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Reconciling conflicts in pelagic fisheries under climate change

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ABSTRACT

Fishing in the open ocean often results in unwanted effects on target species, and interactions with non-target species (direct interactions) or influences on the prey or habitat of target and non-target species (indirect interactions). A number of conflicts and trade-offs exist in the harvesting of pelagic species, including (i) maximizing future food production given the depleted state of some stocks; (ii) minimizing bycatch of non-target species, (iii) setting ecosystem allocation rules for non-target top predators, such as seabirds, and (iv) maximizing value and livelihoods for local economies. Climate change can be expected to exacerbate some of these conflicts as the ranges of species and their habitats change over varying geographic, depth and temporal scales. Understanding the distribution of these impacts can be difficult due to the scarcity of observational data on species and ecosystems. Resolving all these conflicts is achievable with current approaches and technologies. Nevertheless, managing fishery production systems to provide fish for food security and conserving biodiversity will be particularly challenging. The complexity added by climate change can be managed with greater use of early warning systems and precautionary management.

1. Introduction

Open ocean pelagic fishing using a range of gears, including longline, purse seine, pole and line, and midwater trawl, takes place in deep waters within national management boundaries and on the high seas. A wide range of species are sought, from sardines and mackerels, to tunas and billfishes. Across these regions, a wide range of management approaches, regulations and organizations exist primarily to manage the harvest of the target species; particularly tuna and billfish (Ban et al., 2013; de Bruyn et al., 2013), with smaller pelagic species having received less management attention. These management structures seek to ensure the sustainable use of oceanic resources, although much has been made of apparent management failures (Myers and Worm, 2005; Cullis-Suzuki and Pauly, 2010) despite evidence to the contrary (Hampton et al., 2005; Polacheck, 2006; Hilborn, 2007; Banobi et al., 2011). While much of the focus has been on management successes or failures with regard to the target species, there are also a number of other conflicts that exist for pelagic fisheries.

Trade-offs between different management goals appear to be inevitable in multiple use marine systems, particularly around maximizing sustainable catches and minimizing bycatch (Brander, 2010a; Ban et al., 2013). However, pathways to optimize these particular trade-offs have been proposed, including use of spatial closures and bycatch reduction via gear modification (Worm et al., 2009; Brander, 2010a, Rice and Garcia, 2011). Other conflicts arise around reconciling the contributions from industrial oceanic fisheries to economic development with the need to increase access to fish for food security and artisanal livelihoods (Bell et al., 2011). These issues will become more pressing in future, due to the interrelated drivers of climate change and human population growth (Gillett and Cartwright, 2010, Rice and Garcia, 2011, Hall, 2011). Maintaining biodiversity in the open ocean and increasing food supplies will be challenging, as will providing for broad-based socio-economic development of regional communities.

The future of fisheries science and management will be permeated by considerations of climate change (Brander, 2010b; Polovina et al., 2011; Salinger and Hobday, 2013). Model projections indicate that over the next century average surface ocean pH may decline by up to 0.3 pH units, surface temperatures rise by up to 3 °C, and O_2 concentrations below the mixed layer will fall by up to $30\ \mu mol\ kg^{-1}$ (Caldeira and Wickett, 2005; Hofmann and

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Schellnhuber, 2009; Hoegh-Guldberg and Cai, 2014). In some regions, climate-related changes may be even larger (e.g. Hobday and Pecl, 2014). In response to warming, horizontal and vertical range shifts in coastal fishes are already occurring (e.g. Rijnsdorp et al., 2009; Nye et al., 2009; Last et al., 2011, Cheung et al., 2013). Warming of the surface ocean is expected to cause eastward shifts of tuna stocks in the tropical Pacific, with improved habitat in the east and declines in the Warm Pool region (Loukos et al., 2003; Lehodey et al., 2010; Lehodey et al., 2013, Bell et al., 2013). Higher mixed layer temperatures are increasing stratification and decreasing ventilation, which, combined with lower gas solubility, is causing decreases in oxygen concentration (Keeling et al., 2010). While ~60 μmol kg^{-1} O_2 is frequently used to define hypoxic water, there are reductions in fish growth at concentrations as high as 192 μmol kg^{-1} O_2 (Chabot and Dutil, 1999) and avoidance of habitat at 156 μmol kg^{-1} O_2 (Prince and Goodyear, 2006). Tunas are known to be extremely sensitive to oxygen levels, with yellowfin tuna avoiding waters with moderate hypoxia (65% saturation, generally ~130 μmol kg^{-1}) (Brill, 1994). Therefore, in some ocean regions, particularly the eastern Pacific and the tropical north-east Atlantic, deoxygenation will have major impacts on distribution of pelagic fishes and sharks (Stramma et al., 2011) and temperature, oxygen and pH changes may act synergistically. In addition to these direct impacts of climate change on the fished species, indirect impacts on productivity and pelagic foodweb structure (Polovina et al., 2011; Le Borgne et al., 2011; Doney et al., 2012) will also have flow on effects, which may exacerbate existing conflicts.

Here, we consider four conflicts involving pelagic capture fisheries: (i) food security-fish stock conservation, (ii) bycatch reduction, (iii) ecosystem allocation to top predators, via consideration of seabirds, and (iv) fish and livelihood availability for local people. In each case, we describe the conflict and the context in which it occurs and the prospects for resolving each conflict in the face of climate change. Resolution of these conflicts is important if pelagic fisheries are to continue to provide seafood into the future.

2. Conflicts in pelagic fisheries

2.1. *Food security and conservation of fish stocks*

Due to previous overharvesting, a return to biomass levels that can be considered sustainable requires a reduction in fish catch for many stocks (Worm et al., 2009). This involves a trade-off between food provision now and in the future. Thus, rebuilding fish stocks where necessary may involve near-term loss, before a long term benefit is realised (Grafton, 2010; Bell et al., 2011).

Planning for the longer-term benefit is essential because an additional 75 million tonnes of fish is likely to be needed to provide adequate nutrition for the world's population by 2050 (Rice and Garcia, 2011), above the current harvest of ~144 million tonnes (~90 million from wild fisheries). While much of this additional fish will need to come from aquaculture (Merino et al., 2012), marine capture fisheries must remain an important source of seafood (Hall et al., 2013). The tropical Pacific region, where large-scale coastal aquaculture for food production will be difficult for some small island developing states (SIDS) due to exposed coasts, and where the rich tuna resources of the Western and Central Pacific Ocean (WCPO) support a globally significant capture fishery (Williams and Terawasi, 2013), illustrates some of the tradeoffs needed to reconcile food security and biodiversity conservation.

For Pacific SIDS, potential conflict arises because economies of scale in the surface fishery for tuna (based mainly on skipjack tuna *Katsuwonus pelamis*) have resulted in widespread use of purse-seine vessels and drifting fish aggregating devices (FADs) (Dagorn et al., 2013). When used in unison, these fishing methods have increased bycatch and the proportion of small tuna taken by the industrial fleet (Leroy et al., 2013). In response, the eight island States that are members of Parties to the Nauru Agreement[1] have trialed a range of regulations intended to minimize the impacts of industrial tuna fishing on biodiversity and reduce overfishing (but see Sibert et al., 2012), but they do not necessarily improve the supply of fish needed for future food security. A range of measures and supporting policies will be needed to increase access to tuna in the tropical Pacific for domestic consumption. We base this conclusion on the fact that an additional 115,000 tonnes of fish per year (above average annual fish consumption of 245,000 tonnes) will be required for good nutrition of the region's population by 2030 (Bell et al., 2009). The rich tuna resources of the WCPO can easily meet this need. In fact, by 2030 the additional amount of fish needed for food security is expected to represent $<10\%$ of the tuna catch from the exclusive economic zones of Pacific SIDS. Increased access to tuna for food security will not be needed by all Pacific SIDS, however, because these small countries and territories fall into three groups: (1) those where coastal fisheries (based mainly on coral reefs) are expected to meet local demands for fish for many years to come; (2) those with potential to produce enough reef fish for food security but where it is difficult to transport the fish from remote locations to population centers; and (3) those where sustainable harvests from coral reefs are not expected to provide the recommended quantities of fish for good nutrition of rapidly growing populations (Bell et al., 2009).

Because not all Pacific SIDS have the same needs for fish, approaches to providing sufficient access to tuna for nutrition will differ between countries, and between rural and urban areas within countries. However, mixing and matching two solutions that have already been developed holds great promise. The first of these solutions involves using the small tuna previously discarded by purse-seine vessels, and bycatch, to supply some of the fish needed by rapidly growing urban populations These fish are brought ashore during transshipping operations when purse-seiners transfer their catch to fish cargo vessels. This ‘vehicle’ for increasing access to tuna has now been established in Solomon Islands and Kiribati and has potential to supply low-cost fish to urban and semi-urban areas wherever transshipping occurs. However, consideration will need to be given to the impacts of these landings on small-scale fishers supplying tuna to urban markets (Section 2.4), as well as to the potential to create dependence on such landings and the erosion of existing sources of employment and income.

The second solution is greater use of anchored FADs placed close enough to shore to increase catches of tuna by subsistence fishers in rural areas, and small-scale commercial fishers supplying rural and urban centers (Bell et al., 2011, SPC, 2012). Several studies (Chapman et al., 2005, Sharp, 2011, 2012) have demonstrated that the value of fish caught around FADs far exceeds the costs of deploying them in a range of Pacific SIDS.

2.1.1. *Knowledge gaps— reducing the conflict in the face of climate change*

Distribution and movements of fish stocks are projected to increase further under climate change (e.g. Cheung et al., 2010; Hobday, 2010; Lehodey et al., 2010; Lehodey et al., 2013). Thus, resolving the food security conflict is expected to become more challenging as the climate continues to change (Salinger and

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[1] Members are: Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands and Tuvalu (www.pnatuna.com).

Hobday, 2013). In the tropical Pacific Ocean, if the projected redistribution of skipjack tuna to the east eventuates (Lehodey et al., 2013) it will progressively reduce tuna resources for SIDS in the west of the region, which have higher populations and rates of population growth than those to the east (Bell et al., 2013). Ultimately, for several of the SIDS in Group 1 (e.g. Papua New Guinea, Solomon Islands and Nauru) the combination of redistribution of tuna and human population growth will increase the percentage of the national tuna catch required to fill the emerging gap between the fish needed for food security and the fish available from coastal fisheries.

An important question for such SIDS is 'what strategies will result in the best nutritional outcomes for the nation's population'? Two broad alternative strategies are (1) increasing the purchasing power of individuals to buy fish and other food through maximizing national economic benefits derived from access fees for industrial fleets, and from the contributions of tuna fishing and tuna processing to gross domestic product; and (2) allocating the necessary (small) proportion of average national tuna catches to food security and supporting and developing small-scale fisheries around nearshore FADs to increase the supply of tuna to urban and rural markets? It is important to note that the second strategy is unlikely to be adversely affected by climate change. Although the distribution of tuna is projected to shift progressively to the east, tuna are still expected to remain in the waters of SIDS in the western Pacific, like Papua New Guinea and Solomon Islands, in relatively high numbers (Lehodey et al., 2013). Therefore, nearshore FADs are expected to continue to yield good catches of tuna for small-scale fishers. This assumption is based on the fact that 5- to 7-fold returns on investment have been achieved for nearshore FADs deployed in SIDS with relatively low densities of tuna, such as Cook Islands and Niue (Chapman et al., 2005).

These considerations also apply to SIDS in the Indian Ocean basin and the Atlantic Ocean, but equivalent modeling and adaptation options have not yet been considered in these regions. Without resolving the food security-conservation conflict, pelagic fisheries will not make the needed contribution to the projected quantities of fish required by local communities and world's population.

2.2. Bycatch reduction and sustainable fishing

A wide range of organisms are taken as bycatch[2] in pelagic longline, trawl and net fisheries, from rare and iconic species such as turtles, whales and seabirds, to abundant non-commercial species (Northridge 1984; Gilman 2011). The rarer species can be threatened by fisheries even if the target species are being managed sustainably (e.g. Tuck et al., 2001; Rivalan et al., 2010; Carruthers and Neis, 2011). The most severe bycatch problems arise when fisheries interact with species having both low fecundity and restricted geographic range. For example, the vaquita (*Phocoena sinus*) in the northern Gulf of California is critically endangered, in part due to mortality in gillnets (Rojas-Bracho and Taylor, 1999; Morzaria-Luna et al., 2013).

As a result, there is considerable conflict in pelagic fisheries around bycatch (e.g. Baum et al., 2003; Cullis-Suzuki and Pauly, 2010; Gilman, 2011); particularly when charismatic species are involved (e.g. Perrin, 1968; Mannocci et al., 2012). Sharks are frequently taken as bycatch in pelagic fisheries (Baum et al. 2003; Gilman 2011) and are recognized internationally as threatened: 62% of shark species face a major conservation threat and of these 67% are reported as bycatch (Molina and Cooke, 2012). At least 20 odontocete species are captured in longline fisheries, causing major conservation conflicts and impacting the profitability of the fisheries through depredation and restrictive management measures (Hamer et al. 2012). Bycatch is the biggest threat to seabirds at sea, with 41% of threatened species impacted (Croxall et al., 2012). Pelagic fisheries are responsible for the annual death of ~200,000 seabirds worldwide in longline fisheries (Anderson et al., 2011) and a yet unknown, but suspected similar order of magnitude of deaths (mostly procellariforms) in trawl fisheries (Watkins et al., 2008). Gillnet (also called driftnet) fisheries historically caused the death of millions of seabirds through entanglement and drowning until they were banned in international waters in 1991 (U.N. Resolution 46/215). Gillnets are still authorized in many territorial waters and, although comprehensive global figures are lacking, are estimated to be responsible for the annual death of at least 400,000 diving seabirds from many different taxa (Artyukhin and Burkanov, 2000, Žydelis et al., 2013).

The bycatch of commercially valuable species also results in a conflict, in that these fishes are then unavailable to different fisheries that target them (Armsworth et al., 2011). The total discards of commercial species is estimated at 7.3 million tonnes/year, or 8% of global catch (Kelleher, 2005). Recruitment overfishing is a common problem, since many commercial species are taken as bycatch at juvenile stages (Hall et al., 2000). In western Pacific Ocean skipjack tuna purse-seine fisheries, juvenile bigeye tuna are taken as bycatch, reducing the stock of bigeye available at larger body sizes to longline fisheries (Leroy et al., 2013). There are also instances in which bycatch of a very abundant species can disrupt the fishery for the target species. The increase of jellyfish in some ecosystems (Duarte et al., 2013) has lead to problems of excessive bycatch in purse-seine fisheries, resulting in major economic losses (Quinones et al. 2013). Resolving the bycatch problems with pelagic fisheries is critical for sustainability of fishing and conservation of threatened species.

Reducing bycatch may involve restrictions being placed on fishing activity, although such regulation is a particular challenge in the open ocean (Gilman, 2011; Ban et al., 2013). In many countries the adoption and enforcement of bycatch reduction measures is a low priority (Gonzalez-Carman et al., 2012) while in countries or regions where bycatch is regulated, fisheries may experience significant financial losses as a result of these management measures. Fisheries may be closed, seasons may be shortened, and marketable catch may have to be discarded by law (Hobday and Hartmann, 2006; Howell et al., 2008). In the United States, the annual cost of bycatch management is US$ 34–453 million for closures, US$ 427 million for regulatory discards, US$ 4.2 billion in lost seafood sales, and US$ 1.5 billion in income (Patrick and Benaka, 2013). While there may be net benefits to managing bycatch, the costs are not borne equally by all players, so finding mutually acceptable solutions can be complex.

Bycatch can be managed by deterrents, gear and fishing technique modifications, and area or time closures (Table 1). Gear modification, for example, reduces the selectivity of the fishing gear for the bycatch species, and represents the majority of bycatch reduction efforts for pelagic fisheries (Gilman, 2011). Area closures and time restrictions have received less attention (Molina and Cooke, 2012). In most cases, providing fishermen with training in new methods, or the use of new bycatch mitigation technologies, is critical to their success (Bratten and Hall, 1997).

While new innovations in bycatch mitigation are important, a great deal of progress could be made simply by using existing techniques and gears known to reduce bycatch. The best approaches to managing bycatch may be determined by the nature of the bycatch and the way it is taken in a fishery, based on space, time, predictability, association with target species, and whether

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[2] Bycatch is defined here as that part of the fisheries catch that is discarded at sea, dead, or injured to an extent that death is the result (Hall, 1996).

Table 1
Summary of bycatch mitigation approaches used with pelagic fisheries to reduce conflicts with a range of species.

Bycatch mitigation	Approach
Reduce attraction to fishing boats	• Discharge management (offal and discards) has been regulated in a range of fisheries to reduce attractivity. • Seabirds and longliners: options include night setting, line protection, line weighting, underwater setting devices, line shooters, bait throwers, side setting, blue-dyed bait or olfactory deterrents (Løkkeborg 2011). • Seabirds and trawlers: options involve warp cable protection (bird scaring lines, bird bafflers) and net protection (net binding) or modification (mesh size) (Bull 2009).
Deterrents	• Sharks: e.g. lanthanide electropositive metals or magnets that could theoretically irritate the electrical sense of elasmobranchs. • Odontocetes:e.g. acoustical devices that produce unpleasant sounds (Kraus et al. 1997). Longline bycatch of odontocetes can be mitigated by acoustic or mechanical deterrents (Hamer et al. 2012). • Seabirds: primarily based on devices that scare birds away from active fishing gear, such as tori poles or water spray (Gilman 2011).
Gear modifications	• Longline bycatch of sea turtles: switching from J hooks to circle hooks has the advantage of reduced gut-hooking and higher rates of live releases (Gilman 2011), and setting at greater depths http://bmis.wcpfc.int/ • Longline bycatch of sharks: switching from wire to nylon leader material results in many sharks cutting through the leader and 'self-releasing'. However, since circle hooks tend to hook at the corner of the jaw and thus protect leaders from the teeth, self-releasing with nylon leaders is not effective when using circle hooks (Afonso et al. 2012). • Trawl fisheries: sorting grids can exclude organisms according to size (Larsen and Isaksen 1993), while turtle excluder devices can reduce sea turtle bycatch (Magnuson et al. 1990). • Purse-seine fisheries: species selection by size using sorting grids has been successful for some species, but resulted in high mortality for others (Misund and Beltestad 2000). Various changes to purse-seine nets to reduce dolphin bycatch, notably the Medina Panel, an area of fine mesh that prevents entanglement in the region where dolphins contact the seine (Barham et al. 1977). • Seabirds and gillnet fisheries: e.g. dying nets to increase visibility to birds, acoustic alerts, or setting nets at greater depths (Løkkeborg 2011).
Area closures, time restrictions and moratoria	• Modeling studies seek to predict the distributions of key species in the dynamic marine environment and then manage access to these regions (Hobday and Hartmann 2006; Howell et al. 2008; Žydelis et al. 2013).

fishers can control the take (Hall, 1996). The structure of incentives that are produced by the interaction of market forces, regulations, and at-sea conditions is also important in determining bycatch outcomes. Effective incentives for bycatch reduction include measures such as individual vessel by-catch limits (Gosliner, 1999), and fleet-wide limits (Dunn et al., 2013). Creating the right incentive structures will focus the creativity and ingenuity of fishermen to develop solutions (Hall et al., 2000). In some cases, bycatch reduction can be substantial, as was observed with changed tuna fishing methods on dolphin schools in the eastern Pacific (Hall et al., 2000). In South Africa and Chile, seabird bycatch reductions of 80% were obtained in pelagic longline and trawl fisheries with simple cost-effective mitigation measures (Croxall et al., 2012). In hook fisheries such as longlining, a hook taken by a bycatch species is a hook that is unavailable to a target species. Therefore, measures to reduce bycatch can have positive impacts on target catch and profitability (Gandini and Frere, 2012).

2.2.1. Knowledge gaps for bycatch—reducing the conflict in the face of climate change

Effective management of bycatch in the face of climate change will require a combination of approaches (Hamer et al., 2012). Bycatch of highly migratory species must be managed across national and international waters. Therefore, knowledge of the migratory behaviors and habitats of such species are critical (Gonzalez-Carman et al., 2012) and they are also expected to respond to climate-related changes in the ocean environment (Hobday, 2010; Hartog et al., 2011; Hazen et al. 2013). Survival and health of live-released bycatch is a key area of research that has been the subject of only a few studies (e.g. Carruthers et al., 2009), and survival in warmer and/or less oxygenated waters may become more problematic. Effective use of time-area closures and other spatial-temporal effort modifications requires large amounts of biological knowledge about the species of interest, which is not always available (Table 1). The habitat distribution of target and bycatch species may change in future, thus, ongoing tagging studies will be important when building species distribution models that underpin habitat identification and spatial measures for bycatch reduction (Hobday et al., 2010; Hazen et al., 2013; Abecassis et al. 2013). Establishing predictability of bycatch interactions is a critical research area (Hall et al., 2000), and the impact of climate change in areas where these interactions are expected to increase deserves more attention (Hartog et al., 2011).

2.3. Ecosystem allocation to higher trophic levels: the case of seabirds

Human consumption of mid-trophic level fishes can result in the shortage of food for higher trophic level groups such as whales, seabirds and large pelagic fishes (Gislason et al., 2000). We consider this challenge with a focus on seabirds. Seabirds are the most threatened birds globally, with 5% critically endangered, 9% endangered, 15% vulnerable and an additional 11% near-threatened (Croxall et al., 2012). Because of their aerial and/or terrestrial life phases, seabirds are often overlooked as being an integral part of the marine environment. Nevertheless, seabirds play a major role as top predators, with estimates of annual consumption of marine organisms equivalent to that caught by fisheries, i.e. around 100 million tons (Brooke, 2004, Karpouzi et al., 2007). In addition to being unwanted as bycatch (Section 2.2), seabirds have an important indirect interaction with pelagic fisheries through competition for target species, particularly forage-fish such as sardine and anchovy. Thus, a conflict between fish for fisherman and fish for the birds arises (Cury et al., 2011); a conflict that is generalizable to other top predators 'competing' with fisheries for fish (e.g. Goldsworthy et al. (2001); Morissette et al. (2012)).

'Overfishing' is estimated to impact food availability for 10% of threatened seabird species (Croxall et al., 2012). Such a figure is probably conservative since it is difficult to detect or measure the level of prey competition - birds may respond more slowly to the

Table 2
Globally threatened and near-threatened seabird species affected by prey competition with a pelagic fishery (not exclusive from other threats). Data were retrieved from the IUCN Red List of Threatened Species (IUCN, 2012) by refining the search for birds in the threat category 'fishing and harvesting aquatic resources'. A score of the certainty of the competition has been included: 'good' means the competition has been identified, 'suspected' means it is probable but remains to be demonstrated and 'hypothesis' means that it is suspected but has not been studied. Species affected are either penguins (53%), or species belonging to the guild of 'coastal' seabirds. Almost all species in the table were also identified by the Red List as threatened by decreased marine productivity due to increased sea surface temperatures induced by climate change. Only two seabird species, the Red-legged Cormorant *Phalacrocorax gaimardi* (near-threatened) and the Bank Cormorant *Phalacrocorax neglectus* (endangered) were excluded because they are thought to compete with a benthic, rather than a pelagic fishery.

Species	Latin name	IUCN status	Competing fishery	Region	Confidence
Marbled Murrelet	*Brachyramphus marmoratus*	Endangered	Sardine	N.E. Pacific	Good
Red-legged Kittiwake	*Rissa brevirostris*	Vulnerable	Pollock	N. Pacific	Suspected
Elegant Tern	*Sterna elegans*	Near-Threatened	Anchovy, Sardine	E. Pacific	Hypothesis
Guanay Cormorant	*Phalacrocorax bougainvillii*	Near-Threatened	Anchovy	Humboldt	Good
Cape Cormorant	*Phalacrocorax capensis*	Endangered	Anchovy, Sardine	Benguela	Good
Socotra Cormorant	*Phalacrocorax nigrogularis*	Vulnerable	Anchovy, Sardine	N.W. Indian	Hypothesis
Peruvian Diving-Petrel	*Pelecanoides garnotii*	Endangered	Anchovy	Humboldt	Good
Cape Gannet	*Morus capensis*	Vulnerable	Anchovy, Sardine	Benguela	Good
Adelie Penguin	*Pygoscelis adeliae*	Near-Threatened	Krill, Finfish	Antarctic	Suspected
Magellanic Penguin	*Spheniscus magellanicus*	Near-Threatened	Anchovy	S. America	Hypothesis
Humboldt Penguin	*Spheniscus humboldti*	Vulnerable	Anchovy	Humboldt	Suspected
Macaroni Penguin	*Eudyptes chrysolophus*	Vulnerable	Krill	Sub-Antarctic	Suspected
N. Rockhopper Penguin	*Eudyptes moseleyi*	Endangered	Squid	Sub-Antarctic	Suspected
Fiordland Penguin	*Eudyptes pachyrhynchus*	Vulnerable	Squid	New Zealand	Suspected
Snares Penguin	*Eudyptes robustus*	Vulnerable	Squid	New Zealand	Suspected
Royal Penguin	*Eudyptes schlegeli*	Vulnerable	Krill	Sub-Antarctic	Hypothesis
African Penguin	*Spheniscus demersus*	Endangered	Anchovy, Sardine	Benguela	Good

fishing pressure (relative to bycatch responses) and it can take several years for a decline in prey to result in a measurable population drop in seabirds, making causation difficult (Furness, 2002). There are several cases where fisheries have contributed visibly to the decrease of threatened seabird populations through the depletion of their prey resource and a number of other situations where such competition is suspected (Table 2). For example, the decline in sardine abundance in central California, in part due to fishing pressure, corresponded with a decline in the Marbled Murrelet *Brachyramphus marmoratus*; which over the same time period, also shifted to lower trophic-level food items (Becker and Beissinger, 2006). In the Humboldt current, the Guanay Cormorant *Phalacrocorax bougainvillii* population crashed from ca. 15 million to ca. 2.5 million individuals after 1965—a level at which it remains today—in part due to overharvesting of anchoveta (Crawford and Jahncke, 1999). Even when a seabird species is not threatened globally, it is possible to observe the detrimental effects of fisheries on local populations. For example, the Atlantic Puffin *Fratercula arctica* declined in Norway in the 1980s due to repeated reproductive failures following the stock collapse of the herring in the late 1960s (Anker-Nilssen and Wiggo Røstad, 1993) and in the North Sea, the Black-legged Kittiwake *Rissa tridactyla* decreased after 1990 partly because its breeding success is very sensitive to the effect of sandeel (*Ammodytes marinus*) fisheries (Frederiksen et al., 2004).

A solution to this conflict has been proposed via the ecosystem approach to fishing (Gislason et al., 2000), which recognizes the prey needs of other elements in the marine system, particularly high trophic level non-target species such as marine mammals and birds, sharks and reptiles. Determining prey allocations for seabirds has been based on time series of seabird breeding success and fish stock biomass to help indicate minimum densities of food required (Furness, 2007). It is now believed that fisheries need to maintain forage fish biomass above at least one-third of the maximum observed long-term biomass to sustain seabird productivity (Cury et al., 2011). Another proposed solution to the conflict is via establishment of spatial fishery closures in critical breeding or foraging areas (e.g. Lascelles et al., 2012). Typically, such areas are delimited using at-sea surveys or satellite tracking data. Although very large closed areas can considerably improve seabird breeding success (Daunt et al., 2008), the efficiency of smaller reserves surrounding breeding colonies is still under debate (e.g. Pichegru et al., 2010, Coetzee, 2010, Ryan et al., 2010, Butterworth et al., 2010).

Adequate adult and juvenile survival outside the breeding season is just as important as good reproductive success during the breeding season (e.g. Sherley et al., 2013). Therefore, although small closed areas may, in some specific cases, increase breeding success through enhanced prey availability inside foraging grounds adjacent to colonies, solutions which involve closed areas and appropriate spatial and temporal management of fisheries and new quotas at the regional scale are likely to be more effective. For example, the Benguela region is a biological hotspot because it supports large numbers of seabird species year round. However, it is unlikely to be made a closed area, despite hosting three endemic threatened seabird species (the Cape Cormorant *Phalacrocorax capensis*, the Cape Gannet *Morus capensis* and the African Penguin *Spheniscus demersus*) which have been declining since the sardine fishery collapsed in the 1960s (Crawford, 2007). Management of this region's purse-seine fishery will therefore necessitate accounting for the needs of seabird species which breed at different times of year and in different areas along the coast and have contrasting foraging ranges and dispersal capabilities. Research to determine the appropriate combination of management actions that reduce such conflicts are needed for many regions around the world.

2.3.1. *Knowledge gaps for ecosystem allocations—reducing the conflict in the face of climate change*

Climate change adds an additional layer of complication to resolving the conflict for fish. In the North Sea, breeding success of the Black-legged Kittiwake *Rissa tridactyla* is lower in years preceded by warmer sea surface temperatures and even lower with the additional effect of sandeel fishing (Frederiksen et al., 2004). Ocean warming increases stratification of water masses, decreasing advection of nutrients from cold bottom waters to the photic zone. The consequences are well known for the guano seabirds of the Humboldt Current, which naturally incur high mortality during El Niño events. However, the respective effects of overfishing and climate change on forage fish are difficult to separate: severe crashes in guano bird populations have only been apparent since fishing activities intensified in the Humboldt region (Tasker et al., 2000). This is because overfishing leads to changes in the way the exploited population responds to environmental fluctuations. This is particularly apparent in the Benguela example, where the combined effects of environmental forcing and fishing have modified the food web and possibly even fish distribution, with detrimental effects on seabirds (Young et al., 2014). As with bycatch species, shifts in seabird foraging regions, changes in fish distribution and phenology (Durant et al., 2007), and foodweb changes all complicate management because of their cumulative impacts and remain as critical knowledge gaps. Given this complexity, early warning systems for changes in hydrography (e.g. indicators of ocean productivity) and in food web structure (e.g. indicators of feeding level—Young et al., 2014) are crucial instruments to support future management decisions. Until we have a better understanding of the interaction between climate change, seabirds and fisheries, the rule of the precautionary principle should apply. In some cases, by local closure of fisheries or a reduction in fishing quotas, managers may enhance the resilience of seabirds and other top predators in the ecosystems to climate change.

2.4. *Local economies—food and livelihoods*

Many local economies, in both developing and developed countries, rely on pelagic species for a portion of their seafood needs. From the point of view of local economies and societies, pelagic fishes can have different importance across a range of uses (Fig. 1). In many local coastal economies, these valuable ecosystems services support societal needs, including jobs, food, recreational opportunities, health benefits, and cultural heritages and generate regionally significant economic output (Kildow et al., 2009). In such local communities pelagic fishing is often driven by a combination of local and extra-regional pressures—namely provision of fishing products to local and global markets—which affect local ecosystems, which then influence catches in a feedback cycle. Uncertainty regarding the rate and magnitude of change in these resources attributable to climate change is considered a major limitation to assessing potential socio-economic impacts. The synergistic, antagonistic, or cumulative impacts that result are also uncertain (Griffis and Howard, 2013).

In providing broad ecosystem services, fisheries for pelagic species involves management trade-offs between environment, social, and economic objectives, such as maximizing biodiversity protection, employment or economic value. The extraction of food for human consumption does change the environment. How significant those costs are for broader ecosystem services, how they are viewed by different stakeholders, and how to minimize them seems to vary substantially among different regional or local economies. While some societies rate conserving biodiversity as a priority, others are facing the challenge of conserving human populations. Human rights issues and fishing rights can intersect on livelihoods and economies (Gasalla, 2011, United Nations, 2012). In terms of allocations, international agreements may also complicate the resolution of trade-offs at local levels: quota issues may be resolved at the level of Regional Fisheries Management Organizations, without reference to local management systems and needs.

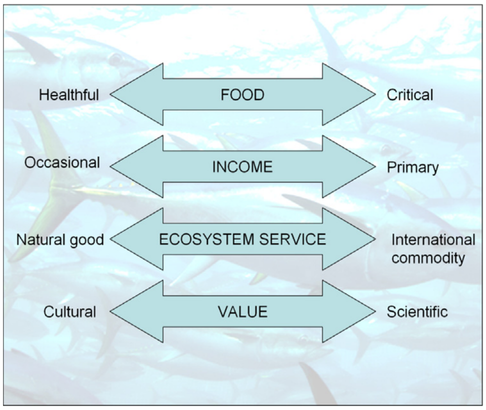

Fig. 1. Fish from the open ocean can have different importance across a range of uses for local economies and societies, ranging from (i) a source of costly but healthy food to a unique source of food; (ii) a primary source of income to an occasional employment alternative; (iii) a natural good and heritage to an international market commodity; and (vi) an important part of the culture to a scientific research subject (based on Gasalla 2009).

The trend towards allocation of property rights to fish, through instruments such as individual-based quotas, may also be in conflict with the systems in place in local economies. Particularly in developing countries, management where it exists, tends to be based on input controls (e.g. regulation of fishing effort) in attempts to maximize fisheries benefits. The trade-offs in regulating effort are difficult as maximum fishery yield typically comes at an intermediate fishing effort—yet employment benefits (jobs) often increases with effort, and ecosystem preservation is maximized when effort is minimal (Brander, 2010a). Where fishing is not for subsistence, economic overfishing can occur at lower exploitation rates than those associated with yield overfishing for some species. This may be an advantage with regard to resolving trade-offs as fishing for maximum profit requires less fishing pressure than is permitted under traditional management objectives like MSY and hence overlaps with biological conservation objectives.

Thus, in terms of management the most important gaps in local economies are agreement on a set of broader objectives, and ensuring compliance with measures for keeping fishing mortality rates low enough to prevent ecosystem-wide overfishing, reducing or eliminating by-catch and avoiding destructive fishing methods, while still sustainably providing other ecosystem services (food and employment). These goals are objectives under ecosystem-based fisheries management, which also considers trophic interactions and habitat issues (Hilborn, 2011) (Section 2.3). While robust models of the trophic interactions are more often applied in highly managed ecosystems, area-based management approaches are being trialed in developing economies and complement effort-based management efforts in local economies (Hilborn, 2011). In many regions there is also a trend of decreasing reliance on local fish as a food source as people shift from a subsistence-oriented economy to a cash economy (Levine and Allen, 2009). This raises a number of issues, as discussed in the next section.

2.4.1. *Knowledge gaps for local economies—reducing conflict in the face of climate change*

From the perspective of local economies, the need for reliable information is the most challenging knowledge gap. For instance, most local economies in developing nations lack basic data on the pelagic species and fisheries and reliable statistics upon which stock size estimates may be based. The changing climate will exacerbate this problem as shifts in the distributions of species occur. Vessel monitoring systems and electronic catch reporting may also be useful in generating reliable catch statistics in these regions (Weng et al., 2015). At higher levels, regional management plans often lack the market data, value chain information, and socioeconomic indicators that can inform decision-making (Gasalla et al., 2010). A second important gap is the understanding of the organization of markets that value fish products and sustainability. In Brazil, for example, some fair trade programs based on concepts of social-ecological justice (NCSE, 2011) have begun to engage coastal fisheries (Gasalla, 2011) but this has not yet occurred for those involved in pelagic offshore fishing which is a large-scale industrial activity for this region.

As economic opportunities arise and fishers move from subsistence- to trade-fisheries, incentives are needed to underpin sustainable exploitation. One increasingly popular market-based instrument for ecological stewardship is the use of certification and eco-labeling programs to highlight sustainable fisheries with low environmental impacts (Gutierrez et al., 2011). Ecolabelling certification can provide access to premium markets for seafood products and has resulted in environmental benefits for various fisheries, from promoting vessel monitoring systems providing accurate electronic environmental footprints to the adoption of fishing gear with better selectivity and bycatch reduction (Kaiser and Edward-Jones, 2006). Certification processes have refocused the behavior and attitudes of fishermen and in some cases, has delivered conservation benefits more effectively than formal non-participatory legislation (Kaiser and Hill, 2010). With respect to oceanic fisheries and the cost of eco-labeling, certification of large fisheries appear to be much more cost-effective than small fisheries (Hilborn and Cowan, 2010), thus, involvement in such schemes remains a challenge for developing economies and small-scale fisheries. Appropriate market-based instruments are currently lacking for smaller operations.

Shifts in the abundance and distribution of species as a result of climate change means that local consumers and fishing communities will need to adapt to new species and the dwindling presence of traditional species (Cheung et al., 2013). Climate change and population growth will have compounding effects on livelihoods, markets, and consumption patterns, and place increased pressure on coping strategies and social protection measures. This additional stress means that local economies will have great difficulty in eliminating overfishing of the main species, reducing bycatch and habitat impacts, and protecting endangered or charismatic species without firmer policy guidance regarding the social objectives of fisheries. Resources will be required to aid this adaptation, particularly in tropical countries, and solutions must take account of environment, social and economic needs.

3. Synthesis—resolving the conflicts and the influence of climate change

A range of solutions for each of these conflicts with pelagic fisheries have been proposed (Table 3), although tools and approaches to further investigate the nature of each conflict can still be improved. Options to resolve some of the conflicts have been implemented in a range of locations, as demonstrated in the previous sections, yet could be more widely employed. Advances in observing tools, such as electronic tags, vessel monitoring and satellite products can all help to reduce the bycatch conflict. For example, habitat maps that show expected distribution of pelagic species have helped reduce bycatch by separating fishing effort from locations where bycatch species are abundant (Howell et al., 2008; Hobday et al., 2010; Abecassis et al. 2013). Willingness of fishery managers to use dynamic spatial management has reduced the areal restrictions for fishers (Hobday and Hartmann, 2006), one of the main arguments against spatial closures (i.e. they are too big). Novel technologies, including the instrumentation of FADs used by industrial fishing vessels may also provide additional information on species composition in different regions and provide a way to reduce the overlap between target and bycatch species (Dagorn et al., 2013). Unfortunately, solutions to one of the conflicts may work against a solution for another—for example, spatial closures might lead to reduced bycatch and increased availability of prey for seabirds, but result in decreased harvests for food security and local livelihoods (Sibert et al., 2012; Dueri and Maury, 2013). Integrated end-to-end models are needed to fully explore these trade-offs (Fulton et al., 2011). Low impact fishing options that have reduced bycatch and still provide for incomes and food do exist—pole and line fishing is a more benign way of catching tuna—but such methods may not be economically viable or provide the volumes of fish needed.

The examples presented here show that even where climate change may not make the conflicts any worse, climate change brings additional uncertainty to the solutions that exist (Table 3). For example, as species redistribute in response to climate change, new fishery interactions will occur. There is also an emerging conflict between maximizing yield of target species and maintaining ecosystem structure/function (Allain et al., 2012). As the yield of target species increases, the species composition, size structure, temporal dynamics of the ecosystem can change with subsequent impacts on protected species, food security, and local economies, in similar ways to those described in the case studies. This conflict might be addressed by an overarching system-wide balanced harvesting approach for optimum yield (Zhou et al., 2010) or by multispecies maximum yields. Both approaches will also likely be sensitive to climate change, which should be considered as for our selected case studies. Thus across all the conflicts, there is a need for ongoing data collection on the physical environment, the spatial and temporal location of species, and their feeding habits (Hobday et al., 2013; Salinger and Hobday, 2013). These data can then be used in habitat models that combine real time or forecasted ocean conditions to inform dynamic ocean management (Hobday et al., 2014).

Given this complexity and the spatial and temporal scale of these pelagic fishery conflicts, two approaches are warranted—

Table 3
A summary of resolutions to pelagic fishery conflicts and the impacts of climate change.

Conflict	Current conflict resolution	Impact of climate change	Proposed action under climate change
Food security	Management measures and policies to increase access to tuna for national food security that have minimal effects on efficiency of industrial fishing operations.	Greater uncertainty in distribution of tuna, and changes in the local catchability of tuna	Robust, no regrets strategies that empower local communities and strengthen national economies
Bycatch	A range of approaches exist to reduce bycatch (Table 1)	Greater uncertainty in distribution of the interactions	Ongoing monitoring and development of dynamic habitat models that update distribution and potential areas of interaction
Allocation to other top predators (e.g. seabirds)	A combination of approaches including accounting for ecosystem components when undertaking quota setting and providing for spatial closures in areas where feeding could be disrupted.	Greater uncertainty in distribution of the interactions and quality of the prey for seabirds	Use of indicators to provide early warning of system changes, use of precautionary principle when accounting for needs of top predators.
Local economies	Spatial segregation of industrial-scale pelagic fisheries to ensure higher catch rates for local people, make formal resource allocation to local communities, increase recognition of the value of pelagic species in local economies	Changing species mix for local uses, changing distributions and unknown impacts on catch shares	Generate up to date and reliable catch information, more support for communities encountering changes in the availability of species for harvest.

early warning systems and precautionary management to preserve future options (Salinger et al., 2013). Early warning systems can support management decisions where the indicator has been linked to a desirable or undesirable outcome. These early warning systems are likely to be based on indicator habitat metrics and species. Collection of some indicators can only happen through coordinated data collection programs – challenging given the size of the open ocean (Nicol et al., 2013). Thus, studies of marine ecosystem responses, and models of multispecies interactions and ecosystem models with fisheries and people included (Brander, 2010b; Fulton et al., 2011; Hobday et al., 2013), will be needed to contextualize the behavior of the indicators, and test the potential of different management strategies to meet multiple objectives (e.g. Dichmont et al., 2013). Until we have a better understanding of the interaction between climate change, fisheries, bycatch, seabirds, and people (including population growth pressures), the precautionary principle should be considered in management actions aimed at reducing these conflicts.

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