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INGREDIENTS FOR ADDRESSING THE CHALLENGES OF FISHERIES BYCATCH

RL Lewison, CU Soykan, T Cox, H Peckham, N Pilcher, N LeBoeuf, S McDonald, J Moore, C Safina, and LB Crowder

ABSTRACT

Minimizing fisheries bycatch, the incidental capture of non-target species, is a global environmental challenge. In many regions, bycatch of imperiled species is one of a number of issues that threatens species viability and impedes the development of sustainable fisheries. Effectively addressing bycatch of species of conservation concern and improving fisheries sustainability require cross-sectoral integration of information on the biological, socioeconomic, and political contexts of each fishery. Several gaps present simultaneous challenges, including: limited engagement with fisher communities, a lack of data, a need for more robust analyses of available data, and a need for coordinated governance from local to global scales. Here we present a framework to address fisheries bycatch that builds on established methods in community collaboration and engagement, field-based interviews, quantitative bycatch analyses, and ocean policy governance. Although these individual approaches to reduce bycatch are well established, there has yet to be a comprehensive application of an integrated approach. We review these essential approaches and present a broadly applicable model for their integration.

Fishing effort has increased substantially over past decades, leading to concerns regarding the negative impacts on vulnerable, non-target species and habitats (Chupendagee et al. 2003, Lewison et al. 2004, Stewart et al. 2010). Incidental capture of non-target individuals, termed bycatch, was identified as a key issue for species of conservation concern as early as the 1970s (Lo et al. 1982, Coe et al. 1984), but the ability to address this global issue has been hampered by a lack of awareness and engagement with fisher communities, insufficient data, the need for improved quantitative methods to analyze bycatch data, and the need for more robust policies to regulate and mitigate bycatch. These challenges are manifest across the fisheries development spectrum (small-scale to industrial) although the drivers may vary among fisheries. The multidisciplinary nature of these challenges, coupled with the need to work across local to ocean-wide scales, suggests that to address fisheries bycatch effectively requires an integrated approach involving researchers from multiple disciplines working with partners from local communities up through international governance regimes.

Although this level of cross-sectoral integration has not been achieved, ongoing efforts within each sector serve as examples and templates of how these new approaches are redefining our ability to effectively address the issue of bycatch in small-scale and industrial fisheries—both within exclusive economic zones and on the high seas. In some developing Central and Latin American countries, community involvement, coordination, and collaborations have been established to address bycatch in small-scale fisheries (Hall et al. 2007, Peckham and Maldonado-Diaz in press), yielding promising results in these focused areas. Combining education, outreach, and cooperative fisheries management, these efforts provide a clear model of participatory bycatch assessments and ultimately bycatch mitigation (Hall et al. 2007). Addressing data-gaps through systematic and representative data collection efforts has also proved to be a fruitful and necessary step towards understanding the extent and magnitude of bycatch, particularly in small-scale fisheries (sensu Moore et al. 2010). Quantitative analysis of existing bycatch data has developed substantially over the past 10 yrs and plays an important role in understanding population-level effects of bycatch, linking bycatch species distributions to environmental variables, and characterizing bycatch hotspots (Howell et al. 2008, Wallace et al. 2008, Lewison et al. 2009). Policies to address the issue of bycatch require action at local, national, and international levels. The Food and Agriculture Organization (FAO) International Plans of Action (IPOA) for sharks and seabirds and the recently published FAO Best Practice Technical Guidelines for National Plans of Action serve as templates for how national and international policy can be structured. In December 2010, the FAO convened a meeting aimed at finalizing broad technical guidelines for reducing bycatch in international fisheries. Using these templates as a guide, bycatch mitigation approaches by some Regional Fisheries Management Organizations (RFMOs) in international waters have been very effective (Croxall and Nicol 2004, CCAMLR 2006, Cox et al. 2007).

The development and application of these individual approaches to addressing bycatch is not new. However, in the past 10 yrs, there have been innovative developments that have substantially advanced bycatch reduction and mitigation efforts in each sector. While many of these individual elements are applied widely around the world, there are only a few fisheries or fishing regions where any cross-sectoral integration exists and, to our knowledge, there is no current example that spans all sectors. Here, we review recent developments from the individual sectors and present a framework for how integration across sectors could be implemented to promote more comprehensive and effective bycatch reduction.

Community Involvement

Engaging fishermen and their communities is essential to reducing bycatch in all fisheries. For small-scale fisheries, in particular, command-and-control approaches, such as fisheries closures and mandated technological fixes, are often impractical and may only provide short-term solutions (Berkes et al. 2001, Hilborn et al. 2005, McClanahan et al. 2006). Numerous studies have shown that engaging fishermen from the outset of bycatch research and reduction initiatives can augment the development and adoption of long-term solutions (Hall et al. 2000, Kennelly 2007, Campbell and Cornwell 2008), in part because investment in the conservation process may increase fishers' subsequent adoption of conservation strategies (Cox et al. 2007, Jenkins et al. 2008). In the context of small-scale fisheries, which predominantly occur in developing nations where management and enforcement are limited, engaging fishers and their communities can be particularly important because bycatch mitigation programs are essentially voluntary (McClanahan et al. 2006, Jackson 2007).

One current example that demonstrates community involvement and participation instrumental in tackling bycatch in small-scale fisheries is the Grupo Tortuguero's Proyecto Caguama. Grupo Tortuguero is a grassroots sea turtle conservation network that connects fishers, communities, and conservation organizations in Baja California, Mexico (http://www.propeninsula.org/content/1/2/10.html). Proyecto Caguama, one of Grupo Tortuguero's conservation projects, has played a key role in reducing bycatch of endangered loggerhead turtles in small-scale fleets of Mexico's Baja California peninsula. Prior to the program, turtles were caught by small-scale gillnet and longline skiffs at among the highest rates documented globally, representing one of the greatest threats to the endangered North Pacific loggerhead population (Peckham et al. 2008). However, due to the high catch rates, local fishers felt that turtles were numerous and unlikely to be vulnerable, a misperception common to many fisheries (Hall et al. 2007). Despite strong protection by Mexican law (Namnum 2002), sea turtle protection was poorly enforced in the early 2000s along the isolated Pacific coast of the Baja California peninsula. Starting in 2002, a team of conservation scientists partnered with local fishers and their families to assess and convey the importance of local bycatch with the ultimate goal of bycatch mitigation. Their efforts were guided by a conservation mosaic strategy consisting of three approaches, each informed by an established literature and differing degrees of proven effectiveness (Nichols 2003). The effectiveness of the mosaic emerges from strategic integration of each approach: (1) building a conservation network of fishermen, students, teachers, activists, researchers, managers, and other coastal people (social networks, Laszlo Barabasi 2002); (2) drawing on these partnerships to derive new knowledge through participatory research to develop locally practical solutions (participatory research, Fortmann 2008); and (3) communicating this knowledge in resonant ways to encourage fishers to avoid bycatch (e.g., social marketing; MacKenzie-Mohr and Smith 1999).

By building capacity through technical training and leadership development, offering support for conservation work across communities, organizing international exchanges, and through organized events, including sea turtle festivals, workshops, and trainings, Grupo Tortuguero has been building a network of fishers and their communities combined with strategic academic, government, and NGO alliances. In terms of participatory research, fishers co-developed and carried out a comprehensive on-board observer program, shoreline stranding surveys, and bycatch mitigation trials. As a result, fishers were instrumental in the discovery of Pacific-wide impacts of their local bycatch, delineation of a regionally important loggerhead high-use area, and development and testing of locally effective bycatch reduction solutions (Peckham et al. 2007). A multi-year bycatch awareness campaign was developed and implemented in response to local market research about how best to raise awareness and inspire bycatch solutions. Mass media, such as internet and broadcast television, were rejected due to fishers' limited access to them. Instead, the campaign was focused on murals, comic books, flyers, and local AM radio programming. In these media, all messaging was designed to be positive and empowering, rather than critical. Loggerheads were celebrated as a valuable resource unique in Pacific Mexico to only several small fishing towns on the Baja California peninsula with the core message that the future of the north Pacific loggerhead population lay largely in the hands of local fishers and their families (Hall et al. 2007). Regional festivals, school enrichment programs, and student and fisher internships were offered, with an emphasis on stakeholder empowerment and the benefits to stakeholders from loggerhead protection (Peckham and Maldonado-Diaz in press).

Following the Grupo Tortuguero network model, fishers and their families were engaged and empowered through educational, technical, and social workshops and meetings, plus fisher exchanges on local, regional, and international levels (Delgado and Nichols 2004). By interacting with colleagues from other towns, regions, and countries, fishers and their family members came to appreciate the global impact of their local bycatch and were inspired to develop solutions for reducing it (Peckham and Maldonado-Diaz in press). By deciding to discontinue the use of bottom-set longlines and adopting spatiotemporal closures for the local gillnet fleet, fisher communities prevented hundreds and possibly thousands of loggerheads from being caught each year (Peckham et al. 2008). This example demonstrates the importance of directly engaging local fishers and their families in all steps of the bycatch mitigation process, from initial research to developing solutions to outreach. Similar methods have been utilized to successfully mitigate bycatch in other contexts, including an international, multi-sector project to reduce bycatch in longlines throughout the Eastern tropical Pacific (in Hall et al. 2007). The Inter-American Tropical Tuna Commission (IATTC) and World Wildlife Fund (WWF) have partnered with industrial and small-scale fishers, exporters, fisheries agencies, and other conservation organizations to build a strong, regional network across eight countries that focuses on the adoption of gear modifications and best fishing practices to reduce bycatch.

Filling the Data Gaps

Our current understanding of bycatch and bycatch mitigation are primarily focused on developed countries and industrial fisheries where there is a relative wealth of data. As articulated in the previous section, data are limited from small-scale fisheries in developing countries, where even basic observations of the number of fishers, types of gear used, and species taken as bycatch are unavailable (McCluskey and Lewison 2008). However, recent studies have demonstrated that bycatch in small-scale fisheries can be extremely high and detrimental to species of conservation concern (e.g., Peckham et al. 2007, Alfaro Shigueto et al. 2008, Moore et al. 2010). Turtles, dugongs, and dolphins are often caught in gillnets, cetaceans are encircled by purse seines, turtles drown in trawls, and all of these species get entangled in longline, and hook and line fisheries (Lewison et al. 2004, Peckham et al. 2008, Gilman and Lundin 2009). Directed take also accounts for substantial reductions in populations, but is typically underreported, unreported, or unquantified (but see Marsh et al. 1997, http://www.fao.org/fishery/statistics/global-capture-production/en). Traditionally, on-board observer programs have been used to estimate bycatch in fisheries. However, small-scale fisheries present unique challenges to collecting data in this manner. Research on these fisheries is often cost-prohibitive due to their diffuse nature and the number of observers required for adequate sampling, particularly given the limited research and management budgets of developing country fisheries. In addition, the relatively small size of vessels often used in small-scale fisheries cannot easily (if at all) accommodate observers. Finally, many of the fishing ports and villages are difficult to access, thus increasing the cost and overall logistical challenges. The sheer number of fishers in small-scale fisheries creates challenges in documenting fishing effort and bycatch. The FAO has estimated that > 95% of fishers worldwide operate in small-scale fisheries, and yet, the actual magnitude of fishing effort is difficult to assess because national, regional, and global fisheries statistics are imprecise (but see Chuenpagdee et al. 2006, Stewart et al. 2010).

To address these challenges, several researchers have turned to interviews and surveys to collect data on fishing effort and the associated bycatch (Gomez-Munoz 1990, Hutchings and Ferguson 2000, Gladstone 2002, Okada et al. 2005, Otero et al. 2005). Most of these studies have been limited in spatial scale and used different methods. Consequently, most interview-based results to date cannot easily be extrapolated to sizeable study areas or compared across studies or regions. A recent research effort piloted a survey methodology in seven countries in four ocean regions (Moore et al. 2010). The interview-based survey was designed to sample fishers using a short (5 min) interview protocol and a smaller number of fishers using a longer (30 min) interview protocol (for more detailed information on the fishery), and was field tested in Tanzania, Comoros, Nigeria, Cameroon, Sierra Leone, Malaysia, and Jamaica. The surveys collected detailed information on gear characteristics, vessel specifications, catches, and distribution of effort, so that bycatch could be contextualized with fishery effort. Although it is in its nascent stages, this survey instrument has pointed to clear patterns in bycatch and fishing effort among regions that has allowed managers and researchers to identify new research priorities.

One region where this new survey protocol was implemented is in Sabah, Malaysia. Sabah is one of two Malaysian states on the island of Borneo and has the country's longest coastline (~1600 km). Coastal and near-shore fisheries in the state are well developed, while deep sea mechanized fishing is in its infancy. More than 8000 vessels of varying lengths target primarily fish and shrimp, with the balance composed of squid and other invertebrates. The fisheries and aquaculture industries produce about 200,000 mt of fish worth ~200 million USD annually, or some 2.8% of Sabah's annual gross domestic product (Sabah Fisheries Department 2007).

Employing snowball sampling, the survey assessment efforts resulted in more than 2600 interviews in 161 fishing villages, an estimated 85%–90% of all fishing communities in Sabah State. These efforts were successful in documenting information on fishing gear deployed, as well as generating coarse catch and bycatch estimates. Gillnets and hook and line fishing were the most commonly used fishing gears. However, these gears did not represent the largest proportion of catches; this came from the purse seine and trawl fishing boats.

The fishing effort information from this survey effort formed the context for evaluating bycatch of endangered large marine fauna in an area where bycatch information was absent. The prevalence of gillnets, a gear typically associated with high bycatch and related mortality for sea turtles and marine mammals (Read et al. 2006, Gilman et al. 2010, Wallace et al. 2010), is notable. Although only 25% of fishers reported catching turtles, these captures likely accounted for the mortality of some 4500 sea turtles per year, with an average estimate of 10 turtles caught by each fishing vessel per year. Marine mammal bycatch was far less common. These results highlight the type of data interview-based surveys can generate. Though imprecise, the data are extremely valuable from a comparative standpoint for identifying communities, gear types, and bycatch species of particular concern. By filling in data gaps, surveys provide a foundation for community involvement activities, as well as quantitative bycatch analyses.

Quantitative Bycatch Research

Another primary challenge to addressing bycatch effectively is the need for rigorous data analysis (Soykan et al. 2008). Analyses are essential to answer fundamental questions such as: (1) Is bycatch in a particular area having a population-level effect on a species of conservation concern? (2) Is bycatch of a species or taxa significantly associated with particular oceanographic variables? And (3) If fishing effort redistribution is required to reduce bycatch, where and when should that fishing be redistributed? Linking bycatch to population-level effects is limited by a lack of data on the age and sex class of bycatch. In some species, there may be ontological spatial segregation, i.e., different life stages occupy different ocean habitats, so spatially distinct fisheries operations of the same gear type can have differential impacts on the same population. This is evident in sea turtles, where post-hatchling juveniles are transported by major current systems to oceanic feeding areas until, years later, they recruit to neritic areas. An example of one method to understand relative effects of different fisheries on loggerhead populations is to determine how size distributions of loggerheads caught as bycatch vary among fishing areas. Linking size with age class estimates, it is possible to calculate reproductive values for an individual, where reproductive value represents the relative contribution of an individual to future population growth (Wallace et al. 2008). In an analysis of loggerhead bycatch from trawl and longline vessels in the North Atlantic, North Pacific, and Mediterranean, Wallace et al. (2008) asked whether bycatch from particular gear types or ocean regions differentially impacted loggerhead populations in different fishing areas. They found that trawls in the Mediterranean were likely having a relatively larger impact on loggerhead populations than other gears in other ocean areas.

A second critical research question is whether bycatch of a particular species or taxa is significantly correlated to dynamic or fixed oceanographic features, or is more likely to occur in areas where individuals are abundant. Quantitative analysis of satellite telemetry and other distribution data has enabled the identification of high use areas of vulnerable megafauna populations (James et al. 2007, Peckham et al. 2007, Shillinger et al. 2008). Linking species occurrence with environmental features provides insight into the spatial ecology of an organism (Guissan and Zimmermann 2000). From a management perspective, if bycatch likelihood can be reliably linked to environmental features, managers can act proactively to avoid exposing species of concern to bycatch by redistributing fishing effort. Braun-McNeill et al. (2008) identified a significant relationship between Cheloniid sea turtles and sea surface temperature (SST), leading to the conclusion that these turtles are physiologically limited to waters above a certain temperature range. This significant association makes it possible to predict when these turtles will travel north along the Atlantic coast in spring and back south in fall, which has important management implications. Managers could plan spatio-temporal closures for those fisheries known to interact with threatened sea turtles along the US Atlantic coast during their migratory transitions. This relationship between ocean conditions and turtle distribution has generated a more formal tool for fisheries managers. Howell et al. (2008) developed a software product based on SST to reduce loggerhead-gear interactions in the Hawaii-based pelagic longline fishery. The field-tested product, called TurtleWatch, has fishers avoid areas colder than the 18.5 °C isotherm during the first quarter of the year to reduce sea turtle bycatch.

The final question focuses on another critical management issue: if managers decide fishing effort should be redistributed to reduce bycatch either spatially or temporally, to what areas or times should that effort be moved? Researchers have tackled this question from one of two angles: biological or economic. From a biological perspective, spatial analyses of bycatch patterns in the Atlantic and Pacific suggest that bycatch events and high bycatch rates are spatially correlated and that in some areas bycatch occurrence is clustered across species and taxa (Lewison et al. 2009). From an economic perspective, analyses that consider the consequences of effort redistribution by using full fleet dynamics, ideal free distributions, or uniform redistribution of fishing effort have all been developed to generate predictions of where vessels will go (Sanchiro and Wilen 2001, NMFS 2006, Sanchirico and Wilen 2005, Smith et al. 2008, Powers and Abeare 2009). Encompassing a wide range of model complexity, these economic analyses have provided a tool by which we can assess the likely outcomes should a fishing area be closed from a short-term closure or the establishment of a marine protected area, based in large part on the relative differences between benefit (expected catch per unit effort) to costs (associated with moving to the new location). Assuming bycatch exhibits detectable and persistent spatial patterns, as it has been shown to do in some areas (Lewison et al. 2009), incorporating both single and multispecies bycatch into models of fishing effort redistribution is an essential next step. As with outreach and data collection efforts, including fisher expert knowledge in the analytical process has been shown to help characterize the dynamic responses of fisheries and human behavior to different management actions (Haapasaari and Karjalainen 2010).

The Role of Governance

Bycatch of imperiled species often takes place within the Exclusive Economic Zones (EEZs) of fishing nations. National legislation and local cooperatives offer a foundation upon which managers, industry, conservation organizations, academics, and others can work together to solve issues of shared concern and often sets the tone for prioritizing efforts to assess and address bycatch across fishing sectors and bycatch taxa. The content of and compliance with such legislation varies widely among nations and reflects not only societal values, but also the relative importance of legal mandates to on-the-ground changes in any given nation.

In addition to addressing bycatch within nations' EEZs for many highly migratory species vulnerable to fisheries interactions, reducing bycatch on the high seas is critical to their long-term conservation. Indeed, with some species, e.g., sea turtles and seabirds, the same individuals may cross multiple ocean basins in a lifetime or even in a single year (e.g., Birdlife 2004). It is for this reason that RFMOs and their member nations must collaborate to address bycatch.

RFMOs are international bodies made up of nations whose responsibility is to manage target fish stocks for long-term extraction. Each RFMO sets forth a binding management regime for fisheries within its convention area. RFMO members and their contracting parties are expected to comply with conservation and management measures adopted by consensus. There are more than 20 RFMOs worldwide, although the bycatch of many species of conservation concern falls under the aegis of six RFMOs (Small 2005): Commission on the Conservation of Southern Bluefin Tuna (CCSBT), Inter-American Tropical Tuna Commission (IATTC), International

Commission for the Conservation of Atlantic Tunas (ICCAT), Indian Ocean Tuna Commission (IOTC), the Western and Central Pacific Fisheries Commission (WCPFC), and Convention on the Conservation of Antarctic Marine Living Resource (CCAMLR). Some of the RFMO treaties have been in place for decades, before the need to reduce bycatch of non-target species was formally contemplated. Global agreements, such as the United Nations (UN) Agreement on Straddling and Highly Migratory Fish Stocks and the voluntary FAO Code of Conduct for Responsible Fishing, however, call for precautionary and ecosystem approaches to fisheries. These globally adopted standards and, in some cases, re-negotiated fisheries treaties, have more recently expanded RFMO responsibility to include the conservation of living marine resources other than target stocks.

Efforts to reduce bycatch have varied greatly among RFMOs and among taxa of bycatch species. For example, substantial progress has been made in the identification and application of bycatch mitigation measures for seabirds in some tuna RFMOs, while few tuna RFMOs have sought to address the bycatch of marine mammals outside of the IATTC's work to reduce dolphin interactions with purse seines in the eastern tropical Pacific Ocean. In the case of sea turtles, the tuna RFMOs have made moderate progress, including the adoption of voluntary dehooking and resuscitation protocols. Perhaps more challenging is the development of governance regimes to reduce the bycatch of species which are both target and non-target stocks, e.g., many shark species, subadult tunas, and billfish species. Reducing bycatch for these species is complicated by their uneven treatment as either bycatch or target species across RFMOs, and because they are more likely retained for food or for sale by the small-scale and inshore RFMO fleets. As with exclusively non-target species, the long-term conservation and management of these species depend on accurate stock and bycatch assessments—information that is typically lacking.

Models for effective design and implementation of bycatch reduction measures can be found in other RFMOs, such as CCAMLR, which manages fisheries in the Southern Ocean. CCAMLR has substantially reduced seabird bycatch by taking a risk-averse approach, using scientifically proven methods for mitigating bycatch, and monitoring the results using onboard observers. In recent years, CCAMLR has been recognized as the clearest and most successful RFMO model to reduce seabird bycatch (Croxall and Nicol 2004, CCAMLR 2006, Cox et al. 2007). CCAMLR members individually and as a Commission have expressed an interest in working with the tuna RFMOs at reducing the bycatch of seabirds which nest in CCAMLR waters and forage in adjacent RFMOs (CCAMLR 2006).

A significant limiting factor to progress has been a lack of information regarding the impact of tuna fisheries on bycatch species' populations, resulting in reluctance by some RFMO members to support the precautionary principle. This occurs when the status and distribution of the affected species is largely uncertain and when the RFMOs themselves lack the expertise to collect and assess needed information. A combination of limited RFMO mandates, finite national capacities to conduct needed research, and a lack of RFMO-wide at-sea monitoring of interactions of RFMO fisheries with bycatch species all contribute to this unfortunate stalemate. Several of the RFMOs have begun to address critical research and data needs, as well as apply management tools that aid in decision-making and assessing whether their existing bycatch-related conservation measures are meeting their objectives. Some of the approaches the RFMOs are undertaking include prioritizing research and management objectives, conducting ecological risk assessments, developing standardized monitoring and reporting schemes, and prescribing periodic review and evaluation of the effectiveness of conservation measures.

Advancing common national and organizational objectives across RFMOs, including bycatch reduction, is a logical next step. Some RFMOs have already begun to coordinate their efforts with other RFMOs and inter-governmental organizations. Critical collaborations and information sharing have taken place between RFMOs and the Agreement on the Conservation of Albatrosses and Petrels (ACAP). ACAP members are fishing nations and members of RFMOs with a vested interest in both seabird conservation and the sustainability of the RFMO fisheries. Efforts by ACAP member nations within RFMOs of which they are members, such as sharing state-of-the-art technological advances at reducing bycatch, serve as an excellent example of how coordinated action can avoid duplication of efforts and increase efficiencies.

There remain many opportunities for RFMOs to work more efficiently to improve bycatch management, expand onboard observer programs, collect standardized data within and across programs, and adopt proven mitigation methods. Without adequate information in hand, RFMOs will continue to be faced with making decisions in a world of uncertainty. Given the dire conservation status of many of the bycatch species involved, it is critical that RFMOs have access to much-needed data, and that they rely on external expertise and all available resources for making decisions in the most efficient and collaborative manner. RFMO action also depends heavily on the technical capacity and political will of individual RFMO members to prioritize addressing both needs. Lasting advances in bycatch reduction also require the use of new information as it becomes available whether through the application of research results or results of periodic evaluations of effectiveness or compliance. While RFMOs should seek to increase their capacity to deliver new information, there are also abundant opportunities for outside experts such as social scientists, ecologists, and conservation biologist to contribute to RFMO deliberations. External experts can offer their findings to the RFMOs by obtaining official observer status at RFMO meetings or by participating as members of RFMO members' delegations.

As RFMOs seek to make progress at the multilateral level, the United States and the European Union have taken steps to integrate their domestic and international conservation objectives through enacted legislation (e.g. the U.S. Magnuson-Stevens Fishery Conservation and Management Act, Section 403 and the EU Council Regulation (EC) No 1005/2008)) requiring them to monitor and potentially restrict imports of seafood based upon harvesting nations' levels of compliance with RFMO and other international conservation measures, particularly those regarding combating illegal fishing and reducing bycatch. These legal instruments are relatively new and, therefore, their effectiveness remains to be seen.

An Integrated Framework

The individual elements presented above are well-known and widely applied, although the examples provided focus on more recent, innovative developments and applications. Historically, policy development, social science, community involvement, and biological science research have not been common bedfellows in any field. However, as our knowledge of the importance of fisheries to the world's population increases (FAO 2004) and the challenge bycatch presents to imperiled species and

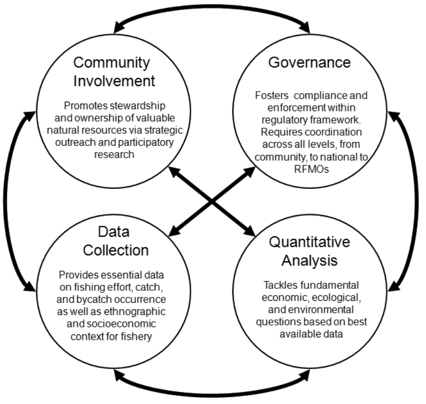

Figure 1. Comprehensive framework for bycatch reduction. Note the nonlinear relationships and feedback loops among components. Though each is necessary and important on its own, integration across components offers the greatest potential for successful by-catch reduction.

fisheries sustainability intensifies (Smith et al. 2010), the need for an integrated approach to developing sustainable solutions to reduce bycatch becomes all the more clear.

Where are the critical junctions for integration across disciplines and scales? Although some of the current work discussed and referenced herein represents varying levels of cross-sectoral integration, a comprehensive application of this integrated approach has yet to be implemented. In Figure 1, we present a framework that illustrates an integrated approach to reducing fisheries bycatch. As this figure illustrates, the relationships among sectors are not linear or unidirectional. Indeed, the key component of this framework is feedback among each of the sectors, highlighting the need for social scientists, ecologists, and conservation biologists to collaborate in new and innovative ways to more fully understand the socioeconomic and ethnographic context of fisheries, as a critical step in developing sustainable and practical strategies to reduce bycatch.

The bedrock of this integrated approach is community engagement and involvement from the outset of bycatch management. This initial step is non-trivial; engaging fishers and their communities is necessary, but requires resource investment, as creating dialogue and building trust with fishers can take years and requires long-term financial support (Hall et al. 2007). Community-focused conservation action has been successful in a number of countries where communities are inspired to take pride in their natural assets and offered viable means to protect these assets (http://www.rareconservation.org).

An engaged fishing community facilitates data collection, which is most effective when guided by the needs of the community, managers, and scientists. One of the clearest strengths of the data collection survey in Sabah was that it quickly yielded an assessment of the fishing gear, effort, and its potential link to bycatch. However, the survey yielded other important results, e.g., that larger, commercial vessels encroached on small-scale vessel fishing zones (within 3 nm), and that while bycatch was unintentional, there were also few efforts to minimize take of endangered species. Community-based activity also provides an opportunity for natural and social scientists to frame bycatch within ecologically and socially relevant frameworks. Community participation in data collection documenting patterns of natural resource use and the socio-economic context of those activities provides an understanding of how socio-cultural and economic factors influence fishing practices and, by extension, bycatch impacts. Evidence suggests this is an essential step towards developing socially relevant, acceptable, and sustainable bycatch solutions (Campbell and Cornwall 2008).

Data collected in such a manner fuels quantitative bycatch research and provides an opportunity for oceanographic, demographic, and ecological analyses that cycle back to improve data collection while also strengthening the motivation and development of governance, and providing content for community outreach and education programs. In addition to answering these quantitative questions, this approach provides another opportunity to integrate natural and social science. The identification of socioeconomic costs allows for an assessment of how changes in fisher behavior may influence catch and bycatch, and focuses attention on the costs and benefits to the fisher community (Smith et al. 2010). A more complete integration of socioeconomic, management, and ecological models is an important next step. Quantitative analyses also play a critical role in providing the necessary information for policy development by using best-available science to evaluate management alternatives and consider both ecological and economic impacts of proposed management scenarios. One of the key achievements of fisher community engagement and involvement on the Baja California peninsula, namely the estimation of regional bycatch rates and the development of bycatch mitigation solutions, relied on partnerships between community members and scientists. The development of effective policy and management strategies has proven to be most effective when policy makers and managers work closely with fishers and industry to articulate management objectives, goals, and viable solutions—this is relevant for small-scale and industrial fisheries. Fisher involvement in development, testing, and pilot programs has also proven to be necessary to facilitate adoption and compliance (Cox et al. 2007).

The development of governance vehicles and structures also provides a key opportunity to integrate across these elements. At the local level, co-management, where local stakeholders work with centralized authorities, has been promoted in various forms for more than two decades as a key facet for effective fisheries management (Pinkerton 1989, Berkes et al. 2001), especially for small-scale fisheries. At the regional and ocean-wide scale, coordination among multi-national stakeholders has begun, but remains underdeveloped. Lack of data is typically cited as one of the primary factors that limits governance development and points to the necessary linkages between quantitative analyses and governance development. Governance that is based on best available data, articulates on existing legislative frameworks, and involves fishing sectors is more likely to be feasible and enforceable.

It is important to recognize that each of the sectors makes essential and different contributions to the ultimate objective of reducing bycatch of endangered species. For example, community involvement activities may focus particular attention on social networking, participatory research, and social marketing. In contrast, data collection via fisher surveys is aimed at collecting data on fishing effort and bycatch. The quantitative analyses are designed to determine whether bycatch is having an effect on population viability, or whether there are any environmental correlates of bycatch. Finally, the goal of international governance at the level of RFMOs is to encourage compliance with sustainable fishing practices outlined in various international agreements. Though clearly inter-related, they are not redundant.

While the need for cross-sectoral integration is clear, what is less clear is the mechanism by which this integration could occur. Few organizations or agencies have the expertise needed across all sectors, and poor pathways of communication among fishers, scientists, and policy makers have been well documented (Shanley and Lopez 2009). Integrated marine science forums, such as the International Marine Conservation Congress, play an important role in bringing together some (but not all) of the constituents involved in bycatch assessment and mitigation. As such, they provide a valuable opportunity to share ideas and contemplate big picture issues beyond the purview of any individual participant. An important goal for future forums should be to build upon this conceptual framework, identifying specific mechanisms of how to achieve cross-sectoral integration.

Decades of work on bycatch has made clear the need to address this issue on many fronts: sociology, ecology, economics, and governance. Examples of successful bycatch reduction efforts in both small-scale and industrial fisheries provide support for the need for a multi-scaled and interdisciplinary response within a context of building sustainable fisheries. While progress has been made in each sector, there exists an opportunity to more fully integrate approaches as we continue to develop new bycatch solutions. Faced with clear evidence of declining catches of target species (Sala et al. 2004, Chassot et al. 2010) and growing evidence of the impact of bycatch across a wide range of species (Chuenpagdee et al. 2003, Lewison et al. 2004), the need for a more focused and coordinated approach to bycatch has never been stronger.

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Literature Cited

Alfaro Shigueto J, Mangel JC, Seminoff JA, Dutton PA. 2008. Demography of loggerhead turtles *Caretta caretta* in the southeastern Pacific Ocean: fisheries-based observations and implications for management. Endang Species Res. 5:129–135. doi:10.3354/esr00142

Berkes F, Mahon R, McConney P, Pollnac R, Pomeroy R. 2001. Managing small-scale fisheries: alternative directions and methods. International Development Research Centre, Ottawa.

Birdlife International. 2004. Tracking ocean wanderers: the global distribution of albatrosses and petrels.

Braun-McNeill J, Sasso CR, Epperly SP, Rivero C. 2008. Feasibility of using sea surface temperature imagery to mitigate cheloniid sea turtle–fishery interactions off the coast of northeastern USA. Endang Species Res. 5:257–266. doi:10.3354/esr00145

Campbell LM, Cornwell ML. 2008. Human dimensions of bycatch reduction technology: current assumptions and directions for future research. Endang Species Res. 5:325–334. doi:10.3354/esr00172

CCAMLR Resolution 22/XXV-2006. International actions to reduce the incidental mortality of seabirds arising from fishing. Available from: http://www.fakr.noaa.gov/protectedresources/seabirds/CCAMLR_bird_resolution22xxv.pdf.

Chassot E, Bonhommeau S, Dulvy NK, Mélin F, Watson R, Gascuel D, Le Pape O. 2010. Global marine primary production constrains fisheries catches. Ecol Lett. 13:495–505. PMid:20141525. doi:10.1111/j.1461-0248.2010.01443.x

Chuenpagdee R, Morgan LE, Maxwell SM, Norse EA, Pauly D. 2003. Shifting gears: assessing collateral impacts of fishing methods in US waters. Front Ecol Environ. 1:517–524. doi:10.1890/1540-9295(2003)001[0517:SGACIO]2.0.CO;2

Chuenpagdee R, Ligouri L, Palomares MLD, Pauly D. 2006. Bottom-up, global estimates of small-scale marine fisheries catches. Fish Cent Res Rep. 14(8).

Coe JM, Holts DB, Butler RW. 1984 The 'tuna-porpoise' problem: NMFS dolphin mortality reduction research, 1970–81. Mar Fish Rev. 46:18–33.

Cox TM, Lewison RL, Zydelis R, Crowder LB, Safina C, Read AJ. 2007. Comparing effectiveness of experimental and implemented bycatch reduction measures: the ideal and the real. Conserv Biol. 21:1155–1164. PMid:17883481. doi:10.1111/j.1523-1739.2007.00772.x

Croxall JP, Nicol S. 2004. Management of southern ocean fisheries: global forces and future sustainability. Antarctic Sci. 16:4:569–584. doi:10.1017/S0954102004002330

Delgado SG, Nichols WJ. 2004. Saving sea turtles from the ground up: awakening sea turtle conservation in northwestern Mexico. Marit Stud. 4:89–104.

FAO 2004. State of World Fisheries and Aquaculture (SOFIA) - SOFIA 2004. FAO Fisheries Department.

Fortmann L. 2008. Participatory research in conservation and rural livelihoods: doing science together. Wiley-Blackwell, Chichester.

Gilman E, Lundin C. 2009. Minimizing bycatch of sensitive species groups in marine capture fisheries: lessons from commercial tuna fisheries. *In:* Grafton Q, Hillborn R, Squires D, Tait M, Williams M, editors. Handbook of marine fisheries conservation and management. Oxford University Press, Oxford.

Gilman E, Gearhart J, Price B, Eckert S, Milliken H, Wang J, Swimmer Y, Shiode D, Abe O, Hoyt Peckham S, et al. 2010. Mitigating sea turtle bycatch in coastal passive net fisheries. Fish Fish. 11:57–88. doi:10.1111/j.1467-2979.2009.00342.x

Gladstone W. 2002. Fisheries of the Farasan Islands (Red Sea). NAGA, WorldFish Cent Q. 25, 30–34.

Gomez-Munoz VM. 1990. A model to estimate catches from a short fishery statistics survey. Bull Mar Sci. 46:719–722.

Guisan A, Zimmermann NE. 2000. Predictive habitat distribution models in ecology. Ecol Model. 135:147–186. doi:10.1016/S0304-3800(00)00354-9

Hall MA, Alverson DL, Metuzals KI. 2000. Bycatch: problems and solutions. Mar Pollut Bull. 41:204–219. doi:10.1016/S0025-326X(00)00111-9

Hall MA, Nakano H, Clarke S, Thomas S, Molloy J, Peckham SH, Laudino-Santillán J, Nichols WJ, Gilman E, Cook E, et al. 2007 Working with fishers to reduce bycatches. *In:* Kennelly SJ, editor. Bycatch reduction in the world's fisheries. Springer-Verlag. doi:10.1007/978-1-4020-6078-6_8

Haapasaari P, Karjalainen TP. 2010. Formalizing expert knowledge to compare alternative management plans: sociological perspective to the future management of Baltic salmon stocks. Mar Policy. 34:477–486. doi:10.1016/j.marpol.2009.10.002

Hilborn R, Orensanz JM, Parma AM. 2005. Institutions, incentives and the future of fisheries. Philos Trans R Soc London Biol. 360:47–57. PMid:15744918. PMCid:1636099. doi:10.1098/rstb.2004.1569

Howell EA, Kobayashi DR, Parker DM, Balazs GH, Polovina JJ. 2008. TurtleWatch: a tool to aid in the bycatch reduction of loggerhead turtles *Caretta caretta* in the Hawaii-based pelagic longline fishery. Endang Species Res. 5:267–278. doi:10.3354/esr00096

Hutchings JA, Ferguson M. 2000. Temporal changes in harvesting dynamics of Canadian inshore fisheries for northern Atlantic cod, Gadus morhua. Can J Fish Aquat Sci. 57:805–814. doi:10.1139/cjfas-57-4-805

Jackson JBC. 2007. Economic incentives, social norms and the crises of fisheries. Ecol Res. 22:16–18. doi:10.1007/s11284-006-0075-z

James MC, Sherrill-Mix SA, Myers RA. 2007. Population characteristics and seasonal migrations of leatherback sea turtles at high latitudes. Mar Ecol Prog Ser. 337:245–254. doi:10.3354/meps337245

Jenkins LD, Mast RB, Hutchinson BJ, Hutchinson AH. 2008. Key factors in the invention and diffusion of marine conservation technology: a case study of TEDs. NOAA Technical Memorandum NMFS SEFSC: 73.

Kennelly SJ. 2007. Bycatch reduction in the world's fisheries. Springer Verlag. doi:10.1007/978-1-4020-6078-6

Laszlo Barabasi A. 2002. The new science of networks. Perseus Books Group.

Lewison RL, Crowder LB, Read AJ, Freeman SA. 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends Ecol Evol. 19:598–604. doi:10.1016/j.tree.2004.09.004

Lewison RL, Soykan C, Franklin J. 2009. Mapping the bycatch seascape: multispecies and multi-scale spatial patterns of fisheries bycatch. Ecol Appl. 19:920–930. PMid:19544734. doi:10.1890/08-0623.1

Lo NCH, Powers JE, Wahlen BE. 1982. Estimating and monitoring incidental dolphin mortality in the eastern tropical Pacific tuna purse seine fishery. Fish Bull. 80:396–401.

MacKenzie-Mohr J, Smith W. 1999. Fostering sustainable behavior. Washington, DC: Academy for Educational Development and Gabriola Island, BC, Canada: New Society Publishers.

Marsh H, Harris ANM, Lawler IR. 1997. The sustainability of the indigenous dugong fishery in the Torres Strait, Australia Papua New Guinea. Cons Biol. 11:1375–1386. doi:10.1046/j.1523-1739.1997.95309.x

McClanahan TR, Marnane MJ, Cinner JE, Kiene WE. 2006. A comparison of marine protected areas and alternative approaches to coral-reef management. Curr Biol. 16:1408–1413. PMid:16860739. doi:10.1016/j.cub.2006.05.062

McClusky SM, Lewison RL. 2008. Quantifying fishing effort: a synthesis of current methods and their applications. Fish Fish. 9:188–200. doi:10.1111/j.1467-2979.2008.00283.x

Moore JE, Cox TM, Lewison RL, Read AJ, Bjorkland R, McDonald SL, Crowder LB, Aruna E, Ayissi I, Espeut P, et al. 2010. An interview-based approach to assess marine mammal and sea turtle captures in artisanal fisheries. Biol Conserv. 143:795–805. doi:10.1016/j.biocon.2009.12.023

Namnum S. 2002. The inter-American convention for the protection and conservation of sea turtles and its implementation in Mexican law. J Int Wildl Law Policy. 5:87–103. doi:10.1080/13880290209354000

Nichols WJ. 2003. Biology and conservation of sea turtles in Baja California, Mexico. PhD Dissertation. School of Renewable Resources, University of Arizona, Tucson, AZ USA.

NMFS 2006. Final consolidated Atlantic highly migratory species fishery management plan. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Sustainable Fisheries, Highly Migratory Species Management Division, Silver Spring, MD. Public Document, 1600 p.

Okada EK, Agostinho AA, Gomes LC. 2005. Spatial and temporal gradients in artisanal fisheries of a large Neotropical reservoir, the Itaipu Reservoir, Brazil. Can J Fish Aquat Sci. 62:714–724. doi:10.1139/f05-015

Otero J, Rocha F, Gonzalez AF, Gracia J, Guerra A. 2005. Modelling artisanal coastal fisheries of Galicia (NW Spain) based on data obtained from fishers: the case of *Octopus vulgaris*. Scientia Marina. 69:577–585.

Peckham SH, Maldonado D, Walli A, Ruiz G, Nichols WJ, Crowder LB. 2007. Small-scale fisheries bycatch jeopardizes endangered Pacific loggerhead turtles. PLoS One. 2(10): e1041. PMid:17940605. PMCid:2002513. doi:10.1371/journal.pone.0001041

Peckham SH, Maldonado-Diaz D, in press. Empowering small scale fishermen to be conservation heroes: a trinational fishermen's exchange to protect loggerhead turtles. Seminoff JA,

editor. *In:* Sea turtles of the eastern Pacific Ocean: natural history, conservation challenges and signs of success. University of Arizona Press, Tucson.
Peckham SH, Maldonado-Diaz D, Koch V, Mancini A, Gaos A, Tinker MT, Nichols WJ. 2008. High mortality of loggerhead turtles due to bycatch, human consumption and strandings at Baja California Sur, Mexico, 2003–7. Endang Species Res. 5:171–183. doi:10.3354/esr00123
Pilcher NJ, Ramachandran T, Dah TC, Ee LS, Beliku J, Palaniveloo K, Hin LK, Ling LS, Hui LC. 2008. Rapid Bycatch Assessment- Malaysia. Submitted to Project GloBAL January 2008.
Pinkerton E. 1989. Co-operative management of local fisheries: new directions for improved management and community development. University of British Columbia Press, Vancouver.
Powers JE, Abeare SM. 2009. Fishing effort redistribution in response to area closures. Fish Res. 99:216–225. doi:10.1016/j.fishres.2009.06.011
Read AJ, Drinker P, Northridge S. 2006. Bycatch of marine mammals in the US and global fisheries. Conserv Biol. 20:163–169. PMid:16909669. doi:10.1111/j.1523-1739.2006.00338.x
Sabah Fisheries Department. 2007. Sabah Annual Fisheries Statistics Book.
Sala E, Aburto-Oropeza O, Reza M, Paredes G, López-Lemus LG. 2004. Fishing down coastal food webs in the Gulf of California. Fisheries. 29:19–25. doi:10.1577/1548-8446(2004)29[19:FDCFWI]2.0.CO;2
Sanchiro JN, Wilen JE. 2001. A bioeconomic model of marine reserve creation. J Environ Econ Manag. 42:257–276. doi:10.1006/jeem.2000.1162
Sanchiro JN, Wilen JE. 2005. Optimal spatialmanagement of renewable resources: matching policy scope to ecosystem scale. J Environ Econ Manag. 50:23–46. doi:10.1016/j.jeem.2004.11.001
Shillinger GL, Palacios DM, Bailey H, Bograd SJ, Swithenbank AM, Gaspar P, Wallace BP, Spotila JR, Paladino FV, Piedra R, Eckert SA, Block BA. 2008. Persistent leatherback turtle migrations present opportunities for conservation. PLoS Biol. 6:1408–1416. PMid:18630987. PMCid:2459209. doi:10.1371/journal.pbio.0060171
Shanley P, Lopez C. 2009. Out of the loop: why research rarely reaches policy makers and the public and what can be done. Biotropica. 41:535–544. doi:10.1111/j.1744-7429.2009.00561.x
Small CJ. 2005. Regional fisheries management organisations: their duties and performance in reducing bycatch of albatrosses and other species. Cambridge, UK: BirdLife International.
Smith MD, Zhang J, Coleman FC. 2008. Structural econometric modeling of fisheries with complex life histories: avoiding biological management failures. J Environ Econ Manag. 55:265–280. doi:10.1016/j.jeem.2007.11.003
Smith MD, Roheim CA, Crowder LB, Halpern BS, Turnipseed M, Anderson JL, Asche F, Bourillón L, Guttormsen AG, Khan A, et al. 2010. Sustainability and global seafood. Science. 327:784–786. PMid:20150469. doi:10.1126/science.1185345
Soykan CU, Moore JE, Zydelis R, Crowder LB, Safina C, Lewison RL. 2008. Why study bycatch? An introduction to the theme section on fisheries bycatch. Endang Species Res. 5:91–102. doi:10.3354/esr00175
Stewart K, Lewison RL, Dunn D, Bjorkland R, Kelez S, Halpin P, Crowder LB. 2010. Characterizing fishing effort and spatial extent of coastal fisheries. PLoS ONE. 5(12):e14451. doi:10.1371/journal.pone.0014451
Wallace BP, Heppell SS, Lewison RL, Kelez S. 2008. Using reproductive value analyses to assess relative impacts of fisheries bycatch on loggerhead turtle populations worldwide. J Appl Ecol. 45:1076–1085.
Wallace BP, Lewison RL, McDonald SL, McDonald RK, Kot CY, Kelez S, Bjorkland RK, Finkbeiner EM, Helmbrecht S, Crowder LB. 2010. Global patterns of fisheries bycatch of marine turtles: implications for research and conservation. Cons Lett. 3:131–142. doi:10.1111/j.1755-263X.2010.00105.x

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Addresses: (RLL) *Institute for Ecological Monitoring and Management, San Diego State University, 5500 Campanile Dr, San Diego, California 92182-4614.* (CU) *Soykan, National Oceanic and Atmospheric Association, National Marine Fisheries Service, Southwest Fisheries Science Center, 8604 La Jolla Shores Dr., La Jolla, California 92037.* (TC) *Savannah State University, 3219 College Street, Savannah, Georgia 31404.* (HP) *Grupo Tortuguero de las Californias, Cuautémoc 155, La Paz, Baja California Sur, Mexico.* (NP) *Marine Research Foundation, 136 Lorong Pokok Seraya 2, Taman Khidmat, 88450 Kota Kinabalu, Sabah, Malaysia.* (NLeB) *National Marine Fisheries Service, 1315 East-West Hwy, Silver Spring, Maryland 20910-3282.* (SMcD) *Duke University, Center for Marine Conservation, 135 DUML Rd., Beaufort, California 28516.* (JM) *Protected Resource Division, Southwest Fisheries Science Center, 3333 North Torrey Pines Court, La Jolla, California 92037-1022.* (CS) *Blue Ocean Institute, 250 Lawrence Hill Road, Cold Spring Harbor, New York 11724.* (LBC) *Duke University, Center for Marine Conservation, 135 Duke Marine Lab Rd., Beaufort, North Carolina 28516.* Corresponding Author : (RLL) *E-mail: <rlewison@sciences.sdsu.edu>.*