Solutions for Recovering and Sustaining the Bounty of the Ocean

Combining Fishery Reforms, Rights-Based Fisheries Management, and Marine Reserves

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ABSTRACT. Food security, economic opportunities, and other benefits provided by a healthy ocean are in jeopardy because of years of overexploitation of many fisheries, and the challenges will intensify in many locales as climate and the environment continue to change. The good news is that solutions are gaining traction. Mandates to end overfishing that use scientifically determined catch limits and rights-based approaches to fishery management have produced impressive results in ending overfishing and recovering depleted stocks. Similarly, spatial protections, such as fully protected marine reserves, are increasing the diversity, size, and abundance of species within reserves; some of that bounty reaches fished areas outside of them. We review the effects of combining catch limits, rights-based fisheries approaches, and establishment of marine reserves and discuss additional advantages of these combined solutions in securing sustainable and profitable fisheries, community goals, and healthy ecosystems. This paper highlights the contribution of emerging science-based solutions and the steps needed to replicate and scale these successes. Triple-wins for the environment, the economy, and society can be achieved through integrated fisheries management and protection as conscious steps toward reversing the current degradation of our ocean's living resources.

INTRODUCTION

The sustainability of global fisheries is of growing concern, given the historical and current overfishing of many fish stocks that threatens food provision and ocean biodiversity (Jackson et al., 2001; Halpern et al., 2008), and in many cases jeopardizes communities that rely on fisheries for food and livelihoods. Small-scale coastal fisheries, most of which are understudied and undermanaged, are generally in the worst condition (Costello et al., 2012) and may be the most crucial for local food security in the developing world. Globally, nearly three billion people rely on fish for at least 20% of their average per capita animal protein intake, a number that can exceed 50% on small islands that are also developing states (FAO, 2014). Although fish consumption is projected to grow dramatically in coming decades, marine-capture fisheries landings have leveled off since the mid-1990s (FAO, 2014). Aquaculture will play an increasing role in meeting this growing demand (FAO, 2014), but the declines in small-scale fisheries in developing states create pressing food security challenges as well as lost opportunities to alleviate poverty and create economic opportunity.

A hopeful counterpoint to these challenges is emerging from interdisciplinary science-based approaches. These approaches are providing pathways to more sustainable practices and policies: scientifically determined catch limits in fisheries, rights-based fisheries (RBF) management, and fully protected marine protected areas that are generally called marine reserves (MRs). Ending overfishing begins with science-based mandates that strictly limit annual catches. With the intent of aligning economic and ecological goals, RBFs (also called "catch shares" in the United States) assign fishers[1] and communities secure tenure rights to a fishery. By protecting those rights, environmental stewardship can be incentivized (Hilborn et al., 2005a; Costello et al., 2008). Two common RBF strategies include assigning rights to harvest a given fraction of the scientifically determined total allowable catch (e.g., individual transferable quotas, ITQs) or assigning spatial rights to harvest in a specific region (e.g., territorial use rights in fisheries, TURFs). Either approach can be allocated to individuals or groups, such as communities and cooperatives. Encouragingly, when properly designed (Hilborn et al., 2005b; Wilen et al., 2012), RBF management strategies show success in preventing fisheries collapse (Costello et al., 2008), improving compliance with catch limits (Grimm et al., 2012), stabilizing catches (Essington, 2010), and reversing some of the damage of overfishing (Chu, 2009).

Another response to depletion and disruption of ocean ecosystems has been the implementation of MRs and networks of MRs. By fully protecting portions of marine ecosystems from extractive activities, the abundance, individual body size, and diversity of species generally tend to increase inside the area, often quite substantially (Lester et al., 2009). Both large, open-water MRs such as the Pacific Remote Islands Marine National Monument and the Pitcairn Islands MR as well as smaller coastal MR networks such as those along the California coast are strong efforts to protect biodiversity and ecosystem functioning. In turn, these increases within a reserve can lead to increases in fish abundance in adjacent fished areas (Halpern et al., 2010), and under certain conditions may even increase fishery profit (White et al., 2008). Despite the documented benefits of MRs, resistance by extractive sectors such as oil, gas, minerals, and fisheries can be fierce. Fishers often fight loss of access to fishing grounds and fear mixed socioeconomic impacts of MR establishment (Mascia et al., 2010; Fox et al., 2012). In those fisheries lacking secure fishing rights, an MR only decreases fishers' short-run profits, and other fishers can capture the promised long-term benefits. If, however, fishers have secure access to fishing grounds adjacent to an MR, as in a TURF, explicitly pairing MRs and RBFs represents a potential way to optimize both conservation and

[1] We recognize that many fishermen and fisherwomen have expressed preference for the term "fishermen" to describe themselves, but we use "fishers" here to remain gender-neutral and consistent with FAO's terminology.

fishing goals (Costello and Kaffine, 2010). The benefits of such "TURF-Reserves" are supported by the observation that fishers who are granted TURFs sometimes create their own MR (Ovando et al., 2013).

In this review, we highlight recent results and developments from the natural and social sciences on fishery reforms, emphasizing RBF management and MRs, and explore the potential benefits of pairing RBFs and MRs, specifically the case of TURF-reserves. Further, we discuss projects that are underway to explore this strategy, with particular attention to the contributions of interdisciplinary collaborations and partnerships between scientists, local fishing communities, and nongovernmental organizations. Finally, we discuss the role of science-based solutions in scaling and replicating these local successes on the global stage. In light of the difficult challenges facing marine ecosystems and the many services they provide, reversing degradation deserves paramount attention, and the general class of solutions analyzed here provides a promising path forward.

FISHERY REFORM AND RBF MANAGEMENT

Strong policy mandates to end overfishing are emerging. If properly designed and implemented, they can have powerful results. A full examination of the policy reforms, governance structures, and capacity needed to facilitate an end to overfishing is beyond the scope of this review, but we discuss two recent reforms that exemplify policies dedicated to ending overfishing. For example, in the United States, the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (hereafter 2006 MSA) required an end to overfishing, with strict timelines, annual catch limits, and accountability measures for every federally managed fishery. Strict catch limits set a firm, scientifically determined cap on annual catches that is designed to end overfishing and recover depleted stocks. However, the use of annual catch limits allocated at the fishery sector level can still contribute to the "race to fish." Thus, the advent of RBF approaches, particularly for commercial fisheries, has been increasingly important as a complementary approach in North America and elsewhere. After the 2006 MSA allowed the option of using RBF management, and encouraged by NOAA's 2010 Catch Share Policy (NOAA, 2010), RBFs in the United States have increased in number (Figures 1 and 2) as benefits of this approach were demonstrated. The combination of RBF and strict catch limits has been effective in ending overfishing and recovering depleted fisheries in a number of US fisheries (Box 1, Table 1). By mid-2011, the very significant reforms required by the 2006 MSA had been implemented by the eight regional fishery management councils for all 478 of the

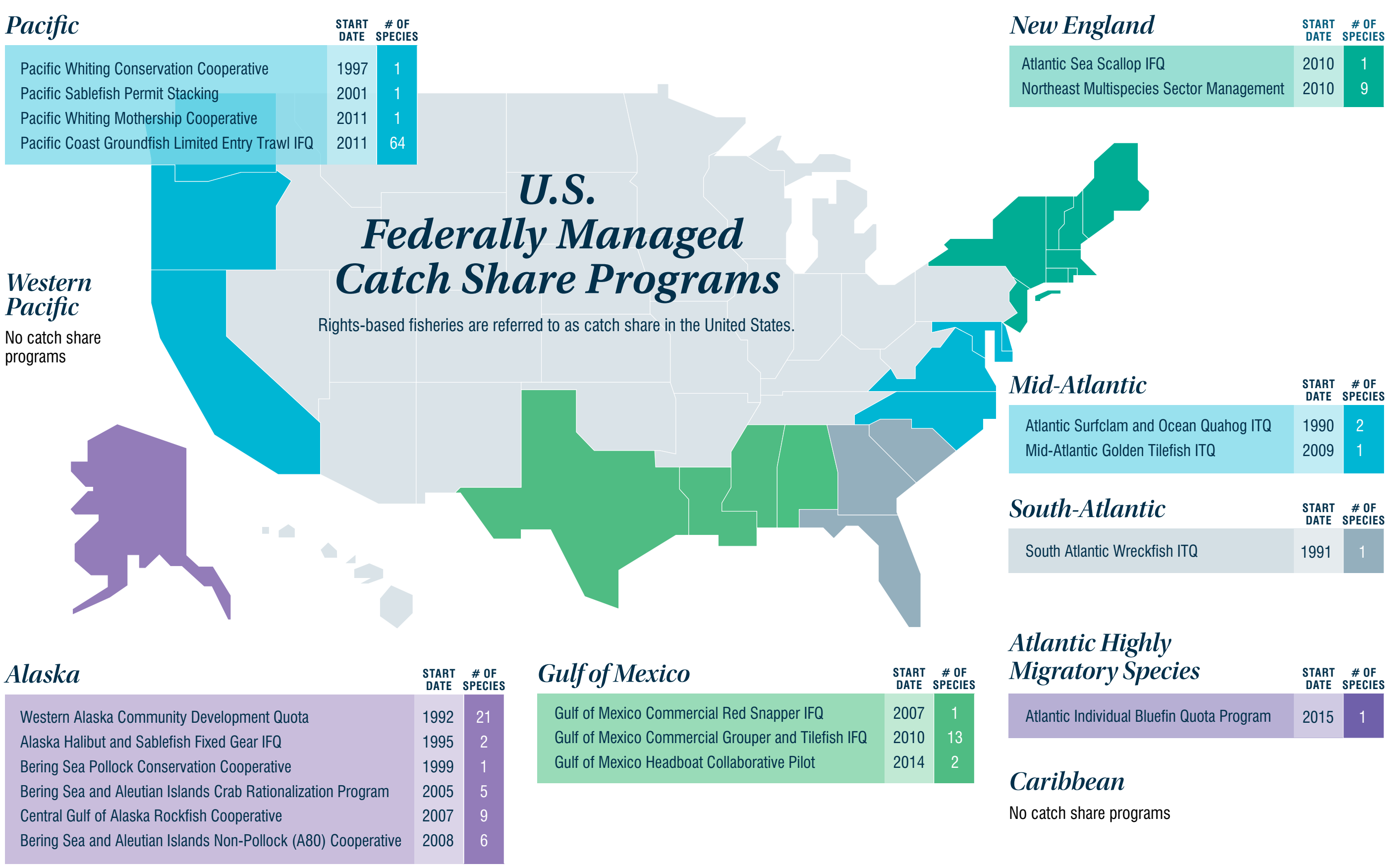


FIGURE 1. Federally managed US rights-based fisheries (RBF) programs across regions, organized by fishery management plan, its start year, and the number of species managed by that program.

federally managed fish stocks. An analysis of the consequences of this implementation concluded that by 2012, 64% of analyzed overfished stocks were rebuilt or showing significant rebuilding progress (Sewell et al., 2013). Economic indicators in US RBF fisheries are also showing improvement, with increased economic benefits and efficiency, reduced fishing capacity, and an overall reduced "race to fish" (Brinson and Thunberg, 2013). A snapshot of indicators comparing 2000 and 2013 speaks to the progress made in US fisheries (NMFS, 2001, 2015; Table 1).

In 2013, the European Union approved a comprehensive overhaul of its Common Fishery Policy, with similar goals of ending overfishing and recovering depleted fisheries. As with the US approach, the EU approach includes strong mandates with teeth and timetables, regional approaches, and the option of using RBF approaches (see FAO Code of Conduct for Responsible Fisheries, http://www.fao.org/fishery/code/en). Given this promising alternative management strategy and the legal capacity that enables it, effort is now being shifted toward evaluation of the purported benefits of RBFs.

As important as strict mandates and catch limits are, additional measures are often needed to achieve the goals of sustainable fisheries. Commercial, industrial-scale fisheries management is often a top-down common property system, employing a fleet-wide quota cap, which incentivizes fishers to compete to secure a portion of the total catch before the quota is reached. This "race to fish" frequently leads down a path of serial stock depletion, despite the best efforts of fishery managers (Caddy and Cochrane, 2001; Grafton et al., 2006). In contrast, RBF management can reduce the common-pool race to fish by directly incentivizing sustainable behavior of fishers through the assignment of exclusive, legally protected tenure rights to individuals or groups (Grafton et al., 2006; Thébaud et al., 2012) and by requiring accountability for an individual's catch. Theoretically, by providing these secure rights through time, fishers will both protect their access and collectively work toward conservation objectives, because the value of these tenure rights is directly related to stock abundance (Hilborn, 2007; Grimm et al., 2012).

Pros and Cons of RBF Management

Although there is accumulating evidence that in the presence of these enabling conditions RBF management can reverse many of the detrimental effects of overfishing, there are ample lessons to be learned in the design, implementation, and management of RBF programs. The adoption rate of RBF in major commercial fisheries is a relatively recent trend, having begun to gain significant traction only in the 1970s (Costello et al., 2008; Branch, 2009). Costello et al. (2008) provide one of the strongest cases for broader adoption of RBF management using empirical data and modeling to show that RBF implementation may counter the global trends toward fishery collapse. Model-based analysis of the performance of RBFs relative to traditional management confirms those empirical results (Costello et al., 2008; Péreau et al., 2012; Melnychuk et al., 2012). Similarly, most recent analyses of empirical data show that, with effective design, enforcement, and compliance monitoring, RBFs will adhere to market principles and can benefit communities economically, socially,

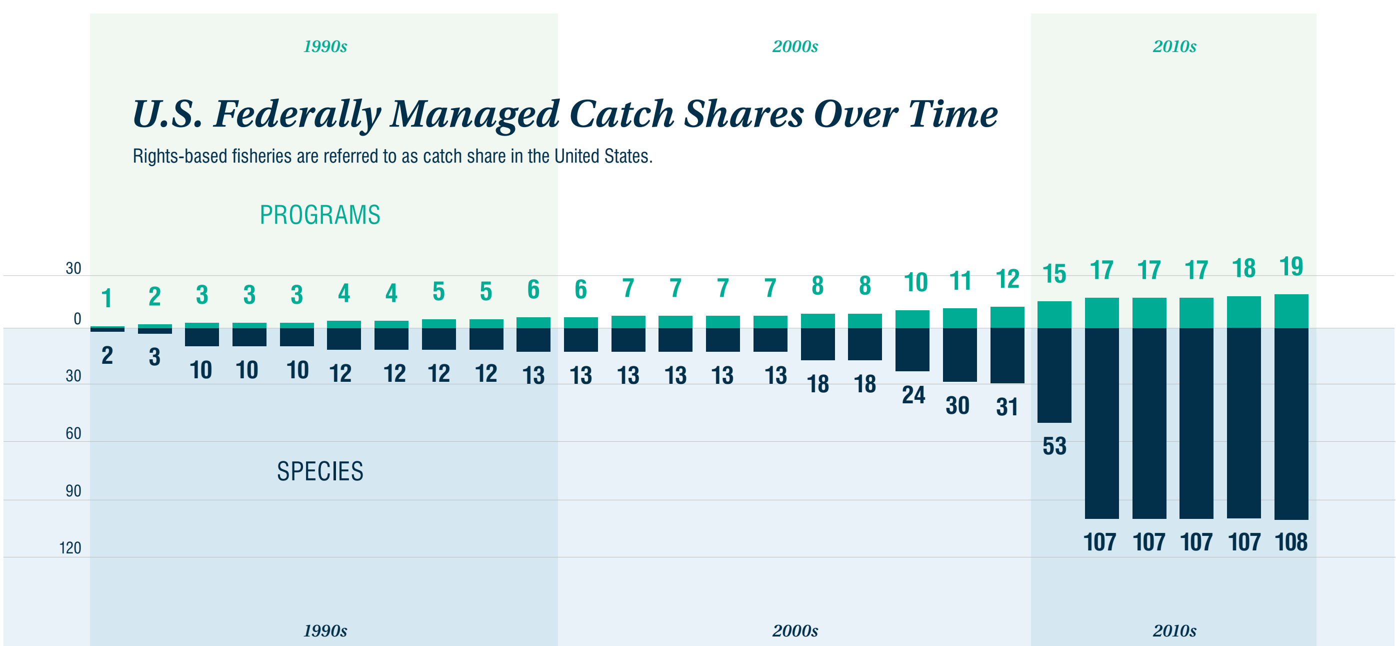


FIGURE 2. Timeline of federally managed US RBF program implementation by the number of RBF management plans (top; green) and the number of unique species managed by a RBF plan (bottom; blue).

and environmentally (Newell et al., 2005; Grimm et al., 2012; Thébaud et al., 2012).

Importantly, the effects of RBFs are not always consistent, and right-based approaches are not a panacea for all the problems of the overfished ocean (Hilborn et al., 2005b; Branch, 2009; Chu, 2009). As with many approaches to resource management, designing RBF programs to account for local context, to be equitable, and to achieve multiple objectives is critical for success (Aswani, 2006; Aburto et al., 2013). Many assertions about the problems of RBFs (e.g., they disadvantage smaller boats and communities [Olson, 2011], or they lead to consolidation of quota in the hands of a few [McCay, 2004]) may actually be the result of flawed design of a specific RBF program (see Olson, 2011), not an inherent problem with the RBF approach; moreover, those problems also often occur in non-RBF fisheries. Additionally, even if the RBF approach produces positive benefits for one sector (e.g., commercial) but overshoots its allocation in another sector (e.g., recreational), overfishing can persist. In designing an RBF program, practitioners should consider the multiple environmental and social objectives of fishery management (Bonzon et al., 2013) and the potential for greater integration of traditional knowledge from local fishers (Heyman and Granados-Dieseldorff, 2012).

Global RBF Case Studies

Success stories resulting from adoption of RBF management are found around the world in both small- and industrial-scale fisheries and both developing and developed countries. Some RBFs have been implemented for long enough to have a well-documented literature detailing results, such as the New Zealand ITQ fisheries (Mace et al., 2013) and the Chilean TURF fishery for the *loco* mollusk (Gelcich et al., 2010, Aburto et al., 2013). Other evidence is emerging from more recently adopted RBF programs. In US federally managed fisheries, impressive recovery and bycatch reduction have been documented following the implementation of policy reforms (Box 1; Grimm et al., 2012). For example, in the Gulf of Mexico, red snapper populations have increased more than 300% from their pre-reform levels despite continuing overfishing in the recreational sectors (SEDAR, 2013). RBF programs have now spread to fisheries large and small in seven regions of the United States (Figures 1 and 2). In the developing world, both ITQ and TURF RBF programs are showing significant benefits for overfished ecosystems (Box 2). After the Namibian hake fishery suffered a total collapse in the 1980s due to decades of foreign exploitation, the fishery was

Box 1. RBF Success Story: US Pacific Groundfish

Along the Pacific coast of the United States, the groundfish fishery, in decline for decades under common pool management, has significantly recovered following the 2006 MSA and the switch to RBFs in 2011. Consisting of a diverse complex of over 90 groundfish species, more than 100 boats, nearly 50 landing/processing sites, and an annual worth over $50 million, this fishery was progressively depleted following its expansion and industrialization after World War II (Shaw and Conway, 2007; Matson, 2014). Decades of the fishery being over capacity, under-resourced, and overfished finally led to economic and ecological collapse and the declaration of a Federal Fishery Disaster in 2000 (Shaw and Conway, 2007). Two changes turned this important fishery around. First, the 2006 MSA required the end of overfishing and recovery of depleted stocks. Second, in 2011, a type of RBF called an individual transferable quota (ITQ) plan was implemented for the groundfish fishery (PFMC and NMFS, 2010; Kaplan et al., 2013). The result has been significant social, economic, and environmental benefits. Early results indicate that adoption of the groundfish ITQ quickly led to decreased bycatch and reduced catch of depleted species relative to the years before ITQ implementation through incentivized innovation in the fishery (Matson, 2013; Somers et al., 2014). Revenues for the non-whiting fleet for the two years after ITQ implementation (compared with the two years before) have increased by 12.5% (Matson, 2013). A strong indicator of successful turnaround and recovery occurred in 2014 when the independent Marine Stewardship Council certified 13 species in the US West Coast groundfish fishery as sustainable. (For more information, see http://www.msc.org/newsroom/news/u.s.-west-coast-groundfish-achieves-msc-certification.) Similarly, in 2014, the Monterey Bay Aquarium Seafood Watch Program upgraded its rankings for 21 species in this fishery, and nearly all of the groundfish in the fishery are now rated "best choice" or "good alternative" (Pelc et al., 2015).

restructured in 1990 as an ITQ RBF by the newly independent Namibian government (Oelofsen, 1999). Ten years after the ITQ was established, the hake fishery is beginning to achieve social and economic goals: the hake stocks have grown by 30% and their value has increased by 40% (Lange, 2003).

TABLE 1. State of US fisheries. Data are compiled from the annual National Oceanic and Atmospheric Administration (NOAA) Status of the Stocks reports (NMFS, 2001, 2015) and from the Environmental Defense Fund's Fishery Solution Center database. Overfished is defined in the NOAA reports as any stock that has a biomass level low enough to jeopardize that stock's capacity to produce maximum sustainable yield.

	2000	2014
Number of overfished stocks	92	37
Number of rebuilt stocks	0	37
Number of unique species under federal RBF	13	107
Number of federal rights-based plans	6	18

RBF Design and Implementation

One of the conclusions emerging from recent analyses of RBF is that they work best when designed and supported in partnership with fishers. In some cases, fisheries success can depend as heavily on social factors, such as strong community leadership and community cohesion, as it does on fisheries management strategy (Gutiérrez et al., 2011). In Belize, stakeholder-centered approaches to fisheries management are the foundation for an effort to restore declining fish stocks through the creation of an RBF system, locally known as Managed Access (Foley, 2012). Established in 2011, Managed Access is a trial-run program resulting from a partnership among the Belize Fisheries Department, seven local and international nongovernmental organizations, universities in Belize and the United States, and representatives from the major fishing cooperatives (Weigel et al., 2014). The success of Managed Access in increasing compliance with regulations and reducing illegal fishing is motivating plans to expand and scale the program nationwide (Weigel et al., 2014). Even in Namibia, where there was a strong top-down approach to implementing RBF through fisheries reforms, bottom-up efforts aided success

Box 2. RBF Success Story: Samoan Safata District Customary User Rights Program

Customary tenure rights programs were once common in many Pacific Islands (Johannes, 2002; Aswani, 2006), but the modern legal infrastructure in these countries often conflicts with or doesn't incorporate traditional fishing practices and customary management (Aswani, 2006). As a result, many customary forms of fisheries management may still exist in practice, but may not be legally enforceable. In Samoa, years of overfishing and nearshore degradation combined with ineffective national legislation led to large declines in inshore fisheries catch by the late 1980s (Fa'asili and Kelekolio, 1999). Despite the best efforts of community members to continue management by customary practices, without the legal ability to regulate illegal fishing by outsiders, inshore fisheries continued to be depleted (Johannes, 2002). A model of RBF success for the Pacific Islands, the territorial use rights in fisheries (TURF) program in the Samoan Safata District was enabled by a series of national legislative reforms that incorporated customary management practices into the modern legal system and promoted management collaborations between local communities and the Samoan government (Young, 2013).

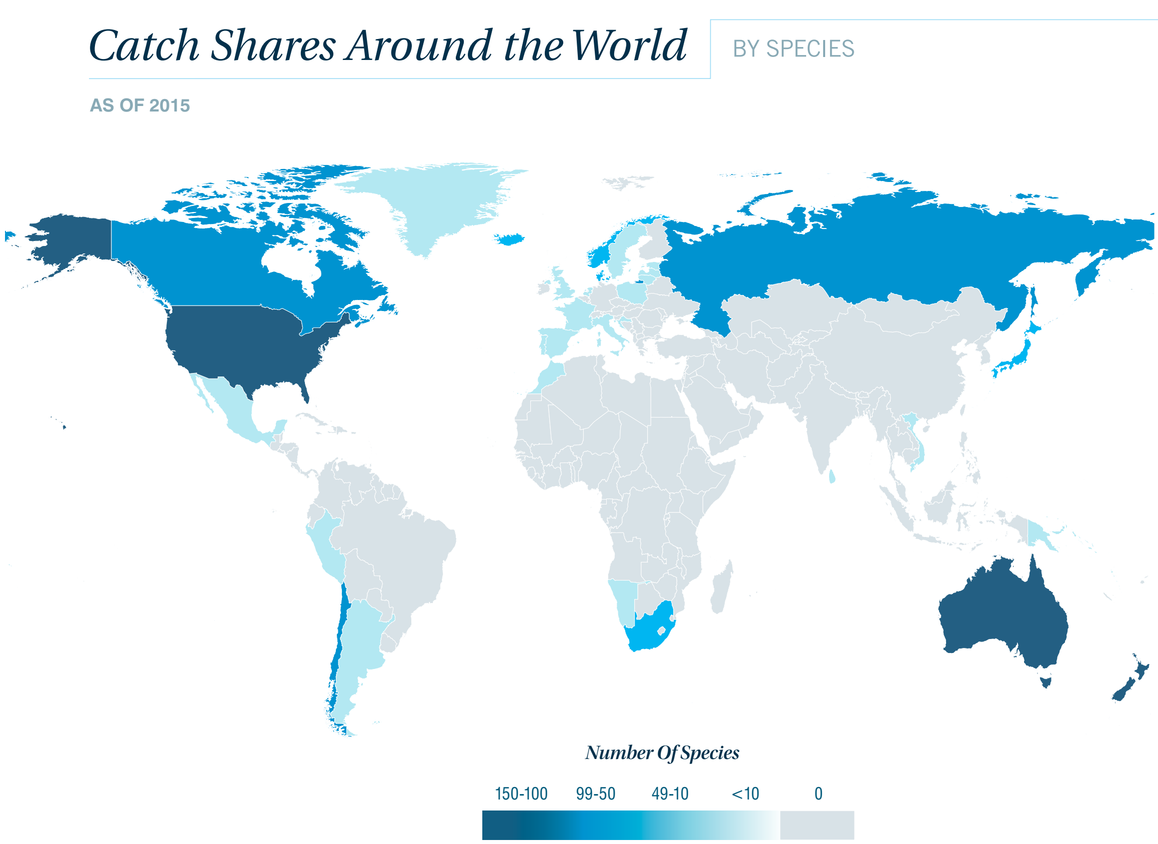
Located on the southern coast of Upolu Samoa, the Safata District is composed of nine villages that have traditionally managed local fisheries with secure and exclusive tenure access to traditional fishing grounds (known as *matai*; Young, 2013). Major reforms to Samoan fishing legislation that began in the late 1980s, followed by decades of hard work between Samoan communities and the government, have greatly strengthened community-based management across Samoa. These reforms enabled community-based management with a series of actions by the Samoan government that (1) created a formal process to legally codify existing local laws at the national level, (2) returned management authority over local fishing areas to the local council of chiefs (*fono*), (3) gave the *fono* full legal jurisdiction to regulate and enforce their management plans, and (4) developed a government-led Fisheries Extension Program to aid villages in developing their local fisheries management plans (Fa'asili and Kelokolo, 1999; King and Fa'asili, 1999; Johannes, 2002; Young, 2013). In the Safata District, leaders implemented a district-wide TURF in 2000, through extensive consultation with the Samoan government (Young, 2013). The TURF covers about 40 km^2 of mangrove and reef habitat and manages all species found within the boundaries. Additionally, Safata's leaders have created 10 village-level marine reserves, covering about 20% of the inshore reefs and lagoon habitat, where fishing pressure is the highest (Govan et al., 2009; Young, 2013). Overall, biological, social, and economic impacts of the Safata TURF are positive: with strong community support, local enforcement of boundaries, and high compliance with TURF regulations, the area reports increases in catch, decreases in fishing time, and increased tourism (Johannes, 2002; Govan et al., 2009; Young, 2013).

by incentivizing Namibian ownership of fishing vessels, establishing Namibian training facilities for fishers, and campaigning to encourage Namibian fish consumption (Oelofsen, 1999).

RBFs have now been implemented around the world (Figure 3) and account for 20% to 25% of global landings by biomass. Recent policy reforms in key industrialized states have enabled RBFs (US reforms in 2006 and EU reforms in 2013), putting many countries on track to sustainable fisheries. Secure tenure rights are being increasingly encouraged for small-scale fisheries as a tenet of responsible management and sustainable development (FAO, 2015). However, only 22 of 109 coastal developing countries have RBF programs (Jardine and Sanchirico, 2012; Figure 3), and roughly half of the worldwide value of catch comes from regions where legal and capacity barriers currently prevent the implementation of RBFs (Diekert et al., 2010). Much work is needed to implement the legislation that will enable RBF programs and build the capacity and governance structure on the ground to allow RBF management to be effectively designed and to work (FAO, 2015). Where enabling conditions do exist, efforts by international institutions are leading the way to train policymakers and fisheries managers in RBF approaches. For example, a recent joint workshop on capacity building for fisheries management sponsored by The World Academy of Sciences, the American Association for the Advancement of Science, and the Environmental Defense Fund brought together participants from Belize, Brazil, Chile, Cuba, Mexico, and Peru (for more information, see http://twas.org/article/helping-small-fisheries-prosper). Additionally, the global master's degree in communication offered by the University of Texas at El Paso and Rare currently trains more than 50 local leaders in seven countries to launch TURF-Reserves as part of the Fish Forever program (Box 3). Once proven effective under multiple conditions, this curriculum can be delivered through e-learning platforms and alternative, lower-cost training providers.

FULLY PROTECTED MARINE RESERVES

Fully protected marine reserves (MRs) are widely recognized as a powerful tool to protect biodiversity. Well-designed, permanent, enforced MRs result in long-term increases in species abundance, biomass, and whole-community diversity (Lubchenco et al., 2003; Lester et al., 2009). A range of studies also indicates that benefits of MRs exceed those of MPAs that are only partially protected (Lubchenco et al., 2003; Lester and Halpern, 2008; Sciberras et al., 2015).



COUNTRY	NO. OF SPECIES
New Zealand	117
United States	117
Australia	106
Chile	78
Canada	64
Russian Federation	55
Iceland	22
Denmark	18
South Africa	12
Japan	12
Norway	11
Mexico	9
Netherlands	9
Portugal	8
Italy	8
Sweden	6
Namibia	6
Argentina	5
United Kingdom	4
Sri Lanka	4
Estonia	3
Latvia	3
Lithuania	3
Spain	2
Solomon Islands	2
Peru	2
Poland	2
France	2
Cook Islands	1
Papua New Guinea	1
Vietnam	1
Vanuatu	1
Samoa	1
Greenland	1
Malta	1
French Southern Ter.	1
Morocco	1
Croatia	1
Falkland Islands	1

FIGURE 3. Map of global RBF programs, with gradation by the number of species managed through RBF plans by country. Data are from Environmental Defense Fund's Fishery Solution Center database, http://fisherysolutionscenter.edf.org/database.

Well-designed MRs may enhance fisheries through spillover of juveniles and adults and export of larvae (Halpern et al., 2010; Harrison et al., 2012), especially when multiple marine reserves are implemented as an interconnected network (Gaines et al., 2010). An empirical demonstration of the benefits of MRs for fisheries comes from southern Belize, where the Government of Belize and stakeholders created the Gladden Spit and Silk Cayes MR adjacent to the fishing grounds for the mutton snapper fishery (Granados-Dieseldorff et al., 2013). With the establishment of this MR in 2000, annual abundance, individual sizes, and sex ratios in the mutton snapper fishery recovered from a pre-1999 crash in annual catch and were stable through 2011 (Granados-Dieseldorff et al., 2013). These benefits have been found in recreational fisheries as well: the number of world records for game fish has been increasing since the 1970s in the areas adjacent to the fully protected Merritt Island National Wildlife Refuge in Florida (Roberts et al., 2001). In addition, because protected areas have larger, more fecund individuals, MRs can help increase resilience of populations of harvested species during extreme climate events (Micheli et al., 2012).

Despite the documented ecosystem benefits of well-designed and enforced MRs, ocean ecosystems are still minimally protected: less than 1% of the global ocean area is strongly to fully protected,[2] and most of that is within a few very large strongly protected areas in the Pacific where human population is low (Thomas et al., 2014). The low coverage of coastal MRs is largely a reflection of opposition to MRs by many coastal ocean users. Opposition has resulted from a variety of sources, which include user conflicts close to shore, top-down imposition of MRs and MPAs without community input (Christie and White, 2007), and loss of fishing grounds without direct benefits to compensate for short-term lost revenue (Smith et al., 2010). The impact of MRs on fisheries is dependent on the design of the reserves and the characteristics of the target species (mobility, dispersal, and demography; Hilborn et al., 2004; Oracion et al., 2005; Gaines et al., 2010). The diverse MRs that have been implemented do not have uniformly positive social and economic impacts. Negative social or economic impacts often result from imperfections in the design or implementation of the MR (Mascia et al., 2010; Fox et al., 2012). Additionally, MR implementation can potentially disrupt deeper cultural and philosophical views on traditional practices of open-access fishing and the ownership of common pool resources (Oracion et al., 2005). A challenge with MRs is that the short-run reductions in catch due to loss of fishing grounds are often borne by existing fishers (Smith et al., 2010), and the long-run benefits are likely to be captured by other fishers. Even well-known MRs may be fished, due in part to lack of funds for enforcement, and also the common lack of any incentive for fishermen not to fish inside them. Thus, MRs alone are commonly not a comprehensive solution for the recovery of depleted fisheries and need to be coupled with other efforts to reform the fishery itself.

[2] The scientific and policy literature and this paper distinguish between "fully protected" (no-take) and other types of MPAs that are only partially protected. Recent events suggest another category of use may be appropriate to consider. The Pacific Remote Islands Marine National Monument is a very large set of MPAs that forbid commercial fishing, mining, and extraction of oil and gas, but allow subsistence and recreational fishing. However, because these areas are so remote, with no indigenous inhabitants and virtually no current residents, even though fishing is allowed, it rarely occurs. We call these areas "strongly protected" to acknowledge they are not, strictly speaking, "fully protected," but they are functionally more like "fully protected" than other types of MPAs.

Box 3. Fish Forever, a Collaborative TURF-Reserve Pilot Program

Building on the success of TURF-Reserve management, projects like Fish Forever are bringing creative, science-based solutions to vulnerable communities most affected by overfishing and degradation. A collaboration between scientists from the University of California, Santa Barbara, and the nonprofits Environmental Defense Fund and Rare, Fish Forever works with local communities in small-scale fisheries to implement a customized, context-dependent suite of solutions, with TURF-Reserves as a central theme. In addition to guaranteeing exclusive spatial access to fishing grounds (TURFs) and establishing paired fully protected marine reserves ("fish recovery zones"), Fish Forever also focuses on six other key components to success: (1) scientific monitoring of biological and fishery status before and after TURF-Reserve implementation (Lundquist and Granek, 2005), (2) building strong community support for the TURF-Reserve (Gutiérrez et al., 2011), (3) involving communities in design, implementation, surveillance, and enforcement of TURF rights and protection of the reserve (Byers and Noonburg, 2007), (4) linking local fishers and broader markets via development of technology and infrastructure, (5) aiding local fisheries managers with a suite of science-based, adaptive fisheries management toolkits that can be applied even in settings where little data are available (Fujita et al., 2014), including Fisheries Landscape and Goal Setting Toolkit, TURF-Reserve Design, Marine Reserve Evaluation and Design, and Adaptive Fisheries Assessment and Management, and (6) incorporating TURF-Reserve practices into fishery management policies at the appropriate governance levels in respective countries. Projects with these elements have been established in Belize, Brazil, Indonesia, Mozambique, and the Philippines. See http://www.fishforever.org for more information.

PAIRED TURFS AND MARINE RESERVES: TURF-RESERVES

If RBFs promote long-term stewardship and economic gains and MRs provide spillover benefits and a conservation buffer for imperfect management as well as protection of biodiversity and ecosystem functioning, it is natural to ask whether their combination achieves synergistic benefits. For many coastal fisheries, this could be accomplished by pairing TURFs with MRs, or "TURF-Reserves," where secure tenure access rights to the areas adjacent to MRs potentially allow fishers to capture reserve spillover and larval export. TURF-Reserves have received recent attention in the literature (Costello and Kaffine, 2010; Costello, 2012; Afflerbach et al., 2014; Yamazaki et al., 2015). Bioeconomic models in particular have been crucial to setting the stage for developing TURF-Reserves, with the flexibility to explore impacts of TURF-Reserves before implementing pilot programs. Modeling results are striking: setting aside 20% of a coastline as an MR can theoretically maximize net fishery profit under certain circumstances (White et al., 2008). From modeling results for fin fisheries on the Great Barrier Reef, a fishery does better when an MR is established, when evaluated using both economic and conservation targets, and there is a wide range of complementarity between reserves and rights-based approaches for this fishery (Little et al., 2011; Yamazaki et al., 2015). Costello and Kaffine (2010) imposed an MR on a TURF system using a bioeconomic model that incorporates larval dispersal to connect sites. In this modeled fishery, the effect of MRs on fishery profits depend strongly on whether TURF fishers fully share total profits—a result that can help in the design and implementation of paired TURF-Reserves by considering the effect of owner cooperation on the benefit of reserves (Costello and Kaffine, 2010).

Beyond optimization of fishery profits, a wide class of other socially desirable benefits may result from properly designed TURF-Reserve systems. These potential benefits can be grouped into seven categories for consideration.

1. Previous research shows that community-initiated MRs could emerge naturally in a TURF system where fishers with tenure rights coordinate and close certain areas to enhance fishing profits (Costello and Kaffine, 2010; Ovando et al., 2013).
2. Because TURFs could allow creation of "private" MRs through control of spatial tenure rights, conservationists or ecotourism operators could manage a TURF and turn it into an MR, potentially circumventing the long and costly political process of implementing an MR in highly contested waters.
3. On the other hand, when the movement of fished species connects TURFs, there may be an economic incentive to overharvest each TURF, because fishers suspect that "their" fish will be harvested elsewhere. In this case, a TURF-Reserve system could be designed with reserves acting as buffers between TURFs (Costello and Kaffine, 2010). Carefully designed TURF-Reserve networks will facilitate scaling beyond individual communities.
4. Alternatively, if TURFs are explicitly paired with an adjacent MR used to generate tourism revenue, fishers could be offered a share in the profit from the tourism, thereby potentially reducing opposition to reserve implementation (Sala et al., 2013). Although this benefit only works if the MR generates sufficient revenue, there is evidence to suggest a high value of tourism in MPAs (Gravestock et al., 2008). From a simulation of the Medes Islands MR, Spain, the value of the ecosystem doubled with reserve implementation, due more to tourism revenue than to fishery profit (Sala et al., 2013).
5. MRs could also be used to replace some bycatch restrictions in multispecies ITQs by creating large reserves and eliminating bycatch accounting, observer programs, and the need for costly assessment and individual catch limits for minor stocks. The new RBF approach for the US Pacific groundfish fishery has incentivized fishers to cooperate and decrease fishing in key areas where the most depleted bycatch species are found, thus creating a type of industry-driven protected area (Holland and Jannot, 2012).
6. If each global Exclusive Economic Zone (EEZs) can be considered as spatial property owned by the adjacent country, then the high seas could be considered as under open-access management. As a thought experiment, consider EEZs as TURFs. In this case, closing the high seas to fishing would be analogous to implementing a global TURF-Reserve system, with large increases in fishery profits and fish abundance within EEZs following closure of the high seas (White and Costello, 2014). In January 2015, UN member states agreed to begin negotiations on high seas biodiversity protections beyond areas of national jurisdiction in coming years (UN BBNJ Working Group, 2015).
7. Finally, despite the positive fisheries management reforms, illegal, unreported, and unregulated fishing (IUU) continues to undermine legitimate fishing and threatens the effectiveness of MRs (Vincent and Harris, 2014). If TURF holders do not perceive sufficient benefits from the MR, they may have an incentive to harvest fish illegally from within the MR. However, well-designed and explicitly paired TURF-Reserves may decrease illegal fishing, as seen in the Belize TURF-Reserve program, emphasizing the importance of bottom-up, community-based engagement and use of scientific information in the design of TURF-Reserve programs.

The overarching message from the empirical and theoretical scientific literature is that a more widespread, intentional, and well-designed pairing of fisheries and MRs can help optimally achieve conservation, economic, and social goals.

Growing interest in TURF-Reserves in many parts of the world is based on the large body of scientific literature supporting both the fisheries benefits of MRs and showing the successes of TURFs. A recently compiled data set found 27 explicitly paired TURF-Reserves from 10 countries: Belize, Brazil, Chile, Fiji, Japan, Mexico, Philippines, Samoa, Spain, and Vanuatu (Afflerbach et al., 2014). In two-thirds of the TURF-Reserves, the TURF system was created before an MR was included, reinforcing the importance of theoretical studies like Costello and Kaffine (2010) that examine the consequences of adding MRs to existing TURFs of different forms. As implementation of TURF-Reserve pilot projects and full-scale programs continues globally, important next steps include rigorous scientific monitoring of the effects of these programs on biological, economic, and social targets, with a special emphasis on monitoring before, throughout, and after the transition to TURF-Reserve management (Fox et al., 2012). Because most of these programs are relatively young and understudied, such monitoring could inform the next generation of design and implementation, with the ultimate goal of adaptive management for long-term success. Fish Forever is an example of a collaborative, international effort to pilot and scale TURF-Reserve systems (Box 3).

A HOPEFUL OUTLOOK AND WAYS FORWARD

Despite anthropogenic pressures that have depleted fish populations at a global scale, altering food webs and driving biodiversity loss, several complementary strategies give us reason to be cautiously optimistic about the future ocean and its use by humans. Fishery reforms that mandate ending overfishing and rebuilding stocks using scientifically determined catch limits, carefully designed RBF management, and well-designed and enforced networks of MRs collectively can provide a potential path to healthier ocean ecosystems, sustainable fisheries, and food security for billions. TURF-Reserves pair a sustainable, alternative fisheries management strategy with the benefits of properly designed MRs or MR networks, and offer a way forward to maximize both fisheries and conservation goals. Recent analyses suggest that marine ecosystems have the capacity to sustain increased fish consumption through 2050, despite global population demands and climate change, but only if marine capture fisheries are sustainably managed and aquaculture is modified to be sustainable (Merino et al., 2012).

Given the promise of paired TURF-Reserve programs, emphasis should be placed on engaging both top-down (centralized government) and bottom-up (community) approaches to design, implementation, and management. Local communities can self-organize to great success, but the potential benefits may be muted and successes might not scale beyond local communities without: (1) legal authorities, prioritization, and facilitation on the part of national governments for RBF policies, (2) market engagement to build incentives for communities to adopt more sustainable systems, (3) experimentation and prototyping to determine the minimum viable approach over time (Fox et al., 2012; Box 3), and (4) scientific guidance to determine appropriate catch limits. Importantly, TURF-Reserves must have community support from the ground up and long-term economic self-sufficiency, as individual TURF-Reserves should ultimately function independent of government regulation and funding. Practitioners may be able to use pilot programs to estimate the potential economic benefits of TURF-Reserves and leverage expected increases in value to expand the creation of the TURF-Reserve system.

Collaborations around the world are providing promising solutions for the troubles of the global ocean, bringing together biologists and social scientists with fishers and local communities, and with governments and nonprofit organizations. Some of the most encouraging success is coming from fisheries reforms, alternative fisheries management approaches, and the pairing of spatial RBF strategies with MRs, especially for small-scale fisheries (FAO, 2015). With designs informed by science and support from local communities and national governance, TURF-Reserves are paving the way to maximize economic, social, and environmental wins globally.

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