The right incentives enable ocean sustainability successes and provide hope for the future

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Healthy ocean ecosystems are needed to sustain people and livelihoods and to achieve the United Nations Sustainable Development Goals. Using the ocean sustainably requires overcoming many formidable challenges: overfishing, climate change, ocean acidification, and pollution. Despite gloomy forecasts, there is reason for hope. New tools, practices, and partnerships are beginning to transform local fisheries, biodiversity conservation, and marine spatial planning. The challenge is to bring them to a global scale. We dissect recent successes using a complex adaptive-systems (CAS) framework, which acknowledges the interconnectedness of social and ecological systems. Understanding how policies and practices change the feedbacks in CASs by altering the behavior of different system components is critical for building robust, sustainable states with favorable emergent properties. Our review reveals that altering incentives—either economic or social norms, or both—can achieve positive outcomes. For example, introduction of well-designed rights-based or secure-access fisheries and ecosystem service accounting shifts economic incentives to align conservation and economic benefits. Modifying social norms can create conditions that incentivize a company, country, or individual to fish sustainably, curb illegal fishing, or create large marine reserves as steps to enhance reputation or self-image. In each example, the feedbacks between individual actors and emergent system properties were altered, triggering a transition from a vicious to a virtuous cycle. We suggest that evaluating conservation tools by their ability to align incentives of actors with broader goals of sustainability is an underused approach that can provide a pathway toward scaling sustainability successes. In short, getting incentives right matters.

complex adaptive systems | conservation solutions | fisheries | rights-based fishery management | marine reserves

The grand challenge for humanity is to meet the basic needs of people in an equitable manner today while simultaneously restoring and maintaining ecosystem functioning for future generations. We must do so in the face of growing numbers of people and the concomitant need for resources, and with environmental changes, such as climate change, already underway. The ocean is integral to this global mission. Ocean and coastal ecosystems provide a range of critical ecosystem services that people depend upon, such as food, oxygen, climate regulation, control of pests, protection from storm surges, recreational opportunities, and cultural value (1, 2). The ocean is home to rich biodiversity and plays key roles in many global processes, from primary production to nutrient cycling to climate and weather (3).

Ocean-based activities and livelihoods are both enabled by and affect complex interactions among ecological, social, and economic systems. The global market value of marine and coastal resources and industries is estimated at $3 trillion per year (4). Over 3 billion people depend upon the oceans to provide their primary source of protein, and marine fisheries directly or indirectly employ over 200 million people (4). Other benefits, such as cultural or inspirational values, are harder to quantify but nonetheless essential. The pervasive importance of the ocean to human well-being led the United Nations to identify an explicit Ocean Sustainable Development Goal when it crafted its highest priority areas for the 2015–2030 agenda (5).

Many of the over 150 coastal nations, especially developing ones, are taking a fresh look at the ocean for new opportunities for economic development, poverty alleviation, and food security. The significant promise of this so-called "Blue Economy" (6, 7) will be realized and continued only if activities are actually sustainable. A rush to exploit ocean resources could repeat or even exacerbate mistakes of the past, eroding the resilience of ocean ecosystems and causing long-term economic and social harm.

Prospects for the Ocean: Doom and Gloom?

The challenges of achieving the Ocean Sustainable Development Goal targets are immense. Overfishing, habitat loss, and pollution (8) have depleted and disrupted ocean ecosystems, threatening economic, social, and environmental benefits. Global-scale stressors, such as climate change and ocean acidification, exacerbate the effects of many more localized impacts. As a result, the ocean is becoming higher, warmer, stormier, more acidic, lower in dissolved oxygen (9), and more depauperate (10). These impacts pose significant challenges to the continued provisioning of ecosystem services from the ocean: challenges that may seem overwhelming now, but even more so in light of the difficulties in addressing the complex drivers and reversing trends. In short, threats to ocean life and the provision of vital ecosystem services are unquestionably serious and pressures on ocean resources are escalating.

Glimmers of Hope for Sustainable Use of the Ocean

Despite these daunting challenges, there is reason for cautious hope. Around the globe, many positive changes are underway: awareness, attitudes, and social norms are changing; economic incentives are shifting; efforts to educate consumers are increasing; new policies are leading to stronger mandates and more effective governance, compliance, and enforcement; and practices are changing with the development of better technologies, new products, and business strategies that reflect the circular economy (11), greater engagement of scientists, and improved understanding of trade-offs. As a result, effective models for change based in natural

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and social science are being developed and implemented by a diverse set of actors.

For example, robust progress has been made in: fishery reforms (12–14); community efforts that combine biodiversity protection with sustainable fishing (14); smart spatial planning in coastal regions to reduce conflict between different ocean uses and consider cumulative impacts (15); international collaboration to rein in destructive illegal fishing (16); and creation of large fully protected marine reserves (17), among others. These successes are encouraging. Although few of these reforms are currently implemented at the scale needed to influence the global trajectory, these models can empower communities, incentivize businesses, inspire leaders, improve human well-being, strengthen economies, and create a tsunami of change. A major question that remains is how to learn from, replicate, and scale up these successes.

The science underpinning these successful efforts reflects significant interdisciplinary progress in understanding the functioning of ocean ecosystems and the services they provide, the factors affecting human values and choices, and the deep connections across social, economic, and ecological systems: for example, through ecosystem services (2), planetary boundaries (18), and telecoupling (19).

A Complex Adaptive System Perspective: The Theory

Replicating and scaling-up ocean conservation successes will require a deeper understanding of the elements that confer success and the impediments that prevent progress. The idea that ocean ecosystems are complex, adaptive, and interconnected with social and economic systems is a central tenet. Rather than separate systems, ecological and social systems can be viewed as a single, coupled system integrated through connections and feedbacks (20, 21).

These coupled systems fit into a more general category of complex adaptive systems (CASs): systems where the behaviors of individual actors at the local scale influence interactions and emergent properties at the regional or global scale (22). Emergent properties, in turn, can feed back to the small scale and influence subsequent behaviors of the individuals. Although these actors may largely act independently, the collective effect of individual behaviors influences the larger-scale properties such that actors adapt to the changing conditions of the system context (23).

One insight emerging from a CAS framework is that the goal of management—and a major departure from previous approaches—should be to enhance robustness and resilience of the system, rather than trying to control the system state itself (23–25). CASs display nonlinearities, slow feedbacks, unexpected changes, tipping points, thresholds, and path dependence, which make it difficult to anticipate all responses of the system to management actions. However, management efforts that fail to embrace this complexity are less likely to succeed (21, 25). Importantly, CASs are distinguished by not only being complex, but also adaptive in that the individual components of the system adapt to the conditions of the larger system state. However, because such adaptation is at the level of system components rather than the system as a whole, it may actually undermine system robustness. Thus, the essential challenge in management is often to modify the incentives of individual actors in such a way that collective benefits are maximized. Achieving such outcomes is the focus of this report.

The adaptive responses of system components can either reinforce or thwart sustainable management (24). Insights from a CAS framework suggest that policies and practices that target feedbacks within the system and influence the adaptive behavior of system components at small scales could be particularly effective at changing the system state. For example, if the focus of management is on controlling the system state (rather than its robustness or resilience), regulators typically impose limits on the effort of individual actors (such as effort controls on fishers). This can create unpredictable or undesirable behaviors (26) [e.g., fishers creating innovative ways to bypass gear restrictions (24), leading to more overfishing]. Identifying where strong feedbacks between resource users and the emergent system properties lead to unsustainable system states can provide opportunities to shift these feedbacks toward reinforcing positive changes. Policies may be particularly successful if they enable actors to benefit individually while being aligned with collective benefits of the overall system.

A Focus on Incentives

Elements of CASs can be used directly to inform approaches to management and policy. Without diminishing the importance of the other features of CAS dynamics, we focus here on the nature of feedback loops and how incentives that drive behavior affect emergent properties of the system. We examine a few recent, successful projects to understand the characteristics that underpinned their success. A persistent feature that emerges is that the right change in incentives can motivate actors at multiple scales to alter their behavior to achieve more favorable outcomes. In particular, across numerous examples, incentives shifted from reinforcing behavior that supports unsustainable resource exploitation to those that support more sustainable use.

The incentives we discuss can be broadly categorized as either "economic incentives" or "social norms" affecting behavior, with the latter including both reputation-driven and personally motivated norms. Economic- and reputation-based incentives tend to be influenced and promoted by external actors, such as governments, industry, or consumers (27–29). They reinforce behaviors that enable individual actors to act in their self-interest in a fashion that also aligns their behavior with the larger goals of communities or society. Positive incentives (the "carrot" approach) are generally considered more powerful and durable than negative incentives ("the stick"). Personally motivated incentives tend to be primarily intrinsic and driven by a belief in what constitutes "correct" individual behavior (30). These types of incentives can also be motivated by the desire or need to be seen in a positive light and to maintain a particular reputation among peers or to oneself. Of course, what is deemed "desirable" may well be subject to social norms (28, 29).

Historically, incentives for using natural resources involved feedbacks that disregarded environmental impact, leading to the unsustainable use of common-pool resources driven primarily by self-interest of individual actors. Fisheries, for example, are classic common-pool resources in which individual incentives are inadequate to achieve the collective optimum. They exemplify what Hardin (31) called the "tragedy of the commons," whose maintenance could only be achieved through "mutual coercion, mutually agreed upon." For Hardin, governmental structures were essential in enforcing the required coercion. However, even strongly enforced fishery management may be insufficient if the short-term economic or social incentives for fishers favor increased exploitation (13).

In the tragedy of the commons, the initial—and often quite logical—actions of individuals unintentionally eroded robustness and resilience of the system, bringing diminished future social and economic benefit from what can be considered a "gilded trap" (32). Often, incentives stemming from policies are misaligned with environmental stewardship. Recent changes to policy, the recognition that business-as-usual is not profitable in the long-term, and the desire of nations and businesses to have a favorable reputation among their citizens and consumers, have collectively begun to support feedbacks that realign economic and conservation outcomes for sustainability.

Various alternative approaches to align conservation and economic incentives have been proposed and implemented.

Ostrom (see, for example, ref. 33) focused on one class of solutions: self-organization and self-regulation in small societies. Another approach seeks to align long- and short-term economic incentives for individual fishers through rights-based fishery (RBF) or secure-access systems. Others focus on modification of social norms, including reputation-based schemes. Here, we highlight the role that economic and behavioral incentives can play in helping to strengthen feedbacks that lead to desirable and sustainable systems. We focus on economic incentives in fisheries and coastal/ocean planning, and behavioral incentives through changing social norms for international policy, national actions, and business practices.

Economic Incentives and Fishing: Results and Lessons Learned

Because CASs have emergent properties driven by actions and self-organization of the individual components of the system, policies that change behavior of local actors have the potential to alter the system state significantly. Local actors, such as fishers, largely make decisions based on individual benefit. In open-access, race-to-fish fisheries, each fisher is motivated to catch the most fish, as soon as possible. In this case, the economic incentive, which is to make the largest profit by catching the most fish today, does not achieve the overall goal of maintaining fish populations at sustainable levels. Despite the best efforts of managers and enforcers, overfishing often results because the immediate economic incentive to fish remains strong.

In contrast, well-designed secure-access fisheries align individual economic and conservation incentives by providing fishers predictable access to a portion of the allocated harvest (either a share of the total allowable catch or an area in which to fish). This approach provides motivation for fishers to act as stewards of the resource and allows fished populations to increase (34). The switch to RBFs has seen successes at the local and national levels, further illustrating how this approach, if appropriately used, can be scaled to strengthen the feedbacks that lead to desired economic, social, and environmental outcomes (13, 35).

The United States, for example, has seen impressive turnaround in multiple fisheries as a result of both (*i*) strong national legislation—the Magnuson Stevens Fishery Conservation and Management Act Amendments of 1996 and 2006 (MSA), which required ending overfishing and rebuilding stocks through firm science-based annual catch limits and severe consequences for exceeding those limits—and (*ii*) a new policy finalized by the National Oceanic and Atmospheric Administration in 2010 to encourage and facilitate RBF management, called "catch shares," in appropriate United States fisheries in federal waters (14, 36–38). We discuss three examples of the results of these changes.

In the West Coast Groundfish Individual Fishing Quota (IFQ) fishery in United States federal waters, the changes have moved a disaster fishery to a model of fisher stewardship. Even after becoming a limited entry fishery in 1994, the economic incentives for individual fishers, coupled with insufficient understanding of the life histories of some species, favored overexploitation. The result was that in 2000, this multispecies fishery was declared a federal disaster after decades of overexploitation under conventional fishery management (39). The combined "stick" of the MSA, plus the "carrot" provided by the IFQ (a catch–share) program begun in 2011, helped turn things around.

The IFQ program removed perverse incentives associated with conventional management and realigned short-term and long-term incentives so they were no longer in conflict. Because fishers have a guaranteed fraction of the catch, they benefit directly from a well-managed, healthy fishery and are incentivized to ensure the catches are not too high, the ecosystem is healthy, and cheaters are not tolerated by their peers. In this case, new economic incentives reset social norms with positive benefits. The IFQ approach synchronized conservation and economic incentives such that fishers' economic interests coincide with the health of the fishery. Moreover, with the flexibility of knowing the amount of fish each shareholder can catch, fishers can plan their fishing season, make reasonable financial and business decisions, form risk-pools to minimize risk from catching non-target species, establish new no-fishing zones, and fish under safe weather conditions. The secure access lowered the perverse incentive to race-to-fish that was harmful to fish stocks and habitat and it provided more predictable financial security and more stable access to the market. Since the IFQ has been implemented, fishers have seen reductions in bycatch and depleted species (14) and increases in fishery profits (40), and scientists have documented recoveries of many of the species associated with the fishery (38), often significantly faster than projected.

The biological results from implementing catch limits together with the flexibility and innovation allowed by IFQs have been dramatic, with 7 of the 10 overfished species of groundfish now rebuilt, or nearly so (41, 42). In addition, 14 species from this fishery are now certified as "sustainable" by the Marine Stewardship Council (MSC) and nearly 40 are rated "best choice" or "good alternative" by the Monterey Bay Aquarium's Seafood Watch certification program (43).

The Gulf of Mexico commercial red snapper fishery provides another about-face fishery recovery in the aftermath of MSA reforms and adoption of catch shares. On the brink of collapse after decades of overfishing, the commercial fishery was converted to RBF management in 2007. Since then, the spawning potential has tripled, discards have dropped more than 50%, catch limits have more than doubled, revenue is up 70%, the fishery is safer, and its rating by the independent Monterey Bay Aquarium's Seafood Watch certification program has improved from "avoid" to "good alternative" (44, 45).

In striking contrast, the recreational fishery for individual anglers catching the same red snapper in the Gulf of Mexico continues to be managed under conventional approaches, with incentives remaining short term. For many years, the recreational red snapper sector overshot its catch limits, resulting in the scheduled fishing season dwindling to less than 2 wk in 2016 (46). Interestingly, the subsector of for-hire boats for recreational fishers is moving in the direction of the commercial fishery by adopting RBF approaches to management to fish sustainably throughout the year (47, 48). In its first year in 2014, an RBF pilot program for headboats showed a 114% increase in fishing trips, while reducing red snapper and gag grouper discards by 43% and 59%, respectively (49). Tensions across the different groups are high, politics are complex, and management is continually challenged. Nonetheless, the improved economic and environmental outcomes that followed adoption of RBF management for the commercial fishery provide powerful evidence of the merits of altering incentives.

In light of these and other successes (37), why are RBF systems often controversial and sometimes difficult to initiate? What lessons have been learned about unanticipated feedbacks created by RBF, both positive and negative? One reason these systems can be controversial is that they are relatively new as a fishery management tool. Another is that a number of early RBF systems had what are now understood to be flaws in the design of the rules governing that particular RBF, such as quotas based on fixed landings, rules that allowed consolidation of quota by a few quota holders, or insufficient mechanisms to ensure accountability. Newer RBFs, like the examples above, have incorporated lessons learned from previous experiences, contributing to their successes.

However, even a well-designed RBF system has challenges that must be overcome to be adopted and succeed. Some of the biggest impediments include controversies around the initial allocation of quota. In addition, if stocks are already significantly

depleted, reductions in catch are necessary to rebuild stocks regardless of the management system. Moreover, warmer waters and other impacts of climate change may introduce new stresses on fished populations, fishing communities, and ecosystems (50).

A catch–share program in the New England groundfish fishery has had mixed results. Some species are at record high abundances, but overfishing continues in several others (41). Weak accountability, including low levels of monitoring, continued from the previous command-and-control system to the new catch–share system, resulting in on-going cheating. In addition, historic overfishing and unprecedented warming of the Northwest Atlantic have resulted in slow recovery and changing baselines for some of the iconic, high-profile stocks (50).

Multiple lessons emerge from these collective experiences. The design of a catch–share program matters. Accountability by fishers and good monitoring are key. Transition, implementation, and compliance costs are real and must be dealt with, ideally from the outset. Allocation must be sensitive to a range of considerations, including equity. The West Coast IFQ groundfish fishery and the Gulf of Mexico red snapper commercial fishery RBF programs both took years to design, and benefited from abundant earlier lessons. And all fisheries must be managed in light of escalating impacts of climate changes and ocean acidification.

Today, fisheries overall in the United States are improving dramatically (36–38). Around 65% by volume of the fish caught in United States federal waters are under a RBF fishery management system (51). The overall effectiveness of management, and resulting condition of fish stocks, is high and improving each year, with a dramatic decrease in overfished stocks and continuing strong improvements in the federal fish stock sustainability index (51, 52). RBF management continues to make an important contribution to this turnaround.

At the global scale, today there are over 200 RBFs covering over 500 species in 40 countries (53). After 40 y of trial-and-error, RBFs are now gaining traction as the benefits of changing incentives for fishers become better known and are realized, and as lessons accrue about how to tailor the design of any particular RBF system to meet a combination of social, ecological, and economic goals. RBFs are also recognized as an effective pathway to eco-certification (54). RBFs are not a panacea, and each must be designed appropriately for the local conditions. Good science and strong community engagement are essential to enable the success of the RBF approach, including setting appropriate science-based catch limits.

Another form of secure-access fishery management is with territorial-use rights in fisheries (TURFs). TURFs are used increasingly, especially in developing countries, and are leading to beneficial outcomes for fishers because they create or strengthen feedbacks that lead to sustainability. TURFs assign spatial fishing rights to individuals or communities and provide fishers with secure access to a portion of the total fishery.

Recent work in Belize (55) has shown that when TURFs are paired with marine reserves (i.e., areas where no fishing or other extractive activities are allowed), fishers can take advantage of the spillover of fish from the reserves. This process leads to increases in catch and profit while also conserving important habitat and providing a refuge for fish (55, 56). Known as a TURF-reserve, the pairing of secure-access fishing rights with marine reserves creates economic incentives for fishers to be stewards of their own fishing area, not overfish, and reduce illegal fishing. Following implementation, Belize saw a 60% decline in violations of fishing regulations (56). In addition, the TURF-reserve strengthens personally motivated incentives for ocean stewardship by sustaining cultural values, as well as community and individual pride in maintaining fisheries as a livelihood. Based on the pilot program success, the Belizean government recently implemented a national RBF program for small-scale fisheries (57). User input in the design of the rights-based management scheme was an essential element of success.

Incentivizing Planners, Managers, and Policy Makers

Aligning short-term incentives with long-term goals of improved environmental, social, and economic outcomes can begin with a demonstration of the potential for change and an exploration of trade-offs or new ways to build incentives. We highlight three recent examples that envision a future system state and quantify the potential economic benefits.

Costello et al. (35) recently reported that reforming fisheries management using RBF approaches could result in annual increases of over 16 million metric tons in catch, US $53 billion in profits, and 619 million metric tons in fish biomass in the ocean, compared to business as usual. Appropriate reforms could also lead to a median recovery time of under 10 y for most fisheries. By exploring the transition of fisheries to secure-access management, Costello et al. showed that the associated economic incentives can benefit individual fishers and industry, as well as align with the societal interest of restoring and sustainably managing fish stocks. Analyses such as this provide a powerful incentive for governments and fishers to tackle the difficult business of fishery reform by making the path to a desirable system state more visible. But a compelling rationale is only the starting point. Realizing potential benefits is not easy and requires: sustained political leadership to reform policies; the strong engagement of fishers, fishing communities, and concerned citizens; the availability of financing for transition costs; scientific capacity to determine catch limits; and adequate catch accounting, compliance, and enforcement.

Shifting economic incentives to synchronize with conservation goals is also relevant to coastal development. Ecosystem services provide a framework that allows managers, developers, policymakers, and stakeholders to examine the trade-offs between development and conservation. Recently, the government of Belize worked with scientists to develop the Belize Integrated Coastal Zone Management Plan (58), based on a systematic analysis of the trade-offs between the development of the fisheries and tourism sectors and the ecosystem services provided by three key habitats: corals, mangroves, and seagrasses (59). The process entailed quantification of certain ecosystem services (coastal storm protection and provision of habitat-supporting fisheries) offered by intact habitats. Through robust scientific methods and strong engagement of the local community, the project ensured that stakeholders' concerns were incorporated through the process, resulting in a well-supported and comprehensive plan leading to greater returns on both conservation and development. The plan has been endorsed by the government and is in the process of adoption at the national level (60).

Innovative conservation strategies are also beginning to use economic incentives that engage new actors and stimulate novel feedback pathways. Debt-for-nature swaps originated in the 1980s as a way to reduce foreign debt in exchange for the protection of land (61). Whereas this approach has been widely applied to terrestrial systems, with mixed success, only recently has the model been adapted for marine conservation. In 2015, the Republic of Seychelles, a country comprised of 115 small islands with 99% of its total area in the ocean, exchanged US $27 million worth of debt for (*i*) increasing marine protection of its exclusive economic zone (EEZ) from less than 1% to 30% (400,000 km^2) (62) through the creation of the second largest marine protected area in the West Indian Ocean, (*ii*) creating and implementing a marine spatial plan for the whole EEZ, and (*iii*) creating a climate adaptation fund (63). The debt-for-nature swap allows the Seychelles to invest in its own local coastal economy—fisheries and tourism—rather than sending the money to other countries to cover debt. This arrangement allows investment in nature as a viable development strategy.

Behavioral Incentives and Social Norms

Although economic incentives play an important role in driving behavior, they are only one means of effecting change. Altruism, ethical values, reciprocity, and other types of intrinsic motivation can also be powerful drivers of change unless they are undermined by perverse economic incentives (30, 64). Reputation and self-image can lead individuals, businesses, organizations, and governments to engage in activities that support sustainability (28). Personally motivated incentives, driven by self-image and intrinsic motivation, lead individual actors to do good because it allows them to derive personal satisfaction (29).

Both reputation and self-image of individual actors reflect larger social norms and values. Thus, shifts in social norms are key to aligning associated incentives with desired sustainability outcomes. A wide variety of actors, including civil society, scientists, faith communities, businesses, nonprofit organizations, and governments can condition the social climate for change through education. Governments, civil society, and businesses can build on this awareness and use "naming and shaming" approaches to reward desirable or dissuade undesirable behaviors. Stockholders and employees can demand change from businesses; businesses can carve out a niche as a leader; consumers can influence vendors to deliver more sustainably caught or produced goods.

Reputation. Two examples of reputation-based incentives that are beginning to change behaviors globally are the 2009 Food and Agriculture Organization (FAO) Agreement on Port State Measures to Prevent, Deter, and Eliminate Illegal, Unreported, and Unregulated Fishing (PSMA) and the European Union's issuance of warnings and trade sanctions to countries with unsustainable fisheries behaviors. Both tools help combat illegal, unregulated, and unreported (IUU) fishing, which is reported to create as much as US $23.5 billion in losses annually, directly impacting the health of fisheries and the seafood market where IUU fish are sold (65). When IUU fish are profitable, incentives to fish legally are undermined, law-abiding fishers are penalized in the marketplace, and managers have difficulty managing fish stocks effectively. Depleted stocks lead to more restrictive management, which increases the incentive to fish illegally and creates a negative feedback (66). Moreover, much of IUU fishing involves highly destructive fishing gear and little regard for the well-being of crews or accidental observers, if not outright slave labor. However, recognition that IUU fishing has negative consequences for fishers, the health of fisheries, and human rights has resulted in a global call to action to fix the problem.

The PSMA is an international voluntary agreement to harmonize port state standards that promote cooperation and prevent IUU boats and fishers from accessing ports and onshore markets (16). Not only does this agreement create direct economic disincentives for fishers to IUU fish because their catch can no longer access markets and their boats may be seized, it also incentivizes those who catch, process, distribute, and sell fish. It builds support for global collective action to address IUU fishing by building solidarity among states that have ratified the agreement and by putting pressure on nonadhering governments. In May 2016, the United Nations FAO announced that the requisite number of countries (>25), representing >62% of worldwide fish imports and >49% of fish exports, have formally agreed to adhere to the PSMA. Thus, the world's first international agreement specifically targeting IUU fishing entered into force on June 5, 2016 (67). By mid-September 2016, more than 60 countries were on board.

The European Union has also implemented strong anti-IUU measures by issuing warnings and trade sanctions—known as "yellow cards" and "red cards," respectively—to disincentivize countries from IUU fishing. For example, Thailand was issued a yellow card in 2015 because it had taken insufficient action over the previous 5 y to effectively monitor or control IUU fishing, and lacked appropriate sanctions for those who engaged in IUU fishing (68). However, the threat of trade sanctions with the European Union incentivized Thailand to reform its fisheries policy, or at least to be seen as doing so. Yellow cards and red cards have been effective in combatting IUU fishing in other countries. Korea and the Philippines were issued yellow cards in 2013 and 2014, took appropriate measures to reform their fisheries systems, and were issued a "green card" after making policy and legal changes to stop IUU fishing.

The PSMA and the European Union carding system leverage the desire of countries to be seen by peers and citizens in a positive light, doing the "right thing," and contributing to the greater cause of stopping IUU fishing. The carding system illustrates how different types of incentives can have an additive effect by leveraging economic disincentives of trade sanctions on top of the shaming associated with being carded. Both are examples of incentives that represent a cross-scale feedback: a change in policy at the national level affected the behavior of local actors, whose actions in turn supported the policies in place.

Reputation-based incentives can also apply to businesses and industry, where reputation affects building and maintaining a consumer base and supply chain. An example of reputation-based incentives that also aim to improve fisheries sustainability in the business sector has been the pledge by large retailers to source only seafood products certified as sustainable. In 2006 Walmart, the world's largest retailer, announced it would transition toward all MSC-certified seafood in North American markets by 2011 (69). Walmart later added fisheries "actively working toward certification or involved in a Fisheries Improvement Project" (70). Subsequently, other large fish sellers, such as Costco, Whole Foods, and Target followed suit. Now more than 80% of North American retail and institutional food service enterprises have seafood sustainability policies in partnership with environmental nongovernment organizations (71). Such decisions by retailers are often motivated by the desire to promote a reputation as environmentally responsible. Independent certification provides credibility with consumers. Although these decisions reflect an emerging demand for sustainable products, reputation is an important incentive behind the transition to offering certified seafood products. Previous studies have shown that obtaining higher prices was not a major motivation behind decisions to carry certified products (72). Regardless of the efficacy of sustainable seafood certification programs (some of which have been controversial; see, for example, ref. 73), the adoption of certified seafood by retailers stems from to the desire of businesses to maintain reputation and gain competitive advantage (72). In addition, governments are increasingly requiring traceability of fishery products, strengthening PSMA efforts, and enhancing transparency for seafood buyers. Suppliers of sustainable seafood have struggled to keep up with overall demand, and these shortfalls could worsen with climate impacts (74).

Personal Motivation. Personally motivated incentives stem from an intrinsic desire of individuals to perceive themselves or be seen by others in a certain way. This type of motivation can also apply when groups of actors work together to achieve a goal, creating a sense of camaraderie and shared investment that drives behavior. Even the perception of collective behavior can act as an incentive. Personally motivated incentives can be strong drivers for positive change if they align with a sustainable, desired system state. However, the use of economic incentives can undermine personally motivated incentives if the latter are altruistic, as in a classic case where offering blood donors money decreased the likelihood that they would donate blood (75).

At the national level, desire to leave a legacy can motivate leaders to take action. For example, designating large marine reserves might be motivated in part by self-image and legacy considerations. Marine reserves (fully protected areas) have clear ecological benefits, provide strong economic and social benefits (e.g., potential for increased fisheries yields, opportunities for ecotourism, and protection of cultural heritage) (14, 76, 77), and can be seen as a gift to future generations. However, because they are generally lobbied strongly against by powerful extractive industries (fishing, oil, gas, and mining), their designation has been very difficult. Despite calls by the conservation community for increased ocean protection, the global area protected remained at ∼1% of the ocean for decades, with only 0.1% as strongly protected (17). Scientific documentation of strong benefits from fully protected areas and increasing recognition of degradation of ocean ecosystems changed the dynamic and led to sophisticated campaigns to create large strongly protected areas. Once a few nations created large strongly protected areas and were widely praised for doing so, momentum grew for a new era of designating large, remote, strongly-to-fully protected marine areas. Many nations, including Chile, New Zealand, Seychelles, Ecuador, Palau, the United Kingdom, Cuba, Russia, and the United States have committed to protecting more of their EEZs, largely through the creation of large marine reserves. This process has led to a total of around 4.5% of the global ocean now committed to some kind of protection, with 2.6% announced to be strongly protected (17, 62, 78). Although still far short of the 10% Aichi Target 11, set as part of the United Nations Convention on Biological Diversity, there has been a greater than order-of-magnitude increase in strongly protected areas in the last decade, with nations announcing larger and larger marine reserves (17, 78). The pattern suggests friendly competition among global leaders for "the biggest marine reserve in the world." A related competition focuses on the fraction of a country's EEZ that is strongly protected. Palau leads, strongly protecting 83% of its EEZ; the United States is second, strongly protecting 25.7% of its EEZ, with the recent expansion of Papahānaumokuākea Marine National Monument in Hawai'i and the creation of the New England Canyons and Seamounts Marine National Monument in the Atlantic. Marine reserves can build national pride in protecting areas of cultural or biological importance and creating a legacy for future generations. Motivations may differ based on national context and culture, but research suggests that successful strategies for marine conservation build on stakeholders emotions about the uniqueness of an area and of pride and identity (79). The Our Ocean Conference, begun by US Secretary of State John Kerry in 2014, has provided an annual venue for world leaders to announce new such commitments (strengthening the competition), as well as a mechanism to ensure accountability (progress in achieving a commitment is expected in subsequent years) (62). Social norms around marine reserves have changed significantly as a result of new scientific information, greater public engagement, and a forum for leaders to make announcements.

The need to verify compliance and assist with enforcement of large marine reserves, coupled with the desire to tackle IUU, have created additional incentives for innovation around new technology platforms to "see" what is happening on the water, even in remote locations [e.g., with "Project Eyes on the Sea" (80) and the Global Fishing Watch (globalfishingwatch.org)].

Conclusions: Incentives Are Powerful Tools to Scale Up Successes

Incentives—positive and negative—are pervasive in driving the behavior of individuals, communities, businesses, and nations. As the world increasingly faces the delicate challenge of balancing population growth and development with the use of resources and environmental protection, it is imperative that these incentives facilitate rather than undermine sustainable trajectories. With recognition of the integrated nature of social and ecological systems, implementation of incentives can act as a linchpin, shifting feedbacks to alter behavior and emergent properties. Looking more deeply at recent conservation and management successes reveals that changing incentives can work on actors at multiple scales—from the individual to the global community—and can help to strengthen the feedbacks that support sustainability. Well-designed economic incentives help spur individuals to act in ways that support conservation and management efforts, while retaining important income and profit. Incentives based in social norms, both in the form of reputation and personal motivation, help drive behavior through the positive or negative consequences of actions seen through the eyes of others or oneself. Economic incentives and social norms can be strong enough to effectively work alone, but they often interact, sometimes positively and sometimes negatively (75). If economic incentives can be designed to reinforce and support incentives driven by personal motivation and reputation, there may be a "sweet spot" that allows mutual reinforcement, strengthening feedbacks that lead to sustainable resource use.

Beyond economic and personal incentives, it is also possible to incentivize change by creating tools and spaces where actors can envision a system state that benefits them while elucidating the behaviors needed to arrive at that state. In many resource systems, users are stuck in perverse feedbacks, where the best action for individuals in the short term is detrimental in the long term. By clarifying the links between changed behaviors and positive outcomes, resource users can better recognize how they can benefit, see their role in realizing those benefits, and be more likely to engage in behavior that leads to win-win outcomes.

Underlying the use of policies and practices that alter incentives for conservation is the understanding that within a CAS, collective action by individual system components can drastically change emergent system properties. Thus, the trick is to change incentives by finding sets of tools that are generalizable and scalable, work to disrupt feedbacks leading to undesirable system states, and reinforce feedbacks that make the system sustainable and robust. The examples highlighted suggest that certain methods may be especially effective for achieving goals across systems and resources, but also that the toolkit for shifting incentives is diverse. For example, RBF can break negative feedback loops, shifting incentives by allowing local actors to have secure access to a resource in ways that promote stewardship that benefits all. Emerging techniques for the management of marine resources, such as re-envisioned debt-for-nature swaps, can motivate actors at higher decision-making levels by creating new frameworks for conservation. Certification schemes for sustainable products make the environmental costs of unsustainable resource use more explicit, which in turn creates new incentives for businesses and producers to improve their image with consumers by offering products that minimize these costs.

Such examples highlight the importance of using a CAS framework to think about global problems tied to the ocean and the need for flexible and adaptive policies. Despite attempts to fully understand social and ecological systems, there will always be uncertainty that requires approaches capable of anticipating, detecting, and reacting to change. In a given situation, actors make decisions based on many incentives of different types, magnitudes, and sources. However, actors do not always act rationally, and small changes to the system state from external or internal sources may change incentives and behaviors significantly. For example, in a fisheries social-ecological system, incentives for fishers to comply with rules can decrease when stocks are at low biomass because of high variability and low credibility of stock assessments, which can cause further overfishing (81). Building policies that change incentives requires iterative actions on the

part of resource users and managers. Adaptive governance and comanagement, along with other existing frameworks, seek to solve this challenge of managing resources by allowing flexibility in policies, building decision-making at multiple levels, and reinforcing trust and dialogue. These frameworks also align with the idea of polycentricity (33), wherein some level of autonomy between resource users and managers can lead to better, more efficient management of common-pool resources.

A focus on changing incentives is not a new idea; in fact, many have examined the role of incentives in fisheries, conservation, and management (81–84). However, recognizing the extent to which incentives can be explicitly used to achieve outcomes related to biodiversity, ecosystem health, and sustainability, and highlighting the ways in which these incentives can be designed to shift specific feedbacks in social ecological systems, holds particular promise for conservation and management efforts in the ocean.

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