Compensatory mitigation as a solution to fisheries bycatch–biodiversity conservation conflicts

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Globally, fisheries catch of non-target species has major environmental impacts, resulting in social conflict, litigation, and fisheries closures. We use a bio-economic approach to demonstrate that compensatory mitigation – an innovative, market-influenced approach to fishery–conservation conflicts – can facilitate high-value uses of biological resources and cost-effective conservation gains for species of concern. We illustrate the strategy with a seabird example: levying fishers for their bycatch and using the funds to remove invasive mammals from breeding islands. Removal of invasive predators is 23 times more effective from a return-on-investment perspective (ie percent increase in population growth per dollar invested) in comparison to fisheries closures, and is more socio-politically feasible. A bycatch levy, which would increase with endangerment, provides an individual incentive for avoiding bycatch, the most effective mechanism for sustainable management of fisheries. Compensatory mitigation provides an opportunity to address a global concern, optimize conservation interventions, and forge an alliance between conservation and fisheries organizations.

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Globally, fisheries provide approximately 16% of all protein consumed by humans, employ about 200 million people, and are valued at US$82 billion (Botsford *et al*. 1997; FAO Fisheries Department 2004). Eight percent, or 7.2 million tons, of the global catch is comprised of non-target species and discarded, and this mortality is having major impacts on species and ecosystems (Botsford *et al*. 1997; Spotila *et al*. 2000; Baker *et al*. 2002; FAO Fisheries Department 2004; Lewison *et al*. 2004). The social and economic importance of fisheries and the biological realities of overfishing and bycatch result in cardinal tensions over ocean resources. Encouragingly, fishing gear modifications and other low-cost measures are effective in reducing bycatch for some species and are currently being implemented (Gilman *et al*. 2005). However, in other cases, avoiding unacceptable levels of mortality has proven difficult, and costly regulatory interventions are becoming commonplace. New Zealand's squid (US$122 million per year in revenue in 2006) and Hawaii's pelagic longline fishery (US$50 million per year in revenue in 2000) have both been recently closed due to bycatch of endangered marine vertebrate species (Ito and Machado 2001; Lane 2005; Martin 2005; Anonymous 2006a, 2007) .

In a nutshell:

- Fisheries bycatch is causing serious environmental damage, resulting in social conflict, litigation, and fisheries closures
- We demonstrate that a compensatory mitigation approach, reducing other mortality sources to offset the impact of fisheries bycatch, can yield a conservation return on investment 23 times greater than a fishery closure
- If funded by a fee to fishers for their bycatch, this approach provides an individual incentive that increases with extinction risk, which has been shown to be the best predictor of sustainable fisheries management

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Many species that are impacted by fisheries bycatch, such as seabirds and sea turtles, spend part of their lives on land. Events in these terrestrial habitats also often lead to high levels of mortality. For instance, while fishery bycatch is affecting seabirds globally, particularly albatrosses, petrels, and shearwaters (Brothers *et al*. 1999), this threat pales in comparison with the impact of invasive mammals on breeding colonies (Figure 1). Invasive predators such as feral cats (*Felis catus*) and rats (*Rattus* spp) have decimated seabird breeding colonies worldwide, preying on eggs, chicks, and adults of many species (Atkinson 1985; Nogales *et al*. 2004). Three-quarters of seabirds listed by the IUCN are threatened by invasive species, compared with 49% threatened directly or indirectly by fisheries (Figure 2a). Indeed, invasive mammals are responsible for most vertebrate extinctions over the past 6 centuries, and the overwhelming majority of these extinctions have occurred on islands (Groombridge 1992; MacPhee and Flemming 1999).

Courtesy of RW Henry

Courtesy of D Barton

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Figure 1. *Laysan albatrosses colonized Guadalupe Island, Mexico, in 1983 and were undergoing exponential growth until (a) fewer than 20 feral cats killed (b) half of the main island adult breeding population, (c) representing ~10% of the entire annual fishery bycatch in the northern Pacific. (Between 1993 and 1999, the estimated total longline fishery bycatch of Laysan albatross in the Bering Sea and Aleutian Islands was 568 [±69, 95% CI]; Livingston* et al. *2001.) A control program removed cats for less than US$86 per cat; eradication would contribute significantly to the long-term persistence of Laysan albatross.*

Invasive species remain a premier threat to biodiversity today. Invasive rodents have been introduced to over 80% of the world's major island groups, ranging from the Arctic to the Antarctic, and feral cats also occur on most of the world's islands, including the islands of Australasia and the Atlantic, Pacific, and Indian Oceans (Atkinson 1985; Long 2003).

Despite the cosmopolitan threat posed by invasive mammal predators to many marine vertebrates, research and management is often directed at obvious and perhaps higher profile mortality sources. For example, seabird conservation has largely focused on pollution and bycatch (Dunnet *et al.* 1982; Brothers *et al.* 1999; Baker *et al.* 2002; Gilman *et al.* 2005). This narrow focus on particular mortality sources can lead to conservation actions that are economically inefficient and demographically ineffective. An integrated approach to seabird conservation would focus on two goals across all mortality sources: population growth rates that are stable or positive and maintenance of adequate habitat.

Also lacking in the debate, particularly regarding bycatch and marine conservation, is a holistic analysis of the economic costs of various conservation interventions and their relative return on investment. While the effectiveness will vary between species, the cost of reducing mortality due to invasive mammals in some seabirds may be substantially less than a similar reduction in bycatch rates and may also offer greater conservation benefits. In melding demography and economics, the fundamental question is, "How large an increase in population growth (λ), or expected population size, can be anticipated per dollar invested in a given conservation action?" A corollary to this is, "Is it possible to allow revenue-generating biodiversity impacts, such as fisheries, to offset their impacts by funding a reduction in revenue-neutral or revenue-negative impacts such as invasive mammals, that is, taking a compensation approach to bycatch management?"

A worked example: seabirds and Australian longliners

In Australia's US$32 million eastern tuna and billfish fishery (ETBF), an input-controlled pelagic longline fishery, mitigation measures have been imposed to reduce seabird bycatch, including the prohibition of setting longlines during daylight hours and mandatory use of heavily weighted lines (ABARE 2006). However, three concerns remain: these measures (1) may not provide adequate bycatch reduction for some species, (2) may be costly for fishers and agencies, and (3) may be difficult to enforce. While mitigation measures have reduced albatross bycatch, Australian-operated vessels alone kill several thousand shearwaters annually. Flesh-footed shearwaters (*Puffinus carneipes*) suffer the greatest mortality, estimated at 1800–4500 birds per year (Priddel *et al.* 2006). With the entire eastern Australian population breeding on Lord Howe Island, and with evidence of a decline (Priddel *et al.* 2006), fishery closures may be implemented.

Demographic impacts on flesh-footed shearwaters from bycatch may be overshadowed by on-island threats such as habitat loss, predation by invasive predators (including rats, and formerly cats), and ingestion of plastic (Priddel *et al.* 2006). As a stark comparison, the entire annual ETBF bycatch of flesh-footed shearwaters would cause damage equivalent to that of 7–18 feral cats preying on the breeding colony, based on predation rates for a related species (*Puffinus opisthomelas*; Keitt *et al.* 2002). Other seabirds suffer similar impacts from cats on islands around the globe, as well as from rat and house mouse (*Mus musculus*) predation, often resulting in widespread extirpations (Atkinson 1985; Cuthbert and Hilton 2004; Nogales *et al.* 2004; Towns *et al.* 2006).

To explore the potential for cost-effective conservation actions using offsets, we modeled the flesh-footed shearwater population using a bio-economic approach. Using demographic rates for flesh-footed shearwaters (Priddel *et al.* 2006) and metabolic estimates of rat consumption of shearwaters (Keitt *et al.* 2002; Stapp 2002), we compared the impact of fishery bycatch and rat predation on the annual population growth rate of flesh-footed shearwaters on Lord Howe Island (WebPanel 1). Concurrently, we estimated the (static) expected economic cost and (static) conservation benefit of implementing conservation measures (ie spatial closures for bycatch and control or eradication for rats; WebPanel 1). These threats and conservation scenarios are applicable to many seabird species worldwide. Over half of the IUCN-listed seabirds that are explicitly threatened by fisheries bycatch are concurrently threatened by invasive species on their breeding grounds (Figure 2b).

Figure 2. *(a) Threats to seabirds listed by the IUCN: non-native species (NNS), habitat destruction and/or direct persecution (HD), fisheries bycatch and competition for resources (FISH), pollution, including hydrocarbons, plastics, and light (POLL), climate change (CLIM), and disease (DIS). Many species are experiencing multiple threats. Includes all seabirds listed as critically endangered, endangered, vulnerable, and extinct. (b) Percent of seabirds listed by the IUCN that are explicitly threatened by fisheries bycatch at sea and also by non-native species on breeding islands. Includes all seabirds listed as critically endangered (CR), endangered (EN), and vulnerable (VU). Data from Birdlife International's World Bird Database, n = 104.*

Conservation interventions differ substantially in their predicted effect on flesh-footed shearwaters (Figure 3). Closure of a 750-km radius around Lord Howe Island results in a 6% increase in λ of the shearwater population, with an economic cost approaching US$3 million. Eradication of rats, costing approximately US$500 000, results in a 32% increase of λ, making such an action 23 times more effective than fishery closure from a conservation return-on-investment perspective (Figure 3). While this increase is complicated by the effects of a shift in the age structure, examining the effects of the interventions on the population growth rate after 20 years yields relatively similar results. Eradication results in a 64% increase in the annual population growth rate, while fishery closure yields a 63% increase; however, eradication is much less expensive, and so, on a per-investment basis, still appears advantageous.

Conservation actions also differ over the time period that costs must be borne. While effective, the net present value of the cost of the current rat control program (US$39 000 a year, at a 5% discount rate) is over five times as costly as eradication for a similar conservation return (Figure 3). The ongoing nature of this cost implies that eradication is substantially preferable to control, although the difference depends on the discount rate and horizon.

Problems and opportunities

While we have examined a single shearwater population as an illustration, similar opportunities may exist for

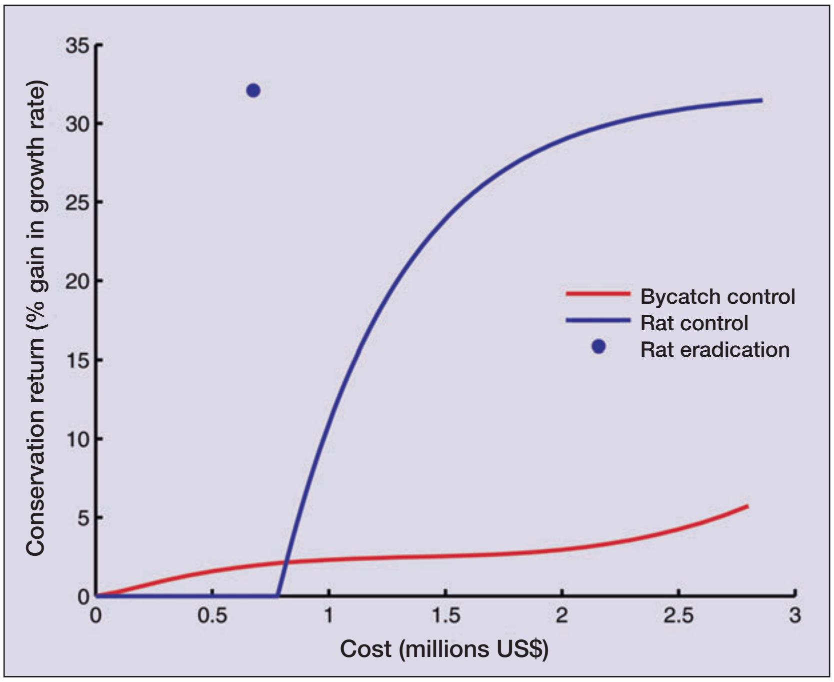

Figure 3. *Increase in population growth rate with investment in various conservation actions. We presume a base of 17 462 breeding pairs of shearwaters, with the population in stable age distribution. Mortality in the model results from two sources. With no conservation intervention, there are 48 rats per hectare and annual losses of 4500 birds to fishery bycatch. We limited the maximum fishery closure to the 750-km radius around Lord Howe Island, as that includes the majority of the fishery.*

other species impacted by fishing. Even albatrosses, which many consider to be primarily threatened by fisheries bycatch (Brothers *et al.* 1999; Tasker *et al.* 2000; Cuthbert *et al.* 2005), suffer from invasive species impacts and other terrestrial-based threats. Feral cats recently decimated a Laysan albatross (*Diomedea immutabilis*) colony on Guadalupe Island, Mexico (Keitt *et al.* 2006; Figure 1). The Tristan albatross (*Diomedea dabbenena*), the third rarest albatross and a species that is currently declining, is largely restricted to Gough Island (sub-Antarctic). Incidental mortality from longline fisheries is considered the main threat (Cuthbert *et al.* 2005), yet chick predation from house mice is reducing breeding success to a mere 23% in some breeding colonies, compared to 64–76% for related albatrosses (Cuthbert and Hilton 2004; Cuthbert *et al.* 2004).

Although not included in our analyses, it is also possible to re-establish seabird colonies from islands where they have been extirpated. Fossil evidence suggests that seabirds were once much more widespread and abundant in their breeding distributions (Steadman 1995; Worthy and Holdaway 2002). Inexpensive techniques (eg US$87 000 per year for Atlantic puffins; S Kress pers comm) are now available for re-establishing seabird colonies (Kress 1997), and with the fossil and historical records as guideposts, these techniques could also be implemented as compensatory mitigation.

While we have focused on seabirds, a similar approach could be explored for sea turtles. Many endangered populations are impacted by a variety of factors, including human consumption of adults and eggs, nest predation by invasive mammals, and fisheries bycatch from both artisanal and industrial fishing fleets (Crowder *et al.* 1994; Hawkes *et al.* 2006; Koch *et al.* 2006; Plotkin 2007). Each of these threats offer conservation opportunities, and the effective allocation of resources to reduce overall mortality represents an optimization problem best tackled with a system-wide approach, avoiding tendencies toward a perceived single-factor solution. The use of compensation strategies for some species may ease trade-offs between those and other species. For instance, although a switch from "J" hooks to circle hooks reduces sea turtle bycatch, in some systems it may increase shark bycatch (Read 2007). Sea turtle species that take decades to mature sexually present unique conservation challenges due to disparities in reproductive values among life stages (Crouse *et al.* 1987). Such disparities may limit the effectiveness of some compensatory mitigation opportunities; however, to date, analyses have not included economic costs, and thus the conservation potential of such an approach is currently unclear.

Designing an effective policy tool

There is a history of compensatory mitigation schemes designed to accommodate concurrent goals of economic development and biodiversity conservation, particularly in two contexts: filling of wetlands and loss of threatened species habitat. These two programs are illustrative of the current state and potential pitfalls in the application of compensatory schemes. Wetland destruction in the US and Canada is regulated by national laws which require compensation for wetland losses with creation or restoration of similar wetland elsewhere. Despite such legal frameworks, after several decades of policy implementation, audits of resulting compensations document widespread non-compliance (eg Quigley and Harper 2006). Of particular concern is the pattern that compensatory wetlands do not match the function or the specified quantity of destroyed wetlands. Superficially, this failure may be due to shortfalls in enforcement; however, the ultimate cause is the lack of an overarching model which directly links the impacts of a proposed development to the mitigation necessary to offset that impact, resulting in vague policy and arbitrary offsets that are onerous to enforce (Brown and Lant 1999; Quigley and Harper 2006).

The conflict over the conservation of chinook salmon

(*Oncorhynchus tshawytscha*) in the US Pacific Northwest provides a contrasting example. Several runs of Snake River chinook are listed as endangered under the US Endangered Species Act, and have been in decline since the early 1970s, presumably due to dam construction for hydropower and other human uses (Nemeth and Kiefer 1999). Initial solutions to this problem involved transporting migrating fish around dams, a mitigation action that has been unsuccessful in terms of arresting population decline (Nemeth and Kiefer 1999). Removal of dams was then suggested, and a series of analyses were conducted to consider alternative management actions and their relative efficacy for reversing the ongoing decline (Nemeth and Kiefer 1999; Peters *et al.* 2001). In contrast to wetlands mitigation, these analyses were based on specified quantitative demographic models and the potential interventions (eg dam removal and transportation) were explicitly linked to the desired outcome (ie reduced extinction risk). However, the analyses are post-hoc, in the sense that the impacts (ie dams) had already occurred. Of fundamental importance is the fact that these analyses stop at the anticipated biological impacts, failing to incorporate the economic costs of the mitigation options and the economic benefits derived from the impact(s).

Several lessons can be drawn from the wetland and dam examples for the framework we propose. First, it is essential that compensation actions be identified prior to the proposed impact occurring. This ensures that an adequate compensation option exists and that it is possible for the impact-generated revenue to fund it. Second, there must be an explicit, quantitative link (eg demographic model) between all ongoing impacts and the policy objective (eg not exceeding a specified extinction risk). The policy objective must be ecologically, not politically, based; otherwise, offset strategies are likely to fail (Barnes 2006; Rosales 2006). Third, outputs should be viewed in a return-on-investment perspective for each mitigation alternative, emphasizing bio-economic cost effectiveness. Finally, the framework must be dynamic. Mitigation actions must aim to offset the current situation, and thus the quantitative link needs to be updated as new information becomes available, and mitigation requirements decreased or increased accordingly. In a precedent-setting step, the hydropower relicensing process in the US has begun to use models which take a bio-economic approach to evaluate alternative mitigation scenarios in dam relicensing, including fish passages and dam removal (Gowan *et al.* 2006). Encouragingly, this process conforms to the criteria above and has received positive support from groups across the stakeholder spectrum, including the hydropower industry, environmental groups, and resource agencies (Gowan *et al.* 2006).

Conclusions

Compensatory mitigation, in conjunction with direct bycatch mitigation efforts, is an effective, enforceable, and economically feasible strategy for seabird conservation. Our analysis for flesh-footed shearwaters provides support for this approach, with rat eradication resulting in conservation benefits (ie effect on λ) that are not achievable with bycatch mitigation measures and at a fraction of the cost (Figure 3). Given the number of seabirds that are threatened by both fisheries bycatch and invasive species (Figure 2b), the proposed conservation approach is likely to prove applicable and effective in many scenarios worldwide. As important, the proposed strategy is technically and socio-politically feasible. Invasive cats and rodents are being removed from larger and larger islands (eg rats from 113 000-ha Campbell Island, New Zealand), and have already been successfully eradicated from over 400 islands worldwide (Nogales *et al.* 2004; Howald *et al.* in press; Donlan in press).

Designing effective policy tools to support sustainable exploitation of marine resources is complex, and from a bycatch perspective involves at least three considerations: (1) What is the optimal level of ecosystem disruption or extinction risk? (2) What is the most cost-effective way of achieving the goal? (3) Who should pay the cost for achieving it?

The first consideration is a social question and therefore lies outside our analysis. Standards do exist; in Australia, the Commonwealth has chosen to regulate the acceptable risk generated by particular mortality sources, including rats and fisheries bycatch (Anonymous 2006 b,c). The final question is also to some extent a matter of public policy. While we believe that users of public resources who derive an economic benefit have a responsibility to pay the cost of mitigating their impact (eg Barnes 2006), the extent of this responsibility is in large part politically determined. The main focus of our analysis is on the second point: given that there is some conservation standard, and that resource users are responsible for some set fraction of the cost of meeting that standard, what is the most cost-effective way to achieve the goal?

When designed under the proper framework, compensatory mitigation provides a mechanism for generating revenue from impacts to common-pool resources that can be used to support high-impact conservation actions. Returning to the fisheries context, using individual vessel levies set at the cost of offsetting the bycatch they take:

(1) provides regulatory certainty for operators by reducing the "race to fish" generated by closures, an essential ingredient for effective businesses;
(2) with adequate fee levels, creates individual incentives for fishers to avoid bycatch;
(3) could fund actions that effectively offset bycatch that does occur; and
(4) may accelerate the rate of development of new bycatch avoidance technologies.

By indexing these levies against the true cost of offsetting bycatch impacts, economic costs would increase with the extinction risk, further motivating fishers to reduce their bycatch.

As opposed to command-and-control approaches (eg fisheries closures), incorporating market externalities into the costs of fishing allows fishers an opportunity to develop innovative ways of avoiding bycatch. The lack of such opportunity is a common complaint in the fisheries sector, and individual incentives have been shown to be the single most important factor determining the sustainability of fisheries (Hilborn *et al.* 2005). This "induced innovation" shows some promise for reducing environmental impacts by industry (Jaffe *et al.* 2002). Further, compensatory mitigation would have important marginal benefits, since not only bycatch species but an entire suite of species, and frequently entire ecosystems, would benefit from the removal of invasive mammals and other on-island restoration actions. Compensatory mitigation provides an opportunity to constructively address a global conservation concern and forge an alliance between conservation and fisheries organizations.

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