Hall, M.A. 2015. More on Bycatches: Changes, Evolution, and Revolution. In: G.H. Kruse, H.C. An, J. DiCosimo, C.A. Eischens, G.S. Gislason, D.N. McBride, C.S. Rose, and C.E. Siddon (eds.), Fisheries Bycatch: Global Issues and Creative Solutions. Alaska Sea Grant, University of Alaska Fairbanks. http://doi.org/10.4027/fbgics.2015.12

More on Bycatches: Changes, Evolution, and Revolution

Martin A. Hall
Inter-American Tropical Tuna Commission, La Jolla, California, USA, mhall@iattc.org

Abstract

I attempt to provide a perspective on some developments around the bycatch problem. The definition of bycatch continues to be an unsettled matter, but for most people it has a clear negative connotation, and I try to reflect that.

The options to reduce bycatch are better understood using the components of bycatch estimates: effort and bycatch per unit of effort. Factors affecting BPUE can be used to find adequate strategies. The bycatch/catch ratio is useful to minimize the losses in production while reducing bycatch and it reflects the “ecological cost” of production. The evolution of the role of observers is traced through time, and the improvements developing mitigation programs are discussed.

Populations: Using numbers of incidental mortalities to assess the impacts on the so-called “bycatch species” populations are simplistic and alternative metrics (e.g., the characteristics of the individuals killed) should be considered.

Ecosystems: Obstacles to the progress of ecosystem-based fisheries management range from institutions and advocates with narrow foci, to the difficulties of choosing between alternative impacts. If the decisions made by managers are influenced by the intensity of the advocacy, or by the charisma of the different species, then we will be ignoring our objective of ecosystem-based fisheries management.

A conceptual revolution proposes an alternative way to harvest an ecosystem based on a diversification of the harvest, reducing species, and size selectivities. This seems to be a better way to preserve the ecosystem while utilizing its resources.

Even though much progress has been achieved through improvements in fishing gear technology, the real revolution has not happened: a change from gear that causes mortality to most of what is captured,

and then a portion is retained, to a system based on live captures, where only those meant to be retained are killed.

Introduction

After thirty years involved in bycatch issues, it is a good opportunity to assess the changes in the approach of scientists and managers to the problem, what we have learned, where the main gaps in our knowledge are, how have our methods to organize and implement mitigation programs evolved, and the evolution that has taken place in the attitudes and views of fishers and other stakeholders interested on the subject. It is also important to trace our progress toward the inclusion of bycatch management objectives as part of a more holistic approach to fisheries management. This is an obvious component of the changes needed to include ecosystem considerations in fisheries management. Whichever definition of ecosystem-based fisheries management is chosen (e.g., Murawski 1992, Rochet and Trenkel 2003, Graham et al. 2007, Smith et al. 2007, Pitcher et al. 2009, Tallis et al. 2010, Fletcher et al. 2010, Hilborn 2011), dealing with impacts on species other than the main targets will be included in the new and more varied set of objectives to achieve successful sustainable fisheries, understanding that that goal cannot be achieved in degraded, altered ecosystems. It is by no means the only addition needed, and new indicators, monitoring of ecosystem changes in several characteristics, etc., will also be part of the change.

The perspective of this paper is inspired by the work of my friend and teacher Dr. Dayton "Lee" Alverson, who brought the issue of bycatch to the forefront, and set the basis for much of the work on bycatch that followed (Alverson et al. 1994, Alverson and Hughes 1996).

Some significant issues have been left out simply to keep a narrower focus. These include:

- The issue of cryptic mortality from different sources (e.g., individuals killed by the gear but not retained, facilitated predation by the disturbance caused by the fishing operations on prey species), subject of recent reviews (Broadhurst et al. 2006, Gilman et al. 2013).

- The issue of the ecological impacts of bycatches on pelagic and benthic communities: the fate of the discards, and their cycling (Cushing 1984, Daan 1991, Buck 1992, Borges et al. 2001).

- The issue of the ecological and economic impacts of the no discard policies that have been adopted in some countries.

- The issue of incentives to reduce bycatch including rights-based management, consumer pressure approaches, and economic approaches (Gjertsen et al. 2009, Martin et al. 2012, Agnew et al.

2014, Pelc et al. 2015). This is acknowledged to be a major component of many successful approaches to bycatch management, excluded simply to limit the extent of the document.

The definition of bycatch

The "bycatch issue" originated in very diverse settings. The high level of waste and its economic consequences in some fisheries was critical for some (Clucas 1997; Clucas and James 1997; Pascoe 1997; Catchpole et al. 2005a,b; Harrington et al. 2005). Others were mostly concerned with the conservation impacts of the incidental mortality of members of the megafauna (long-lived and charismatic vertebrates: marine mammals, sea turtles, seabirds, etc.) and the need to include mitigation measures in the management of fisheries (Morizur et al. 1999; Crowder and Murawski 1998; Lewison et al. 2004; Wallace et al. 2010, 2013). Others were focused on the waste of undersized individuals of the target species that reduced the yields of the fishery. Some saw the bycatch as a bonus that could be utilized. Some fisheries caught species that they could not retain for legal reasons, and in some cases they interfered with the production of other fisheries (Stevens 1990, Davies et al. 2009). Words like "unintended," "incidental," "unwanted," "non-target," and "unmanaged" grew out of these different views, and the concept of bycatch could not be defined to everyone's satisfaction. We are still there, and the inconsistency of the definitions muddles many discussions. In spite of all the variants, for the public, and especially for the environmental organizations, bycatch has a negative connotation. Examples from the World Wildlife Fund, Seafood Watch Program, and NOAA website based on the Magnuson-Stevens Conservation and Management Act follow. These are the first definitions to appear in a Google search:

> "Wherever there is fishing, there is bycatch—the incidental capture of non-target species such as dolphins, marine turtles and seabirds. Thousands of miles of nets and lines are set in the world's oceans each day. Modern fishing gear, often undetectable by sight and extremely strong, is very efficient at catching the desired fish species—as well as anything else in its path. A staggering amount of marine life—including turtles, dolphins and juvenile fish—is hauled up with the catch, and then discarded overboard dead or dying.
>
> Fishing industry leaders increasingly realize the need to reduce this phenomenon. Proven solutions do exist, such as modifying fishing gear so that fewer non-target species are caught or can escape. In many cases, these modifications are simple and inexpensive, and often come from fishers themselves."—http://www.worldwildlife.org/threats/bycatch

> "Many fisheries around the world throw away more fish than they keep. Some of the biggest offenders are shrimp fisheries. In the worst cases, for every pound of shrimp caught, up to six pounds of other species are discarded. And this incidental catch of unwanted or unsellable species, known as 'bycatch,' doesn't just include fish—turtles, seabirds and other animals also suffer." —http://www.seafoodwatch.org/cr/cr_seafoodwatch/issues/wildseafood_bycatch.aspx

> "Fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards. Such term does not include fish released alive under a recreational catch and release fishery management program." —http://www.nmfs.noaa.gov/by_catch/bycatch_whatis.htm

The common thread to all these definitions is that bycatch is a negative outcome of a fishery, and that the individuals discarded are dead or dying. Normally, the documents talk of "bycatch reduction" and/or "bycatch mitigation" as objectives of fisheries management or of campaigns. The idea is, rather than replace the popular perception with a definition shrouded in legalese, simply to accept the negative perception of bycatch that permeates all the literature that the public receives on the subject (Hall 1996).

To follow this argument, *Bycatch means Discarded Dead, of any species. Release then is left for the Live Discards*, those individuals that are released alive, and presumed to survive. The economic component of the fishing operation is the *Catch: all that is retained and utilized in any form,* and therefore it has economic value to the fishers.

In order to describe the physical act of capturing many species and sizes, and its product, we define Capture as the sum of all components retained in the gear. *Capture = Catch + Bycatch + Release.* The impact of the fishing operations on the populations or on the ecosystem is reflected in the sum of *Catch + Bycatch*, since the Release is returned unharmed. The need to create a term *Capture*, different from catch appeared because the observer programs had started giving us knowledge that was not available before. Without knowledge of what happens at sea, the only impacts of the fishery are measured by the landings, and in most statistics, the catches presented are only landings and not total captures.

These definitions avoid the use of the expression target species or bycatch species because these definitions are not fixed in economic terms, and can change over time and even seasonally according to the needs of markets, prices, and availability of different species. Many multispecies fisheries, especially in tropical areas, "target" a large number of species in the same operations.

Fisheries are a dynamic activity that changes with resource availability changes, environmental changes, technological changes, economic changes, etc. Some fisheries have identifiable targets because of the gear and the way it is utilized, and the vessel characteristics: tuna purse seining, shrimp trawling, lobster trapping, scallop dredging, clam digging, etc. But even these fisheries may retain several species, and these choices may vary over time. Target is an economic term and/or a legal term, in the sense of what is authorized, and both of these meanings may change with time.

The basic bycatch equation

In order to produce the transition from an emotional issue to a problem that could be faced and solved (Alverson and Hughes 1996), it has been very useful, from a communication point of view, to highlight the two components of all bycatch issues that transpire from the estimation formula (Hall 1996):

Bycatch = Effort x Bycatch per unit of effort = Effort x BPUE

Basically, to reduce bycatch, you fish less (lower the effort term) or you fish "better" (reduce the BPUE term). The equation also shows the fact that reductions in BPUE by improving technology, behavior, etc., can be nullified by increases in effort in a fishery, so you cannot decouple bycatch mitigation from fisheries management.

For simplicity I will use a single equation, but in practice the estimate may be generated after stratification by time periods, areas, gear types, etc. As BPUE is the impact of a unit of effort, the options to reduce it can also be seen using a statistical approach. To lower a mean or median, you may lower the values of the elements of the distribution (e.g., using a technological improvement that reduces the hooking rates in many longline sets), or you may try to eliminate elements from the upper tail of the distribution (e.g., by closing hotspots, excluding careless skippers). The BPUE values are frequently characterized by distributions with many zeroes and long tails of extreme values (e.g., Hall and Roman 2013).

If the bycatch caused by a fishing operation happens randomly with respect to vessels or crews, and it is uniformly distributed in time (diel, seasonal, etc.) and space (horizontally or vertically) then you cannot identify the elements of the upper end of the distribution or predict their occurrence. This problem is compounded for rare or endangered species, where the bycatch events are themselves rare, resulting in major statistical challenges for their estimation and analyses (Li and Jiao 2015). But as it happens in most cases, there are circumstances that result in the higher values, then you can take action to reduce or eliminate those.

What we use as the bycatch unit (a species, a group of species, all the species discarded), and whether it is expressed as numbers or weights, may change with the circumstances and the goals of the study. Caution should be exercised with these options, as poor choices may lead to misleading results. For instance, opposite trends in different species may be obscured in aggregate units. Some examples follow.

Performance heterogeneities

Performance heterogeneities may be present when equipment, skills, and decision-making of the captains and crews influence the BPUE of a vessel. The average mortality of dolphins per set in the tuna purse seine fishery was extremely heterogeneous, with some skippers and/or vessels performing much better than others. A small proportion of the fleet was responsible for a very large proportion of the mortality. This was caused by a combination of captain and crew skills in the release maneuvers, good (risk-averse) decision-making, and vessel condition and maintenance. By using individual vessel dolphin mortality limits (DMLs), assigning equal levels of mortality to all vessels, a very strong economic sanction was applied to the poor performers, and that caused the boat owners to replace them rapidly. In a couple of years, the upper tail of the distribution had shrunk toward the median, and the BPUE dropped precipitously. This was a “Darwinian” selection of the best performers (Hall et al. 2001).

Environmental heterogeneities

In the same fishery, night sets (sets performed when it was dark) had higher mortality rates than day sets (Hall et al. 2001), because the lack of light impaired the behavior of dolphins and/or crews. These sets were banned. Another type of environmental heterogeneity was not predictable: vessels would encounter strong subsurface currents when the net was in the water, and these currents tended to cause the net to lose its usual shape and entrap dolphins. As they were not predictable they could not be regulated, but the skippers’ response to an occurrence of this type was to move to other areas trying to avoid the problem; their adaptive decision-making replaced the regulation. In some cases, environmental conditions are used to separate target and bycatch species according to their preferences (e.g., Polovina et al. 2000, Hobday and Hartmann 2006, Brazner and McMillan 2008)

Risk-averse behavior

In the same purse seine fishery, tuna schools may be found accompanying dolphin herds of different sizes. Although the medians were on the order of 300-500 individuals, it was not rare to find a group of over 1000 dolphins. In the early years of the fishery these groups were frequently encircled, but when the DMLs were introduced the skippers attempted to separate the group to encircle fewer dolphins.

Spatial heterogeneities

Spatial heterogeneities may come from vertical characteristics of the distribution of the target species and the bycatches, or from horizontal characteristics. Examples of the vertical separation are the proposed modification of longline gear to eliminate the shallower hooks to reduce sea turtle interactions (Gilman et al. 2006a). Marine protected areas or spatial closures during a limited season have been proposed to eliminate the higher BPUE values, if they are spatially aggregated (Grantham et al. 2008). For hotspots that are not fixed in time-space, adaptive measures based on fleet communication have been used (Gilman et al. 2006b). During the nesting seasons of some species, thousands of individuals approach the nesting areas (e.g., arribadas for olive ridley sea turtles). Given the very high densities, it is difficult to believe that mitigation actions other than spatial closures could eliminate the problem.

When there are heterogeneities in BPUE, we have the possibility to utilize them for mitigation. However, there are many cases where the preferences of the target and bycatch species coincide, and if there is a linear relationship between catch and bycatch in the strata explored, then reductions in bycatch achieved by closures will be roughly proportional to the losses in the production of the fishery.

Another issue related to spatial or temporal closures is the alternative impacts caused by the redistributed effort in time or space, or changes in fleet efficiency to make up for the lost effort opportunities. These may shift impacts to other vulnerable species, and the trade-offs among catches and bycatches of different species need to be considered (see below).

Bycatch/catch ratio (B/C)

The best metric to analyze the probability of finding good opportunities to reduce bycatch minimizing the losses of the catch is the use of the bycatch/catch ratio (Hall 1996, Bartram et al. 2010), rather than only the BPUE. Ratios are challenging measures from a statistical point of view (biases, zero denominators, etc.) but they reflect the "ecological cost of production." A simple example to illustrate this is a fishery with two areas, one with a BPUE of 20/set, and a CPUE of 50/set, and another with a BPUE of 10/set and a CPUE of 20/set. If there is a quota of 5000 for the fishery, it can be filled in 100 sets with a bycatch of 2000 in one stratum or with 250 sets and a bycatch of 2500 in the other. If this situation is managed only on the basis of BPUE the impact on the production of the fishery is much higher.

The B/C ratio also lends itself to economic analyses, adding the economic costs of production to the ecological costs. In the example above there may be a cost associated to each set, or a more complex economic assessment of the alternatives. It also lends itself to turning from a single species bycatch to a more encompassing ecological measure of impact, as will be discussed later.

Changes: the role of observers

As bycatches happen at sea, and records are rarely kept in the logbooks, only the presence of observers on the boats allowed assessing the mortality caused by the fishing operations. Following occasional observations from biologists on board fishing boats, or statements from fishers, the different bycatch problems became visible to the public, and there have been strong reactions to some of them (e.g., the tuna-dolphin problem, Hall et al. 2003).

The early observer programs had, in many cases, the main goal of estimating the incidental mortality of the "bycatch species." The data collection was geared to that objective. With time and more interactions with the fishers, it became apparent that a variety of factors contributed to causing or increasing the mortality levels. The data collection and analyses were modified to try to understand which factors, from a long list that included environmental conditions, gear characteristics and crew skill and motivation, were the drivers of the bycatch levels (e.g., Murawski 1993; Klaer and Polachek 1998; Borges et al. 2001; Hall et al. 2003, 2007; Rochet and Trenkel 2005; Catchpole et al. 2005a,b; Graham et al. 2007; Belda and Sanchez 2001; Favero et al. 2011; Feekings et al. 2012). This information is frequently used to discuss with the best skippers what the solutions were to the different problems. For instance, in the tuna-dolphin fishery the presence of strong subsurface currents caused the net to fold and produce mortality. The experienced skippers recommended several countermeasures, such as towing the net with speedboats. These solutions were confronted with the results in the database, and if they were proven effective, they were communicated to all skippers (Hall et al. 2003).

In recent programs with the goal of reducing sea turtle mortality in longlines, the observers had the added role of training the fishers in the best practices to handle the sea turtles, when and how to remove hooks, etc. (Parga 2012). This role took precedence over mortality estimation because there were no good estimates of total effort to produce the estimates, and increasing sea turtle survival post-release was considered a reasonable goal.

Bycatch evolution and revolution

Evolution: sequential approach to research and mitigation

After an unstructured start for the bycatch reduction programs, where many different experiments were proposed and some were carried out, a more structured approach has developed, exploring the different instances where opportunities were available (e.g., Gilman et al. 2006a, Hall et al. 2012).

The first stage is *avoiding capture*. This is the preferred choice in all cases, and it is the only one in some: most seabirds hooked are very unlikely to survive, so all the mitigation efforts should be directed to avoiding capture.

The second stage is *releasing from the gear*. The dolphin backdown, the turtle excluder devices, and many mesh regulations allow the escape of the individuals from the net. The tuna-dolphin purse seine fishery focused in releasing from the net, after trying to reduce the captures by "cutting out" as many dolphins as possible. Best practices for releasing hooked or entangled individuals play the same role.

The individuals that cannot be released in the first two stages can still be *released from the deck*. The chances of survival decrease because the chances of stress or injuries increases, but for many species there is still a good chance of a successful release (Epperly et al. 2004, Swimmer et al. 2006, Campana et al. 2009, Davis 2011, Parga 2012). It is critical that veterinary sciences are applied to the determination of the best practices for handling and release of the individuals that are not to be retained (Parga 2012). In many cases, significant increases in survival can be obtained from a better treatment. As an example of a practice to be eliminated, the release of manta rays from the deck of purse seiners was carried out in a way that was harmful or lethal to the animals, and alternatives are being considered. This could result in a substantial reduction of their mortality (Hall and Roman 2013).

Finally, what cannot be released alive should be utilized if possible, and managed and regulated (Clucas 1997, Blanco et al. 2007). The tuna purse seine fishery has reduced the proportion discarded from 80% of the capture of non-tuna species, to 20%. Tuna discards have gone from over 15% to under 2%. A combination of higher prices for tunas and management banning discards has produced these declines. Examples of the sequential approach including many actions to reduce sea turtle mortality in longlines can be found in Gilman et al. (2006a), and Hall et al. (2013).

Bycatch mitigation programs have a few components that are quite similar in different fisheries:

- Data collection: Observer programs or electronic means (e.g., autonomous cameras mounted on vessels) with the goals of producing bycatch estimates and identifying factors that cause bycatch (Hall et al. 2003, Hilborn 2011). Increasing the number and extent of high quality observer programs is a key component in allowing the implementation of most changes proposed in this document.
- Interactions with fishers: Using the knowledge obtained from the data, develop a systematic approach to seek the input and cooperation from fishers, net makers, or others involved with the specific expertise required to identify the solutions to the problems identified. Cooperative research is an integral part of this process.
- Develop or implement technological and/or operational changes based on the previous steps.
- Communicate the changes proposed, and train skippers and crews on the new technology, best practices, etc. These are workshops like those organized to address tuna-dolphin or sea turtle–longline problems and solutions.
- Implement the solutions through intelligent, flexible management, with adequate incentives and enforcement.

Needed evolution: population issues

The traditional reporting of bycatches has been a figure in numbers or weights according to the case (e.g., Read et al. 2006, Amande et al. 2010). Even though these figures are useful for comparisons over time, they are clearly deficient as a measure of impact because the consequences to the population of the removal of, say, a young immature individual or a fully grown reproductive female, may be very different. The correct metrics for understanding and estimating population impacts depends on the particular dynamics of each species. There are different examples to consider.

In some seabird populations, two parents are required to raise a chick. The mortality of either parent will result in the mortality of the chick (Mills and Ryan 2005). Additionally, if the species pairs for life, or if it takes time for the remaining member of the pair to breed again, it will have an impact on overall fecundity.

In sea turtles, the reproductive value or the relative reproductive value have been proposed (Wallace et al. 2008, Bolten et al. 2010), and it can be developed to include specific mortality risks. For example, the value of an individual sea turtle may depend on sex, size, reproductive condition, and proximity to the nesting beach. This last variable is more difficult to evaluate, but a female very close to the nesting beach, and another that may be several thousand miles away and about to start a migration to nest, have very different chances of reproducing because of the mortality risks during the migration.

For sharks, the reproductive potential, a sum of all reproductive values of individuals, has been proposed (Gallucci et al. 2006) as a management variable to compare the impacts of different harvest strategies, a better alternative than just using numbers.

Another factor that is seldom included in the population models for the species taken incidentally is the subsidy that they receive from the fisheries. Some encounters with fishing gear lead to mortality, but others provide easily accessible food to predators or scavengers with a low cost (less search time, lower expenditures of energy in chase and capture, handling, etc.), an activity sometimes called provisioning. Depending on the type of gear, many individuals may steal the catch or the bait and escape successfully (Hill and Wassenberg 1987, 1990; Hudson and Furness 1988; Blaber and Wassenberg 1989; Furness 1993; Bugoni et al. 2010). These receive a subsidy that may result in higher growth, reproductive, or survival rates, but because it is difficult to evaluate and quantify the models can't include a possible important factor in the population dynamics. From an ecosystem point of view, these subsidies may alter the competitive interactions between species that receive subsidies, and others that don't.

Needed evolution: ecosystem issues

Although most scientists, managers, environmentalists, etc., would agree that we need to move toward ecosystem-based fisheries management, progress has been extremely difficult. We'll review some of the reasons.

1. Fragmentation of the participants in lobbying and decision-making:

    - Governmental organizations: for example, in the United States the Marine Mammal Commission has specific functions and objectives. There are no sea turtle or shark commissions, or ecosystem commissions.

    - Intergovernmental organizations: tuna Regional Fisheries Management Organizations (RFMOs), Pacific Halibut Commission, Whaling Commission, Agreement for the Conservation of Albatross and Petrels, Inter-American Sea Turtle Convention, etc.

    - Conservation organizations: the Whale and Dolphin Conservation Society, Birdlife International, Shark Advocates International, Manta Trust, Leatherback Trust, the Billfish Foundation, are organizations that have agendas that are clearly dominated by a species or group of species.

- The power and influence of these organizations, in many cases, depends on the interests of the foundations that provide their support, and the public response to their campaigns. More charismatic species are likely to receive more attention, but charisma is not a significant ecological property of a species, and it is not a synonym of relevance.

2. The difficulties in evaluating impacts of alternative gears or management schemes when they affect different species, habitats, etc.

The two types of mitigation measures for bycatch problems follow.

Specific solutions

Specific solutions are modifications of the gear or operational modes that only affect the species (or group of species) of interest. A clear example is the backdown maneuver to release dolphins from a tuna purse seine. Only the dolphins are released, and the maneuver doesn't affect the tuna catch or the capture of other species taken incidentally. Another example are the "tori lines" used to scare seabirds away from longlines; the only impact is to reduce the capture of seabirds. By the action of the tori lines, more bait will be left on the hooks and the line may fish more, but it will not change its selectivity for species or sizes.

Nonspecific solutions

In the case of nonspecific solutions, the solution proposed may alter the selectivity patterns of the gear with respect to the species been sought, or of all or some taken incidentally. Most of the examples of technological or operational changes to reduce bycatch fall in this category. Changing hook type (circle vs J, offset vs not offset, etc.), hook size, mesh size, net or line depth (shallow or deep), time of setting (day vs night), will most likely have consequences on the selectivity of the gear for many species (Watson et al. 2005, Jenkins and Garrison 2013). Table 1 (from Andraka et al. 2013) will serve to illustrate the problem. Circle hooks of size 18/0 (C18) were tested to study the possibility of mitigating sea turtle bycatches.

The circle hooks were effective, reducing hooking rates of the olive ridley (*Lepidochelys olivacea*) and the black (*Chelonia mydas agassizii*) sea turtles by a large and statistically significant amount. But they increased the hooking rates of some sharks (*Carcharhinus falciformis* and *Sphyrna* spp.) in a significant way. So the question is: should the mitigation measure tested be adopted, in view of these results? There is not an easy answer. It depends on the status of the species or stocks involved. In our case, the populations of the turtles involved are increasing in size, or are relatively stable (Eguchi et al. 2007). But the populations of the silky shark (Hall and

Table 1. Capture per unit of effort in individuals per 1000 hooks of J-hooks and circle hooks size 18 (C18). Randomization methods as described in Manly (2007), and Inter-American Tropical Tuna Commission (2008).

Species or group of species	CPUE J hook	CPUE C18 hook	*P* value
Xiphias gladius	0.52	1.03	0.037
Carcharhinus falciformis	15.55	25.36	0.002
Sphyrnidae	0.71	0.92	0.036
Chelonia mydas agassizii	0.50	0.03	0.000
Lepidochelys olivacea	0.79	0.33	0.012
All turtles	1.31	0.35	0.000

CPUE is capture per 1000 hooks (reduced table: only significant differences shown, from Andraka et al. 2013).

Roman 2013) and of the hammerheads have been declining. We should also consider if the swordfish (*Xiphias gladius*) is being overfished or not in this fishery.

Table 1 is a reduced version of one describing the totality of the impacts, so the assessment will be even more complex. The decisions need to be taken based on ecological considerations, and the scientific bases for these types of decisions are not well developed (Gilman 2011). Fishery managers need an objective method to evaluate if the impacts caused by the alternative gear are preferable to those caused by the original gear (examples: Hall 1998, Erzini et al. 2003, Criales-Hernandez et al. 2006). This forces us to compare "apples and oranges." If the decisions are influenced by the intensity of the advocacy, or by the charisma of the different species, then we will be ignoring our objective of ecosystem-based fisheries management. If objective tools were available to make this type of call, managers may be protected from stakeholder pressures.

If you set up a spatial closure (temporal or permanent) to reduce bycatch of a species, then the displaced effort will increase impacts on other locations unless additional actions are in place to deal with this "side effect." Again, the comparison needs to be made. If the closure had been proposed to protect a given species, without taking into account the spillover of impacts to other habitats and species, then we are ignoring our objective of ecosystem-based fisheries management.

A way to approach the issue of giving a "value" to each individual impacted by a fishery or other impact could be assigning to individuals a "replacement value" from the ecosystem point of view. Individuals in lower trophic levels would require less ecosystem resources (food, etc.) to be "replaced" than those in higher trophic levels. Individuals of the same species will have different values according to their sizes (e.g., to replace a 100 kg tuna costs much more than to replace a 2 kg tuna). Losses in ecosystem or genetic diversity may increase the value of the rare or endangered species. The reproductive values can also be considered. This is a very complex idea, but the solution to the problem will not be simple.

Balanced harvest: a conceptual revolution

For decades, fisheries managers have stated that species and size selectivity were highly desirable, and management was oriented to achieve those goals. Mesh sizes, regulations on minimum sizes, etc., were developed in that direction. The reasons to select sizes came from the concept of maximizing the yield of a cohort of the targeted species by harvesting it at the size it had reached its maximum biomass. The reasons to select some species were of course economics (prices and markets), but also included species with conservation concerns or cultural taboos.

However, even an intuitive approach to the ecosystem suggests that concentrating the impacts on a few sizes of a few species cannot be an effective strategy to retain the structure and functioning of the ecosystem. The question was visited at an informal workshop by a select group of ecologists and fishery scientists in Seattle in 1995, (Hall 1996, Appendix) where it became apparent that there was no evidence produced by experiments in tanks or lakes, or by models to support the selectivity approach as a strategy that was sound from the ecosystem point of view. The management actions taken were based on narrow goals, and without consideration of the ecosystem impacts. Other authors have also questioned the approach (Caddy and Sharp 1986:133, Hall 1996, Bundy et al. 2005, Zhou 2008) but only recently a series of experiments with ecosystem models produced by M.-J. Rochet, A. Bundy, and E. Fulton, and reported in Garcia et al. (2012) have developed and strengthened the theory supporting the intuition. In any case, this discussion has served to bring to the attention of the fisheries ecologists and managers the fact that there was no valid "ecosystem thinking" in the traditional approach to fisheries. Distributing the impacts of fisheries along and across food webs and over a wider range of sizes of the species taken (Law et al. 2012, 2013; Jacobsen et al. 2014), but maintaining control over the harvest levels of the different species, would contribute to maintaining ecosystem structure and functioning without losses (or without significant losses) in production. But care should be exercised before generalizing the answers to all ecosystems and all fisheries (Rochet et al. 2011).

The approach is a conceptual revolution of fisheries management and especially to bycatch management, and as such it has stirred controversies. It is feared by some as an approach that would open up fisheries to a catch-all system, eliminating management. This is clearly not the case, since it requires a well-controlled harvest of the many species fished.

It is also feared by others as an approach that would justify the harvest of whales and the take of many endangered or charismatic species. A society is not going to relinquish its cultural values because of a model or theory, and all it takes to account for those cultural values is to exclude some species from the "harvestable" ecosystem, and allocating to them their share of the balanced harvest, just like another fishing fleet. For species where the incidental harvest is not sustainable, efforts will need to continue to conserve them by making fisheries selective in this respect.

A balanced harvest system is considered by others a utopic, impracticable approach. Even though it is clear that the transition to such a system would have to be long, gradual, complex and painful, that should not deter us from adopting it as a goal that in the long term will yield positive results for all. We have accepted the laws of supply and demand as almost physical laws determining our behavior. Perhaps it is time to reconsider the ecological costs of those options and explore wiser alternatives.

Needed revolution: technological issues

Many bycatch issues have been addressed by a combination of technological developments and understanding of species behavior. The sources of these changes have been the fishers themselves or gear technologists, and very significant advances have been made (Kennelly and Broadhurst 2002, Hall and Mainprize 2005). These need to continue, and additional funding to train new technologists and to develop more programs would be a vital investment.

But at the same time, we have not explored major innovations in the way we fish. The traditional ways of fishing used in the industrial fleets can be described in a rather crude way as:

> "capture and kill a bunch of individuals and then decide what to keep."

If we view the fishing process this way, then the fisheries of the future should be based on a different concept:

> "capture alive and only kill what you mean to keep."

This approach would be suitable for any management system, but it would facilitate the implementation of a balanced harvest system. Achieving this goal would require in many cases major modifications of the way we capture and manage the capture of fish, and this needs innovators that would stray away from the “envelope.” Perhaps fishers tend to stay close to the techniques they are familiar with, and we need to add innovators from other backgrounds that could introduce fresh approaches to the challenge.

Acknowledgments

I want to acknowledge the organizers of the Wakefield Symposium for the opportunity to share in this event, the observers in many fisheries for their contributions to our work, and the creative fishers and gear technologists who have played a very significant role in most of our successes. M.-J. Rochet and A. Bundy made valuable suggestions to the ecosystem section, and two reviewers contributed to many sections of the document.

References

Agnew, D.J., N.L. Gutiérrez, A. Stern-Pirlot, and D.D. Hoggarth. 2014. The MSC experience: Developing an operational certification standard and a market incentive to improve fishery sustainability. ICES J. Mar. Sci. 71:216-225. http://dx.doi.org/10.1093/icesjms/fst091

Alverson, D.L., and S.E. Hughes. 1996. Bycatch: From emotion to effective natural resource management. In: Solving bycatch: Considerations for today and tomorrow. Alaska Sea Grant, University of Alaska Fairbanks, pp. 13-28.

Alverson, D.L., M.H. Freeberg, S.A. Murawski, and J.G. Pope. 1994. A global assessment of fisheries bycatch and discards. FAO Fish. Tech. Paper 339. 233 pp.

Amande, M.J., J. Ariz, E. Chassot, A. Delgado de Molina, D. Gaertner, H. Murua, R. Pianet, J. Ruiz, and P. Chavance. 2010. Bycatch of the European purse seine tuna fishery in the Atlantic Ocean for the 2003-2007 period. Aquat. Living Resour. 23:353-362. http://dx.doi.org/10.1051/alr/2011003

Andraka, S., M. Mug, M. Hall, M. Pons, L. Pacheco, M. Parrales, L. Rendon, M.L. Parga, T. Mituhasi, A. Segura, D. Ortega, E. Villagran, S. Perez, C. De Paz, S. Siu, V. Gadea, J. Caicedo, L. Zapata, J. Martínez, P. Guerrero, M. Valqui, and N. Vogel. 2013. Circle hooks: Developing better fishing practices in the artisanal longline fisheries of the eastern Pacific Ocean. Biol. Cons. 160:214-224. http://dx.doi.org/10.1016/j.biocon.2013.01.019

Bartram, P.K., J.J. Kaneko, and K. Kucey-Nakamura. 2010. Sea turtle bycatch to fish catch ratios for differentiating Hawaii longline-caught seafood products. Mar. Pol. 34(1):145-149. http://dx.doi.org/10.1016/j.marpol.2009.05.006

Belda, E.J., and A. Sanchez. 2001. Seabird mortality on longline fisheries in the western Mediterranean: Factors affecting bycatch and proposed mitigating measures. Biol. Cons. 98.3:357-363. http://dx.doi.org/10.1016/S0006-3207(00)00178-6

Blaber, S.J.M., and T.J. Wassenberg. 1989. Feeding ecology of the piscivorous birds Phalacrocorax varius, P. melanoleucos, and Sterna bergii in Moreton Bay, Australia: Diets and dependence on trawler discards. Mar. Biol. 101:1-10. http://dx.doi.org/10.1007/BF00393473

Blanco, M., C.G. Sotelo, M.J. Chapela, and R.I. Pérez-Martín. 2007. Towards sustainable and efficient use of fishery resources: Present and future trends. Trends Food Sci. Tech. 18(1):29-36. http://dx.doi.org/10.1016/j.tifs.2006.07.015

Bolten, A.B., L.B. Crowder, M.G. Dodd, S.L. MacPherson, J.A. Musick, B.A. Schroeder, B.E. Witherington, K.J. Long, and M.L. Snover. 2010. Quantifying multiple threats to endangered species: An example from loggerhead sea turtles. Front. Ecol. Environ. 9(5):295-301. http://dx.doi.org/10.1890/090126

Borges, T.C., K. Erzini, L. Bentes, M.E. Costa, J.M.S. Goncalves, P.G. Lino, C. Pais, and J. Ribeiro. 2001. By-catch and discarding practices in five Algarve (southern Portugal) métiers. J. Appl. Ichthyol. 17:104-114. http://dx.doi.org/10.1046/j.1439-0426.2001.00283.x

Brazner, J.C., and J. McMillan. 2008. Loggerhead turtle (*Caretta caretta*) bycatch in Canadian pelagic longline fisheries: Relative importance in the western North Atlantic and opportunities for mitigation. Fish. Res. 91(2):310-324. http://dx.doi.org/10.1016/j.fishres.2007.12.023

Broadhurst, M.K., P. Suuronen, and A. Hulme. 2006. Estimating collateral mortality from towed fishing gear. Fish Fish. 7(3):180-218. http://dx.doi.org/10.1111/j.1467-2979.2006.00213.x

Buck, E. 1992. Full utilization, bycatch and waste management concerns. In: Proceedings of the World Fisheries Congress, May 3-8, 1992, Athens, Greece.

Bugoni, L., R.A.R. McGill, and R.W. Furness. 2010. The importance of pelagic longline fishery discards for a seabird community determined through stable isotope analysis. J. Exp. Mar. Biol. Ecol. 391:190-200. http://dx.doi.org/10.1016/j.jembe.2010.06.027

Bundy, A., P. Fanning, and K.C.T. Zwanenburg. 2005. Balancing exploitation and conservation of the eastern Scotian Shelf ecosystem: Application of a 4D ecosystem exploitation index. ICES J. Mar. Sci. 62:503-510. http://dx.doi.org/10.1016/j.icesjms.2004.12.008

Caddy, J.F., and G.D. Sharp. 1986. An ecological framework for marine fishery investigations. FAO Fish. Tech. Paper 283. 152 pp.

Campana, S.E., W. Joyce, and M.J. Manning. 2009. Bycatch and discard mortality in commercially caught blue sharks *Prionace glauca* assessed using archival satellite pop-up tags. Mar. Ecol. Prog. Ser. 387:241-253. http://dx.doi.org/10.3354/meps08109

Catchpole, T.L., C.L.J. Frid, and T.S. Gray. 2005a. Discarding in the English north-east coast *Nephrops norvegicus* fishery: The role of social and environmental factors. Fish. Res. 72(1):45-54. http://dx.doi.org/10.1016/j.fishres.2004.10.012

Catchpole, T.L., C.L.J. Frid, and T.S. Gray. 2005b. Discards in North Sea fisheries: Causes, consequences and solutions. Mar. Pol. 29(5):421-430. http://dx.doi.org/10.1016/j.marpol.2004.07.001

Clucas, I. 1997. A study of the options for utilization of bycatch and discards from marine capture fisheries. FAO Fish. Circular 928. 59 pp.

Clucas, I.J., and D.G. James. 1997. Papers presented at the Technical Consultation on Reduction of Wastage in Fisheries, Tokyo, Japan. FAO Fish. Report 547. 338 pp.

Criales-Hernandez, M.I., L.O. Duarte, C.B. García, and L. Manjarrés. 2006. Ecosystem impacts of the introduction of bycatch reduction devices in a tropical shrimp trawl fishery: Insights through simulation. Fish. Res. 77(3):333-342. http://dx.doi.org/10.1016/j.fishres.2005.10.005

Crowder, L.B., and S.A. Murawski. 1998. Fisheries bycatch: Implications for management. Fisheries 23:6, 8-17. http://dx.doi.org/10.1577/1548-8446(1998)023<0008:FBIFM>2.0.CO;2

Cushing, D.H. 1984. Do discards affect the production of shrimps in the Gulf of Mexico? In: J.A. Gulland and B.J. Rothschild (eds.), Penaeid shrimps: Their biology and management. Fishing News Books, Farnham, England, pp. 254-257.

Daan, N. 1991. A theoretical approach to the evaluation of ecosystem effects of fishing in respect of North Sea benthos. ICES C.M. 1991/L:27

Davies, R.W.D., S.J. Cripps, A. Nickson, and G. Porter. 2009. Defining and estimating global marine fisheries bycatch. Mar. Pol. 33(4):661-672. http://dx.doi.org/10.1016/j.marpol.2009.01.003

Davis, M.W. 2011. Key principles for understanding fish bycatch discard mortality. Can. J. Fish. Aquat. Sci. 59(11):1834-1843. http://dx.doi.org/10.1139/f02-139

Eguchi, T., T. Gerrodette, R.L. Pitman, J.A. Seminoff, and P.H. Dutton. 2007. At-sea density and abundance estimates of the olive ridley turtle *Lepidochelys olivacea* in the eastern tropical Pacific. Endanger. Species Res. 3(2):191-203. http://dx.doi.org/10.3354/esr003191

Epperly, S.P., L. Stokes, and S. Dick. 2004. Careful release protocols for sea turtle release with minimal injury. NOAA Tech. Memo. NMFS-SEFSC-524. 42 pp.

Erzini, K., J.M.S. Gonçalves, L. Bentes, P.G. Lino, J. Ribeiro, and K.I. Stergiou. 2003. Quantifying the roles of competing static gears: Comparing selectivity of longlines and monofilament gill nets in a multi-species fishery of the Algarve (southern Portugal). Sci. Mar. 67(3):341-352.

Favero, M., G. Blanco, G. García, S. Copello, J.P. Seco Pon, E. Frere, F. Quintana, P. Yorio, F. Rabuffetti, G. Cañete, and P. Gandini. 2011. Seabird mortality associated with ice trawlers in the Patagonian shelf: Effect of discards on the occurrence of interactions with fishing gear. Anim. Conserv. 14:131-139. http://dx.doi.org/10.1111/j.1469-1795.2010.00405.x

Feekings, J., V. Bartolino, N. Madsen, and T. Catchpole. 2012. Fishery discards: Factors affecting their variability within a demersal trawl fishery. PloS one 7(4). http://dx.doi.org/10.1371/journal.pone.0036409

Fletcher, W.J., J. Shaw, S.J. Metcalf, and D.J. Gaughan. 2010. An ecosystem based fisheries management framework: The efficient, regional-level planning tool for management agencies. Mar. Pol. 34(6):1226-1238. http://dx.doi.org/10.1016/j.marpol.2010.04.007

Furness, R.W. 1993. Implications of changes in net mesh size, fishing effort and minimum landing size regulations in the North Sea for seabird populations. Joint Nature Conservation Committee Rpt. No. 133. 60 pp.

Gallucci, V.F., I.G. Taylor, and K. Erzini. 2006. Conservation and management of exploited shark populations based on reproductive value. Can. J. Fish. Aquat. Sci. 63:931-942. http://dx.doi.org/10.1139/f05-267

Garcia, S.M., J. Kolding, J. Rice, et al. 2012. Reconsidering the consequences of selective fisheries. Science 335:1045-1047. http://dx.doi.org/10.1126/science.1214594

Gilman, E. 2011. Bycatch governance and best practice mitigation technology in global tuna fisheries. Mar. Pol. 35(5):590-609. http://dx.doi.org/10.1016/j.marpol.2011.01.021

Gilman, E.L., P. Dalzell, and S. Martin. 2006a. Fleet communication to abate fisheries bycatch. Mar. Pol. 30(4):360-366. http://dx.doi.org/10.1016/j.marpol.2005.06.003

Gilman, E., P. Suuronen, M. Hall, and S. Kennelly. 2013. Causes and methods to estimate unobservable fishing mortality. J. Fish Biol. 83(4):766-803.

Gilman, E., E. Zollett, S. Beverly, H. Nakano, K. Davis, D. Shiode, and I. Kinan. 2006b. Reducing sea turtle by-catch in pelagic longline fisheries. Fish Fish. 7(1):2-23. http://dx.doi.org/10.1111/j.1467-2979.2006.00196.x

Gjertsen, H., M.A. Hall, and D. Squires. 2009. Incentives to address bycatch issues, Chapter 14. In: R. Allen, J. Joseph, and D. Squires (eds.), Conservation and management of transnational tuna fisheries. J. Wiley, pp. 225-248.

Graham, N., R.S. Ferro, W.A. Karp and P. MacMullen. 2007. Fishing practice, gear design, and the ecosystem approach—three case studies demonstrating the effect of management strategy on gear selectivity and discards. ICES J. Mar. Sci. 64(4):744-750. http://dx.doi.org/10.1093/icesjms/fsm059

Grantham, H.S., S.L. Peterson, and H.P. Possingham. 2008. Reducing bycatch in the South African pelagic longline fishery: The utility of different approaches to fisheries closures. Endanger. Species Res. 5(2-3):291-299. http://dx.doi.org/10.3354/esr00159

Hall, M.A. 1996. On bycatches. Rev. Fish Biol. Fish. 6:319-352. http://dx.doi.org/10.1007/BF00122585

Hall, M.A. 1998. An ecological view of the tuna-dolphin problem. Rev. Fish Biol. Fish. 8:1-34. http://dx.doi.org/10.1023/A:1008854816580

Hall, M.A., and M. Roman. 2013. Bycatches and non-tuna catches in purse seine fisheries of the world. FAO Fish. Aquac. Tech. Paper No. 568. 249 pp.

Hall, M.A., M. Campa, and M. Gomez. 2003. Solving the tuna-dolphin problem in the eastern Pacific purse-seine fishery. In: E. Mann Borgese, A. Chircop, and M. McConnell (eds.), Ocean yearbook, Vol. 17. Univ. Chicago Press, pp. 60-92. http://dx.doi.org/10.1163/221160003x00069

Hall, M.A., Y. Swimmer, and M. Pargas. 2012. No "silver bullets," but plenty of options: Working with the eastern Pacific artisanal fishers to reduce sea turtle mortality in fisheries. In: J.A. Seminoff and B. Wallace (eds.). Sea turtles of the eastern Pacific Ocean: Natural history, conservation challenges, and signs of success. University of Arizona Press, Tucson, pp. 136-153.

Hall, M.A., H. Nakano, S. Clarke, S. Thomas, J. Molloy, H. Peckham, J. Laudino-Santillan, W.J. Nichols, E. Gilman, J. Cook, S. Martin, J.P. Croxall, K. Rivera, C.A. Moreno, and S.J. Hall. 2007. Working with fishers to reduce by-catches, Chapter 8. In: S.J. Kennelly (ed.), By-catch reduction in the world's fisheries. Springer, pp. 235-288. http://dx.doi.org/10.1007/978-1-4020-6078-6_8

Hall, S.J., and B.M. Mainprize. 2005, Managing by-catch and discards: How much progress are we making and how can we do better? Fish Fish. 6(2):134-155. http://dx.doi.org/10.1111/j.1467-2979.2005.00183.x

Harrington, J.M., R.A. Myers, and A.A. Rosenberg. 2005. Wasted fishery resources: Discarded by-catch in the USA. Fish Fish. 6(4):350-361. http://dx.doi.org/10.1111/j.1467-2979.2005.00201.x

Hilborn, R. 2011. Future directions in ecosystem based fisheries management: A personal perspective. Fish. Res. 108(2):235-239. http://dx.doi.org/10.1016/j.fishres.2010.12.030

Hill, B.J., and T.J. Wassenberg. 1987. Feeding by the sand crab *Portunus pelagicus* on material discarded from prawn trawlers in Moreton Bay, Australia. Mar. Biol. 95:387-393. http://dx.doi.org/10.1007/BF00409569

Hill, B.J., and T.J. Wassenberg. 1990. Fate of discards from prawn trawlers in Torres Strait. Aust. J. Mar. Freshw. Res. 41:53-64. http://dx.doi.org/10.1071/MF9900053

Hobday, A.J., and K. Hartmann. 2006. Near real-time spatial management based on habitat predictions for a longline bycatch species. Fish. Manag. Ecol. 13(6):365-380. http://dx.doi.org/10.1111/j.1365-2400.2006.00515.x

Hudson, A.V., and R.W. Furness. 1988. Utilization of discarded fish by scavenging seabirds behind whitefish trawlers in Shetland. J. Zool. London 215:151. http://dx.doi.org/10.1111/j.1469-7998.1988.tb04890.x

Inter-American Tropical Tuna Commission. 2008. Special Report No. 17. Workshop on Turtle Bycatch Mitigation for Longline Fisheries: Experimental Design and Data Analysis, 7-8 November 2007, San Ramón, Alajuela, Costa Rica.

Jacobsen, N.S., H. Gislason, and K.H. Andersen. 2014. The consequences of balanced harvesting of communities. Proc. Royal Soc. B. 281.1775. 9 pp.

Jenkins, L.D., and K. Garrison. 2013. Fishing gear substitution to reduce bycatch and habitat impacts: An example of social-ecological research to inform policy. Mar. Pol. 38:293-303. http://dx.doi.org/10.1016/j.marpol.2012.06.005

Kennelly, S.J., and M.K. Broadhurst. 2002. By-catch begone: Changes in the philosophy of fishing technology. Fish Fish. 3:340-355. http://dx.doi.org/10.1046/j.1467-2979.2002.00090.x

Klaer, N., and T. Polacheck. 1998. The influence of environmental factors and mitigation measures on by-catch rates of seabirds by Japanese longline fishing vessels in the Australian region. Emu 98(4):305-316. http://dx.doi.org/10.1071/MU98042

Law, R., J. Kolding, and M.J. Plank. 2013. Squaring the circle: reconciling fishing and conservation of aquatic ecosystems. Fish Fish. 16(1):160-174. http://dx.doi.org/10.1111/faf.12056

Law, R., M.J. Plank, and J. Kolding. 2012. On balanced exploitation of marine ecosystems: results from dynamic size spectra. ICES J. Mar. Sci. 69(4):602-614. http://dx.doi.org/10.1093/icesjms/fss031

Lewison, R.L., L.B. Crowder, A.J. Read, and S.A. Freeman. 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends Ecol. Evol. 19(11):598-604. http://dx.doi.org/10.1016/j.tree.2004.09.004

Li, Y., and Y. Jiao. 2015. Modeling spatial patterns of rare species using eigenfunction-based spatial filters: An example of modified delta model for zero-inflated data. Ecol. Model. 299(10):51-63. http://dx.doi.org/10.1016/j.ecolmodel.2014.12.005

Manly, B.F. 2007. Randomization, bootstrap and Monte Carlo methods in biology. 3rd edn. Chapman and Hall/CRC.

Martin, S.M., T.A. Cambridge, C. Grieve , F.M. Nimmo, and D.J. Agnew. 2012. An evaluation of environmental changes within fisheries involved in the Marine Stewardship Council certification scheme. Rev. Fish. Sci. 20(2):61-69. http://dx.doi.org/10.1080/10641262.2011.654287

Mills, M.S., and P.G. Ryan. 2005. Modelling impacts of long-line fishing: What are the effects of pair-bond disruption and sex-biased mortality on albatross fecundity? Animal Conserv. 8(4):359-367. http://dx.doi.org/10.1017/S1367943005002386

Morizur, Y., B. Caillart, and D. Tingley. 1999. The problem of discards in fisheries. Encyclopedia of Life Support Systems Open Access version. http://archimer.ifremer.fr/doc/00000/1237/

Murawski, S.A. 1992. The challenges of finding solutions in multispecies fisheries. In: R.W. Schoning, R.W. Jacobson, D.L. Alverson, T.G. Gentle, and J. Auyong (eds.), Proceedings of the National Industry Bycatch Workshop, February 4-6, 1992, Newport, Oregon. Natural Resources Consultants, Inc., Seattle, Washington, pp. 35-45.

Murawski, S.A. 1993. Factors influencing by-catch and discard rates: Analyses from multispecies/multifishery sea sampling. NAFO SCR Doc. 93/115. 17 pp.

Parga, M.L. 2012. Hooks and sea turtles: A veterinarian's perspective. Bull. Mar. Sci. 88(3):731-741. http://dx.doi.org/10.5343/bms.2011.1063

Pascoe, S. (ed.) 1997. Bycatch management and the economics of discarding. FAO Fish. Tech. Paper 370. 137 pp.

Pelc, R.A., L.M. Max, W. Norden, S. Roberts, R. Silverstein, and S.R. Wilding. 2015. Further action on bycatch could boost United States fisheries performance. Mar. Pol. 56:56-60. http://dx.doi.org/10.1016/j.marpol.2015.02.002

Pitcher, T.J., D. Kalikoski, K. Short, D. Varkey, and G. Pramod. 2009. An evaluation of progress in implementing ecosystem-based management of fisheries in 33 countries. Mar. Pol. 33(2):223-232. http://dx.doi.org/10.1016/j.marpol.2008.06.002

Polovina, J.J., D.R. Kobayashi, D.M. Parker, M.P. Seki, and G.H. Balazs. 2000. Turtles on the edge: Movement of loggerhead turtles (*Caretta caretta*) along oceanic fronts, spanning longline fishing grounds in the central North Pacific, 1997-1998. Fish. Oceanogr. 9(1):71-82. http://dx.doi.org/10.1046/j.1365-2419.2000.00123.x

Read, A.J., P. Drinker, and S. Northridge. 2006. Bycatch of marine mammals in US and global fisheries. Conserv. Biol. 20(1):163-169. http://dx.doi.org/10.1111/j.1523-1739.2006.00338.x

Rochet, M.J., and V.M. Trenkel. 2003. Which community indicators can measure the impact of fishing? A review and proposals. Can. J. Fish. Aquat. Sci. 60(1):86-99. http://dx.doi.org/10.1139/f02-164

Rochet, M.J., and V.M. Trenkel. 2005. Factors for the variability of discards: Assumptions and field evidence. Can. J. Fish. Aquat. Sci. 62(1):224-235. http://dx.doi.org/10.1139/f04-185

Rochet, M.J., J.S. Collie, S. Jennings, and S.J. Hall. 2011. Does selective fishing conserve community biodiversity? Predictions from a length-based multispecies model. Can. J. Fish. Aquat. Sci. 68(3):469-486. http://dx.doi.org/10.1139/F10-159

Smith, A.D.M., E.J. Fulton, A.J. Hobday, C. Smith, and P. Shoulder. 2007. Scientific tools to support the practical implementation of ecosystem-based fisheries management. ICES J. Mar. Sci. 64:633-639. http://dx.doi.org/10.1093/icesjms/fsm041

Stevens, B.G. 1990. Survival of king and Tanner crabs captured by commercial sole trawls. Fish. Bull. 88:731-744.

Swimmer, Y., R. Arauz, M. McCracken, L. McNaughton, J. Ballestero, M. Musyl, K. Bigelow, and R. Brill. 2006. Diving behavior and delayed mortality of olive ridley sea turtles *Lepidochelys olivacea* after their release from longline fishing gear. Mar. Ecol. Prog. Ser. 323:253-261. http://dx.doi.org/10.3354/meps323253

Tallis, H., P.S. Levin, M. Ruckelshaus, S.E. Lester, K.L. McLeod, D.L. Fluharty, and B.S. Halpern. 2010. The many faces of ecosystem-based management: Making the process work today in real places. Mar. Pol. 34(2):340-348. http://dx.doi.org/10.1016/j.marpol.2009.08.003

Wallace, B.P., S.S. Heppell, R.L. Lewison, S. Kelez, and L.B. Crowder. 2008. Impacts of fisheries bycatch on loggerhead turtles worldwide inferred from reproductive value analyses. J. Appl. Ecol. 45:1076-1085. http://dx.doi.org/10.1111/j.1365-2664.2008.01507.x

Wallace, B.P., C.Y. Kot, A.D. DiMatteo, T. Lee, L.B. Crowder, and R.L. Lewison. 2013. Impacts of fisheries bycatch on marine turtle populations worldwide: Toward conservation and research priorities. Ecosphere 4(3). http://dx.doi.org/10.1890/ES12-00388.1

Wallace, B.P., R.L. Lewison, S.L. McDonald, R.K. McDonald, C.Y. Kot, S. Kelez, and L.B. Crowder. 2010. Global patterns of marine turtle bycatch. Conserv. Lett. 3(3):131-142.

Watson, J.W., S.P. Epperly, A.K. Shah, and D.G. Foster. 2005. Fishing methods to reduce sea turtle mortality associated with pelagic longlines. Can. J. Fish. Aquat. Sci. 62(5):965-981. http://dx.doi.org/10.1139/f05-004

Zhou, S. 2008. Fishery by-catch and discards: A positive perspective from ecosystem-based fishery management. Fish Fish. 9:308-315. http://dx.doi.org/10.1111/j.1467-2979.2008.00291.x