ECOSYSTEM-LEVEL IMPACTS OF FISHERIES BYCATCH ON MARINE MEGAFAUNA: BIODIVERSITY CONSERVATION THROUGH MITIGATION, POLICY, ECONOMIC INSTRUMENTS, AND TECHNICAL CHANGE

Report of an IUCN-CEM-FEG Scientific Workshop

IUCN, Gland, Switzerland, 7-10 October 2013.

Dale Squires and Serge M. Garcia (Editors)

ACKNOWLEDGEMENTS

This report one of the outcomes of the *Multidisciplinary Workshop to Address Ecosystem-Level Impacts of Fisheries Bycatch on Marine Megafauna: Biodiversity Conservation through Mitigation, Policy, Economic Instruments, and Technical Change*. The workshop was co-organized in the IUCN HQs in Gland (Switzerland) from 7 to 10 October 2013 by NOAA-Fisheries; the Center for Environmental Economics (CEE) and the Institute for Global Cooperation and Conflict (IGCC) of the University of California in San Diego (USA); the International Sustainable Seafood Foundation (ISSF), the Inter-American Tropical Tuna Commission (IATTC), The Nature Conservancy (TNC), the Centre for Fisheries & Aquaculture Economics & Management (FAME, Denmark), The European Bureau of Conservation and Development (EBCD) and the Fisheries Expert Group of the IUCN Commission on Ecosystem Management (IUCN/CEM/FEG). These institutions have supported the meeting in various ways for which we are extremely grateful.

Despina Symons and Kathleen Lassy, from the European Board of Conservation and Development (EBCD, Belgium) coordinated the meeting preparation and running. The meeting was kindly hosted and efficiently facilitated by the IUCN Global Marine and Polar Programme and our particular thanks go to Carl Gustaf Lundin and François Simard for the patient collaboration.

The workshop was co-chaired by Serge M. Garcia (IUCN-CEM-FEG) and Dale Squires (NOAA-NMFS, USA).

We owe our most grateful thanks to all the participants for their contribution at the meeting: Bull, J. Balance, L.; Bisack, K., Charles, A.; Chopin, F., Compeán, G.; Cook, C.; Dagorn, L.; De Young, C.; Dutton, P.; Fordham, S., Fowley, S.; Fox, W.; Gilman, E.; Graff-Zivan, J.; Hall, M.; Herrick, S., Marcovaldi, M.; Milner-Gulland, E.J.; Pulvenis de Seligny, J-F.; Ravenga, C.; Restrepo, V.; Rice, J.; Shrader, J.; Small, C.; Squires D.; Vestergaard, N. and Williams, M.

Citation: Squires, D and Garcia, S.M (Editors). 2014. Ecosystem-Level Impacts of Fisheries Bycatch on Marine Megafauna: Biodiversity Conservation through Mitigation, Policy, Economic Instruments, and Technical Change. Report of an IUCN-CEM-FEG Scientific Workshop, Gland, Switzerland, 7-10 October 2013. Gland, IUCN: 81 p.

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Ecosystem-Level Impacts of Fisheries Bycatch on Marine Megafauna: Biodiversity Conservation through Mitigation, Policy, Economic Instruments, and Technical Change.

1. Workshop Rationale

The selectivity of fishing operations is such that despite the sustained efforts made during the last decades to reduce it, the accidental capture of living marine resources (bycatch) sometimes followed by their discarding at sea[1] remains an important point of friction between fisheries and biodiversity governance systems, particularly when emblematic, endangered or particularly vulnerable species are concerned. Bycatch reduction practices have traditionally focused on command-and-control measures (e.g., time-and-area closures, effort reduction) or technology standards and associated legislative changes (e.g., mesh size, hook types, bycatch excluder devices, and mandated requirements that freeze technology in place). Incentive-based bycatch reduction practices such as use rights (e.g., Dolphin Mortality Limits, DMLs), taxes, credit schemes, or insurance, may more directly and cost-effectively reduce bycatch. This approach has received insufficient attention.

In addition, conventional bycatch reduction approaches give insufficient attention to the holistic (ecosystem-level) impacts of bycatch. Bycatch reduction simply focused on at-sea catch ignores opportunities offered by more cost- and ecologically-effective bycatch mitigation measures that may directly and more effectively increase impacted populations elsewhere in their geographic range or life cycle. Finally, at-sea bycatch reduction runs the danger of obtaining increasingly smaller increments in bycatch reduction at increasingly larger increments in costs (i.e. marginal costs) to the point where additional gains in bycatch reduction are outweighed by additional costs of bycatch reduction leading to a net loss in economic benefits. A net loss in economic benefits can also lead to a net loss in biodiversity and ecological benefits if the foregone economic benefits preclude conserving biodiversity at some other point in the holistic process, i.e. there can be an opportunity cost to at-sea bycatch reduction within a broad-based and holistic bycatch perspective. A broader-based ecosystem approach to biodiversity conservation thus allows incorporating a broader range of policy instruments, applied at life stages and geographical ranges other than those of the strict harvesting process to achieve better cost- and ecological effectiveness.

One of the most important forces reducing bycatch is technical change. Examples include for tuna purse seine fisheries the backdown procedure and Medina panel that reduce dolphin bycatch or current development of ecological Fish Aggregating Devices (FADs), and for pelagic longline swordfish fisheries circle hooks and mackerel type bait that reduce sea turtle bycatch and post-hooking mortality.. However, many conventional policy instruments, such as catch rights, time and area closures or effort reduction, even when aimed at bycatch reduction, are insufficient to cover all species, do not directly create desired economic incentives, are not cost-effective because they unnecessarily reduce profitable fishing opportunities that can help finance less expensive and more effective conservation elsewhere,

[1] The last (and already dated) estimate of FAO indicated that about 7.3 million tonnes of fish were still discarded annually during the period 1992-2001 (Kelleher, 2005).

and limit vessel flexibility to efficiently respond to changes in market, environmental, technological, or ecological conditions.

The challenge is to develop a portfolio of bycatch management instruments that not only directly reduce bycatch, but also create incentives to stimulate and direct bycatch-saving technical change. A related question is the impact of alternative mixes of bycatch-reducing instruments, since invariably multiple instruments are imposed.

Biodiversity mitigation (offsets) is part of a holistic approach addressing all phases of a species' life history throughout its geographic range and that provides the lowest risk, least-cost approach to conservation. It is not necessarily intended to offset current fishing or to substitute for current at-sea and other bycatch-reducing measures. Instead, it is intended to complement existing activities to provide a holistic conservation strategy that is least-cost and addresses species conservation over the entire geographical range and life history of species. As part of a comprehensive bycatch reduction conservation strategy, biodiversity mitigation enables consumers, processors, traders and brokers, and fishers to continue their activities and generate sufficient economic surplus to finance the mitigation that leads to population increases, not simply no net loss. This approach recognizes that there are cost-effective conservation measures that can be taken other than at-sea bycatch reduction devices and that these can have higher marginal biological and economic effectiveness than simple continued emphasis on steadily increasing bycatch reduction through conventional measures (with debatable efficiency due in part to diminishing returns).

Many questions arise about the best way to organize bycatch-saving technical change, *inter alia*: (i) the nature of public-private partnerships; (ii) the type and amount of research and development (R&D); (iii) financing methods in taxes and kind; (iv) who pays?; (v) length of R&D projects, (vi) and role and form of subsidies, etc.

The meeting will address many of these questions, but will focus on: (i) Endangered, vulnerable and other emblematic species bycatch in fisheries for highly migratory species; (ii) Economic and financial instruments to efficiently strengthen by-catch reduction policies; (iii) A broader-based ecosystem approach to by-catch reduction; and (iv) Concrete biodiversity mitigation strategies for the aforementioned bycatch species..

2. Summary Conclusions

Bycatch reduction practices have traditionally focused on avoiding and reducing bycatch through command-and-control measures (e.g., time-and-area closures, effort reduction) or technology *standards*[2] and associated legislative changes (e.g., mesh size, hook types, bycatch excluder devices

[2] Standards specify a quantity that constraints the behavior of fishers. A standard can specify a maximum, such as the maximum amount of bycatch allowed, or a minimum, such as the minimum amount of bycatch saving technology or input use. Some standards are voluntary, such as MSC, and others are limited to legal requirements. Because standards are prescriptive, they are sometimes called "command-and-control" approaches to bycatch reduction. Standards constrain the activities of fishers with different cost structures, different systems, or different catch mixes. Because they require that all fishers behave in the same way, standards are less flexible than market-based incentives, such as taxes or transferable bycatch credits or rights, which allow fishers to decide on their own how to respond to the incentives. This inflexibility increases the costs of achieving any particular target compared to market-based incentive approaches, because fishers who face great difficulty meeting the standard must achieve the same target as fishers who are already in compliance. A major advantage to standards is that they draw a clear distinction between compliance and noncompliance, which can lead to easier enforcement. The primary disadvantage of standards is their inflexibility and as a consequence they are not cost-effective; however, they can be differentiated to improve their cost-effectiveness.

and other mandated requirements that tend to freeze technology in place). Incentive-based bycatch reduction practices such as property rights (e.g., bycatch property rights), taxes, credit schemes, or insurance, may more directly and cost-effectively reduce bycatch but have until now received insufficient attention. Incentive-based approaches can also lead to *least-cost conservation*[3].

Conventional bycatch avoidance and reduction approaches also give insufficient attention to the holistic (ecosystem-level) impacts of bycatch and to the potential to mitigate the impact at the broader ecosystem level. It simply focused on at-sea catch ignoring opportunities offered by more cost- and ecologically-effective bycatch mitigation measures that may directly increase *bycatch populations*[4] locally or elsewhere in their geographic range or life cycle. Finally, at-sea bycatch reduction runs the danger of producing increasingly smaller increments in bycatch reductions (marginal gains) at increasingly larger increments in costs (marginal costs) to the point where additional gains in bycatch reduction are outweighed by its additional costs, leading to a net loss in economic benefits. Such a loss can also be accompanied by a net loss in the biodiversity and ecological benefits that could have been made by intervening at some other point in the holistic production process, generating an opportunity cost to at-sea bycatch reduction.

A broader-based ecosystem approach to biodiversity conservation thus allows incorporating a broader range of policy instruments, applied at life stages and geographical ranges other than those directly impacted by the strict harvesting process to achieve least-cost and lower risk. This approach has emerged in management instruments designed for conservation of terrestrial ecosystems and mitigation of greenhouse gasses, and has included direct incentive-based approaches, such as *Payments for Ecosystem Services (PES)*[5]and other benefit-sharing arrangements as well as indirect incentive-based approaches, including community based conservation (CBC) and integrated development and conservation projects (IDCPs), and offsets such as sea turtle nesting protection that mitigates at-sea mortality, often at lower cost.

One of the most important forces reducing bycatch is *induced technical change*[6] and *biased technical change*[7]. Examples include: the tuna purse seine backdown procedure and Medina panel that reduce dolphin bycatch; circle hooks and mackerel type bait that reduce sea turtle bycatch and post-hooking

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[3] Least-cost conservation requires that participants have sufficient flexibility in choosing the means for improving performance, allowing each participant to meets its own individual requirements at least cost. It requires that marginal costs be equated across all vessels with bycatch (the equi-marginal principle).

[4] Bycatch population refers to the associated and dependent species referred to by the 1982 LOSC that are impacted through accidental harvest (as opposed to targeted harvest) during fishing of a target population.

[5] A PES is defined as: (1) voluntary transaction in which (2) well-defined environmental service, or a form of land use likely to secure that service (3) is bought by at least one ecosystem service buyer (4) from a minimum of one ecosystem service provider (5) if and only if the provider continues to supply that service (conditionality).

[6] Induced technical change: A form of technical change that occurs when a change in supply side conditions, notably the availability or relative price of inputs and knowledge to production, influences the rate and direction of technical progress in order to economize on the input that has become relatively scarce and expensive (i.e. replace this relatively more scarce and expensive input) or to use relatively more of an input as it becomes relatively more abundant and its relative price falls. See also: directed technical change.

[7] Biased technical change: A shift in the harvesting and post-capture handling technology that favors either the relative use of an input over another or the relative harvest of an output (species) over another. More technically, biased technical change is a shift in the production technology that favors one input over another (or output over another) by increasing its relative productivity and therefore its relative demand. The direction of technical change, whether bycatch using or saving, may be determined endogenously by innovators' economic incentives shaped by relative input (or output) prices, the size of the market, and institutions. Technical change that is not biased is neutral technical change.

mortality in pelagic longline fisheries for swordfish: and current development of ecological Fish Aggregating Devices (FADs) for tuna purse seine fishing.

Further, bycatch-reducing technical change will be a fundamental component of ecosystem based fisheries management, because many policy instruments, such as catch rights, time-and-area closures or effort reduction, even when aimed at bycatch reduction, are insufficient to cover all species or are not cost-effective because they unnecessarily reduce profitable fishing opportunities that can help finance less expensive and more effective conservation elsewhere. The costs of dealing with bycatch reduction, and more broadly ecosystem-based fisheries management, will depend on the development of new technologies.

One question that arises is developing a portfolio of bycatch management instruments that not only directly reduce bycatch, but also create incentives to stimulate and direct bycatch-saving technical change. A related question is the impact of alternative mixes of bycatch-reducing instruments, since invariably multiple instruments are imposed. Some bycatch-reducing instruments, such as transferable bycatch rights, may not widely bind on all vessels after sufficient bycatch-saving technical change has occurred[8], but may instead serve to create economic incentives that prevent backsliding. It is likely that reductions in purse seine-related bycatch in tuna fisheries will be facilitated through the combination of multiple approaches (Dagorn et al. 2012). At some point, some management measures may become redundant and candidates for removal.

Much of the gear and equipment that reduces bycatch through technical progress is embodied with information technology, scientific knowledge, and knowledge gained through at-sea experience (called *embodied technical change*[9] and learning by doing). Embodied technical change can lead to technological obsolescence and economic depreciation (as opposed to physical depreciation).

The comparatively low cost and short economic lives of most this technology-embodied bycatch-saving gear and equipment raises the benefit-cost ratio and marginal rate of return of embodied bycatch-saving technical change and facilitates rapid diffusion of the new technologies. Most fishing gear have a short economic life, and many gear types have comparatively low costs that facilitate rapid replacement of the existing capital stock with technology-embodied gear that is relatively better at bycatch-saving and at comparatively low cost. The short economic lives and comparatively low cost of the gear and equipment raise the question of whether immediate bycatch-saving policy instruments, such as taxes, property rights, technology *standards,* quotas, or time-area closures should be designed more to facilitate rapid technical change than for immediate bycatch reduction. That is, these "second-order" effects from policy instruments may be as much as or more important and self-sustainable in the long term than the "first-order" immediate effects.

[8] If sufficient bycatch saving technical change has occurred, DMLs would seldom be binding because not enough dolphins are caught as bycatch. However, having a management measure like a DML in place keeps vessels from becoming complacent and backsliding.

[9] Technical change incorporated into an input (typically the physical capital stock). It is usually incorporated into the fishing process through investment in the physical capital stock. Examples include new designs in the hull, propeller, and gear, changing materials (e.g. steel versus wood hull, monofilament nylon net instead of natural materials), Medina panel, information technology-embodied electronics and gear, all largely meant to improve productivity (fishing power). Other embodied technical change is intended to improve safety and crew comfort or to reduce bycatch, such as the Medina panel, circle instead of J hooks, Tori lines, nylon instead of steel wire leaders for longline gear, Turtle Excluder Devices, trawl net mesh design and size to increase juvenile groundfish escapement, pingers for gill nets, etc.

Technology policy can potentially contribute to bycatch policy, which induces and finances research and development and recognizes that knowledge is under-provided and subject to *free riding*[10]. Questions that arise about the best way to organize bycatch-saving technical change include: (i) the nature of public-private partnerships; (ii) the type and amount of research and development (R&D); (iii) financing methods in taxes and kind; (iv) who pays?; (v) length of R&D projects, etc. Subsidies to finance bycatch reducing technology can take the form of fairly general tax credits, matching funds provided to firms for specific research proposals, and in areas where the public research institutions have specific expertise, joint ventures between industry, government and universities. Subsidies have been important in dolphin, sea turtle and seabird longline, and ecological-FAD R&D. Subsidies for gear and equipment and training boost diffusion of positive technical changes.

Biodiversity impact mitigation[11] can be conservatory or compensatory. Conservatory measures are usually applied on-site and intend to avoid or reduce impact or to restore the system. Compensatory measures (including offsets) compensate partially or totally an unavoidable residual impact and may be introduced, often off-site, only after conservatory measures have been applied as much as possible. Offsets should complement priority conservation activities and should produce additional conservation gains, i.e. gains that would not have occurred without the offsets. Together, conservatory and compensatory instruments constitute a *mitigation hierarchy*[12] of interventions for a holistic approach to conservation, addressing all phases of the species' life history throughout their geographic range that provides the lowest risk, least-cost approach to conservation.

When conceived as a last resort activity addressing residual impacts, offsets substitute for additional conservatory measures that are, however no longer possible, either technically or economically. When they are conceived as part of a comprehensive package and not solely a last resort activity, offsets may complement existing conservatory activities and contribute to a holistic and least-cost conservation strategy. There can be a net gain in that integrated strategy if any saved funds from least-cost conservation can in turn be used in another activity or location for conservation or to extend current conservation efforts, any of which would have not otherwise been conducted. Conservatory offsets[13] can even lead to lower bycatch mortality when the fishery's target and bycatch species are transboundary, subject to fishing by multiple nations, and the target catch is actively traded 'internationally (Sarmiento 2006, Rauser et al. 2009, Bartram et al. 2010, Chan and Pan 2012, Mukherjee in press). In this case, the expected benefit of reduced fishing by the regulated fleet to reduce bycatch mortality can actually be cancelled by an increase in bycatch mortality generated by other nations' unregulated fleets and/or gear that have higher bycatch and higher post-bycatch handling

[10] A situation in which individuals or organizations consume more than their fair share of a resource, or shoulder less than a fair share of the costs of its production.

[11] In this report, a hierarchy of activities intended to conserve biodiversity avoiding or/and reducing the impact of economic activities, usually on-site (*conservatory mitigation*). It aims also to compensate fully (*offsets*) or partially for biodiversity loss, usually off-site (*compensatory mitigation*).

[12] The holistic set of *conservatory* and *compensatory* approaches and instruments that can be used to manage the impact of economic activities on biodiversity. The mitigation hierarchy comprises: (1) avoidance or measures taken to avoid adverse impacts from the beginning; (2) minimization or measures taken to reduce the duration, intensity, and/or extent of impacts that cannot be practically avoided; (3) restoration or measures taken to rehabilitate a degraded ecosystem or restore cleared ecosystems following exposure to impacts that cannot be completely avoided and/or minimized; (4) offset s(compensation) or measures taken to either (a) compensate for adverse impacts that cannot be avoided, minimized, and/or restored or (b) form part of a comprehensive package rather than serving as a last resort addressing the residual after avoidance/minimization/restoration.

[13] i.e. offsets that are part of a comprehensive conservation package rather than a last resort activity and allow a tightly regulated, observed, and enforced fishery to continue fishing,

mortality as the unregulated fishery target catch substitutes for the regulated fishery catch in consumption through imports.

Offsets that are part of a comprehensive *Biodiversity impact mitigation* package are not necessarily associated with a legal mandate and/or conservation hard caps, and may instead form part of an overall conservation strategy that may be incentivized by consumer market preferences, certification and *standards*, general regulatory goals, or ecosystem management. Voluntary *biodiversity impact mitigation* can occur beyond legal mandates or bycatch caps if the compensating entity enjoys some benefit such as satisfying market mandates, supply chain standards, certification including eco-labeling, or meeting consumer preferences. Offsets then offer opportunities for consumers, supply chain firms, or other entities such as NGOs to directly conserve without having to rely upon vessels and/or regulatory bodies, i.e. it opens up conservation to otherwise effectively excluded groups

The use of conservatory offsets recognizes that there are cost-effective measures that can be taken other than conventional conservatory measures for bycatch reduction with higher marginal biological and economic effectiveness than steady increases in conventional measures the efficiency of which is debatable due to: (i) progressively diminishing returns; (ii) disregard of the sector's flexibility and capacity to innovate and to reduce bycatch through creative responses of its own, leading also to least-cost conservation; and (iii) failure to recognize that other fleets that serve the same consumption markets may have higher rates of bycatch mortality and post-bycatch mortality. A holistic approach allows fully regulated, observed, and enforced fisheries with lower bycatch rates to continue in place of fishing on the same transboundary target and bycatch species' stocks by less regulated fisheries with higher bycatch rates

This book focuses on conservatory mitigation approaches (command-and-control and, principally, economic incentives). It reviews the ways to better reduce ecosystem-level impacts of fisheries bycatch on marine megafauna in large pelagic ecosystems and fisheries by:

1. Placing the bycatch issue as part of biodiversity conservation and the ecosystem approach to fisheries management, Balanced Harvest strategies (Garcia et al., 2011; 2012; see also section 2), broad-based conservation, and defining megafauna of explicit concern;

2. Addressing bycatch reduction within this broader context through a broader-based conservation approach with particular focus upon *biodiversity impact mitigation* and least-cost conservation over the life history and geographic range of the species and recognizing that many target and bycatch species are transboundary with multiple sources of mortality and products serving the same consumption markets are internationally traded. A specific objective is to identify the conditions under which biodiversity impact mitigation can be used as a conservation tool and contribute to ecosystem-based fisheries management;

3. Expanding the scope of bycatch reduction policies from conventional "command-and-control" approaches such as effort reduction and time-area closures, individual or industry bycatch quotas (performance *standards*) and regulation of gear, equipment, and operations (technology standards) to consider economic policy instruments that create direct economic incentives to reduce bycatch, such as transferable bycatch use rights, assurance bonds, taxes, and insurance schemes. Economic incentive- or market-based approaches price bycatch and thereby establish explicit and direct incentives to reduce it through lowering both the proportion of bycatch in total catch and the total amount caught. In contrast, conventional "command-and-control" or direct approaches raise the total and average cost of "dirty" production of target species, thereby establishing only implicit, indirect, and less targeted incentives to reduce the mix of bycatch in total catch. Command-and-

control approaches establish incentives to reduce the level of effort and all catch and only through this manner do these regulations reduce bycatch;

4. Examining the impact of economic incentives that increasingly arise out of consumer markets and standards and certification in the supply chain, rather than arising out of fisheries bycatch reduction policies, and which include voluntary agreements and programs;
5. Evaluating from the conservation literature economic policy instruments that create direct *economic incentives*, such as payments for ecosystem services, indirect economic incentives such as community based conservation and integrated conservation and development projects;
6. Examining the opportunities to open up the conservation process from solely at-sea vessel regulation to allow entities other than vessels and regulatory bodies – notably, consumers, supply chain firms, and NGOs – to participate and create economic incentives through offsets, voluntary incentive approaches such as payments for ecosystem services and conservation easements, eco-labeling, establishing supply chain standards and certification, and information programs;
7. Examining *bycatch-saving technical change*[14] and factors (market forces, supply chain standards and certification, policies, non-governmental organizations or NGOs, resource conditions) that direct and induce *biased technical change*[15], including the policy instruments best suited to induce such change and how these instruments interact and compare with conventional policy instruments focused directly on conventional bycatch reduction;
8. Examining technology policy that creates and diffuses bycatch-saving knowledge and technical change through formal and informal research and development by the private and public sectors and the best means of organizing and financing the effort

These conclusions are very preliminary and will be revised and expanded in a book being prepared on the subject by all those who have participated in the meeting.

[14] Change that reduces the relative amount of bycatch resource stock inadvertently harvested compared to the target resource stock harvested. Bycatch-saving technical change thus reduces the relative ratio of bycatch to target resource stock(s) and can vary by species. A form of biased technical change.

[15] A shift in the harvesting and post-capture handling technology that favors either the relative use of an input over another or the relative harvest of an output (species) over another. More technically, biased technical change is a shift in the production technology that favors one input over another (or output over another) by increasing its relative productivity and therefore its relative demand. The direction of technical change, whether bycatch using or saving, may be determined endogenously by innovators' economic incentives shaped by relative input (or output) prices, the size of the market, and institutions. Technical change that is not biased is neutral technical change.

ANNEX 1 - WORKSHOP OBJECTIVES

This workshop investigated ways to better reduce ecosystem-level impacts of fisheries bycatch on marine megafauna in large pelagic ecosystems and fisheries by:

9. Placing the bycatch issue as part of biodiversity conservation and the ecosystem approach to fisheries management, balanced harvest strategies (Garcia et al., 2011; 2012), broad-based conservation, and defining megafauna of explicit concern;
10. Addressing bycatch reduction within this broader context through a broader-based conservation approach with particular focus upon biodiversity mitigation and least-cost conservation over the life history and geographic range of the species. A specific objective is to identify the conditions under which biodiversity mitigation can be used as a conservation tool;
11. Expanding the scope of bycatch reduction policies from conventional "command-and-control" approaches such as effort reduction and time-area closures, individual or industry bycatch quotas (performance standards) and regulation of gear, equipment, and operations (technology standards) to consider economic policy instruments that create direct incentives to reduce bycatch, such as transferable bycatch use rights (individual and group), assurance bonds, taxes, and insurance schemes;
12. Evaluating from the conservation literature economic policy instruments that create direct economic incentives, such as payments for ecosystem services, indirect economic incentives such as community based conservation and integrated conservation and development projects;[16]
13. Examining induced (directed) bycatch-saving technical change and factors (market forces, policies, non-governmental organizations or NGOs, resource conditions) that direct and induce this biased technical change, including the policy instruments best suited to induce the desired technical change and how these instruments interact and compare with conventional policy instruments focused directly on bycatch reduction;
14. Examining technology policy that creates and diffuses bycatch-saving knowledge and technical change through formal and informal research and development by the private and public sectors and the best means of organizing and financing the effort.

[16] Economic incentives are *direct* if they directly alter behavior in a desired manner. For example, payments for ecosystem services create direct incentives because they are payments that are received conditional upon a verifiable outcome. *Indirect economic incentives* alter behavior only indirectly by working through another outcome or as a byproduct or joint product of another outcome such as economic development. Integrated conservation and development projects create indirect biodiversity conservation incentives because biodiversity conservation is a byproduct of economic development such as with eco-tourism.

ANNEX 2 - WORKSHOP AGENDA

Monday 7 October: 09:00 – 17:15		
PLENARY SESSION 1		
09:00 - 09:30:	Opening, welcomes: IUCN (Host); NMFS, EBCD/FEG, ISSF, IATTC, TNC	
09:30 - 10:00	Adoption of the Agenda; Tasks. Expected outcomes: D. Squires; S.M. Garcia	
10:00 - 10:30	**Coffee break**	
By catch reduction: a resource-based perspective		
10:30 – 11:00	FAO International Guidelines on Bycatch: F. Chopin	
11:00 – 11:30	Review of Traditional Bycatch Policies: M. Hall	
11:30 – 12:00	Bycatch-Saving Technological Change: J. Shrader et al.	
12:00 – 12:30	Bycatch Property Rights: K. Bisack	
12:30 – 14:00	**Lunch break**	
14:00 – 14:30	Bycatch Policies: Lessons from Conservation: EJ Milner-Gulland	
14:30 – 15:00	Bycatch, Biodiversity Mitigation, and Ecosystems (tentative.): J. Rice	
15:00 – 15 -15	**Coffee break**	
15:15 – 15:45	Bycatch Reduction in In Swordfish Longline Fisheries : E. Gilman	
15:45 – 16:15	Bycatch Reduction in Tuna Purse Seine Fisheries with FADs: L. Dagorn	
Biodiversity impact mitigation: an ecosystem perspective		
16:15 – 16:45	Biodiversity Mitigation: General Issues : J. BULL	
16:45 – 17:15	Ecological & economic aspects of Balanced Harvest : T. Charles; S.M. Garcia; J. Rice	
Tuesday 8 October: 09:00-17:30		
PLENARY SESSION 2		
09:00 -- 09:30	Conservation Issues with Sea Turtles :P. DUTTON , M. MARCOVALDI	
09:30 -- 10:00	Conservation Issues with Sharks:	
10:00 – 10:30	Conservation Issues with Seabirds: L. BALANCE	
10:30 – 10-45	**Coffee break**	
10:45 --11:15	The concept of Payments for Environmental Services : a fishery perspective: C. De YOUNG	
11:15 --11:45	Bycatch Reduction: Lessons from Env. Economics & Climate Change: N. VESTERGAARD et al.	
11:45 – 12:30	**Organization of split Working Groups: agendas, rooms, chairs, reporting**	
12:30 – 14:00	Lunch break	
	WG1: Biodiversity mitigation issues	**WG2: Mitigation projects**
14:00 – 17:00		
17:00 – 17:30	**PLENARY SESSION 3: Progress reports of WGs**	
Wednesday 9 October: 09:00 – 17:30		
	WG1: Biodiversity mitigation issues …	**WG2: Mitigation projects …**
17:00 -- 17:30	**PLENARY SESSION 3: Progress reports of WGs**	
Thursday 19 October: 09:00 – 12:30		
09:00 -- 12:00	**WG1: Biodiversity mitigation issues …**	**WG2: Mitigation projects …**
12:00 – 12:30	**PLENARY SESSION 4: Summary conclusions of WGs and of the meeting**	

ANNEX 3 - ATTENDANCE AND COMPETENCIES AVAILABLE

The meeting was attended by 29 Participants from 23 institutions:

1. **Bull, Joseph, W.:** Imperial College Conservation Science. London (UK). j.bull10@imperial.ac.uk
2. **Charles**, **Tony:** Professor of Finance, Management Science and Environmental Studies, Saint Mary's University; Member of the IUCN/CEM/Fisheries Expert Group. Tony.Charles@smu.ca
3. **Chopin**, **Francis:** Senior Fishery Officer. FAO Fisheries and Aquaculture Department. Fishing technology. Francis.Chopin@fao.org
4. **Compeán, Guillermo:** Director of Inter-American Tropical Tuna Commission (IATTC). gcompean@iattc.org
5. **Cook, Chuck:** Director, California Coastal and Marine Program, The Nature Conservancy. ccook@tnc.org
6. **Dagorn, Laurent : P**urse seine bycatch expert (Senior Scientist, Institut de Recherche Pour Le Développement, France; Scientific Committee ISSF. laurent.dagorn@ird.fr
7. **De Young, Cassandra:** Economist dealing with biodiversity issues. FAO Fisheries and Aquaculture Department.. Cassandra.DeYoung@fao.org
8. **Dutton, Peter:** NMFS, sea turtle expert, co-editor of *Conservation of Pacific Sea Turtles* University of Hawaii Press (2011) and co-PI of original Bellagio sea turtle project. peter.dutton@noaa.gov; pdutton1@san.rr.com
9. **Fordham, Sonja:** Shar Advocates International. sonjaviveka@gmail.com
10. **Fowler, Sarah**: Save Our Seas Foundation. sarah@saveourseas.org
11. **Fox, William:** Head of WWF Fisheries US and former Director of NOAA Fisheries, Board of Directors ISSF. Bill.Fox@wwfus.org
12. **Garcia**, **Serge M.:** Chair of the Fisheries Expert Group of the Commission on Ecosystem Management of IUCN. garcia.sergemichel@gmail.com
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The competencies available in the meeting included: (i) Policy & Law (US domestic and international); (ii) Terrestrial and other marine models of environmental mitigation (What works?); (iii) Population risks and threats - assessment and modeling; (iv) Mitigation tools for sea turtles and seabirds including bycatch- community-based artisanal fisheries and nesting beaches and breeding colonies; (v) Mitigation tools for oceanic sharks;; (vi) Bioeconomic ecosystem modeling; (vii) Environmental economics and financial instruments, economics of technological change; (viii) Conservation biology at the ecosystem level with a strong focus on synthesis; and (ix).Ecology, technology, and economics of bycatch.

ANNEX 4 - OUTPUTS OF THE WORKSHOP

PRESENTATIONS.

The following presentations made at the meeting and which have been submitted with the author(s)' authorization are posted on the FEG website at: http://ebcd.org/en/IUCN_CEM_FEG/Multidisciplinary_workshop_addressing_Ecosystem-Level_Impacts_of_Fisheries_Bycatch_on_Marine_Megafauna.html.

1. Workshop overview, goals, objectives and specific questions. Dale Squires (NOAA-NMFS)
2. FAO international guidelines on bycatch management and reduction of discards. Frank Chopin, (FAO)
3. Payments for ecosystem services: lessons from terrestrial experience. Milner-Gulland (Imperial College. UK)
4. Payments for ecosystem services - A fisheries and aquaculture perspective. De Young, Cassandra (FAO)
5. Ecosystem-based governance of bycatch and collateral effects of pelagic longline fisheries. Eric Gilman (Hawai Pacific University, SSF)
6. By-catch, biodiversity mitigation and ecosystem management. Jake Rice (DFO-Canada; UCN-CEM-FEG)
7. Bycatch-saving technological change. Jeffrey Shrader- (UC San Diego); Kathleen Segerson (Univ. Connecticut, Dpt. Economics); Dale Squires (NOAA-NMFS); Niels Vertergaard (Univ. Souther Denmark.
8. Bycatch property rights. Kathrin Bisack (NE Fisheries Center, USA)
9. By-catch reduction in tuna purse-seine fisheries with FADs. Laurent Dagorn (IRD, France)
10. Seabirds and conservation challenges. Lisa Balance (Scripps, USA)
11. A review of traditional bycatch policies. Martin Hall (IATTC, USA)
12. Conservation issues with sharks. Sarah_Fowler. (SoSF; IUCN-SSC Sharks; PEW)
13. Balanced Harvest: issues and economic insights. Tony Charles (St Mary University, Halifax, Canada) and Serge, M. Garcia (IUCN-CEM-FEG)
14. Bycatch Reduction: Lessons from Environmental Economics and Climate Change- Niels Vestergaard (Southern Denmark Univ.)
15. Brazilian sea turtle conservation Program. Neca Marcovaldi (TAMAR, Brazil)
16. Compensatory mitigation for biodiversity: challenges. Joe W. Bull (Imperial College, UK)

BACKGROUND PAPER

The background paper prepared for the meeting to provide a common understanding is attached as **Annex 5** to this report and available on the web at: http://www.ebcd.org/pdf/en/353-Background_Workshop_on_economic_biodiversity_mitigation_final.pdf

A Comprehensive Book

A comprehensive book on **Mitigation of Ecosystem-Level Impact of Fisheries Bycatch on Marine Megafauna. Policy, economic instruments and technical change** by Squires* D.; Shrader, J.; Bull, J. and Garcia, S.M, With the collaboration of Balance, L.; Bisack, K., Charles, A.; Chopin, F., Compeán, G.; Cook, C.; Dagorn, L.; De Young, C.; Dutton, P.; Fordham, S., Fowley, S.; Fox, W.; Gilman, E.; Garcia* S.M.; Graff-Zivan, J.; Hall, M.; Herrick, S., Marcovaldi, M.; Milner-Gulland, E.J.; Pulvenis de Seligny, J-F.; Ravenga, C.; Restrepo, V.; Rice, J.; Shrader, J.; Small, C.; Vestergaard, N. and Williams, M.

Draft Table of Content

A Multidisciplinary Workshop To Address Ecosystem-Level Impacts of Fisheries Bycatch on Marine Megafauna

Biodiversity Conservation through Mitigation, Policy, Economic Instruments, and Technical Change

Gland (Switzerland) 10-13 September 2013 (tentative)

Prepared by D. Squires[17] and S.M. Garcia[18]

Preamble

This document has been prepared to provide participants with a common background on the complex set of issues that the meeting will address. It does not pretend to be exhaustive and will certainly be improved during and after the meeting.

Because of the multidisciplinary nature of the workshop, it has been considered useful to provide the participants with a Glossary of terms as a means to improve communication. The Glossary terms are in italic in the core text. The definitions are given in footnote for direct access by the reader and grouped in **Appendix I.**

Executive summary

Bycatch reduction practices have traditionally focused on command-and-control measures (e.g., time-and-area closures, effort reduction) or technology standards and associated legislative changes (e.g., mesh size, hook types, bycatch excluder devices, and mandated requirements that freeze technology in place). Incentive-based bycatch reduction practices such as use rights (e.g., Dolphin Mortality Limits, DMLs), taxes, credit schemes, or insurance, may more directly and cost-effectively reduce bycatch. This approach has received insufficient attention.

Conventional bycatch reduction approaches also give insufficient attention to the holistic (ecosystem-level) impacts of bycatch. Bycatch reduction simply focused on at-sea catch ignores opportunities offered by more cost- and ecologically-effective bycatch mitigation measures that may directly increase *bycatch populations*[19] elsewhere in their geographic range or life cycle. Finally, at-sea bycatch reduction runs the danger of increasingly smaller increments in bycatch reduction at increasingly larger increments in costs (i.e. marginal costs) to the point where additional gains in bycatch reduction are outweighed by additional costs of bycatch reduction leading to a net loss in economic benefits. A net loss in economic benefits can also lead to a net loss in biodiversity and ecological benefits if the foregone economic benefits preclude conserving biodiversity at some other point in the holistic process, i.e. there can be an opportunity cost to at-sea bycatch reduction within a broad-based and holistic bycatch perspective.

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[19] The term *bycatch population* is extensively used in the document to refer to the associated and dependent species referred to by the 1982 LOSC that are impacted through accidental harvest (as opposed to targeted harvest)

A broader-based ecosystem approach to biodiversity conservation thus allows incorporating a broader range of instruments, applied at life stages and geographical ranges other than those of the strict harvesting process to achieve better cost- and ecological effectiveness.

This approach has emerged in management instruments designed for conservation of terrestrial ecosystems and mitigation of greenhouse gasses, and has included direct incentive approaches, such as payments for ecosystem services (PES), indirect incentive approaches, including community based conservation (CBC) and integrated development conservation projects (IDCPs), and biodiversity mitigation[20], such as sea turtle nesting protection that mitigates at-sea mortality, often at lower cost.

One of the most important forces reducing bycatch is "induced" and "biased" bycatch-saving technical change.[21] Examples include: the tuna purse seine *backdown procedure* and Medina panel that reduce dolphin bycatch; circle hooks and mackerel type bait that reduce sea turtle bycatch and post-hooking mortality in pelagic longline fisheries for swordfish: and current development of ecological Fish Aggregating Devices (FADs) for tuna purse seine fishing.

Further, bycatch-reducing technical change will be a fundamental component of ecosystem based fisheries management, because many policy instruments, such as catch rights, time and area closures or effort reduction, even when aimed at bycatch reduction, are insufficient to cover all species or are not cost-effective because they unnecessarily reduce profitable fishing opportunities that can help finance less expensive and more effective conservation elsewhere.

One question that arises is developing a portfolio of bycatch management instruments that not only directly reduce bycatch, but also create incentives to stimulate and direct bycatch-saving technical change. A related question is the impact of alternative mixes of bycatch-reducing instruments, since invariably multiple instruments are imposed. Some bycatch-reducing instruments, such as transferable bycatch rights (e.g. Dolphin Mortality Limits or DMLs), may not widely bind on all vessels after sufficient bycatch-saving technical change has occurred[22], but may instead serve to create economic incentives that prevent backsliding. It is likely that reductions in purse seine-related bycatch in tuna fisheries will be facilitated through the combination of multiple approaches (Dagorn et al. 2012). At some point, some management measures may become redundant and candidates for removal.

Much of the gear and equipment that reduces bycatch through technical progress is embodied with information technology, scientific knowledge, and knowledge gained through at-sea experience (called *embodied technical change* and *learning by doing*). The comparatively low cost and short economic lives of most this gear and equipment raises the benefit-cost ratio and marginal rate of return of embodied bycatch-saving technical change and facilitates rapid diffusion of the new technologies. Most

[20] *Biodiversity mitigation* is conservation actions intended to compensate for the residual, unavoidable harm to biodiversity caused by development projects, so as to ensure no net loss of biodiversity.

[21] *Biased technical change* is a change in which the relative proportions of bycatch to target species stocks changes. It produces a relative reduction of bycatch. *Bycatch-saving technical change* is a change leading to lower relative bycatch amounts being taken. It is expected to produce an absolute reduction of by-catch, but increases in effort could still lead to increased absolute amounts of bycatch if the overall increase in bycatch exceeds the reduced bycatch proportions for a given level of target catch. *Induced technical change* endogenously emerges in response to changes in market, resource, or policy conditions. *Embodied technical change* is embodied in the physical capital stock through investment, such as information technology embodied in gear and equipment, both of which are physical capital stocks.

[22] If sufficient bycatch saving technical change has occurred, DMLs would seldom be binding because not enough dolphins are caught as bycatch. However, having a management measure like a DML in place keeps vessels from becoming complacent and backsliding.

fishing gear have a short economic life and many gear types have comparatively low costs that facilitate rapid replacement of the existing capital stock with technology-embodied gear that is relatively better at bycatch-saving at comparatively low cost. The short economic lives and comparatively low cost of the gear and equipment raise the question of whether immediate bycatch-saving policy instruments, such as taxes, property rights, technology standards, quotas, or time-area closures should be designed more to facilitate rapid technical change than for immediate bycatch reduction. That is, these "second-order" effects from policy instruments may be as much as or more important and self-sustainable in the long term than the "first-order" immediate effects.

Technology policy can potentially contribute to bycatch policy, which induces and finances research and development and recognizes that knowledge is under-provided and subject to *free riding*.[23] Questions that arise about the best way to organize bycatch-saving technical change include: (i) the nature of public-private partnerships; (ii) the type and amount of research and development (R&D); (iii) financing methods in taxes and kind;, (iv) who pays?; (v) length of R&D projects, etc. Subsidies can take the form of fairly general tax credits, matching funds provided to firms for specific research proposals, and in areas where the public research institutions have specific expertise, joint ventures between industry, government and universities. Subsidies have been important in dolphin, sea turtle and seabird longline, and ecological-FAD R&D. Subsidies for gear and equipment and training boost diffusion of positive technical changes.

Biodiversity mitigation (offsets)[24] is part of a holistic approach addressing all phases of a species' life history throughout its geographic range and that provides the lowest risk, least-cost approach to conservation. Biodiversity mitigation is not necessarily intended to offset current fishing or to substitute for current at-sea and other bycatch-reducing measures. Instead, biodiversity mitigation is intended to complement existing activities to provide a holistic conservation strategy that is least-cost and addresses species conservation over the entire geographical range and life history of species. Biodiversity mitigation as part of a comprehensive bycatch reduction conservation strategy will enable consumers, processors, traders and brokers, and fishers to continue their activities and generate sufficient economic surplus to be able to finance the mitigation that leads to population increases, not simply no net loss.

This approach recognizes that there are cost-effective conservation measures that can be taken other than at-sea bycatch reduction devices and that these can have higher marginal biological and economic effectiveness than simple continued emphasis on steadily increasing bycatch reduction through conventional measures (with debatable efficiency due in part to diminishing returns).

This workshop will investigate ways to better reduce ecosystem-level impacts of fisheries bycatch on marine megafauna in large pelagic ecosystems and fisheries by:

15. Placing the bycatch issue as part of biodiversity conservation and the ecosystem approach to fisheries management, balanced harvest strategies (Garcia et al., 2011; 2012; see also section 2), broad-based conservation, and defining megafauna of explicit concern;

16. Addressing bycatch reduction within this broader context through a broader-based conservation approach with particular focus upon biodiversity mitigation and least-cost conservation over the

[23] The *free rider problem* is a situation in which some individuals or organizations consume more than their fair share of a resource, or shoulder less than a fair share of the costs of its production.

[24] Biodiversity offsets have been defined by ten Kate (2004) as conservation actions intended to compensate for the residual, unavoidable harm to biodiversity caused by development projects, so as to ensure no net loss of biodiversity, i.e., what remains after everything possible has been done to avoid inflicting that harm.

life history and geographic range of the species. A specific objective is to identify the conditions under which biodiversity mitigation can be used as a conservation tool;

17. Expanding the scope of bycatch reduction policies from conventional "command-and-control" approaches such as effort reduction and time-area closures, individual or industry bycatch quotas (performance standards) and regulation of gear, equipment, and operations (technology standards) to consider economic policy instruments that create direct incentives to reduce bycatch, such as transferable bycatch use rights, assurance bonds, taxes, and insurance schemes;
18. Evaluating from the conservation literature economic policy instruments that create direct economic incentives, such as payments for ecosystem services, indirect economic incentives such as community based conservation and integrated conservation and development projects;[25]
19. Examining bycatch-saving technical change and factors (market forces, policies, non-governmental organizations or NGOs, resource conditions) that direct and induce this biased technical change, including the policy instruments best suited to induce the desired technical change and how these instruments interact and compare with conventional policy instruments focused directly on bycatch reduction;
20. Examining technology policy that creates and diffuses bycatch-saving knowledge and technical change through formal and informal research and development by the private and public sectors and the best means of organizing and financing the effort

1. Background[26]

Bycatch consists of those species caught, besides the target species. When the bycatch is (i) landed; (ii) reported; (iii) used; (iv) integrated in fisheries assessments; and (v) and sustainable, it is just another "catch" and could be managed as such. It becomes a problem when it consists of protected, threatened or particularly vulnerable species or, for other species, when it is *discarded*[27] at sea as waste, leading to underestimating mortality and the related impacts. Bycatch must therefore be reduced if it creates a significant risk of adverse (including non-reversible) damage and this situation is the focus of this workshop.

The workshop will focus on pelagic fisheries on highly migratory species, using essentially purse seines (often with fish aggregating devices (FADs) and long lines Bycatch in purse seine and pelagic longline tuna fisheries, the two primary gear types for catching tunas, is a primary source of mortality for some populations of seabirds, sea turtles, marine mammals and elasmobranchs (sharks, skates, and rays) (Gilman 2011). Cetacean bycatch can also present a problem. Reductions in purse seine-related bycatch may be facilitated through the combination of multiple approaches (Dagorn et al. 2012).

[25] Economic incentives are *direct* if they directly alter behavior in a desired manner. For example, payments for ecosystem services create direct incentives because they are payments that are received conditional upon a verifiable outcome. *Indirect economic incentives* alter behavior only indirectly by working through another outcome or as a byproduct or joint product of another outcome such as economic development. Integrated conservation and development projects create indirect biodiversity conservation incentives because biodiversity conservation is a byproduct of economic development such as with eco-tourism.

[26] The background section draws very heavily from Gillman (2011); Gilman and Lundin (2010); Dutton, Gjertsen and Squires (2010) and Dagorn et al. (2012).

[27] *Discards* are marine species accidentally harvested by various insufficiently selective gear that are then thrown back into the sea, i.e. they are "discarded". These discards may be alive or (mostly) dead. The process itself is "discarding."

Bycatch in pelagic longline swordfish fisheries is another important source of mortality for sea turtles, seabirds, and sharks. Populations of these species are particularly vulnerable to overexploitation and disappearance of older age classes (age structure truncation), can decline over short temporal scales (decades and shorter), and are slow to recover from large declines due to their K-selected life-history strategy characterized by long life spans, slow growth, delayed sexual maturity, low fecundity, and low natural mortality rates of older individuals. Bycatch of juvenile tunas and unmarketable species and sizes of other fish in purse seine fisheries, and juvenile swordfish in longline fisheries, contributes to the overexploitation (through growth overfishing) of some stocks, and addressing the problem may raise an allocation issue (e.g. between coastal populations fishing juveniles in a country and industrial fleets from other countries fishing offshore). Bycatch in drift gillnet and longline fisheries similarly contributes to sea turtle and shark mortality.

Overexploitation of incidentally caught species, including juveniles of commercially targeted species, can cause growth and recruitment overfishing, threaten populations and their recoveries. It adversely affects future catch levels threatening the long-term capacity to provide food and livelihood and results in allocation issues between fisheries. Furthermore, discarded bycatch (or discards) raises a social issue over waste. It also raises a scientific issue regarding the data needed to assess the real levels of removals and the resulting state of related populations.

Purse seine, pelagic longline and pole-and-line fisheries are the primary commercial fishing methods for catching tunas. Large longline vessels generally catch older age classes of bigeye tuna (*Thunnus obesus*), Bluefin tunas (*Thunnus maccoyii* [southern], *Thunnus orientalis* [Pacific] and *Thunnus thynnus* [Atlantic]) for the sashimi market. Some longline fleets target albacore (*Thunnus alalunga*) for canning and swordfish (*Xiphias gladius*) for fresh and frozen markets. Purse seine vessels target younger age classes of skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares*) tuna for canning with an incidental catch of bigeye tuna. Purse seine vessels also catch a small volume of Bluefin tuna for ranching. Pole-and-line vessels catch mostly skipjack and small/juvenile yellowfin, albacore, and bluefin, primarily for canning.

Much of the bycatch issue for purse seine vessels harvesting tropical tunas arises through the increased use of Fish Aggregating Devices (FADs), initially as an alternative to setting on dolphins in the Eastern Pacific Ocean and later on, in all oceans, as an enhancement of fishing efficiency and even serving as an informal allocation instrument among purse seine vessels[28]. During the past two decades, more than half of the total tropical tuna catch from purse seine vessels came from tunas associated with artificial or natural floating "objects" (some of which are alive, like dolphins) (Miyake et al. 2010), highlighting the efficiency of this fishing method. The majority of the remaining tuna catch comes from sets on free-swimming schools (Dagorn et al. 2012) and from sets on dolphins Focusing on the current topical issue of great concern, sets on free schools and drifting FADS, These two fishing modes generate varying amounts of bycatch. Fishing on FADs generates approximately five times more total bycatch (in mass) than fishing on free-swimming schools. Levels of non-tuna bycatch are comparable to or less than in other commercial tuna fisheries and are primarily comprised of species that are not considered threatened (Dagorn et al. in press). For purse seiners, by-catch species are usually divided into six categories: tunas other than target species, miscellaneous bony fishes[29], billfishes (*Istiophoridae*,

[28] If it is considered unethical to set ones purse seine on someone else FAD (to be checked)

[29] Although up to 55 different bony fish species can be taken from around floating objects, this category is usually dominated by very few species: oceanic triggerfish (*Canthidermis*

maculatus, Balistidae), rainbow runner (Elagatis bipinnulata, Carangidae), dolphinfish, wahoo (Acanthocybium solandri, Scombridae) (Dagorn et al. in press).

Xiphiidae),[30] sharks (*Carcharhinidae*),[31] rays (*Dasyatidae, Mylionatidae*) and sea turtles (*Cheloniidae*) (Dagorn et al. in press).

Although the bycatch rates are low compared to some other fisheries (e.g. tropical shrimp trawl fisheries), the large volume of tuna caught can make bycatch of sea turtles, elasmobranchs, and other fish sufficiently sizeable as to contribute to a growing global concern. Sea turtles are occasionally entangled in FAD appendages and caught in pursed nets or entangled in lost FADs, but nonetheless sea turtles are caught in small numbers by purse seiners and are usually (?) released alive relatively easily (Dagorn et al. in press).[32] Silky shark (*Carcharhinus falciformis*) is the predominant shark species, comprising up to 90% of the shark catch, followed by the oceanic whitetip (*Carcharhinus longimanus*). The Pacific purse seine catch of silky sharks can be an order of magnitude lower than levels in longline fisheries. The ratio of catches of sharks per landed catches of target tuna for purse seiners fishing on floating objects is very low (<1%), when compared to other fisheries such as pelagic longline (Gilman et al. 2008). Longline fisheries have quite variable ratios of shark catches depending on their strategy (target species), but sharks correspond up to a quarter of total catches (Gilman 2011), even in fisheries that do not target sharks (Dagorn et al. 2012). Because they have slow growth, late maturation, low fecundity and long reproductive cycles, sharks in general (and silky and oceanic white tip sharks in particular) are among the least resilient of fish species to intense exploitation. IUCN lists silky shark as near threatened or vulnerable depending on the ocean and lists oceanic white tip shark as vulnerable or critically endangered (Dagorn et al. 2012). Seabird bycatch is not an issue for purse seine vessels. The capture of non-target species associated with floating objects could negatively impact biodiversity either by removing by-catch species in unsustainable quantities or by selective removal of some components of the pelagic ecosystem (Dagorn et al. in press).

Longline seabird bycatch is problematic primarily in higher latitudes. This bycatch primarily arises while longline gear is being set, seabirds are hooked or entangled and drown as gear sinks. Of the 61 species affected by longline fisheries, 26 are threatened with extinction, including 18 albatross species. High levels of bycatch have killed vast numbers of birds with a recent estimate for mortality in global longline fisheries ranging from 160,000 to 320,000 birds annually (Anderson et al. 2011)[33] [34]

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[30] Billfishes captured at floating objects are mainly marlins and spearfishes from the genera Makaira and Tetrapturus (Dagorn et al. 2012).

[31] Shark bycatch around floating objects is almost exclusively composed by two species: silky

sharks (Carcharhinus falciformis, Carcharhinidae) that represent up to 90% of shark catches in numbers (Gilman 2011) and oceanic white tip sharks (C. longimanus, Carcharhinidae) (Dagorn et al. in press).

[32] Turtles, however, can get entangled in the underwater netting or in the nets covering the bamboo rafts that form the FAD float. Mortality of this type is usually not estimated (Dagorn et al. 2012).

[33] Because seabirds are long-lived (10s of years) with low reproductive rates (generally 1 offspring per year) and limited numbers of breeding sites, even low-level, chronic impacts can cause the steady decline of populations. Of global extinctions of birds, 25% have been seabirds. The proportion of seabird species listed as Threatened on the IUCN Red List is high, at 31% (~102 out of 328 seabird species), with 18 seabirds (5% of seabird species) classified as Critically Endangered (IUCN 2010). Overall, seabirds are more threatened than other comparable groups of birds and their status has deteriorated faster over recent decades (Croxall et al. 2012). Of 346 seabird species considered by Croxall et al. (2012), 97 (28%) are globally threatened 17 (5%) are in the highest category of Critically Endangered, and a further 10% are Near Threatened.

[34] it would be interesting to figure out how many die naturally each year, by comparison, to get an idea of the dtress this added mortality represents) Yes – this would require an estimate of global populations size thought – something we really do not have much of a handle on for most species.

Technologies for reducing bycatch can be successful. For example, by requiring the use of such technologies, the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) has decreased bycatch of seabirds in Southern Ocean longline fisheries by 99% and set the standard for what can be achieved in bycatch reductions (Fabra & Gascon 2008). Restrictions, such as catch limits and area closures to fisheries can address the issue of competition for forage species. Recent research sets out simple guidelines for fishery managers to allocate biomass to seabirds (Cury et al. 2011). The use of monofilament leaders rather than wire leaders in longline fisheries can reduce shark bycatch (Ward 2008, Afonso 2011, Alfonsoa 2012).

Sea turtle bycatch largely occurs in the tropics and subtropics. Hard-shelled turtles tend to get caught by biting baited hooks; leatherbacks by foul-hooking on the body and entanglement in nets. Sea turtle bycatch in longline fishery was estimated as 10 000s to 100 000s caught each year in each ocean (Gilman 2011). Sharks can be up to a quarter of the total catch in some pelagic longline tuna fisheries, where pelagic sharks can be a target or bycatch and may be landed or discarded.

2. Biodiversity conservation and fisheries: the case of bycatch

The "bycatch" issue can be more broadly placed as part of *ecosystem based fisheries management,*[35] balanced harvest strategies, and broad-based biodiversity conservation. Fisheries and biodiversity conservation need to function as an integrated whole to achieve both conservation and sustainable use (Rice and Ridgeway 2010). Viewed from this perspective, "bycatch" is not simply a byproduct of harvesting, but part of a broader conservation and ecosystem issue in which "bycatch" species are part of a balanced harvest strategy that attempts to maintain ecosystem structure and function, as required by an Ecosystem Approach, recognizing that "bycatch" is one source of mortality for species – sometimes even only during select periods of their life history and geographic range. This broader perspective leads to more potential "bycatch solutions" to lower population risk and to conservation interventions that are lower cost. These interventions can, in some instances, even be least cost over some range of conservation, such as nesting site protection compared to at-sea bycatch reduction in the Hawaiian pelagic longline fishery for swordfish and the California drift gillnet fishery (Gjertsen et al. 2013). This broader approach also allows introducing policy approaches that have been used to conserve some marine and many terrestrial ecosystems and species, including biodiversity mitigation (offsets), payments for ecosystem services (PES) and other direct conservation approaches, as well as indirect conservation approaches that create indirect conservation incentives such as integrated development conservation projects (IDCPs) and community based conservation (CBC) that attempt to generate conservation as a "byproduct" of economic development (eco-tourism is the classic example).

Balanced harvest (BH) strategy is a *fishing strategy that maintains ecosystem structure by keeping fishing pressure moderate and distributing it across ecosystem components (species, sizes, and tropic levels) in proportion to their productivities (Garcia et. al., 2011, 2012)*. It requires fishing "all" sizes and species in proportion to their natural productivity and reconciles objectives of maintaining community structure and returning the highest yields. Balanced harvest strategy says that in order to fulfill the CBD requirement for an ecosystem approach to fisheries management (to maintain the structure and function of the ecosystem) all species in the trophic chain must be exploited with an equal

[35] Ecosystem-based Fisheries Management (EBFM) also referred to as Ecosystem Approach to Fisheries Management (EAFM) attempts to address ecosystem concerns and essentially reverses the order of management priorities to start with the ecosystem rather than target species (Pikitch et al. 2004, Garcia 2010). Ecosystem based fisheries management aims to sustain healthy marine ecosystems and fisheries they support.

pressure, proportional to their productivity (i.e. natural mortality). Fishers must be equitable and parsimonious predators, equitable in fishing every species in the same relative way, and parsimonious in maintaining the predation pressure at a low enough level not to threaten any population in the trophic food web. A key implication is to fish more juveniles and small species and protect more the old adults and large species (the opposite of many, if not most harvest strategies). This strategy reduces or eliminates the evolutionary drift of the species (towards faster growth and earlier maturation), reduces ecosystem oscillations, maintains age structures, and may increase yields substantially.

While the concept is not new and is intuitively correct and supported by abundant modeling, its practical policy, economic and operational implications are not completely clear yet. The workshop will offer an opportunity to discuss, in particular, the economic implications of such an approach.

3. Economic Incentives and Bycatch Policy Instruments

Although banning the use of FADs has been proposed by some NGOs[36], it is very unlikely that industry will willingly abandon this efficient fishing tool (Dagorn et al. 2012). The bycatch problem they raise needs, therefore, to be addressed. Further, the economically optimum amount of bycatch that must be reduced is not zero, and at some level of bycatch reduction, the marginal costs of bycatch reduction outweigh the marginal benefits. The question becomes how to cost-effectively reduce bycatch.

3.1 Command-and-Control Bycatch Policy Instruments

Bycatch reduction policies have traditionally focused upon traditional "*command-and-control"* measures[37] that mandate fishers to undertake specific actions (or suffer sanctions for non-compliance). Examples of command-and-control measures include time and area closures, effort reductions, bycatch quotas, discards bans (an implicit tax), prohibition of the deployment and fishing on FADs or restrictions on the number of FADs (Hall 1996; Pascoe 1997; Hall 1998; Hall et al. 2000; Hall and Mainprize 2005; Abbott and Wilen 2009; Squires et al. 2011). Industry-wide bycatch caps induce the "race for bycatch" in a manner similar to "race to fish" under industry-wide TACs for target species (Abbott and Wilen 2009).[38] Governments also resort to moral suasion[39], in which states convince players to act in a socially desirable manner. Effort reductions, such as a limit on the number of sets per vessel, cannot induce economically efficient avoidance and activity levels (Segerson 2010).

3.2 Bycatch quotas (performance standards)

Despite popular appeal, managing fishery bycatch with restrictive hard caps is a strategy that can

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[36] http://www.greenpeace. org/international/en/press/releases/Greenpeace-Calls-for-Urgent-Ban-on-FAD-Fishing-to-Save-Pacific-Tuna/

[37] *Command-and-control* measures refer to environmental policy that relies on regulation (permission, prohibition, standard setting and enforcement) as opposed to economic incentives, that is, economic instruments of external cost or external benefit internalization. Command and control regulations require entities to undertake specific activities to meet specific standards. By contrast, "market-based" regulations give companies the choice on how to meet specific standards. Instead of mandating specific activities, companies can look for the most efficient way they can reduce bycatch.

[38] A race for bycatch occurs because under open access or otherwise ill-structured property rights vessels face incentives to catch as much as possible of the target species TAC as possible before the bycatch limit is reached.

[39] *Moral suasion* is defined in the economics as "the attempt to coerce private economic activity via governmental exhortation in directions not already defined or dictated by existing statute law."

produce unexpected negative outcomes (such as the race for turtle bycatch seen in the Hawaiian swordfish fleet in 2006; Sugihara et al. 2009). This is particularly true when bycatch exhibits wide variation in numbers from year to year or is a "rare event" such as bycatch in the form of an Endangered Species (e.g., sea turtles; Sugihara et al. 2009, Segerson 2011). When bycatch species exhibit wide variation in numbers, the fundamental weakness of a restrictive hard cap is that it protects bycatch populations exactly when they need it least (when they are most abundant) and offers no protection when bycatch populations are most vulnerable (when they are least abundant, and encounters are low; Sugihara et al. 2009). That is, a fixed hard cap or performance standard creates incentives to reduce bycatch independent of bycatch abundance. Moreover, because bycatch abundance is not easily predicted, it is difficult to determine a cap in advance of the season so that a bycatch quota program can be adapted to current conditions. Policies that demand regulation at all time in anticipation of "worst case" scenarios impose special design considerations, in addition to being more costly (Wilen 2009).

Though intuitively appealing, such simple measures can actually harm bycatch populations by encouraging more careless fishing exactly when encounter rates should be lowest (provoking a higher overall bycatch rate than would occur otherwise). Simple hard caps and plans based on semi-fixed performance standards punish the industry most severely when bycatch need least protection and offer no penalty when bycatch are rare. These simplistic management strategies are well intentioned, but ultimately destructive to industry profitability and bycatch conservation.

Bycatch quotas (performance standards) typically uniformly apply across vessels or vessel size classes without regard to heterogeneous cost structures and bycatch avoidance abilities. Skippers whose previous fishing led to lower bycatch rates are penalized the same as less able or motivated skippers. Vessels that can avoid bycatch with lower costs than other vessels whose bycatch avoidance entails higher costs are penalized the same.

3.3 Technology Standards

Technology standards[40] (or regulation of gear, equipment and fishing practices), a form of command-and-control policy instruments, are also central to bycatch reduction practices. Examples include mandatory use of dehooking devices and line cutters to reduce post-hooking sea turtle mortality, turtle excluder devices (TEDs), circle hooks with mackerel type bait rather than J hooks and squid bait for swordfish longliners, monofilament rather than wire leaders to reduce pelagic longline shark bycatch, and the recent practice of attaching satellite-linked echo-sounder fish finder units to floating objects (further improving efficiency by informing fishers as to which ones might have fish underneath and are then worth visiting; Dagorn et al. in press). Technology standards can be explicitly designed to force technology, mandating performance levels that are not currently viewed as technologically or economically feasible or mandating technologies that are not fully developed (Jaffe et al. 2002). They are not generally cost-effective, since they impose the same standard across vessels of heterogeneous production and cost efficiencies.[41] At their worst, technology standards can freeze the development of technologies. Under regulations that target (constrain) technologies, as opposed to bycatch levels, an

[40] Technology standards refer to mandatory design and equipment requirements and include operating standards (Squires et al. 2011).

[41] From a technical economics standpoint, technology standards and performance standards (quotas) violate the equi-marginal principle, in which economic efficiency is achieved by equating marginal costs of harvest and bycatch reduction across heterogeneous vessels. In contrast, market-based approaches that allow vessels to flexibly achieve their goal through systems such as transferable bycatch rights allow vessels to alter production in ways that equate marginal costs across vessels.

open question arises whether or not there are economic incentive for vessels to exceed control targets, and the adoption of new technologies is discouraged. Under a "Best Available Control Technology" (BACT) standard, a business that adopts a new method of bycatch reduction may be "rewarded" by being held to a higher standard of performance and thereby not benefit financially from its investment, except to the extent that its competitors have even more difficulty reaching the new standard (cf. Hahn and Stavins 1991). To be effective, technology standards require frequent revision, but in practice regulations and legislation tends to lag. On the plus side, technology standards are effective, even if not cost effective, among the most easily accepted and implemented regulations, are often monitored and verified with comparatively low costs and ease, and are typically regulatory centerpieces (Squires et al. 2011). Technology standards are a pragmatic approach when there is uncertainty about the effects of bycatch and the political costs are lower compared to market based instruments.

Technology standards in multilateral fisheries tend to require the less demanding coordination rather than the more demanding cooperation among nations (Barrett 2003, 2006).[42] Technology standards are thus often easier to implement and obtain compliance than performance standards (bycatch quotas). For example, with TEDs, a technology standard, nations do not have to actually formally cooperate, particularly through formal and binding multilateral agreements, such as with Dolphin Mortality Limits and the Agreement on the International Dolphin Conservation Program (see below). Instead, nations can simply adopt TEDs and coordinate their technical designs; in effect, working side-by-side in parallel. Up to some point, a technology standard may induce a positive feedback or strategic complement on either the benefit or cost side so that, as one country does more, another country does more (Barrett 2003). Compliance with coordination is often easier to verify than use rights and performance standards, such as Dolphin Mortality Limits, because the technology standard can be checked on a routine basis in port, whereas performance standards require ongoing monitoring, perhaps by at-sea observers. International environmental agreements based on performance standards (quotas) tend to be comparatively narrow but deep and, in contrast, international agreements built on technology standards can be broader but shallower and easier to involve the cooperation of comparatively more nations. With technology standards, a limited group of like-minded nations can start coordination and then expand from this initial grouping. Technology standards can also be more rapidly implemented than formal performance standards. Technology standards address the problem solely as a technological problem and do not consider the behavioral issues involved, which is where economic incentive approaches enter the picture.

3.4 Economic Incentives

Command-and-control measures are top down and have not worked well in pollution or greenhouse gas control and the same recognition is growing for fisheries bycatch (Wilen 2009).[43] They are gradually being abandoned in pollution and greenhouse gas control for methods that create explicit incentives at the level of individual decision maker to reduce pollution. Increasing the cost of emitting pollution by making marginal units of emissions costly is necessary to change incentives at the plant level in order

[42] Coordinated behavior is nonbinding and does not require ratification of formal multilateral cooperative agreements, such as treaties and conventions, by member parties to enter into force, behavior can be quickly organized, which is critical for endangered populations. Coordinated behavior can also more easily be narrowed to those parties with a genuine interest, helping to sidestep the potential problem of "broad but shallow" agreements that can arise with larger numbers of participants, especially in formal multilateral cooperative agreements (Barrett 2003; Victor 2006).

[43] Fisheries bycatch problems share many features that are virtually identical with pollution problems (Wilen 2009). The inadvertent harvesting of bycatch in pursuit of profits from target species fishing is fundamentally no different from producing pollution as a byproduct of the pursuit of profits from electricity generation

to induce decisions that reduce emissions. Such concerns hold for bycatch reduction as well. Policies such as area closures and shortened seasons due to bycatch caps will not resolve the problem.

Command-and-control bycatch policies imposed at the level of the fishery as a whole may not by themselves transmit proper incentives to individual decision makers to avoid bycatch because an industry cap creates race for fish incentives.[44] Industry-wide policies are subject to several disadvantages, including the potential for free-riding behavior by individual vessels on the bycatch-reducing activities of other vessels. Incentives can also be established that induce the race to fish (Abbott and Wilen 2009, Gjertsen et al. 2010, Segerson 2011).

Economic incentives establish conditions so that harvesters, processors, and consumers consider the costs and benefits not presently captured by market values, i.e. consider and face external costs and external benefits. Without economic incentives, which effectively price bycatch, individual skippers make inappropriate decisions on when, where, and how to fish to avoid bycatch. The key to altering behavior is to impact decisions at the *margins* of individual vessel decision-making, so that catching additional (marginal) bycatch becomes increasingly costly to the vessel and more costly than adopting bycatch reducing behavior. Economic incentive approaches establish pressures for participants to reduce bycatch efficiently and to innovate and are usually more cost-effective or economic efficient than top-down, "command-and-control" regulations and laws.

Economic incentives can focus on modifying technology, such as technical change (discussed below) or introducing technology standards such as Tori lines. Alternatively, economic incentives can be process centered (such as changes in time and spatial placement of gear), or performance centered and focused on outcomes (such as the amount of bycatch). This typology corresponds to incentives that address choice and state of technology, inputs and how they are used (process), or the outputs or outcomes of applying technology and inputs (performance). Incentives affecting process are more indirect and weaker than when focused on performance, including outcomes, such as bycatch quotas and property rights. Performance-centered incentives are stronger, because they directly address the desired outcome, but in some instances they may be more difficult and costly to verify, especially in fisheries where production occurs at sea and the catch and can be difficult to observe and can differ from the landings due to discards. Process centered incentives are more indirect because only some of the inputs and practices are targeted and the relationship between inputs and outputs can be indirect and nonlinear. For example, simply restricting effort does not necessarily directly translate into reduced bycatch. Economic incentives can be classified as positive (and called "carrots"), such as property rights, or negative (and called "sticks"), such as taxes and fines). Using positive rather than negative rewards stems from working with many private users and political difficulties of imposing and enforcing sanctions (Polasky & Segerson 2009).

Enforcement and transaction costs may be substantially lower for a management measure that effectively eliminates the external benefit of reducing bycatch than for a measure that limits the bycatch choices of fishermen through technology standards or performance standards such as general bycatch quotas or reduced effort. Economic incentive measures have lower information requirements for fishery management decision makers and, in fact, provide information that is required by fishery management decision-makers. These measures also provide increased incentives for fishers to use their knowledge and ingenuity to decrease bycatch effectively and efficiently.

Economic incentives that directly motivate individual vessels can be approached in two ways: (1) directly implement policies at the individual vessel level or (2) implement policies on groups of vessels

[44] There are exceptions, see Segerson (2011), some of which is discussed below.

sufficiently small to devise and self-manage their own bycatch reduction scheme (Wilen 2009, Segerson 2011). Examples of the latter include group insurance (Holland 2010) and bycatch quotas (Segerson 2011). Industry-based approaches can have several advantages, particularly in the presence of uncertainty such as bycatch that is rare and stochastic, thereby allowing for possible risk sharing or risk pooling, such as an insurance scheme. Industry-wide limits can also increase incentives for vessels to work collectively to ensure that the bycatch target is met through, for example, sharing information about bycatch density in specific areas. Industry-wide policies are subject to several disadvantages, including the potential for free-riding behavior by individual vessels on the bycatch-reducing activities of other vessels. Incentives can also be established that induce the race to fish (Abbott and Wilen 2009, Gjertsen et al. 2010, Segerson 2011).

3.4.1 Incentives effects and fiscal effects

While policies must be costly at the margin to affect behavior, they need not impose burdensome fiscal costs that are directly incurred by fishers (Wilen 2009, Segerson 2011). (This section briefly discusses the issue and is given further attention when discussing taxes following Segerson (2011)). A bycatch tax, for example, can induce vessels to avoid bycatch but be accompanied by a lump sum rebate that alleviates some of the fiscal impact. In general, the fiscal effect of economic policy instruments that increase the cost of each additional bycatch to the decision maker and induces behavioral change can be mitigated through lump sum changes in compensation. Care must be taken to avoid canceling incentive effects by making the lump sum dependent on the incentive penalty. For example, a policy that charges decision makers with a fee per bycatch and then rebates the precise amount paid has different behavioral implications than a charge for undesirable outcomes and an independently and predetermined lump sum.

3.4.2 Asymmetric information, incentives, and regulation

Asymmetric information problems arise, in which buyers (principals) and sellers (agents) hold different amounts and quality of private information, their interests misalign, and problems are thereby created for incentives aligning between principals and agents in the desired direction of the principal (Vestergaard 2010). In simple language, the agent, such as fishers reducing bycatch, do not face the same incentive as the principal – the fishery regulator -- to reduce bycatch. A standard asymmetric information problem in fisheries is the “principal-agent problem”. A “principal-agent problem” arises whenever an individual or public agency or regulator (the principal) has another person, office, or firm (the agent) perform a service on its behalf and cannot fully observe the agent’s actions, inducing information asymmetry. Principal-agent theory focuses on mechanisms to reduce the “problem” of asymmetric information, such as defining and selecting the “right” types of agents, implementing incentive contracts, including instituting forms of monitoring and various amounts of positive (“carrots”) and negative sanctions (“sticks”). The underlying assumption is that the agent’s interests may differ from those of the principal. Strategies to mitigate the problem produce a type of transaction cost, reflecting the fact that without cost, it is impossible for the principal to be sure that agents will act in the principal’s best interest. In other words, an economically efficient allocation cannot be obtained.

In regulated industries, such as fisheries, the regulator, i.e. fishery manager, acts as principal, designing an incentive scheme or contract for the vessels (agents), whose activities are being regulated. The incentive scheme or contract in fisheries can be viewed as a management measure or regulation or as a private arrangement between various gear groups or fishing vessels. In reality, it is very difficult for the fishery manager to control the actions taken by fishers. The situation in which the fishery manager (principal) cannot precisely control the fishers (agent) has been termed a principal-agent problem.

Regulatory authorities typically find that the information they need during the planning phase is known only by those who are to be regulated (Kwerel 1997). In this situation a serious incentive problem may arise. Unless a system can be designed which makes the objectives of the individual agents coincide with the regulator's objectives, self-interested agents will systematically deceive the regulatory authority when asked to reveal their information. From a policy management point of view, regulating while assuming full information will create an inefficient allocation of resources, and therefore the regulator has to create an incentive compatible regulation where the agents will reveal their private information. This has a cost, but the allocation is better than just going ahead with regulation assuming full information. The two key features of principal-agent problems are that (1) the principals know less than the agents about something important, and that (2) their interests conflict in some way (Vestergaard 2010).

There seem to be two sources of asymmetric information problems (Vestergaard 2010):

1. Problems where agents can do some costly action to improve outcomes for the principal but the principal cannot observe the action. The unobserved behavior occurs after a contract or regulation. These are known as moral hazard or hidden action problems. For example, this can involve fishers' effort in the harvesting process to reduce "bycatch" species, where reducing bycatch is costly. With bycatch quotas, the information about the variable—catches—is typically known only by the fishers, who are to be regulated (Vestergaard 2010). Self-interested fishers will systematically deceive the regulator, when asked to reveal their information about catches, unless a system can be designed that aligns the motives of the fishers with the social objectives. Without on-board observers or electronic observing systems and fines to punish for violations ("sticks"), fisher incentives are not aligned with that of the regulator. Moral hazard can also arise through misreporting, illegal landings, and the like. Ideally, positive incentives are created in which fishers receive net benefits for reducing bycatch and that overcome the incentive to violate or free ride on other fishers' bycatch reductions. Vestergaard (2010) and Segeson (2011) discuss various tax schemes.
2. Problems in which there are different types of agents, and principals cannot distinguish between them. These are known as adverse selection or hidden information problems when the types are fixed and the question is which agents will participate. Vessel buyback programs to reduce bycatch, for example, would face an adverse selection problem because fishers selling their vessels might have been exiting the fishery anyway or they offer "lemons", i.e. vessels of poor quality, since the buyback authority typically does not observe variations in vessel quality and instead bases decisions on a standardized metric. Adverse selection, in which unobserved behavior occurs before contract or regulation, could arise if: vessels inflate their catch history prior to establishing transferable bigeye property/use rights or in programs of payments for environmental services from longliners to purse seiners to reduce bigeye catches (see below) there are different types of purse seiners that longliners cannot distinguish and participation and performance are unclear; or purse seiners would have reduced bigeye catch anyway because of consumer market incentives. The longline payment if not structured to account for information asymmetry does not overcome principal-agent problems, since vessels can free ride on other vessels' reductions or payments. Formal revenue sharing between longliners and purse seiners for reduced purse seine bigeye catch that increases longline catch is an example of an agreement with positive incentives that help contain asymmetric information issues, since payments target observable results.

3.4.3 Self-enforcing international agreements with transboundary fisheries

Transboundary resource and jurisdictional problems arise because there is no central authority to organize and enforce conservation. Conservation and recovery limited to unilateral measures by individual nations are likely to fall short of the required conservation level, which instead requires cooperative and multilateral conservation, involving the efforts of multiple nations acting in tandem. Because there is no central authority to organize and enforce conservation in these situations, self-enforcing and voluntary agreements are required (Barrett 2003).

3.4.4 Technology of public good supply and economic incentives

How global public goods are supplied affects incentives (Barrett 2007, Arriagada and Perrings 2011). (See Appendix IV for further discussion.) *Additive* public goods, the simple sum from each supplier, cannot be supplied by a single provider, and instead depend on all entities' combined efforts, such as reduced carbon emissions to lower ocean acidification. Unilateral shark conservation by a single vessel or fleet is ineffective, because shark mortality is inflicted by other vessels or fleets and there may be little or no net conservation gain. The most effective provider supplies *single-shot* public goods, such as conservation technology available to all, allowing unilateral supply and minimal free riding problems, such as U.S. development of circle hooks and mackerel-type bait rather than J-hooks, squid bait for swordfish longline harvesting, Medina panels for tuna purse seines nets to protect dolphins, or French-Spanish development of tuna purse seiner eco-FADs. Benefits from *weakest link* public goods depend upon the least effective provider, and benefits from *weaker link* public goods depend on all links, with the weakest link the most important; supply incentives are weak, free riding problematic, and conservation should first begin with the weakest link. Bluefin tuna conservation is a weaker link public good because spawning ground protection is critical, but conservation throughout the life cycle counts. Fish with downstream externalities, in which one fleet harvests juvenile fish and another fleet harvests adults also show characteristics of weaker link public goods, with bigeye tunas possibly fitting this category, where purse seiners harvest younger bigeye before longliners can harvest adults. North Pacific loggerhead sea turtles nest only on southern Japanese beaches and South Pacific loggerhead sea turtles nest solely on Australian beaches, so that these are weaker link public goods; multiple countries impart bycatch mortality on these turtles but they have a single nesting location, the weaker link.

The implication for bycatch reduction is that different bycatch conservation policies have to be crafted and financed depending upon the nature of the issue at hand. Bycatch saving technical change can be best shot and rely upon a single nation or a consortium of nations, which in fact tends to be the case, so, for example, that little time and effort needs to be wasted going through Regional Fishery Management Organizations to organize research and development. Bycatch species with distinct breeding areas, pupping grounds, nesting sites, or rookeries may be weaker link and when combined with cost-effectiveness considerations, augers for biodiversity mitigation (offsets) and a broad-based conservation approach rather than a narrow at-sea bycatch focus that is the only consideration.

3.4.5 Distribution of benefits and costs and incentives

The distribution and nature of costs and benefits of conservation contributes to a misalignment of incentives for conservation and recovery (Dutton et al. 2011). Benefits from conservation of some charismatic megafauna are largely enjoyed by populations in high-income, developed countries or high-income groups in developing countries. These benefits are predominately non-market economic values, notably existence value and, to a lesser extent, indirect use value. As economic values without markets, the question arises of how to create markets or other mechanisms to express consumer demand for indirect use and nonuse value associated with conservation. The costs, in contrast, sometimes fall on lower-income local communities, largely in developing countries, many of which are marginal to their societies and can ill afford to adopt costly conservation measures. This issue is particularly acute with sea turtle conservation focused on nesting sites. These costs are also immediate and tangible through lost incomes and consumption of turtles, turtle eggs, fish, shrimp, and other marine-related resources associated with turtles (i.e., these costs are largely opportunity costs of direct use values forgone). Actual compensation from the gainers to the losers or those bearing the costs (side payments) for the conservation measures may then be required, so that all parties gain from the conservation action.

3.5 Policy Instruments that Create Economic Incentives

A number of policy instruments generate economic incentives (Boyce 1996; Herrera 2005; Bisack and Sutinen 2006; .Sugihara et al. 2009; Wilen 2009; Segerson 2010; Pascoe et al 2010). They include: (i) taxes, fines and subsidies; (ii) deemed values; (iii) bycatch insurance schemes; (iv) trade measures; (v) individual tradable encounter credits; and (vi) harvest priority programmes. These instruments are examined in more detail in the following sections. Sections 6 and 7 introduce policy instruments that generate economic incentives and that are not drawn from the fisheries and pollution literature, but from the biodiversity conservation literature.

3.5.1 Taxes, fines and subsidies

The first general grouping is taxes, fines, and subsidies. Bycatch can be directly taxed, providing a penalty upon capture, that forces vessels to internalize external costs and alters fishers' behavior in the direction of reduced bycatch rate and mix (Segerson 2011). MCS and enforcement issues arise and the most difficult is establishing the tax rate, whether to tax bycatch directly, or tax target species at a presumed bycatch rate; the latter is less accurate and provides weaker incentives and periodic sampling of catches is required through onboard observers.

Taxes that are lump sums, as opposed to the bycatch rate, do not directly establish incentives at the margin. Fiscal effects of taxes can be mitigated by lump sum rebates, although they must avoid canceling the incentive effects by making the sum dependent on the incentive penalty. Penalties and fines raise costs, but are difficult with rare event bycatch such as sea turtles.

Fines can be levied on bycatch exceeding target levels. Fines must be set high enough that vessels receive higher profits by complying than not complying. Reward systems when bycatch quota is not reached can be credits used in other years or payments (Segerson 2011, Sugihara et al. 2009). Fines when bycatch is high can be used to finance incentive payments when bycatch is low. When fines equal rewards there is no rent generation, although the distribution among fishers may differ. When penalties and rewards are applied they can lead to efficient incentives for both fishing activity and bycatch avoidance and not create incentives for free-riding if each vessel is penalized and rewarded according to the amount of bycatch, i.e. if penalized or rewarded "at the margin."

Direct taxes or limits can be applied on FADS, with two effects on incentives: (1) creating incentives to reduce the overall level of effort by raising costs, which in turn reduces both bycatch and target species catches and (2) creating incentives to shift to unassociated sets. Full retention of bycatch is an indirect tax that creates both direct and indirect costs that create incentives to alter behavior. Direct costs include sorting, handling, and marketing of bycatch and indirect costs are the opportunity cost of foregone hold space and profit for target species with bycatch retention. The net cost of full bycatch retention is bycatch profit-reduced target profit.

Bycatch reduction subsidies or tax breaks can also lower bycatch by subsidizing adoption of conservation policies, but raise the issue of financing. Relieving import taxes and tariffs could be eliminated for the importation of bycatch reduction devices and thereby reducing the cost of bycatch reduction.

3.5.2 Deemed values

Deemed values are another bycatch reducing approach that charges vessels in proportion to the landed value for any catch of quota species for which they do not hold quota (Sanchirico et al. 2006, Pascoe et al. 2010). The primary purpose of deemed value system is to provide an incentive to cover catch with available quota for fishers. The deemed value approach reduces discarding of over-quota bycatch and ideally does not provide an incentive to continue to target it. The deemed value charged to the fisher can increase as their level of accounted for (over quota) bycatch increases. The object of the deemed value fee is to provide sufficient incentive to land the over-quota bycatch but not sufficient incentive to target the species. Port prices are used as the main indicator of market value, which implies that the deemed values are a proportion of port prices.

3.5.3 Bycatch insurance schemes

Bycatch insurance schemes (Holland 2010) share bycatch risk among a group of vessels, and are similar to bycatch quotas. They are especially useful for rare event / highly uncertain species such as sea turtles. As with all insurance schemes, both moral hazard and adverse selection issues arise. Assurance bond approaches (Pascoe et al. 2010) place a sum of money into trust and the bond is refundable provided bycatch damage is not incurred beyond some level or is repaired such as through biodiversity mitigation.

3.5.4 Trade measures

Additional approaches include trade measures (Joseph 1994; Joyner and Tyler 2000; Barrett 2003, LeGallic 2008; Gjertsen et. al. 2010) and consumer market responses such as such as dolphin-safe tuna and MSC labeling or consumer education through Seafood Watch (Teisal et al. 2002; Ward and Phillips 2010). Trade restrictions, to be effective, need to be sufficiently severe so that, when imposed, behavior will be changed and credible, meaning that given that a country chooses not to cooperate, or not to comply, the cooperating countries are better off for imposing restrictions. This approach can be used effectively only by countries with economic leverage. Trade measures, acting as a credible threat, include measures to prohibit imports and to prohibit landing, port use, and transshipments. Trade measures are subject to production and trade leakages (also called transfer effects). Production leakages occur when regulation production, such as harvesting subject to bycatch limits, relocates to another country or flag state vessel or a vessel reflags to circumvent the bycatch regulation. If a production leakage is severe enough, unilateral conservation may only redistribute production and has no long-term favorable impact on mortality. Such a production leakage occurred with limits on sea turtle bycatch in the Hawaiian shallow set pelagic longline fishery for swordfish (Rausser et al. 2009). Trade leakages occur when vessels from nations facing a bycatch regulation and a trade restriction divert international trade of fish from the country imposing the trade measure to another country without such a measure, to its domestic market, or launders the fish through a third party.

3.5.5 Individual tradable encounter credits

Individual tradable encounter credits (ITEC) programs are a market-based bycatch credits trading plan (Sugihara et al. 2009). Sectors are allocated fixed annual allocations of bycatch credits amounts under the industry-wide hard cap. These are then distributed to individual vessels according to a specifically designed uniform allocation rule (the Legacy Allocation Rule) that provides vessel-level incentives to avoid bycatch encounters. Vessels can use or trade credits within and across sectors to offset bycatch encounters and these transfers of ITEC are moderated by rules that further strengthen incentives and prevent potential abuses.

ITEC programs *reward* individual vessels with low (relative to other vessels at that time) bycatch levels, by: (1) providing higher credits allocations in the subsequent year (so called “bonus credits”), and (2) creating an additional source of revenue, through the selling of excess credits to vessels that need them (Sugihara et al. 2009). Conversely, ITEC systems *penalizes* vessels with high encounter levels by: (1) decreasing credits allocations in the subsequent year (so-called “credits penalty”), and (2) requiring vessels that have run out of credits to decide to either buy credits (cost) or lease their target species to cleaner vessels having extra ITEC.

ITEC programs are comprised of two main components, *legacy allocation* and *transfer component* (Sugihara et al. 2009). The *legacy allocation* is comprised of rules to reallocate ITEC among vessels, which addresses long-term financial incentives. The legacy allocation reallocates ITEC away from vessels with higher encounter rates toward cleaner fishing vessels. Incentives to avoid bycatch are strongest in years of low bycatch abundance. A key incentive mechanism is the allocation of credits based on current and past (legacy) encounter rate behavior. The intrinsic fishery value of credits can be very high, and in years of high bycatch abundance the cost of forgone target species catch under a bycatch hard cap can represent a significant loss. Having extra bycatch encounter credits or so-called “bonus credits” over and above the initial allocation based purely on target species makes the value of avoiding current encounters high if in the future there are years of high or moderate bycatch abundance. This requires forward thinking similar to buying insurance. Having extra credits reduces the risk of expenses associated with encountering years of moderate to high bycatch abundance.

The *transfer component,* the second main component of ITEC programs, is a set of rules to regulate ITEC trading between vessels. The transfer component addresses both long- and short-term financial incentives. The program: (1) discourages chronically bad players who place a drag on the fleet; (2) reinforces individual incentive requirements, and (3) to specifically keep the realized bycatch far below the hard cap whenever possible (i.e. through dynamic bycatch savings). The Transfer component limits the number of credits that a vessel can purchase and significantly reduces the excess supply of credits especially during low abundance years. It reinforces the long-term incentives of the allocation scheme as well as the short-term incentives created by trading ITEC by promoting higher credits prices in times of low encounter rates. The incentive structure is similar to the incentives for trading pollution offset credits, however it also involves a dynamic bycatch savings to control possible excess supply at times of low bycatch abundance.

In sum, ITECs: (1) Provide incentives to avoid bycatch that operate at the *individual vessel level;* (2) *Reward* vessels that successfully avoid bycatch and/or *penalize* vessels that fail to avoid bycatch; (3) Incentivize vessels to avoid bycatch at *all levels of abundance in all years and* (4) Incentives must influence fishing decisions *at levels below the hard cap.*

The Scottish Conservation Credit Scheme is another credit scheme (van Riel et al. 2012). Vessels complying with avoiding the entire cod stock fished in Scottish waters are allowed extra kilowatt days at sea as a compensation for not fishing in cod dense areas. Non-compliance is penalized by lowering the extra days received. The scheme eventually gave additional days for vessels using specified cod avoidance gear.

3.5.6 Harvest priority programs

Harvest priority programs require the existence of target catch quotas or seasons and reserve part of target catch quotas or seasons for vessels that meet specific bycatch standards.

Rights-based mechanisms

Rights-based mechanisms allocate rights to a fishery, such as to individual fishers, companies or associations, typically with an aim to avoid exceeding optimal catch levels, but the concept is also of relevance to meeting bycatch mitigation objectives. Dolphin Mortality Limits under the Agreement on the International Dophin Conservation Problem for tuna purse seine vessels in the Eastern Pacific Ocean setting on dolphins to catch large yellowfin tunas are an example (Joseph 1994, Hall 1998, Gjertsen et al 2010, Hannesson 2010, Segerson 2010). They have also been proposed by harbor porpoise bycatch in the New England gillnet fishery (Bisack and Sutinen 2006). Transferable bycatch rights, unlike individual transferable quotas for target species, have nothing to do with incentives to maximize the value of the catch or maximize the cost of taking it, and instead are more akin to quotas intended to limit the emission of harmful substances such as sulfur dioxide (Hanneson 2010). An overall bycatch quota limits the overall catch and is then allocated to individuals or to states and then to individuals. Transferable bycatch quotas help minimize the losses and are helpful when there are skill differences among vessel captains and crews in avoiding bycatch mortality. Captains better skilled at avoiding bycatch would be willing to buy bycatch quotas from less skilled captains at a price the latter would find acceptable, allowing the purchaser to harvest greater catches of tunas or swordfish for given levels of dolphin mortality. When bycatch is a rare event or a purely random process, individual quotas become problematic and a common or group quota may be preferred (Hannesson 2010, Segerson 2010). Issues arise as to individual or group quotas, transferability or limits on it, duration and divisibility of quota, whether to specify by area and individual species or groups of species (DMLs for example pertain to four species of dolphins), and other factors.

Transferable bycatch property/use rights

Transferable bycatch property/use rights can also be used to address “upstream” and “downstream” harvesting on the same species by two different gears in different geographic areas and at different stages of the species life. Tuna purse seine vessels setting on drifting FADs to supply tuna canneries, for example, harvest bigeye tunas that are often smaller and younger (even sexually immature) than when tuna longline vessels set on bigeye for sushi markets. A number of studies have shown that letting the FAD-caught bigeye to grow and sexually reproduce leads to a higher overall economic rent in the fishery and allows a higher bigeye maximum sustainable yield (Campbell 2000, Sun et al. 2010). Transferable bigeye property rights allocated to the purse seine and longline vessels would in principle allow the bigeye rights to rest in the hands of the highest-valued vessels and gear type with gains from trade for both gear types.

Several factors must be explicitly incorporated into the benefit-cost calculus for transferable bycatch rights. Observer programs may be required at considerable cost. As with DMLs under the Agreement for the International Dolphin Conservation Program, a sophisticated and transparent multilateral verification system would be required. Because property rights are established in a multilateral context, considerable fishing on the high seas occurs, and because the existing international observer program is involved, formal Regional Fishery Management Organization participation is required. Both the multilateral procedure to establish and then operate such a system generates additional costs that must be weighed against rent gains.

Property rights in principle could be allocated based on historical catch and grandfathering, but potential for discord and high transaction costs exists. In effect, purse seiners, the “upstream” entity, hold considerable sway and their “catch history” grew with the advent of FAD sets. Longliners, whose historical catch has progressively fallen as PS sets on FADs have grown and who are the “downstream” entity with less sway, may even object to allocating rights to an “upstream” entity that in their eyes has progressively usurped their catches.

Additional responses creating economic incentives include third party eco-labeling for marine capture fisheries, adoption of scientifically rigorous sustainable seafood sourcing policies by retailers, and other market-based mechanisms that are becoming an increasingly effective ‘voluntary’ incentive to improve fishing practices and governance. Implementation of sustainable seafood sourcing by a rapidly increasing number of retailers suggests that growing demand for certified seafood may result in an increased supply and market penetration and is a major source of economic incentives through the market effect.

4. Spatial closures

Spatial closures (also “time-area” closures) are one of the tools commonly used by fishery managers, can be considered an input control, and include conventional spatial restrictions used in fisheries management (such as refugia or fisheries reserves) and Marine Protected Areas (MPAs) *stricto sen*su (ISSF 2012). Pelagic spatial closures for bycatch species may be more effective than for target species. Spatial closures can be static or dynamic in space. Environmental influences can change the distribution of the species of interest, and this should be considered in the design of closures. Spatial closures are likely to be most effective in large pelagic fisheries if they are considered not in isolation but in conjunction with other fishery management measures, and if they are implemented as MPA networks to cover the whole habitat and life cycle.

Three mechanisms through which conservation benefits might be realized with spatial closures are possible (Martin 2012). The first is protection of individuals for a proportion of their life span long enough to allow populations to recover. Differences in mobility between pelagic species may make some species more predisposed to protection with spatial closures than others, so that spatial management in the pelagic environment is likely to offer the greatest benefits to less mobile species groups (small oceanic pelagics; large and nearshore pelagics) which may gain from relatively small closures if the majority of their distribution is protected. The second mechanism, protection of a particular life history stage through targeted spatial closures, depends on whether the gains are greater than the losses generated from effort displacement outside the closure and is also highly dependent on the identification of the most appropriate areas to protect that provide the greatest conservation benefit and the response of fishing fleets to closures. The third mechanism is the elimination of incidental impacts of fishing on non-target species and benthic habitats. Benefits could also include through spill-over of adults in adjacent fishing grounds and net export of eggs and larvae.

MPAs can best aid conservation of sharks and rays if they cover bycatch hotspots and minimize exploitation of aggregations, particularly at key life stages (Fordham 2012). Some of the issues of concern include deciding when, where, and how large the closure should be. Identification of “hot spots” should involve examining both areas of high bycatch/catch ratios, but also areas of high total catch.

Examining species assemblages could help identify potential closures that reduce bycatch of more than one species (ISSF 2012). Care should be taken to avoid transferring the problem elsewhere or to another species due to redistribution of fishing effort. Dynamic closures may be necessary in some cases to accommodate temporal changes in species distributions.

Sustaining biodiversity is often the stated reason behind calls for MPAs (ISSF 2012). The connection between tuna fisheries management and biodiversity protection is somewhat attenuated. In the oceanic environment, closures could potentially have to be very large to ensure meeting this goal, or use MPA functional networking principles, depending on the location and features of interest. In practice, it may be easier to use target closures to deal more directly with species of concern, such as with reducing bycatch. In some cases, a closure can potentially reduce biodiversity if fishing effort is redirected and concentrated outside the closed area.

Oceanic closures would probably have to be very large to maintain relatively undisturbed ecosystems and their processes (ISSF 2012). Other than the effect of removal of target and non-target species by the fishery and although there is active debate over hypotheses surrounding potential ecosystem-level effects by drifting FADs themselves, there was no evidence presented at the workshop that tuna fisheries disturb ecosystems such as altering habitat or ecosystem function.

Because ISSF held the 2012 workshop on spatial closures, including MPAs, for tuna and other pelagic fisheries, the proposed workshop does not need to revisit this topic other than to note that spatial closures, including MPAs, can be an effective management measure to address bycatch. The above discussion draws directly from the final report (ISSF 2012).

5. Bycatch-saving Technical Change and Policy Instruments

5.1 Bycatch-saving Technical Change

Technical change has been one of the most important methods to reduce bycatch in the fisheries for large pelagic species, notably the dolphin-tuna, circle hooks and sea turtles, and seabird and pelagic longline issues. Specifically, the bycatch-saving technical change responses taken have largely been aimed at: changing technology *embodied*[45] in the capital stock, such as the Medina panel when purse seines set on dolphins in the Eastern Pacific Ocean (Joseph 1994; Hall 1998; Gjertsen et al. 2010) or gear selectivity (Hall 1996); *disembodied technological change*[46] through altering fishing and post-capture handling practices and learning by doing (Joseph 1994; Gjertsen et al. 2010; Dagorn et al. in press) in order to reduce the amount of bycatch relative to target catch, i.e. to change the *bias of technical change*. [47]

Bycatch-saving technical change[48] reduces the relative amount of bycatch compared to the target catch. Examples include: acoustic pingers to reduce cetacean bycatch in gill-nets sorting grids to reduce groundfish bycatch brought aboard such as the Nordmore grate in temperate water shrimp fisheries,;

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[45] *Embodied technical change* is technical change that is incorporated into an input, typically the capital stock, and usually incorporated into the fishing process through investment. Examples include new designs in the hull, propeller, and gear, changing materials (e.g. steel versus wood hull, monofilament nylon net instead of natural materials, Medina panel, information technology-embodied electronics and gear, and design of FADs (including eco-FADs).

[46] *Disembodied technical change* refers to technical change that is not embodied in an economic input, notably the capital stock or is not investment-specific, i.e. it is independent of physical capital accumulation. Disembodied technical change often refers to learning how to work with new technology that leads to changes in fishing and post-capture handling practices..

[47] *Biased technical change* is a shift in the harvesting and post-capture handling technology that favors either the relative use of an input over another or the relative harvest of an output (species) over another. More technically, biased technical change is a shift in the production technology that favors one input over another (or output over another) by increasing its relative productivity and therefore its relative demand. The direction of technical change, whether bycatch using or saving, may be determined endogenously by innovators' economic incentives shaped by relative input (or output) prices, the size of the market, and institutions.

[48] *Bycatch-saving technical change* reduces the relative amount of bycatch resource stock inadvertently harvested compared to the target resource stock harvested. Bycatch-saving technical change thus reduces the relative ratio of bycatch to target resource stock(s) and can vary by species.

Tori lines to reduce seabird bycatch by longlines; circle hooks rather than J-hooks to reduce sea turtle bycatch with pelagic longlines for swordfish; trawl net mesh design and size to increase juvenile groundfish escapement; turtle excluder devices for shrimp trawls; the "Eliminator Trawl" to reduce cod bycatch while maintaining target catch (haddock); modified hanging ratios and aspects in gillnets; turtle and flatfish reduction devices in scallop dredges; selection vents in trap gear; weak links in risers from fixed gears, and more.

This technical change is responding to increasing bycatch stock relative scarcity and also reflects the market effect in which changing consumer preferences for "sustainable" seafood establishes a demand-pull price effect and a market large enough in many fisheries for increasing technology embodied in capital and for research and development (R&D). The continued growth of information technology and its falling costs give a technology-push thrust to bycatch-saving technical change. Bycatch-saving technical change is biased (because the relative proportion of bycatch to target species declines), and is always comprised of disembodied and usually embodied technical change.

Learning by doing[49] in the form of changing fishing practices contributes to bycatch-saving innovation, such as avoiding hot spots, time-area closures, shorter duration trawl net tows or shorter longline soaking time to lower sea turtle drowning. (Here we focus on only changes in technology, not policy instruments such as quotas, property rights including DMLs, etc.). Other changes in practices include selection of large schools (Dagorn et al. 2012), avoidance of areas where sharks[50] are known to be abundant (Watson et al. 2009), the immediate release of live sharks as soon as they are brought on deck (Dagorn et al. 2012), and luring sharks away from FADs by distracting them with a bag of chum in the water.. Learning by doing through post-capture handling practices contributes to bycatch-saving technical change and means that bycatch-saving in the resource stock and in landings are not exactly related since bycatch can be released alive. Examples include using line cutters for sea turtles or backdown procedure by tuna purse seiners to allow dolphins to escape the net.

Bycatch-saving technical change depends in part on the ability to distinguish and separately harvest target and bycatch species resource stocks during the actual fishing process and post-capture handling practices that reduce relative bycatch mortality, such as sorting grids for groundfish or line cutters for sea turtles. Research and development (R&D) and at-sea trial and error generate scientific, engineering, and practical knowledge that enters the gear and equipment design, vessel electronics, and learning by doing (bycatch avoidance fishing practices)

The comparatively low cost and short economic lives of the information technology- and knowledge-embedded gear and equipment required for bycatch-saving technical progress raises the benefit-cost ratio and marginal rate of return of this technical change and facilitates rapid diffusion of the new technologies. Most fishing gear has a short economic life and many gear types have comparatively low costs that facilitate rapid replacement of the existing capital stock with gear that is relative bycatch-saving at comparatively low cost. While not inexpensive, adding the Medina panel to tuna purse seine nets was vastly more inexpensive to the purse seine vessels setting on dolphins in the Eastern Pacific

[49] *Learning by doing*, a form of disembodied technical change, describes how production costs tend to fall and efficiency rise as producers gain production experience.

[50] Ward et al. (2009) provide a comprehensive analysis of the biological and socio-economic impacts of banning wire leaders, which are associated with higher shark catch rates. Their conclusions are promising; overall, this gear alteration (replacement with monofilament line) increased the catchability of target species (in this case bigeye tuna) while decreasing shark catch rates by 58 percent, and the increased returns outweighed the costs of replacing and repairing gear damaged by sharks (Ward et al. 2008).

Ocean than foregoing target yellowfin tuna catch. Adopting Tori lines is similarly comparatively inexpensive. Economic costs include direct gear and equipment costs and foregone profits.

5.2 Research and Development (R&D) and Technical Change

R&D develops new ideas and knowledge (Jaffee et al. 2005). The R&D process is costly, requiring the investment of capital by firms and government. Innovation responding to the needs of the marketplace is *demand-pull* and to new research opportunities provided by knowledge advances is *technology-push*. For example, the adoption of information technology embodied in capital stock to find fish and reduce bycatch corresponds to technology-push and the adoption of scientific knowledge and information technology to reduce bycatch in response to consumer demand for eco-labeled fish is demand-pull. Both demand-pull and technology-push sources of innovation affect the expected marginal rate of return from innovation. Demand-pull influences raise MRR by making the potential innovation more valuable. For example, consumer demand for eco-labeled seafood with a price premium and market share creates a market for bycatch-saving innovations such as sorting grids for groundfish or turtle excluder devices for trawl-caught shrimp. The considerable advances in information technology in the military, aerospace, and information technology industries, which are technology-push, increase marginal rate of return by improving the likelihood of finding and catching fish and at lower cost or by avoiding bycatch.

Private firms do not have incentives to provide the socially optimal level of research activity due to knowledge spillovers that result in a wedge between private and social rates of return to R&D (Jaffee et al. 2005). Technological knowledge is a public good that is non-rivalrous, so that one vessel's use of knowledge does not affect the amount of knowledge available to another. One firm's provision of technology through R&D or learning by doing creates an external benefit that other firms can enjoy without paying for this knowledge, i.e. free riding.

These spillovers lead to under-provision of technology, a public good, by private firms and a role for government, whose R&D can help to fill the underinvestment gap. In principle, public R&D considers the social returns when making investment decisions. R&D subsidies encourage the creation of new technologies, but they do not create incentives for the adoption of new technologies unless they reduce the cost of the new capital. Subsidies can come through tax credits, matching funds provided to firms for specific research proposals, and in areas where the public research institutions have specific expertise, joint industry–government-university ventures.

5.3 Technology-based policy for bycatch reduction

Market failures (externalities) associated with bycatch interact with market failures associated with the innovation and diffusion of new technologies (Jaffee et al. 2005). The external benefits and free riding associated with bycatch or biodiversity and technology provision arise because both are public goods, and the incentives for private provision lead to under-provision and at levels below the social optimally level.

Policies that internalize the external cost from bycatch (i.e. make consumers and producers pay the otherwise unpriced environmental cost) stimulate the creation of environment-friendly technology by increasing the demand for low-cost bycatch-saving methods (Jaffe et al. 2005). This demand-pull or market effect spurs innovative activity by increasing the value of new innovations. Thus, bycatch reduction policy instruments, such as time and area closures or bycatch quotas or retained catch policies, not only lower bycatch, but also create incentives that induce bycatch-saving *biased technical* *change.*[51]

Bycatch policy instruments chosen in isolation and without regard for the incentives directing bycatch-saving technical change may not be optimal when these incentives plus the direction and amount of *induced biased technical change* (see footnote 51*)* are jointly considered. Some bycatch policy instruments create more specific and targeted innovation incentives than others. For example, temporary bycatch taxes or permanent bycatch property rights, such as DMLs, generate stronger incentives to innovate than less discriminatory command-and-control policy instruments such as time and area closures or effort limits and may also have lower adverse impacts on target species catches. More specific bycatch policy instruments more directly increase the bycatch shadow price than more general policies, and hence alter relative factor prices that induce innovation, coupled with potentially lower foregone profits.

The trick is to choose the bycatch policy instruments creating the strongest direct incentives to reduce bycatch and to innovate plus combine this policy with a more basic R&D policy to foster bycatch-saving technical change. Much bycatch-saving technical change comes through the private sector in the form of LBD and trial and error at sea, but much also comes through public R&D such as turtle excluder devices or the replacement of J-hooks and squid bait by circle hooks and mackerel type bait for pelagic swordfish longlining to reduce sea turtle bycatch (Watson 2005). As is the case with sea turtles, circle hooks appear to decrease mortality of hooked sharks, because most individuals are externally hooked in the mouth or jaws, in contrast with J and tuna hooks (Watson et al. 2005, Carruthers et al. 2009, Campana et al. 2009, Alfonso et al. 2011). Circle hook capture is also associated with less internal injury and a higher chance of survival (Campana et al. 2009, Carruthers et al. 2009, Cosandey-Godin et al. In Press).

Technology policy can help provide the optimal level of the public good, technical change. Private provision of knowledge, a public good, is insufficient to attain the social optimum, i.e. privately provided technical change will be insufficient. Public and NGO involvement is required due to the external benefits, free riding incentives, and knowledge spillovers. The best approach is public-private-NGO partnerships. Given the intertwining of two market failures due to the bycatch and technology externalities (both are impure or pure public goods), the optimum technology and bycatch policies are designed in concert to reinforce both over the short and longer runs.

An alternative to bycatch policy instruments that directly and immediately reduce bycatch is policies that recognize the induced and biased nature of the required innovations and that create incentives to directly and cost effectively reduce bycatch and that concomitantly create incentives to direct bycatch-saving technical change. Technology policy is the second fundamental required component of bycatch policy, one that induces and finances research and development and recognizes that knowledge is under-provided and subject to free riding. Bycatch reducing technical change will be a fundamental component of EBFM because catch rights, even for bycatch, are insufficient to cover all species.

6. Biodiversity Mitigation

[51] Biased technical change is a shift in the production technology that favors one input over another (or one output over another) by increasing its relative productivity and, therefore, its relative demand. Traditionally, technical change is viewed as factor-neutral. The direction of technical change–e.g. whether new capital complements skilled or unskilled labor or bycatch is saved or used – may be determined endogenously by innovators' economic incentives shaped by relative prices, the size of the market, and institutions.

Biodiversity mitigation of commercial activities that create a byproduct of environmental damage is well established in the international arena and allows continued commercial activities through *compensatory mitigation*[52] (Madsen et al 2010) or *biodiversity offsets* [53]

Biodiversity mitigation or offsetting is a market-based conservation tool generating positive economic incentives that measures negative impacts on biodiversity, replacing the loss through improvements usually nearby. Biodiversity offset policies essentially require vessels to fully compensate for any 'unavoidable' or 'residual' biodiversity impacts they cause through fishing. To do so, they must maintain an equivalent amount of biodiversity elsewhere that would otherwise be lost or create/enhance additional equivalent biodiversity somewhere nearby.

The point of offsetting or mitigation is not to allow fishers to destroy habitats or kill off species that they would not have been able to otherwise. Rather, offsetting is generally intended to provide compensation for losses that would have been permitted, but not compensated for, without the offset policy. Consequently, it is widely intended for use where biodiversity is currently falling through the cracks in the system, as a way of providing a safety net for species when they wouldn't otherwise be protected, either in that specific case or in general.

Offsets are sometimes distinguished from mitigation in that offsets are meant to offset reductions of a single species, whereas mitigation often refers to credits to offset impacts to whole ecosystems, such as wetland or endangered species habitat. Offsets and mitigation credits can be further subdivided based on whether the credit seller or buyer is covered by government regulation:

- *Regulated-regulated* trades occur when a regulated entity sells emissions allowances that it does not need to another regulated entity. These trades could occur in a cap-and-trade system.
- *Regulated-voluntary* trades occur when a regulated entity offsets its emissions by paying for reductions by an unregulated (or voluntary) entity.
- *Voluntary-voluntary* trades occur when an unregulated entity voluntarily purchases offsets from another unregulated entity.

These mitigation strategies are based on the premise that ecological-environmental damage caused in one location or time can be offset by beneficial activities elsewhere. In the compensatory procedures, the main assumption is that lost ecosystem services or functions are equal to the level of ecosystem services or functions gained as a result of the compensatory measures. Reviews of the ecological effectiveness of the principle of environmental mitigation have been mixed, with negative findings largely linked to non-compliance with the regulation due to poor enforcement rather than deficiencies in the principle itself. Nonetheless, they have been endorsed by the CBD.

The Kyoto Protocol provides allowances for "sinks"—credits for the absorption of carbon dioxide by forests, cropland management, and re-vegetation. The Clean Development Mechanism allows an

[52] In the US, the term "mitigate" (or "compensatory mitigation") is often preferred to "offset" (ten Kate, Bishop and Bayon 2004). This refers to activities designed to compensate for unavoidable environmental damage, generally in the context of a regulatory framework that mandates offsetting activities and that has created a market in which biodiversity and wetland credits can be traded. In Europe the term "mitigate" means to minimize harm or to make it less severe, so offset is seen as a distinct activity that compensates for unavoidable harm once this mitigation has taken place.

[53] Biodiversity offsets have been defined by ten Kate (2004) as conservation actions intended to compensate for the residual, unavoidable harm to biodiversity caused by development projects, so as to ensure no net loss of biodiversity, i.e., what remains after everything possible has been done to avoid inflicting that harm.

Annex I country to mitigate its emissions by undertaking abatement within a non-Annex I country.[54] The Montreal Protocol established the Multilateral Fund for mitigation.[55] The U.S. Endangered Species Act (ESA) provides for mitigation to counter environmental degradation. Once a species is listed as endangered or threatened, it can be used as the basis for a conservation bank. Wetlands Mitigation Banking in the United States curtails wetland loss and encourages protection and rehabilitation of wetlands as a precondition for developing other areas. Mitigation has also been applied for fish habitat. Such an approach has also been endorsed by the Convention on Biological Diversity. Nonetheless, such approaches can face complexity when the ecology is complex, and controversy still surrounds the approach, despite its widespread application.

Biodiversity mitigation has been proposed for sea turtles, seabirds, and other marine species (*Bellagio Blueprint for Action on Pacific Sea Turtles* 2004, Wilcox and Donlan 2007, Donlan and Wilcox 2007, Finklestein et al. 2008, Dutton and Squires 2008, Dutton et al. 2010) and in fact has been used since before these proposals by the California drift gillnet fleet as discussed by Janisse et al. (2010). In response to the Bellagio Blueprint, the U.S. tuna processors of Bumble Bee, StarKist, and Chicken of the Sea, and the International Seafood Sustainability Foundation, assess longline caught tunas to fund nesting site protection and artisanal fishery mitigation that is not compensatory, but instead is meant as a complementary means to rebuild bycatch populations.

Under biodiversity mitigation, fishing continues with a *levy* to finance biodiversity mitigation, i.e. to mitigate residual and excessive bycatch mortality. Rather than closing fisheries or restrictive bycatch quotas, mitigation conserves at a fraction of the cost. Protection cost of Pacific Leatherback nesting sites is 1% of comparable at-sea fisheries closures (Gjertsen 2011). Rodent protection in seabird rookeries is 10% of at-sea protection cost (Pascoe et al. 2011). In short, continued fishing finances least-conservation of bycatch species.

Biodiversity mitigation is best initiated once realistic efforts and action have been undertaken to avoid, reduce, and manage adverse development impacts. Biodiversity offsets are based on the “avoid, minimize, offset” hierarchy established under the United Nations Convention of Biological Diversity.

Bycatch mitigation focuses necessarily only upon one phase of a species life history and its encounter with a fishery often in one specific geographic area, which is particularly problematic in pelagic ecosystems. However, it is now increasingly recognized that a holistic approach addressing all phases of a species’ life history throughout its geographic range provides the lowest risk, least-cost approach to conservation (Dutton and Squires 2008, Dutton et al. 2011, Grafton et al. 2010). In addition, biodiversity mitigation (of which by-catch mitigation is a component) can be explicitly compensatory, in which there are direct and explicit offsets to bycatch mortality that allow larger target catches, or

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[54] *The Clean Development Mechanism of the Kyoto Protocol* allows an Annex I country to mitigate its emissions by undertaking abatement within a non-Annex I country. The Clean Development Mechanism allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one ton of CO2. These CERs can be traded and sold, and used by industrialized countries to a meet a part of their emission reduction targets under the Kyoto Protocol.

[55] *Montreal Protocol’s Multilateral Fund for Mitigation* or as it is formally known. The *Multilateral Fund for the Implementation of the Montreal Protocol*, is dedicated to reversing the deterioration of the Earth's ozone layer. It was established in 1991 to assist developing countries meet their Montreal Protocol commitments. Since 1991, the Fund has approved activities including industrial conversion, technical assistance, training and capacity building worth over US $2.8 billion. *The Montreal Protocol on Substances that Deplete the Ozone Layer* is an international environmental agreement that aims to protect the earth’s ozone layer by phasing out the production and consumption of ozone depleting substances (ODS).

simply as a least-cost and holistic complement to other bycatch mitigation approaches.

Biodiversity mitigation is not intended to offset current fishing or to substitute for current at-sea and other bycatch-reducing measures. Instead, biodiversity mitigation is intended to complement existing activities to provide a holistic conservation strategy that is least-cost and addresses species conservation over the entire geographical range and life history of species. Biodiversity mitigation as part of a comprehensive bycatch reduction conservation strategy will enable consumers, processors, traders and brokers, and fishers to continue their activities and generate sufficient economic surplus to be able to finance the mitigation that leads to population increases, not simply no net loss.

This approach recognizes that there are cost-effective conservation measures that can be taken other than at-sea bycatch reduction devices and that these can have higher marginal biological and economic effectiveness than simple continued emphasis on steadily increasing bycatch reduction through conventional measures (with debatable efficiency due in part to diminishing returns). That is, while bycatch reduction can remain the centerpiece for sustainable bycatch populations, proportionally higher gains in population increases at some level of bycatch reduction can come from reducing mortality elsewhere spatially and/or at a different stage in the life cycle. A similar concern holds for economic costs, where after some level of bycatch reduction the marginal cost and benefit in terms of reduced mortality of additional bycatch reduction may be exceeded by reducing mortality in another location and/or during another stage in the life cycle of the animal.

Sea turtle nesting sites and coastal artisanal and commercial fisheries off these nesting sites and in sea turtle migration corridors and foraging grounds provide a natural focal point for environmental mitigation and conservation investments, because sea turtles return as adults to their natal beaches to lay eggs that require a period of incubation. Conservation investments can take the form of protecting the turtles, nesting sites, eggs and hatchlings, and reductions of incidental takes and post-entanglement or hooking mortality by fishers off nesting sites and at feeding grounds, and can actively increase turtle populations. Conservation investments can also be made to alter gear and fishing practices in "hot spots" of turtle concentrations, such as the loggerhead turtle (*Caretta caretta*) foraging area along the Pacific Coast of the Baja California Peninsula, Mexico, or the Large Marine Ecosystems used as feeding grounds by leatherbacks in the Pacific (Benson et al. 2011, Bailey et al. 2012). Effective sea turtle conservation investments are embedded in a holistic approach to sea turtle population recovery that addresses multiple sources of mortality, including technical change and technology standards that introduce gear modifications, such as turtle excluder devices and circle hooks; measures to reduce post-gear encounter mortality; and fisher and community education; and directly addresses "hot spots" with sea turtle concentrations, among other measures. Appendix III provides short descriptions of the ISSF-supported mitigation projects that give a concrete sense of what these projects are.

Protection of key habitats, both on land and at sea, can help ensure the stability of seabird populations and work is already moving forward on the designation of Important Bird Areas (IBAs). In a few cases, threatened species of seabirds are recovering, but more importantly, for several of the major threats to seabirds, there are proven solutions. Eradications of introduced species on breeding colonies have resulted in re-colonization of abandoned sites and recoveries of declining populations. Other threats, including climate change, plastic debris and pollution, still lack credible solutions.

In fisheries, as in most other sectors of the economy, biodiversity mitigation has largely focused on habitats, and has generally been an *in-kind* trade of habitat for habitat (e.g. salmon) or the red cockaded woodpecker. However, for some species that are impacted by fishing, non-fishing related conservation interventions might be more ecologically- and cost-effective than limiting fishing activity.

7. Economic Policies Drawn from Conservation

Addressing "bycatch" as one source of mortality that impacts biodiversity conservation and ecosystem integrity and resilience opens up the possibility of applying policies developed for terrestrial conservation and at stages in a species' life history and geographic range other than when the gear is encountered and in stages of production, processing, and consumption other than solely harvesting. Biodiversity mitigation was one of these approaches. Many standard conservation policies are largely biological in orientation (e.g. closure of biodiversity hotspots) or based on technology standards, such as required use of turtle excluder devices, circle hooks, Medina panels. Other policies of increasing use are those that directly or indirectly create economic incentives. These policies are drawn from the biodiversity conservation literature.

7.1 Direct Incentive Approaches to Conservation: Payments for Ecosystem Services

Direct incentive approaches to conservation link economic incentives to desired conservation outcomes. Most notable are payments for ecosystem services (PES) (Ferraro 2011, Kinzig et al. 2011). Applications include REDD$^+$ (Reduced Emissions from Deforestation and Degradation) and payments to preserve cities' watersheds, land purchases, conservation easements, conservation banking, compensatory mitigation, tradable development rights, conservation concessions, and markets for biodiversity and ecosystem services. PES sustainability is vulnerable to sustainable financing and changes in government policies. PES are difficult to value, since biodiversity markets are missing or incomplete, but should exceed opportunity costs of recipients. PES face additional issues: blue carbon PES, for example, reward carbon sequestering but do not directly pay for biodiversity conservation (bundling, stacking), or may pay for a seemingly homogeneous product but receive lower quality products (adverse selection), or projects may have been implemented regardless (additionality, moral hazard).

Payments for ecosystem services (PES) directly create economic incentives and can address incidental catches in two broad circumstances: (1) finfish catch that may or may not be marketed and that can include "bycatch" or (2) incidental takes of sea turtles, sharks, sea birds, marine mammals, and other marine megafauna in which PES are part of biodiversity mitigation.[56] Here we concentrate on the first case, in which one fleet's harvest of a non-target species reduces the available target-species harvest for another, "downstream" fleet. The "upstream" producers have little or no incentive to account for these foregone benefits to the "downstream" fleet, i.e. costs external to "upstream" vessels aren't considered when they make their harvest decisions.

Under the PES approach, those who benefit from ecosystem services compensate those who manage or utilize the ecosystem in such a way that it provides the desired ecosystem service PES is based on the notion that those who benefit from ecosystem services ("downstream" fleet) should pay for them, and those who generate these services ("upstream" fleet) are compensated for providing them, internalizing

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[56] Engel et al. (2008) define PES as: (1) voluntary transaction in which (2) well-defined environmental service (ES), or a form of land use likely to secure that service (3) is bought by at least one ES buyer **(**4) from a minimum of one ES provider **(**5) if and only if the provider continues to supply that service (conditionality). See also Kinzig et al 2011)

[56] The basic assumption is that with many fishers, asymmetric information, and uncertainty, assessment of each fisher's real catches is prohibitively costly, leading to defining the problem as moral hazard in groups. Solving formulates the policy instrument as a function of the state of stock biomass (Vestergaard 2010).

what would otherwise be an asymmetric externality. The party supplying ecosystem services normally holds the property rights over an environmental good that provides a flow of benefits to the demanding party in return for compensation. With private contracts, the ecosystem services beneficiaries are willing to pay a price expected to be lower than their welfare gain due to the services. Ecosystem service providers can be expected to be willing to accept payment greater than the cost of providing the services.

One solution that sidesteps contentious creation and allocation of property rights and high costs of running an international observer program and compliance and enforcement of rights is PES from longliners to purse seiners to reduce bigeye catches. This alternative is entirely voluntary ("Coasian") bargaining between two parties. PES on a progressive scale creates progressively increasing incentives and compensates for increasing marginal costs as PS bigeye landings fall. Numerous arrangements can be negotiated, including PES based on observable and verified reductions in landings. (Processor receipts are checked against landings.)

An alternative to a formal landings-based program simply arranges payments based on increased bigeye stock and TAC.[57] Payments would necessarily lag catches. Dockside verification and enforcement prevent PS black market bigeye landings, and detailed record keeping is already in place. Dockside sampling of bigeye is far easier and more accurate than at-sea sampling and is already in place.

The onus of compliance and enforcement shifts to the private sector and their flag states rather than IATTC because the arrangement is voluntary. For international environmental agreements to succeed, enforcement must be initially built into the arrangement (Barrett 2003). Enforcement is facilitated with purse seiners setting on FADs because tunas are landed at a limited number of ports, at-sea transshipment is banned, and only a limited number of major processors exist, facilitating low-cost monitoring and enforcement. Free entry into the purse seine fishery is deterred by IATTC Resolution C-02-03 and into the longline fishery by the longliner's allotted share of the TAC. Internal coordination and asymmetric information problems for purse seiners and longliners become the crux of the issue, and these are indeed more complicated in a multilateral context, and these costs are shifted onto the private rather than public sector. Property rights are not established and allocated; instead, existing longliner share of bigeye TAC serves as the basis of the allocation between purse seiners and longliners gear-groups.

Several precedents, albeit inexact, exist for such a PES solution. The U.S. tuna fleet, in a revenue-sharing arrangement with the Forum Fisheries Agency, pays a fee based on a progressively sliding scale for skipjack tuna prices above a base level as an incentive to cap fishing capacity in the Western and Central Pacific tuna fishery (Squires et al. 2006). The Alaska Pollock fishery cooperatively manages its share of the pollock TAC. The most important example is the North Pacific Fur Seal Treaty, in which two nations stopped pelagic sealing and there was a complex web of profit sharing between former (higher cost) pelagic sealing nations and nations with (lower cost) land-based harvesting at breeding grounds (Barrett 2003).

The voluntary agreement (VA) literature suggests three key conditions influencing likely VA success, such as PES (Segerson 2010): (1) sufficiently strong participation incentives, (2) clearly identified

[57] The basic assumption is that with many fishers, asymmetric information, and uncertainty, assessment of each fisher's real catches is prohibitively costly, leading to defining the problem as moral hazard in groups. Solving formulates the policy instrument as a function of the state of stock biomass (Vestergaard 2010).

standards for behavior or performance, and (3) sufficient monitoring to determine voluntary compliance with those standards. Potential for free riding exists with group VAs. While the existence of free riding does not necessarily imply an unsuccessful VA, it will generally reduce policy efficiency, reinforcing the purse seiners and longliners internal coordination challenge.

Potentially strong free riding incentives exist for purse seiners and longliners. Not all vessels have to participate if the program is designed correctly, although full participation increases potential gains. Individual purse seiners continuing to catch bigeye at their current rate do not incur potentially foregone profits and without a well-designed program could even receive PES. Free riding is most serious with individual longliners, which can enjoy increased catches without paying for them. Success requires preventing (or at least controlling) free riding (Segerson 2010). If information about individual vessel bycatch is shared, peer pressure might be an effective means for controlling free-riding incentives or industry groups could imposes fines after landings if improvements from baselines are not found. Industry groups paying vessels their PES share according to performance create a positive incentive. Alternatively, a combined approach could be used, under which vessels receive incentive payments when catch is at or below their target and pay fines for catch levels above the target (Segerson 2010). Fines in periods of high catch could be used to finance incentive payments when catch is low.

Asymmetric information problems will arise, in which buyers and sellers hold different amounts and quality of information, and contracts between purse seiners and longliners, and perhaps even among the nations comprising these coalitions, will have to be written accordingly. When these information problems are explicitly taken into account when writing the PES contract both between purse seiners and longliners and among their respective groups, performance improves. Adverse selection, in which unobserved behavior occurs before the contract, could arise if vessels can inflate their catch history. Moral hazard, in which unobserved behavior occurs after the contract, is likely a more serious issue through misreporting, illegal landings, and the like. Incentives are created to eliminate at-sea purse seine bigeye discards or misreporting of bigeye landings since the stock is adversely impacted by this unrecorded mortality and accordingly PES lower, but this incentive is incomplete since vessels can free ride on other vessels' reductions. Onshore MCS and payments for landings not catches help contain asymmetric information issues with contracts.

External benefits and free riding are created by the increased provision of the biodiversity public good with lower FAD fishing. Asian longliners will induce lower bycatch of other marine species with lower FAD fishing. Consumers will enjoy nonmarket benefits from increased biodiversity and purse seiners and processors will benefit in product markets from lower consumer and non-governmental organization (NGO) pressures to reduce FAD-caught skipjack, creating a potential for bundling, in which NGOs provide PES for reduced bycatch of other species.

Incentive agreements, for example, have been used to conserve sea turtles in Rendova, Solomon Islands (Ferraro & Gjertsen 2009, Gjertsen and Stevenson 2011). A villager observing a leatherback turtle coming onto the beach at night to nest brings the turtle monitor to the turtle and the villager and monitor receive a payment, which compares favorably with the daily wage for local laborers. If the observer disturbs the turtle in any way the payment is not made. The monitor records data, photographs the turtle, which records the date and time for verification. In addition to individual payments, a payment is placed in the community fund managed by a board of community member. If the nest hatches successfully, the initial finder and monitor and community each receive an additional payment. The project creates multiple incentives for turtle conservation. Every villager and turtle monitor has the potential to access a cash payment for reporting and not disturbing or consuming turtles or their eggs.

The community as a whole also has some (albeit limited incentive), because it receives contributions to the fund if no one disturbs the turtles or their nests. In this manner, an individual who did not observe the nest and who will not receive an individual payment perceives some benefit via the community fund from not harvesting. Other forms of community incentives have been used in a number of the sea turtle projects supported by ISSF in Indonesia, Solomon Islands, Tanzania, Nicaragua, and India (see Appendix III).

PES can target gears that reduce habitat damage, improve fishing practices, alter locations, or simply pay fishers not to target species or to fish in certain areas. Watamu Turtle Watch pays Kenyan fishers to release live turtles from fishing gear (Milne & Niesten 2009, Ferraro 2007, Ferarro and Gjertsen 2009). Since 1997, the local, non-governmental Watamu Turtle Watch has run a conservation program, pays villagers performance payments for nest protection, and pays fishers to release live turtles from fishing gear and to participate in a tag and recapture study. Payments are made directly for releasing turtle bycatch rather than subsidies for using gear that reduces turtle bycatch. The turtle bycatch release incentive program began informally in 1998 as a compensation program for fishing net damage from turtle interactions. When fishers catch a live turtle they remove it return with it to one of a small number of landing sites, and report the turtle to Watamu Turtle Watch (fishers are trained to reduce the stress on the turtle during transport). Fishers receive 500 Kenya shillings for a turtle greater than 70 cm curved carapace length, which corresponds to adults and subadults, and 300 Kenha schillings for a smaller turtle, after which the turtle is measured, tagged, and released.

7.2 Community Based Conservation (CBC) and Integrated Conservation and Development Projects (IDCPs)

Indirect conservation integrates conservation and development by rewarding local communities for conserving habitat in ways that also improve their living standards, giving them a stake in conservation, and are largely applied in developing countries (McNeely et al. 2005), although their effectiveness is unclear (Wells 1992). Community conservation attempts to link development and conservation to achieve both. Indirect conservation uses development initiatives and indirect incentives to align local resource users' behavior with conservation. Individuals and communities are not directly_rewarded for pursuing conservation activities or directly punished for degrading activities. Instead, conservation is a joint product with development through indirect incentives by redirecting labor and capital away from activities that degrade ecosystems, encouraging commercial activities that supply ecosystem services as joint outputs (e.g., ecotourism), raising incomes to reduce dependence on resource extraction that degrades the ecosystem (McNeely et al. 2005).

Indirect incentives approaches can be used for biodiversity mitigation of sea turtle nesting sites, such as Proyecto Tomar (Marcovaldi 2011, one of the ISSF-supported projects (see Appendix III). The International Coral Reef Action Network in Kenya's Malindi/Watamu Marine National Parks and Reserves supports community activities, including improved repair and maintenance facilities for vessels belonging to local tour-boat operators, improved visitor accommodation facilities and increasing capacity among tour-boat operators and park staff in visitor guiding skills (Waruinge 2003). New ecotourism projects (e.g., mangrove boardwalks) generate funds for school fees. Sponge farming in Pohnpei and coral farming in Federated States of Micronesia give alternative livelihoods.

Indirect approaches may work best in developing countries, building upon community property and social norms, customary management, and co-management (Ostrom 1990; Cinner & Aswani 2007). Developed in the terrestrial realm, they are not yet widely used in the marine realm except in marine ecotourism (especially with coral reefs), sea turtle conservation, and habitat restoration; for example, community-based conservation for Coral Triangle reef fisheries (Hamilton et al. 2011) and Bangladesh fish sanctuaries (Hossain & Ahmed 2008).

The difficulty in applying indirect conservation is complicated by the marginal geographical and social role of marine communities, absence of clearly defined property rights and enforcement difficulties, and difficulties in developing alternative livelihoods, especially in areas with low ecotourism potential and limited alternative economic activities and without subsidies. Viable alternative livelihoods for fishing communities would enhance upper Gulf of California vaquita conservation through bycatch reduction. Efforts to replace blast and cyanide fishing on coral reefs with alternative livelihoods struggle with finding viable alternatives, weak property rights, and emigration.

8. Advancing the concept of biodiversity mitigation

Bycatch Reduction

Reducing discards is a concern for fishermen as they often damage the catch and increase deck processing time. Limitations on skills, technology and markets as well as discard exclusion costs are such that discards, that have decreased from about 20-27 million tonnes in the 1980s (Alverson et al (1994) to about 7 million tonnes in the 1990s (Kelleher, 2005) still persist, raising issues of political, ethical, ecological, technological, economic and operational management nature. Their reduction is called for in numerous international instruments, the FAO Code of conduct for responsible fisheries and its guidelines and action plans. There is also comprehensive legislation and numerous programmes at international, regional and national levels for the specific protection of threatened, vulnerable or charismatic species.

Direct bycatch reduction (leading to an effective reduction of the number of species and quantity of bycatch per fishing operation and as a whole) is the first line of international action. When all possible (affordable, manageable) bycatch reduction instruments have been used, there may remain a level of bycatch referred to as “unavoidable” or “residual”. That level might be “acceptable” to society in that it might be a sustainable source of mortality. It might be “unacceptable” for ethical and other reasons. Bycatch mitigation instruments intend to address that last part of the bycatch reduction process.

Bycatch reduction is not directly addressed in this document and in the workshop. It is a subject on which a large number of international, regional and national institutions have been working, apparently with some success (given the reduction of discards observed across two decades) and much more need to be done (Gillmann, Passfield and Nakamura, 2012). Some of the key issues relate to:

1. Monitoring (e.g. with deck videos, on-board observers; VMS records) and quantifying discards
2. Quantifying discards: sampling difficulties (e.g. by on-board observers) and raising factors;
3. Understanding better the implications of different approaches to no-discards policies
4. Tailoring anti-discard strategies to different fisheries, environmental and socio-economic contexts;
5. Selectivity: improving existing technology to increase escapement of non-wanted species; improving knowledge on survival rates of stressed animals released “alive”, from the deck or directly underwater from the gear (unaccounted mortality);
6. Ensuring wider use of already available selective technologies;
7. Improve understanding of the role of trade measures to provide incentives for bycatch/discard reduction;
8. Developing best practices;

9. Improving /promoting sustainable utilization of bycatch;
10. Adding economic incentives to command-and-control strategies;

Identification of Potential Biodiversity Mitigation Projects for Sea Turtles, Seabirds, and Oceanic Sharks

Projects would be assessed according to issues discussed in the workshop and some of which are outlined below. Priorities would be established according to least-cost, compliance and verification, impact on population, tractability and feasibility, geographical location, and other factors. Projects can focus upon sea turtle nesting site and seabird rookery mitigation, small-scale and artisanal and shrimp fisheries with substantial bycatch of sea turtles, seabirds, and sharks, enforcement of shark finning measures, etc. The Appendix summarizes a number of current ISSF-initiated and financed sea turtle mitigation projects, including the Pro-Delphinus project in Peru that addresses gillnet "hotspots". It would be nice to find a common "currency" for the "biodiversity" of those marine ecosystems.

For seabirds, projects can include invasive predator eradication at breeding colonies, recolonization of extirpated breeding colonies via social attraction techniques, and habitat restoration. At-sea projects include financing skipper workshops, Tori lines, for small-scale longline vessels that otherwise not mitigate. For sharks, buyouts of low value shark fisheries or increased interdiction of illegal fisheries may be options, enforcement of shark finning bans, financing replacement of wire leaders (steel traces) on longlines by monofilament leaders that lower shark bycatch mortality for small-scale fisheries (sharks can bite through the leaders to escape). For sea turtles, reductions in human harvesting, nesting site protection, gear provision (circle hooks) to small-scale longline fleets. Skipper and fisher workshops on methods of bycatch avoidance. The portfolio of ISSF-supported projects (Appendix III) provides examples of mitigation options applied at the community level for sea turtles that are low cost and high impact. Some projects enhance other ongoing efforts that focus on direct threats and thus provide value-added benefits, such as loggerheads in the Cape Verde islands, where direct harvest of adult nesters is a pressing problem and is being addressed by several groups working directly on each of the nesting beaches. These conservation efforts are undermined by the persistent demand for turtle meat and lack of enforcement in the human population centers, and one of the ISSF projects involves a comprehensive outreach campaign directed at cape Verdean legislative and law enforcement authorities as well as restaurant owners and local food markets to increase awareness and reduce the demand for turtle meat. A growing network of "turtle friendly" restaurants has been established across Sal and Santiago Islands where most of the turtle consumption occurs (Appendix III).

The concept of "No Net Loss".

The requirement of "no net loss" is perhaps the most important. A reference point for biodiversity must be identified that serves as a benchmark against which various potential biodiversity mitigation projects can be measured and compared. The nature of "no net loss" (e.g. species, habitat, community, structure, function) and the scale at which it is considered (e.g. local ecosystem to LME) needs to be specified. Other design requirements include (Bull et al. in press b): (1) consideration of a discount rate;[58] (2) whether to measure no net loss against a dynamic baseline that incorporates trends; (3) whether no net loss is at the project or landscape level.

Resource users are often required to purchase more than one standard unit of mitigation for each unit of

[58] *Discounting* refers to the process of assigning a lower weight to a unit of benefit or cost in the future than to that unit now. The further into the future the benefit or cost occurs, the lower the weight attached to it. The *discount rate* is the rate at which the future value of a unit of benefit or cost is converted to the present value.

biodiversity lost. This approach minimizes risk through taking a conservative value. For example, terrestrial developers must purchase habitat similar to that they plan to develop and more than one hectare of mitigation for each hectare of habitat converted. *Mitigation credits* can be sold when they are approved and meet agreed performance criteria according to a fixed timetable. Many mitigation banks require that a portion of credit sales revenue be used to endow a trust fund for long-term management, but for fisheries this same aim would be achieved by on-going annual assessments and the funds used in an agreed upon manner, much as the ISSF-Bumble Bee-StarKist-Chicken of the Sea-Ocean Foundation sea turtle biodiversity mitigation project (Appendix III).

What Do We Need to Measure?

Determining "no net loss" raises the issue of what needs to be measured and how. This is the direct and indirect impacts upon biodiversity.

What is the Currency or Numeraire for Biodiversity Mitigation?

Biodiversity requires a numeraire or metric, a unit of measurement. There could be a single compound or multiple numeraires (Bull et al. in press b). Terrestrial conservation tends to specify two types of currency to be traded, hectares and habitat functions, in which case compensation should clearly relate to the impact in these currencies to ensure that habitat function and species are truly preserved. Trading should be *like-for-like*. As is well understood, area is a crude proxy for biodiversity, even in similar ecosystems. As noted in the discussion of "no net loss," multiples of area are commonly used in terrestrial conservation to ensure a sufficient margin so that offsetting activities more than compensate for losses. The Kyoto Convention addressing climate change includes six greenhouse gasses (carbon dioxide methane, nitrous oxide, PFCs, HFCs, SF6) and the Montreal Protocol for Ozone-Depleting Substances addresses ozone-depleting chemical compounds (halons, CFCs, HCFCs, methyl chloroform, carbon tetrachloride, and methyl bromide), all which can be expressed in a common numeraire of CO_2 equivalent.

Equivalency of mortality and reduced mortality for different sea turtle life stages must recognize the high reproductive value and mortality of at-sea juveniles and adults versus low reproductive value of eggs. For example, a potential sea turtle numeraire to convert eggs to adults is a sexually mature female (Wallace et al 2008).

The currency for pelagic marine ecosystem biodiversity lost as bycatch, notably sea turtles, seabirds, and oceanic sharks, remains an open question and poses one of the key questions for the workshop. Another question might be the possibility to elaborate a single biodiversity value/loss based on a bundle of impacts on different elements and taking uncertainty into account.

Another design issue that arises is whether to incorporate a measure of ecological functioning as well as biodiversity (Bull et al. in press b). The stated intention of offsets is commonly to ensure no net loss of biodiversity. However no net loss can also mean no loss in ecosystem function, or in the value provided to society by functioning biodiversity, i.e. ecosystem services.

Biodiversity Loss, Mitigation Risk and Uncertainty.

The first three points above all raise the issue of risk and uncertainty, since compensation or mitigation of biodiversity loss confronts uncertainty in population dynamics (and worse, in ecosystem dynamics when dealing with biodiversity as a whole), appropriate numeraire or currency, spatial correspondence between the biodiversity loss as bycatch and mitigation measures in a spatially different and distinct location (discussed below), and mitigation measures. The requirement of multiples of the numeraire to be conserved as the biodiversity loss is mitigated is a form of risk management. This approach simply uses conservative values to address risk and uncertainty.

An overarching population and risk assessment model is needed to directly link the impacts of a proposed development to the types of mitigation necessary to offset fishery impacts. The cumulative effects can be important for some species, such as eastern Pacific leatherbacks, where there is a pervasive low level of threat throughout the life history and range. Any one fishery or source of mortality might by itself not be a substantive threat (e.g. low probability of take and mortality), but the cumulative effective may tip the balance. In this scenario, essentially every animal, and especially reproductive females, count and no (or no additional) level of mortality is sustainable. The importance of each life stage and source of mortality would also be assessed and addressed. For example, it may be insufficient to mitigate adult mortality via increased nest protection, requiring a need to prevent death of large subadults and adults, both male and female so that there are sufficient animals to lay fertile eggs.

Sub-issues include: No net loss versus population recovery and growth; species-by-species mitigation accounting as opposed to ecosystem/biodiversity level accounting; built-in risk, precautionary approach. We note that quantitative biologists and ecological modelers with knowledge of risk assessment can make an important contribution to this discussion.

The concept of risk management and its application to pelagic marine ecosystem biodiversity loss poses another key question for the workshop.

Location: Where Should Conservation Activities be Located to Mitigate Unavoidable Biodiversity Loss from Bycatch?

The mitigation location is linked to the type of ecosystem and species to be conserved. If the mitigation goal is to conserve equivalent (or more) biodiversity to that damaged by fishing, the location of the mitigating activity is likely to be influenced by where similar ecosystems may be found that conserve. There are local implications and costs of mitigation projects and equity issues in the like-to-like approach (within a community, a country, between countries). A difficult issue relates to the way in which impacts from other than fisheries sources (e.g. beach destruction of turtle nesting sites by coastal development project) are factored in the compensation equation and in the equitable distribution of the payments burden.

Proximity to the affected site is important. The further away the mitigation location is from the original site, the greater the probability of a tenuous connection and the less is the political support. Proximity may be of less immediate concern for many pelagic species. For example, sea turtle nesting sites and seabird colonies corresponding to the bycatch-affected species and populations may not be in immediate proximity but they are clearly linked through migration. This linkage is explicitly recognized in the US Pacific sea turtle Recovery Plans[59] and other international plans[60] and is the basis for several bilateral sea turtle conservation programs (Dutton et al. 2002, Dutton et al. 2011). Conservation costs must also be factor in, where least-cost conservation is the guiding principle. For example, more accessible mitigation sites may have lower costs than more remote ones of greater biological importance, and from a least-cost perspective the more accessible one could be more cost-effective.

Although proximity is important, there may be other, more valuable and critically endangered

[59] http://www.nmfs.noaa.gov/pr/recovery/plans.htm#turtles

[60] Bellagio Action Plan: *Bellagio Blueprint for Action on Pacific Sea Turtles*. 2004

ecosystems and species that need to be protected elsewhere. For example, the Eastern Pacific leatherback population is at a more critical population level than the Atlantic leatherback population nesting on St. Croix, and a legitimate question is whether some of the funds raised from Atlantic longline vessels inflicting leatherback mortality could be legitimately applied to Eastern Pacific nesting site protection. Loss of distinct segments increases threat of extinction, so that more than just the nesting site or segment most closely associated with a fishery may be important. IUCN population assessments recognize the need to identify segments. Approaching sites and segments as parts of meta-populations and assessing the impacts of individual sites or patches on the overall population growth and risk of extinction can increase recovery, help select cost-effective sites, and reduce the risk of extinction.

Mitigation sites and activities can be either fixed or dynamic (Bull et al. in press b). Mitigation of sea turtle nesting sites or sea bird colonies and some closed areas are fixed in time and space but other areas, such as some spatial closures, may change over time with migration and season.

Duration. How Closely Should Duration of the Mitigating Project Relate to Duration of the Expected Impact?

In no case should mitigation last less than the expected impacts. For example, if a sea turtle reaches sexual maturity at 20 years, mitigation of bycatch mortality should last at least 20 years. Moreover, the cumulative impacts over time must be considered, which can be especially important and difficult to identify with long-lived species and late age at sexual maturity. If economic and ecological impacts are irreversibile, here such as population extinction, then duration could conceivably extend to perpetuity. When damage from bycatch is long lasting but reversible, then the mitigation can replace loss of biodiversity during the period of restoration or recovery. Another duration issue relates to when the damage is done compared to when the mitigation takes place.

Adverse Selection or Additionality.61

Adverse selection (additionality) arises due to asymmetric information between the buyers and providers of biodiversity mitigation prior to the conservation "contract" and is a form of market failure. In general with asymmetric information, the ecosystem service provider knows more about the service provided than the buyer, hence leading to asymmetric information between the two contracting parties. Adverse selection or additionality arises if the favorable conservation mitigation outcome would have taken place independently of the mitigation project or if the mitigation is a new one that would not have otherwise arisen. Providers of biodiversity mitigation may have incentives to offer projects they would have undertaken anyway. Investors may also have incentives to select these projects.

Bundling. Mitigation of biodiversity loss from bycatch aims at one specific task, but may also conserve additional ecosystem services or other species not of direct concern.

For example, sea turtle nesting site protection may conserve an entire beach from economic development, thereby conserving the beach, its ecosystem services, contributions to open space, and conservation of other species whose habitat is the beach. Seabird rookery protection for one species of concern to longline vessels may also protect rookeries for other species on the same island. Protection

[61] Adverse selection or additionality arises if the favorable conservation mitigation outcome would have taken place independently of the mitigation project or if the mitigation is a new one that would not have otherwise arisen.

of rain forests to sequester carbon through REDD+ payments also conserves overall biodiversity and other rain forest ecosystem services such as water regulation and habitat provision. Conversely, providing biodiversity mitigation may not cover the opportunity cost of the entire ecosystem required to achieve the biodiversity mitigation. In this case, the entire suite of ecosystem services and biodiversity conservation might be bundled and sold as a single product. In these instances, often no attempt is made to add up the individual values of ecosystem services and biodiversity conservation to determine payment levels. Distribution of the services could be an issue and the market might be able to deal with social ones.

Two issues arise with bundling: whether different environmental services are complementary and the geographical extent of the demand. Some environmental services are complementary, such as preventing removal of forest cover adjacent to sea turtle nesting sites that regulates beach temperature (and hence hatchling sex determination) but also conserves habitat and other services. In some instances, not all environmental services are complementary, so that increasing yield of one particular environmental service might adversely impact the availability of another. Species in predator-prey relationships provide an example, and increasing the population of apex predators such as sharks can reduce the populations of other species. Different species of seabirds subject to bycatch mortality may compete over prime foraging grounds or rookery sites on the same island. Some services have local demand while others have potential regional or global demand.

Stacking.

Stacking occurs when providers of biodiversity mitigation receive multiple payments for ecosystem services and biodiversity conservation provided from the same land parcel or activity. This provides multiple revenue streams for the provider of services and creates additional economic incentives to manage for multiple ecosystem services and biodiversity conservation. Conceivably, establishing information systems coupled with payments for sea turtle bycatch avoidance for say small-scale fishers could also reduce shark bycatch, and the two mitigation services could be stacked.

Stacking can be a problem when there is double counting and adverse selection or additionality. Double counting arises when one ecosystem service is sold twice to mitigate two separate impacts. Mitigation projects may have occurred without the payments and hence do not generate additional benefits for the additional payment.

Conservation or Capacity Building?

Biodiversity mitigation generally takes the form of investments in habitat restoration or conservation. But investment in “out-of-kind” mitigation such as building the capacity of conservation agencies or environmental education may also be important and should receive consideration.

Financing Biodiversity Loss Mitigation

Financing biodiversity loss mitigation raises a number of questions such as: Who pays? How are payments assessed? What are adequate rates? If rights are used, what is their value? Is there a risk of speculation? Is transparency ensured? What might be the risks of aggregation of rights in fewer hands? What night be the impacts on livelihoods?

Adequate Property Rights for Mitigation and Conservation “Contracts”

Section to be developed later

Is Mitigation Credit Banking Allowed?

Can mitigation credits earned in one period be saved or banked to be used in a subsequent period? Should such credits be allowed to grow with interest or conversely to depreciate with time? A decision must be made whether to allow a temporal gap between bycatch reduction and offset gains (Bull et al. in press b); these are sometimes called *time lags*. Time lags interact with fluctuations in biodiversity credit prices to result in reduced efficiency in biodiversity markets (Drechsler & Hartig, 2011).

Legal Issues

What are they? The meeting may help fill in this gap.

Verification, Compliance, and Enforcement.

How will mitigation projects be verified, compliance insured, and deviations from the agreement enforced?

Indicators to assess the impact and to assess the losses and the gains acquired through the compensatory measures, as well as to estimate the costs associated with these compensatory measures.

Bilateral vs. Multilateral Biodiversity Mitigation and Biodiversity Credit Markets.

Could there be conservation and economic arguments that support a domestic or internationally tradable system of biodiversity offsets or conservation credits, analogous to the international trade in carbon credits?

Who Makes Decisions and Who is Responsible?

In the absence of an international government, there are multiple nodes of decision-making through companies, individual companies, and tuna Regional Fishery Management Organizations plus civil society through industry and environmental non-governmental organizations. Who is involved in designing a mitigation project and who decides whether it is acceptable? Who determines what is fair and acceptable? Who implements a biodiversity offset? Government, local communities, NGOs and the companies planning a commercial development may agree on a biodiversity offset project, but who is to carry it out? Should the company maintain sole responsibility or residual involvement in implementation, or should government, local communities or a third party such as an NGO be responsible for conducting the conservation activities involved? Who judges success? Role of the market?

Biodiversity Mitigation Investments and Subsequent Induced Economic Activity

Mitigation may create new economic opportunities. For example, protection of nesting beaches and sea turtles may create new opportunities for ecotourism and additional economic benefits to the community, even if the mitigation payment was only for protecting or not harvesting turtles and eggs. What about opportunities in investing in biodiversity bonds even if someone does not care about biodiversity but only on the profitability of the bonds? This is an aspect that could be further explored.

Equivalence

Equivalence must be demonstrated between biodiversity losses and gains (Bull et al. in press b). How equivalent is the mortality of a sexually mature sea turtle with additional protection of eggs at a nesting site? How equivalent is one sea turtle nesting site or species with another?

Reversibility

A decision must be made about how reversible bycatch impacts must be (Bull et al. in press b).

Reversibility must be defined, recognizing that a “reversed” depleted population may look different. Reversibility has no objective definition, and policy must define it explicitly. Should all biodiversity losses be reversible? Should a sea turtle nesting site that has been impacted by both at-sea bycatch and nesting site degradation be the sole responsibility of the bycatch source? What if there are multiple fleets inflicting at-sea bycatch mortality?

Thresholds

Define threshold biodiversity values beyond which offsets are not acceptable (Bull et al. in press b). This involves making value judgments. In this context, thresholds are considered a type or magnitude of loss beyond which impacts are deemed non-off-settable. For example, species extirpation could be considered unacceptable, and therefore “non-offsettable”, whereas temporary nesting site impacts might be deemed acceptable.

Compliance and Monitoring

Define threshold biodiversity values beyond which offsets are not acceptable (Bull et al. in press b). Noncompliance can lead to offset projects being implemented partially or not at all.

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Appendix I – Draft Glossary

To be completed at and after the meeting

Terms ***in bold*** within a glossary item are defined either in the item itself or elsewhere in the glossary

Adverse selection

Adverse selection (or ***additionality***) arises due to ***asymmetric information*** between the buyers and providers of biodiversity mitigation or an ecosystem service prior to the conservation "contract" or transactions. It is a form of market failure. The costs of acquiring information for the buyer may be high or even prohibitive. Adverse selection arises if the favorable conservation mitigation outcome would have taken place independently of the mitigation project or if the mitigation is a new one that would not have otherwise arisen. Providers of biodiversity mitigation may have incentives to offer projects they would have undertaken anyway. Investors may also have incentives to select these projects. In addition, most offset programs include an "additionality" criterion that requires any payment or credit received to be associated with an increment of additional services that would not have been supplied without the payment. This is required so that the program generates new ecosystem services or biodiversity mitigation to offset ecosystem or biodiversity reductions by other entities.It may be hard, however, to show that 'maintenance' offsets result in outcomes that would not otherwise happen.

Also referred to as: ***Additionality***

Additionality

See: ***Adverse selection***

Asymmetric information.

In general with asymmetric information, the ecosystem service provider knows more about the service provided than the buyer prior to the transaction, hence leading to asymmetric information between the two contracting parties. Asymmetric information arises when parties to a transaction hold differing quantities and quality of information.

Balanced harvest (BH) strategy

A fishing strategy that maintains ecosystem structure by keeping fishing pressure moderate and distributing it across ecosystem components (species, sizes, and tropic levels) in proportion to their productivities. It requires fishing "all" sizes and species in proportion to their natural productivity and reconciles objectives of maintaining community structure and returning the highest yields. Balanced harvest strategy says that in order to fulfill the requirement of the Convention on Biological Diversity (CBD) for an ecosystem approach to fisheries (to maintain the structure and function of the ecosystem) all species in the trophic chain must be exploited with an equal pressure, proportional to their productivity (i.e. natural mortality). Fishers must be equitable and parsimonious predators, equitable in fishing every species in the same relative way, and parsimonious in maintaining the predation pressure at a low enough level not threaten any population in the chain. A key implication is to fish more juveniles and small species and protect more the old adults and large species (the opposite to what we do now). This strategy reduces or eliminates the evolutionary drift of the species (towards faster growth and earlier maturation), reduces ecosystem oscillations, maintains age structures, and may increase yields substantially.

Biased technical change

A shift in the harvesting and post-capture handling technology that favors either the relative use of an input over another or the relative harvest of an output (species) over another. More technically, biased technical change is a shift in the production technology that favors one input over another (or output over another) by increasing its relative productivity and therefore its relative demand. The direction of technical change, whether bycatch using or saving, may be determined endogenously by innovators' economic incentives shaped by relative input (or output) prices, the size of the market, and institutions.

Biodiversity compensation

"A set of actions that lead to measurable conservation outcomes, designed to compensate for residual biodiversity impacts that arise from the activities of an existing or new project and that remain after appropriate prevention and mitigation measures have been implemented" (see http://bbop.forest-trends.org/)

Biodiversity offsets

Have often been defined by ten Kate (2004) as conservation actions intended to compensate for the residual, unavoidable harm to biodiversity caused by development projects, so as to ensure no net loss of biodiversity, i.e. what remains after everything possible has been done to avoid inflicting that harm. Biodiversity offsets are based on the "avoid, minimize, offset" hierarchy established under the CBD.

Bundling (of ecosystem services)

One ***ecosystem service*** (e.g., freshwater provision) is not delivered in isolation from others and instead is combined with other related ecosystem services (e.g. wetlands protection, carbon sequestation, water quality, species conservation). The Millennium Ecosystem Assessment demonstrated the interdependencies among ecosystem services. Overuse of one ecosystem service may lead to a decline in other ecosystem services as well. Ecosystem management approach ensures that interdependent ecosystem services are identified and that an ecosystem-specific analysis revolves around the bundled set of ecosystem services rather than individual services. Bundling of ecosystem services provides an improved method for integrating markets

Bundling of ecosystem services is a complex task. Studies have shown, however, that there are varying degrees of interdependence and the ones that need to be targeted are those with strong inter-linkages. Bundling involves mapping of strong interdependent ecosystem services. The final bundle of ecosystem services that emerges will have a high level of interdependence and clear implications for human well-being and poverty reduction for developing countries.

Bycatch mitigation

Focuses only upon one phase of a species life history and in one specific geographic area, which is particularly problematic in pelagic ecosystems

Bycatch population

Refers to the associated and dependent species referred to by the 1982 LOSC that are impacted through accidental harvest (as opposed to targeted harvest)

Bycatch-saving technical change

Change that reduces the relative amount of bycatch resource stock inadvertently harvested compared to the target resource stock harvested. Bycatch-saving technical change thus reduces the relative ratio of bycatch to target resource stock(s) and can vary by species.

Cap-and-Trade

Cap and trade is an environmental policy tool that delivers results with a mandatory cap on emissions while providing sources flexibility in how they comply. Successful cap and trade programs reward innovation, efficiency, and early action and provide strict environmental accountability without inhibiting economic growth. http://www.epa.gov/captrade/

Clean Development Mechanism (of the Kyoto Protocol)

A protocol that allows a country listed in Annex I to mitigate its emissions by undertaking abatement within a non-Annex I country. The Clean Development Mechanism allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one ton of CO2. These CERs can be traded and sold, and used by industrialized countries to a meet a part of their emission reduction targets under the Kyoto Protocol.

Command-and-control policy

Refers to environmental policy that relies on regulation (permission, prohibition, standard setting and enforcement) as opposed to economic incentives, that is, economic instruments of external cost or external benefit internalization. Command and control regulations require entities to undertake specific activities to meet specific standards. By contrast, “market-based” regulations give companies the choice on how to meet specific standards. Instead of mandating specific activities, companies can look for the most efficient way they can reduce bycatch.

Compensation Fund

A third-party mechanism that collects and administers fees from developers to offset their impacts on biodiversity. The money may go directly towards compensating biodiversity loss, or to more indirect biodiversity-related projects (i.e. funding protected area management, research).

Compensatory mitigation

It is based on the premise that ecological-environmental damage caused in one location or time can be offset by beneficial activities elsewhere. In the compensatory procedures, the main assumption is that lost ecosystem services or functions are equal to the level of ecosystem services or functions gained as a result of the compensatory measures.

Conservation easement.

Under a conservation easement, a landowner retains ownership of his or her land but cedes certain rights to develop the land. In general, conservation easements are flexible instruments, and the details of allowed management can change from contract to contract. Easements often do not explicitly outline who owns the ecosystem services generated by the eased land—the landowner or the easement holder. Easements are often held by land trusts or other conservation organizations that manage the lands for a landowner. Whether a landowner who has sold a conservation easement retains rights to sell ecosystem services remains unclear. Although conservation easements are a ceding of development rights, they are not necessarily a ceding of the right to sell ecosystem services.

Credit

A unit of measure representing the environmental commodity that can be traded (this can be functional or measure of area), based on the environmental activity.

Deemed values

Deemed values are charges to vessels in proportion to the landed value for any catch of quota species for which they do not hold quota. The primary purpose of deemed value system is to provide an incentive to cover catch with available quota for fishers. As a result, it is no longer a criminal offence to catch fish which fishers have no rights; instead they pay a deemed value to cover any catch without bycatch rights. Thus deemed values provide an incentive to purchase ACE to cover the bycatch. If deemed values are not paid, then the fisher’s permit will be suspended and it is criminal offence fishing without a permit.

Directed technical change

A modern version of ***induced technical change***, adds several key insights to induced innovation, notably that profit incentives affect both the amount and direction of technical change. It also considers increasing relative input supplies more than their scarcity, profits and output prices rather than solely cost minimization and only relative input prices, and increasing returns to scale due to external benefits and spillover effects from knowledge. Two important components are the ***price effect*** and the ***market size effect.*** See also ***induced technical change***.

> ***Price effect:*** occurs if there are stronger incentives to innovate when: the good produced by these technologies commands higher prices or when there are relatively scare inputs and correspondingly relatively high input prices to reduce their use (since goods produced by relatively scarce inputs are relatively more expensive, lowering profits).
>
> ***Market size effect***, which can potentially outweigh the price effect, occurs when it is more profitable to develop technologies that have a larger market and more abundant inputs.

Discards

Marine species accidentally harvested by various gear that are then thrown back into the sea, i.e. they are “discarded”. These discards may be alive or dead. The process itself is “discarding.”

Discounting

Discounting refers to the process of assigning a lower weight to a unit of benefit or cost in the future than to that unit now. The further into the future the benefit or cost occurs, the lower the weight attached to it. The process of discount converts values over time to equivalent values at the present. Discounting takes into account the time value of money (the idea that money available now is worth more than the same amount available in the future because it could be earning interest). Discounting also takes into account consumers’ time rate of preference, in which present consumption is preferred to future, all things equal.

Discount rate.

The discount rate is the rate at which a unit of future benefits or costs is converted (scaled down) to a unit of present benefits or costs.

Disembodied technical change

Refers to technical change that is not embodied in an economic input, notably the capital stock or is not investment-specific, i.e. it is independent of physical capital accumulation. Disembodied technical change often refers to learning how to work with new technology that leads to changes in fishing and post-capture handling practices.

Economic incentives

An incentive is something that motivates an individual to perform an action. Economic incentives may be direct or indirect, positive or negative (disincentives)

> ***Direct economic incentives*** directly alter behavior in a desired manner. For example, payments for ecosystem services create direct incentives because they are payments that are received conditional upon a verifiable outcome.
>
> ***Indirect economic incentives*** alter behavior only indirectly by working through another outcome or as a byproduct or joint product of another outcome such as economic development. Integrated conservation and development projects create indirect biodiversity conservation incentives because biodiversity conservation is a byproduct of economic development such as with eco-tourism.
>
> ***Positive economic incentives*** leave you better off if you do what was asked of you. These incentives benefit you in some way. They reward you with money or some sort of financial gain such as a better price, a free item, or an upgraded item. They are called positive because they are associated with things many people would like to get.
>
> ***Negative economic incentives*** leave you worse off financially by making you pay money. These incentives cost you money. Fines, fees, and tickets can be negative economic incentives. They are called negative because they are things you don't want to get.

Ecosystem-based management

A fisheries management that attempts to address ecosystem concerns and essentially reverses the order of management priorities to start with the ecosystem rather than target species. Ecosystem-based management aims to sustain healthy marine ecosystems and fisheries they support.

Ecosystem services

The benefits that people may obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other non-material benefits.

Ecosystem resilience

The level of disturbance that an ecosystem can undergo without crossing a threshold to a situation with different structure or outputs. Resilience depends on ecological dynamics as well as the organizational and institutional capacity to understand, manage and respond to these dynamics.

Elasmobranchs

The Subclass of cartilaginous (Chondrichthyans) fish that includes sharks, skates and rays.

Endangered species habitat credits

They are used to achieve compliance with section 10 of the Endangered Species Act (ESA) which allows landowners to impact endangered species habitat if they obtain a permit from the U.S. Fish and Wildlife Service (FWS) or the National Marine Fisheries Service (NMFS). FWS has implemented this policy by allowing the establishment of conservation banks, which restore, create, or otherwise protect endangered species habitat. Landowners who seek to impact endangered species habitat may purchase credits from conservation banks to offset their impacts

Endogenous technical change

Technical change due to intentional actions by firms that respond to market incentives, government policies and changes in knowledge or resource conditions.

Embodied technical change

Technical change that is incorporated into an input (typically the capital stock) and is usually incorporated into the fishing process through investment. Examples include new designs in the hull, propeller, and gear, changing materials (e.g. steel versus wood hull, monofilament nylon net instead of natural materials, Medina panel, information technology-embodied electronics and gear, all largely meant to improve productivity (fishing power). Other embodied technical change is intended to improve safety and crew comfort and to reduce bycatch, such as the Medina panel, circle instead of J hooks, Tori lines, nylon instead of steel wire leaders for longline gear, Turtle Excluder Devices, trawl net mesh design and size to increase juvenile groundfish escapement, pingers for gill nets, etc.

FADs

See: ***Fish aggregating devices***

Fish Aggregating Devices (FADs)

Permanent, semi-permanent or temporary structures or devices made from any material and used to lure fish. Naturally occurring objects such as logs, cetaceans, and whale sharks also serve as natural aggregating devices for pelagic species. FAD construction material ranges from simple use of palm fronds and bamboo to more intricate construction and construction materials. FADs can include sonar or more general hydro-acoustical equipment and GPS or radio capabilities so that the operator can locate the FAD and remotely contact it via satellite to determine the population under the FAD. There are different types of FADs;

Drifting FADs are not tethered to the ocean bottom.

Anchored FADs are tethered to the ocean bottom.

Ecological FADs are designed to minimize the inadvertent or incidental mortality of species other than those of direct interest (target species). Sets on drifting FADs by tuna purse seine vessels are usually made at night and during early periods of the morning near sunrise to capture fish as they move upward in the water column and to disguise the net from the fish.

Free riding

A situation in which individuals or organizations consume more than their fair share of a resource, or shoulder less than a fair share of the costs of its production.

Induced technical change

A form of ***technical change*** that occurs when a change in supply side conditions, notably the availability or relative price of inputs and knowledge to production, influences the rate and direction of technical progress in order to economize on the input that has become relatively scarce and expensive (i.e. replace this relatively more scarce and expensive input) or to use relatively more of an input as it becomes relatively more abundant and its relative price falls. See also*:* ***directed technical change***.

In-kind

See***: like-for-like***

Leakage

If not chosen properly, offsets could simply displace impacts that would have happened anyway, for example, if you create a protected area to offset the impacts of a mine, those who were previously harming biodiversity in the area (e.g. illegal timber/poaching) move to another location and have the same impact there

Learning by doing

A form of ***disembodied technical change***, describes how production costs tend to fall and efficiency rise as producers gain production experience. Learning by doing is disembodied in that it arises from increases in the stock of knowledge, independently of the characteristics of inputs used**,** but rather explains differences across vessels in the productivity of the same levels and types of inputs. It includes routinization of tasks, organizational learning such as matching tasks with individuals, skipper and crew learning, experience gained with information technology-embodied capital such as electronics, finding fish, navigation, gear handling, and knowledge of the environment and resource conditions e.g. currents, weather conditions, water temperature breaks, resource stock densities, etc.

Learning by using

A concept closely related to ***learning by doing***, occurs during utilization of a product. Designers of new technologies, or even improvements in well-known technologies, are rarely able to anticipate all issues arising in actual use or new opportunities that users often find. Observation of new technology adoption by others is important in this learning.

Levy

Refers to a tax.

Like-for-Like

Conservation of the same type of biodiversity as that affected by the project. (through the biodiversity offset) .Also referred to as ***in-kind*** conservation..

Marine megafauna

Large or relatively large marine animals, as of a particular region or period, considered as a group. – Marine megafauna include elasmobranchs (sharks, skates, rays), marine turtles, seabirds, and cetaceans (whales, dolphins, and porpoises).

Marine protected area (MPA)

The CBD defines MPA as: "Any defined area within or adjacent to the marine environment, together with its overlying waters and associated flora, fauna and historical and cultural features which as been reserved by legislation or other effective means, including custom, with the effect that its marine and/or coastal biodiversity enjoys a higher level of protection than its surroundings."

Mitigation

The action of reducing the severity or seriousness of something.

Mitigation of biodiversity loss

Mitigation of biodiversity loss from bycatch aims at reducing or compensating for the loss caused by accidental capture of a species), but it may also conserve additional ecosystem services or other species not of direct concern. For example, sea turtle nesting site protection may exclude economic development from an entire beach, thereby conserving it, its ecosystem services, contributions to open space, and conservation of other species whose habitat is the beach. Seabird rookery protection for one species of concern to longline vessels may also protect rookeries for other species on the same island. Protection of rain forests to sequester carbon through REDD+ payments also conserves overall biodiversity and other rain forest ecosystem services such as water regulation and habitat provision. Conversely, providing biodiversity mitigation may not cover the opportunity cost of the entire ecosystem required to achieve the biodiversity mitigation. In this case, the entire suite of ecosystem services and biodiversity conservation might be bundled and sold as a single product (if they can be estimated!). In these instances, often no attempt is made to add up the individual values of ecosystem services and biodiversity conservation to determine payment levels.

The mitigation of biodiversity loss may take the form of ***offsets*** *or* ***mitigation credits*** depending on whether thay intend to mitigate impacts on a single species or a whole ecosystem. Both can be further subdivided based on whether the credit seller or buyer is covered by government regulation: (i) ***regulated-regulated trades***; (ii) ***regulated-voluntary trades***; and (iii) ***voluntary-voluntary trades***.

Offsets and mitigation credits can be further subdivided based on whether the credit seller or buyer is covered by government regulation:

> ***Regulated-regulated trades*** occur when a regulated entity sells emissions allowances that it does not need to another regulated entity. These trades could occur in a ***cap-and-trade system***.
>
> ***Regulated-voluntary trades*** occur when a regulated entity offsets its emissions by paying for reductions by an unregulated (or voluntary) entity.

Voluntary-voluntary trades occur when an unregulated entity voluntarily purchases offsets from another unregulated entity.

Mitigation banking

The restoration, creation, enhancement, or preservation of a wetland, stream, or habitat conservation area that offsets expected adverse impacts to similar nearby ecosystems. The goal is to replace the exact function and value of the specific wetland habitats that would be adversely affected by a proposed project. ***Mitigation banks*** place a perpetual ***conservation easement*** on the land, with a trust to fund its stewardship.

Mitigation banks

They are essentially where providers have created offset projects in exchange for biodiversity credits, which can subsequently be sold to compensate for developments with comparable residual ecological impacts

Mitigation credits

Mitigation credits often refers to ***credits*** intended to mitigate impacts to whole ecosystems, such as wetland or endangered species habitat. They are the units of exchange used in ***mitigation banking*** and are defined as the ecological value associated with, say, one-acre (4,000 m^2) of a wetland or ecosystem and the linear distance of a stream functioning at the highest possible capacity within the service area of the bank.

Montreal Protocol's Multilateral Fund for Mitigation

Formally known as the *Multilateral Fund for the Implementation of the Montreal Protocol*, it is dedicated to reversing the deterioration of the Earth's ozone layer. It was established in 1991 to assist developing countries meet their Montreal Protocol commitments. It is managed by an Executive Committee with equal membership from developed and developing countries. The Fund Secretariat in Montreal assists the Committee in this task. Since 1991, the Fund has approved activities including industrial conversion, technical assistance, training and capacity building worth over US $2.8 billion.

Montreal Protocol on Substances that Deplete the Ozone Layer

An international environmental agreement that aims to protect the earth's ozone layer by phasing out the production and consumption of ozone depleting substances (ODS). The Montreal Protocol, founded on the principle of common but differentiated responsibilities, is the only multilateral environmental agreement with universal ratification.

Moral hazard

A ***moral hazard*** is a type of asymmetric information. A problem that arises between the buyers and providers of biodiversity mitigation or ecosystem services after the transaction or contract (informal or formal). There is an inability to control behavior after the deal and incentives are to evade the contract or transaction requirements. It can arise when an individual or institution does not bear the full consequences of its actions, creating an incentive to act less carefully than it otherwise would. A conservation buyer may contract with a seller of sea turtle nesting site protection (a seller or provider of ecosystem services/biodiversity mitigation) to conserve nesting sites but the provider does not fully protect the nesting site.

Moral suasion

Defined in the economics as "*the attempt to coerce private economic activity via governmental exhortation in directions not already defined or dictated by existing statute law*" (Romans, 1996). There are two types of **moral suasion**: "Pure" moral suasion refers to an appeal for altruistic behavior and is rarely used in economic policy. "Impure" moral suasion, or simply "moral suasion", is backed by explicit or implicit threats by authorities in order to provide incentives to comply with their wishes. Moral suasion differs from direct suasion using laws and regulations in that penalties for non-compliance are not systematically assessed on non-compliers. Moral suasion will be "an effective economic policy whenever the expected cost of non-compliance [for the user] is made to exceed the cost of compliance".

No net loss

The term "No Net Loss of biodiversity" could be compared to the term "carbon-neutral" for climate change: it is the ambition to conduct activities in such a way that after adding positive and negative impacts zero negative environmental impacts result. This way, a (business) activity is made sustainable with respect to biodiversity. Hence, for a company No Net Loss is an ambition, policy or target being met through (voluntary) compensation efforts at the level of its activities throughout its business. http://www.gemeynt.nl/nl/component/docman/doc_view/8-compensation-for-biodiversity-loss

Offsets

Offsets are meant to mitigate reductions of a single species,

Payments for ecosystem services (PES)

A PES is defined as: (1) voluntary transaction in which (2) well-defined environmental service, or a form of land use likely to secure that service (3) is bought by at least one ecosystem service buyer **(**4) from a minimum of one ecosystem service provider **(**5) if and only if the provider continues to supply that service (conditionality) (Engel et al., 2008)

Price effect

See: **Directed technical change**

Regulated-regulated trades

See: ***Mitigation of biodiversity loss***

Regulated-voluntary trades

See: ***Mitigation of biodiversity loss***

Restoration difficulties

Some habitats, like grasslands and heathlands, can be difficult to restore in terms of the time and technical skills required, others, such as ancient woodland, are impossible to recreate within human timescales

Selectivity

The process through which fishing obtains a catch with a composition (in size, sex, or species) that differs from that of the natural habitat on which it operatives. It is the probability of a species, sex, size, or age to be caught. It results from the appropriate selection of: (1) the fishing area and depth; (2) the fishing season and time; and (3), the fishing gear, its characteristics and operation. Usually it is defined at vessel, fishery, community, and ecosystem levels. It is conventionally regulated to: (1) maximize long-term yield from each recruit of the target species and (2) reduce catch of unwanted or protected species. (Garcia et al, 2011)

Sinks (of the Kyoto Protoco)l

Credits for the absorption of carbon dioxide by forests, cropland management, and re-vegetation.

Social norms

Explicit or implicit rules specifying what behaviors are acceptable within a society or group.

Stacking

Refers to combining payments for ecosystem services, credits, or mitigation activities. Stacking can be thought of as selling different products from a single activity, like selling both the wool and the meat from a sheep. Ecosystem service providers have begun to ask whether they can receive multiple payments for ecosystem services for services generated on a single land parcel, a practice known as *stacking.* Two issues that arise are double counting, in which one ecosystem service is sold twice to offset two separate impacts, and lack of ***additionality,*** in which projects would have occurred without the conservation investment/biodiversity mitigation/payment for ecosystem services, thereby not generating additional benefits (known as adverse selection in economics).

Taxa (singular Taxon)

A taxonomic unit, whether named or not, i.e. a population, or group of population organisms which are usually inferred to be phylogenetically related and which have characters in common which differentiate (q.v.) the unit (e.g. a geographic population, a genus, a family, an order) from other such units. A taxon encompasses all included taxa of lower rank (q.v.) and individual organisms.

Technical change

Refers to changes in techniques of production at the firm (vessel) or industry level resulting from application of new knowledge of scientific, engineering, or other principles to techniques of production.

Technology standards

Refer to mandatory design and equipment requirements and include operating standards. Examples include the required prohibition of sundown sets to reduce dolphin takes when setting on dolphins to capture large yellowfin tunas in the Eastern Pacific Ocean, use of the backdown procedure to let dolphins out of the purse seine net, discarding offal on the opposite side of the longline boat from the side from which gear is released, selectivity requirements for gear, use of circle hooks with mackerel-type bait rather than J-hooks with squid bait, required use of Tori lines to reduce seabird takes on longline vessels, required use of pingers on drift gillnets to reduce cetacean interactions, etc. On land, miles per gallon or kilometers per liter of gasoline standards and use of catalytic converters for automobiles or the requirement of double-hulled oil tankers and prohibitions of cleaning oil tanks with sea water close to shore are also technology standards. Technology standards may be the result of technical change.

Voluntary-voluntary trades

See: ***Mitigation of biodiversity loss***

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Appendix II - Technical Change

Technical change refers to changes in techniques of production at the firm (vessel) or industry level resulting from application of new knowledge of scientific, engineering, or other principles to techniques of production. It excludes changes in factor (input) productivities that result in choices among known techniques or from changes in the output mix due to changes in the relative prices of inputs or outputs. Technical change can lead to lower costs per unit of effort or increased catch rates per unit of effort given any level of resource stock.

Economic incentives play an essential role in the process by which new knowledge is introduced into the production process by new ways to find, capture, and handle fish. Not everyone who contributes to technical change is motivated by economic incentives, but nonetheless, economic incentives play a fundamental role.

New production processes are *process innovations* and new products are *product innovations*. Process innovations can be confined to those innovations not apparent in the physical properties of the product, whereas product innovations require some adjustment on the part of the consumer. The power block or new ways to catch fish are process innovations and new species harvested are product innovations. Although the distinction is not always clear, such as new species harvested because of fishing in previous inaccessible areas (e.g. harvesting grenadier on the deep continental slope), fisheries harvesting is largely concerned with process innovations.

Exogenous technical change occurs when technical change and its rate are largely independent of economic forces. The exogenous source is assumed to reflect progress in science, and in fisheries reflects its antecedents in military, aerospace, and IT sectors (Squires and Vestergaard in press). The major assumption is that technology is free and is publicly available as a non-excludable, non-rival good. (Rivalry refers to whether or not consumption of a good depletes the amount available for another's consumption.) Exogenous technical change is sometimes call "manna from heaven."

Disembodied technical change refers to technical change that is not embodied in an economic input, notably the capital stock or is not investment-specific, i.e. it is independent of physical capital accumulation (Solow 1957, 1960). Disembodied technical change can in part be viewed as a learning-by-doing and –using, once process innovations and investments have been introduced (Arrow 1962).

Learning by doing (LBD) describes how production costs tend to fall and efficiency rise as producers gain production experience. Learning by doing is disembodied in that it arises from increases in the stock of knowledge, independently of the characteristics of inputs used**,** but rather explains differences across vessels in the productivity of the same levels and types of inputs. It includes routinization of tasks, organizational learning such as matching tasks with individuals, skipper and crew learning, experience gained with IT-embodied capital such as electronics, finding fish, navigation, gear handling, and knowledge of the environment and resource conditions e.g. currents, weather conditions, water temperature breaks, resource stock densities, etc. (Squires and Vestergaard in press). *Learning by using*, a concept closely related to learning by dong, occurs during utilization of a product. Designers of new technologies, or even improvements in well-known technologies, are rarely able to anticipate all issues arising in actual use or new opportunities that users often find. Observation of new technology adoption by others is important in this learning. Adopters of a new technology create a positive externality for others in the form of the generation of information about the existence, characteristics, and success of the new technology. (Externalities are cost or benefits associated with one agent imposed on other agents without financial compensation.)

The process of learning occurs in social networks (Acemoglu et al. 2011). Because information and knowledge are public goods (one person's use does not reduce the amount available to others – nonrivarly- and no person's use prevents the use of another -nonexclusion), important learning externalities are involved.

Embodied technical change is incorporated into an input. Capital-embodied technical change leading to "better" capital is equivalent to "more" capital (Fisher 1965). One physical unit of new capital expressed in efficiency units represents more capital than one physical unit of an older vintage. The total "size" of this capital stock is the number of efficiency units it embodies, and the growth in this stock is the results of two factors: the arrival of more investment and the arrival of better investment. Examples are legion in fisheries, including hull, propeller, and gear design and changing materials, IT-embodied electronics and gear, all largely meant to improve productivity (fishing power). Other investment-specific technical change is intended to improve safety and crew comfort and to reduce bycatch (discussed below).

Factor augmenting technical change increases the productivity or efficiency of the factors of production, i.e. inputs, which enjoy this process innovation. Capital augmenting technical change increases the productivity of capital, and labor augmenting technical change, such as training and education, increase the productivity of labor. Wild species of fish are not augmented by technical change, but labor and capital often are. Nonetheless, wild species can alter through natural selection in response to fishing, such as younger age of sexual maturity; because this is not due to purposeful human activity means that it is not part of technical change. Cultured species of fish are augmented by technical change through breeding and selection and biotechnology affecting DNA. Resource augmenting technical change can increase the productivity of cultured or hatchery fish, such as salmon or tilapia, and is the focus of considerable attention, such as with Bluefin tuna, and more in the future can be expected.

Hicks neutral technical change does not favor use of any input, with ratios between inputs or input proportions remaining constant. Technical change can be *biased* toward using or saving a particular input or output depending upon the relative impacts upon the relative proportions of inputs used. *Biased technical change* can be capital *using* when the proportion of capital (say gear) used in the harvesting process increases and bycatch-*saving* when the relative proportion of bycatch caught declines.[62] Biases can be in input or outputs, with biases away from undesirable outputs such as bycatch desired. Biased technical change differs from factor augmenting technical change due in part to substitution between inputs (Acemoglu 2002).

Biased technical change is a shift in the production technology that favors one input over another (or one output over another) by increasing its relative productivity and, therefore, its relative demand. Traditionally, technical change is viewed as factor-neutral. The direction of technical change–e.g. whether new capital complements skilled or unskilled labor or bycatch is saved or used – may be determined endogenously by innovators' economic incentives shaped by relative prices, the size of the market, and institutions.

Resource-using technical change is a form of biased technical change that allows more effective use of the entire, existing resource stock, such as allowing exploitation of formerly unreachable and unexploited fishing grounds or detection of formerly unknown stocks or harvesting different age or size classes of fish formerly unavailable (Squires and Vestergaard in press). This bias does not increase the overall stock size or give more catch biomass from existing stock biomass, because man-made inputs do not substitute for fish in a stock-flow production process.

Bycatch-saving technical change is a form of biased technical change that reduces the relative amount of bycatch resource stock inadvertently harvested for a given relative target-bycatch resource stock proportion. With the exception of cultured fish, resource-using and bycatch-saving technical change are not due to factor-augmenting technical change, but are largely due to capital-using, and sometimes labor-using, technical change along with LBD for fishing and post-capture handling practices and locations.

Endogenous technical change is due to intentional actions by firms that respond to market incentives, government policies, and changes in knowledge or resource conditions.

Induced technical change is a form of endogenous technical change that occurs when a change in supply side conditions, notably the availability or relative price of inputs and knowledge to production, influences the rate and direction of technical progress in order to economize on the input that has become relatively scarce and expensive (i.e. replace this relatively more scarce and expensive input) or to use relatively more of an input as it becomes relatively more abundant and its relative price falls (Hicks 1932). Changes in current input relative prices induce input substitution, whereas persistent changes in longer-run input relative prices induce the development of new technologies.

Directed technical change (Acemoglu 2002, 2007, Acemoglu et al. 2012), a modern version of induced technical change, adds several key insights to induced innovation, notably that profit incentives affect both the amount and direction of technical change. It also considers increasing relative input supplies more than their scarcity, profits and output prices rather than solely cost minimization and only relative input prices, and increasing returns to scale due to external benefits and spillover effects from knowledge. Two important components are the *price effect* and the *market effect*. The *price effect* occurs if there are stronger incentives to innovate when: the good produced by these technologies

[62] More technically, Hicksian biases refer to ratios of marginal products change at constant factor prices or constant factor ratios. An increase (decrease) in this ratio gives input-using (-saving) technical change. Biases can also be measured through changes in relative cost shares or in the ratios of optimal factor demands. Output biases can be similarly defined.

commands higher prices or when there are relatively scare inputs and correspondingly relatively high input prices to reduce their use (since goods produced by relatively scarce inputs are relatively more expensive, lowering profits). The *market size effect*, which can potentially outweigh the price effect, occurs when it is more profitable to develop technologies that have a larger market and more abundant inputs.

A general result of directed technical change is the *weak equilibrium (relative) bias effect* in which an increase in the relative supply of an input always induces technical change biased toward this input (Acemoglu 2002). An example is the increase in IT embodied in capital, such as vessel and gear electronics, where one of the major trends throughout the general economy is the rising supply at falling prices for IT.

Directed technical change adds to the standard induced innovation theory emphasis on relative ease of substituting inputs, which can give results that contrast with the standard theory. The *strong equilibrium (relative) bias effect* occurs if the elasticity of substitution (measure of ease of substituting one input for another) between inputs is sufficiently large, so that an increase in the relative supply of an input induces sufficiently strong technical change biased toward this factor. Although there is no empirical verification, perhaps the substitution between vessel electronics for finding fish and fuel is sufficiently high that the increase in IT-embodied electronics is inducing technical change biased toward this factor.

Appendix III – ISSF Turtle Conservation Programme

1. Western Pacific

***Project Title*: Leatherback conservation in Bird's Head region, Papua Barat, Indonesia.**

Recipient: State University of Papua

Funding: $15,000 (2010); $18,000(2011); $18,000 (2012)

***Project Title*: Community based leatherback conservation in Solomon Islands.**

Recipient: The Nature Conservancy

Funding: $13,000 (2010); $15,000(2011)

2. Eastern Pacific

***Project Title*: Prevention and reduction of marine turtle fishery bycatch in Peru**

Recipient: Associacion Pro-Delphinus

Funding: $6,000 (2010); $10,000 (2011); *$13,000* (2012)

Summary: Operating a high frequency radio from a fixed base station in Lima, Peru, Pro Delphinus (PD) is able to communicate with fishermen at sea in real time. Ports that have been engaged in the project now number nineteen and extend from Manta, Ecuador in the north to Iquique, Chile in the south, a distance of over 2,500 km. When accounting for the crew member of each vessel contacted, the Radio Conservation has handed information on marine endangered fauna such as marine turtles to over 3000 fishermen operating along the Peruvian coast, including few vessels from Ecuador and Chile. Workshops were conducted to train fishers on how to safely disentangle and remove hooks from bycatch turtles. With support of ISSF, in 2011 PD was able to continue and expand this project to over 1000 communications to date with fishermen at sea. ProDelphinus has distributed line-cutters and dehookers to fishers that have visited from remote locations. ProDelphinus through use of HF radio broadcasts and workshops has engaged fishermen in turtle safe handling and release techniques and distributed line cutters and knives at ports with a high incidence of bycatch identified from the reports to the radio communication. This program is being expanded in 2012-13 to Chile in collaboration with a partner (ONG Pacifico Laud) based in Valparaiso. The resurgent gillnet fishery in Chile has been identified as a pressing threat to leatherbacks, and there is great interest in Chile from the fishing communities for radio support and capacity building. Currently PD receives some calls from fishers in northern Chile and has purchased a radio that would be installed in Valparaiso, extending the communication deep into the fishing area off Chile.

***Project Title*:** **Hawksbill conservation in Nicaragua**

Recipient: The Ocean Foundation-Eastern Pacific Hawksbill Initiative – ICAPO

Funding: $12,000 (2010); $13,000 (2011); $18,000 (2012)

Summary: This has been a model project for integrating community members in the conservation effort in a short period of time and word of their work is spreading throughout the region. ICAPO has maintained and enhanced activities at Padre Ramos in Nicaragua, and expanded the program into El Salvador at Bahia, including establishing beach hatcheries that protected more than 90% of all the nest laid in the Eastern Pacific. They tagged a total of 44 female turtles in 2011, more than in the entire eastern Pacific combined. They released a total of 14,874 hatchlings from the hatcheries and protected nests. Prior to establishment of this program at Padre Ramos and Bahia, 100% of the nests laid were collected for consumption or sale. A combined nest protection rate of more than 85% at both program sites is a phenomenal achievement. They had enthusiastic support from the local communities. Other activities included establishment of 'Estero Padre Ramos Natural Reserve Hawksbill Conservation Committee', holding 6 workshops each year with 10 stakeholder communities and holding the first and second Annual Festivals of the Hawksbill Turtle in Padre Ramos and Bahia. The survival of hawksbill turtles in the eastern Pacific largely hinge on the strengthening of these locally led conservation initiatives. Support by ISSF since 2010 has been crucial to ICAPO's hawksbill conservation successes at Padre Ramos and Bahia, and in leveraging additional support from other program partners to continue and improve the program at both sites.

***Project Title*:** **Ocean Leaders: Empowering young people from urban and diverse backgrounds to become tomorrow's leaders in fisheries science, fisheries management, and conservation**

Recipient: Ocean Discovery Institute

Funding: $5,000 - $19,500 requested 2012

Summary: ODI involves students from urban environments in the USA and local fishing community in Baja California, Mexico with research and conservation being done by an ongoing program to reduce sea turtle bycatch in coastal gillnet fisheries. A cornerstone component of Ocean Leaders is an intensive research experience through which students work with practicing scientists at government agencies and academic institutions. This experience includes field work in Baja California, Mexico; data analysis; and poster and oral presentations at conferences, scientific meetings, and at the Report to the Community, a special event held each August that is attended by approximately 300 community members and science and conservation professionals. ODI participants will work with NMFS and Mexican scientists on bycatch mitigation experiments that are part of an ongoing project funded by other sources. This project enhances the conservation value of the bycatch research, adding several dimensions: building capacity in students and local community, and facilitating international cultural, professional and information exchange and engagement with local fishing community.

ISSF funds allows ODI to support up to 6 high school and 2 college fellows, and the participation of local fishermen (including training to conduct research, workshops, and interviews) in the project and to leverage funds from multiple sources to increase number of student beneficiaries.

3. Indian Ocean

***Project Title*: Seychelles Islands sea turtle conservation.**

Recipient: Seychelles Islands Foundation

Funding: $18,000 (2010)

Summary: This project was supported in 2010 to use satellite telemetry on green turtles nesting within the Aldabra Protected Area to establish post-nesting migrations and identify foraging areas these turtles go to outside the protected areas where they are exposed to other threats. This is being done within an outreach and education framework to address trans-boundary conservation issues. ISSF funds were used to leverage additional funds for an expanded program which is ongoing

***Project Title*: Monitoring and conservation of sea turtles in the Andaman and Nicobar Islands, Sri Lanka**

Recipient: Dakshin Foundation

Funding: $5,000 (2010); $5,000 (2012)

Summary: This project continues to be a conservation need for the region, which is a priority area for leatherback conservation. ISSF started supporting this project in 2011 and this has made a significant impact. Camps were set up at the remote sites on Little Andaman Island to focus on Leatherback conservation. This is the most important known site for leatherbacks in the Indian Ocean, but there has been no monitoring in the past. Field teams and community members have so far documented more than 175 nests (through the 15th of February), the highest recorded so far for the beaches. The monitoring camps and the regular patrolling of the beaches have ensured that there have been no disturbances on the nesting sites and also no poaching of nests and animals (of other species of turtles) at these sites. A survey of the main pre-tsunami leatherback nesting beaches of the Great and Little Nicobar islands is scheduled for the month of April. The survey will be very critical in understanding the post-tsunami status of leatherback nesting in these islands and in reviving the long-term monitoring camps that where once operational at Galathea Bay, Great Nicobar Island. The program has managed to garner local support and recognition and the project is gaining considerable momentum and growth. ISSF funds are used for leveraging support to provide great conservation value at low cost.

***Project Title*: Community based sea turtle conservation in Tanzania.**

Recipient: Sea Sense

Funding: $5,000 (2011), $5,000 (2012)

Summary: Sea Sense works with local communities and government, including working closely with community-based groups known as Beach Management Units (BMU's) who are key fisheries stakeholders for the purposes of fisheries planning, management, conservation and development. A number of training, education and awareness workshops with BMU's established in 2 communities in Tanzania. Sea Sense is expanding this effort to a 3rd community in the Temeke District which is one of the most important green turtle nesting sites in Tanzania and also a major hotspot for dynamite fishing which is destroying critical foraging and breeding habitat. ISSF funds are also being used to strengthen capacity amongst District Fisheries staff who are responsible for enforcing Tanzanian Fisheries Regulations protecting sea turtles.

***Project Title*: Working with local fishermen to mitigate loggerhead bycatch on Masirah Island, Oman.**

Recipient: Environment Society of Oman (ESO)

Funding: $5,000(2010); $5,000 (2011)

Summary: An agreement was established with a leader in the local fishing community who owns several fishing boats, uses various fishing gear, and processes and sells the fish to participate in this project. A working relationship with the community fishers through a series of workshops and the ESO who also have an ongoing community-based nesting beach monitoring program on Masirah. Work is underway to assess bycatch and train fishers in sea turtle bycatch mitigation activities. The US State Department is interested in supporting future efforts to engage the support of the Govmt of Oman, and ISSF funds will allow inroads to be made by ESO with the Oman government and continue to engage the local fishing community to develop and implement local ideas and solutions to mitigating bycatch. This project is building confidence and respect of the fishing community, understanding the extent of turtle bycatch, and developing bycatch reduction strategies.

<u>4. Atlantic</u>

***Project Title*: Sea turtle conservation in Brazil.**

Recipient: Proyecto Tamar

Funding: $9,000 (2010); $15,000 (2011); $15,000 requested (2012)

Summary: Tamar has an excellent track record and are global leaders in community conservation. They monitor 30km of beaches from the Praia do Forte station on the coast of Bahia as one of a broad portfolio of projects. The nesting season for loggerheads extends from September to March. Tamar hires 6 tartarugueiros (local fishermen hired by TAMAR to patrol the beaches every day), a local agent, a biologist and four interns who are responsible for data collection, management and environmental education activities. Currently, more than 65% of nests remain *in situ* (original oviposition site for females) which has been identified as the best management strategy. The rest of the nests that are threatened by erosion or predation are relocated to safe sections of the beach or to hatcheries. During the 6 month nesting season Tamar and the community have protected over 700 loggerhead nests and released over 45,000 hatchlings each year. ISSF funding has allowed continuity and expansion of the efforts to monitor the females and protect additional nests on additional stretches of the beach by involving more community staff. This is another keystone project with great conservation value and high global visibility.

***Project Title*: Mitigation of turtle meat consumption on Santiago Island, Cape Verde.**

Recipient: Cape Verde Sea Turtle Network (CVSTN)

Funding: $14,000 (2010); $10,000 (2011); $10,000 (2012)

Summary: The archipelago of Cape Verde supports one of the largest loggerhead sea turtle nesting populations in the world, and extensive exploitation of turtles for their meat and eggs poses one of the biggest threats to this population. CVSTN sea turtle projects throughout Cape Verde have increasingly expanded their conservation efforts in an attempt to mitigate the high levels of exploitation occurring on nesting beaches. The CVSTN were able to initiate this outreach and training of enforcement and management personnel. The "Nha Terra" (= "This land is my land") campaign was launched as parto f this Project to focus on the heritage of the marine turtle in Cape Verde and the need to preserve them for future generations. The main message is that, in common with the Capeverdian people, marine turtles leave their place of birth to travel the world, but remain Capeverdian, and deserve to have a safe place in this country when they return to lay their eggs. Project achievements include:

1. Nineteen events involving National media campaign attended by approx 1500 people
2. 102 workshop attendees from the Armed forces, National Police, national & local government and the judiciary (see below)
3. Production of a Batuka song about turtles (traditional music from the island of Santiago)
4. Production of a short film about turtles in Cape Verde
5. Road show in major neighborhoods throughout Santiago in conjunction with local partners with the following format:
    a. Workshop for officials discussing the law & methods of enforcing the law. Small
    b. incentives such as notebooks, pens and certificate of participation will be provided.
    c. Public concert featuring Batuka performance, film show and discussion.

ISSF funding has allowed a sustained effort to expand outreach, education and promotion of enforcement of laws, urgently needed as exploitation continues, despite sea turtles being legally protected by Cape Verdian law. The project is currently expanding their campaign to partner with restaurants.

Appendix IV – Technology of Public Good Supply

Public goods are heterogeneous, and how they are supplied --the technology public goods supply -- affects incentives, the amount supplied, and their financing (Hirschleifer 1983, Sandler 2004, Barrett 2007, Arrigada and Perrings 2011). This heterogeneity in public goods and their supply in turn affects the nature of the external benefits, free riding, and type of cooperation or collective action that is require to secure the public good provision.

The question becomes how to aggregate the individual contributions to the provision of the public good. The aggregation function indicates how individual contributions to the public good combine to determine the overall level of the public good that is available for production as a public input. Individual environmental contributions z_i may collectively be important and form a composite public good, so that $z = \mathrm{f}(z_1, z_2, \ldots, z_N)$, where $f(\cdot)$is the aggregator function and there are N contributions.

Additive public goods are supplied as the simple or weighted sum from each supplier, cannot be supplied by a single provider, and instead depend on all entities' combined efforts. *Simple sum* public goods can be defined as $z = f(\cdot) = \sum_{i=1}^{N} z_i$, where the aggregator function is simply summation, there are not interactions since $\partial z/\partial z_i = \partial z/\partial zj = 0, \forall i, j \epsilon N$, and not all contributions are critical. *Weighted average* public goods are also additively separable and can be defined as $z = f(\cdot) = \sum_{i=1}^{N} \omega_i z_i$, where ω_i denotes the weight for $z_i$and $\sum_{i=1}^{N} \omega_i = 1$. Free rider problems arise in both instances, with the severity and strength of incentive more critical with weighted average public goods. The larger the relative weight the more critical the provider and the greater the incentive for others to free ride. Reduced carbon emissions to lower ocean acidification is a simple sum additive public good and protecting some species of sea bird rookeries is a weighted sum additive public good.

The most effective provider supplies *best-shot* public goods, allowing unilateral supply and minimal free riding problems that make supply vulnerable, although there is considerable potential for free riding, and $z = \max(z_1, z_2, \dots, z_N)$. Conservation technology available to all is an example, such as U.S. development of circle hooks and mackerel-type bait rather than J-hooks, squid bait for swordfish longline harvesting, Medina panels for tuna purse seines nets to protect dolphins, French-Spanish development of tuna purse seiner eco-FADs, and Japanese longline bycatch-saving technologies such as the 'Yamazaki Double-Weight Branchline' that increases the sinking rate of pelagic longlines and Tori lines. The incentives to supply best-shot public goods can be so strong that countries provide them unilaterally, but in doing so these providers cannot be counted on to account for the interests of other states or organizations (Barrett 2007). Best-shot public goods tend to be supplied by larger and wealthier countries with the greatest stake in the issue. The United States tuna purse seine fleet in the Eastern Pacific Ocean at the time had the largest fleet setting on dolphins and the captured tunas had an important share of the U.S. canned tuna market. France, Spain, and large industry groups and NGOs have the greatest stake in the development of eco-FADs because their fleets provide the largest portion of tuna to European markets, where consumer and environmental group pressures on FAD bycatch are strongest. Northeast Asian countries dominate global large-scale pelagic longlining, with Japan often assuming the lead, and hence had one of the greatest stakes in developing bycatch-saving longline technologies. Similarly, the Endangered Species Act drove the United States to take the lead in sea turtle saving technologies for pelagic longlining for swordfish.

Benefits from *weakest link* public goods depend upon the least effective provider. If the technology critically depends on the least of the environmental contributions $z_1, z_2, \dots, z_N$, so that the smallest effort represents the shared level of the public good, $z = \min(z_1, z_2, \dots, z_N)$. Weakest link public goods entail weak incentives for providers to supply, minimal potential for "free riding" by other providers. Conservation should first begin with the weakest link and depends on the country that does the least or has the sole step in the entire life history of a species. Reflagging with transboundary resources makes fisheries management in general a weakest link collective action problem (Barrett 2007). As long as there is a single state willing to offer open registration, the collective conservation efforts of even a large number of states will be vulnerable.

Benefits from *weaker link* public goods depend on all links, with the weakest link the most important; supply incentives are weak, free riding problematic, and conservation should first begin with the weakest link. Bluefin tuna conservation is a weaker link public good because spawning ground protection is critical, but conservation throughout the life cycle counts. Fish with downstream externalities, in which one fleet harvests juvenile fish and another fleet harvests adults also show characteristics of weaker link public goods, with bigeye tunas possibly fitting this category, where purse seiners harvest younger bigeye before longliners can harvest adults. North Pacific loggerhead sea turtles nest only on southern Japanese beaches and South Pacific loggerhead sea turtles nest solely on

Australian beaches, so that these are weaker link public goods; multiple countries impart bycatch mortality on these turtles but they have a single nesting location, the weaker link. The provision of eco-FADs is a weaker link public good focused on markets and producers dependent on the Indian Ocean.

A general formulation for the different aggregator functions is:

$$z = \gamma \left[\left(\frac{1}{\upsilon}\right) \sum_{i=1}^{N} z_i^{\upsilon} \right]^{1/\upsilon},$$

where γ, υ are exogenous parameters (Cornes and Sandler 1996). When $\gamma = 1$, then $\upsilon \to -\infty$ gives weakest-link, $-\infty < \upsilon < 1$ gives weaker link, $\upsilon = 1$ gives average, $1 < \upsilon < \infty$ gives better shot, $\upsilon \to \infty$ gives best shot, and $\upsilon = 1$ gives additively separable. In the end, most public good supply is unlikely to be a single technology or provider since marginal costs of reductions for any sector or technology are likely to be rising, such as preventing mortality of any dolphins when harvesting Eastern Pacific dolphins, many public goods are transboundary, such as the discussed in this paper, and conservation lies on a spectrum between weak-link and additive public goods, depending on the species and ecosystem.