2009) landings data show 13.3 million pounds of red drum (*Sciaenops ocellatus*) caught compared to only 200,000 pounds by their commercial counterparts. The discrepancies may not be that large, and, for example, recreation fishers took 319 t of the West Australia Dhufish in 2005/2006 compared to commercial fishers who took 163.9 t, 66% of the catch. However, this fish is typically long-living and slow breeding and highly susceptible to overfishing. Where the harvest rates exceed sustainable levels of a target species and affect the abundance and size structure, this is called growth overfishing, and with continued or extreme overfishing, this can affect recruitment (recruitment overfishing). This can affect biodiversity and whole ecosystems. The exploitation rates (i.e. the fraction of the fish in a population at a given time) that is caught and removed during a particular time interval, for example, a year by angling, are highly variable and can range from <10% to > 80% and thus can be substantial but depends on all kinds of factors like regulations, angling gear, and angling effort. In the Mediterranean, Font and Lloret (2014) illustrated that often the size of individual fish caught is below the minimum landing size, which is illegal. Furthermore they found that when comparing the minimum landing size of 17 species targeted to their corresponding size at maturity, they found that only four species had a mean that was greater than their size at maturity which raises questions about the sustainability of the fisheries. This problem of retention of juvenile fish by anglers seems common, and McPhee et al. (2002) documented several examples from Australia, the USA, and South Africa.

15.4.2 Large Species Range

The harvest includes a wide species range, for example, McPhee et al. (2002) gave figures of 201 different taxa by boat anglers in New South Wales, 194 species in S.E. Queensland, and 170 species in Biscayne National Park, Florida. Even small recreation catches though may impact on fish stocks because of their life-history characteristics, like slow growth rate, small population sizes, and restricted ranges.

15.4.3 Endangered Fish Species and Trophy Fishing

These declines in fish stocks are rarely considered a real threat or even halted when endangered species are targeted, and in some cases anglers are drawn to fish because they are rare and endangered species. This seems especially to be the case in trophy fishing where anglers target the largest individuals of a species with the goal of catching a "world record" sized fish which are certified as such by the International Game Fish Association (IGFA). However, they have to be weighed at an official IGFA station which requires transport and killing the fish. This can be an ecological problem because for many species the number of offspring is based on how big they are, and by removing the biggest individual fish this has a disproportionate impact on the population dynamics of a species. For example, removing a single 61 cm long red snapper is equivalent to removing over 200 of 41 cm fish from the population. Larger mothers have higher energy reserves and are able to invest more resources into each individual larva. For example, the black rockfish (*Sebastes melanops*) larvae from larger mothers have larger globules of oil than those from smaller mothers which is a feature associated with growth rates three times as high and survival twice as high as larvae from smaller mothers. As fish exhibit infinite growth, the larger fish are also older and more experienced. Many fish species also show sexual dimorphism where females are larger than the males so that many gravid females are often the largest individual fish within a population. Due to the prestige mentality, it is obvious that despite a low probability of catching a record-sized fish, anglers will land near record fish for weighing. With these factors in mind where species have reduced populations removing the largest, or near largest, individuals can impede a population's recovery or contribute to its decline. Unfortunately in the IGFA World Record List for 1222 species, there are 858 species considered threatened with extinction by the IUCN Red List. Shiffman et al. (2014) discuss these issues and suggest a simple solution: the IGFA should stop issuing records that implicitly require killing the fish for all International Union for Conservation (IUCN) Red List of Threatened Species which would immediately reduce the fishing pressure on the largest individuals of the most vulnerable species. This would still allow anglers to target over 93% of species that records have been issued for.

15.4.4 Size Selection and Fish Community Structure

As many fishing techniques are size-selective, changes in the size structure of populations should be expected. Decreases in mean size of the target fish and reductions in abundance of the larger fish are widely reported as fishing increases. Size-selective fishing will affect different species in different ways because species have different life-history traits so that species with late maturity and slow growth towards a larger maximum size are affected more by size-selective fishing than small, fast-growing species with early maturity. Species composition of fish communities therefore should change and smaller, fast-growing species should dominate the biomass. As this affects a number of life-history traits which are at least partially heritable, it should be expected that the exploited populations should evolve in response to harvesting.

Selective removal of larger fish may affect their predators or prey and is one process that may cause the size distribution of biota within an ecosystem to differ from that predicted by models. In multispecies communities, species with short lifespans and rapid population growth which have early maturity and channel a large proportion of their resources into reproductive activities are likely to respond to fishing rapidly. As long as fishing intensity and recruitment are balanced, they can be fished sustainably at younger ages and higher mortality levels. Slower-growing species, with a later maturity and larger size, are likely to be vulnerable to intensive fishing, despite having more naturally stable population sizes which in the unexploited state are buffered by numerous age classes against recruitment failure of individual cohorts. The larger and late maturing species are more susceptible to exploitation whilst the life histories of smaller species may enable them to sustain higher instantaneous mortality rates than larger species. They may also suffer lower fishery mortality simply because they are less desirable and less accessible targets in a size-selective fishery. So we can see that changes in fish community structure result from combined effects of differential fish mortality and the variable susceptibility of species with different life histories.

Size-selective fishing can have a marked impact on fish population, sex ratios, and artificially curtail reproductive lifespans. The relative fish fecundity increases as they grow, and so a population of a given biomass will have a greater potential fecundity when composed of larger rather than smaller individuals.

15.4.5 Consequences of High Exploitation Rates and Selectivity

Angling therefore adds a further trophic level to aquatic ecosystems, and anglers can be regarded as keystone predators in aquatic ecosystems. The fishing mortality can be rather high for particular, highly valued and sought-after fish species, for example, salmonids, and within these species, larger-size classes are positively selected. The combination of high exploitation rates and pronounced selectivity may have some direct and indirect effects on exploited fish populations.

15.5 Direct Consequences

High fishing mortality has been shown to repeatedly influence fish population dynamics and to contribute to the collapse of recreationally exploited fish populations. The reasons that may play a role are depensatory mechanisms, truncation of age and size structure, loss of genetic variability, and evolutionary changes. These reasons are discussed in detail in Lewin et al. (2006).

15.5.1 Depensation Instead of Compensation

Mechanisms of compensation are central to most classical fisheries biological concepts such as surplus production and maximum sustainable yield. It assumes that compensatory effects (e.g. enhanced growth rate, enhanced fecundity, enhanced juvenile survival) arise through attenuating intraspecific interactions and food competition when fishing reduces the abundance of the target. The compensatory potential of fish populations, however, is a matter of debate, and the relative strength and frequency of density-dependent population regulation depend on environmental conditions and life-history strategies, and there is growing evidence that there are some limits for compensatory responses. Some mechanisms, collectively referred to as depensatory responses, may counteract compensation if the population size is reduced below a specific threshold. After reaching such a threshold, group dynamics and cooperative interactions might be impaired, which compromise mating success, foraging, or anti-predator strategies. Furthermore, large-bodied fish can exert a top-down control on smaller species that are competitors or predators of their own progeny. Reducing the abundance of large piscivores may relax smaller prey species from top-down control and impair the fish potential for compensatory responses once the population is fished down under a threshold level. This might occur when the prey of the fish achieve a competitive advantage over the young of the piscivores. Also environmental stochasticity and genetic mechanisms such as drift and inbreeding may have a stronger influence on small populations and may impair their compensatory potential. Depensatory effects capture the positive relationship between the per capita population growth rate and population density at low population sizes, which increases the per capita mortality probability of intensively exploited fish populations at low population abundances.

15.5.2 Truncation of Age and Size Structure

Size-selective angling may not only reduce the biomass but also truncates the age and size distributions in the targeted fish population. The removal of large individuals may increase the growth rates of juvenile fishes if competition for food is relaxed at lowered population abundances. However, because the fish size correlates with many reproductive traits, the selective removal of most of the large individuals will affect the reproductive capacity of the exploited fish population despite compensatory growth of surviving individuals. Older fishes often have a higher hatching success than first-time spawners which may be attributed to a variety of factors, such as egg size and quality, or ideal spawning time. In many marine and freshwater fishes, larger age, size, or weight results in the production of larger eggs. The egg size, influenced by maternal effects (condition factor, weight, size, or age at maturity), positively correlates with offspring survival. For example, large salmonid eggs have higher survival rates than smaller eggs, when the concentration of dissolved oxygen is low.

Old and large fish also increase their reproduction success in breeding competition because they have higher competitive abilities which enable them to obtain better spawning sites or, in the case of salmonids, to dig deeper redds. Moreover, the fecundity in fish exponentially increases with age and size. Larger fish produce more eggs simply because of geometric constraints but also because they provide a greater proportion of energy stores to egg production. The fish age also influences the spawning time. Younger and smaller fish may start later with spawning, because they emerge from the winter with lower lipid reserves than larger individuals and the need to acquire sufficient energy reserves may delay spawning. The spawning time influences the recruitment, as the larval survival depends highly on the coincidence of larval production and peak zooplankton production. An earlier birthdate may enhance the survival of the progeny, presumably as a result of a longer growing season. For fishes showing age-related temporal spawning, the removal of old age classes will shorten the spawning season and can result in recruitment failure in years when successful recruitment depends on early spawning time.

Furthermore, it has been shown for some fish species, they are capable of social learning from more experienced and sometimes older individuals concerning anti-predator behaviour, migration and orientation, mate choice, foraging, and communication behaviour (for a review, see Brown and Laland 2003). In addition, the recruitment in populations is not only influenced by cannibalism or intraspecific competition for food or space among fish of the same size. Older fish may also contribute to the regulation as is assumed for pike and various salmonid species.

15.5.3 Loss of Genetic Diversity

The genetic variability plays a crucial role in the survival of species and is essential for their potential for successfully evolving in response to short- and long-term environmental changes. This aspect is of crucial importance, especially in freshwater populations. Local populations of freshwater fishes are genetically more divergent than those of marine species and are more susceptible to the loss of genetic variability, in particular, small and isolated freshwater populations that are confronted with a high selective mortality.

Many fish species targeted by recreation fishers have a spatially phylogeographic structure defined by evolutionary history, demographic processes, the level of gene flow, and genetically based adaptations to the local environment, which is detectable on different spatial scale. The biodiversity at the level of discrete populations ensures their adaptive potential and the resilience against environmental changes of a species and plays a critical role in keeping fisheries sustainable. In particular populations living in an uncommon or variable habitat constitute an important part of the evolutionary legacy. The reduction of population densities can lead to the loss of populations which obviously results in a loss of genes, or gene combinations. In addition, demographic bottlenecks are expected to reduce the number of rare alleles by genetic drift and inbreeding.

A loss of genetic variation may further be caused by the skewing of the sex ratio as a result of the selective removal of male or female individuals from a population. In addition, the removal of the largest individuals may lower the genetic variability. In general, the loss of genetic diversity and allelic richness decreases the adaptive potential and lowers the long-term fitness of populations. In addition, there is some evidence that the genetic diversity on the level of individual organisms can provide fitness benefits and may increase disease resistance.

15.5.4 Evolutionary Changes Due to Selective Angling

As many commercially exploited fish stocks declined and failed to recover even after exploitation ceased, there is growing concern that heavy and selective exploitation over decades results not just in demographic consequences for targeted and non-targeted fish species but may have led to detrimental evolutionary changes in some life-history characters. The changes of life-history parameters in response to fishing are well known, and the possibility that the fishery may inevitably change exploited fish stocks has been discussed for decades, but there is great difficulty in determining whether the change of life-history traits reflects phenotypic variability or is caused by genetic changes. However, the prerequisites for evolutionary changes in fish population in response to recreational fishing such as local adaptation, heritable population variation, and a high and selective fishing mortality exist. The perception that evolution is a very slow process has been challenged by studies on fish species demonstrating that, under an appropriate life history and a sufficient strong selection pressure, a so-called contemporary evolution can occur in comparatively short time periods and change production-relevant life-history traits, such as age and size at maturation, growth rate, and annual reproductive investment.

Also behavioural traits might undergo a selection in response to fishing as behavioural individuality has a genetic basis. It has been demonstrated that angling creates a selection for avoidance behaviour. Behavioural traits are usually determined by genes of more than one locus. Consequently, behavioural traits that are related to the vulnerability to angling can be correlated with other characteristics, such as metabolic rates and parental care. A selection against aggressive behaviour may reduce the fitness of the surviving population. The aggressiveness of some nesting male fish correlated positively with the quantity of eggs in a male's nest. Consequently, the males with the greatest potential to contribute to annual recruitment were those fished and removed by anglers.

To sum up, angling may have the potential to cause an evolution in some life-history traits. Angling may select for, or against, certain life-history traits provided that the fishing mortality is high and the survivors represent genotypes that are less vulnerable to the force of mortality and then proliferate in subsequent generations. A prediction of the effects on life- history evolution though is difficult, because the effects depend on the multiple interactions within the aquatic ecosystem, and it has been argued that evolutionary change induced by fishing is slow and therefore unimportant to fisheries management. Yet Conover and Munch (2002) concluded that fisheries-induced selection from a simulated harvest from a hypothetical fishery resulted over four generations in the removal of large individuals. So changes in size-related, life-history traits can influence population persistence and yield.

The higher the rate of fishing mortality and the higher the number of generations over those that a population has been fished, the greater the probability that genetic responses occur. The outcomes of the selection are not necessarily positive, neither from the populations nor from the angler's point of view. Genotypes that survive fishing pressure may be less than optimal with respect to natural selection, and this may prevent a recovery of a population, even after the fisheries have ceased. Sutter et al. (2012) nevertheless show that size-selective fishing or even a just elevated level of fishing mortality has the potential to induce rapid evolutionary change in a range of production-related traits in fish populations. Using males from two lines of large-mouth bass (*Micropterus salmoides*) selectively bred over three generations for either high or low vulnerability to angling as a model system, they show that the trait vulnerability to angling positively correlates with aggression, intensity of parental care, and reproductive fitness. This experimental research has demonstrated that angling vulnerability is heritable in large-mouth bass and is correlated with elevated resting metabolic rates (RMR) and higher fitness.

However, whether such differences are present in wild populations is unclear. Hessenauer et al. (2015) sought to quantify differences in RMR among replicated exploited and unexploited populations of large-mouth bass. They collected large-mouth bass from two Connecticut drinking water reservoirs unexploited by anglers for almost a century and two exploited lakes, then transported and reared them in the same pond. Field RMR of individuals from each population was quantified using intermittent-flow respirometry. Individuals from unexploited reservoirs had a significantly higher mean RMR (6%) than individuals from exploited populations. These findings are consistent with expectations derived from artificial selection by angling on large-mouth bass, suggesting that recreation angling may act as an evolutionary force influencing the metabolic rates of fishes in the wild. Reduced RMR as a result of fisheries-induced evolution may have ecosystem-level effects on energy demand and be common in exploited recreation populations globally.

Recreation angling therefore selectively captures individuals with the highest potential for reproductive fitness. This suggests that selective removal of the fittest individuals likely occurs in many fisheries that target species engaged in parental care. As a result depending on the ecological context, angling-induced selection may have negative consequences for recruitment within wild populations of large-mouth bass and possibly other populations of exploited species in which behavioural patterns that determine fitness, such as aggression or parental care, also affect their vulnerability to fishing gear.

15.5.5 Discards or By-Catch from Recreational Fishing

There is substantial discarding of fish which include unwanted species, juveniles, and catch limits, and it has been estimated that the rates vary between 30% and 76% from various studies in the USA and Australia, and Cooke and Cowx (2004) estimated that 60% were returned overall. There are also management rules or legislation that demands the release of all captured fish or of fishes of protected size or species.

Voluntary catch-and-release (CR) behaviours where anglers release fish because it is the modus operandi or for ethical, conservation, or sporting reasons (Policansky 2002) are also a characteristic of recreation fisheries, which may contribute to the view that recreational fishing is benign relative to commercial fishing. In some fisheries, voluntary release rates can reach nearly 100%, such as in the coarse fisheries of Western Europe or elitist resources such as bonefish (Policansky 2002). However, an unknown proportion of fish captured by anglers and released under the assumption that they will survive die post-release which brings us on to a consideration of CR effects.

15.5.6 Catch-and-Release Impacts

There are two perspectives on CR. Some people see fishing solely as a means of catching fish and consider that there is no purpose to catch a fish other than pleasure, and so CR is an unethical fishing practice which can cause distress and physical damage to the fish. Another view is that CR is ethical and a conservative approach to sustaining recreation fisheries and preferable to catch-and-kill. However, CR can be an effective practice in offsetting angling-induced impacts to individual fish and their populations and can encourage the biological, economic, and social sustainability of a fishery (Bartholomew and Bohnsack 2005). Numbers involved can be high. In 2011, the National Marine Fisheries Service estimated that while 393,193 striped bass were harvested in New Jersey, over 900,000 were released (NMFS 2012).

In CR angling strategy is the assumption that fish experience low mortality and minimal sublethal effects and that they are released in good condition and will return to the common population, with negligible effects on lifetime fitness.

Sometimes this is the case but mortality is highly dependent on species and a range of other factors like water depth, temperature, and type of tackle used. It can vary from 0% to 95%. Poor CR practices can cause physical injury and physiological stress to fish. In fact, according to a review by Cooke et al. (2002) in virtually all CR fisheries, some proportion of released fish die as a result of being captured, while others experience sublethal effects, such as injury, physiological disturbance, behavioural alterations, and fitness impairments.

In a review of the impacts of CR practice on striped bass (*Morone saxatilis*), Tiedemann and Danylchuk (2012) found that despite the best intentions of anglers practising CR angling, the mortality rate associated with this practice was not trivial. The Atlantic States Marine Fisheries Commission currently applies an 8% hooking mortality rate for striped bass caught and released by recreation anglers in saltwater ecosystems (ASMFC 2011). This mortality rate is based on the results of a study on mortality of hooked and released striped bass in a saltwater impoundment in Massachusetts by Diodati and Richards (1996). Applying this mortality rate to estimates of striped bass caught and released annually in New Jersey yields the annual discard mortality estimate of 72,366 out of 904,576 released. This mortality rate may, in part, be due to a general lack of understanding among anglers as to how CR techniques can physically injure and physiologically stress fish. Many anglers make the assumption that all fish released survive the experience since they observe that the fish appear relatively unharmed and swim away, with dead fish rarely resurfacing but in fact the behaviour of released fish is a poor indicator of whether fish live or die. Muoneke and Childress (1994) reported that fish that appear to be healthy when they are released may exhibit post-release injuries or stress caused by angling and handling and actually experience mortality sometime after release.

Angled striped bass may experience stress for a variety of reasons. The exercise induced by angling is the first cause of physiological stress response. Environmental factors can then exacerbate the rate of stress during angling, including water temperature, air temperature, and salinity. A number of studies have documented the fact that stress and stress-related mortality in striped bass caught-and-released is temperature dependent. In general, as water temperatures rise above the bass' optimum temperature range, angler-induced stress increases, along with increased potential for post-release mortality. Therefore, it can be assumed that the warmer the water temperature, the longer it will take for a bass to recover from a fight or factor related to stress and stress-induced mortality. It has been documented that high mortality of striped bass released in freshwater occurs during the warm summer months, with air temperature when fish were landed and handled as the most important factor related to mortality. Any abrupt or substantial temperature increase experienced by angled striped bass, even for a brief period of time, can also add physiological disruption to that caused by fighting during angling. This is especially important during hot weather, when there are large differences between water and air temperatures. In general, research has shown that environmental stress and stress-induced mortality of caught-and-released striped bass is potentially higher in freshwater ecosystems (Diodati and Richards 1996). In marine waters, salinity appears to help moderate physiological imbalances associated with stress. This is an important consideration for anglers participating in the coastal striped bass fishery, as fish caught in low-salinity areas, such as the upper portions of estuaries, are more likely to experience stress during CR than bass taken in high-salinity waters.

The tackle type including the number and style of hooks and the type of bait used are all factors that can affect anatomical hooking location and the likelihood of physical injury to organs and tissue from hook wounds. Anatomical location of hook wounds has been found to be one of the most important factors influencing survival rates for released striped bass and, in general, mortality is highest if the wound site includes a vital organ. For example, a fish hooked in the jaw stands a much better chance of survival than a fish that is hooked in the gills, oesophagus or stomach. Diodati and Richards (1996) reported that the odds of death for gut-hooked fish were almost six times the odds of death for fish hooked in the lip. Deep hooking was the single most important factor that caused death of striped bass caught and released in studies by the Maryland Department of Natural Resources. Between 1996 and 2000, nearly 1300 striped bass were used in their CR studies and they estimated a 17-times higher chance of dying if a striped bass is deep hooked rather than shallow hooked (MD DNR 2010). Deep hooking in striped bass is often higher with live baits or natural baits than with artificial baits, because fish often swallow hooks and baits more deeply which increases the possibility of injury and mortality.

Many studies have reported this lower mortality and injury to striped bass when fish are angled with artificial baits. However, while lures generally hook fish in the jaw or mouth, they can also present problems. For example, large plugs rigged with multiple treble hooks can cause injury to a bass since the free hooks often swing around and catch in the fish's gills or eyes. Treble hooks may also require an inordinate amount of time for removal.

To counter these concerns, it is often recommended that anglers replace treble hooks on plugs and metal lures with single hooks. The IGFA endorsed the idea of replacing treble hooks with single hooks to facilitate easy dehooking and faster release of fish (IGFA 2011). However, even single hooks can cause problems with hook removal if they are barbed hooks, and it is recommended crushing hook barbs, or using barbless hooks on plugs and lures to facilitate easy hook removal and reduce handling time and hooking injuries.

Aside from physical injury from deep hooking, physiological stress from fighting is another important factor that can result in angler-induced mortality of striped bass caught and released by recreation anglers. Fish that struggle intensely for prolonged periods of time during angling become exhausted. When fish are angled to exhaustion, lactic acid builds up in the tissues of the fish from muscle function. Increased levels of lactic acid can lead to a situation known as acidosis, and exhausted fish may reach a point where physiological imbalance, muscle failure, or death is possible. Therefore, the longer a fish is fought, potentially the less likely it is to survive after release. A fish that is landed quickly has a better chance of survival after release than one that has been exhausted by a lengthy fight.

The inability of striped bass to recover from physiological stress incurred during capture can disrupt normal feeding patterns, increase vulnerability to attack from predators, and reduce the striped bass' ability to fight off diseases and parasites or heal wounds caused by hooks.

Stress and the potential for post-release mortality also increase dramatically if fish are mishandled. Landing, handling, and release methods all may further exacerbate stress and result in post-release mortality. For example, the longer a fish is kept out of the water, the lower its chances for post-release survival, especially if it has endured a prolonged fight (see Cooke and Suski 2005).

Therefore mortality can be attributed to physical damage from hooking injuries or to physiological stress associated with stress-inducing hypoxia due to lifting the fish out of the water for hook removal or photography. To evaluate the effects of air exposure and angling-induced exhaustive exercise on released grayling condition, Lennox et al. (2016) observed the blood physiology and reflexes after angling and air exposure in fish from the subarctic River Lakselva (Norway). Blood samples were drawn 30 min after angling and analysed for lactate abions, glucose, sodium ions, and pH. Reflex impairment was determined with orientation and tail grab reflex action assessment immediately after landing, after air exposure, and after 30 min holding. Blood physiology did not indicate an exacerbating effect of air exposure relative to just angling-induced exercise but significant and prolonged reflex impairment associated with the 120 s air exposure interval.

The conclusion was that anglers must take care to minimise air exposure to adhere to best handling practice and this was under 10s for European grayling at summer water temperatures. Similarly Bower et al. (2016) angled blue-finned mahseer using a range of bait/lure types and angling and exposure times. There were no cases of mortality observed, and the rates of moderate to major injury were low with 91% hooked in the mouth. More extreme physiological disturbances (blood lactate, glucose, pH) were associated with longer angling times. 33% exhibited at least one form of reflex impairment so that the conclusion here was that these fish were fairly robust to CR but that anglers should avoid unnecessarily long fight times and minimise air exposure to decrease the likelihood of sublethal effects that could contribute to post-release mortality.

However, Pope and Wilde (2004) found no effect on largemouth bass caught on plastic grubs. There was no difference in weight gain between caught and uncaught fish over a 40-day angling and recovery period which was much less than the 22% and 38% reported from previous studies. It seems that angling mortality varies with anatomical location in which the fish is hooked. All of the fish in this study were hooked in locations for which mortality is generally low (under 2%). Angling mortality was twice as great among fish that bleed from hooking wounds (only 3% in this sample). It is clear that CR mortality varies substantially among species and a number of observations suggest that sublethal effects are at least equally variable. This can be shown too from Thomé-Souza et al.'s work (2014) on the sustainability of sportfishing for peacock bass (Cichla spp.) in the Brazilian Amazon, where they found that fish caught through CR fishing had mean mortalities of only between 2.3 and 5.2% for three species. The fish lengths were between 4–26 and 79 cm but only fish under 42 cm died. They found that hooking was more dangerous to fish if it occurs in the throat or gills and no fish died with injuries to the lip, jaw, or mouth region.

Tiedemann and Danylchuk (2012) summarised the existing literature to develop five general trends that could be adopted for species for which no data are currently available: (1) minimise angling duration, (2) minimise air exposure,(3) avoid angling during extremes in water temperature, (4) use barbless hooks and artificial lures/flies, and (5) refrain from angling fish during the reproductive period. These generalities provide some level of protection to all species, but do have limitations. Therefore, a goal of conservation science and fisheries management should be the creation of species-specific guidelines for CR.

15.6 Impact of Invasive, Non-native Species

Inland waters in particular are often enhanced through stocking with introduced species, and this practice has been ongoing for a long time. Salmonids have had an impact on a variety of native fauna through predation and competition and have been implicated in reducing the diversity of macro-invertebrate assemblages and population declines and/or the reduction and fragmentation of the ranges of several species endemic to Australia and New Zealand. Predation by salmonids is also considered to have played a major role in the decline of the critically endangered spotted tree frog and possibly other frog species in South Eastern Australia, whilst the populations of at least two bird species in New Zealand (the crested grebe and the blue duck) have had their prey availability reduced by salmonids.

In the extensive fishless lake and stream habitats in the montane ecosystems of North America, salmonid fish have been introduced since the mid-1800s, and the fish stocking has been undertaken by the various agencies responsible for the management of fish and wildlife since the mid-1900s. Trout stocking has stopped in most national parks in western North America during the 1970s and 1980s but continues in other protected areas such as those managed by the United States Forest Service. These stocking programmes have transformed the formerly fishless aquatic ecosystems so that of the estimated 1600 naturally fishless lakes in the Western USA, 60% of all lakes and 95% of larger, deeper lakes now contain non-native trout and over 7000 mountain lakes are regularly stocked with trout, usually with the use of aircraft. This has been controversial as the fish introductions have dramatically altered the native vertebrate and invertebrate communities, often leading to the dying out of native fish, amphibians, zooplankton, and benthic macroinvertebrates (McGarvie Hirner and Cox, 2007). In a review of this process by Knapp et al. (2001), it has been shown that the spread of introduced trout from headwater lakes has had a disproportionately larger effect on native fishes than introductions lower in the drainage systems and that in many river basins the remaining populations of native fish are concentrated in headwater refugia, where they are already protected by natural barriers from introduced species that are already established at lower elevations. It has also been shown that in the formerly fishless, oligotrophic lakes, there is increased phosphorus and this new nutrient source results in increased algal biomass and production. Further it has been shown that the abundance of all life stages of long-toed salamanders and spotted frogs was lower in lakes containing non-native trout than in those that remained fishless.

However, although it is generally assumed that the introduction of a non-native species to an area with numerous endemic species would be deleterious to the recipient ecosystem, in several shallow New Zealand lakes, it was found that the addition of non-native, brown and rainbow trout did not alter the lakes' original invertebrate composition on any appreciable level (Wissinger et al. 2006). This is in contradiction to findings in North America and Europe which showed dramatic invertebrate compositional shifts after trout introduction. This illustrates that environmental characteristics of the lakes can determine whether the invasive species is detrimental or not and shows that the result of the invasion depends on more than invader characteristics.

Nevertheless the round gobies in the USA, which are bottom-dwelling fish introduced into the Great Lakes from Central Eurasia via the ballast water of ocean-going, cargo ships, show food chain predation (Fig. 15.3). They have competed successfully with native, bottom-dwelling fish, like the sculpins and darters. There have been major reductions in the local populations of these species where round gobies are established, and this impacts the food chain of recreationally important fish, like the smallmouth bass and the walleye. Whilst there is direct predation of darters and other small fish, they also feed on the eggs and fry of lake trout. Moreover they eat large quantities of zebra mussels, another invader which has been successful. Whilst this might be thought a good thing, there is a problem, because as filter feeders the mussels consume toxins/contaminants and as the gobies are preyed on by sportfish this can cause a direct transfer of the contaminants to these fish, such as the small mouth and rock bass, walleyes, and brown trout. The round gobies are nuisance competition too, and they fish aggressively and take bait from hooks. Anglers in the Detroit area have reported that at times they can catch only gobies when they are fishing for walleye.

Fig. 15.3 Round goby (*Neogobius melanostomus*). Accidentally introduced into Great Lakes probably by ballast water transfer from cargo shipping. Originally from Sea of Marmara, Black Sea, Sea of Azov, and rivers of Crimea and Caucasus. Source: National Digital Library of the US Fish and Wildlife Service. Photographer: Eric Engebretson

Another problem fish is the northern snakehead (*Channa argus*) which is a top predator invasive species which is native to parts of China and possibly Korea and Russia and disrupts the natural aquatic feeding structure (Fig. 15.4). It was found in California in 1997 and is now established in many states on the east coast of the USA. Its presence is thought to have resulted from aquarium owners discarding unwanted exotic captive species into local waterways, although it could have been to create a local food source for recreational fishing. Many native species have been outcompeted for food sources:

Fig. 15.4 Northern snakehead (*Channa argus*). This is a top-level predator which poses a major threat to freshwater fish. Originally native to China, Russia, and North and South Korea but introduced to other regions where it is a major invasive species. Photo by Brian Gratwicke

fish, crustaceans, small amphibians, reptiles, and even some birds and mammals. During the spawning season and after the young are born, they can become very aggressive towards trespassing species.

Burgin (2017) reviews the introduction of the carp into Australia where since the mid-1800s it has become the most abundant large freshwater fish in South East Australia and the catch is around twice as great as any other species, with over 2 million annually. The impact of this species has been exacerbated due to the hybridisation of two taxa with the subsequent emergence of the vigorous Boolarra strain and the associated large increase in carp numbers. The impacts have been destruction of aquatic plants and an associated increase in water turbidity which result in reduced prey availability and further impacts on native fish that require sight, for example, for foraging. The carp tend to outcompete native species because of their greater abundance, high fecundity, robustness, and tolerance of a wide range of aquatic environments.

15.7 Indirect Impacts of Recreational Fishing

There are many, diverse, indirect impacts of recreational fishing that are not associated with the exploitation and harvesting of fish which have the potential to be detrimental to the long-term sustainability of both freshwater and nearshore ecosystems which now need to be considered, such as habitat disturbance, wildlife disturbance, or loss of fishing gear.

15.7.1 Disturbance of Habitats

Recreation fishermen have access to nearshore and littoral habitats which are of crucial importance for many fish species, and as interfaces between terrestrial and aquatic ecosystems, littoral zones fulfil a variety of physical and ecological functions. They delay or prevent the transport of nutrients to lakes from eroding upland soils, enhance local energy and nutrient availability fostering a higher biological productivity, support material and energy cycles and a variety of life-history strategies (Lewin et al. 2006). The diverse riparian zone processes affect biodiversity, reproduction, feeding, and predator-prey interactions. Woody debris and submerged or emerged macrophytes are refuge or feeding habitats for juvenile fish and invertebrates, and macrophytes serve as spawning substrate for phytophilic species (species associated with plants). At the same time, the alteration of littoral habitats by human activities has resulted in a loss of refuge habitats and resource heterogeneity which has affected fish communities by changing the fish species richness, biomass, growth rates, and the spatial distribution of fish.

15.7.1.1 Walking Tracks (See Burgin 2017)

Anglers can affect littoral habitats if they make paths to gain access to the water and walk parallel to the shoreline. A medium or heavy use of pathways and shores can change, or destroy, the natural plant communities of freshwater or marine littoral habitats. Anglers may also cut bank vegetation and remove submerged vegetation at the beginning of the fishing season. The removal of the aquatic plants and shoreline vegetation can affect phytoplankton development, invertebrates, fishes, and birds, enhance erosion processes, and change nutrient fluxes.

15.7.1.2 Impacts of Off-Road Vehicles

Tracks from the use of such vehicles could cause indirect impacts especially when used near the water's edge, for example, with the movement of watercraft and/or trailers and the carrying of fishing gear to the lake shore. Compared with other recreation activities, the effects of angling on the aquatic vegetation may be of minor importance but can still have ecological consequences.

15.7.1.3 Wading Associated with Instream Angling

Significant differences in egg and larvae development have been found where anglers waded. A single wading on shallow, salmonid-spawning habitats during the period before the hatching killed 43% of eggs and fry, while a twice-daily wading killed up to 96%.

15.7.2 Disturbance of Wildlife

Nearly all activities carried out on the shores are potentially disturbing wildlife who live in littoral areas or are sitting on the surface. The disturbances associated with recreational fishing originate mainly from direct contact, sound, and sight. Above all, water birds are closely associated with littoral and shoreline habitats. Therefore, the research on human disturbance of wildlife in aquatic ecosystems concentrates mainly on water birds. Quan et al. (2002) demonstrated that species richness and abundance on a highly exploited lake were correlated with human disturbance and not to habitat quality. Human disturbances, especially those caused by recreation activities, can affect distribution, species richness, and abundance of waterbirds by disturbing overwintering, resting and feeding, and reproduction (e.g. the prelaying phase and the egg and chick phase). The disturbance of feeding may be more pronounced if the feeding is restricted to certain places or time periods and can result in adults having insufficient time to fulfil their own energy demands and those of their chicks. The disturbances to the nesting birds can result in higher rates of non-hatching and abandonment, in the exposure of eggs to predators, or unfavourable environmental conditions, such as solar radiation, or thermal stress and may therefore decrease breeding success. Compared to other land-based activities such as bird watching, walking, or picnicking, shore angling is considered to have serious impacts on water birds, since anglers often use vehicles to gain access to the angling sites and remain there for long periods. Furthermore, they frequently show long periods of inactivity, interspersed with short periods of rapid movements. Liddle and Scorgie (1980) cite some studies which showed that activities by anglers substantially decreased the breeding success and breeding stocks of different water bird species. Anglers had a similar effect as boats on water birds, creating an area around them within which birds did not venture. According to this, Sudmann et al. (1996) observed a reproduction failure of breeding waterbirds in a reservoir during years when angling took place. The reproduction improved after termination of angling.

The avoidance and redistribution in response to human disturbances are species-specific.

Species that do not avoid disturbance may be affected by disturbance even more seriously, if they are forced to tolerate the disturbance in case suitable other alternative habitats are lacking. Other bird species may show an adaptation to recreation disturbances. The great crested grebes left their nest at shorter distances to approaching rowing boats, presumably as an adaptation to recreation activities. However, the short flight distances were disadvantageous, as the birds did not cover their eggs before leaving, so that the clutch was not protected from predation.

Few studies deal with the angling-associated, indirect disturbance of taxa other than birds. Angling may disturb otter (*Lutra lutra*) populations if there is a lack of sufficient refuges, such as dense woodland structures along river banks, especially if anglers prefer remaining cut-back trees and stumps as fishing sites.

15.8 Plastic in Various Forms

Plastic degrades extremely slowly or not at all and gets into the food chain. For example, Possato et al. (2011) noted that in an investigation into three catfish species in a tropical estuary in North East Brazil that individual catfish had ingested plastics (*Cathorops spixii* 18%, *C. agassizii* 33%, and *Sciades herzbergii* 18% of individuals). Nylon fragments from fishing activity played a major role in this contamination. Sigler (2014) also noted that small pieces of plastic had been found in fish stomachs and that it is of concern because these fragments may facilitate the transport of absorbed pollutants to predators within the food chain. Raison et al. (2014) further report that as the popularity and use of soft plastic lures (SPLs) by recreation anglers have increased recently, there are anecdotal reports of them being found in the digestive tract of a variety of fish species and in aquatic environments. Fieldwork was carried out in Charleston Lake (Eastern Ontario), a system known to have a SPL problem based on angler's reports, in lake trout and smallmouth bass. Snorkel surveys revealed about 80/km of shoreline/yr had SPLs and when immersed in water at two temperatures of 4 °C and 21 °C they showed little evidence of decomposition. Anglers interviewed reported 18% had found at least one ingested SPL when cleaning lake trout but when the lake trout were samples by gill net and smallmouth bass by rod and reel, there was only 2.2% and 3.4%, respectively, affected. What is needed is angler education to rig SPLs so that they are less likely to be lost during fishing, and the tackle industry needs to develop SPLs less likely to be pulled off by fish and/or degrade quickly. Meanwhile Skaggs and Allen (2016) reported that studies showing the occurrence or abundance of SPL ingestion by wild fish populations are rare but that there may be inconsistency in diet reporting. Hence the degree to which SPLs are ingested across fish species remains unknown. Studies showing the effects of SPL ingestion are also rare, but it is possible from one study that consumption of SPLs caused reduction in body weight and condition in brook trout (Danner et al. 2009). Regulations to restrict use of SPLs in order to protect fish populations and fisheries currently would not be based on good scientific proof of impacts, despite the consideration of a ban from Maine Department of Inland Fisheries and Wildlife in 2014.

15.9 Fishing Gear Loss

Attempts at broad-scale quantification of marine litter enable only a crude approximation of Abandoned Lost and Discarded Fishing Gear (ALDFG) which comprise less than 10% of global marine litter by volume, with land-based sources being the predominant cause of marine debris in coastal areas and merchant shipping, the key sea-based source of litter. The impacts of ALDFG can be:

- *Continued catch of target and non-target species*. This is called "ghost fishing." The state of the gear at the point of loss is important. For example, lost nets may operate at maximum fishing efficiency and will thus have high ghost-fishing catches and, if well anchored, be slow to collapse. Some abandoned or lost gear may collapse immediately and have lower initial fishing efficiencies, unless they become snagged on rock, coral, or wrecks where they are held in a fixed fishing position. Discarded gear or parts thereof would also have a low fishing efficiency. Fish that are killed in nets may also attract scavengers that are then caught in the nets, resulting in cyclical catching by the fishing gear.
- *Interactions with threatened/endangered species*. ALDFG, especially when made of persistent synthetic material, can impact marine fauna, such as sea birds, turtles, seals, or cetaceans through entanglement or ingestion. For example, a census by the Australian Seabird Rescue Group in the Richmond River (New South Wales) showed that of the 108 resident pelicans, 37 were suffering injuries from being entangled or hooked by fishing tackle and a later survey of Australian pelicans showed that 92% of human-induced injuries were from entanglement. Wells et al. (1998) concluded that the number of deaths or serious injuries to bottlenose dolphins in Florida from recreational fishing line entanglement exceeded that from the region's commercial fishing. Entanglement is generally considered far more likely a cause of mortality than ingestion, and, although rec-

reational fishing gear losses may be important, it is the commercial fishing gear that really causes the biggest impacts. While it is an important commercial gear, hook and line is also used by a large number of recreation and subsistence fishers, and therefore losses, especially within shallow inshore waters, may be very high. In the Florida Keys, it was reported that the debris type causing the greatest degree of damage was hook-and-line gear (68%), especially monofilament line (58%), and that it accounted for the majority of damage to branching gorgonians (69% of damage), fire coral (83%), sponges (64%), and colonial zoanthids (77%). This indicated that a gorgonian sponge-dominated reef would be more susceptible to damage from lost hook-and-line gear than coral-dominated reefs.

Asoh et al. (2004) assessed the extent of damage from monofilament fishing lines as a cause of cauliflower coral (*Pocillopora meandrina*) damage or death in fished and unfished areas in Hawaii. They found a positive linear relationship between the proportion of colonies entangled with fishing lines and the proportion of dead or damaged corals which indicated a negative impact on the health and survival of *P. meandrina* colonies.

15.10 Boat Strike and Boat Traffic Impacts

Wolter and Arlinghaus (2003) categorised the effects of boat traffic on fish, most notably on fish larvae, into direct and indirect stressors. Direct effects were caused by the physical forces generated from moving boats, directly related to fish mortality (propeller action, waves, wash waves, and dewatering). Indirect effects result from stress, disturbances which prevent fish from feeding or nest guarding, dislodgement of eggs or larvae, an increase of turbidity, or a loss of macrophytes following wave action. Their review deals mainly with the impacts of commercial navigation in waterways, and some effects may be restricted to large vessels. However, wave effects may also result from recreation boat traffic. Experimental studies have shown that shear stress can increase the mortality of eggs and larvae from different fish species, but given the smaller size of the boats used by recreation fishermen, impacts of shear stress, stranding, and dewatering following wave action may be less important. But obstructing nest-guarding behaviour and dislodgement and redistribution of eggs and larvae may affect the fitness of fish populations. Small recreation boats travelling at slow speed near the nests drove males of longear sunfish (*Lepomis megalotis*) from the nests, thus increasing the likelihood of egg predation. Boats moving at higher speeds increased the turbidity and therefore the possibility of the predation success. The passage of even a single paddle or motorboat over low-density organic mud can lead to a resuspension of sediments and if the frequency of boat traffic is sufficient during the season, it may result in an increase of turbidity. An increase in turbidity beyond the natural level may have physiological effects (gill trauma, sublethal stress response) and behavioural effects (avoidance, predator-prey interactions). Additionally, the increased turbidity may contribute to a loss of macrophytes in littoral habitats, and macrophytes serve as colonisation substrate for various species and as feeding and refuge habitat for juvenile fish.

Motorboat traffic in rivers, lakes, and along the coastline results in the emission of inorganic and organic compounds into the water and into the air near the surface, which is toxic to zooplankton and fishes. Also in marine ecosystems, the engine emissions from outboard motors can contribute to the surface microlayer, and the toxic substances on the air-water interface can significantly affect the survival and development of early life-history stages of marine fishes and other surface-dwelling organisms. However, even if it is not possible to quantify the effects of boat traffic linked exclusively to recreational fishing, given a substantial level of boating activity, there could be some negative effects on the aquatic environment or fish stocks, whereas the effects depend on motor type, travelling speed, bottom structure of the ecosystem, or slope of the shoreline. However boat strike is the single biggest cause of marine turtle mortality in Queensland and between 12.8% and 48.5% sampled had injuries consistent with propeller strike, and in Florida it has been reported as a significant source of manatee mortality.

15.11 Nutrient Input

Groundbaiting or chumming is widely practised in freshwater by some anglers to attract fish, such as the cyprinids bream, carp, or tench to the angling site (Arlinghaus and Mehner 2003). Groundbaiting up to a certain limit can be effective in increasing the carrying capacity of the fishery and the catch of cyprinid fishes. Higher groundbaiting rates can negatively affect the catch though, and the existence of an upper limit may result from negative impact of not consumed baits on the water quality and invertebrate community. Groundbaiting over the entire fishing season may lead to significant changes in the benthic invertebrate community. The rapid breakdown of cereal baits by microbial activity resulted in a high oxygen consumption of the sediment, and presumably, as a result of the alteration of the microbial and chemical conditions through the decay of uneaten baits, the densities of naididae, cyclopoidae, and cladocera decreased. Only tubificidae showed no reductions in density. In general, the lack of oxygen on the sediment surface can result in diminished decomposition rates, causing an accumulation of organic surplus. The decay of this organic matter can enhance the ammonium flux from the sediment and initiate the redox-dependent release of iron-bound phosphorus, therefore contributing to the internal nutrient loading. At the same time, nutrients especially phosphorus from the egestion or excretion of fish after having fed these baits or from uneaten baits may substantially contribute to anthropogenic eutrophication and therefore either directly or indirectly enhance primary production and algal growth (Arlinghaus and Mehner 2003). On the other hand, the angler harvest can counterbalance the nutrient input from groundbaiting. However, such a harvest rate may be unrealistic as many specialised anglers mainly practise CR fishing. However, the contribution of groundbaiting to an anthropogenic eutrophication is strongly dependent on local conditions. Water depth, trophic state, effective nutrient load and loading history, water retention time, as well as fisheries-connected factors (harvest rates, digestibility, and nutrient composition) affect the impact of the groundbaiting on the water body. Small, shallow, oligotrophic lakes with long water retention times, high angler densities, and low harvest rates may be sensitive to groundbaiting (Arlinghaus and Mehner 2003). Preservatives that may leach from commercial baits have received little scientific attention. The impacts of effluent discharge from shore-based recreation facilities like detergents and chemical toilet discharge can cause extensive pollution, but those associated with recreational fishing are an unknown fraction of the total (Burgin, 2017).

15.12 Exotic Species of Bait and Bait Gathering Effects

With the popularity of recreational fishing, the demands for live bait rise. Some studies on marine coastal habitats have shown that bait digging can locally influence the littoral fauna and size structure of harvested, benthic organisms. Some of the species intensively used have a role in structuring the bottom communities. Therefore, an intensive harvest affects not only the harvested species but other components of the fauna, as well as bacteria and algae. For example, such cascading effects can result from an intensive collection of sandprawns (*Callianassa kraussi*). Ghost shrimps (*Trypaea australiensis*), a popular bait species in Australia, changed the distribution and abundance of other benthic taxa (polychaetes, amphipods, soldier crabs). In addition, the reduction of benthic organisms (cockles or worms) may potentially affect the behaviour and foraging success of higher trophic level species, such as shorebirds. The bait digging or pumping and the associated trampling can involve a considerable disturbance to the sediment and affect taxa, sensitive to disturbance of the sediment structure.

There is some evidence that the intensive bait digging for lugworm (*Arenicola marina*) and ragworm (*Nereis diversicolor*) reduced the abundance of cockles (*Cerastoderma edule*). The digging can lead to a burial of many cockles and to a surface exposure of some other species. In addition, bait collecting can affect not only the biological but also the physical and chemical sediment parameters. Bait pumping and trampling changed the porosity, organic carbon content and redox potential of the sediment and increased the chlorophyll concentration. There are also indications that the perturbation of the sediment through intensive digging influences bioavailability and uptake of heavy metals (lead and cadmium) by polychaetes.

The intertidal and subtidal boulders on rocky shores exhibit a diverse assemblage of sessile and mobile fauna. Consequently, a frequent sampling can cause short-term effects on the abundances of sessile organisms. For example, the collection of mussels used as baits by anglers significantly reduced cover, density, biomass, and size of the mussels (*Mytilus californianus*) on rocky shores even during a period of high natural disturbance.

The use of exotic species as bait can be a threat to the coastal ecosystem, and the introduction of exotic species resulting from the release of certain baits has been well documented. Also to keep them alive and moist, the live bait can be packed with living substrates, like algae which can then be discarded. These can contain living organisms such as small crustaceans, snails, and worms which may establish themselves in a new ecosystem. It has also been shown that live or dead bait can transfer viruses that can significantly affect wild fish stocks. An example here is viral haemorrhagic septicaemia virus (VHSv which was found in Canada's Lake St. Clair in 2003 and has spread throughout the Great Lakes). The virus affects a wide variety of fish species and has killed 28 freshwater species since 2006, yet more than 50 species may be susceptible. It rapidly leads to internal bleeding and haemorrhaging from open sores (Fig. 15.5). It seems to be spread through fishing bait, and bait dealers around the Great Lakes have to certify that the fish they use as bait are disease-free.

So we can see that the invertebrate harvest for bait constitutes an important component of angling's ecological footprint and the concern can be illustrated by a new law approved in 2006 in Croatia which prohibited fishing with live bait.

Fig. 15.5 Gizzard shad with VHSv, a deadly infectious disease which causes bleeding. It affects over 50 freshwater and marine fish species in the northern hemisphere. Source: https://open.nim.nih.gov/detailedresult.php?img=PMC3386630

15.13 Pathogen Transmission

Virus strains have been spread from Asia to North America, for example, the whirling disease, a parasitic infection affecting young trout and salmon which enters the fish's head and, due to pressure, makes the fish swim erratically. In Australia native species such as the Macquarie perch are vulnerable to a fatal infection by the epizootic haematopoietic virus which may be carried by introduced redfin and trout. Through fish introductions such as carp, there has been established the Asian fish tapeworm which infects native fish. In Europe nearly 100 known pathogens originating from a wide range of taxa have been introduced to European freshwaters, and, although aquaculture was likely to be the main source, recreational fishing was also a pathway.

15.14 Inadvertent Overland Dispersal of Non-native Plants

The movement of vehicles, boats, and trailers between freshwater bodies has the potential to support dispersal of organisms, including the non-native invasive aquatic weeds like alligator weed and salvinia, which seem to have been transported long distances in Australia. These types of plants could result in hydrological changes as they can form dense stands that blanket the water, affect other species of plant, and ultimately can impact on water chemistry and quality, faunal and floral diversity, and ultimately freshwater fisheries. The movement of such fishing-related vehicles in North America seems to have played a role in the continued dispersal of invasive aquatic species and appears to be a vector in weed transmission.

15.15 Management of Recreational Fishing Impacts

There are a whole range of organisations which have at least as part of their brief to attempt to manage some of the impacts of recreational fishing that have just been described. These range from voluntary codes of practice, fishing clubs, to state and government laws to regulate fishing. Various types of zones and protection areas have also been established to regulate recreational fishing. The traditional regulatory options imposed by government agencies, such as harvest and gear restrictions, represent the standard in recreation fisheries management, at least in developed countries, but there are other methods discussed by Cooke et al. (2013) which hold out great promise because they involve the recreation anglers themselves in the practices, and Cooke et al. (2014) suggest that these types of informal institutions/practices may be as effective as formal regulations when addressing fishing management issues.

For example, there is a Standard for National Environmental Assessment of Tournament Fishing set up by national organisations, such as NEATFish organised by RecFish Australia (www.neatfish.com), where the participation is voluntary, but the Standard must be adhered to by organisations of all tournaments which claim certification under NEATFish (Neatfish 2009). It is based on a five-star model which classifies fishing tournaments on their environmental, social, and economic impacts. In its development it drew on two national initiatives, the National Code of Practice for Recreational and Sport Fishing and the National Strategy for the Survival of Released Line Caught Fish. RecFish Australia consulted widely with stakeholders in the recreational fishing industry, including national fishing agencies, recreation fishers themselves, state and government fisheries authorities, research organisations, and consultants in natural resource management. The purpose is to recognise that tournaments have a potential impact on fish stocks at specific locations and on particular species. Other issues such as fish welfare in CR tournaments needed to be considered. The Environmental Assessment includes outcomes that there are no adverse impacts on the sustainability of fish stocks, a minimisation of detrimental impacts on the environment, and the provision of useful data to fisheries research and management.

Some of the alternatives include the use of angler education programmes that attempt to evoke voluntary changes in angler behaviour, resulting in the emergence of voluntarily motivated, resource-conserving, informal institutions. These “softer” approaches to aquatic stewardship and fisheries management can be developed in cooperation with stakeholders and in many cases are led by avid anglers and angling groups. Examples of such measures include voluntary sanctuaries, informally enforced seasonal closures, personal daily bag limits, self-imposed constraints on gear, development of entirely live-release fisheries, and adoption of fish and aquatic ecosystem conservation-oriented gear and release practices. Education efforts that provide anglers with knowledge on best practices and empower them to modify their behaviour hold great promise to meet formal management goals and objectives but seem to be underutilised relative to formal regulations. Cooke et al. (2013) highlight the benefits and challenges of relying on informal institutions as alternatives to traditional regulatory options but informal institutions that protect resources and help overfished stocks recover hold great promise in both developed and developing countries, particularly when there is a single stakeholder group or when the capacity to enforce traditional regulations or to invest in stock assessments is limited. Informal institutions may help make formal institutions more effective or can even be alternatives to costly institutions that depend on enforcement to be effective.

However, sometimes regulations are needed, for example, in Quebec a regulation prohibited the targeted angling of all redhorse and suckers in regions where the endangered copper redhorse (*Moxostoma hubbsi*) was present. This was because it was extremely difficult to distinguish this species from other redhorse and sucker species. An educational campaign alone was deemed not likely to succeed so a more sweeping ban was thought to be needed.

Veiga et al. (2013) in Portugal suggested that the existence of fishing regulations is a good starting point for effective management, despite the lack of acceptance and detailed knowledge of the regulations in place by fishers based on almost 1300 interviews before and after the 2006 restrictions to control recreational fishing harvests. This may result in lack of compliance and hinder the success of recreational fishing regulations in Portugal. This was also the case in British Columbia where Lancaster et al. (2015) found a lack of knowledge related to rockfish conservation measures, and they suggested that public outreach and an educational campaign was necessary. Alós et al. (2009) suggested the use of shrimp as bait as opposed to worms to reduce the catch of undersized fish and the incidences of deep hooking. Here managing bait type might complement standard harvest regulations and facilitate more sustainable exploitation rates.

Bag or creel limits aiming to regulate the harvest of individual anglers per fishing event, or angling day, are widely used and can successfully limit the angler effort (Beard et al. 2003). However, bag limits may not be sufficient to limit total harvest (Cox et al. 2002) which may be related to the fact that they may restrict the harvest by the individual anglers but often do not restrict neither the amount of anglers nor the total harvest. In addition, bag limits may affect only the catch of the experienced anglers, because many anglers do not catch their bag limits. High bag limits may increase the attractiveness of a lake to the anglers and may set a target. As the angling satisfaction is linked to the catch and influences the management preferences of anglers, the dissatisfaction following unrealistic expectations may reduce the acceptance of sustainable management practices, such as habitat management (Arlinghaus and Mehner 2005). If the angler effort varies with the bag limits, independent of quality or density of the exploited fish population, high bag limits may fail to protect the fish population. In case the bag limits are higher than the biological capability of the fisheries, lowering the bag limits is often suggested to prevent over-exploitation. However, although a lowering of bag limits may be meaningful from a biological point of view and may work educationally altering the perceptions on fishing success and reminding anglers that their resource is not unlimited, some aspects may counteract the effects of lower bag limits. Low bag limits may lead to the replacement of small fish with larger fish after the bag limit is reached.

Quotas on the total recreation catch are thought to be impractical but currently New Jersey anglers are permitted to harvest two fish per day with a minimum size of 28 inches and an additional fish at a minimum size of 28 inches, if the angler obtains a bonus permit from the New Jersey Division of Fish and Wildlife (NJDEP 2012).

Widespread restoration of habitats is probably not a realistic aim when we consider the range and extent of environmental impacts that have occurred in lake and river wetland habitats and in the nearshore marine environments, but Lewin et al. (2006) discuss the possibilities. The best way forward here would be voluntary involvement of the recreational fishing community on small-scale restoration schemes. This has been stressed by McPhee (2017) when outlining the importance of recreation fisheries in Australian urban coastal cities. Recreation fishers can be important drivers for improvements to urban coastal environments that are subjected to cumulative stressors. Typical fisheries management frameworks and management objectives are not optimal for recreation fisheries and, in particular, urban recreation fisheries. Although a number of specific traditional fisheries management tools, such as minimum legal sizes and gear restrictions, remain relevant, they are insufficient however for the full benefits of recreational fishing to be realised. There are important issues that affect the fishery which are outside the traditional fisheries management frameworks. Major Australian coastal cities should have specific Urban Fisheries Management Plans that recognise the specific issues associated with urban recreation fisheries. These plans should coordinate within and between levels of government and have clear management objectives relevant to urban fisheries. These plans need to incorporate opportunities where relevant for habitat restoration, or habitat creation, as well as necessary infrastructure support which can enhance the recreational fishing experience. Urban recreation fisheries represent a substantial catalyst for habitat restoration activities in particular, which can have wider benefits for aquatic conservation. Stock enhancement is also a relevant potential tool for urban fisheries management. Citizen science opportunities are significant within the scope of urban recreational fisheries and are a chance for stakeholders to take greater stewardship of the local resource and collect valuable monitoring information in a cost-effective manner. Overall, Urban Fisheries Management Plans are a substantial opportunity to make fisheries management more holistic and more focused on end-user requirements, without compromising the resource base.

Sutinen and Johnston (2003) have outlined how angling management organisations could be important in the integration of the recreation sector into fishery management, but because of the multiplicity of regulations related to recreational fishing in particular, this does not seem to have occurred. As Sanchirico et al. (2010) describe, there needs to be comprehensive planning, dominant-use zones, and user rights, rather than the 321 regulations related to recreational fishing and 226 spatially explicit regulations in state and federal waters on the Californian coast (1 January 2005). Within these figures catch-limit regulations that apply to a single species, such as bag limits or boat trip limits, are not included in these figures because they are so numerous. They do not combine to create a coordinated set of interlocking regulations but rather they are a cluster of single species and single gear-type regulations that have little relationship to other regulations. There is similar fragmentation in the regulations in Massachusetts so a much more integrated set of coastal and inland fisheries plans seems to be the next stage for future fishery management. In fact as long ago as 2002 Dayton et al. suggested that the way to resolve the recreational fishing management problems was to adopt a proactive, precautionary management regime based on planning and marine zoning. This has only slowly been developed.

So far marine protected areas (MPAs) have been established as the most immediate and most effective means to conserve threatened marine ecosystems, and they have been established in highly productive coastal environments, like estuaries and reefs, many in the same habitats frequented by recreation anglers. These areas are associated with and relative to unprotected areas, increased species diversity, biomass, organism size, and density. They serve as a protection for vulnerable species and habitats and can export biomass to surrounding waters. The most common approach is to prohibit all extractive or consumptive activities that result in the harvest of organisms. They are known as "no take" MPAs and the reserves that permit recreational fishing show differences in population structure and abundance from those where no fishing is permitted (Cooke and Cowx 2004). These types of MPAs circumvent the problem of non-compliance by anglers with management measures because infringements are clearly visible (McPhee et al. 2002). They have not been popular in Australia compared with South Africa, and McPhee et al. (2002) suggested several reasons for this.

As an example of what can happen by removing recreational fishing from MPAs is the Poor Knights Islands marine reserve in New Zealand. This was closed to commercial fishing in 1981, but by 1998 it was clear that there were not significant benefits for protecting snapper populations and the reserve was made fully protected. The result was that the snapper population increased to 14 times their previous abundance in just 5 years. There was noticed that there were seasonal variation in snapper numbers too which means that some large fish were migrating to the surrounding waters where they were accessible to fishers. The environmental impact of the depletion of large fish had been that sea urchins had thrived and reduced the kelp cover over the rocks. This was thought normal until the marine reserve was established, and within a few years renewed populations of large snapper and crayfish had eaten many of the urchins, allowing the kelp to regrow and increase the productivity of these coastal waters. Similarly at Rottnest Island (Western Australia) when a marine reserve was established, the density of lobsters was about 34 times higher, and the density of lobsters above the minimum legal size was around 50 times higher than in other areas around the island, where recreational fishing was allowed. The mean carapace length, the total biomass, and egg production of lobsters in the reserve were significantly higher than in the adjacent fished areas. An alternative approach would be to restrict recreational fishing to particular zones and/or to mandate CR or to permit fishing for certain species in MPAs that can be clearly targeted and do not involve substantial by-catch. More detailed discussion can be found in Cooke et al. (2006). The usefulness of partial MPAs that implement some form of fisheries management regulations, but do not ban fishing and the take of fish entirely, has been questioned due to its perceived limited conservation benefits. However, Alós and Arlinghaus (2013) provide empirical data demonstrating fish conservation benefits of partial MPAs when the stocks in question are mainly exploited by recreation angling. They studied a multispecies recreation fishery from the Balearic Islands (Mediterranean Sea) comparing three kinds of spatially close, managed areas. The implementation of a partial MPA decreased the fishing pressure attracted, and the protected areas hosted greater abundances and larger-sized fish compared to areas of open access. Possibly the greatest conservation benefit of partial MPA resulted from the reduced fishing effort attracted, likely as a result of aversion of anglers to use areas where some form of management is affecting the recreation experience. In addition, the constraints on artisanal fishing may also have contributed to the conservation benefits found. Depending on the right social and ecological context, partial MPA may therefore work as expected.

Another strategy might be to provide local communities and stakeholders like anglers and guides, with a bigger role in determining the goals for MPAs. In some cases only recreational fishing is involved, and an approach is the establishment of voluntary sanctuaries where community stakeholders promote sustainable fisheries through education (Suski et al. 2002). Another approach would be to have zones that prohibit or mandate certain fishing gear, such as barbless hooks or live bait. If clearly defined and combined with an education programme, such regulations can be clearly enforced and need testing in MPAs (Smallwood and Beckley, 2012).

The Magnuson-Stevens Fishery Conservation and Management Act sets strict, scientifically adjusted, annual catch limits on US commercial, charter, and recreation fisheries in order to sustain saltwater fish stocks. It is seen as a model of fishery management globally. However, a new piece of legislation going through the American senate at the moment may effectively deregulate saltwater fishing to a large degree. This is officially known as the Modernizing Recreational Fisheries Management Act of 2017 (Ortolani, 2017). It has been praised by sportsmen, boating and outdoor organisations, but it has also drawn strong opposition from conservationists and some commercial and charter fishermen, and critics say that the new act would muddy the waters between federal and state management and allows political and economic considerations to override science in management decisions. There appears to be a major loophole in that annual recreation catch limits would be no longer required for stocks whose fishing rates were being maintained below their federal target and annual catch limits would be removed for fisheries in which overfishing is not occurring. Currently the status of US fisheries is annually assessed by the NOAA which tracks 474 stocks or stock complexes where fish are grouped for management. In 2016 the overfishing list included 30 stocks and stated that 444 stocks were not at present overfished. Under this Act those stocks would lose their current requirement for science-based, sustainable annual limits on catch for recreational fishing. When the NOAA set the shortest recreation snapper season ever in the Gulf of Mexico (three days in June 2017), recreation fishers lobbied the Trump administration. The Commerce Department issued a rule that permits overfishing of red snapper in the Gulf of Mexico by private anglers while acknowledging that it will delay the stock rebuilding schedule for the species by six years. This overrules good science and could eventually reduce fishing opportunities.

15.16 Education Related to Recreational Fishing Impacts

15.16.1 Trade Sector and Recreation Fisheries Conservation

The recreation angling community is composed of diverse stakeholders, including the trade sector responsible for the manufacturing, distribution, and sales of tackle, boats, and clothing, angler-based travel, revenue-generating popular media, and angling services. Through marketing and promotion, fishing companies compete for customers by convincing anglers as to what success means when they go fishing. If the angling trade can influence the social norms in the recreation angling community, then this could hold true for norms related to the conservation of recreationally targeted fishes and their habitats. Danylchuk et al. (2016) questioned whether individuals working within the fishing trade are adequately informed about best practices for recreation fisheries conservation, since these perceptions could, in turn, influence the values portrayed in the marketing and promotion of fishing. They surveyed fishing trade employees during five industry and consumer shows to evaluate their perceptions about recreation fisheries conservation and where they believe their consumers learn about these issues. Across events, respondents believed that commercial fishing and habitat loss were the greatest threats to recreation fisheries. Specific to the angling event, physical injury when handling (e.g. during hook removal) and duration of the fight were selected as having the greatest impacts on fish, with between 74% and 91% of respondents indicating that they felt impacts were species-specific. Respondents believed that their customers received information on best practices and conservation predominantly from peer-to-peer interactions, social media, and fishing magazines. They also indicated that one of the primary roles of the angling trade when it comes to recreation fisheries conservation is to convey best practices in marketing and promotion. Overall, the trade sector appears to be an important mechanism for reaching anglers, yet more work is needed to ensure that the conservation information they share is consistent with science-based, best practice and this needs to be pursued in the future.

15.16.2 Mandatory Education Programmes

Associated with licencing in MPAs, this has been suggested as it may be an effective strategy for ensuring that anglers understand the purpose of the MPA, how to minimise CR mortality, and how to minimise their footprint on the environment (Cooke et al. 2006), and it has been successfully used in Germany and Switzerland related to the licencing process. So formal course training should be required to obtain fishing licences prior to granting permission to fish for endangered species (Cooke et al. 2014). It could also be a mandatory requirement to hire fishing guides/charter captains when targeting endangered species. This might ensure proper handling, compliance with regulations, and the date and control of the fishing effort as long of course as the guides are adequately trained in, and committed to, conservation of best practices. This would require fishing guide certification programmes and could be an effective way of fostering respect for endangered fish (Cooke et al. 2014).

15.16.3 Best Practices Guidelines for Catch-and-Release in General and, As an Example, Guidelines for Striped Bass Catch-and-Release

There has been much research related to best practices that anglers should carry out in this vital aspect of fish conservation and fish welfare, and it has been suggested that what needs to be developed are techniques which are species-specific (Cooke and Suski 2005; Cooke and Shramm 2007; Nguyen et al. 2013; Gagne et al. 2017).

15.16.3.1 Techniques to Increase Survival of Released Fish

Anglers control many factors that can exacerbate stress imparted on striped bass that are caught and intended to be released (Tiedemann and Danylchuk 2012). For example, when fishing for striped bass, anglers should use appropriate weight-class tackle that allows fish to be brought in quickly to reduce exhaustion and minimise stress. Other angler-controlled factors include terminal tackle type, playing time, landing, handling and unhooking techniques, and release methods.

15.16.3.2 Terminal Tackle Type

Terminal tackle type, including the number and style of hooks and the type of bait used, can affect anatomical hooking location and the likelihood of physical injury to organs and tissue from hook wounds. Two types of hooks that are known to reduce injury and mortality of released striped bass are barbless hooks and circle hooks. In addition, corrodible, non-stainless steel hooks are encouraged. When fishing with plugs and lures with multiple treble hooks, removing one or two sets of hooks or replacing them with single hook should be considered. Single, barbless hooks are even better, as they reduce tissue damage and handling stress because they can be quickly and easily removed. In general, then fishermen should use single barbless hooks whenever possible, or crimp, bend, file, or flatten the barbs on the hooks to make them easier to remove. When fishing with natural or live bait, non-offset circle hooks should be used to minimise gut hooking and the chance of lethal wounding of striped bass to be released. The unique shape and hook point location of a circle hook ensures that when a fish takes a bait and continues to swim, or make a turn, the hook pulls until the point catches the fish in the corner of the mouth. This causes minimal damage, reduces the chance of lethal wounding, and makes it easier to unhook and quickly release the fish. Even if a circle hook is swallowed by the fish, it will slide out of the stomach when the fish moves off with the bait. As the line is pulled through the fish's mouth, it guides the hook around the jaw where it locks in place.

15.16.3.3 Playing Time

The longer a fish fights, the higher the stress level and greater the chance for exhaustion and physiological disturbance which reduces the chance of survival after release. When a strike is felt, the hook should be set quickly. Setting the hook as soon as you feel a strike will help prevent the fish from taking the hook deep in its throat where it may cause internal organ damage and be hard, or impossible, to remove. Once a fish is hooked, it should be landed quickly, rather than playing it to exhaustion. A fish brought to the boat or shore quickly has a much better chance of survival after release than one that has been exhausted by a lengthy fight.

15.16.3.4 Landing and Handling Techniques

If at all possible, striped bass should be kept in the water while hooks are removed. If a fish must be removed from the water to unhook it, always try to minimise the amount of time it is kept out of the water, handle the fish as little as possible, and release it quickly. Avoid using gaffs to land striped bass that are going to be released. In a jetty situation, if a gaff must be used, gaff fish in the jaw or corner of the mouth only.

When using a landing net, use a net with small mesh made out of rubber, knotless nylon, or other soft nonabrasive material rather than a large mesh polypropylene landing net. These materials remove less slime and reduce potential wounding. Make sure the net basket is shallow and of sufficient circumference so that it does not bend the fish severely. If a fish must be removed from the water, refrain from holding the fish in a vertical position to avoid displacing or stressing internal organs. If you are bringing a striper onboard a boat using a lip gripper or other landing device to hold the fish while you remove the hook, grab the fish by the lower jaw. However, do not lift the fish clear of the water with the gripper to avoid placing the fish's entire body weight on the jaw. Hold fish horizontally by firmly gripping the lower jaw with one hand and gently supporting its weight under the belly with the palm of the other hand. Once a striper is landed, keep it from thrashing around and injuring itself. Stripers can be calmed down by covering their eyes and head with a wet rag, or towel, or by turning them on their back. When unhooking a striped bass, handle fish carefully using wet hands, wet cotton gloves, or a wet towel to minimise removal of the fish's protective mucous layer. Striped bass have a protective mucous layer that prevents disease and infection from entering through the skin. The more a fish is handled, the more of this protective slime that is removed. Avoid touching or injuring the eyes. Never touch the gills or insert your hand into a gill cover to hold a striper as this will damage the gills and impair the fish's ability to breath.

15.16.3.5 Unhooking Techniques

Striped bass should be unhooked quickly and carefully in the water whenever possible, to reduce stress and the potential for injury or post-release mortality, especially when air temperature is much higher than water temperature. Do not tear tissue when removing the hook. If a hook is embedded in a fish's throat or difficult to remove by hand, use a proper dehooking tool for hook removal, such as long-nosed pliers, hemostats (forceps), or a commercially available hook removal tool. Do not forcefully remove the hook if you cannot see it or if it appears that you may cause greater harm to the fish by attempting to remove the hook when a fish is hooked deep in the throat, or stomach, or hooked in the gills. Cut the leader as close to the eye of the hook as possible and leave the hook in the fish. There is evidence that fish are capable of rejecting, expelling, or encapsulating hooks by secreting an inert matrix of calcified cellular material.

15.16.3.6 Release Methods

Fish in good condition should be quickly and gently returned to the water head first in an upright position. Fish that are stressed by the fight, or handling and unhooking, should be revived prior to release. Exhausted fish can be revived by holding them head first into the current, or direction of the seas, in the swimming position with one hand under the tail and the other under the fish's belly, or by grasping its jaw between the thumb and forefinger. Gently move the fish to get water flowing through the mouth and over the gills. Use a figure-8 pattern to always keep the fish moving forward and never move the fish backwards. When the fish is revived, let it swim away on its own. Do not let the fish go until it clamps down on the thumb or is able to swim strongly and freely out of the grasp.

There is growing interest in educating anglers on CR best practices, yet there is little information on whether angler education programmes yield measurable improvements in fish condition and survival. As such, Delle Palme et al. (2016) conducted a study focused on mixed-gender youth groups (aged 8–10) and contrasted three levels of training intervention. Treatment 1 training had no mention of CR best practices. Treatments 2 and 3 training involved visual aids to illustrate best practices, while Treatment 3 added a hands-on demonstration. When caught by the most highly trained participants, fish experienced the least amount of air exposure but were handled for longer periods, as trained anglers were more careful. Higher levels of training led to a higher likelihood that anglers wet their hands and used a bucket filled with water while handling fish but all treatment groups yielded similar incidences of deep hooking and bleeding. Overall, mortality (initial and after ~12 h) was low across all treatments. These findings suggest that a short (~20 min) fishing workshop can transfer information on CR practices, at least in the short term, that can lead to some improved conditions for angler-caught fish. It is unclear the extent to which this information is retained in the long term, or how different target populations or training strategies might influence knowledge transfer and adoption and thus biological outcomes. With growing interest in sharing CR best practices with anglers, it was suggested that there is a need for additional research on outreach strategies to ensure that such efforts are effective and yield meaningful benefits to fish welfare and conservation, and it has been suggested by Cooke et al. (2017) that anglers need to be involved much more in the science and practice of CR science.

15.17 Behavioural Response of Anglers to Management Actions

A primary concern in managing recreation fisheries is the behavioural response of anglers to management actions. Use restrictions on public sport fisheries are often necessary because the demand for a superior fishing experience in terms of catch puts pressure on fish populations and the sustainability of aquatic systems. Efficient fisheries management requires that agencies be able to anticipate angler reactions to new fishing regulations considering they ultimately alter the attractiveness of the affected fishing opportunity (Beardmore et al. 2011). Furthermore, fisheries agencies may also be concerned about the impact of regulations on participation because most of their revenues are derived from licence and equipment sales. Klatt et al. (2014) present a model of anglers' reactions to regulations designed to slow the spread of an aquatic infectious disease. This is a critical issue for fisheries managers because aquatic diseases (and, similarly, invasive species) tend to suppress catch rates by increasing the mortality and altering the behaviour of fish. Furthermore, anglers that travel between different lakes and rivers become an important vector through which aquatic diseases can spread and thereby trigger reductions in the fishing quality of an entire region. Yet there is little research that addresses disease regulations in fisheries.

The results demonstrated that anglers significantly alter their behaviour at the site choice and participation levels in response to a new disease and its regulations. Specifically, it was found that disease regulations implemented by the Michigan Department of Natural Resources to slow the spread of VHSv have had an impact on angler behaviour for areas where the virus is present and most heavily regulated. Anglers were less likely to visit a site considered to be VHSv positive and subject to bait use restrictions and more likely to choose a site free of disease regulations. This suggests that the VHSv regulations have been successful in reducing the opportunities for the disease to be spread by anglers. Furthermore, there is evidence that the presence of these regulations affected how anglers fished the Great Lakes through their choice of bait, but not through boat use.

To be clear, there is no absolute clarity explicitly distinguishing among two possible effects driving these results: the influence of VHSv on resource quality and the influence of the disease management zone restrictions on angler actions per se. Moreover, the extent to which the regulations have prevented damage to the fishery by limiting the spread of VHSv cannot be measured.

In Europe research and policy debates point to the need to increase efforts to rehabilitate or restore habitat structure and function, at the expense of a traditional recreation fisheries management approach which is to intensively stock fish.

Arlinghaus and Mehner (2005) consider that rehabilitation of habitat on larger scales can be considered as the most sustainable recreation fisheries management strategy. This particularly applies in densely populated countries such as Germany, where most aquatic ecosystems have experienced anthropogenic disturbances dating back several centuries. Although habitat-orientated recreation fisheries management offers solutions to many management problems, major advances in research and training, restructuring of institutions, and support from all stakeholders, including the public, are needed. Anglers are amongst the key players in this shifting fisheries management policy as they are often users and at the same time managers in Central Europe, but other stakeholders are clearly equally important, like water management authorities or land owners. Arlinghaus and Mehner (2005) suggest that multiple factors are responsible for anglers being orientated towards a more sustainable habitat management as opposed to a less sustainable stocking management approach. These factors offer insights into paramount variables that might be targeted by managers. Obviously, the most promising way is to increase the pro-ecological values and attitudes of anglers, for example, by appropriate education outreaches. The most efficient ones will include anglers in habitat management project design, implementation, and evaluation, which ensure that anglers directly experience potentially positive effects of habitat improvements or alternatively possible negative effects of habitat modifications. Personal experiences might be judged as one of the most effective ways of environmental education.

There are also situations where continuous stocking seems appropriate, for example, in artificial fisheries, or to preserve fish at risk of extinction. One paramount factor that emerged in their analysis was that to satisfy anglers, what was essential was catching fish to meet catch expectations. The most straightforward implication might be that angler satisfaction should be enhanced by increasing the catch quality, which in turn would increase the probability of habitat management as opposed to stocking to be supported by anglers. This might most easily be achieved by simply improving the effectiveness of traditional inland fisheries practices, such as appropriately planned harvest regulations, closed seasons, or promotion of CR practices. However, increasing the fish stock quality as perceived by the anglers may not always increase the catch quality for individual anglers due to increased angling effort/mortality directed at the recovering water with unlimited access. Some access restrictions may therefore be needed in specific vulnerable fisheries because high-quality (here equalled with high catch rates) angling is often only found in waters where: (1) high cost/time required to access the fishery (e.g. remote waters without driving routes) exclude anglers or (2) access and effort is strictly controlled by private or local interests. Angling effort to indirectly increase stock abundance, catch quality, angler satisfaction, and support for habitat management may be controlled by lottery or licence rotating systems, individual transferable effort or access quotas, protected areas, or high access costs (e.g. time or money). This procedure is already being pursued in some of the highest-quality recreation fisheries, which is particularly feasible in private property fisheries that characterise large parts of Central Europe.

15.18 Voluntary Codes of Practice, Codes of Conduct, and Angler's Codes of Ethics (Like the Fly Fishers Code of Ethics, 2002)

There are many such codes which are available, both nationally (e.g. RecFish Australia 2014), and regionally (like the Code of Conduct for Recreational Fishing in the Kimberley, Western Australia, 2012). Other voluntary codes of practice exist like in the UK where the National Angling Alliance produced a Code of Conduct for Coarse Anglers covering aspects like the care of the environment, general behaviour, tackle and fish handling. The Nordic Angler Association established a code for recreation angling covering the whole of Scandinavia, including Iceland. European Codes cover recreational fishing (FAO 2008) and recreational fishing and invasive alien species (Owen 2013). The main problem with all these codes is that whilst they are available on the internet, the average recreation fisher is unlikely to spend time delving into these codes and there needs to be better ways of establishing educational outreach to anglers with the information that they contain.

Anglers can help by:

- Promoting ethical behaviour in the use of aquatic resources.
- Never disposing trash, waste, or plastics into the ocean. Avoiding spilling and never dumping any pollutants on land or in the water.
- Recycling rubbish, including worn-out lines, leaders, and hooks.

- Limiting the use of boats and vehicles to approved areas thus avoiding sensitive marine habitats.
- Volunteering for beach clean-ups and wetland restorations.
- Starting their own fishing line recycling programme if there is no convenient location in their community.
- Participating in community natural resources planning efforts.
- Getting involved in protecting essential fish habitat.
- Reporting pollution problems to local, state, or federal authorities. They can also follow the Angler's Code of Ethics which is modified from the US National Marine Fisheries Service's code.
- Demonstrating and promoting, through education and practice, ethical behaviour in the use of aquatic resources.
- Valuing and respecting the aquatic environment and all living things. Avoiding spilling and never dumping pollutants, such as gas or oil.
- Keeping fishing sites litter-free.
- Purchasing and keeping current their fishing licence, if necessary. If they are exempt, they may still purchase a licence as a way to contribute to conservation.
- Treating other anglers, boaters, and property owners with courtesy and respect.
- Respecting property rights, and never trespassing on private lands or waters.
- Keeping no more fish than needed for consumption and never wastefully discarding fish.
- Carefully handling and releasing alive all fish that are unwanted or prohibited by regulation.
- Using tackle and techniques that minimise harm to fish when CR angling.

Concluding Remarks

It is clear that the way forward with recreation fisheries management is to involve the participants much more in this process with a hands-on approach and to find the best ways of educational outreach, with important scientific knowledge related to fisheries so that the recreational fishing community becomes better informed. This includes the wider recreational fishing industry too and the tourism-related aspects of fishing holidays, guiding, and charter trips. Participation in recreational fishing creates one of the strongest social and political constituencies for environmental education and the conservation of aquatic resources. Planning of the coastal ecosystems worldwide must include recreational fishing as one important component, and the protection of both coastal and inland wetlands must be extended. One of the biggest future issues this century is the likely influence of climate change, and it will have effects on recreational fishing and there will need to be further research into this topic. Jones et al. (2013) suggested that the US cold-water fisheries were highly vulnerable to climate change through loss of suitable habitat. With a low-emission trajectory, it was estimated that there would be 18% less habitat by 2100, but under high emissions the cold-water fish habitat will disappear from most of New England, the Appalachians, and Upper Midwest by that year. Other stressors before then may be affected by increased temperature and precipitation variability which in some areas will make streams and lakes unsuitable for fish populations before climatic effects occur so that there will be changes in nutrient budgets, changes in run-off and riparian vegetation. Gilbert and Smith (2016) say that so far research on the effects of climate change on recreational fishing has been conducted at a coarse scale making specific impacts of climate change uncertain. Meanwhile there has been a special issue of Fisheries Magazine (issue 41) in July 2016 on the Effects of Climate Change on North American Inland Fisheries, and rather more specifically Clark et al. (2017) propose that wild populations in a warming climate may become skewed towards low-performance phenotypes which would have ramifications for predator-prey interactions and community dynamics and influence fish evolution in the future.

References

Alós, J., & Arlinghaus, R. (2013). Impacts of partial marine protected areas on coastal fish communities exploited by recreational angling. *Fisheries Research, 137*, 88–96.

Alós, J., Arlinghaus, R., Palmer, M., March, D., & Alvarez, I. (2009). The influence of type of natural bait on fish catches and hooking location in a mixed-species marine recreational fishery, with implications for management. *Fisheries Research, 97*, 270–277. https://doi.org/10.1016/j.fishres.2009.03.003.

Arkenford Ltd. (2014). *Watersports Participation Survey 2013*. Retrieved from http://www.britishmarine.co.uk/pdf/WatersportsReview2013ExecutiveSummary.pdf.

Arlinghaus, R., & Cooke, S. J. (2009). Recreational fisheries: Socioeconomic importance, conservation issues and management challenges. In B. Dickson, J. Hutton, & W. M. Adams (Eds.), *Recreational Hunting, Conservation and Rural Livelihoods: Science and Practice* (pp. 39–58). Chichester: Wiley-Blackwell.

Arlinghaus, R., & Mehner, T. (2003). Socio-economic characterization of specialized common carp (*Cyprinus carpio* L.) anglers in Germany, and implications for inland fisheries management and eutrophication control. *Fisheries Research, 61*, 19–33.

Arlinghaus, R., & Mehner, T. (2005). Determinants of management preferences of recreational anglers in Germany: Habitat management versus fish stocking. *Limnologica—Ecology and Management of Inland Waters, 35*, 2–17.

Armstrong, M., Brown, A. Hargreaves, J., Hyder, K., Pilgrim-Morrison, S., Munday, M., et al. 2013. Sea Angling 2012—A survey of recreational sea angling activity and economic value in England. Retrieved from www.marinemanagement.org.uk/seaangling/documents/finalreport.pdf.

Asoh, K., Yoshikawa, T., Kosaki, R., & Marschall, E. A. (2004). Damage to cauliflower coral by monofilament fishing lines in Hawaii. *Conservation Biology, 18*, 1645–1650.

Atlantic States Marine Fisheries Commission. (2011). Atlantic States Marine Fisheries Commission striped bass stock assessment update, November 2011.

Bartholomew, A., & Bohnsack, J. A. (2005). A review of catch-and-release angling mortality with implications for no-take reserves. *Reviews in Fish Biology and Fisheries, 15*, 129–154.

Beard, T. D., Cox, S. P., & Carpenter, S. R. (2003). Impacts of daily bag limit reductions on angler effort in Wisconsin walleye lakes. *North American Journal of Fisheries Management, 23*, 1283–1293.

Beardmore, S., Dorow, M., Haiden, W., & Arlinghaus, R. (2011). The elasticity of fishing effort response and harvest outcomes to altered regulatory policies in eel (*Anguilla anguilla*) recreational angling. *Fisheries Research, 110*, 136–148.

Bower, S. D., Danylchuk, A. J., Raghavan, R., Danylchuk, S. C., & Pinder, A. C. (2016). Rapid Assessment of the physiological impacts caused by catch-and-release angling on blue-finned mahseer (Tor sp.) of the Cauvery River, India. *Fisheries Management and Ecology, 23*, 208–217.

Bowker, J. M., & Askew, A. E. (2012). US Outdoor Recreation Participation Projections to 2060. In H. K. Cordell (Ed.), *Outdoor Recreation Trends and Futures: A Technical Document Supporting the Forest Service 2010, RPA Assessment* (pp. 105–124). General Technical Report SRS-150. Asheville, NC: USDA Forest Service, Southern Research Station.

Brown, C., & Laland, K. N. (2003). Social learning in fisheries: A review. *Fish and Fisheries, 4*, 280–288.

Burgin, S. (2017). Indirect consequences of recreational fishing in freshwater ecosystems: An exploration from an Australian perspective. *Sustainability, 9*, 280. https://doi.org/10.3390/su9020280.

Clark, T. D., Messmer, V., Tonin, A. J., Hoey, A. V., & Pratchett, M. S. (2017). *Rising Temperatures may Drive Fishing-Induced Selection of Low Performance Phenotypes*. Scientific Reports 7, 40571. https://doi.org/10.1038/srepp40571.

Conover, D. O., & Munch, S. B. (2002). Sustaining fisheries yields over evolutionary time scales. *Science, 297*, 94–96.

Cooke, S. J., & Cowx, I. G. (2004). The role of recreational fishing in global fish crisis. *Bioscience, 543*, 857–859.

Cooke, S. J., Danylchuk, A. J., Danylchuk, S. E., Suski, C. D., & Goldberg, T. L. (2006). Is catch-and-release-recreational angling compatible with no-take marine protected areas? *Ocean and Coastal Management, 49*, 342–354.

Cooke, S. J., Hogan, Z. S., Butcher, P. A., Stokesbury, M. J. W., Raghavan, R., Gallagher, A. J., et al. (2014). Angling for endangered fish: Conservation problem or conservation action? *Fish and Fisheries, 17*, 249–265.

Cooke, S. J., Palensky, L., & Danylchuk, A. J. (2017). Inserting the angler into catch-and-release angling science and practice. *Fisheries Research, 186*, 599–600.

Cooke, S. J., Schreer, J. E., Dunmall, K. M., & Philipp, P. (2002). Strategies for quantifying sub-lethal effects of marine catch-and-release angling—Insights from novel freshwater applications. *American Fisheries Society Symposium, 30*, 121–134.

Cooke, S. J., & Shramm, H. L. (2007). Catch-and-release science and its applications to conservation and management of recreational fisheries. *Fisheries Management and Ecology, 14*, 73–79.

Cooke, S. J., & Suski, C. D. (2005). Do we need species-specific guidelines for catch-and-release recreational angling to effectively conserve diverse fishery resources? *Biodiversity and Conservation, 14*, 1195–1209.

Cooke, S. J., Suski, C. D., Arlinghaus, R., & Danylchuk, A. (2013). Voluntary institutions and behaviours as alternatives to formal regulations in recreational fisheries management. *Fish and Fisheries, 14*, 439–457.

Cordell, H. K. (Ed.). (2012). *Outdoor Trends and Futures: A Technical Document Supporting the Forest Service 2010 RPS Assessment*. General Technical Report SRS-150. Asheville, NC: USDA Forest Service, Southern Research Station, 167pp.

Cox, S. P., Beard, T. D., & Walters, C. (2002). Harvest control in open-access sport fisheries: Hot rod or asleep at the reel? *Bulletin of Marine Science, 70*, 749–761.

Danner, G. R., Chacko, J., & Brautigern, F. (2009). Voluntary ingestion of soft plastic lures affects brook trout growth in the laboratory. *North American Journal of Fisheries Management, 29*, 352–360.

Danylchuk, A. J., Tiedemann, J., & Cooke, S. J. (2016). Perceptions of recreational fisheries conservation within the fishing industry: Knowledge gaps and learning opportunities identified at east coast trade shows in the United States. *Fisheries Research*. https://doi.org/10.1016/j.fishres.2016.05.015.

Dayton, P. K., Thrush, S., & Coleman, F. C. (2002). *Ecological Effects of Fishing in Marine Ecosystems of the United States*. Arlington, VA: Pew Oceans Commission, 44pp.

Delle Palme, C. A., Nguyen, V. M., Gutowsky, L. F. G., & Cooke, S. J. (2016). Do fishing education programs effectively transfer "catch-and-release" best practices to youth anglers yielding measurable improvements in fish condition and survival? *Knowledge and Management of Aquatic Ecosystems, 417*, 42. https://doi.org/10.1051/kmae/2016029.

Diodati, P., & Richards, R. A. (1996). Mortality of striped bass hooked and released in salt water. *Transactions of the American Fisheries Society, 125*, 300–307.

FAO. (2008). *EIFAC Code of Practice for Recreational Fisheries*. FAO of the United Nations European Inland Fisheries Advisory Committee. EIFAC Occasional Paper 42, Rome, 54pp.

Fly Fishers International. (2002). *Federation of Fly Fishers Code of Angling Ethics*. Fly Fishers International.

Font, T., & Lloret, J. (2014). Biological and ecological impacts derived from recreational fishing in Mediterranean coastal areas. *Reviews in Fisheries Science and Aquaculture, 22*, 73–85.

Gagne, T. O., Ovitz, L., Griffin, L. P., Brownscombe, J. W., Cooke, S. J., & Danylchuk, A. J. (2017). Evaluating the consequences of catch-and-release angling on golden dorado (*Salminus brasiliensis*) in Salta, Argentina. *Fisheries Research, 186*, 625–633.

Gilbert, L., & Smith, J. W. (2016). *The impact of Climate Change on Inland Recreational Fishing*. Institute of Outdoor Recreation and Tourism, Utah State University. IORT-PR-2016-01, 3pp.

Hessenauer, J.-M., Vokoun, J. C., Suski, C. D., David, J., Jacobs, R., & O'Donnell, E. (2015). Differences in the metabolic rates of exploited and unexploited fish populations: A signature of recreational fisheries induced evolution? *PLoS One, 10*(6). https://doi.org/10.1371/journal.pone0128336.

Hoffman, N. (2009). *Gone Fishing: A Profile of Recreational Fishing in Canada*. Statistics Canada.

IGFA. (2011). IGFA school of sportfishing tips and techniques in modifying lures. *International Angler, 74*(5).

Jones, R., Travis, C., Rodgers, C., Lazar, B., English, E., Lipton, J., et al. (2013). Climate change impacts on freshwater recreational fishing in the United States. *Mitigation and Adaptation Strategies for Global Change, 18*, 731–758.

Klatt. J., Lupi, F., & Melstrom, R. (2014). A natural experiment identifying disease regulation effects on recreational fishing. In *Agriculture and Applied Economics Association's Annual Meeting*, Minneapolis. Retrieved from http://purl.umn.edu/170580.

Knapp, R. A., Corn, P. S., & Schindler, D. E. (2001). The introduction of normative fish into wilderness lakes: Good intentions, conflicting mandates, and unintended consequences. *Ecosystems, 4*, 275–278.

Lancaster, D., Dearden, P., & Ban, N. C. (2015). Drivers of recreational fisher compliance in temperate conservation areas: A study of rockfish conservation areas in British Columbia, Canada. *Global Ecology and Conservation, 4*, 645–657.

Lennox, R. J., Mayer, I., Havn, T. B., Johansen, M. R., Whoriskey, K., Cooke, S. J., et al. (2016). Effects of recreational angling and air exposure on the physiological status and reflex impairment of European grayling (*Thymallus thymallus*). *Boreal Environment Research, 21*, 461–470.

Lewin, W.-C., Arlinghaus, R., & Mehner, T. (2006). Documented and potential biological impacts of recreational fishing: Insight for management and conservation. *Reviews in Fisheries Science, 14*, 305–367.

Liddle, M. J., & Scorgie, H. R. A. (1980). The effects of recreation on freshwater plants and animals: A review. *Biological Conservation, 17*, 183–206.

Maryland Department of Natural Resources. (2010). Deep hooking is the single most important factor causing sport angled fish to die. MDDNR Fisheries Service. Retrieved from http://www.dnr.state.md.us/fisheries/recreational/circlehookFisheriesHomePage.html.

McGarvie Hirner, J. L., & Cox, S. P. (2007). Effects of rainbow trout (*Oncorhynchus mykiss*) on amphibians in productive recreational fishing lakes of British Columbia. *Canadian Journal of Fisheries Aquatic Science, 64*, 1770–1780.

McPhee, D. (2017). Urban recreational fisheries in the Australian coastal zone: The sustainability challenge. *Sustainability, 9*, 422. https://doi.org/10.3390/su9030422.

McPhee, D. P., Leadbitter, D., & Skilleter, G. A. (2002). Swallowing the bait: Is recreational fishing in Australia ecologically sustainable? *Pacific Conservation Biology, 8*, 40–51.

Muoneke, M. I., & Childress, W. M. (1994). Hooking mortality: A review for recreational fisheries. *Reviews in Fisheries Science, 2*, 123–156.

National Marine Fisheries Service. (2012). *Atlantic States Marine Fisheries Commission 2011*.

National Survey of Fishing, Hunting and Wildlife Association. (2011). US Department of the Interior, US Fish and Wildlife Service, US Department of Commerce, US Census Bureau 2011. US National Survey of Fishing 2011, Washington, DC, 161pp.

NEATFish. (2009). *A Standard for National Environmental Assessment of Tournament Fishing*. Neatfish, 55pp.

Nguyen, V. M., Rudd, M. A., Hinch, S. G., & Cooke, S. J. (2013). Recreational anglers' attitudes, beliefs and behaviours related to catch-and-release practices of Pacific salmon in British Columbia. *Journal of Environmental Management, 128*, 852–865.

NJDEP. (2012). *The Striped Bass Bonus Program*. New Jersey Department of Environmental Protection, Division of Fish and Wildlife. Retrieved from https://www.njfishandwildlife.com/bonusbas.htm

NOAA. (2009). *Fisheries of the United States 2009*. Current Fishery Statistics No. 2009, Final report. Silver Spring, MD.

Ortolani, G. (2017). Modern fish act: Boon to recreational fishing or risk to US fishery? Retrieved from http://news.mongabayu.com/by/giovanni-ortolani/.

Outdoor Foundation. (2014). *Special Report on Fishing*. Recreational Boating and Fishing Foundation, The Outdoor Foundation. 63pp.

Owen, M. G. (2013). *European Code of Conduct on Recreational Fishing and Invasive Alien Species*. Strasbourg: Council of Europe, 35pp.

Policansky, D. (2002). Catch-and-release recreational fishing—A historical perspective. In T. J. Picher & C. E. Hollingworth (Eds.), *Recreational Fisheries: Ecological, Economic and Social Evaluation*. Oxford: Blackwell Science.

Pope, K. L., & Wilde, G. R. (2004). Effect of catch-and release angling on growth of largemouth bass (*Micropterus salmoides*). *Fisheries Management and Ecology, 11*, 39–44.

Possato, F. E., Barletta, M., Costa, M. F., Ivar do Sul, J. A., & Dantas, D. V. (2011). Plastic debris ingestion by marine catfish: An unexpected fisheries impact. *Marine Pollution, 62*, 1098–1102.

Post, J. R., Sullivan, M., Cox, S., Lester, N. P., Walters, C. J., Parkinson, E. A., et al. (2002). Canada's recreational fishery: The invisible collapse? *Fisheries, 27*, 6–17.

Prato, G., Barrier, C., Francour, P., Cappanera, V., Markantonaton, V., Guidetti, P., & et al. (2016). Assessing interacting impacts of artisanal and recreational fisheries in a small Marine Protected Area (Portifino), NW Mediterranean Sea. *Ecosphere 7*(12), 18pp. e01601. https://doi.org/10.1002/ecs2.1601.

Quan, R.-C., Wen, X., & Yang, X. (2002). Effects of human activities on migratory waterbirds at Lashihai Lake, China. *Biological Conservation, 108*, 273–279.

Raison, T., Nagrodski, A., Susk, C. D., & Cooke, S. J. (2014). Exploring the potential effects of lost or discarded soft plastic fishing lures on fish and the environment. *Water Air Soil Pollution, 225*. https://doi.org/10.1007/s11270-014-1809-1.

Recfish Australia. (2014). *A National Code of Practice for Recreational and Sport Fishing*. Recfish Australia.

Sanchirico, J. N., Eagle, J., Palumbi, S., & Thompson Jr., B. H. (2010). Comprehensive planning, dominant-use zones and user-rights: A new era in ocean governance. *Bulletin of Marine Science, 86*, 1–13.

Shiffman, D., Gallagher, A. J., Wester, J., MacDonald, C. C., Thaler, A. D., Cooke, S. J., et al. (2014). Trophy fishing for species threatened with extinction: A way forward building on a history of conservation. *Marine Policy, 50*, 318–322.

Sigler, M. (2014). The effects of plastic pollution on aquatic wildlife: Current situation and future solutions. *Water Air Soil Pollution, 225*. https://doi.org/10.1007/s11270-104-2184-6.

Simpson, D., & Mawle, G. W. (2010). *Public Attitudes to Angling 2010*. Bristol: Environment Agency.

Skaggs, J., & Allen, M. S. (2016). Data needs to assess effects of soft plastic lure ingestion on fish populations. American Fisheries Society, January 11, Essays, *Fisheries Magazine News*.

Smallwood, C. B., & Beckley, L. E. (2012). Spatial distribution and zoning compliance of recreational fishing in Ningaloo Marine Park, North-Western Australia. *Fisheries Research, 125–126*, 40–50.

Sudmann, S. R., Distelrath, F., Mayer, B. C., & Bernert, P. (1996). Auswirkungen der Einstellung des Angelsports auf den Brutvogelbestand am südlichedn Teil des Altheim Bienen-Praest. *Natur und Landschaft, 12*, 536–540.

Suski, C. D., Phelan, F. J. S., Kubacki, M. R., & Philipp, D. P. (2002). The use of community-based sanctuaries for protecting smallmouth bass and largemouth bass from angling. *American Fisheries Society Symposium, 2002*(31), 371–378.

Sutinen, J. G., & Johnston, R. J. (2003). Angling management organizations: Integrating the recreational sector into fishery management. *Marine Policy, 27*, 471–487.

Sutter, D. A. H., Suski, C. D., Philipps, D. P., Kleforth, T., Wahl, D. H., Kersten, P., et al. (2012). Recreational fishing selectively captures individuals with the highest fitness potential. *PNAS, 109*(51), 20960–20965.

Thomé-Souza, M. J. F., Maceina, M. J., Forsberg, B. R., Marshall, B. G., & Carvalho, A. L. (2014). Peacock bass mortality associated with catch-and-release sport fishing in the Negro River, Amazonas state, Brazil. *Acta Amazonica, 44*, 527–532.

Tiedemann, J., & Danylchuk, A. (2012). Assessing impacts of catch and release practices on striped bass (*Morone saxatalis*). Implications for Conservation and Management, 15pp. Retrieved from http://www.monmouth.edu/uploadedFiles/Resources/Urban_Coast_Institute/Best20%PracticesStriped%20BassCatchandRelease.

Topline Survey. (2017). *Outdoor Recreation Participation*. Outdoor Foundation, Washington, 12pp.

Veiga, P., Pita, C., Leite, L., Ribeiro, J., Ditton, R. B., Gonçalves, J. M. S., et al. (2013). From a traditionally open access fishery to modern restrictions: Portuguese anglers' perceptions about newly implemented recreational regulations. *Marine Policy, 40*, 53–63.

Wales Outdoor Recreation Survey. (2015). *Wales Outdoor Recreation Survey 2014 Final Report*. Cardiff: Natural Resources Wales, 108pp.

Wells, R. S., Hoffman, S., & Moors, T. L. (1998). Entanglement and mortality of bottlenose dolphins, *Tursiops truncates* in recreational fishing gear in Florida. *Fisheries Bulletin, 96*, 647–650.

Wissinger, S., McIntosh, A., & Greig, H. S. (2006). Impacts of introducing brown and rainbow trout on benthic invertebrate communities in shallow New Zealand lakes. *Freshwater Biology, 51*, 2009–2028.

Wolter, C., & Arlinghaus, R. (2003). Navigation impacts on freshwater fish assemblages. The ecological relevance of swimming performance. *Reviews of Fish Biology and Fisheries, 13*, 63–89.

World Bank. (2012). *Hidden Harvest—The Global Contribution of Capture Fisheries*. Report No. 66469, Washington, DC, 92pp.