Alcoa Foundation's Conservation and Sustainability Fellowship Program

In Partnership with the World Conservation Union

Exploring Biodiversity Offsets as a Tool for Fisheries Bycatch

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The social and economic importance of fisheries and the biological realities of overfishing and bycatch result in cardinal tensions over ocean resources. The objective of my project was to develop the necessary framework that would allow biodiversity offsets to play a role in the management of species impacted by fisheries bycatch, particularly seabirds and sea turtles. Given that conservation dollars are limited, marine biodiversity offsets provide an opportunity to address a global environmental concern, optimize conservation interventions, and forge an alliance between conservationists and fisheries.

Over the past year, my colleagues and I have built on my original work that presented biodiversity offsets as a possible tool for fisheries bycatch management (Wilcox and Donlan 2007). This work has focused on three aspects,

- A use rights approach to managing fisheries bycatch,
- Integrating invasive species management and biodiversity offsets for fisheries bycatch management, and
- Scoping opportunities for offset programs for sea turtles and seabirds on a global basis.

This report is broken into three chapters reporting on the above aspects. First, I describe a use rights framework that could reduce biodiversity threats from fisheries. The most concentrated impact the marine environment comes from commercial fishing, which affects not only the commercially harvested species, but also other species that are caught incidentally, known as bycatch. Management of these impacts has been somewhat *ad hoc* to date, based on policies that are not developed at the population scale and use mechanisms that may result in policy failures. Moreover, the public often bears the largest share of the costs of managing species threatened by bycatch. I discuss the allocation of use rights as an alternative method for managing bycatch. I review their application in managing commercially harvested species, and illustrate how this mechanism might be utilized for incidentally captured species. When embedded in a management cycle that sets allowable mortalities, allocates those to rights holders, and monitors their outcomes, a use rights framework appears to address many of the shortcomings of the existing policies for managing the impact of commercial fishing on threatened marine vertebrates. As fisheries are increasingly being pressured to address their environmental impacts, new regulatory approaches will likely parallel the systems currently used for target species management. It is essential that conservation scientists and advocates consider all the available tools, engage in, and lead this discussion to ensure the policy goals are ecologically defined, that industries bear the costs of their environmental impacts, and that the public receives the full value from use of its resources.

Second, I discuss the opportunities of island restoration to serve as biodiversity offsets for fisheries bycatch management, which could result in conservation gains for seabirds and sea turtles. The removal of invasive mammals from islands is one of society's most powerful tools for preventing extinctions and restoring ecosystems.

Given the demonstrable high conservation impact and return on investment of eradications, new networks are needed to fully leverage invasive mammal eradications programs for biodiversity conservation at-large. There have been over 800 invasive mammal eradications from islands, and emerging innovations in technology and techniques suggest that island area will soon no longer be the limiting factor for removing invasive mammals from islands. Rather, securing the necessary social and economic capital will be one main challenge as practitioners target larger and more biologically complex islands. With a new alliance between conservation practitioners and the fisheries sector, biodiversity offsets may be a promising source of capital. A suite of incentives exists for fisheries, NGOs, and governments to embrace a framework that includes fishery bycatch offsets for seabirds and sea turtles. A bycatch management framework based on the hierarchy of "avoid, minimize, and offset" from the Convention on Biological Diversity would result in cost-effective conservation gains for many threatened seabirds and sea turtles affected by fisheries. Those involved with island conservation and fisheries management are presented with unprecedented opportunities and challenges to operationalize a scheme that will allow for the verifiable offset of fisheries impacts to seabirds and sea turtles, which would likely result in unparalleled marine conservation gains and novel cross-sector alliances.

Lastly, I present one technique to quantify and synthesize anthropogenic hazards to species that we have little empirical data, such as sea turtles. This process is critical is the first step toward scoping biodiversity offset opportunities at a global level. The natural history of organisms is central to biology and subsequently biodiversity conservation. Yet, for the majority of organisms we know little about their natural history and even less about how specific anthropogenic hazards interact with their biology. Quantifying regional hazards is particularly challenging for data-poor species like sea turtles, given that they are notoriously difficult to study, migratory, long-lived, and commonly face multiple anthropogenic threats. Expert elicitation, a technique used to synthesize the opinions of experts, while assessing the uncertainty around those views, has been in use for several decades in the social sciences and risk assessment sectors. We used an Internet-based expert opinion survey to globally assess the relative impacts to sea turtle populations at the regional level, and the uncertainty around those impacts for a range of known hazards. Fisheries bycatch and coastal development were most often ranked as top hazards to sea turtle species in a geographic region, followed by nest predation and direct take. While no survey data exist from decades past on how researchers and conservationists perceived anthropogenic hazards to sea turtles, the results from our survey suggest that they now consistently identify sea turtles as having multiple threats, including substantial threats from at-sea hazards. Resources invested by the sea turtle community, however, still appear biased toward terrestrial-based impacts. Predicted impact scores from the survey, along with their respective uncertainty, are useful for conservation planning as they provide estimates of relative impacts on species of a suite of hazards, along with a measure of consensus among researchers and practitioners. Our survey results also revealed clear patterns of expert bias. Respondents with no experience with respect to a sea turtle species tended to rank hazards affecting that sea turtle species higher than respondents with experience. A more striking pattern was with hazard-based expertise: the more experience a respondent had with a specific hazard, the higher he or she would score the impact of that hazard on sea turtle populations. Priority setting for the conservation of threatened and endangered species cannot wait for exhaustive empirical research. Bias-controlled expert opinion surveys focused on threatened species and their hazards can help guide and expedite effective recovery plans.

This research was made possible through the assistance of the Alcoa Foundation's Conservation and Sustainability Fellowship Program, and the World Conservation Union. This work is a result of much collaboration, including with the participants of the market-based strategies for marine conservation working group funded by the US National Center for Ecological Analysis and Synthesis, which I directed with my colleague Chris Wilcox.

Chapter 1: License to Kill: Can A Use Rights Approach Improve Bycatch Management? [1]

The global impact of human use on marine ecosystems is increasingly well documented (Halpern 2008). The most concentrated of these impacts comes from commercial fishing, which affects not only the targeted species but also the structure of the ecosystems (Myers & Worm 2003; Pauly et al. 2002). These wholesale impacts affect also affect bycatch species, which include not only fish and sharks, but also seabirds, sea turtles, and marine mammals with no commercial value that are killed during fishing enterprises. While controlling the impacts of fishing on commercially fished species have been a focus of management for a long time, efforts to address bycatch, particularly of species of conservation concern, have really only picked up momentum in the last decade.

When bycatch impacts have been managed, the strategies are often *ad hoc*, and in some cases have produced damaging outcomes. For example, since all sea turtles found in U.S. waters are listed under the Endangered Species Act, the U.S. Government issues permits for their incidental take on a fishery-by-fishery basis. While these allocations may be small when viewed individually, the cumulative result is an authorized annual kill of nearly ten thousand endangered sea turtles and more than three hundred thousand additional non-lethal interactions – a cumulative impact that runs afoul of the statute's intent to rebuild species and prevent jeopardy (Griffin et al. 2006).

Similarly, management rules are often not aligned to policy objectives. To manage seabird bycatch, many countries mandate that fisheries use maximum allowable catch rates (e.g., 0.05 birds per 1000 fishing hooks deployed; Anonymous 2006b). A bycatch rate is arguably a poor management instrument for threatened species. A fixed allowable bycatch rate means that the number of seabirds killed, for example, will fluctuate with fishing effort: more effort begets more dead seabirds. The implication is that a fishery could operate within legal limits and yet drive a seabird species to extinction – utterly failing to achieve the objective of the bycatch policy. This reliance on catch rates may stem in part from the underlying assumption in fisheries management that there is an inherent feedback in the system - at low catch rates (i.e., inferred lower population size of the target species) it will be uneconomical to fish (i.e., "commercial extinction"). However, such a safety valve does not exist for bycatch species, as by definition they do not have a direct effect on the income of fishers.

Recent shifts in the management of commercially fished species may provide some useful lessons for the management of bycatch, particularly for species of conservation concern. We discuss the lessons that can be drawn from the application of rights-based management to commercial fisheries, illustrate a structure for how this system could be applied to managing bycatch, particularly for species of conservation concern, and finally cover some challenges that will arise if management does move to a rights basis. When integrated into a formal

[1] Reprinted from Wilcox, C., K. Fletcher, M. Turnipseed, C.J. Donlan, S. Pascoe, and R. Sagarin. in review. A use rights approach can reduce biodiversity threats from fisheries. Conservation Letters.

management structure that considers impacts at the population scale, instead of the scale of individual impacts, this framework could provide a resolution to the issues of untracked cumulative impacts and management rules that are not aligned with policy objectives.

Learning from Fisheries

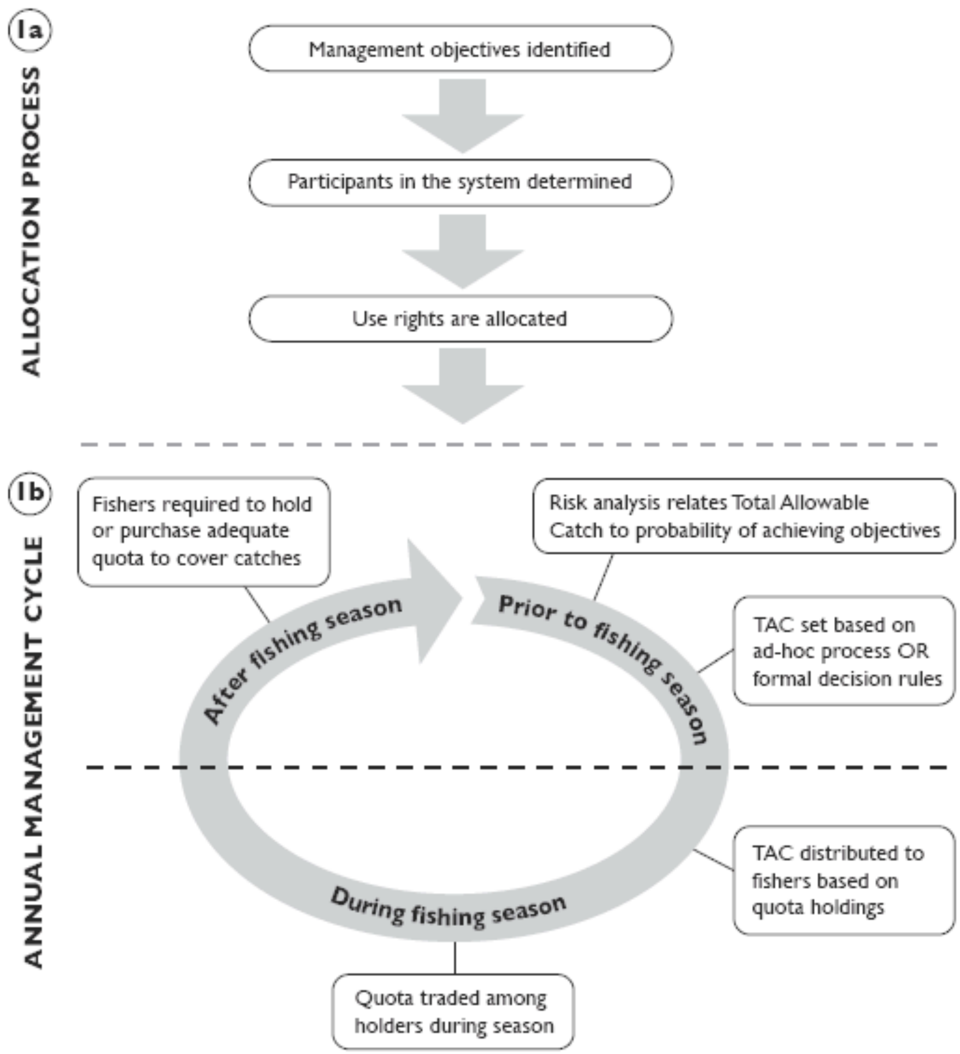
Much intellectual and operational effort has been invested in designing management schemes for commercial fisheries, and spectacular failures have given managers and conservation advocates pause to consider the effectiveness of past approaches. As a result, there has been an increasing consensus since the 1950's that the best mechanism for regulating fisheries is the creation and allocation of use rights (Mansfield 2004).[2] The consensus has made its way into regulatory and political circles, translating into strong pressure for reform. For instance, in Australia, the Minister for Agriculture, Fisheries, and Forestry recently issued a directive to the national fisheries management agency to "implement the long standing government policy of managing fisheries using output controls in the form of individual tradable quotas" (Macdonald 2005). The move to an individual tradable quota (ITQ) system is an attempt to stem tragedy-of-the-commons dynamics by allocating the right to own and/or the right to use a common pool resource to a group of individuals, creating individual incentives that lead to the sustainable use of those resources. These incentives arise because the quota owners have exclusive rights to the resource, thus their profit motives are directly harnessed to the long-term conservation of the resource (Mansfield 2004). Not surprisingly, the net result depends critically on the intricacies and established rules of the implemented framework; but in some cases a use-rights approach to managing fisheries has achieved better outcomes than traditional management systems (Bryant & Huppert 2006; Hilborn et al. 2005).

Townsend et al. (Townsend et al. 2006) provide a thorough discussion of a management system design based on use rights. In general these systems are based on 1) defining a group of entities (i.e., individual fishers, vessels, harvesting cooperatives) that have use rights, 2) allocating each entity a portion of the total allowable catch (TAC) of the target species (called "quota"), and, in more recent times, 3) allowing the trading of the allocations. An important point in considering the rights-based approaches used for managing commercially harvested species is that they are embedded in a formal decision-making framework (Figure 1). This structure includes an allocation step, generally done when the management system is established (steps 1 and 2 above, Figure 1a), followed by an annual cycle of population assessment, catch allocation distribution, and redistribution via trading as catches are realized (Figure 1b). The system of annual updates effectively incorporates a passive adaptive management (see Parma et al. 1998) into the use

[2] While the phrases "property rights" and "use rights" are often used interchangeably in practice, this essay employs the legally accurate term of "use rights" as that bundle of rights related to a private claim of a public resource. For bycatch quotas, as this essay reflects, use rights can include economic claims to the resource but do not rise to the level of a legal property right.

rights system. It is worth noting that use rights systems frequently also stipulate that fishers hold a fishing license, or employ other measures such as spatial or temporal restrictions on fishing, which impose further conditions on fishers' operating practices.

Figure 1. A simplified schematic view of rights-based management of commercial fisheries.



Developing a Use Rights Based System for Managing Fisheries Bycatch

A use rights approach to managing bycatch impacts of fisheries has received relatively little discussion, with the main focus being on regulating bycatch of commercially important fish species (Diamond 2004; Edwards 2003; Holland & Ginter 2001). In exploring the application of use rights to bycatch management for non-commercial species, we first cover the annual management cycle (Figure 1b) and its relation to the management objectives. There is some precedent for this aspect of the approach, based on management of the Eastern Pacific tuna purse seine fishery to reduce dolphin bycatch, the only long-running application of use rights to a non-commercial species (Bisack & Sutinen 2006; Hall 1998). We then return to the more complex and less established questions around allocation, duration, and ownership of the use rights (Figure 1a).

Total Allowable Mortality, Objectives, and Decision Rules

While bycatch is undesirable, eliminating bycatch entirely comes at a substantial cost to industry, and subsequently to coastal communities and seafood consumers. As with pollution, there is an optimal level of bycatch that balances the costs associated with its control with the sustainability of the resource.

The first step in finding this optimal level is the setting of a Total Allowable Mortality (hereafter TAM) which is the beginning of the annual management cycle (Figure 1b). A shift from *ad hoc* rules, like incidental take permits or catch rates, to a formal TAM setting exercise would have several advantages. Procedures for setting a Total Allowable Catch (TAC), the equivalent quantity for commercial target species, are well defined in fisheries, and generally include an explicit statement of objectives, development of a quantitative risk assessment, and clear specification of decision rules. Setting the TAM based on ecological objectives will be critical for success (Rosales 2006). For example, for an endangered sea turtle an ecological management objective might be a positive population growth rate or an ecologically effective population size (Soulé et al. 2005).

A formal TAM-setting process for bycatch species would also tie management actions to species protection legislation (e.g., Australia's Ecosystem Protection and Biodiversity Conservation Act and the U.S.'s Endangered Species and Marine Mammal Protection Acts). This legislation is often stronger in its regulatory law and legal precedent in terms of species protection than the bycatch policies promulgated under fisheries management regulations, and frequently has fairly explicit guidelines for management objectives. For instance, the U.S. Congress acknowledged the link between marine species management and ecosystems in the Marine Mammal Protection Act (MMPA), which declares that certain species and population stocks of marine mammals "should not be permitted to diminish beyond the point at which they cease to be a significant functioning element in the ecosystem of which they are a part, and… not be permitted to diminish below their optimum sustainable population" (16 U.S.C. sec. 1361 (2) (b)).

There are some limited demonstrations of the use of TAMs and use rights for managing threatened species, based on objectives ranging from sustainable mortality to elimination of bycatch. Under the U.S. MMPA for example, the National Marine Fisheries Service (NMFS) establishes annual potential biological removal (PBR) limits for marine mammals captured in fisheries, which basically function as TAMs. When NMFS sets annual PBR limits, there is a clear definition of the objective in terms of how a fishery affects population depletion (Wade 1998). However, despite the frank analysis of sustainable mortalities, the PBR approach does not allocate, lease, or permit trading of use rights. The New Zealand arrow squid fishery uses a similar system to regulate the mortality of threatened New Zealand sea lions, but goes further by explicitly setting a fishery-wide allowable kill limit. This is a subtle, but significant difference, as the New Zealand policy is actually permitting the mortality of the animals, as opposed to setting a level below which the fisheries or conservation agency will not intervene. However, neither PBRs nor the NZ sea lion allowable kill is allocated to individual operators, which reduces the effectiveness of these policies in generating incentives for responsible behavior (Diamond 2004).

In addressing dolphin bycatch in the Eastern Tropical Pacific tuna fishery, the international fishery management authority, the Inter-American Tropical Tuna Commission (IATTC), went a step further. It set a TAM for dolphin bycatch and then allocated proportions of the annual TAM to individual vessels via a quota system. In addition, the TAM was set more conservatively with time, providing an increasing incentive for operators to develop new innovations to reduce their bycatch levels. The outcome was encouraging: changes in fishing practices led to an a decline in the annual deaths of dolphins in the fishery from over 130,000 animals in 1986 to less than 1,200 in 2005 (Anonymous 2007Hall, 1998 #226).

A final example is New Zealand's draft National Plan of Action for Sharks, its contribution to an international shark conservation plan promulgated by the United Nations Food and Agriculture Organization (Anonymous 2008). In the New Zealand proposal, the Ministry of Fisheries outlines the use of its Quota Management System, which is currently applied to 11 of the 74 shark and fish species caught by New Zealand fishers, to controlling shark catch. While some shark species covered by the plan are targeted by commercial or recreational fishing, the majority are caught as bycatch. Although the outcomes of this plan are hard to predict, it is the first instance of a fully tradable use-rights based system for managing bycatch in a commercial fishery and will provide an instructive case study as its implementation moves forward.

Fisheries quota systems, whether they are tradable or not, also recognize that risk analyses are must be regularly updated and that an adaptive, dynamic management framework is necessary for achieving desired management outcomes. From a conservation perspective, this type of annual cycling system (Figure 1b) provides a potentially major advantage: it moves the process from a one-off effort to identify the threatened species killed in fisheries and set long-term rules to reduce their bycatch rates to one of actively managing the threats to all species killed in a fishery on an ongoing basis. A recent trend in the management of commercially targeted species has been toward formalization of this process as a "harvest strategy", in which managers agree on an objective, a monitoring and assessment strategy, and decision rules for adjusting TACs annually based on the assessment outcomes, codifying the process outlined in Figure 1b (Rayns 2007; Smith et al. 2007). By pre-determining the decision rules, this approach prevents the deadlocks that are commonplace to annual updates to fishery regulations when different interest groups champion conflicting objectives. Many studies demonstrate that these sorts of formalized harvest rules can be very effective in achieving desired outcomes, even when they include biodiversity objectives and economic goals, which are often in direct conflict (e.g. Milner-Gulland et al. 2001).

A similar formal decision-making framework for TAMs, which includes risk analyses and decision rules, would address one of the major shortcomings in bycatch mitigation - the difficulty in addressing cumulative impacts. For instance, at the outset of a program to address sea turtle bycatch in U.S. fisheries, population biologists and fishery managers would determine the decision rules for each population of sea turtles affected. The establishment of a single national (or international) TAM for each population would prevent the *ad hoc* permitting in the U.S. that adds up to the legal take each year in the U.S. of tens of thousands of sea turtles (Griffin et al. 2006).

Allocation of Use Rights

Leaving the questions around objective setting and the annual management cycle, and moving to considering the allocation aspects of the system, there are two critical considerations: 1) who can obtain use rights to the fishery, and 2) how are these *initially* allocated. Use rights and quota allocations have typically been determined on the basis of historic investment. In most instances, individuals who can prove investment in capturing a targeted fish species – for instance, by having purchased boats and fishing gear and maintaining an ongoing involvement – have legal, preemptive claims to fish allocated in a quota management system. However, sea turtles and seabirds captured as bycatch are strictly an externality, and thus, there are no preemptive claims on use rights for them. In the absence of a preemptive claim, there is a reasonable argument that not only are the resources common property, but that their use rights are also commonly owned and can be allocated to advance the public good (Barnes 2001; Edwards 2003). If the public does own these use rights, they can then reasonably be leased to fishing enterprises as quota for bycatch, allowing fishers to "use" their quota of bycatch animals, as established by the TAM setting process. Alternatively, fishers could re-sell the leased quota if they are able to avoid catching the protected species.

Mechanisms such as an annual auction of bycatch quota with a fixed reserve price would provide the public a lever to incentivise responsible private behavior. In return, the revenue from the sales of leases can be used to cover public costs for monitoring and management of the species. Many of the costs for recovering threatened species fall to the public (e.g., protecting sea turtle nesting beaches); and in the absence of a responsible party, the public bears the cost for the remediation of destructive private acts. As such, it is reasonable for the public to recover these costs from the ongoing uses of its resources. Furthermore, attaching a minimum price to the mortality of threatened marine species ensures there will be an incentive for private enterprises to reduce their contribution to the mortality.

Access to Use Rights

Several considerations regarding access to use rights will affect whether the system is responsive to conservation concerns. Edwards (Edwards 2003) argues that the use rights granted to fishers should include rights to non-commercial species and to habitat impacts. We suggest an alternative approach, which also acknowledges that these environmental impacts are currently externalities: retain the ownership of those rights in the public, but allow institutions other than commercial harvesters to lease them on an annual basis. If organizations or individuals concerned foremost with the species being impacted by fisheries bycatch can establish their right to hold quota, they could compete for it, allowing them to affect both the volume of quota available to other users and its price. This may be the greatest advantage of a move to a use rights system, more significant than either the formalization of the decision-making process or the removal of externalities from private actions. Conservation interests would be able to express their goals via their behavior in the market – animal rights groups might want to purchase all of the available quota and sequester it, while sustainable fisheries advocates might only manipulate the price or availability to encourage fishers to innovate ways to avoid excessive bycatch. In some cases such groups are already taking these kinds of initiatives: for instance, in the U.S., The Nature Conservancy (TNC) leases and purchases submerged lands for conservation and restoration purposes (Anonymous 2002). TNC has leased back some of the lands for shellfish cultivation, but with mechanisms that ensure that harvesting will be sustainable (Anonymous 2002). On the U.S. west coast TNC delved further, by purchasing both vessels and permits in the groundfish trawl fishery. The conservancy was able to negotiate with the industry for restrictions on fishing, due to the increase in revenues when the number of vessels competing for fish was reduced. They are considering releasing the permits back into the fishery, but with restrictions that ensure sustainability.

The Nature Conservancy's success in accessing use rights and using them as a tool to conserve species targeted by commercial fishing is encouraging. Clearly there are possibilities for abuses in this system, and it will be necessary to provide some regulation to ensure that private interests don't trump the public good. For instance, well funded minority interest groups may act to distort the quota market to the detriment of commercial fisheries. Limits on consolidation of quota by any one party could be established in advance of the definition of the eligible quota holders to prevent this situation. Similarly, utilizing an annual leasing system will reduce the ability of participants to accumulate quota over time during market fluctuations. Consolidation may also be less of an issue for bycatch species, as innovative operators may not need quota, and thus quota leaseholders will not be able to drive up the price as in the case of permanently held quotas on commercially harvested species. In any event, it will be necessary to ensure that access to quota is not overly restricted – either through inflated prices or by removing it from the fishery – as quota shortages will generate incentives to non-comply with the management measure, diverting innovation effort from avoiding bycatch to avoiding bycatch controls.

In contrast to these disadvantages, a major advantage is that this market-based approach extends the debate over conservation policy outside the regulatory agencies, returning it to the public and allowing people to express their preferences via their charitable donations and market preferences.

Institutions, Monitoring and other Challenges

Clearly, the implementation of a rights-based system for managing bycatch impacts of commercial fisheries will bring a number of challenges, including monitoring and assessing bycatch, creating institutions to allocate, trade, and manage quotas, and a conceptual shift in how many conservation agencies approach their policy mandate. However, similar institutional frameworks have been created in other contexts, both at a national and an international level. IATTC was able to create and allocate quota for dolphins, member countries abided by the system and the conservation outcomes were decidedly positive (Hall 1998). At a national scale, many of the industrialized nations set bycatch limits and monitor the progress of fisheries in regard to those limits. While these are generally not individual rights based systems, they contain most of the requisite components including the assessment of allowable mortality levels, monitoring of the fishery using either observers or electronic mechanisms, and a periodic review process to evaluate fishery progress against conservation objectives.

Furthermore, some systems, like harvesting cooperatives, have demonstrated their ability to self-regulate, and may be able to monitor and enforce a bycatch quota system with minimal government supervision. Fishers in the US Pacific whiting and Bering Sea Pollock fisheries pursued harvesting cooperatives when they were unable to get individual fishing quotas, and found that the well-defined and relatively small number of participants resulted in abundance of accurate and transparent data and a scale of operations that could support the cost of implementing and monitoring the arrangement. (Sullivan 2004). A recent critical evaluation of bycatch quotas suggests that similar patterns may hold more broadly, with bycatch quotas working well where they are allocated to individuals or cooperatives, in fisheries with relatively few operators, and where monitoring and enforcement is relatively effective (Diamond 2004).

A consistent challenge in quota systems, even when they are operating well, is how to manage the possibility of a fishery exceeding its allowable catch. In some cases fisheries management agencies have held a portion of the TAC back, allowing a buffer for the potential for overcatch. Other, more putative approaches have ranged from fisheries closures when the TAC is exceeded to the levy of fees on landings by individual fishers when they exceed their quota. Fisheries closures due to excessive bycatch are becoming increasingly common, although some evidence suggests that they may have unintended negative consequences as less well regulated fleets fill the increased market demand for target species (Sarmiento 2006b). Similarly, levies on overcatch may not be a panacea. Evidence from New Zealand demonstrates that the levy system can be problematic if the levies are not adequate to serve as an incentive (Holland & Herrera 2006). Another possibility for species of conservation concern is to require fishers to fund conservation activities to offset the impact of their overcatch (Wilcox & Donlan 2007a). This may be a useful alternative to an arbitrary levy system, as it would set the fee at the cost of ameliorating the impact.

Clearly there is extensive experience with the institutional structures essential for rights-based management and the process of assessing progress against objectives, adjusting the operating conditions as necessary, and creating incentives for responsible behavior. Perhaps the most challenging aspect of instituting a rights-based system for bycatch management will be achieving the conceptual shift from reacting to the impacts that economic activities have on biodiversity, to pro-actively harnessing economic dynamics by setting allowable limits on bycatch impacts and giving individuals permission to act at their discretion within those limits.

Conclusion

The reluctance by conservation scientists, advocates and policy makers to discuss allowable mortality as a management strategy has effectively promoted the continued use of ineffective *ad hoc* policies, such as fixed catch rates. With increasing political pressure to adhere to ecosystem-based management principles, fisheries managers are revisiting the standards by which bycatch is managed; and, the regulatory outcomes will likely parallel the systems used for target species management. It is essential that conservation scientists and advocates consider all the available tools, engage in, and lead this discussion to ensure the policy goals are ecologically defined, that industries bear the costs of their environmental impacts, and that the public receives the full value from use of its resources.

Chapter 2: Integrating Invasive Mammal Eradications And Biodiversity Offsets For Fisheries Bycatch: Conservation Opportunities And Challenges For Seabirds And Sea Turtles[3]

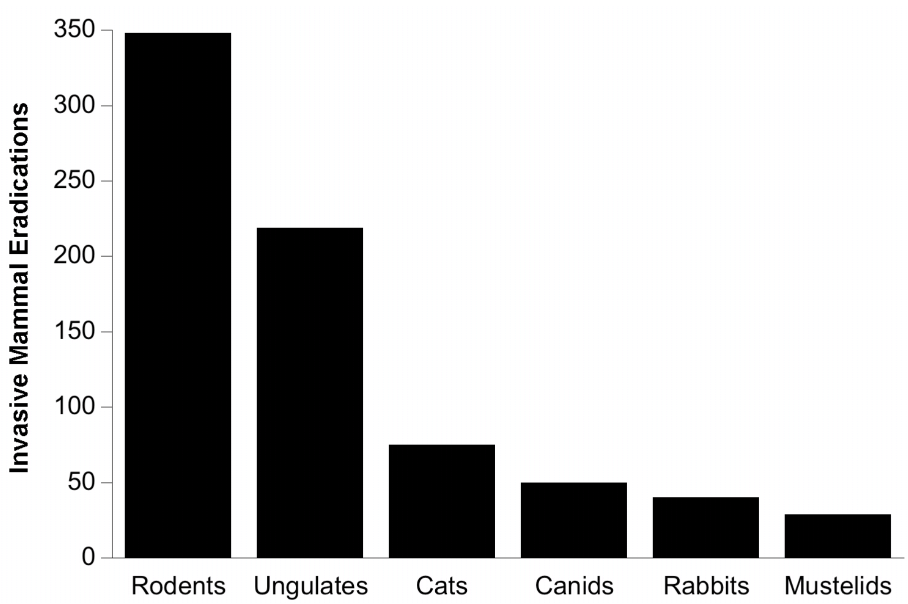
Anyone who has visited an island before and after rats have been removed has likely witnessed first-hand the conservation power of eradication. Tremendous progress has been made over the past two decades in terms of our ability to eradicate invasive mammals from islands (Towns & Broome 2003; Veitch & Clout 2002). Twenty-five years ago, New Zealand conservationists were struggling to eradicate rats (*Rattus* spp.) from islands the size of a football field (Thomas & Taylor 2002). In 2002, they did so on an island the size of 16,000 football fields (11,300 ha), and the Campbell Island eradication campaign was run so efficiently that it serves as a case study for innovation in the public service (McClelland & Tyree 2002; Wright & Joux 2003). Halfway around the world, other eradications are taking place that were deemed impossible a decade ago. The Galápagos National Park and the Charles Darwin Foundation recently eradicated goats (*Capra hircus*) from the two largest islands in the Galapagos archipelago: Santiago (58,465 ha) and Isabela Island (458,812 ha). Those interventions were more swift and cost-effective than ever before: over 160,000 goats were removed from the two islands in less than five years for ~$18 per hectare (US$2006 dollars; F. Cruz, V. Carrion, K. Campbell, and C.J. Donlan, unpublished data). Others have developed techniques to successful mitigate for non-target impacts from rodenticide applications during eradications, which has facilitated successful invasive rat removals on two islands where native small mammals are present that were equally susceptible to the rodenticide (Howald et al. 2007). From many perspectives, the bar for invasive mammal eradications has been raised by magnitudes.

Now more than ever, the removal of invasive mammals from islands is one of society's most powerful tools for preventing extinctions and restoring ecosystems. Accumulating pre-eradication impact and post-eradication recovery studies now support the alleged biodiversity benefits of eradication. (Croll et al. 2005; Donlan et al. 2002; Fukami et al. 2006; Nogales et al. 2004; Towns et al. 2006; Wanless et al. 2007; Whitworth et al. 2005). This is particularly the case for seabirds, which invasive species are the primary threat followed by fisheries interactions and habitat loss (Buckelew 2007). For example, feral cat eradication decreased Black-vented shearwater (*Puffinus opisthomelas*) mortality by 90%, and experimental black rat control programs on Cory's Shearwater (*Calonectris diomedea*) colonies decreased chick mortality by over 50% (Igual et al. 2006; Keitt & Tershy 2003). These documented benefits in Mexico and Spain are becoming commonplace and cosmopolitan, yet outside of New Zealand and Australia, eradication arguably remains in the shadows of biodiversity conservation practice (Donlan et al. 2003; Simberloff 2001).

[3] Reprinted from Donlan, C.J. & C. Wilcox. 2008. Integrating invasive mammal eradications and biodiversity offsets for fisheries bycatch: conservation opportunities and challenges for seabirds and sea turtles. Biological Invasions 10:1053-1060

Policy makers and on-the-ground practitioners are uninformed of the current technology and techniques available to tackle this biodiversity threat. Few are aware that rats have been removed from an island the size of Washington D.C. and goats from an island the size of Rhode Island. At the same time, awareness of the impacts of invasive species has exploded over the past decade, creating significant research programs and opportunities (e.g., the U.S. government spent $635 million on invasive species in 2000). Yet, relatively few resources have been invested in actively removing invasive mammals from islands. Nonetheless, there have been over 800 invasive vertebrate eradications from islands, with larger and larger islands being targeted (Figure 2). Recent successes indicate that island size may no longer be limiting for the eradication of species such as goats and Norway rats (R. norvegicus, Campbell & Donlan 2005; Howald et al. 2007). However, island size still appears to be a factor limiting the removal of other invasive mammals such as house mice (*Mus musculus*). Emerging innovations in eradication technology and techniques (Burbidge 2004; Lavoie et al. 2007; Parkes et al. 2005) suggest that island area will soon no longer be the limiting factor for invasive mammal eradications (Table 1). On that assumption, island conservation will face three main challenges as practitioners target larger and more biological complex islands often with human inhabitants: 1) mitigating for non-target impacts; 2) increasing the cost-effectiveness of eradication campaigns; and 3) securing the necessary social and economic capital. In this essay, we discuss one idea regarding the latter.

Figure 2. Number of successful invasive mammal eradications on islands worldwide for rodents, ungulates, cats, pigs, and rabbits. References: Nogales et al 2004; Campbell and Donlan 2005; Howald et al. 2007, Donlan 2007; K. Campbell, personal communication; B. Keitt, personal communication.



Biodiversity offsets may be a promising source for funding systematic and large-scale invasive mammal eradication programs. Biodiversity offsets can be defined 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' (ten Kate et al. 2004, p. 13). Many in the business sector have begun to adopt a no net loss framework under an *avoid, mitigate, offset* hierarchy that flows from the Convention on Biological Diversity (Slootweg et al. 2006; ten Kate et al. 2004). Under this framework, we propose that the fisheries sector could benefit from being strategically and tactically linked to island conservation and vice versa. This potential partnership could facilitate invasive mammal eradications playing a larger, more integrated role in biodiversity conservation, and allow fisheries to minimize their environmental impacts while still making a profit. In fact, we argue that such a partnership is a prerequisite for most fishing enterprises to be impact neutral or positive with respect to seabird or sea turtle bycatch. The proposed alliance and its conservation potential hinges on two observations. First, many of the threatened seabird and sea turtle species affected by fisheries are the biodiversity targets of island conservation practitioners. Second, fisheries management is complex, expensive, and intrinsically involves trade-offs; in contrast, conservation interventions on islands are often cost-effective, high-impact, and relatively straightforward with low opportunity costs.

Table 1. Innovation over the past two decades in the ability to remove invasive mammals from larger and larger islands.

Target Species	1990s	2000s	Planned
House Mice (*Mus musculus*)	710	219	12,800
	Enderby, New Zealand	Frégate, Seychelles	Macquarie, Australia
Kiore (*Rattus exulans*)	1,965	3,083	
	Kapiti, New Zealand	Little Barrier, New Zealand	
Black Rats (*Rattus rattus*)	800	1,022	12,800
	St. Paul, France	Hermite, Australia	Macquarie, Australia
Norway Rats (*Rattus norvegicus*)	3,105	11,300	27,800
	Langara, Canada	Campbell, New Zealand	Kiska, USA
Cats (*Felis catus*)	29,000	12,800	58,640
	Marion, South Africa	Macquarie, Australia	Dirk Hartog, Australia
Rabbits (*Oryctolagus cuniculus*)	1,421	3,450	12,800
	Deserta Grande, Portugal	Norfolk, Australia	Macquarie, Australia
Goats (*Capra hircus*)	21,853	458,812	171,617
	Santa Rosa, USA	Isabela, Ecuador	Galapagos archipelago (in progress)
Pigs (*Sus scrofa*)	21,118	58,465	45,975
	Santa Catalina, USA	Santiago, Ecuador	Aukland, New Zealand

The largest islands (size in hectares) where invasive mammals were successfully removed during the 1990s, 2000s, and currently planned; References: Nogales et al. 2004; Campbell and Donlan 2005; Howald et al. 2007; Springer, personal communication; Campbell, personal communication; Howald, personal communication

Fisheries & Island Conservation: A New Alliance?

The social and economic importance of fisheries and the biological realities of overfishing and bycatch result in major tensions over ocean resources. Globally, fisheries provide over a tenth of all protein consumed by humans, employ hundreds of millions of people, and are valued at ~US$80 billion (Botsford et al. 1997; FAO 2004). Yet, at least a quarter the of the global catch is non-target species and discarded (Alverson et al. 1994). That mortality is having major impacts on species and ecosystems (Hall et al. 2000; Lewison et al. 2004). For many fisheries, much of that discarded bycatch is endangered seabirds and sea turtles—species that spend part of their life breeding on islands and coastal beaches. At those breeding sites, seabirds and sea turtles commonly face additional anthropogenic mortality impacts, such as coastal development, direct human take, and impacts from invasive predators (Caut et al. in press; Engeman et al. 2006; Jones et al. in press). Indeed most seabirds and sea turtles that are threatened by fisheries interactions are concurrently threatened by additional anthropogenic threats (Koch et al. 2005; Mast 2005; Wilcox & Donlan 2007b, Fig. 2).

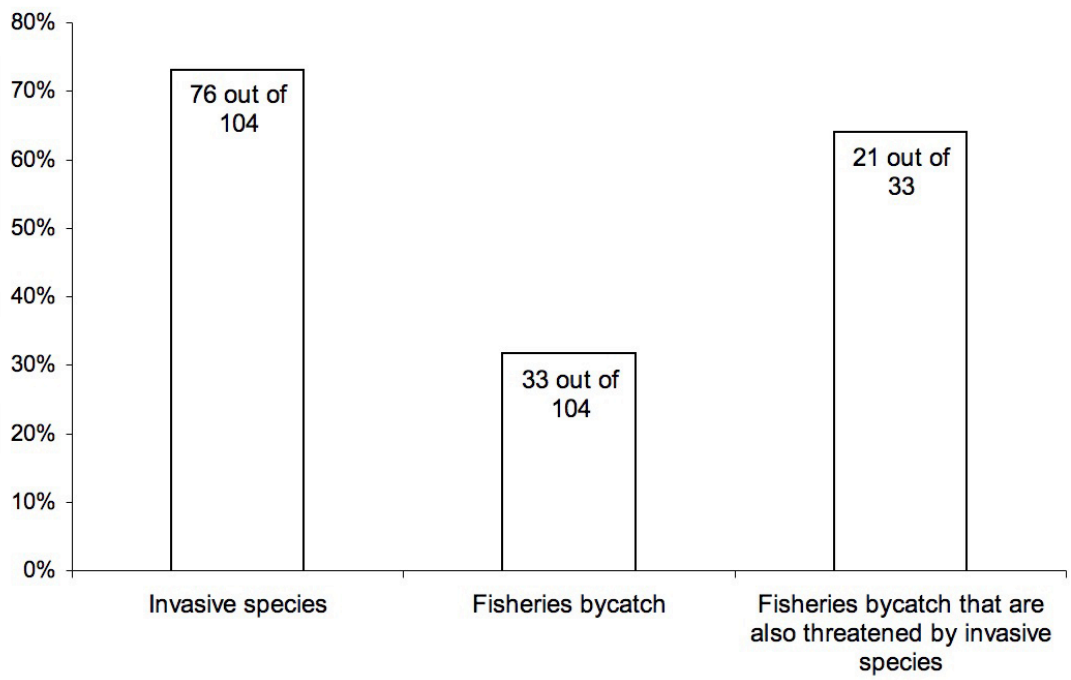
Fisheries are increasingly under national and international pressures to operate more responsibly. Further, many states are moving toward a cost-recovery model in fisheries management, where the industry pays for the costs related to its activities (Cox 2000). These statutory and social pressures include demands to minimize bycatch. Encouragingly, changing in fishing practices and technological innovations have spurred reductions of seabird and sea turtle bycatch (Gilman et al. 2005; Gilman et al. 2006). Many are adopting those measures, such as the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), which is the regional fisheries management organization for the southern oceans. Their effort to reduce bycatch is unprecedented, which includes bycatch data collection, observer and research programs, and mitigation requirements such as streamer poles and weighted lines (Small 2005). Those efforts have produced impressive results: longline seabird mortality in the majority of the convention area was reduced from 6,589 birds in 1997 to 15 birds in 2003 (excluding Economic Exclusive Zones (EEZ), CCAMLR 2003; Small 2005).

Unfortunately, those incidental mortality rates pale in comparison to other regional fisheries management organizations, whose bycatch rates remain largely unknown due to lack of data collection and transparency (Small 2005). Japanese long-line vessels alone are estimated to kill 6,000-9,000 birds per year in the area managed by the Commission for the Conservation of Southern Bluefin Tuna (Kiyota and Takeuchi 2004 cited in Small 2005). But even in the most responsibly managed fisheries such as CCAMLR, seabird and sea turtle bycatch occurs at low levels. Depending on the species, the death of 9,000, 15, or even a single individual can have significant population-level consequences.

Encouraging fisheries to offset bycatch that cannot be mitigated directly (either by avoidance or modifying fishing practices) by funding conservation interventions targeted toward other mortality threats could result in net conservation gains for seabirds and sea turtles (Wilcox & Donlan 2007b). Interventions could include invasive predator control on mainland breeding sites, combating IUU fishing (illegal, unregulated, and unflagged), conservation incentive agreements with artesanal fishing communities that are also impacting the species of concern, or invasive mammal eradications on breeding islands. In some cases, the transfer of capital from a impact that is associated with revenue-generating activities to address an impact that is revenue-neutral or –negative would result in cost-effective interventions with high conservation returns, even after discounting demographic delays (i.e., allowing current impacts for future benefits, Wilcox & Donlan 2007b).

The idea of linking fisheries bycatch management and invasive mammal eradications will be sure to raise many challenges and concerns. We briefly discuss two pivotal questions.

Figure 2. Percent of all seabirds listed by the IUCN that are threatened by invasive species and fisheries bycatch, and the percent of seabirds threatened directly by fisheries bycatch that are also threatened by invasive species. Includes all seabirds listed as critical endangered (CR), endangered (EN), vulnerable (VU), and extinct (EX); data from IUCN / Birdlife International's World Bird Database, n = 104).



Why should fisheries pay for invasive mammal eradications as part of their bycatch management strategy?

Fisheries could benefit from incorporating offsets into their bycatch management strategy. Fishers could be motivated since voluntary offsets would likely contribute to a company's social license to operate, regulatory goodwill, and reputation (ten Kate et al. 2004). Offsets could also lower compliance costs, and responsibly transfer liability to account for seabird or sea turtle to a third-party with specific expertise (e.g., a conservation NGO, ten Kate et al. 2004). Offsets could also address a growing, underappreciated concern of the seafood industry: reliability of supply. Continuity of supply is needed to establish long-term markets, and with court-imposed fisheries closures due to bycatch becoming commonplace, wholesalers, retailers, and restaurants are faced with the dilemma of permanently discontinuing popular but volatile seafood products (Chambers 2000). Lastly, a net-neutral or -positive seabird/sea turtle bycatch fishing enterprise might be able to increase its market access or gain a premium price for its products. Eco-labeling of seafood products, such as Marine Stewardship Council's Fishery Certification Program, has garnered much interest by fisheries and consumers (Roheim 2003). While there are many challenges to effective awareness consumer campaigns (Jacquet & Pauly 2007), consumer demand and access to certified products is growing in the United States, Europe, Australia, and New Zealand, and certified fisheries are experiencing increase access to those markets (Roheim 2003).

Combined with direct bycatch mitigation programs (e.g., circle hooks, weighted lines, etc), a verifiable offset program would give many fisheries an unprecedented opportunity to have a net positive impact on seabirds and sea turtles. Other sectors have set the precedent with similar thinking: the mining industry is now routinely engaging in dialogues that are moving away from dualistic frameworks (e.g., environmental impact versus jobs and profitability) and toward multidisciplinary, holistic approaches that are grounded in the hierarchy of avoid, mitigate, and offset (Hodge 2004; ten Kate et al. 2004). The fisheries sector has expressed interest in similar approaches. The challenge will rest largely in the hands of the conservation NGOs and governments to engage them.

Why should conservation organizations endorse and management agencies allow or require fisheries to offset bycatch that cannot be avoided and mitigated directly via fishing modifications?

Fisheries management is expensive endeavor: the European Union, United States, and Japan spent US$1.7 billion in 1999 on fisheries enforcement, research, and management (OECD 2003). Fisheries management is also increasingly complex, culturally, economically, and environmentally (e.g., Kilgannon 2007). For example, while progress is being made toward the sustainable management of U.S. coastal fisheries (Christensen 2006), many issues and problems are merely exported at a 6:1 ratio: total fisheries imports in 2005 was $25.1 billion compared to $3.9 billion in U.S. landings (NMFS 2007). Globalization and governance present the major challenges for the sustainable management of our oceans (Crowder et al. 2006), including the conservation of marine apex predators that are affected by fisheries bycatch. Opportunity costs and complex trade-offs abound with fisheries management decisions.

In contrast, there are tens of thousands of islands throughout the world's oceans where the eradication of invasive mammals would be feasible, straightforward, and have low opportunity costs. Unlike the public health and other sectors, the biodiversity conservation community are just beginning to incorporate the economic costs of interventions into their planning (Naidoo et al. 2006; Pullin & Knight 2001). While economic data is unavailable for most eradications, recent campaigns suggest that even large-scale eradications are highly cost-effective (Donlan & Wilcox 2007). For example, seabird breeding colonies in northwest Mexico have been protected for the cost of US$21,615 per colony (Aguirre-Muñoz et al. 2007). For many seabirds and sea turtles populations, eradication campaigns at breeding colonies are the 'low-hanging fruit' on the conservation tree. Given that invasive mammals are still present on at least 80% of the world's islands, money will be a major limiting factor to island conservation in the coming decades (Campbell & Donlan 2005; Howald et al. 2007). By engaging fisheries in a dialogue about offsets for seabird and sea turtle bycatch, conservation organizations and governments could generate novel conservation dollars and facilitate cost-effective biodiversity gains. As important, governments could efficiently recover costs from fisheries for services they consume, and seabird and sea turtle conservation could rely less on charity for funding as it turns toward resource users to pay for their impacts on common pool resources (Barnes 2006).

The potential value of biodiversity offsets on fisheries bycatch impacts should rest on the counterfactual: what would have happened if no offset had occurred? Conservationists have yet to fully embrace the measurement of counterfactual outcomes in program evaluations (Ferraro & Pattanayak 2006). The management of the U.S Hawaiian swordfish fishery provides an insightful and intriguing example.

When the Hawaiian swordfish fleet was ordered to stop fishing under the U.S. Endangered Species Act in 2001 due to incidental bycatch of sea turtles, swordfish landings decreased by 93% (Sarmiento 2006a). However, this enforcement and subsequent closure was restricted solely to the U.S. Hawaiian fleet, and thus other fleets moved into the area compensating for the lost fishing effort, including Panama, Ecuador, and other largely unregulated distant water fishing nations (Sarmiento 2006a). Thus, both the counterfactual and conservation outcomes are unclear when the U.S. fleet (worth $50 million per year in revenue in 2000) was sent home again in March 2006 after meeting their annual limit of 17 interactions with the threatened loggerhead sea turtle (Caretta caretta, Anonymous 2006a). However, given the fishing effort compensation by unregulated fleets documented above, sea turtle mortality could have arguably and ironically increased as a result of the U.S Hawaiian swordfish fishery closures.

Would a different approach under the avoid, mitigate, and offset framework endorsed by the Convention on Biological Diversity (Slootweg et al. 2006) lead to a better biodiversity outcome? Entertain a scenario that once the fishing fleet reached the annual limit of sea turtle interactions they would remain at-sea fishing and offset their sea turtle interactions by funding conservation interventions that targeted other mortality sources. The offset ratio would be conservative, and encompass a discount rate and demographic uncertainties (e.g., *X**Y* sea turtles protected or produced for every *X* sea turtle interaction). Contrary to the idea of letting the fishers 'off the hook', the Hawaiian fleet, whom have already significantly reduced sea turtle bycatch by switching to circle hooks (Gilman et al. 2007), would have additional incentives to avoid sea turtle bycatch with a bycatch levy or similar financial instrument (e.g., Pigovian tax, Wilcox & Donlan 2007b). The levy or trust would then fund offsets that could be one of a variety of interventions, including predator control or other conservation programs at nesting beaches (Engeman et al. 2005; Engeman et al. 2002).

For some seabirds and sea turtles offsets will not be a viable option. But for other species, a management framework that includes offsets will likely be a fruitful approach that would result in net conservation gains (Wilcox & Donlan 2007b). However, those potential gains come with substantial challenges.

Embracing the Challenges

The challenge to making biodiversity offsets efficacious for seabird and sea turtle conservation center on a well-designed auditing program and grappling with uncertainty. The benefits to a seabird species from an invasive rat eradication campaign on a breeding island must be quantitatively linked to the impact of the same seabird species by a fishing organization. Ecologists and economists together will have to devise a robust ecological accounting scheme that captures the cost-effectiveness of interventions, life history equivalences, demographic and environmental stochasticity, and discount rates – with the end result being offset ratios. Potential multiple species effects will also have to be addressed on a case-by-case basis (Wilcox & Donlan 2007b). Offsets will have to be undertaken with strict protocols for reporting and performance standards (ten Kate et al. 2004), and third-parties will be needed for certification of both buyers and sellers of the offsets. Such certification programs, however, would bring the added benefit of increased accountability and transparency for both resources users and conservation practitioners. Conservationists and government agencies will need to engage in open dialogues with the fishing sector.

There is a growing consensus that traditional institutions are not sufficiently safeguarding the biodiversity and ecosystems humanity relies on, and that 'desperate times deserve innovative measures' (Richard 2002). Those who restore islands by eradicating invasive mammals could lead the way by engaging in a dialogue with the fisheries sector about offsetting the bycatch impacts to seabirds and sea turtles, resulting in unprecedented conservation gains and new cross-sector alliances. Given the demonstrable high conservation impact and return on investment of invasive mammal eradications, anything less seems a disservice to nature and society.

Chapter 3: Assessing Anthropogenic Hazards To Endangered Species Using Expert Opinion Surveys: A Case Study With Sea Turtles[4]

The natural history of organisms is central to biology and subsequently biodiversity conservation (Dayton 2003; Greene 2005). Yet, for the majority of organisms we know little about their natural history and even less about how specific anthropogenic hazards interact with their biology. This is particularly true for cosmopolitan marine megafauna species, such as sea turtles. For such species, conservation targets and management decisions are often at the regional level—focused on a specific nesting population or ocean basin. Yet, assessments of extinction risk for species are usually conducted at the global level (e.g., Kappel 2005). For example, six of the seven species of sea turtles are listed as *Endangered* or *Critically Endangered* by the World Conservation Union (IUCN) (IUCN 2007). The on-the-ground utility of those assessments, however, is unclear because significant differences in population trends exist among ocean basins. For example, Pacific leatherback turtles (*Dermochelys coriacea*) have experienced major declines over the last decade, while Atlantic populations are stable or increasing (Dutton et al. 2005; Spotila et al. 2000). Without a globally comprehensive quantification of hazards to sea turtle populations at the regional level, it will be challenging to prioritize and strategically implement practical conservation actions (Seminoff 2004b).

Quantifying regional hazards is particularly challenging for data-poor species like sea turtles, given that they are notoriously difficult to study, migratory, long-lived, and commonly face multiple anthropogenic threats. The primary literature is likely to be less useful for assessing sea turtles compared to other taxa. For example, between 2000-2006, nearly twice as many papers were published on seabirds compared to sea turtles [*Biosis Previews*: 785 papers for Topic=sea turtle(s) versus 1,383 papers for Topic=seabird(s)]. Nonetheless, recent collaborative efforts have made substantial progress in documenting the distribution of sea turtle populations globally (Mast et al. 2006, 2007; Mast et al. 2005). Further, the sea turtle research community is large and active: the IUCN Marine Turtle Specialist Group consists of over 270 members in more than 80 countries, and the SeaTurtle.org network, which supports sea turtle conservation and research, has over 10,000 members worldwide (http://www.iucn-mtsg.org and http://www.seaturtle.org). Thus, a copious amount of information for sea turtle conservation planning resides not in the primary literature, but rather in the knowledge and experience of sea turtle scientists, field observers, and conservation practitioners.

Over the past 50 years, the research and conservation communities have shown an increasing awareness and focus on multiple hazards facing sea turtle species. Historically, research focused on nesting dynamics, and management centered on abating direct harvests and protecting nesting beaches. In the mid 1980s, demographic and life history research elucidated that large juvenile and

[4] Reprinted from Donlan, C.J., D.K. Wingfield, L.B Crowder, C. Wilcox. in review. Assessing anthropogenic threats to endangered sea turtles using surveys of expert opinion: a case study with sea turtles. Conservation Biology

adult survivorship, as opposed to fecundity, were the key life history stages driving sea turtle population dynamics. As in-water sea turtle research increased in response in the early 1990s, fisheries bycatch was recognized as a foremost threat to many sea turtle populations. Subsequently, the conservation value of terrestrial-based actions (e.g., head-starting) versus at-sea interventions was hotly debated in the mid-1990s, centered around management of the endangered Kemp's Ridley sea turtle (*Lepidochelys kempii*) (Frazer 1992; Taubes 1992). More recently, climate change and pathogens have been indentified as potential threats to sea turtle populations (Fish et al. 2005; Hawkes et al. 2007; Herbst & Klein 1995). Thus, early in modern sea turtle biology there was arguably a mismatch between research foci, conservation actions, and anthropogenic hazards to sea turtle populations. From this, important questions that arise are: to what degree has this mismatch been abated? Do experts in sea turtle biology conservation agree on the most important anthropogenic hazards to sea turtles?

Expert elicitation, a technique used to synthesize the opinions of experts, while assessing the uncertainty around those views, has been in use for several decades in the social sciences and risk assessment sectors (Kerr 1996). Increasingly being used in the biodiversity conservation sector to guide decision-making, expert elicitation is particularly useful in data-poor scenarios (Aipanjiguly et al. 2003; Halpern et al. 2007; Martin et al. 2005). Here, we use an expert opinion survey to globally assess the relative impacts to sea turtle populations at the regional level, and the uncertainty around those impacts for a range of known hazards. Concurrently, we explore potential biases associated with different types of expertise. While it is well recognized that conflicts of interest can lead to biased views by experts even when those conflicts are disclosed (Cain et al. 2005), potential expert bias in biodiversity conservation settings has received little attention.

METHODS

Expert Opinion Survey

We conducted an Internet-based survey to quantify expert opinion on the relative magnitude of anthropogenic hazards to sea turtle populations at the regional level. Each region was delineated using the most current nesting information for each sea turtle species (Bowen et al. 1997; Bowen et al. 1994; Bowen et al. 1992; Mast et al. 2006; Mast et al. 2005; Meylan & Donnelly 1999; Plotkin 2007; Seminoff 2004a). The number of geographic regions for each species was balanced with the goal of keeping the survey as short as possible to encourage maximum participation. The hazards included in the survey were consistent with those identified by IUCN Marine Turtle Specialist Group (Table 2, Mast et al., 2005). Based on IUCN and Birdlife International's World Bird Database criteria, hazards were scored with respect to timing (i.e., past, continuing, or future), scope (i.e., the proportion of the total population affected), and severity (i.e., the overall decline caused by the hazard; see http://www.birdlife.org/datazone). Respondents were asked to rank seven hazards to sea turtle species in each geographic region with respect to scope, timing, and severity. In keeping with the methodology developed by IUCN/Birdlife International for seabirds, a summed impact score was calculated by summing the timing, scope, and severity scores for each hazard within each species-geographic region combination.

The survey included a series of background questions to gauge the respondents' experience and expertise, in particular their relative experience with each species, geographic region, and hazard. Each respondent was asked to rank his or her experience in each three-way combination of species, region, and hazard (experience rankings 1: No Experience, 2: Little Experience, 3: Some Experience, 4: Much Experience). Survey questions can be found at http://www.advancedconservation.org/turtlesurvey.

Table 2. Anthropogenic hazards to sea turtles that were included in the expert opinion survey.

Hazard	Definition used in survey
CD - Coastal development	Impacts from artificial lighting, beach armoring, beach nourishment, dredging, and/or recreational boat strikes
DT - Direct take	Impacts from anthropogenic harvesting of adults (at sea or nesting site) and/or eggs
FB - Fisheries bycatch	Direct impacts from both industrial and/or artesanal fisheries, including longline, gill net, and trawling operations
GW - Global warming	Impacts from beach erosion, sea-level change, and/or biased hatchling sex ratios.
PA - Pathogens	Impacts from fibropapillomatosis and other diseases
PO - Pollution	Impacts from entanglement in fishing ghost nets or other marine debris, ingestion of marine debris, and/or impacts from oil spills
NP - Nest predation	Includes impacts from native and/or non-native predators on eggs and/or hatchlings

We distributed the survey via two avenues. First, we identified experts with a literature search (Google Scholar) using a combination of sea turtle species, geographic region, and hazard keywords. Emails were sent to 124 corresponding authors indentified from the search, and we encouraged them to pass on the survey to colleagues. Second, the survey was distributed to sea turtle specific list-servers and networks, including SeaTurtle.org, HerpDigest, MedTurtle, CTurtle, Indian Ocean-Southeast Asian Marine Turtle Memorandum of Understanding, and the Wider Caribbean Sea Turtle Conservation Network. Reminder emails were posted to the networks over a period of three weeks. The survey was available on-line, in Spanish and English, for one month.

<u>Analytical Statistics</u>

We analyzed the survey data using linear mixed models in order to control for a respondent scoring multiple questions, and to parsimoniously incorporate the inherent covariance between expert observations (Pinheiro & Bates 2000). In the mixed model, individual respondents were included as a random effect and the species, geographic region, hazard, and expert scores were included as fixed factors. The dependent variable was summed impact score. Asking respondents a repeated set of questions induces an amount of covariance. We modeled that covariance as a random effect, drawn from a normal distribution. To overcome the imbalance present in the species by geographic region combinations, those factors were combined to produce a single factor, representing a sea turtle population. We assessed statistical significance with approximate F-tests, adopting an α-level of 0.05 (Pinheiro & Bates 2000). Predictions of the fixed factor combinations were generated using the methods described in Welham et al. (2004). Those predictions (i.e., summed impact scores) are marginal to the observed set of experts; they are independent of the particular set of experts observed.

Variation amongst the experts was further investigated by modeling the residual random effects. In particular, effects were modeled as a linear combination of the self-reported rankings of experts on three criteria for each survey: species experience, geographic region experience, and hazard experience. This approach is more statistically efficient and credible than predicting random effects (Laird & Ware 1982). All models were fitted using the nlme package for the R environment (Ihaka & Gittleman 1996; Pinheiro & Bates 2000). Quantities (e.g., predictions) needed for sensible interpretation that are not provided by the nlme package were also calculated in R (R Development Core Team 2005).

Lastly, we plotted the mean summed impact scores and respective standard deviations for every geographic region-hazard combination for each sea turtle species. Those mean-standard deviation plots provide a heuristic tool to assess relative impacts of hazards, along with a consensus among respondents regarding those impacts. For example, data points in the lower-right quadrant of mean-standard deviation plots represent hazards that have relatively high impacts with high consensus (i.e., low variance), in contrast to data points in the upper-left which represent low impact-low consensus (i.e., high variance).

RESULTS

A total of 244 people responded to the survey, and 53% of those respondents completed all 121 questions. The majority of respondents were from the non-profit sector (36%) and governmental agencies (32%), and had <10 years of experience with sea turtles (65%, Table 3). Respondents reported working in more than 100 countries. Overall, respondents reported the most experience with loggerheads, nest predation, and the Caribbean region (Fig. 3).

Table 3. Demographics of survey participants. Answers to all questions below, with exception of Research Focus, were mutually exclusive.

Affiliation	%	Primary expertise	%	Years experience	%	Research focus	%
NGO	36%	Ecology	42%	<5 years	32%	Terrestrial	70%
Government	32%	Management & Conservation	30%	5-10 years	33%	Coastal	70%
Academic	26%	Education	9%	10-15 years	15%	Pelagic	28%
For-profit	4%	Other	9%	15-20 years	7%		
Other	2%	Veterinary & Related	4%	>20 years	14%		
		Evolutionary Biology & Genetics	3%				
		Sociology	2%				
		Economics	1%				

From the linear mixed model, we predicted summed impact scores for each sea turtle species-geographic region-hazard combination (Table 4). Fisheries bycatch and coastal development were most often ranked as top hazards to sea turtle species in a geographic region, followed by nest predation and direct take. Pathogens were consistently ranked as a lower hazard in relative and absolute terms, followed by global warming. However, global warming had the highest impact score for flatback turtles (*Natator depressus*).

There were apparent differences between predicted impact scores for sea turtle species when pooled across geographic regions (Fig. 4). For example, leatherback and olive ridley (*Lepidochelys olivacea*) turtles had the highest scores for fisheries bycatch, while olive ridley and hawksbill (*Eretmochelys imbricata*) had the highest threat scores for nest predation. Differences in predicted impact scores were less apparent when scores were pooled at the geographic region level; however, some differences existed (Fig. 5). Direct take, for example, was noticeably low in the western Atlantic and Mediterranean compared to other regions.

While there were no differences between predicted impact scores based on geographic region expertise level, there was a marginally significant effect by species expertise level, with the most inexperienced respondents giving higher scores than other experience levels (Fig. 6). In contrast, there were strong differences between impact scores with respect to hazard expertise level. As a respondent reported more experience with a particular hazard (e.g., coastal development), he or she consistently scored that threat as having a higher impact (Fig. 4).

Across all sea turtle species-geographic region-hazard combinations, there was a negative correlation between predicted impact score and its standard deviation ($r = -0.491$, $p < 0.01$, $n = 217$; Fig. 7). Terrestrial threats, such as nest predation and coastal development often had the lowest variation, while pathogens and global warming were associated with the highest uncertainty or consensus among respondents. With a few exceptions, the majority of the species-geographic region-hazard impact scores fell within the two right quadrants of the mean-standard deviation plots (i.e., high impact–high uncertainty and high impact-low uncertainty).

Table 4. Predicted threat impact scores for sea turtle species by geographic location. Scores account for the correlation between responses within an individual respondent. Scores are consistent with overall impact scores of IUCN/Birdlife International's World Bird Database (0-2: no/negligible impact; 3-5: low impact; 6-7: medium impact; 8-9: high impact). Sample sizes of respondents for each species-geographic region combination are shown in parenthesis. The three highest values for each species-geographic region combination are coded in shades of great (black, dark gray, and light gray, respectively).

	Coastal development	Direct take	Fisheries bycatch	Global warming	Nest predation	Pathogens	Pollution
Flatback (16)	5.2	4.4	5.2	6.1	5.7	4.6	5.4
Green							
Caribbean (32)	6.5	6.1	5.9	5.9	5.8	4.9	6.1
East-central Atlantic (18)	5.4	6.6	6.6	5.7	6.2	5.3	5.9
East-central Pacific (19)	5.4	5.6	5.4	5.5	5.1	5.5	6.4
Northwestern Pacific (14)	5.9	4.9	5.6	5.5	4.9	5.0	5.6
Southwestern Pacific (36)	6.1	6.1	6.0	5.9	6.2	4.8	5.7
Indian Ocean (21)	6.3	6.7	6.7	5.6	6.0	4.9	6.0
Mediterranean (16)	6.2	5.4	6.4	5.7	6.2	5.2	5.9
Hawksbill							
Caribbean (23)	6.7	6.5	6.3	5.8	6.1	4.1	6.3
Eastern Atlantic (12)	5.7	6.8	6.3	6.3	6.8	5.0	6.2
Eastern Pacific (17)	6.3	6.1	6.0	5.9	6.6	4.4	6.5
West-central Pacific (20)	6.8	5.9	5.4	6.2	6.1	4.1	5.6
Indian Ocean (20)	6.9	5.8	6.4	5.9	6.6	4.4	6.4
Kemp's Ridley (27)	5.8	3.9	6.3	5.4	4.7	4.5	5.6
Leatherback							
Caribbean (56)	6.1	5.5	6.3	6.0	6.0	4.8	5.9
Eastern Atlantic (27)	5.0	6.0	6.6	6.2	6.2	5.0	6.2
Southwestern Atlantic (24)	5.4	5.0	6.5	5.6	5.6	5.0	6.1
Northeastern Pacific (48)	5.9	5.6	6.9	5.8	6.4	5.0	6.1
Southwestern Pacific (78)	5.8	5.5	6.8	5.9	6.1	4.9	6.2
Loggerhead							
Caribbean (35)	6.3	5.1	6.4	6.0	5.7	5.1	5.8
Northeastern Atlantic (18)	4.9	5.7	6.4	5.6	6.0	4.9	5.8
Northwestern Atlantic (48)	6.8	2.2	5.9	5.3	4.9	5.1	5.7
Southeastern Atlantic (16)	5.3	5.7	6.6	5.4	6.2	5.0	5.9
Southwestern Atlantic (19)	5.7	5.6	6.2	5.6	5.7	4.6	5.7
Northwestern Pacific (27)	6.3	3.7	6.5	5.7	4.8	5.3	6.2
Southwestern Pacific (45)	5.9	4.5	6.0	6.1	6.0	5.2	6.2
Indian Ocean (18)	5.9	6.0	6.7	5.8	6.1	5.0	5.8
Mediterranean (22)	6.2	4.2	6.7	5.5	5.6	4.7	5.8
Olive Ridley							
Eastern Atlantic (17)	5.6	6.8	7.0	5.9	6.8	5.2	6.1
Western Atlantic (10)	5.9	6.4	6.8	5.4	6.7	4.9	6.5
Eastern Pacific (15)	6.2	7.0	6.8	5.9	6.6	5.0	6.6

DISCUSSION

Historically, sea turtle conservation focused on managing direct harvests. Green (*Chelonia mydas*) and other hard-shelled sea turtles were widely exploited for food. Hawksbills were harvested for their attractive carapace scutes used for jewelry (Bjorndal 1999). Leatherbacks were exploited for leather. As sea turtles were depleted, they became more desirable in some cultures, while direct exploitation was banned in others. As nesting female populations drastically declined, sea turtles were listed under various environmental legislations in the US and elsewhere. By the mid 1970s, all sea turtles were protected under the US Endangered Species Act, and monitoring programs emerged in the early 1980s. Those programs focused almost exclusively on the nesting life history aspects of sea turtles: researchers monitored nesting females, egg numbers, and hatchling success. The dynamics and details of the time between hatchlings emerging from a nest and the small percentage of those hatchlings returning to nest themselves were unknown.

In the late 1980s, life history and demographic research expanded the breadth of sea turtle research and management. In particular, demographic models suggested that nesting beach protection alone was unlikely to significantly contribute to population recovery (Crouse et al. 1987). Large juvenile and adult survivorship, as opposed to fecundity, was shown to be the key process driving population dynamics. At-sea biological details of sea turtles were poorly understood, and it was not until the 1990s that researchers began to investigate the marine stages of sea turtles and the hazards that threatened them there (Crowder et al. 1994; Heppell et al. 1999). It was then that fisheries bycatch emerged as a premier threat to sea turtle populations (Crowder & Murawski 1998; Lewison et al. 2004).

While no survey data exist from decades past on how sea turtle researchers and conservationists perceived anthropogenic hazards to sea turtles, the results from our survey suggest that they now consistently identify sea turtles as having multiple threats, including substantial threats from at-sea hazards, fisheries bycatch in particular. Fisheries bycatch was the top hazard for 18 sea turtle populations, compared to six for coastal development and three for nest predation. Resources invested by the sea turtle community, however, still appear biased toward terrestrial-based impacts. Twenty-eight percent of survey respondents reported conducting research or activities focused in the pelagic environment, compared to 70% for both terrestrial environments and coastal environments. Further, 59% of respondents reported having some or much experience with fisheries bycatch, compared to 80% and 74% with nest predation and coastal development, respectively. This disparity may include a generational effect; for example, 15% of respondents that had >10 years of experience reported conducting research in pelagic environments compared to 24% of respondents with <10 years of experience. A researcher who has focused on nesting beach ecology for 15 years may be less likely than a newer participant to shift research objectives toward another environment or hazard for a suite of reasons. Pathogens and global warming, the two most recently identified hazards to sea turtles, had the most uncertainty around predicted impact scores and the least amount of collective experience (i.e., 35% and 23% of respondents reported having some or much experience with global warming and pathogens, respectively).

Our survey results revealed clear patterns of expert bias, which should be considered in conservation planning. Respondents with no experience with respect to a sea turtle species tended to rank hazards affecting that sea turtle species higher than respondents with experience. A more striking pattern was with hazard-based expertise: the more experience a respondent had with a specific hazard, the higher he or she would score the impact of that hazard on sea turtle populations. For example, those that worked on nest predation scored nest predation impacts consistently higher than those that did not, while those that worked on fisheries bycatch scored fisheries bycatch high, and so on. While the result is not surprising and has been recognized in other sectors (Posner et al. 1996), it is rarely addressed in biodiversity conservation planning, which routinely relies on expert groups and opinions for guidance (Asquith 2001; Bojorquez-Tapia et al. 2003; Burgman 2002). More research on elucidating and controlling for such potential biases would likely result in more effective conservation planning (e.g., Burgman 2005).

Predicted summed impact scores from expert opinion surveys, along with their respective uncertainty, are useful for conservation planning as they provide estimates of relative impacts on species from a suite of hazards, along with a measure of consensus among researchers and practitioners. For example, both pollution and fisheries bycatch ranked high as hazards to the eastern Pacific olive ridley population; however, there was high consensus (i.e., low standard deviation) on fisheries bycatch by survey respondents compared to pollution, which had a level of associated uncertainty (Fig. 8). The negative correlation between predicted impact score and the respective variation suggest that there is overall consensus on the greatest hazards to sea turtle populations. Such information can help inform conservation action plans and steer research priorities. Hazards that show high impact scores and high uncertainty should be research priorities, while high impact-low uncertainty hazards may be strategic conservation investments.

While our survey is the first attempt to provide comparable worldwide estimates of relative impacts from hazards to sea turtle populations, such information is but one factor of many that needs to be considered in conservation planning and prioritization. The life stage(s) that a specific hazard impacts along with the elasticity of that life stage are critical factors (Crouse 1999; Heppell et al. 1999). Alongside those life history factors are economics and opportunities. For example, fisheries bycatch was the highest ranked hazard to the northwestern Pacific loggerhead population, while nest predation ranked sixth (Table 4). Fisheries bycatch affects adult and large juvenile life stages, which have relatively large effects on population dynamics based on demographic elasticity. In contrast, nest predation affects hatchling success, which has low elasticity. Thus, in addition the rankings of hazards, abating the impacts of fisheries bycatch on a per unit basis would be expected to have a disproportional positive effect on sea turtle populations compared to abating nest predation. Naturally, opportunities to abate identified threats must be present. Less recognized, however, is the influence of economics on conservation planning (Naidoo et al. 2006). Low intervention costs could potential shift optimal conservation strategies from an intervention that targets a high elasticity life stage to one that targets a low elasticity life stage (Donlan & Wilcox 2008; Wilcox & Donlan 2007b). For example, if a conservation opportunity existed where it was possible to drastically boost hatchling success at a low cost, it may have a higher conservation return given the funds available for investment in comparison with an intervention targeted at a higher elasticity impact that also carries excessively high costs (e.g., reducing fisheries bycatch). The opportunistic and economic details of potential conservation scenarios will differ on a case-by-case basis.

Expert opinion surveys should not be viewed as a replacement for empirical research, but rather as complimentary. Techniques have recently been developed to incorporate Bayesian models that use both types of information to improve predictions and estimates (Kuhnert et al. 2005; Martin et al. 2005). Expert opinion survey results may be particularly useful in exploring suspected shifts in pervasive hazards to species. For example, critically endangered hawksbill turtles have been heavily exploited historically for their meat, eggs, and ornamental scutes across their range (Bjorndal 1999; Meylan & Donnelly 1999). However, a more recent synthetic review of the species suggests that coastal development may now be a greater threat (Mortimer 2007). Our survey results support this claim: coastal development was ranked as the top hazard in three of the five geographic regions. Results from an expert opinion survey can also serve as a baseline for populations for which little is known with respect to anthropogenic hazards, such as hawksbill turtles in the eastern Pacific (Gaos et al. 2007).

Priority setting for the conservation of threatened and endangered species cannot wait for exhaustive empirical research (Davis et al. 1990). Given the broad reach of the Internet in the 21st century, web-based expert opinion surveys are a strategic way to aggregate information that can help set priorities for conservation action plans and related research. Expert opinion surveys are often low-cost and speedy; they may be particularly useful for species, like sea turtles, that are notoriously difficult to study. At the same time, potential bias should be addressed. The tendency of majority opinions to converge on reality has been long recognized (Galton 1907), and more recently discussions have centered on harnessing such phenomena to provide social value (Surowiecki 2005). Expert opinion surveys focused on threatened and endangered species and their hazards can help guide and expedite effective recovery plans.

Figure 3. Percentage of respondents that reported having no, little, some, or much experience with respect to a) sea turtle species, b) geographic region, and c) hazard type. N = 212 respondents.

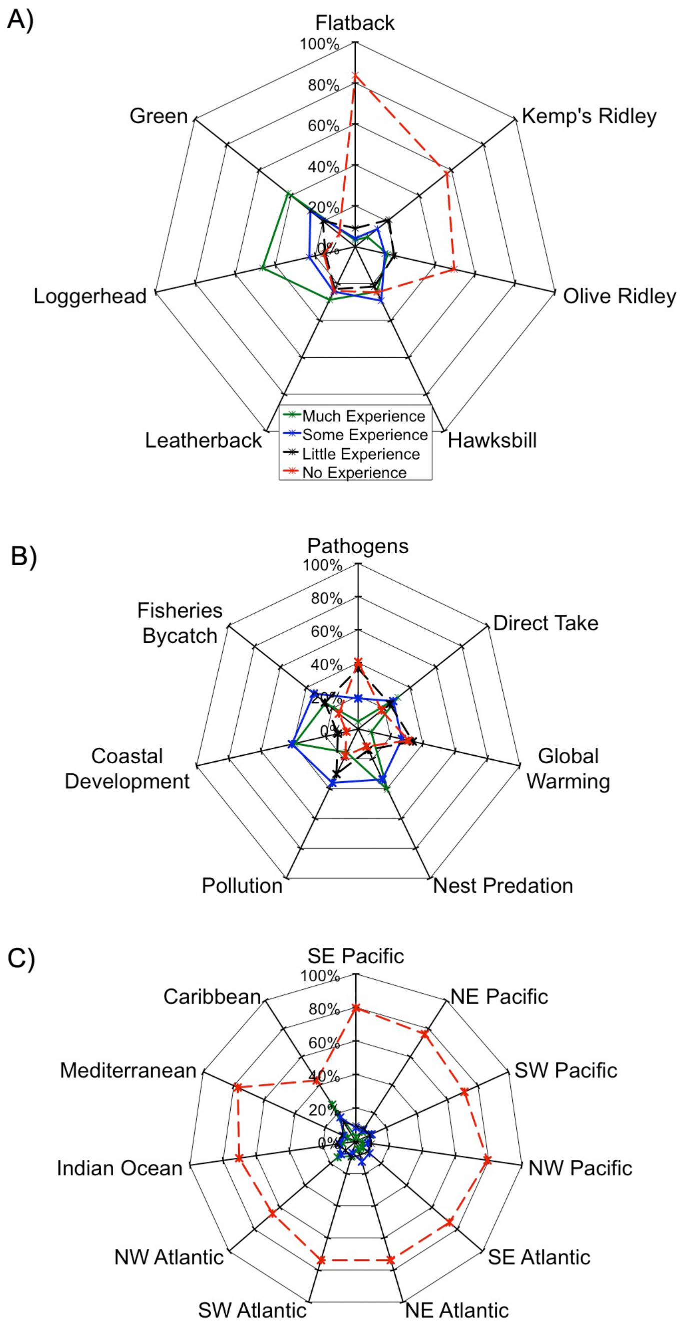


Figure 4. Predicted impact scores for each hazard type pooled across geographic regions for each sea turtle species. Impact scores follow IUCN/Birdlife International scoring scheme: 0-2: no/negligible impact; 3-5: low impact; 6-7: medium impact; 8-9: high impact.

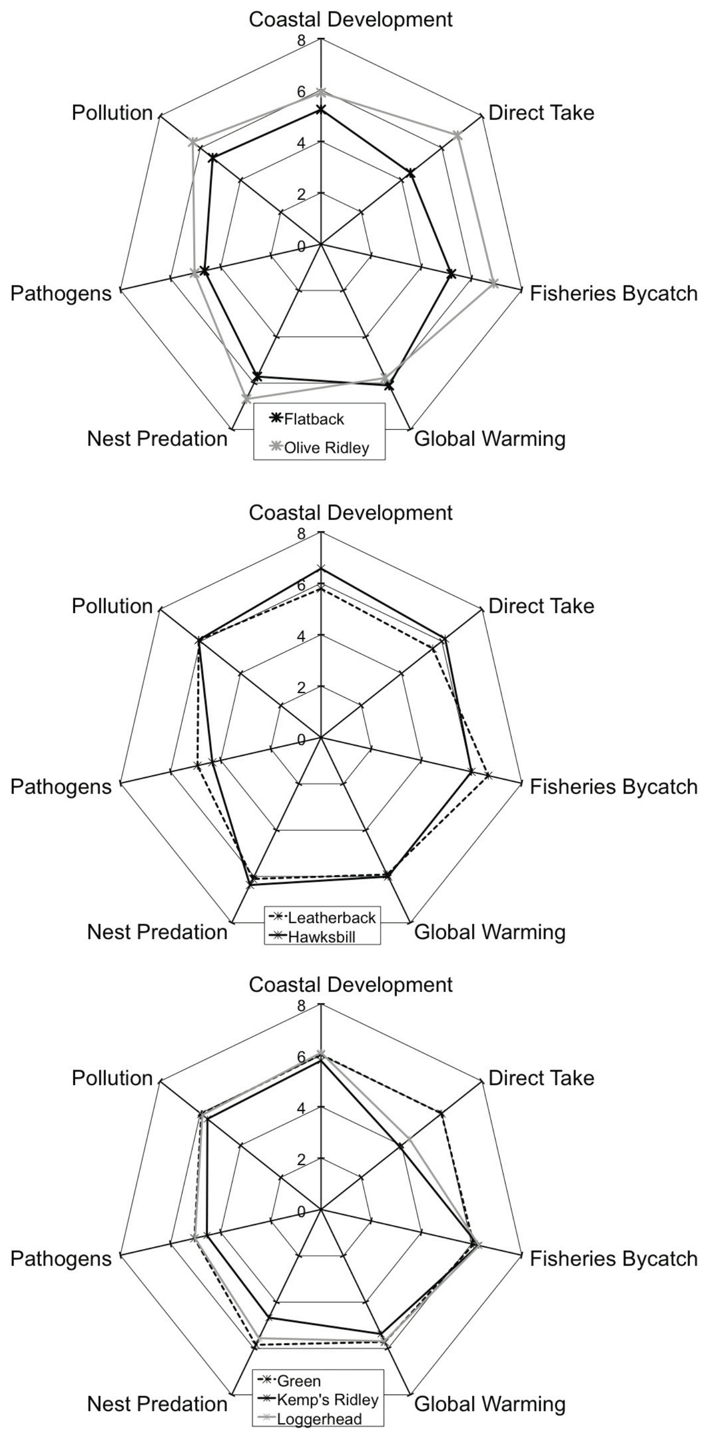


Figure 5. Predicted impact scores for each hazard type pooled across sea turtle species for each geographic region. Impact scores follow IUCN/Birdlife International scoring scheme: 0-2: no/negligible impact; 3-5: low impact; 6-7: medium impact; 8-9: high impact.

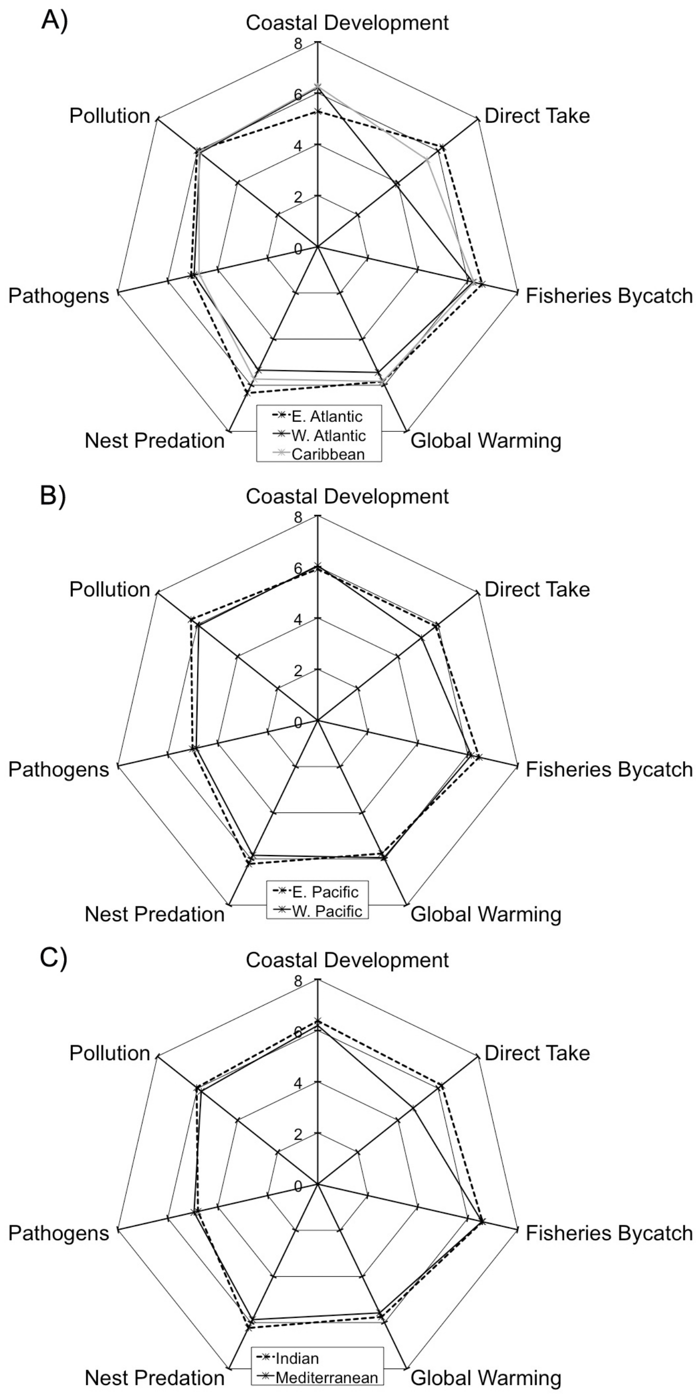


Figure 6. A) Results of an ANOVA testing effects for types of expert, hazard, and sea turtle species on cumulative impact score from the expert opinion survey. Geographic expert level was not significant ($p > 0.10$) and thus not included in the model, while species expert level was marginally significant. B) Predicted mean cumulative impact score (95% CI) for survey respondents with increasing expertise in hazards (black) and species (grey). Impact score differed significantly ($) with species expert level only between the No Experience and remaining expert levels. Impact score differed significantly (*) between all hazard expert levels, with impact score increasing with expertise.

Source	DF	F-value	p-value
Species expert level	3	2.39	0.067
Hazard expert level	3	29.53	<.0001
Hazard	6	4.35	<.0001
Species *x* Geographic region	30	2.27	<.0001
Total	180	3.60	<.0001

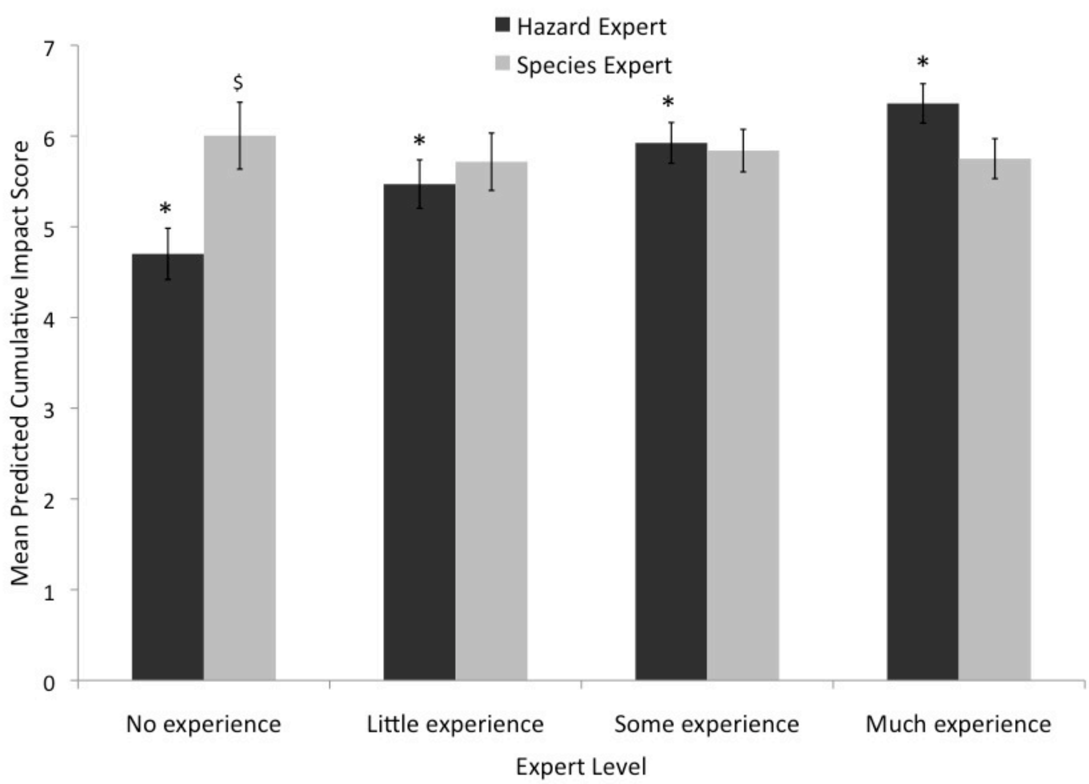
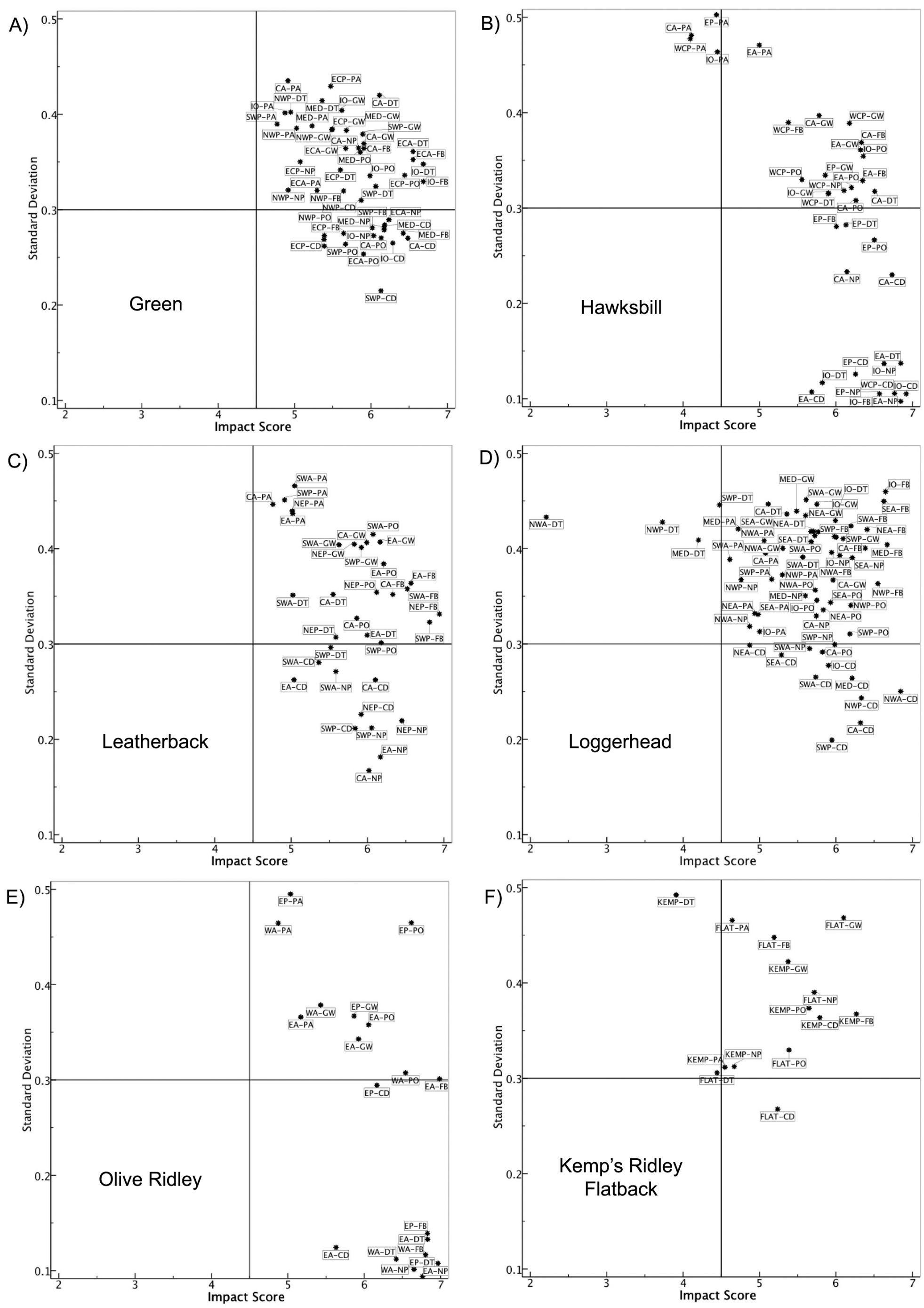


Figure 7. Predicted summed impact scores-standard deviation plots for geographic region-threat combinations for a) green, b) hawksbill, c) leatherback, d) loggerhead, e) olive ridley, and f) kemp's ridley and flatback sea turtles. Data points in the upper left quadrant represent relatively high impact and high uncertainty compared to data points in the lower right quadrant represent high impact and low uncertainty.



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