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Conservation Practice and Policy

The least-cost biodiversity impact mitigation hierarchy with a focus on marine fisheries and bycatch issues

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Abstract: *Least-cost implementation of the mitigation hierarchy of impacts on biodiversity minimizes the cost of a given level of biodiversity conservation, at project or ecosystem levels, and requires minimizing costs across and within hierarchy steps. Incentive-based policy instruments that price biodiversity to alter producer and consumer behavior and decision making are generally the most effective way to achieve least-cost implementation across and within the different hierarchy steps and across all producers and conservation channels. Nonetheless, there are circumstances that favor direct regulation or intrinsic motivation. Conservatory offsets, introduced within the conservatory first three steps of the mitigation hierarchy, rather than the fourth step to compensate the residual, provide an additional incentive-based policy instrument. The least-cost mitigation hierarchy framework, induced through incentive-based policy instruments, including conservatory offsets, mitigates fisheries bycatch consistent with given targets, the Law of the Sea, and the Convention on Biological Diversity.*

Keywords: biodiversity offsets, bycatch, conservation, fisheries, mitigation hierarchy

Jerarquía de la Mitigación de Impacto con Menor Costo con un Enfoque en Pesquerías Marinas y Situaciones de Pesca Accesoria

Resumen: *La implementación de menor costo de la jerarquía de la mitigación de los impactos sobre la biodiversidad minimiza el costo de un nivel dado de la conservación de la biodiversidad, a nivel de proyecto o de ecosistema, y requiere minimizar los costos a lo largo y dentro de los escalones jerárquicos. Los instrumentos políticos basados en incentivos que le otorgan precios a la biodiversidad para alterar el comportamiento de los productores y los consumidores y la toma de decisiones generalmente son la forma más efectiva para lograr la implementación menos costosa a lo largo y dentro de los escalones jerárquicos y en todas las vías de producción y conservación. Sin embargo, existen circunstancias que favorecen la regulación directa o la motivación intrínseca. Las compensaciones de conservación, introducidas dentro de los primeros tres pasos de conservación de la jerarquía de la mitigación en lugar de hacerlo en el cuarto paso para compensar el residuo, proporcionan un instrumento político basado en incentivos adicional. El marco de trabajo de la jerarquía de la mitigación de menor costo a través de los instrumentos políticos basados en incentivos, incluyendo a las compensaciones de conservación, mitiga la pesca accesoria de las pesquerías en consistencia con objetivos dados, la Ley del Mar, y la Convención sobre la Diversidad Biológica.*

Palabras Clave: compensaciones de la biodiversidad, conservación, jerarquía de la mitigación, pesca accesoria, pesquerías

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摘要: *以最低成本实现生物多样性影响分级减控, 是在项目或生态系统层面将既定水平的生物多样性保护成本降至最低, 这需要将级间及级内各步骤的成本最低化。激励性政策工具, 即价格化生物多样性以改变生产者和消费者的行为和决策, 通常是在级间和级内各步骤中以及在所有生产者和保护途径中实现成本最低化的最有效方法。但在某些情况下, 直接的监管或内在的动力会更奏效。在减控方案的前三个步骤中引入保护性补偿, 而不是在第四步中补偿其余无法消除的生物多样性影响, 可以提供一种额外的激励性政策工具。由激励性政策工具催生的最低成本分级减控方案, 包括保护性补偿, 可以减少渔业误捕, 与既定目标、《海洋法》和《生物多样性公约》一致。***【翻译: 胡怡思; 审校: 魏辅文】***

关键词: 保护, 分级减控, 生物多样性补偿, 渔业, 误捕

Introduction

The mitigation hierarchy for addressing development impacts on biodiversity provides an overarching framework to achieve conservation goals (BBOP 2012). The hierarchy was developed for habitat management (wetlands and forests) relative to development projects with close to irreversible impact. Its application is prescribed to proceed sequentially in 4 steps: avoid any impact; minimize unavoidable impact; restore biodiversity as much as practicable; and compensate residual impact (including through offsets). The first 3 steps are conservatory and applied on-site to the affected resource, and the final is compensatory and applied off-site on different, albeit comparable resources, as a measure of last resort. The assumption is that this sequence minimizes ecological risk across all steps, but the risk of failure is not negligible as shown by global biodiversity trends.

Most conservation projects are conducted within a fixed budget, and there is no guarantee that the mitigation hierarchy is least-cost or generates the best conservation outcome overall. In practice, the four steps (and types of action) may be considered sequentially during the ex-ante environmental impact assessment (EIA) needed for the authorization of a development project (e.g., highway, golf course) but are implemented simultaneously during construction. However, the needed offset could be provided beforehand through green banking.

In fisheries, conservation means sustainable use in the long-term, and an EIA is rarely requested. The mitigation hierarchy is never referred to as such, but the conservation approach to target and nontarget resources is similar. This approach (Fig. 1), overlays fishery-management reference values and measures on classic impact-mitigation representation. Measures, such as total allowable catches (TACs), gear controls (technology standards for minimization), effort controls and time-space closures (performance standards for avoidance), and fishing rights (incentive-based policy for avoidance and minimization), have been combined and progressively stacked to avoid overfishing and bycatch. In the case of critical habitat management, the process would be even more similar. Nothing in the Law of the Sea Convention (LOSC), however, impedes managers from applying hierarchy steps simultaneously, even though, logically, stocks cannot be restored before they fall below the maximum sustainable yield (MSY) (equivalent to the no net loss [NNL] mitigation hierarchy reference level).

We applied least-cost conservation across and within the hierarchy steps to marine fisheries bycatch reduction (Squires & Garcia 2014). We developed least-cost mitigation (cost-effective conservation) across and within all hierarchy steps to achieve a given conservation target in (Squires & Garcia 2014; Milner-Gulland et al. 2018) to regulated fisheries. We developed incentive-based policy to achieve least-cost implementation across and within hierarchy steps and across conservation channels for these same fisheries. We considered the importance of intrinsic motivation. We examined the last compensation step in the mitigation hierarchy relative to marine biodiversity conservation and fishery management within the Convention of Biological Diversity (CBD) and LOSC legal frameworks. Finally, we devised conservatory offsets as incentive-based policy in fisheries based on new fisheries examples.

Least-Cost Mitigation of Impacts on Biodiversity

Direct Regulation

Fisheries bycatch can be tackled through direct regulation, but direct regulation has disadvantages. For example, on the U.S. West Coast, trawlers harvesting groundfish produce bycatch of overfished species (Miller & Deacon 2017). Direct regulation, this fishery's traditional approach, lowered bycatch by restricting fishing locations (in, e.g., rockfish conservation areas and essential fish habitat) and period (fishery closures). It also minimized on-site bycatch through regulations that limit allowed bycatch quantities, such as limiting amount of bycatch per trip (performance standards) and prescribe gear types and designs (technology standards). Restoration of bycatch species is realized through stock rebuilding; no compensation for residual bycatch has been contemplated.

In another example, the Scottish North Sea demersal fishery targets cod (*Gadus morbua*), for which catch is limited through direct regulation, and other

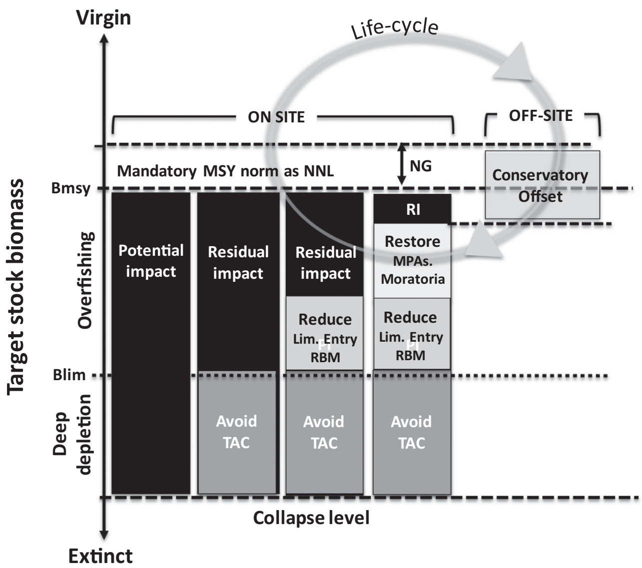

Figure 1. BIM hierarchy as applied in fisheries management. Bmsy, Maximum Sustainable Yield Biomass, is the NNL biomass level imposed by the LOSC. Blim is a precautionary biomass limit below which reproduction may be threatened. TACs, Limited Entry and Rights-Based Management were introduced sequentially in fishery management history. Conservatory offsets are recent and applied offsite but within the life cycle. Modified after BBOP (2012).

groundfish via bottom trawls and demersal seines with large mesh sizes. Juvenile cod taken over the mandatory quota are discarded. Cod bycatch from the Norway lobster (*Nephrops norvegicus*) trawl fishery further contributed to cod overfishing. Prior to incentive-based catch reduction, the fishery was directly regulated (Fernandes et al. 2011; Little et al. 2015) to minimize cod catch on-site through catch quotas assigned to individual vessels (performance standard) and gear restrictions (technology standards) and to avoid cod catch through a limited-entry program and European Union (EU) buyback of capacity. Restoration occurs through stock rebuilding, and no compensation is contemplated for residual bycatch.

Direct regulation has disadvantages associated with informational problems and limits on the ability to optimally engage all bycatch-reduction channels. It does not assign responsibility or impose costs on vessels for residual bycatch that may occur despite compliance with regulations. It implies only partial implementation of the polluter pays principle because vessels pay for compliance but not for residual damages occurring despite compliance. Thus, direct regulation shares conservation-related costs between vessels (for avoidance, minimization, and restoration) and unidentified stakeholders subjected to residual loss of biodiversity and environmental services and related risks. Regulation does not generate funds for compensation of residual damages from such losses; society bears the full cost.

By imposing the same standards on all vessels in and across impact-mitigation steps, irrespective of their level of bycatch, avoidance methods, and costs, direct regulation imposes a one-size-fits-all approach. Yet, skippers differ in their ability to adjust. For example, increasing bycatch avoidance through area closures may require longer travel to and search times in other areas with lower bycatch densities and lower target catch rates. The resulting rising incremental costs of avoidance could be reduced through improved gear selection and application and improved postcatch handling specific to vessel and skipper capacity. Direct regulation does not ensure fishers who could achieve bycatch goals at lower costs than regulatory costs do more. Because vessels do not bear the full social costs of fishing (which include the conservation costs of the residual bycatch), both the level of fishing and the bycatch to target catch ratio are higher than socially efficient. For these reasons, following all the mitigation-hierarchy steps to the maximum extent practicable to reduce bycatch through direct regulation is likely to fall short on several criteria the regulatory body may use to evaluate alternative policy approaches.

Conservation Costs and Diminishing Returns

Conservation measures have direct and indirect economic costs that, together, form total economic costs. Direct costs are directly attributable to the harvesting of fish or bycatch mitigation (e.g., labor, fuel, and gear). Indirect costs are not directly attributable to production and include some overhead costs and, importantly, opportunity costs (OC). An OC is a benefit a vessel could have received but gave up to take another course of action. An OC is often expressed as the difference between the expected return of each option. A vessel's OC of bycatch reduction is the net loss in a vessel's expected profit when the vessel's activity is changed to reduce bycatch (avoidance, minimization) in response to changes in expected mix and quantities of species harvested and even prices received due to changes in fishing areas, times, and methods. Additional direct and indirect economic costs of each additional unit of bycatch reduction, called marginal costs (MCs), tend to increase as conservation requirements increase, at least after some initial level of bycatch reduction, because the easiest bycatch-reduction opportunities are exploited first.

A second type of OC is associated with the resources committed to conservation when each additional unit of mitigation within any step increases conservation at the cost of committing additional conservation resources that could conceivably be used in the next best conservation step or alternative (e.g., for locally more intensive or geographically extended conservation). Both types of OCs are important in different contexts.

In a trawl fishery, skippers focus on target species and try to avoid unwanted bycatch, but their selectivity is unavoidably imperfect. To reduce expected bycatch of a particular species, skippers may be requested to avoid bycatch hotspots as soon as they detect them. More time—and hence labor services and fuel—may then be needed to search and fish in other areas. If the outcome is insufficient, the residual bycatch may be minimized further through gear modifications (e.g., bycatch excluder device), generating additional direct cost. After some level of bycatch reduction, total costs increase and incremental cost per additional unit of bycatch reduction (MC) can increase because the easiest and lowest cost measures are usually implemented first.

In a pelagic longline fishery, Tori lines minimize seabird bycatch and create a direct cost. Weighted branchlines and underwater setting further minimize expected residual bycatch but require new equipment, adding to direct costs. Methods of discharging offal, unwanted fish, and dying bait blue entail additional direct costs but minimize residual bycatch further. Again, after some level of bycatch reduction, total costs increase but MCs should as well because the easiest and least costly bycatch-reduction measures are exploited progressively.

Avoiding bycatch through time and area closures raises direct costs and may raise OCs by lowering expected target catch and revenue. The skipper maximizing expected profits (balancing expected target catch rates and revenues with harvesting costs) or expected target catch first fishes in an area with the highest expected profits and target catch rates. Changing area for bycatch reduction can lower expected profits and target catch rates. Longer trips to areas with lower bycatch can also lower catch quality and hence prices that in turn lower expected revenue and profit. Net decline in expected profit forms an OC to bycatch reduction. Again, after some level of bycatch reduction, the MC due to OCs should rise after the easiest and lowest cost bycatch-reduction opportunities are exploited.

Gear modification minimizes expected trawl bycatch. Altering mesh size or shape to allow small fish to pass through has a direct cost and may lower expected target catch rates. Turtle excluder devices, a direct cost, lower expected shrimp catch rates. These declines in expected revenue and profit add an OC to mitigation-hierarchy step 2.

Operation modification, for example, minimizes pelagic longline seabird bycatch. Longlines are set at night, which may reduce expected profits and target catch. Similarly, setting tuna longlines deeper to minimize sea turtle bycatch can lower tuna catch and hence profits.

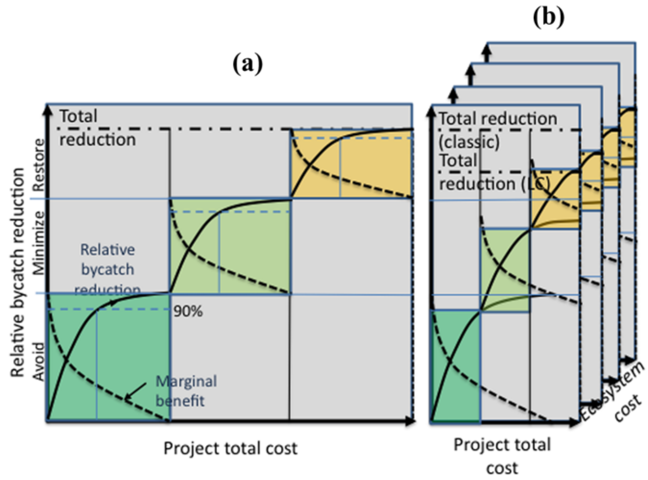

Figure 2. Optimal sequencing of mitigation of impacts to biodiversity: (a) classic sequential impact mitigation and (b) least-cost (LC) sequential impact mitigation. Stacked panels illustrate simultaneous conservation processes for higher-scale optimization.

Diminishing Conservation Returns

As the maximum effect expected in any mitigation-hierarchy step is approached, each additional measure generally results in a disproportionate increase in direct and indirect costs for each additional unit of bycatch reduction (MCs), reflecting the diminishing returns to conservation as each step is progressively pushed to its limit, and the easiest and least costly bycatch reduction opportunities are implemented first. This contention is based on first principles of economics.

Optimal Sequencing for Least-Cost Mitigation

Assume that in a single fishery development project, the mitigation hierarchy is applied sequentially. In each step, conservation (the percent reduction in potential bycatch that can be achieved in a step) increases toward some asymptote, whereas the benefit (percent bycatch saved per unit cost) decreases exponentially (Fig. 2a). In economic terms, the MC to fisheries (i.e., incremental cost paid per additional unit of conservation, e.g., bycatch reduction) increases exponentially. Beyond a certain MC, the risk of noncompliance increases rapidly.

In fully sequential mitigation (Fig. 2a), the sequence proceeds to the next step only when the maximum practicable conservation is obtained. In least-cost sequential mitigation (Fig. 2b), the sequence proceeds until an optimum level of conservation (mandated by a regulatory body) has been achieved in each step. Ideally, the shift occurs when the cost of the last unit of conservation for the fishers has reached the competitive bycatch price that accounts for the cost of all biodiversity loss given

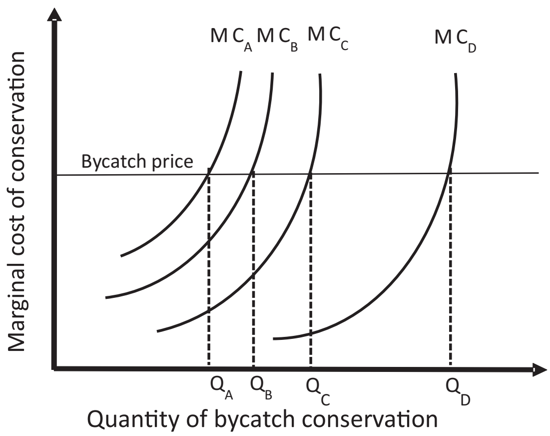

Figure 3. Least-cost mitigation of impacts on biodiversity across or within 4 steps of the mitigation hierarchy or across 4 agents or methods (A–D) of mitigation for bycatch price incorporating cost of biodiversity loss (MC, marginal cost; Q, quantity).

the bycatch target. Overall, bycatch is reduced at lower cost, and savings can be used to add mitigation in this or other fisheries, optimizing conservation at larger scale. Usually many conservation initiatives run in parallel, any savings in one may be usefully invested in others for overall systemic efficiency (Fig. 2b). These sectoral systemic gains are otherwise foregone (and hence a systemic OC) without least-cost impact mitigation.

The final (static) result of least-cost bycatch reduction that equates the rising MC from each hierarchy step to the common bycatch price for a target bycatch quantity (Fig. 3) is based on the implicit assumption that the order of each hierarchy step has been optimally followed to ensure least cost. In Fig. 3, the final least-cost bycatch reduction is illustrated across 4 channels (agents and methods or steps).

Suppose MC of avoidance exceeds MC of minimization for a prescribed bycatch level. In pushing avoidance further, too much is spent on that step that could be spent instead on minimization with better outcomes from a least-cost perspective. Then, lowering bycatch avoidance by relaxing a time or area closure and increasing minimization through a technology standard (e.g., circle hooks) can achieve the same bycatch reduction at lower direct cost (resulting from less fuel use). Lower net indirect costs result from lower foregone target catches if area and time closures are relaxed (i.e., OC is lower).

Incentive-Based Least-Cost Conservation

Bycatch reduction is more than a biological and technological issue. It entails changing producer behavior and decision making (Dutton & Squires 2008; Squires & Garcia 2014; Milner-Gulland et al. 2018). Incentive-based approaches, in which otherwise unpriced or underpriced bycatch are priced, can motivate producers to maximize their capacity and devise new methods to reduce bycatch. They facilitate least-cost application of the mitigation hierarchy within and between steps across all channels by allowing producers sufficient flexibility in choosing how to reduce bycatch (changing scale and mix or scope of production through avoidance and minimization); meeting mandatory bycatch requirements at least cost; and using information usually unavailable to a central regulator. They also incentivize producers who can reduce bycatch at lower costs to do more than they would under direct regulation.

Pricing bycatch thus alters producer and consumer behavior and decision making to account for the direct and indirect costs of bycatch that are not accounted for by market prices (i.e., external costs corresponding to the bycatch target). Then, in principle, every skipper has an incentive to use all bycatch-reduction channels within and across hierarchy steps until a vessel's MC of bycatch reduction equals the common bycatch price (corresponding to the target bycatch quantity), which creates least-cost bycatch reduction (Fig. 3). Some channels can achieve more bycatch reduction than others at the same MC by lowering the bycatch to target catch ratio (substitution effect) and reducing catch of both (lowering scale of production) by avoidance and minimization. The cost of residual bycatch (bycatch is typically not eliminated) created by the bycatch price is incorporated in the price of target catch, which is shared among fishers, supply chain firms, and consumers according to their ability to pass on or absorb these costs.

The bycatch price can be directly created through a secondary market or indirectly arise through the cost created as vessels reduce bycatch in response to incentive-based policies. A transferable bycatch property right or credit program with an explicit bycatch quota creates a bycatch price through the trade of these rights or credits, such as in the U.S. West Coast groundfish fishery. A tax on otherwise unpriced bycatch set at a level to achieve the bycatch quota also creates a common bycatch price for the residual bycatch. Offsets implicitly price bycatch because their implementation raises costs that must be paid for with each unit of residual bycatch and target catch. Offsets explicitly price bycatch if there is biobanking (markets for biodiversity credits that can be purchased to offset development impacts).

Minimizing costs across mitigation-hierarchy steps differs from minimizing costs within a step. The extent to which any given incentive policy is likely to achieve bycatch reduction within and across hierarchy steps and producers depends on the choice of policy and how it is structured. For example, a bycatch tax may lead to least-cost avoidance, but it may not lead to adopting conservatory offsets rather than bycatch-avoidance measures. There are many incentive-based policy instruments

(Squires & Garcia 2015), discussion of which is beyond our scope here.

Direct regulation and incentive-based policy alter costs and create incentives in different ways with different effects. The bycatch price corresponding to a bycatch target quantity, created by incentive-based approaches, adds to the cost of harvesting a unit of bycatch and thereby adds to the average cost of catching the target species, according to the ratio of bycatch to target species catch. These higher unit costs incentivize reducing the scale of production of both target catch and bycatch (scale effect). Raising the MC of residual bycatch incentivizes reducing the bycatch to target catch ratio (substitution effect).

Direct regulation, by not pricing residual bycatch, fails to create a cost of target catch that incorporates the cost of the remaining bycatch associated with each unit of target catch, although the target-catch production costs reflect the variable costs due to direct regulation. The target-catch price will be lower than under bycatch pricing. Direct regulation thus does not incentivize vessels to reduce bycatch sufficiently through reductions in scale of production or to incentivize optimally lowering the ratio of bycatch to target catch through avoidance and minimization. Under incentive-based approaches, but not direct regulation, the external costs corresponding to the bycatch target are accounted for by markets and borne by society.

Least-cost bycatch mitigation across and within mitigation-hierarchy steps can extend beyond interaction with the bycatch species on the fishing ground. This extension includes least-cost bycatch mitigation across the entire species' life cycle and geographic range, where it faces additional, alternative sources of mortality that, if reduced, may provide in-kind, off-site mitigation at lower cost (Fig. 1) (Dutton & Squires 2008; Squires & Garcia 2014, 2015). Such bycatch impact mitigation may be more ecologically effective and least cost because it lowers bycatch impact elsewhere and from another fleet or gear type.

U.S. Groundfish Fishery Example

In the U.S. groundfish fishery, introducing an incentive-based policy instrument—individual transferable quotas (ITQs) that include bycatch species—incentivized fisher behavior and decision making toward least-cost mitigation across and within mitigation-hierarchy steps for the bycatch (Miller & Deacon 2017). An ITQ entails biologically determined limits—TACs on both target and bycatch—divided into discrete units (quotas) allocated to individual fishers. Because ITQs are transferable between fishers, lower-cost fishers can buy from higher-cost fishers, match target catch and bycatch with their quotas, and thereby create an ITQ price. Fishers expect to pay more in quota costs for catching most bycatch species than they would receive from selling them, thereby incentivizing them to reduce bycatch.

Trade in ITQ creates a common bycatch price in the market and a cost for each vessel's remaining bycatch. Vessels adjust their bycatch avoidance and minimization to alter their scale and mix of production and thereby equalize the MCs of harvest within and across BIM steps based on the common bycatch price (Fig. 3). In contrast, under direct regulation, avoidance MC exceeded minimization MC.

Under ITQs, vessels increasing avoidance and reducing minimization can equalize MCs across both steps equal to the common bycatch price, achieving least-cost conservation within and across hierarchy steps, vessels, and bycatch reduction channels. Fishers increase avoidance by not fishing areas with more bycatch, especially near the edges of closed areas. The ideal amount of avoidance depends on where and when; not all areas and times are equal. Fishers increase minimization of bycatch by changing fishing methods. For example, trawl fishers shifted toward night fishing because some bycatch species migrate off the sea floor and become less vulnerable to trawl gear at night, whereas key target species remain near the bottom; shortened net-tow duration to yield higher-frequency information on bycatch and enable quicker location changes when encountering concentrated bycatch; and shifted to more selective gear. Restoration comes through meeting the overall quota achieved by the first 2 steps in the hierarchy.

Scottish Conservation Scheme

The 2008 Scottish Conservation Credit Scheme, which partially replaced direct regulation, reduced target and bycatch cod catch (especially spawning cod) and regulatory-induced discards of marketable cod and market-induced discards of small (typically juvenile) cod (Little et al. 2015). The Scheme involved indirect-subsidy rewards and indirect-tax penalties to incentivize change in fisher behavior and is process rather than performance oriented. The EU full-catch retention policy replaced this program.

Reduction in cod catch is avoided through real time closures of areas with aggregated cod, a form of real time spatial management (RTSM) triggered by cod catch rate, and permanent area (direct regulation) and seasonal closures (substitution effect). Reduction is also effected by reducing effort, which reduces target and bycatch (scale effect); increasing compliance with mandatory selective gear; and voluntarily adopting even more selective gear to reduce the proportion of juvenile, spawning, and small marketable cod in target catch and bycatch (substitution effect).

Limited evidence suggests the scheme lowers discards (substitution effect) (Fernandes et al. 2011). Onboard observers and cameras monitor and further compliance. Over time, direct regulation through total allowable effort and annual effort quotas has progressively tightened, minimizing cod target catch and bycatch (scale effect).

The scheme, an indirect tax subsidy, is incentivized by rewarding vessels with kilowatt days at sea (indirect subsidy) as compensation for the extra time spent searching for cod when avoiding certain cod-dense areas; adoption of RTSM; minimization of bycatch by fishing exclusively with a specified selective gear; and limiting cod catches to a small percentage of total catch weight (substitution effect) (Fernandes et al. 2011). Vessels, rewarded by using their days more flexibly, operate under hours at sea and conserve fuel and operate more efficiently, which lowers direct and marginal costs. Decreasing the vessel's days at sea and reverting to days instead of hours at sea for the remainder of a year, penalizes noncompliance by reducing catch (i.e., higher opportunity and marginal costs), forming an indirect tax and negative incentive. Use of certain specified but undesired gear, mandatory fishing in selected areas, and fewer days at sea penalize vessels. There was avoidance of bycatch due to buybacks of days allocated at a fixed price (scale effect).

Both the Scottish and U.S. incentive-based programs induce more fine-tuned behavioral changes for substitution and scale effects within and across mitigation-hierarchy steps and along many more channels than direct regulation. A central manager trying to alter behavior and technology through direct regulation cannot marshal detailed fisher knowledge that is time-and-place specific and dispersed among vessels with different individual skill and flexibility and thus cannot fully incentivize them to change. As a performance-based approach, ITQs generate more direct and stronger incentives to reduce bycatch through scale and substitution effects from bycatch avoidance and minimization than the Scottish scheme, a process-based approach that is scale oriented.

Intrinsic Motivation

Intrinsic motivations, of which social norms are perhaps the most important, are explicit or implicit rules of socially acceptable behavior that resolve problems of collective action or cooperation. Although long lasting and self-sustaining, they require lengthy and special behavior to create and can be slow to change behavior. Social norms, such as taboos or social rules of resource use, are especially effective when markets are not the primary means to organize economic behavior, whereas incentives can be especially effective in economies primarily organized by markets and when faster changes in behavior are required. For conservation that is lower cost and where central regulatory bodies are weak, applying social norms can be more effective than direct regulation, potentially more enduring, and more community and individual self-enforcing.

Economic incentives can interact with intrinsic motivation in complex ways that change over time and tend to increase or decrease conservation. The effects of incentives on intrinsic motivation depend on their design, the form and circumstances in which they are given, how they interact with intrinsic motivation, and what happens after incentives are withdrawn. Both intrinsic motivation and economic incentives contribute to conservation and can have complex interactions that crowd in or out conservation, and their appropriateness is situational.

Compensation in Biodiversity Conservation and Fisheries

Compensation, the mitigation-hierarchy's fourth step, is used when a residual impact cannot practicably be further reduced or restored. We considered its role in marine fisheries, where its application is complicated by co-existence of the LOSC and CBD.

The LOSC framework requires managing all target fishery stocks "to maintain or restore populations of harvested species at levels which can produce the maximum sustainable yield . . . , as qualified by relevant environmental and economic factors" (Article 61.3) and as such, does not foresee conventional compensation. It also requires "maintaining or restoring populations [of dependent and associated species] above levels at which their reproduction may become seriously threatened" (Article 5e) without further specification. For habitats, only the general environmental provisions calling for protection of the marine environment (Article 192) may be used.

The CBD must be implemented in line with LOSC provisions (Article 22.2). It requires avoidance and minimization of "adverse impacts on ecosystem services, structure and functions as well as other components of ecosystems" (Addis Ababa Principle 5). Conventional (compensatory) offsets are included in the Resource Mobilization Strategy (UNEP/CBD 2008) and in Decision XII/13 (section 38c, of CDB CoP 12 [UNEP/CBD 2014]). This allows their introduction in mitigation-hierarchy step 4 for species whose MSY norm is irrelevant, such as non-aquatic species (seabirds), marine species of no interest to fisheries, protected species (e.g., turtles, corals), and ecosystems (e.g., seagrass beds).

Offsets compensating the residual in the fourth hierarchy step are not allowed in the LOSC and related instruments (UN Fish Stocks Agreement and FAO Code of Conduct for Responsible Fisheries) for target species that should be maintained at MSY, the equivalent for fisheries of NNL (Squires & Garcia 2014, 2015). They are accepted in the International Union for Conservation of Nature and

CBD frameworks and may therefore be applied under the LOSC for species for which the MSY norm is irrelevant (e.g., nonfishery aquatic species, seabirds). We argue that other offsets in earlier hierarchy steps (i.e., conservatory offsets) are usable in fisheries for target and nontarget species.

Conservatory Offsets in Fisheries

Conservatory offsets are offsets because they are obtained off-site, sometimes far from the impact area. They are conservatory because, contrary to the classical compensatory offsets, they are applied to the affected population (in-kind) within its life cycle to restore it.

Conservatory offsets can be used in the first three mitigation-hierarchy steps as a voluntary complement to or substitute for other mitigation measures, yielding a range of benefits from partial recovery to NNL or Net Gain (NG), depending on scheme and context. They can be used early in the conservation process to achieve faster and least-cost conservation (Fig. 2). They relate to the polluter pays principle in that the party inflicting biodiversity loss pays for it. This party has willingness to pay (WTP) and the affected party or society has willingness to accept (WTA) compensation. Maximum WTP for NG and minimum WTA for NNL bound the size of economically rational compensation in monetary values for any voluntary or mandated offsets.

For example, the shallow-set Hawaii longline swordfish (*Xiphias gladius*) fishery has a bycatch of Pacific loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) sea turtles (Gjertsen et al. 2014). Fishers initially used J-hooks baited with squid. The Endangered Species Act led to several direct regulations to halt and reverse negative trends and restore populations through the conventional fisheries management instruments of full avoidance and on-site minimization. In 2001, a 3-year time-and area-fishing closure was implemented. After reopening in 2004, avoidance was reduced, closer to a least-cost level (lower MC), through TurtleWatch, a system that is on stock, in-kind, essentially on-site, and based on RTSM that avoids sea turtle hotspots (Howell et al. 2008). On-site minimization was achieved through application of circle hooks (technology standard) and bait that reduced sea turtle interactions and posthooking mortality; line cutters and dehookers that minimized posthooking mortality; and industry-wide bycatch limits on each species.

In a second example, the California drift gillnet (CDGN) fleet harvesting swordfish avoids Western Pacific leatherback sea turtle bycatch through a 2001 time- and area-closure of about 90% of the fishing ground north of Point Conception (Gjertsen et al. 2014). The closure allowed limited fishing farther south. No bycatch minimization was imposed.

Saving one sexually mature Western Pacific leatherback sea turtle costs US$1 through nesting-site conservation, US$18 through avoidance (time-and-area-closures) in the Hawaii fishery, and US$132 through avoidance (time-and-area-closures) in the California fishery (Gjertsen et al. 2014). Nesting-site conservation would provide least-coast mitigation and would reduce cost of avoidance. Given the high costs of avoidance in these fisheries (through OCs), reducing avoidance by relaxing closures and introducing conservatory offsets would lower MCs of mitigation-hierarchy step 1. Although the lower MC of relaxed avoidance may not equal the MC of introducing conservatory offsets (which have risen from a cost of zero to some positive value), coming closer to this equalization lowers total bycatch-mitigation costs.

The large difference in the avoidance costs from the time and area closures in the Hawaii versus California suggests costs can vary significantly across fisheries, gear, vessels, and locations. Least-cost conservation in one fishery or location may not be least cost in another. Ideally, these two fisheries should be fully, jointly managed to equalize MCs of bycatch reduction across the two fisheries, all vessels, and gear and within and between mitigation-hierarchy steps to induce further cost savings and engage all bycatch-reduction channels.

Similarly, conservatory offsets through rat eradication at seabird nesting sites mitigate bycatch in the Australian eastern tuna and billfish fishery had lower costs more than complete avoidance of bycatch through fishery closure (Pascoe et al. 2011).

In these examples, technology standards for gear, applied through an all-or-nothing, uniform direct regulation, have been implemented for minimization when feasible and cannot be adjusted to alter their MC. Conservatory offsets, on the contrary, can be adjusted as stock abundance, the environment, markets, and technology change. They may result in NNL or even NG in the adult population depending on the amount of reproduction enhancement achieved. Paradoxically, when effective, the increase in turtle abundance, increasing the probability of bycatch and taxation on fishers to finance the conservatory offset (which can also incentivize bycatch reduction), creates a perverse feedback loop. The problem may be resolved by making the tax proportional to the bycatch mortality rate (bycatch or population size) instead of simply number of animals caught.

The International Seafood Sustainability Foundation voluntarily taxed itself to enhance environmental standing in consumer markets. This tax per ton of longline-caught tuna, adopted to yield revenue to finance conservation rather than as an incentive mechanism (although in principle it incentivizes bycatch reduction), annually yields about US$100,000 to finance conservatory offsets for sea turtles worldwide (ISSF 2016). In 2004, the CDGN industry voluntarily levied a lump-sum tax, largely out of intrinsic motivation, to finance nest-site protection of what at the time was thought to be the same leatherback stock in Baja California (Janisse et al. 2010). The impact of this scheme on the leatherback population remains unknown.

Concluding Remarks

Implementation of least-cost bycatch reduction through channels across and within steps of the impact mitigation hierarchy minimizes the costs of meeting a given level of biodiversity conservation at project, landscape, or ecosystem levels. In contrast, implementing each step to the maximum extent practicable leads to economic waste through diminishing conservation returns per monetary unit spent, potential foregone conservation, and suboptimal conservation.

Incentive-based policy instruments implement the least-cost impact-mitigation framework by pricing otherwise unpriced or underpriced bycatch and incentivizing changes in producer and consumer behavior and decision making (changing scale and mix of production through impact avoidance and minimization within and across framework steps). Nonetheless, some circumstances favor direct regulation and intrinsic motivation. When conservatory offsets in the first three hierarchy steps are implemented off-site, they provide an additional incentive-based policy instrument. Conservatory offsets can price bycatch to maximally reduce fisheries bycatch for given targets and politics of regulation at least cost, consistent with the LOS and the CBD.

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