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Extent and implications of IUU catch in Mexico's marine fisheries

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ABSTRACT

It is well recognized that not all fisheries catches are reported or recorded properly by either government or non-government agencies. These unreported catches can be illegal, of unregulated species, or simply not monitored due to logistical barriers. In Mexico, these barriers are an extensive and often not easily accessible coastline, mostly *de facto* open access fisheries, poor administrative practices and generalized corruption in the fishing sector as a whole. These conditions were likely promoted early in the last century through the government's largely successful policies to increase fisheries catches and stimulate employment and economic growth. Many years later and amid declines in fish stocks and subsequent economic benefits, most notably at local scales, it is evidently time for a fundamental change in strategy away from expansion of fishing effort and toward ecological and economic sustainability. An important step in this endeavor is to provide a quantitative *pre-mortem* analysis of Mexico's total marine fisheries catches during the last half-century. Results suggest that from 1950 to 2010, total catches were nearly twice as high as the official reports, with an average annual catch of 1.5 million tonnes (t) compared to 796 thousand t in official statistics. In the last year of available data, 2010, official and total estimated catches were 1.5 million and 2.2 million t, respectively. While these results may be perceived as a criticism of the *status quo* and *ante*, this study actually does not single out a responsible party, but is, rather, a call to the many sectors of society who contribute to a lack of control, to help overcome these conditions, and increase and sustain the benefits from Mexico's marine fisheries.

1. Introduction

The most important lesson learned after a century of modern fishing is that the world's oceans are not inexhaustible, as previously held both in popular and academic circles e.g., [1,2]. Since this (opportune) realization, the main endeavor of the fisheries science community has been to develop quantitative methods by which fish stocks can be monitored and assessed in order to gauge their status with respect to given management reference points e.g., [3–7]. The single most important component of these status indicators is some metric of the catch of a given stock, and it thus has received the most attention in terms of data gathering both at the local and global scale, with a global database of catches since 1950 maintained by the FAO [8]. Though the potential and limitations of catch as a stand-alone indicator of fishery status has been extensively discussed e.g., [9–12], there is no debating that it is the foundation for nearly all other assessment methods, and the only information freely collected by fishing fleets. The current sub-optimal state of most marine fish stocks [13] has prompted organizations at the international, regional and national level to confront fisheries issues with management decisions, with the reliability of catch statistics being of particular concern.

Fisheries in Mexico, reflecting the overarching political system, have historically been characterized by constant shifts in objectives and management schemes [14]. They have thus evolved from an overlooked sector, to a primary source of food and job creation, to a casualty of neo-liberal reform and now to the object of an apparent tug-of-war between laissez-faire management on the one hand and ecological conservation priories on the other [15]. The participation and influence of scientists, academics and conservation organizations in fisheries management has also evolved towards a more holistic understanding of the social, political and ecological context of Mexican fisheries, with an increase in training in and application of novel quantitative methods to assess national fisheries' status [16]. Unfortunately, a lack of effective fisheries governance in general, and catch monitoring in particular, has resulted in highly uncertain fishery statistics, which often lack the quality to be informatively used within quantitative assessments that reflect reality.

Illegal, unreported and unregulated (IUU) fishing is a significant issue all over the world, and can seriously misrepresent fish production at any level [17,18]. In Mexico, a large fishing sector (> 300,000 fishers), versatile boats and gear, an extensive coastline, corruption and a limited capacity for monitoring and enforcement result in significant IUU catch [19]. Even in the case

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of legal fishers, official statistics rely on the compulsory but unenforced submission of catch logs by fishers or buyers to the local fisheries office. In both cases, there is no further validation of catch, and catch logs are often filled in on the spot (and often for a fee) by fishery officers based on the fishers' memory of past catch [20]. A survey of Mexican fishery experts including scientists, officials, fishers and others, found that in some fisheries, "irregular" fishing (unreported and illegal) currently represents 40%–60% of reported catch [21]. This estimate does not account for discards in shrimp trawls, which historically have had a 1:10 shrimp to bycatch ratio and are widely regarded as the single most important source of unreported bycatch [22].

In light of the apparent disconnect between the recognized importance of catch statistics for management and the state of data monitoring in Mexico, alternative methods must be used in order to provide better estimates. Catch reconstructions have been employed extensively to address this issue e.g., [23,24], under the fundamental thesis that "unknown catch" does not equal "zero catch" [25]. Although this is a simple and logical observation, attaching numbers to qualitative knowledge is powerful in conveying the seriousness of the issue and the need for action; this is indeed the main objective of the present study. Following this principle, we provide the first comprehensive estimate of unreported fisheries catches in Mexico, from 1950 to 2010.

2. Methods

The philosophical core of the reconstruction method is that, when it is recognized that catch in official statistics is incomplete but the magnitude of missing catch unknown, a well-informed estimate should replace a zero value [25]. Information can come from a variety of sources, including peer-reviewed literature, gray literature and expert knowledge, but every attempt is made to employ it in a conservative manner [26]. The main difference between the methods used for this reconstruction with respect to those used in the past is that the focus is on reconstructing catch series by particular species, rather than by a fishery sector. The reconstruction of Mexico's marine fisheries catch was thus undertaken within a structured database as explained below. Specific estimation methods for each fishery are presented in Appendix A (supplementary online material).

Statistics for marine fisheries catch by Mexico within its EEZ from 1950 to 2010 were extracted from the FAO database (〈http://www.fao.org/fishery/statistics/software/fishstat/en〉), where catch is specified by FAO area. Due to significant inconsistencies identified in data available directly from the national fisheries agency (see Section 4), these FAO catch series formed the basis for subsequent estimations.

Mexico's subset of the FAO database consisted of 192 individual catch series (96 each for the Pacific and Atlantic Oceans) of varying taxonomical precision, with catch reported by year from 1950 to 2010. A series of descriptive categories were assigned to each catch series, and to every reconstructed series, and included

a. FAO Name: the name for the species or species group as it appears in the FAO data.
b. Taxon: scientific name for the group, as precise as possible.
c. Group: elasmobranchs (e.g., sharks, rays), large pelagic fish (e.g., tunas, jacks), small pelagic fish (e.g., anchovies, sardines), benthopelagic fish (e.g., snappers, triggerfish), benthic fish (e.g., flounders), cephalopods (e.g., octopus, squids), gastropods (e.g., abalone, snails), bivalves (e.g., clams, mussels), echinoderm (e.g., sea cucumbers, sea urchins), other (e.g., seaweeds).
d. Target: main target of fishery (e.g., the "tuna" or "shrimp" fisheries use specific gears but catch many species other than shrimps and tunas, both targeted and as bycatch).
e. Sector: artisanal (open deck, outboard or no engine), industrial (covered deck, inboard engine), recreational (food or sale are *not* the main motive for fishing), subsistence (catch kept for consumption in the household).
f. Type: reported (FAO statistics), unreported legal (non-quantified catch by fishers operating legally), unreported illegal (non-quantified catch by domestic fishers operating illegally in any way), unreported discard (non-quantified discarded catch).
g. Area: Pacific, Atlantic.
h. Individual reference: a binary variable denoting whether specific information related to unreported catch was found for a given fishery.
i. Interpolated: a binary variable denoting whether a time series of catch was interpolated to fill data gaps.

Once the initial database was compiled as outlined above, the reconstruction was undertaken within its framework. For each catch series in the FAO data, the first step was to seek all available information related to the fishery, including gear types employed, observed bycatch (and discard) rates and species, and governance characteristics. Two initial sources of information were invaluable in this respect. The Mexican National Fisheries Charts [27–29] are official documents that list all species recognized as fished, and include a brief summary on every major commercial fishery by area; the assessment and management "Red Book" [30] contains reports on all currently assessed species. If no information was found to justify clear gaps in a catch series, these were linearly interpolated. This included missing data in the first years of recorded catch. For example, if the first four years of a catch series were missing and the fifth was 500 t, the first year was assigned half the value of the fifth (thus assuming the fishery had not grown from zero catch in 1950) and the other years linearly interpolated. Or, if catch records were missing from, say, 1960–1965, these were linearly interpolated from reported catch in 1959 and 1966. Interpolated catch was designated as unreported and used as the new baseline for subsequent estimations of unreported catch.

Whatever specific information was found for a given catch series was used to estimate the magnitude of unreported catch, expressed as a ratio relative to reported catch and then converted into (metric) tonnes (t) per year and entered as new catch series in the database (including the appropriate descriptors). According to an extensive survey of fishery experts in Mexico, on average (over several fisheries) unreported ("irregular") fishing contributes a further 45% of catch (90% of which is illegal) relative to reported landings [21]. Around half of illegal catch is subsequently bought by processors and reported with legal catches (second author's pers. obs.), so these would appear in FAO statistics. A conservative ratio (relative to reported catch) of 15% for unreported legal catch and 22% for unreported illegal catch were added to current reported catches when no other information was available for a specific fishery, or in the case of the broadly defined finfish (*escama*) fishery. According to fishers and buyers, legal unreported catches have decreased during the last decades due to improvements in monitoring, while unreported illegal catch has increased due to a growing number of fishers and the addition of fishery regulations. Therefore, the ratio of unreported legal and illegal catch from 1950–2010 were assumed to vary linearly, from 40% to 15% and from 10% to 22%, respectively. Due to a general lack of data, we were not able to apply sensitivity analyses directly; however, we calculated and report confidence intervals of $+/-15\%$ applied to resulting aggregate catch estimates (based on variance of expert opinions reported in [21]).

A major component of unreported catches in Mexico is bycatch in the shrimp fishery, particularly by industrial bottom trawlers. The high economic value of shrimp results in discarding of bycatch species, which are high due to the tropical environments in which shrimp are caught, and the unselective gears that are used. Catches were first separated into artisanal and industrial sectors based on the historical number of vessels by sector (1970–2007 from [31], other years linearly extrapolated) and current catch ratio [29]. Shrimp catches (which are often reported in aggregate) were split into species based on available yearly catch ratios [27,29] and the average ratio when data were unavailable. Shrimp to bycatch ratios for industrial fisheries were 1:10 and 1:3 for the Pacific and Atlantic Ocean, respectively [32] and, for artisanal fisheries, 1:3 for legal gears and 1:10.5 for illegal gear in both oceans [33]. Bycatch composition and discard rates were variable, with the discard rate reported as being higher in the Pacific and in the industrial fishery [22,32,34,35]; see Appendix A, supplementary online material.

Specific estimation procedures for each fishery are included in Appendix A (Pacific Ocean) and (Atlantic Ocean) (supplementary online material).

Published references regarding unreported catch in Mexican fisheries are scarce, so assumptions on their magnitude were necessary in several cases and are acknowledged as such. This study is intended to be the first iteration in an ongoing effort to improve Mexican fisheries catch statistics, and the resulting catch database is freely available from the first author upon request. Proposed revisions to one or several catch series by other researchers can then be discussed and the database (and documentation) updated.

3. Results

From 1950 to 2010, total unreported catch was estimated at over 44 million t, equal to 91% of official landings as reported to the FAO (48.4 million t). Even with our conservative estimation methods and allowing for potential error in the ratios applied, total reconstructed catch was and remains almost two times higher than official catch as reported to the FAO (Fig. 1). On average during the past 61 years, total reconstructed catch (reported + unreported) was over 1.5 million t/year, compared to 796,000 t/year in the official statistics (Table 1).

Estimated catch by type during the study period are presented in Fig. 2. Catch of Pacific sardine (*Sardinops sagax*) is excluded from this figure, as the high and currently increasing catch of this small pelagic fish can mask overall catch trends.

A total of 192 entries, 96 per ocean, are reported in FAO catch statistics, corresponding to 148 taxa, though five corresponded to marine mammals and reptiles, not considered in this study. The resulting database of reconstructed catch includes 758 entries including reported and unreported legal, illegal and discarded catch by taxon, and a total of 243 taxa. Specific information regarding unreported catch was available for almost 40% of resulting time series, and 73 time series were interpolated to estimate obvious gaps in the time series, most in early years (see Appendix A, supplementary online material). Applying both stationary and varying estimation ratios (e.g., unreported catch, bycatch), to reported catch by species resulted in fluctuating ratios of catch by type, but with an overall decreasing trend in the rate of unreported legal catch and an increasing trend in unreported illegal catch.

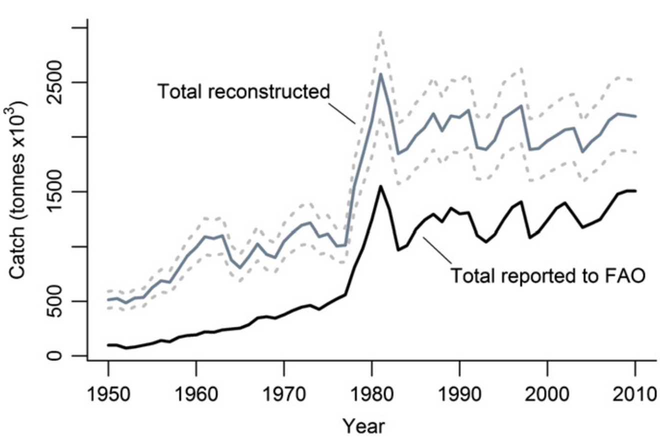

Fig. 1. Total Mexican fishery catch reported to FAO compared to reconstructed catches estimated in this study. Confidence intervals (dashed lines) around estimate represent +/−15% error.

Table 1
Summary of fishery catch statistics by type in Mexico, 1950–2010.

Type	Catch by period (t × 10^3) 1950	2010	Total (1950–2010)	Average/year (1950–2010)
Reported	97	1504	48,556	796
Total unreported	416	683	44,308	727
Unreported legal	322	255	14,480	233
Unreported illegal	76	170	5278	86
Unreported discards	17	258	24,648	404
Total	513	2188	92,864	1522

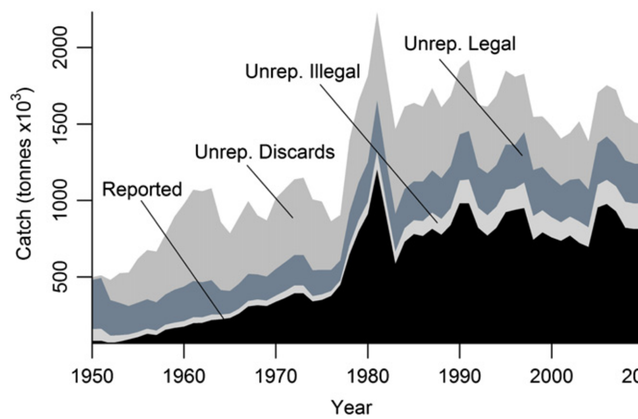

Fig. 2. Reported and reconstructed Mexican fisheries landings, by type (both oceans), excluding catch of Pacific sardine (*Sardinops sagax*).

In the aggregate, bottom trawls targeting shrimp have historically accounted for the highest total estimated catch (reported, unreported, illegal and discarded), with over 37 million t (54% of which was discarded) from 1950 to 2010, followed by finfish gillnets (*escama*; 24 million t), small pelagic seiners (19 million t) and large pelagic seiners and longlines (3.7 million t). Over the same time period, all other fisheries caught almost 11 million t (Fig. 3).

In terms of catch by species group, the highest total catch over the study period corresponded to benthopelagic fish (42.3 million; all catches in tonnes), followed by small pelagic fish (19.6 million), crustaceans (including crabs, lobsters and shrimps; 12.6 million), large pelagic fish (6.4 million), bivalves (3.1 million), cephalopods (1.9 million), elasmobranchs (1.8 million), benthic fish (1.8 million), seaweeds (1.7 million), gastropods (1 million), echinoderms (127 thousand) and unidentified invertebrates (83 thousand).

4. Discussion

Results show that from 1950 to 2010, total fisheries catch was almost twice as high as the official statistics as reported to the FAO (Table 1). As expected from qualitative observation, unreported

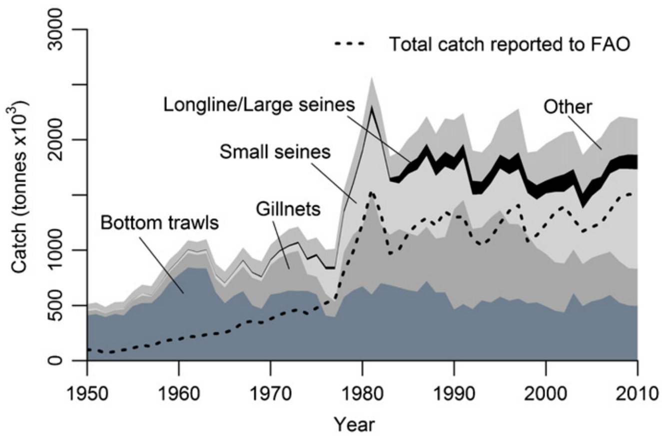

Fig. 3. Total reconstructed catch by major gear type, including all bycatch, for top four target fisheries with highest catch in Mexico (both oceans), 1950–2010. "Other" category includes hook and line, squid jigs, hand collection (intertidal and subtidal) and traps.

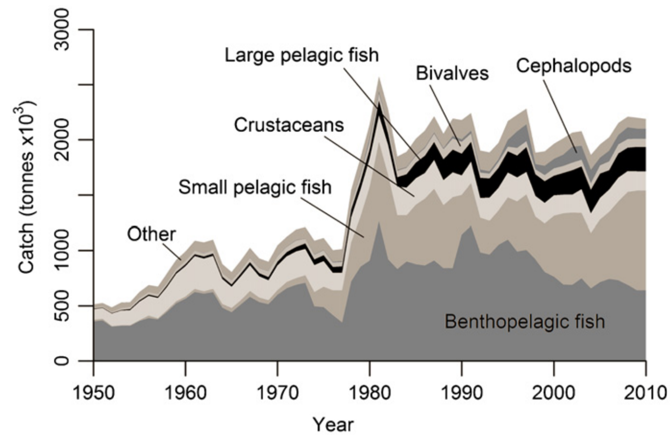

Fig. 4. Total reconstructed catch for taxa groups with highest catch in Mexico (both oceans), 1950–2010. "Other" category includes (in order of total catch) benthic fish, seaweeds, gastropods, echinoderms and unidentified invertebrates.

catch compared to reported catch was higher at the beginning of the study period (4.6:1 from 1950 to 1960). During this time, fishing cooperatives were granted exclusive fishing access, but there was little government interest or oversight of the sector until the creation of the National Fisheries Institute in 1962 [14]. Lack of regulation combined with the introduction of nylon netting and bottom trawl gear since the 1950s led to high unrecorded catch and discards (Figs. 1, 2), particularly in the Gulf of California shrimp and totoaba fisheries [36]. Management was strengthened by the onset of fisheries promotion programs in the 1970s, which were highly successful in increasing fish catches, but did so largely through extensive government subsidies to the fisheries sector, mainly for technology, infrastructure and fuel [15].

Four decades after the push for industrialized fisheries in Mexico, two main issues have arisen. First, as national fishing fleets are now large and relatively well-equipped, further subsidies only serve to finance overfishing, undermining the resource base and jeopardizing future ecological function and economic benefits e.g., [37]. Second, accustomed to ongoing economic incentives, the fishing industry's attitude and strategy follow the expectation of government support without accountability, which results in limited private innovation and investment in efficiency, not to mention a lack of effective management control [14,38]. Thus, the addition of potentially helpful policies intended to limit catch instead results in more unreported catch, now "illegal" (Table 1, Fig. 2). Nevertheless, the overall ratio of unreported to reported catch has decreased over time, from over 4:1 in 1950 to 0.45:1 in 2010 (Table 1). This partly follows from declines in overall catches, lower discarding ratios as more species are retained and landed, and the explosive growth of fisheries for small pelagics (Fig. 4), where almost all catch is reported. But, this also reflects improvements in monitoring capacity and disposition on the part of government agencies, and the work of research centers and non-government agencies within fishing communities to encourage documentation of landings and other pertinent information [16,39]. Total catch has remained relatively stable for the last three decades, though catches have diversified over time, with 40% of taxa present in catches in 1950 compared to 2010. The addition of these new fisheries (notably for jellyfish, squid and swimming crabs), along with recent increases in the abundance of small pelagic fish, have masked declines in catch of benthopelagic fishes and other groups for the last two decades (Fig. 4).

The simplest conclusion of our results is that Mexican fisheries catches are currently not fully captured within government statistics that are subsequently provided to, but differ from, the FAO data (Fig. 1; Table 1). The decision to use FAO data as a baseline for estimations followed from a thorough analysis of national data freely accessible from CONAPESCA (the national governing body for fisheries and aquaculture) in its statistical yearbooks, which revealed clear errors (e.g., identical reported catches for different groups, or abrupt and drastic spikes in catch series). As these discrepancies are largely absent from the FAO data for Mexico, the reporting process from dockside to national to FAO statistics is unclear. However, the fact that statistics are collected at a national level, compiled in a comprehensive manner (errors notwithstanding), and furthermore made freely available over the internet, is an important development in the management of national fisheries and allowed for a study of this scope to take place at all. In many cases, this included the ability to allocate catches by taxa of varying precision, which is invaluable for the application of informative stock assessments.

Quantitative fisheries analysis in Mexico has made significant advances over the last decades as better training and technology are more readily available. Indeed, all but two of the 17 marine fisheries in the official assessment and management reference book [30] incorporate stock assessment methods including age-structured surplus-production models, virtual population analyses, and bioeconomic models. Together with a wider inclusion of stakeholders into the management process [16], moving towards a quantitative understanding of the dynamics of fish stocks certainly aids monitoring of stocks and ecosystem status. However, the current deficiencies in recorded catch statistics as highlighted in this study raise questions about the results of confronting structured statistical models with highly uncertain data. Some metric of fisheries catch is the most important component of any stock assessment [6], so large discrepancies in recorded and true catch can result in erroneous estimates of the parameters and reference points that help inform management action. Furthermore, high uncertainty in parameter estimations following from errors can overwhelm inter- and intra-species interactions, negating the validity of the model itself [40]. Most of the species that are currently assessed do have relatively better catch monitoring in place, but an investment in recording full and accurate catch statistics (not to mention an updated estimate of nominal artisanal fishing effort, reported as static for the last 15 years) is *sine qua non* for the future expansion of stock assessment efforts. In the meantime, it would be highly advisable for any quantitative assessment to consider and present results for a wide range of potential parameter assumptions [41], even those as basic as the actual catch taken by a fishery.

Though discrepancies in reported and real catch have many implications for fisheries status assessments and management strategy, it is perhaps most troubling that in a country where 20 million people are undernourished (95% children; [42]), over 25% of fisheries catch over the last 60 years (currently 400,000 t/year) has been subsequently thrown overboard (Table 1). This highlights a pressing need for economic incentives that re-align these fishing strategies; it is here that subsidies could indeed play a role through development of novel processing methods [43], or perhaps helping enforce retention of bycatch, while boosting prices for "trash" fish that can then be transported and sold at a discount in key regions of the country. Fitting implementation of turtle and fish exclusion devices on trawl gear, which had the highest catch of any gear type (37 million t; Fig. 3), can significantly reduce catch of large fish and turtles [44], but reported bycatch ratios have nonetheless remained high during the entire study period [22,32,45]; Fig. 3 and exclusion devices are often de-activated at sea by fishing crews [46]. Bottom trawling is by no means the only gear type in Mexico with discards e.g., [19,33,47–49], but it is likely where the first efforts to combat this wasteful practice, both through avoidance and retention of bycatch, would be most fruitful [50]. Current Mexican law prescribes that bycatch limits must be set for all fisheries, yet thus far this has only been applied to billfish in commercial shark longliners [28,51]. As more fish stocks become fully or over-exploited, Mexico's fisheries will likely move toward a more efficient use of technology and enforcement to eliminate and/or efficiently use bycatch and discards. Our results provide a first estimate of the magnitude of these currently wasted resources.

This study provides the first estimate of total catch extracted by Mexican fisheries since the middle of the last century. Clearly, many assumptions are required for this type of undertaking [25], though every attempt was made to provide estimates that were both substantiated by available information and erred on the conservative side. The main foreseeable obstacle was a shortage of first-hand information about particular species or fisheries, but in the end, 40% out of a total of 243 taxa were supported by specific information, and sources for aggregate groups (e.g., finfish) most likely adequately represent many others [27–29]. The uncertainty associated with estimations given limited information requires that methods be clearly stated and every assumption made clear, hence the inclusion of methods and sources for each fishery (Appendix A, supplementary online material). Others are encouraged to question the methods used for a given fishery, analyze the raw results, and propose revisions to estimations if better information is available. Ideally, such revisions would update the current database and be included in a living document to that end.

From 1950 to 2010, total fisheries catch in Mexico, including both unreported legal and illegal catch and discarded bycatch, was almost twice as high as official statistics. This reflects a lack of clear policy to discourage such ill practices, as well as deficiencies in the reporting, monitoring and recording process which cannot be attributed to a single responsible party. Nevertheless, the fact that such a study was possible owes to advances in participation and interest in the sustainable use of the marine ecosystem, which we hope will continue and strengthen in the future, helping attain potential societal benefits. For this to become a reality, a change in culture must ensue including fishers, fishing leaders, field and administrative officials, technicians, researchers and all those involved in generating, collecting, processing, storing and publishing data and information. We have highlighted here the urgent need for reform in the fisheries sector; the question now is, where do we begin?

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.marpol.2012.12.003.

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