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Performance of regional fisheries management organizations: ecosystem-based governance of bycatch and discards

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Abstract

A performance assessment was conducted of regional fisheries management organizations' (RFMOs') bycatch governance, one element of an ecosystem approach to fisheries management. Obtaining a mean score of 25%, with a 64% CV, collectively the RFMOs have large governance deficits. Individually, there has been mixed progress, with some RFMOs having made substantial progress for some governance elements. There has been nominal progress in gradually transitioning to ecosystem-based fisheries management: controls largely do not account for broad or multispecies effects of fishing, and cross-sectoral marine spatial planning is limited. Regional observers collect half of minimum information needed to assess the efficacy of bycatch measures. Over two-thirds of RFMO-managed fisheries lack regional observer coverage. International exchange of observers occurs in one-third of programmes. There is no open access to research-grade regional observer data. Ecological risk assessments focus on effects of bycatch removals on vulnerable species groups and effects of fishing on vulnerable benthic marine ecosystems. RFMOs largely do not assess or manage cryptic, generally undetectable sources of fishing mortality. Binding measures address about one-third of bycatch problems. Eighty per cent of measures lack explicit performance standards against which to assess efficacy. Measures are piecemeal, developed without considering potential conflicts across vulnerable groups. RFMOs employ 60% of surveillance methods required to assess compliance. A lack of transparency and limited reporting of inspection effort, identified infractions, enforcement actions and outcomes further limits the ability to assess compliance. Augmented harmonization could help to fill identified deficits.

Keywords bycatch, discards, ecosystem-based fisheries management, performance assessment, RFMO

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Introduction

Marine capture fisheries are a major contribution to food security and livelihoods, particularly in developing countries. They supply some of the most valuable globally traded commodities and, if good governance practices are employed, have a higher capacity to contribute to sustainably meeting growing human demand for animal protein than terrestrial sources (Godfray *et al.* 2010; Pereira *et al.* 2010; Pelletier *et al.* 2011; FAO 2012). An integral component of implementing the ecosystem approach to fisheries, to avoid adverse ecological and socioeconomic consequences, it is necessary to effectively govern all sources of fishing mortality, including from retained target catch, retained and discarded catch of non-targeted species, and cryptic, unobservable mortalities (United Nations 1982, 1995; FAO 1995, 2003, 2011a; Hall *et al.* 2000; Gilman 2011; Gilman *et al.* 2012a).

Regional fisheries management organizations (RFMOs) are intergovernmental regional fishery bodies or arrangements with the competence to establish binding conservation and management measures. RFMOs provide a formal mechanism for fishing States and States in whose jurisdiction common-property fishery resources managed by an RFMO occur to meet their international obligation to cooperate to sustainably govern shared living marine resources throughout their distributions so as to provide for compatible measures in areas within and beyond national jurisdictions (United Nations 1982 [Articles 63, 66(5), 118]; FAO 1995 [Articles 7.1.5, 6.12], 2009b [Article 4 (1)(b)]). RFMOs have played a critical role in multilateral fisheries governance of stocks that straddle or occur beyond national jurisdiction and of highly migratory stocks since the first was established in 1923. While spatial, fishery and taxonomic gaps remain, a large proportion of global marine fisheries are now managed by one or multiple RFMOs, and most areas of the high seas are now covered by at least one RFMO (Lodge *et al.* 2007; FAO 2011c). Relative to coastal ecosystems, high seas ecosystems are still generally pristine (Jackson *et al.* 2001; Halpern *et al.* 2008). However, reported landings from the high seas have been accelerating since the mid-20th century, increasing from under two million tonnes in the 1950s to over ten million tonnes in 2008 (FAO 2010a). As RFMO areas are primarily on the high seas, there is still an opportunity for RFMOs to provide for sustainable fishing operations in high seas ecosystems.

Legal instruments establishing international responsibility to conserve associated and dependent species are relatively recent, first becoming an obligation under the 1982 Law of the Sea Convention, and elaborated further in subsequent instruments and guidance from multilateral organizations (United Nations 1982 [Article 119], 1995 [Article 5(f), Article 10(d), and Annex 1]; FAO 1995, 1999a,b, 2011a,d; CBD 2010). These new instruments and international guidance broadened the mandate of pre-existing RFMOs. There has been increasing recognition of the need for RFMOs to improve their governance of fisheries and conservation and management of fishery resources, including for older RFMOs by expanding their mandates from a target species focus to meet broadened expectations for ecosystem-based management and application of a precautionary approach. This has included calls for establishing explicit limits of acceptable impact on fish and non-fish bycatch species, including associated or dependent species and threatened species, as well as calls for performance reviews of RFMO effectiveness

(United Nations 2006a,b; FAO 2005; Fisheries Agency of Japan 2007; Lodge *et al.* 2007).

Defining bycatch and its components

While used inconsistently, the term bycatch can be defined as being comprised of: (i) the retained catch of non-targeted but commercially valuable species, referred to as 'incidental catch' or 'by-product', which may be landed/transshipped or otherwise consumed by crew, used for bait, or rejected at port; (ii) discards mortality, whether the reason for discarding is economic or regulatory, or results from vessel and gear characteristics; plus (iii) cryptic, generally unobservable mortalities, which are sources of fishing mortality that do not facilitate direct observation and are relatively difficult or impossible to estimate in a commercial setting (Alverson *et al.* 1994; Hall *et al.* 2000; ICES 2005; Broadhurst *et al.* 2006; FAO 2011a; Gilman 2011; Gilman *et al.* 2012a).

Due to inconsistent use, the term bycatch has resulted in confusion. The species, sizes and sexes that are targeted, secondary targets, incidental catch or discards can be highly variable temporally, spatially, within a fleet and by individual vessels in a fleet due to several complex factors (e.g. Gilman *et al.* 2008a; Hall *et al.* 2000). This can cause uncertainty in what the term bycatch is intended to signify. Confusion has also resulted because bycatch has been used synonymously with fishing mortality of protected, endangered and threatened species or with dead discards. Effective fisheries governance requires mechanisms to ensure the ecological and socioeconomic sustainability of total fishing mortality, regardless of the terminology and definitions employed to describe the various components.

From 1992 to 2001, an average of 7.3 million tonnes of fish were annually discarded, representing 8% of the world catch (Kelleher 2005). There have been substantial reductions in discard levels in recent years, in part, due to increased retention as a result of the development of food and non-food markets for previously discarded species and sizes, but also from increased gear selectivity reducing catch rates of unwanted catch (Kelleher 2005; FAO 2012). Fishers may discard catch due to market considerations, such as discarding species and sizes lacking markets, with no or relatively low value, damaged catch with low or no value, and species that can damage the rest of the catch during storage. Another reason for discarding is high-grading, discarding lower-value catch to make room in the hold for higher-value catch, when room in the hold is a limiting factor, and the perceived difference in net value between discards and retained catch is greater than the cost to replace the discard (Arnason 1994; Alverson *et al.* 1994; Hall 1996; Kelleher 2005). Quality, including catch that is unfit for human consumption due to spoilage or toxicity, provides another reason to discard part of the catch. Catch may need to be discarded during the final set of a trip if there is insufficient room to retain all the catch from that set (e.g. IOTC 2009).

Furthermore, output controls can create incentives for discarding. Quota-induced high-grading occurs when a vessel reaches a species-based quota and discards lower-value grades to enable retaining higher-value grades. Over quota discarding occurs in multispecies fisheries when a quota for one species is reached, but quotas for other species are not in place or have not been reached, and the vessel discards additional catch of the species for which the quota has been reached. Discarding sublegal individuals can occur to comply with measures for species-based minimum landing sizes. Discarding may be conducted to meet prescribed catch composition (measures setting limits on the percentage catch composition by species). And, discarding may be conducted to comply with restrictions on retention by sex, such as in some crab fisheries (Arnason 1994; Alverson *et al.* 1994; Hall 1996; Poos *et al.* 2010). Efficacy of discard bans may require broad fishing industry support, flexibility in output controls, and extensive resources for surveillance and enforcement (Crowder and Murawski 1998; Hall *et al.* 2000; Poos *et al.* 2010). In some fisheries, provisions for over-catch, quota substitution, species-based quotas by grades, and deemed value, which reduce revenue to fishers for species/sizes subject to a discard ban, have effectively reduced incentives to discard and increased incentives to reduce catch rates of organisms subject to full retention (Arnason 1994; Peacey 2003; Hall and Mainprize 2005; Iceland Ministry of Fisheries 2011).

Cryptic, unobservable fishing removals, used here to refer collectively to (i) pre-catch losses; (ii) mortalities from ghost fishing; (iii) post-release losses; (iv) indirect, collateral sources of mortality; and (v) mortalities from synergistic and cumulative effects of fishery interactions, are not routinely accounted for in fisheries management due to a lack of adequate data and, for some components, a lack of methods to provide accurate estimates (Gilman *et al.* 2012a). International guidance promotes quantifying and reducing impacts of cryptic mortality, but does not identify best practice methods to estimate cryptic losses (FAO 2011a). Cryptic mortalities can lead to adverse ecological impacts and are a source of wastage, and errors result when stock assessments and population models do not account for cryptic fishing mortality (Broadhurst *et al.* 2006). Pre-catch losses occur when organisms are caught, or collide with the vessel or gear, and die but are not landed onboard, such as when, prior to gear retrieval, catch falls from the gear, crew intentionally release the catch, and predators remove dead catch (Gilman *et al.* 2005; Broadhurst *et al.* 2006; FAO 2011a,b). And organisms may escape from the gear alive but die later (Gilman *et al.* 2005; Suuronen 2005; Broadhurst *et al.* 2006). Post-release mortality occurs when catch is retrieved and released alive but stressed and injured to a degree that causes it to die later (ICES 2005; Gilman *et al.* 2006, 2007a, 2008a; Gilman 2011). Ghost fishing occurs when lost, abandoned and discarded derelict fishing gear continues to catch and kill organisms, problematic primarily with passive fishing gear that becomes derelict after being set (ICES 2005; FAO 2010a, 2011a).

Cryptic mortality sources from collateral effects of fishing operations are indirectly caused by various ecological effects of fishing (ICES 2005; Broadhurst *et al.* 2006). Collateral mortality can result, for instance, from the stress or injuries an organism incurs from avoiding fishing gear (ICES 2005; Broadhurst *et al.* 2006). Loss and degradation of habitat from fishing cause collateral effects (Goñi 1998; Broadhurst *et al.* 2006; Kaiser *et al.* 2006). Collateral effects result from the disposal at sea of offal (processed fish), spent bait and dead catch, which can change foraging behaviour, diet and competition amongst species; community composition; and the distribution of biomass within and between ecosystems, including causing localized hypoxia or anoxia of the seabed (Hall 1996; Hall *et al.* 2000; Gilman *et al.* 2012a). Cryptic mortalities often occur as a consequence of synergistic and cumulative sublethal stressors from fishing operations. Cumulative stress and injury from multiple sublethal fishing interactions, including, for example, when an organism repeatedly avoids capture or is repeatedly caught and released alive, may eventually lead to mortality. Synergistic, interacting effects of multiple fishery stressors can also result in cryptic losses (Broadhurst *et al.* 2006; Gilman *et al.* 2012a).

Aim and objectives of governing bycatch

The socioeconomic sustainability of marine capture fisheries is unequivocally linked to the ecological sustainability of marine ecosystems' processes and structure. Hence, the management of marine capture fisheries via an ecosystem approach has been prescribed in major international fisheries agreements for over three decades (CCAMLR 1982; FAO 2003). Fisheries management systems under an ecosystem approach should consider the sustainable multispecies production of stocks of market species, the effects of fishing on marine ecosystems, and the socioeconomic effects of marine resource management measures (Bianchi and Skjoldal 2008). An overarching aim of governing bycatch is to ensure that impacts do not increase ecosystem susceptibility to reaching tipping points that result in a regime shift, do not have a harmful impact across manifestations of marine biodiversity from genetic diversity to broad ecosystem-level structure and function, and do not compromise the ability to maintain the capacity for sustainable ecosystem services, including fisheries yields (Lawton 1999; Gislason *et al.* 2000; Link *et al.* 2002; FAO 2003; Pikitch *et al.* 2004). Main ecological objectives of governing bycatch include:

1. *Maintaining biomass and exploitation rates of incidental stocks of market species within ecosystem-level reference points*, predicted to sustainably produce maximum multispecies yields (Pace *et al.* 1999; Jackson *et al.* 2001; Pauly *et al.* 1998, 2002; Garcia and Grainger 2005; Beddington *et al.* 2007; FAO 2009a; Worm *et al.* 2009). Multispecies, ecosystem-level thresholds for exploitation rates and biomass of incidental market species could be based on ecosystem-level models and indicators and would provide the basis for ecosystem-level control measures.
2. *Mitigating the bycatch of species that are relatively vulnerable to unsustainable fisheries exploitation* due to their life-history characteristics and susceptibility to mortality in fisheries so as to avoid adversely affecting the viability of a population and allow rebuilding and recovery of endangered, threatened and overexploited units (e.g. CBD 2010; FAO 1999a,b, 2010b).

To achieve this, RFMOs need to monitor all sources of fishing mortality and mitigate problematic bycatch, which may be best achieved by augmenting fishing and gear selectivity (e.g. FAO 1999a,b, 2010b; Gilman 2011). While primarily species with a K-selected life-history strategy, endemics with restricted ranges and species with sporadic recruitment are vulnerable to fisheries overexploitation, even highly fecund species and those with broad distributions (common, generalist species) can be unsustainably exploited (Hall *et al.* 2000; Pauly *et al.* 2002; Gilman *et al.* 2011). Avoiding unsustainable bycatch fishing mortality of phylogenetically distinct species also requires attention in order to avoid changes and loss in marine biodiversity at higher taxonomic levels. Phylogenetically unique species lack or have few close taxonomic relatives and thus have relatively distinct genetic diversity that are of relatively high importance for the potential continuation of evolutionary processes (Diniz 2004; Redding and Mooers 2006; Isaac *et al.* 2007; Gilman *et al.* 2011). The loss of entire higher taxonomic groups and evolutionary lineages could alter the evolutionary processes of affected ecosystems (Redding and Mooers 2006; Isaac *et al.* 2007; Gilman *et al.* 2011). However, evolutionary histories are not available for all taxonomic groups, and there is no standardized way to compare the relative taxonomic distinctness of species from unrelated groups (Bininda-Emonds 2004; Isaac *et al.* 2007).

3. *Mitigating habitat degradation and loss* from fishing operations, including disturbances of sensitive ecosystems and sites of relatively high biodiversity value. Several studies have documented changes in benthic community structure and functions from habitat impacts from fishing gear, which may be irreversible or have very long recovery times (decades or longer) (e.g. Kaiser *et al.* 2006). For instance, pelagic fishing could be restricted within temporally and spatially well-defined sites of high biodiversity value, such as at shallow seamounts and at large-scale oceanographic features and short-lived hydrographic features, largely to avoid interactions with vulnerable species (Gilman *et al.* 2011, 2012b). Several RFMOs have adopted binding measures that include explicit definitions to identify benthic areas as Vulnerable Marine Ecosystems (e.g. seamounts, hydrothermal vents, cold water coral reefs and sponge fields) and restrict demersal fishing at these sites, in part, because they have low resistance and resilience to stressors (FAO 2009a; SEAFO 2009; CCAMLR 2010; NAFO 2010; NEAFC 2010).
4. *Avoiding adverse indirect, collateral effects of fishing operations*. Sources of adverse collateral effects of fishing operations are diverse, complex and relatively difficult to quantify, in part, because there is great uncertainty in inferring what factors were significant in actually causing cryptic mortalities and broad community- and ecosystem-level effects (ICES 2005; Broadhurst *et al.* 2006; Gilman *et al.* 2012a). A sample of examples are presented in the previous section, and Gilman *et al.* (2012a) provide a comprehensive review.

Socioeconomic objectives of bycatch governance include:

1. *Reducing waste* from discarded catch that is fit for human consumption or that is used as feed for aquaculture or animal industries, and from cryptic fishing mortality. International guidance on responsible fisheries promotes minimizing fisheries impacts on non-target species without a caveat regarding the consequent population-level effects (FAO 1995, 1999a). Hence, another objective of bycatch governance is to avoid and minimize discard and cryptic sources of mortality, irrespective of whether mortality levels are ecologically sustainable. Minimizing fisheries waste is mainly a socioeconomic issue, although developing markets for currently discarded catch with concomitant increased retention could reduce fishing mortality of overexploited stocks.
2. *Minimizing fishing mortality of flagship species*. Fishing mortality of flagship, charismatic species has elicited political support for interventions, again, not necessarily with an ecological basis (Caro *et al.* 2004; Gilman *et al.* 2011).
3. *Minimizing reductions in fishing communities' revenue and food security* from bycatch mortality, including by managing the allocation of fishery resources subject to bycatch through measures that meet scientific recommendations. Unsustainable levels of bycatch can have negative socioeconomic consequences for fishing communities, as bycatch is an important

income source and contribution to food supply in some fisheries and countries (Clucas 1997; Kelleher 2005; FAO 2009a). Furthermore, early closure of a fishery due to exceeding a bycatch quota results in unrealized economic gains. Overexploitation of commercially important incidental species, including bycatch of juveniles of a commercial species, can cause growth and recruitment overfishing, leading to a decline in future catch levels (Hall *et al.* 2000; Sumaila and Bailey 2011). This can also result in allocation issues between fisheries, for example, where bycatch, including discards, in one fishery can reduce catch levels and revenue in others (Sumaila and Bailey 2011). Bycatch of juveniles of economically valuable species is economically inefficient: if left to grow to maturity, they would produce higher yields and larger economic gains, but might supply different markets (FAO 2011a; Sumaila and Bailey 2011). Socioeconomic conflicts over the allocation of fishery resources that occur when reductions in exploitation rates are required can result in the adoption of RFMO control measures that deviate from rigorous scientific recommendations. This can prevent rebuilding and in some cases contribute to incentives for overcapacity, to the detriment of all sectors competing for the dwindling resource.

4. *Reducing economic and operational inefficiency* of catching and discarding unwanted species and sizes of catch. It is economically and operationally inefficient to catch and handle organisms that will subsequently be discarded (FAO 2011a). Related, cryptic losses are inefficient, for example, when market species die and fall from the gear or escape and later die due to stress and injury incurred during the fishing interaction (Gilman *et al.* 2012a).

Study scope

This study assessed fundamental elements of global marine RFMO performance in governing bycatch, including discards, which is one element of an ecosystem approach to fisheries management. Findings identify priority gaps and provide the first comprehensive baseline against which to track future progress. Findings enable RFMO Secretariats and Members to benefit from lessons learned by other RFMOs that are implementing current best practices, as well as from the identification of governance deficits to prioritize gradual improvements.

Previous studies evaluated aspects of RFMO performance; however, there are no previous comprehensive assessments of RFMO bycatch governance. FAO Fisheries Circular 1025 reviewed actions taken by regional fishery bodies, including RFMOs, to mitigate bycatch of selected taxonomic groups (sea turtles and seabirds) (Gilman *et al.* 2007b). Gilman (2011) assessed the five tuna-RFMOs' adoption of best practice gear technology methods to mitigate problematic bycatch, and critiqued onboard observer coverage rates and restrictions from data confidentiality rules. Small (2005) assessed the performance of six RFMOs against a criteria suite that included three bycatch-related criteria (commitment to reduce bycatch, bycatch data collection and bycatch mitigation measures). Cullis-Suzuik and Pauly (2010) assessed aspects of RFMO management, with one criterion that assessed the availability of information on bycatch, threatened species, habitats and trophic interactions (but did not assess the efficacy of governance of these parameters).

Several individual RFMOs have undergone performance reviews through assessment against their governing Conventions and relevant international agreements. These have included limited assessment of bycatch governance elements and few recommendations related to bycatch governance (NASCO 2005; CCAMLR 2008; CCSBT 2008a,b; NEAFC 2008; ICCAT 2009; IOTC 2009; NPAFC 2010; SEAFO 2010; GFCM 2011; NAFO 2011; RECOFI 2011). Under UNFSA, a set of recommended minimum criteria were produced for the assessment of RFMO performance, which includes several criteria related to governing bycatch, including criteria on the status and trends in associated and dependent species, adoption of measures for non-target species, adoption of measures to reduce discards and waste, and adoption of measures to reduce ghost fishing (United Nations 2007 [Annex II]). At the first joint meeting of the five tuna-RFMOs, there was agreement that RFMOs would undertake regular performance reviews employing the UNFSA standardized criteria suite (Fisheries Agency of Japan 2007 [Appendix 14]). Subsequently, five RFMOs have conducted self and independent performance reviews employing the joint tuna-RFMO/UNFSA minimum set of criteria (CCSBT 2008a,b; ICCAT 2009; IOTC 2009; GFCM 2011 [Appendix 1]; NAFO 2011 [Appendix II]).

Methods

A performance assessment of governance of bycatch, including discards, was conducted for 13 RFMOs (Table 1). Eight RFMOs were excluded from the study. Of these, one has not had an active managed fishery since the convention came into effect (Convention on the Conservation and Management of the Pollock Resources in the Central Bering Sea), two have not yet entered into force (Southern Indian Ocean Fisheries Agreement and Convention on the Conservation and Management of High Seas Fishery Resources in the South Pacific Ocean), one has ceased to function (International Baltic Sea Fishery Commission), one does not manage marine capture fisheries (International Whaling Commission), and three are bilateral arrangements (International Pacific Halibut Commission, Joint Norwegian–Russian Fisheries Commission and Pacific Salmon Commission) (Table 1). RFMOs that are bilateral arrangements, which generally include convention areas that are exclusively or predominately under national jurisdiction, were not included because it is likely that different governance structures are relevant, for example, for monitoring and surveillance programmes to be managed by national authorities vs. the regional organization (Small 2005; Lodge *et al.* 2007). While the *Report of the Meeting of FAO and Non-FAO Regional Fishery Bodies or Arrangements* defined Regional Fishery Bodies, which includes RFMOs, as requiring three or more Parties (FAO 1999c [Appendix E]), neither the 1982 Law of the Sea Convention, FAO Code of Conduct for Responsible Fisheries nor the Port State Measures Agreement explicitly excludes bilateral bodies and arrangements (United Nations 1982 [Articles 63, 66(5), 118]; FAO 1995 [Article 6.12], 2009b [Article 4(1)(b)]). Three organizations included in this assessment have remits that are broader than managing regional marine fisheries (CCAMLR, NASCO, NPAFC), but still meet the definition of an RFMO, regional bodies with the competence to establish fisheries conservation and management measures, including measures to control bycatch, and thus, their inclusion was deemed relevant.

Table 1 Marine regional fisheries management organizations (RFMOs) (adapted from Gilman *et al.* 2007b; FAO 2011c).

Marine RFMO	Acronym
Commission for the Conservation of Antarctic Marine Living Resources	CCAMLR
Convention on the Conservation and Management of the Pollock Resources in the Central Bering Sea[1]	CCBSP
Commission for the Conservation of Southern Bluefin Tuna	CCSBT
General Fisheries Commission for the Mediterranean	GFCM
Inter-American Tropical Tuna Commission	IATTC
International Baltic Sea Fishery Commission[2]	IBSFC
International Commission for the Conservation of Atlantic Tunas	ICCAT
International Whaling Commission[3]	IWC
Indian Ocean Tuna Commission	IOTC
International Pacific Halibut Commission[4]	IPHC
Joint Norwegian-Russian Fisheries Commission[4]	JNRFC
Northwest Atlantic Fisheries Organization	NAFO
North Atlantic Salmon Conservation Organization	NASCO
North East Atlantic Fisheries Commission	NEAFC
North Pacific Anadromous Fish Commission	NPAFC
Pacific Salmon Commission[4]	PSC
Regional Commission for Fisheries	RECOFI
South East Atlantic Fisheries Organization	SEAFO
Southern Indian Ocean Fisheries Agreement[5]	SIOFA
South Pacific Regional Fisheries Management Organisation[6]	SPRFMO
Western and Central Pacific Fisheries Commission	WCPFC

[1]Not included in this study. There are no active CCBSP-managed fisheries (CCBSP 2012).
[2]Not included in this study. IBSFC has ceased to function (FAO 2011d).
[3]Not included in this study. IWC's mandate is to govern whaling and does not include the governance of fisheries for marine fish (International Convention for the Regulation of Whaling 1946).
[4]Not included in this study. These RFMOs are bilateral arrangements with areas primarily within national jurisdictions, where different governance mechanisms are likely relevant relative to RFMOs with ≥ 3 Members.
[5]Not included in this study. Has not yet entered into force (FAO 2011b).
[6]Not included in this study. Has not yet entered into force (SPRFMO 2012).

Performance in governing bycatch was assessed against a suite of five broad criteria:

Criterion 1. Monitoring via regional observer programmes, comprised of three subcriteria.

Subcriterion 1A. Bycatch data collection protocols intended to be conducted by regional observers.

Subcriterion 1B. Regional observer coverage rates.

Subcriterion 1C. Regional observer programme data set quality.

Criterion 2. Open access to regional observer programme data sets.

Criterion 3. Ecological risk assessment.

Criterion 4. Conservation and management measures to control direct and indirect adverse ecological effects of bycatch, comprised of three subcriteria.

1. **Subcriterion 4A.** Controls to mitigate: (i) problematic bycatch of species relatively vulnerable to fisheries overexploitation due to their life-history characteristics and susceptibility to mortality from fishing operations; (ii) direct effects of fishing operations on habitat; and (iii) adverse indirect, collateral effects from bycatch removals.
2. **Subcriterion 4B.** Controls to mitigate ghost fishing mortality.
3. **Subcriterion 4C.** Controls to mitigate collateral mortalities from discharges at sea of discards, offal and spent bait.

Criterion 5. Surveillance, enforcement and outcomes.

Online Supporting Information provides criteria definitions, scoring and minimum information for assessment against each criteria and subcriteria of the suite. Several previous studies assessed the performance of management systems of RFMOs, aggregated fisheries of a nation and individual fisheries, most of which employed clauses from Articles of the CCRF and UNFSA as the basis for assessment (Caddy 1996; Pitcher 1999; Garcia 2000; Pitcher and Preikshot 2001; Small 2005; FAO 2006; Caddy *et al.* 2007; Lodge *et al.* 2007; United Nations 2007; CCSBT 2008a,b; NEAFC 2008; ICCAT 2009; IOTC 2009; Cullis-Suzuik and Pauly 2010; Marine Stewardship Council 2010; SEAFO 2010; GFCM 2011). We reviewed the criteria suites of these previous studies as a starting point in developing the design of the criteria suite used here, including the selection, definitions and scaling of individual criterion.

Criterion 4 is designed to assess the adoption of controls to address the full suite of ecological objectives of governing bycatch as described in the Introduction: Subcriterion 4A provides a broad assessment, while subcriteria 4B and 4C assess the efficacy of governance of two cryptic mortality sources, employed as indicators of RFMO binding controls for collateral effects from fishing operations.

Scaling of criteria was designed to represent a continuum from none or nominal bycatch governance to optimal best practice bycatch governance. Scaling was therefore not designed to account for preconceived expectations of RFMO progress, for instance, to facilitate having resulting scores range across the full scale from 0 to 100%. However, results are also presented relative to the RFMO with the highest overall score. Thus, nominal scores resulting from the assessment provide an indication of an RFMO's progress in employing *optimal* best practice to govern bycatch, while relative scores are presented in order to provide an understanding of individual RFMO's progress relative to *current* best practice, as defined by the RFMO obtaining the highest mean score across the five criteria.

Scoring for criteria 1 and 4, which contained multiple subcriteria, was calculated as the mean of the percentage of total possible points achieved against each subcriterion. Overall RFMO scores were calculated as the average of the scores resulting for criteria 1–5. The five criteria were assigned equal weights, based on the rational that each provides an indicator of a critical, fundamental element of effective bycatch governance. For each RFMO, the standard deviation (SD) of the population for the mean of five criteria scores was determined. The mean and SD of the population of the 13 RFMOs' scores for each criterion, subcriterion and overall score were also reported. This provides an understanding of the degree of dispersion or variability in scores within and between RFMOs, and hence consistency in governance of each assessed element by the 13 RFMOs. The data series number of RFMO voting members vs. nominal scores was fit to a simple linear regression model to assess goodness of fit.

Information from publicly available materials from RFMO Secretariats was first sought to assess RFMOs against the criteria suite, consistent with international standards on transparency in decision-making on environmental issues (UNEP 1992 [Principle 10]; FAO 1995 [Articles 6.13, 7.1.9]; United Nations 1995 [UNFA Article 12], 2006a,b). Additional information was obtained from peer-reviewed and grey literature and through correspondence with regional experts, including RFMO Secretariat staff.

Consistent with international guidelines on bycatch management, bycatch was defined broadly for this assessment as being comprised of: (i) retained catch of non-targeted but commercially valuable species; (ii) discard mortality; plus (iii) cryptic mortalities (FAO 2011a).

Results

Table 2 presents scores, means and SD of the population of scores from the assessment of RFMO governance of bycatch against the criteria suite. Figure 1 presents scores relative to the RFMO with the highest score, and nominal scores. The 13 RFMO performance assessment reports are available in Gilman *et al.* (2012b) [Appendix 1]).

Scores ranged from 1 to 58%, with a mean of 25% (±16% SD of the population), and 64% CV. 54% of scores fell within ±1 SD of the population from the mean. Of the 13 assessed RFMOs, variability in scores was highest for NAFO (scores ranged from 0 to 95%) and lowest for RECOFI (scores ranged from 0 to 4%). The RFMOs received the highest average score against criterion 5 (39%) and lowest against criterion 2 (10%). Criterion 1 had the highest variability in scores and criterion 4 the lowest (Table 2). RFMO nominal score was not significantly explained by the number of voting members, based on fitting the data series to a simple linear regression model, with poor model fit (p>0.05, R^2=0.1).

Assessed under subcriterion 1A on bycatch data collection protocols for regionally observed fisheries, minimizing impacts on associated and depen-

Table 2 Results of assessment of regional fisheries management organizations (RFMO) governance of bycatch, including discarded catch, against a suite of five criteria.

RFMO	Score (%)[1]											Mean (%)[3]	SD of the population (%)[4]	Relative scale score[5]
	1[2]	1A	1B	1C	2	3	4[2]	4A	4B	4C	5			
CCAMLR	90	88	100	82	40	75	36	67	21	21	50	58	±21	1
CCSBT	42	36	55	36	0	25	21	22	21	21	30	24	±14	0.41
GFCM	3	0	0	9	0	25	13	39	0	0	30	14	±12	0.24
IATTC	65	76	27	91	40	38	34	61	21	21	45	44	±11	0.76
ICCAT	36	36	36	36	0	25	7	22	0	0	30	20	±14	0.34
IOTC	7	20	0	0	0	25	11	11	21	0	45	18	±16	0.31
NAFO	71	40	82	91	0	25	18	39	14	0	95	42	±35	0.72
NASCO	0	0	0	0	0	0	0	0	0	0	30	6	±12	0.10
NEAFC	11	16	9	9	0	25	22	44	21	0	50	22	±17	0.38
NPAFC	1	4	0	0	0	25	20	17	21	21	30	15	±12	0.26
RECOFI	4	4	0	9	0	0	0	0	0	0	0	1	±2	0.02
SEAFO	13	12	0	27	0	25	14	22	21	0	30	16	±10	0.28
WCPFC	62	96	36	55	47	25	30	39	29	21	45	42	±13	0.72
Mean	31.2	32.9	26.5	34.2	9.8	26.0	17.4	29.5	14.6	8.1	39.2	24.8	–	0.42
SD of the population	±30	±32	±33	±34	±18	±17	±11	±20	±10	±10	±21	±16	–	±0.41

[1]Criterion 1: Observer monitoring methods and data set quality.
Criterion 1A. Bycatch data collection protocols.
Criterion 1B. Regional observer coverage rates.
Criterion 1C. Regional observer programme data set quality.
Criterion 2. Open access to regional observer programme data sets.
Criterion 3. Ecological risk assessment.
Criterion 4. Bycatch conservation and management measures.
Criterion 4A. Controls to mitigate problematic bycatch of species relatively vulnerable to fisheries overexploitation, on direct effects of fishing operations on habitat, and on adverse collateral effects from bycatch removals.
Criterion 4B. Controls to mitigate ghost fishing.
Criterion 4C. Controls to mitigate cryptic, unobservable fishing mortality from discharges at sea of discards, offal and spent bait.
Criterion 5. Surveillance, enforcement and outcomes.
[2]Mean of subcriteria scores.
[3]Mean of scores for criteria 1, 2, 3, 4 and 5.
[4]Standard deviation of the population of scores.
[5]Score relative to the highest score obtained.

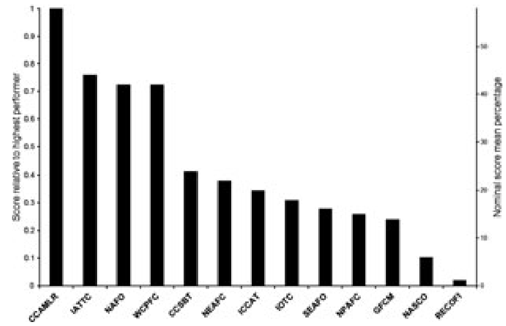

Figure 1 Regional fisheries management organizations (RFMO) scores resulting from an assessment of performance in governing bycatch, including discards. Primary y-axis scale is the score relative to the highest performer. Secondary y-axis scale is the nominal mean percentage score of five criteria.

dent species of non-target fish and non-fish species was not included in five of the 13 RFMO's mandates. Three of the RFMOs have not adopted any binding bycatch conservation and management measures. Of the 10 RFMOs that have adopted binding measures related to bycatch, 49% (67 of 131) of items of information needed to assess the efficacy of the implementation of the measures are not included in regional observer data collection protocols. Of nine RFMOs with a regional observer programme, all but two (NAFO and NEAFC) include the collection of the disposition of released/discarded organisms for at least one species or species group identified as being relatively vulnerable to fisheries overexploitation.

Investigated within subcriterion 1B on regional observer coverage rates, regional observer programmes are in place for nine of the 13 RFMOs. There were seven RFMOs with regional observer programmes for which information on regional observer coverage rates were publicly available; NEAFC and SEAFO do not publicly report observer coverage rates. The average of RFMO mean observer coverage rates was 18.5% (±36.6% SD of the population, 198% CV, $N = 68$ active managed fisheries, ranging from 0 to 100% observer coverage rates). There is international exchange of observers in three regional programmes: CCAMLR uses international observers who are exchanged under a bilateral agreement between the Designating State (deploying the observer) and the Receiving State (CCAMLR 2008). Under the IATTC-administered AIDCP, at least 50% of observers assigned to national fleets are IATTC observers (IATTC 2009). International observers are assigned for the ICCAT Regional Observer Programme for Bluefin Tuna, which is operated on behalf of ICCAT by a consortium between Marine Resources Assessment Group and Cofrepeche, who train and deploy the observers (ICCAT 2008, 2011).

Under subcriterion 1C, which assessed the quality of regional observer programme data sets, six of the 13 RFMO Secretariat possesses a data set of records collected by a regional observer programme, and the data set contains records on bycatch, including discards. The mean time-series length of these six data sets is 13 years (±12 SD of the population). One or more country or entity with fisheries under the RFMO's mandate is not a Member or Cooperating Non-Member for six of the RFMOs.

Assessed as a part of Criterion 2, none of the RFMOs make data sets of primary data records from a regional observer programme publicly available. Only WCPFC provides open access to amalgamated data records of a spatial resolution $\leq 5^{o}$cells from a regional observer programme.

Nine of the 13 RFMOs scored 25% against criterion 3 on ecological risk assessment (Table 2). Eleven RFMOs have conducted ecological risk assessment of the effects of fishing mortality on species subject to bycatch in one or more managed fishery. Two RFMOs conducted ecological risk assessments of broader, indirect effects of bycatch mortality. CCAMLR accounts for the effects of fishery removal levels and spatial location on ecosystem indicator species of dependent predator populations of the ecosystem regulated by Antarctic krill in developing conservation and management measures. Precautionary reference points are set for both prey and predator species so as to ensure that there are sufficient prey populations to sustain predator populations (Constable *et al.* 2000; CCAMLR 2004, 2008), more related to ecosystem effects from target stock removals than bycatch removals. IATTC developed a model of the tropical eastern Pacific Ocean pelagic ecosystem to predict how managed pelagic fisheries (pelagic longline, pole-and-line, and purse seine) and climate variability affect middle and upper trophic levels and to predict trophic cascades from pelagic fishery removals, including of bycatch species (IATTC 2010).

The lowest variability in scores occurred for criterion 4 (±11 SD of the population, scores ranging from 0 to 36% with a mean of 17%), which assessed performance in adopting binding conservation and management measures to control problematic bycatch (Table 2). Of the five criteria, criterion 4 had the second-lowest mean score. Of the three subcriteria comprising criterion 4, the mean score against 4A, controls to mitigate problematic bycatch of species relatively vulnerable to fisheries overexploitation, controls on direct effects of fishing operations on habitat, and controls on adverse indirect, collateral effects from bycatch removals, was highest (30%) (Table 2). Mean scores were relatively low for 4B (15%), measures to mitigate ghost fishing, and 4C (8%), measures to mitigate cryptic mortalities from the discharge of catch, offal and spent bait during fishing operations at sea (Table 2). Assessed under subcriterion 4A, binding measures are in effect to address a mean of 37% ($N = 226$) of identified bycatch problems in fisheries managed by the 13 RFMOs, with large variability in scores (±26% SD of the population), ranging from 0% to 79%. Of these binding measures under subcriterion 4A, 23% ($N = 83$) include quantitative performance standards. None of the RFMOs have assessed ecological risks resulting from, or account for, cryptic losses from ghost fishing or from discharges of discarded catch, offal and spent bait. Six RFMOs have adopted binding measures related to controlling ghost fishing, and one RFMO has a binding measure that manages discharges of organic material. None of the control measures on ghost fishing and on organic material discharges include explicit performance standards. Five RFMOs allow Member States to opt out of binding conservation and management measures.

The RFMOs received the highest average score against criterion 5 (39%), which assessed surveillance, enforcement and outcomes of enforcement actions. Again, there was relatively high variability in the 13 scores (±21% SD of the population), which ranged from 0 to 95% (Table 2). The 13 RFMOs employ 60% ($N = 50$) of surveillance methods required to asses compliance of binding bycatch measures, with large variability in this element across the 13 RFMOs (±36% SD of the population), ranging from 0 to 100%. None of the 13 RFMOs met all three of the following fundamental elements of effective surveillance and enforcement: (i) Members routinely report identified infractions, enforcement actions and the conclusions of these enforcement actions; (ii) the RFMO Secretariat routinely makes information publicly available on detected infringements and enforcement outcomes; and (iii) detected infringements of binding bycatch measures regularly result in sanctions.

Discussion and conclusions

These findings provide a benchmark against which to measure future RFMO progress in governing bycatch. The mean score of 25% for the 13 RFMOs (Table 2) indicates that collectively there are substantial deficits in optimal best practice governance of bycatch, including discards. There was relatively high variability in performance in governing bycatch across the 13 assessed RFMOs, as demonstrated by a 64% CV, mean scores ranging from 1 to 58%, with 6 of the RFMO's mean nominal scores falling outside of ±1 SD of the population from the mean (Fig. 1, Table 2). This is because, individually, there has been mixed progress, with some RFMOs having made moderate to considerable progress for some governance elements.

The number of voting members did not significantly explain scores for performance in governing bycatch. While this variable alone does not significantly determine bycatch governance performance, RFMO decision-making, in particular by consensus, is likely more difficult the larger the number of voting members due to increased difficulty in achieving agreement (ICCAT 2009). Differences in mandates of RFMO Conventions may be a significant variable in explaining observed disparities in bycatch governance. For instance, the five RFMOs that do not include minimizing impacts on associated and dependent species of non-target fish and non-fish species in their mandates (CCSBT, GFCM, ICCAT, IOTC and NASCO) all had low mean scores relative to the four top performing RFMOs (Fig. 1). However, this is likely a symptom and not a cause of poor and inconsistent bycatch governance between the RFMOs, which might be explained by the composition of an RFMO's parties and the relative availability of resources to RFMO Secretariats and Members for fisheries governance. The age and history of RFMOs may also affect efficacy in governing bycatch. Various less-tangible variables may also be significant in causing the wide variability in RFMO performance in bycatch governance, including awareness by RFMO Members of the increasing influence of market-based mechanisms, including those implemented by major seafood buyers, in determining seafood sourcing practices and catalysing changes in fisheries bycatch governance and practices (e.g. Parkes *et al.* 2010). The political will of RFMO Members to prioritize long-term socioeconomic and ecological gains, including food security and poverty alleviation, over short-term adverse consequences on managed fisheries' commercial viability from instituting effective bycatch mitigation methods, is an another likely significant variable determining disparities in RFMO performance in governing bycatch (Lodge *et al.* 2007).

Observer monitoring methods and data set quality

The highest variability in scores occurred for criterion 1 (±30 SD of the population, scores ranging from 0 to 90), indicating that, of the five criteria, there is least consistency in RFMO performance in observer bycatch data collection protocols, observer coverage rates, and data set quality. Four RFMOs lack regional observer programmes and as a result received extremely low scores against the subcriteria for these elements.

A large proportion (five of 13) of the RFMOs do not include in their mandate minimizing impacts by the RFMO's managed fisheries on associated and dependent species of non-target fish and non-fish species. Several RFMOs were established before UNFSA, and some were established prior to the third Law of the Sea Convention. Many of these older RFMOs lack mandates that are consistent with the new responsibilities assigned to RFMOs under UNFSA (United Nations, 1995 [Article 13]). While some RFMOs have assessed the suitability of their mandates and modernized them if determined to be inadequate (e.g. IATTC adopted the Antiqua Convention in 2003 to modernize its mandate; NEAFC and NAFO assessed their mandates), many have not. There is a need to broaden the mandates of these older RFMOs to manage adverse effects of fishing on non-target-associated and dependent species, including those that are relatively vulnerable to fisheries exploitation (Lodge *et al.* 2007).

RFMOs collect only about half of the information via onboard observer programmes required to assess the performance of bycatch measures. In general, most RFMOs do not collect basic information in regional observer programmes needed to understand ecological effects of bycatch, including quantity, weight, species, age classes, length frequency, and date and location caught (Kelleher 2005; Gilman *et al.* 2012c). However, seven of nine RFMOs with a regional observer programme do include the collection of the disposition of released/discarded organisms for at least one species or species group identified as being relatively vulnerable to fisheries overexploitation. This information is critical for estimating post-release mortality rates, one of the components of cryptic fishing mortality that needs to be accounted for to produce precise estimates of total fishing mortality (Gilman *et al.* 2012a).

While the average regional observer coverage rate of 18.5% is encouraging, there was extremely high variability in observer coverage rates of active fisheries managed by RFMOs, as evident by the ±36.6% SD of the population and 198% CV: 47 of 68 active managed fisheries have no regional observer coverage, and 11 had 100% coverage. Of the nine RFMOs with regional observer programmes, only three have international exchange of observers, a practice needed to optimize the objectivity of observer reporting and thus maximize data quality (Gilman 2011).

Observer data are key to identifying and understanding any trends in bycatch rates and levels, and in assessing performance of mitigation measures in a commercial setting, where methods for the employment of prescribed bycatch mitigation methods are known to differ from experimental conditions (Gilman *et al.* 2005, 2008b). Adequate data collection protocols and observer coverage rates are needed to allow for robust statistical analyses of bycatch interactions, including documentation of bycatch rates, fleet-wide extrapolations and identification of when and where interactions occur. The fishery-specific objectives of analyses (i.e. required levels of accuracy and precision of bycatch rate estimates), the frequency of occurrence of bycatch interactions for each bycatch species of interest, amount of fishing effort, and distribution of catch and bycatch determine the requisite onboard observer coverage rate (Hall 1999). In general, the variability in precision and biases in bycatch estimates decrease rapidly as the observer coverage rate increases to 20%, assuming that the sample is balanced and there are no observer effects (Hall 1999; Lennert-Cody 2001; Lawson 2006; Arnande *et al.* 2012). At 5% coverage, the threshold employed in the criteria suite for this study, bycatch estimates will likely have large uncertainties for species with low capture rates, but likely would be sufficient to enable determining when and where bycatch occurs.

Only three of the 13 RFMOs have regional observer programme data sets of sufficient time-series length to support most rigorous research applications (Gilman 2011; Gilman *et al.* 2011). Of the nine RFMOs with regional observer programmes, three do not possess observer programme data sets. Thus, of the 13 RFMOs, three lack observer programme data sets because Parties are not required to report observer data and four lack data sets because they do not have a regional observer programme. The time-series length of the six regional observer programme data sets ranged from 1 to 33 years. Three of the RFMO data sets had very short time series ≤ 4 years, unsuitable for some research applications. The other three RFMOs had relatively long time series ≥ 19 years, likely sufficient for most research applications. Furthermore, because 6 of the 13 RFMOs lack membership of one or more State or entity with fisheries under the RFMO's mandate, this limits the RFMOs' ability to effectively account for and manage bycatch in regional fisheries (FAO 1995 [Article 7.1.5]; Small 2005). Unlike data collection in regional observer programmes, national observer data sets not a part of a regional programme are likely not interoperable. Regional data sets, or pooled domestic data sets collected through standardized collection methods and standardized data set formatting to enable their interoperability, provide larger sample sizes, which can achieve sufficiently long time series needed to determine whether observed patterns are long-term trends or cyclical, short-term, serially correlated patterns, and provide broader spatial coverage across RFMO convention areas (Gilman 2011).

Open access to regional observer programme data sets

Due to the ocean basin-scale distributions of some species subject to bycatch, including marine megafauna, and because bycatch occurs in multinational fleets operating over broad fishing grounds, there is a need for observer data collection over large spatial scales and the ability to access and pool resulting data sets to support large temporal- and spatial-scale analyses (Gilman 2011; Gilman *et al.* 2011). Open access to research-quality data from RFMO observer programmes in interoperable data sets is also necessary for peer review and replication to validate findings.

Ten RFMOs had scores of 0% when assessed against criterion 2, open access to regional observer programme data sets. While CCAMLR, ICCAT and WCPFC had scores of 40, 40 and 47, respectively (Table 2), only WCPFC provides access to amalgamated data records at $\leq 5^{o}$cell spatial resolution and no RFMO provides open access to primary data. WCPFC's public domain data set is inadequate for fundamental research applications due to a lack of critical fields, the amalgamation of certain fields such as lumping non-target species in a single field, and pooling logbook and observer records without identifying sources for individual records.

While ten RFMOs had regional observer programme data sets with relatively short time series (≤ 5 years), and while many RFMO observer data sets lack fields needed to effectively assess binding bycatch measures, Members may possess national observer programme data sets of sufficient quality, including national data sets that predate relatively new regional programmes. However, the standardization in data collection methods and format of data sets with a regional programme enable pooling observer records from member fisheries, while national observer data sets, especially those that predate a regional programme, likely do not. Pooling data sets provides larger sample sizes, which can achieve sufficiently long time series needed to determine whether observed patterns are long-term trends or cyclical, short-term, serially correlated patterns, and provide broader spatial coverage across fishing grounds (Gilman 2011; Gilman *et al.* 2011).

The CCRF calls for regional pooling of fisheries data and making these data sets available, with the caveat that this be conducted in a manner consistent with applicable confidentiality requirements (FAO 1995 [Article 7.4.7]). Methods, such as removing data records where a minimum number of unique vessels did not conduct fishing effort, reducing the spatial resolution of geographic references such as by randomly adjusting recorded positions of fishing operations by several degrees and by amalgamating data by 5^{o} cell, and removing reference to individual vessels, can avoid disclosing the location of fishing effort, fishing gear and methods of individual vessels, and other information that may be captured in observer data sets that are considered commercially sensitive. Instead of employing such methods prior to publicly disclosing regional observer data sets, RFMOs are not making research-grade regional observer programme data sets available. Achieving open access will require addressing confidentiality restrictions and other general impediments to providing open access to research data (Arzberger *et al.* 2004; UNESCO 2008; Gilman *et al.* 2011). Furthermore, there is a need for the cataloguing of rich metadata of fishery-dependent data sets to: (i) enable discovery of relevant data sets; (ii) determine whether pooling individual data sets is suitable, for instance, through analysis of information on sampling effort, data collection methods and estimates of positional error; and (iii) determine how individual data sets can best be integrated (Gilman *et al.* 2011).

Ecological risk assessment

Different levels of risk assessments provide concomitant levels of certainty of the ecological consequences of bycatch, including direct effects on population viability of species subject to bycatch fishing mortality, direct impacts on coastal and marine habitats, and indirect, collateral effects. Indirect effects of bycatch mortality include, for example, reducing genetic diversity of populations subject to bycatch fishing mortality, altering ecosystem regulation or structure due to overexploitation of a bycatch species that is a keystone or foundation species, respectively, effects of bycatch mortality on food web processes, and sources of cryptic removals, including indirect, collateral mortalities (Gilman *et al.* 2011, 2012a). While most of the RFMOs have conducted ecological risk assessments of the effects of managed fisheries on species or groups relatively vulnerable to fisheries overexploitation, including bycatch of seabirds, sea turtles, marine mammals and elasmobranchs, there has been limited assessment or accounting for broad community- and ecosystem-level risks from bycatch removals in RFMO-managed fisheries. This global governance deficit is likely partly linked to the limited state of understanding of broader community- and ecosystem-level effects from bycatch, and a lack of agreed guidance on best practices for management authorities to monitor, estimate and account for these broader effects (Gilman *et al.* 2012a).

Methods for ecological risk assessment of the direct population-level effects of fishing have been categorized into three levels along a continuum from a qualitative first order to quantitative rigorous assessment (Kirby 2006; Marine Stewardship Council 2010; Coelho *et al.* 2011; Hobday *et al.* 2011). Level 1 and 2 assessments are useful mainly for rapid first-order evaluations and where there are data deficiencies with the fishery or species being assessed (Kirby 2006; Coelho *et al.* 2011). Level 1 involves a qualitative assessment based on expert and stakeholder opinion. Level 2 is a semi-quantitative assessment, for example, through a productivity-susceptibility analysis (PSA). In a PSA, assessment of productivity considers the natural growth rate of a population in the absence of fishing mortality, which is an indicator of a population's relative resistance to fishing mortality and ability to recover from depletion. Susceptibility considers whether a population overlaps with the fishery temporally and spatially, what proportion of each age class overlaps the fishery, and what is the probability that this species interacts with fishing vessels, will be captured and will suffer injury or mortality. Finally, a Level 3 quantitative assessment documents population-level effects from mortality levels in a fishery in question, with relatively large data requirements (Kirby 2006; Marine Stewardship Council 2010; Coelho *et al.* 2011; Hobday *et al.* 2011). This hierarchy of risk assessment methods has not been applied to understand indirect, collateral effects of fishing operations.

Conservation and management measures to control problematic bycatch

The 13 RFMOs have large deficits in adopting measures to address problematic bycatch and especially large deficits in managing ghost fishing and discharges of organic material relative to the components covered by the other criteria (Fig. 1, Table 2). Three RFMOs have yet to adopt any binding measures on bycatch. The low variability in scores for the three subcriteria comprising criterion 4 indicates that there is somewhat consistent poor performance across the 13 RFMOs.

RFMOs are managing only 37% of identified bycatch problems in fisheries under their jurisdiction. While none of the RFMOs have assessed or account for cryptic losses from ghost fishing or from discharges of discarded catch, offal from processed catch and spent bait, six RFMOs have adopted a binding measure to govern ghost fishing, such as banning certain gear types with high ghost fishing efficiency and requiring gear marking. Only one RFMO, CCAMLR, has a binding measure related to managing discharges.

Over three quarters of binding bycatch measures covered under sub-criterion 4A lack explicit performance standards. None of the binding measures related to ghost fishing and discharges of organic matter (subcriteria 4B and 4C, respectively) contain performance standards. A binding measure that lacks measurable performance standards does not stipulate expected, target outcomes, for example, explicitly stating a catch rate or level for a measure that requires employment of bycatch mitigation gear technology, or standards for indirect performance, such as minimum sink rates for terminal tackle to reduce seabird interactions (Gilman 2011). In the absence of such measurable performance standards, one approach to assess efficacy of RFMO bycatch measures is to compare standardized bycatch rates before vs. after mitigation measures came into effect (Gilman 2011; Gilman *et al.* 2012c). However, data deficiencies due to inadequate monitoring are often an obstacle to implementing this approach at regional scales. A lack of performance standards, in combination with inadequate observer coverage in a large proportion of regionally managed fisheries and incomplete data collection hinders assessing measures' efficacy. This limits the basis to guide adaptive bycatch governance (Gilman 2011).

A majority (62%) of RFMOs have an opt-out provision, allowing members to not abide by binding measures. While available information indicates that these opt-out measures have been infrequently employed, this mechanism could reduce the effectiveness of regional conservation and management measures. Several RFMOs, including NAFO, SEAFO and WCPFC, have adopted instruments on objection procedures that require parties who lodge objections to a binding measure to explain the reasons for their objection, and establish a formal process for the appointment of an expert panel to analyse the rationale of the objection. While the efficacy of these new provisions has not been assessed, the purpose is to minimize unfounded objections and, for objections with merit, adapt measures accordingly to address these issues (ICCAT 2009).

RFMOs have not considered fishery-specific relative risks across vulnerable populations of a bycatch mitigation method. Potential conflicts resulting from prescribed bycatch mitigation methods has largely not been considered by RFMOs, which have tended to adopt control measures to address problematic bycatch within a single-species group, that is, one measure for turtle bycatch, a separate measure for seabirds, etc. International guidance on managing bycatch has likewise been piecemeal, for instance, International Plans of Action (sharks, seabirds, FAO 1999a,b) do not provide a holistic assessment of consequences of a bycatch mitigation method designed to address problems within one species group. It is critical to identify conflicts as well as mutual benefits amongst species groups from bycatch management strategies. For example, the relative risk from the use of different hook designs and widths to sea turtle, shark and seabird populations subject to bycatch mortality in individual longline fisheries within an RFMOs Convention Area requires consideration. While use of G-shaped circle hooks in place of J-shaped tuna and J hooks, and/or use of a wider hook, has been demonstrated to achieve significant reductions in sea turtle and seabird catch rates in longline fisheries, small ca. 10%, in some cases significant increases in catch rates of some elasmobranch species have been observed in some studies (Watson *et al.* 2005; Ward *et al.* 2009; Piovano *et al.* 2010; Gilman 2011; Gilman *et al.* 2012c). And, for instance, in some regions, setting longlines at night to protect albatrosses and other diurnal foraging seabirds has led to higher bycatch of nocturnal-foraging seabirds (e.g. white-chinned petrels) (Weimerskirch *et al.* 1999).

Subcriterion 4A likely underestimates deficits in governance of indirect, collateral effects from bycatch removals. Subcriterion 4A's assessment method was intended to provide a comprehensive assessment of the proportion of bycatch problems that are subject to RFMO binding controls. However, due to large deficits in knowledge of indirect, broad adverse consequences of bycatch losses, the subcriterion provided a de facto assessment of controls of problematic bycatch of species and groups relatively vulnerable to overexploitation, and, in some cases, controls of adverse habitat effects from fishing operations.

Surveillance and enforcement

To achieve compliance with bycatch control measures, RFMOs require effective surveillance and enforcement frameworks, and penalties must be sufficiently stringent to deter non-compliance. On average, of the five criteria, RFMOs performed the highest against criterion 5, which assessed surveillance, enforcement and outcomes of enforcement actions. However, high dispersion in scores reveals large inconstancy in RFMO performance.

In most cases, there is incomplete or no public reporting on surveillance and enforcement activities. Using CCAMLR as an example, given its scoring highest against the full suite of bycatch governance criteria, a CCAMLR performance review panel concluded that it was not possible to make a quantitative assessment of the proportion of total detected infringements of CCAMLR measures that resulted in sanctions by the CCAMLR Contracting Parties due to insufficient reporting (CCAMLR 2008). The most current report of the CCAMLR Standing Committee on Implementation and Compliance, while reporting all identified infractions during the most current reporting period, did not include information on the conclusion of enforcement actions taken in response to identified infractions from the most previous reporting period, nor did it include information on the results of an assessment of Members' compliance (CCAMLR 2011).

Members do not routinely report surveillance effort, detection of infractions, and enforcement actions and outcomes. While required surveillance methods address 60% of methods required to assess compliance with binding bycatch measures, there remains a large deficit, there was high dispersion in scores, and information is not consistently reported to determine compliance by Member States with required surveillance methods. A lack of harmonization of domestic and regional inspection systems may limit efficacy. RFMOs tend not to prescribe specific enforcement actions, and information is not made public to determine whether Member States have developed requisite legal frameworks for prosecution. RFMOs also largely do not require specific penalties when Members detect infringements of binding measures, and a lack of consistent reporting and transparency prevents determining whether sanctions provide a sufficient incentive for capture sector compliance. Most RFMOs do have formal procedures in place to routinely assess the performance of surveillance and enforcement activities to support adaptive management (e.g. through mandated responsibility of an RFMO Compliance Committee). However, lack of reporting by Member States compromises the efficacy of these compliance review processes. Furthermore, RFMO Secretariats tend to lack the authority to impose sanctions against Members found to not be in compliance with RFMO requirements, including binding bycatch measures, and RFMO Secretariats do not routinely report identified violations made by Member States or actions taken, if any, by the RFMO Secretariat in response. Due to these deficits in RFMO surveillance and enforcement frameworks, including a prevalent lack of transparency, a culture of compliance appears to not exist for most RFMO communities.

Comparison with results of previous performance assessments

Two previous RFMO performance assessments included criteria to assess governance of bycatch: Small (2005) and Cullis-Suzuik and Pauly (2010). Both studies employed sufficiently different criteria definitions from those employed here, and due to changes in governance frameworks of some RFMOs since the previous studies were conducted, this limits a comparison of findings. Cullis-Suzuik and Pauly (2010) included a criterion assessing generally whether an RFMO considers bycatch, threatened species, habitats and ecological interactions, but not assessing performance in governing this subset of bycatch-related issues (Cullis-Suzuik and Pauly 2010). Despite the employment of different criteria, Cullis-Suzuik and Pauly (2010) and the current study had some consistent results, both finding highest scores for CCAMLR, IATTC and WCPFC, lower end of scores for NASCO, NPAFC and GFCM, and ICCAT, SEAFO and CCSBT scoring in the middle. Findings were, however, inconsistent for NAFO, IOTC and NEAFC (Cullis-Suzuik and Pauly 2010). The disparity between mean scores of the present study (25%) and that resulting from assessment against this one criterion related to bycatch that was included in the study by Cullis-Suzuik and Pauly (2010) (55%) reveals that an assessment of availability of information on bycatch, threatened species, habitats and trophic interactions is not a reliable indicator of the performance of core elements of RFMO bycatch governance.

Small (2005) assessed performance against a criteria suite that included three criteria evaluating the efficacy of aspects of bycatch governance: (i) commitment to reducing impact of fisheries on non-target species; (ii) bycatch data collection; and (iii) bycatch mitigation measures, each of which was divided into numerous subcriteria (Small

2005). Four possible scores of 0, 0.5, 0.75 or 1 were awarded for each subcriterion, representing performance of poor, fair, good and excellent, respectively (Small 2005). One of six subcriteria under Small's (2005) criteria 'bycatch data collection', which assessed whether Member States report data on bycatch for target and non-target fish, elasmobranchs, sea turtles, marine mammals and seabirds, could be expected to provide similar assessment results as the RFMO assessment against subcriterion 1A in this study, which included as part of the assessment consideration of what proportion of species relatively vulnerable to bycatch are included in regional observer data collection protocols. Small (2005) awarded mean scores, as percentages of maximum possible scores, of 97, 27, 87, 33 and 8% for CCAMLR, CCSBT, IATTC, ICCAT and IOTC, respectively, while scores under subcriterion 1C here of these RFMOs were relatively consistent: 84, 42, 65, 36 and 7%, respectively (Table 2). Small (2005) did not report information used as the basis for awarded scores. Small (2005) may have accounted for the reporting of bycatch data from all sources, including logbook and survey data, in addition to data from regional as well as national observer programmes, based on IATTC having been awarded a score of 0.75 ('excellent') against the subcriterion on Member State reporting bycatch data on seabirds, this despite there being no regional observer data collection in IATTC-managed fisheries in which seabird interactions are likely to occur.

Opportunities to harmonize RFMO bycatch governance

There are several currently untapped opportunities for RFMO cooperation to improve RFMO efficacy in governing bycatch. RFMOs could standardize data collection protocols and database formats to facilitate pooling across regions (Gilman 2011; Gilman *et al.* 2011). RFMOs could standardize bycatch mitigation measures. This is necessary to avoid having the fishing industry be subject to conflicting requirements, which might prove impractical for vessels that fish in multiple RFMO areas and might cause low compliance. The first and second joint meetings of the five tuna-RFMOs recognized benefits and called for consistency and compatibility in measures employed to manage marine capture fisheries, including bycatch mitigation measures and scientific data collection methods (Fisheries Agency of Japan 2007; European Community 2009). Furthermore, by working together, RFMOs could systematically select and govern high seas protected areas designated by RFMOs and other entities to establish a network of protected sites that optimizes ecological properties and administration (Gilman *et al.* 2011). RFMOs could combine limited resources for research, monitoring (e.g. the Regional Fishery Bodies Secretariats Network's Fisheries Resource Monitoring System), surveillance (e.g. a global VMS system) and enforcement. As a final example, through coordinated implementation of measures to deter IUU fishing, such as through consolidated regional vessel lists, and harmonized catch documentation schemes, RFMOs could more effectively address excess fishing capacity and manage stocks that overlap areas of multiple RFMOs (Fisheries Agency of Japan 2007; Lodge *et al.* 2007; European Community 2009; Gilman 2011). Mandates to harmonize RFMO activities are relatively recent events; as existing mechanisms for inter-RFMO coordination mature, and new initiatives are adopted, RFMOs that have progressed in certain bycatch governance elements can help laggards to improve.

Transitioning to an ecosystem approach to fisheries management

There is documentation of few contemporary marine species extinctions and population extirpations, in part, from marine fisheries (Dulvy *et al.* 2003). Instead, marine fisheries, including through bycatch removals, have primarily altered other components of marine biodiversity, from genetic diversity to ecosystem processes and structure (Pereira *et al.* 2010; Garcia *et al.* 2012). While the socioeconomic sustainability of marine capture fisheries is unequivocally linked to the ecological sustainability of marine ecosystems and, despite having been prescribed in major international fisheries agreements for over three decades, of the RFMOs assessed, only CCAMLR has begun to substantially transition to an ecosystem approach to fisheries management (Constable *et al.* 2000; CCAMLR 2004, 2008). Instead, the prevailing basis for RFMO fisheries governance continues to employ single-species stock assessments, exploiting stocks of principal market species at levels predicted to produce single-species maximum sustainable yields (MSY), mixed progress in mitigating bycatch of species and groups relatively vulnerable to overexploitation, and managing direct habitat effects (Mace 2001; Hobday *et al.* 2011). Modelling has predicted that employing MSY reference points to low-trophic-level species causes large impacts on other parts of the ecosystem, in particular when these species constitute a high proportion of the biomass in the ecosystem or are highly connected in the food web (Smith *et al.* 2011). Implementing single-stock MSY fishing rates as an upper limit to all species of an ecosystem is similarly predicted to alter trophic interactions, including the loss of top predators and single-species declines in spawning stock biomass (Mace 2001; Walters *et al.* 2005; Hall *et al.* 2006). As a result, given the conventional use of single-stock biological reference points, exploitation rates, including from bycatch removals, in most ecosystems are substantially higher than those predicted to produce multispecies maximum sustainable yields and to rebuild the one-third of commercial fish stocks that are overexploited and depleted (Pace *et al.* 1999; Pauly *et al.* 1998, 2002; Jackson *et al.* 2001; Garcia and Grainger 2005; Beddington *et al.* 2007; Worm *et al.* 2009; FAO 2012).

Effectively managing broad, ecosystem-level effects of bycatch removals can be accomplished by developing ecosystem models that then enable establishing rigorous ecosystem-level indicators, target and limit reference point thresholds, and control rules that maintain exploitation rates within levels predicted to produce multispecies maximum sustainable yields (Lawton 1999; Gislason *et al.* 2000; FAO 2003; Pikitch *et al.* 2004; Garcia and Cochrane 2005; Worm *et al.* 2009; Tallis *et al.* 2010). Ecosystem models can define a community's reference state, account for effects of environmental variation including from climatic drivers, account for complex food web processes, consider individual species' vulnerability to fisheries exploitation based on life-history characteristics and susceptibility to fishing operations, consider effects of fishing operations on phylogenetically distinct species, and, in the case of the Atlantis model, assess projected effects of management measures (Paine 1969; Constable *et al.* 2000; Link *et al.* 2002; Pikitch *et al.* 2004; Bascompte *et al.* 2005; Link 2005; Fulton *et al.* 2011; Gilman *et al.* 2011). An understanding of all sources of fishing mortality, including sources of cryptic fishing mortality, the selectivity of removals, knowledge of ecosystem structure and functioning, including connectivity between biogeochemical and physical processes, trophic linkages and the strength of interactions between predators and their prey and concomitant stability of the ecosystem in response to fishing pressure, and life histories of higher trophic level species, is fundamental information needed for reliable ecosystem models (deYoung *et al.* 2004; Bascompte *et al.* 2005; Gilman *et al.* 2012a). Models could explicitly account for ecosystem effects of fishing mortality of keystone and foundation species and guilds, which have disproportionate roles in ecosystem regulation, to enable identifying indicators and thresholds to avoid unacceptable risk of reaching a threshold tipping point where recovery may be protracted or an irreversible regime shift occurs (Paine 1969; Pace *et al.* 1999; Jackson *et al.* 2001; Ward and Myers 2005; Myers *et al.* 2007; Jordan 2009; Pereira *et al.* 2010; Gilman *et al.* 2011).

RFMOs would select and monitor a suite of indicators that track trends in manageable fishing pressures that alter broad ecosystem-level functions and structure, this in addition to indicators of the state of ecosystem components and indicators to measure the response of managers to alter the level of a pressure that has resulted in an unsustainable change in ecosystem state (Jennings 2005; Piet *et al.* 2007). Monitoring these pressure, state and response indicators allows assessing progress towards meeting ecological and socioeconomic management objectives, guiding the adoption of new controls on fishery pressures, and communicating trends in indicators and management actions (Garcia *et al.* 2000; Jennings 2005; Rice and Rivard 2007).

Selective fishing and gear, the prevailing paradigm for fisheries management systems, can be non-ecosystemic by not accounting for community- and ecosystem-level ecological effects from uneven fishery removals (Garcia *et al.* 2012). Instead, it has been proposed that, in concept, balancing fishing mortality across and within trophic levels, species, stocks and populations, sizes, age classes, and sexes, in some cases, by *reducing* fishing and gear selectivity, would be more sustainable (Hall 1996; Zhou *et al.* 2010; Garcia *et al.* 2012). Selective, uneven fishing and gear, by concentrating fishing mortality on a narrow subset of an ecosystem's components, can cause ecological and evolutionary change and loss, reduce ecosystem stability and alter ecosystem function and structure (Zhou *et al.* 2010; Garcia *et al.* 2012). In some regions, marine capture fisheries have fished through food webs and, to a lesser extent, down food webs, but largely at unsustainable levels and still selectively fish within trophic levels (Pauly *et al.* 1998; Essington *et al.* 2006; Branch *et al.* 2010). Balanced exploitation would preserve community structure and size–frequency distributions of species characteristic of unexploited conditions, accomplished by distributing fishing mortality across marine ecosystem components at sustainable levels according to intrinsic production capacities (Hall 1996; Garcia *et al.* 2012). However, in practice, implementing balanced exploitation faces substantial obstacles, in particular for pelagic fisheries. Fisheries managed via a system designed to achieve balanced exploitation would still require selective fishing and gear to provide for sustainable fishing mortality levels of vulnerable species, keystone and foundation species critical for regulating ecosystem structure and processes, and phylogenetically distinct species relatively important for evolutionary processes. Implementation would require overcoming the history of exploitation, market demand and fishing technology. Primarily in developed countries where there are high discard rates due to markets only for a narrow range of seafood products, balanced exploitation would require developing or augmenting markets for currently non-utilized or underutilized species, sizes and sexes (e.g. 'bycatch bank' in Iceland, Clucas 1997) to create demand for their supply at sustainable mortality rates, and avoid dumping of retained but unwanted bycatch following landing (Hall *et al.* 2000; Kelleher 2005), and might require the development of new fishing technology to efficiently catch previously non-targeted resources. Figure 2 exemplifies this obstacle using a hypothetical pelagic ecosystem. Effective implementation of balanced exploitation would further require accounting for all sources of anthropogenic fishing mortality, and not just spatially explicit fishing mortality. For example, a pelagic longline fishery managed under a system adopting balanced exploitation may need to establish limits for pelagic seabird fishing mortality through a population viability assessment that accounts for all mortality sources within marine and terrestrial habitats; thus, a prerequisite for balanced exploitation might be complex integration of spatially explicit planning for all areas of the distributions of these migratory species.

Effective transition to marine ecosystem-based management will also require moving from piecemeal management of human marine activities by sector, species or issue to cross-sectoral, spatially explicit planning (Pikitch *et al.* 2004; Crowder and Norse 2008; Douvre 2008). Marine spatial planning involves the holistic, integrated governance of all place-based ocean activities, achieved by planning uses of marine areas to avoid and minimize conflicts, and to sustain ecosystem integrity and services (Crowder and Norse 2008). The combined efforts of RFMOs alone will not effectively address environmental impacts of a wide range of ocean industries. For example, in addition to bycatch mortality, sea turtle, seabird and marine mammal populations are subject to a wide range of other anthropogenic mortality sources, where effective governance of multiple mortality sources can be necessary to prevent or reverse declines (e.g. FAO 2010b). Furthermore, successful mitigation of the main global drivers of change and loss in marine biodiversity that adversely affect the fishing industry but are nominally caused by this industry sector, including marine pollution, climate change, habitat degradation and the spread of invasive alien species, will increasingly require

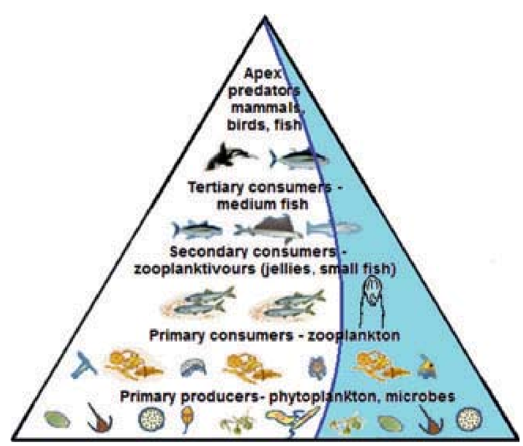

Figure 2 Balancing fisheries exploitation by taking a slice across and within ecosystems' trophic levels at sustainable levels according to natural production capacities. This faces substantial obstacles in practice, where, using a hypothetical pelagic ecosystem, with shaded area indicating sustainable fishery removals, this would require developing markets for currently unutilized and underutilized species, and require accounting for all sources of anthropogenic mortality across marine and terrestrial ecosystems for highly migratory species like seabirds and sea turtles.

effective collaboration of multiple industry sectors (FAO 1999c).

Numerous obstacles limit RFMO progress in transitioning to an ecosystem approach to fisheries management. These include a lack of an agreed methodology and process tools, absence of agreed ecosystem-level indicators and thresholds, and difficulty agreeing on place-based ecosystem management objectives across interest groups often with divergent aims (Tallis *et al.* 2010). Limited progress is also due to large gaps in knowledge of individual ecosystems as well as functional links between ecosystems, where few general rules of community ecology are applicable across ecosystems, and there is limited knowledge of pre-exploitation conditions with which to define reference states (Lawton 1999; Jordan 2009; Gislason *et al.* 2000; Gilman *et al.* 2011). And to develop reliable ecosystem models, for some species, there is a need for improved knowledge of basic life-history characteristics (e.g. pelagic sharks, Musick *et al.* 2000). Furthermore, poor data quality, in particular for non-target species and for cryptic sources of fishing mortality, reduces the certainty of ecosystem model outputs (Hall and Mainprize 2005; Link 2005; FAO 2011a; Gilman *et al.* 2012a). Due to these obstacles, it is necessary for RFMOs to gradually incorporate elements of an ecosystem approach to fisheries management into their existing fisheries management systems, and it is possible for even RFMOs that currently have rudimentary management systems and substantial governance deficits as highlighted in this study to make this gradual transition (Bianchi and Skjoldal 2008).

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Data S1. Criteria suite for performance assessment of bycatch governance by regional fisheries management organizations.