Toward sustainable harvest strategies for marine fisheries that include recreational fishing

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Abstract

Recreational fishing (RF) is a large yet undervalued component of fisheries globally. While progress has been made in monitoring, assessing, and managing the sector in isolation, integration of RF into management of multi-sector fisheries has been limited, particularly relative to the commercial sector. This marginalises recreational fishers and reduces the likelihood of achieving the sector's objectives, and more broadly, achieving fisheries sustainability. We examined the nature and extent of RF inclusion in harvest strategies (HSs) for marine fisheries across 15 regions in 11 nations, to define the gap in inclusion that has developed between sectors. We focused on high-income nations with a high level of RF governance and used a questionnaire to elicit expert knowledge on HSs due to the paucity of published documents. In total, 339 HSs were considered. We found that RF inclusion in HSs was more similar to the small-scale sector (i.e., artisanal, cultural or subsistence) than the commercial sector, with explicit operational objectives, data collection, performance indicators, reference points and management controls lacking in many regions. Where specified, RF objectives focused on sustainability, economic value and catch allocation rather than directly relating to the recreational fishing experience. Conflicts with other sectors included competition with the commercial sector for limited resources, highlighting the importance of equitable resource allocation policy alongside HSs. We propose that RF be explicitly incorporated into HSs to ensure fisheries are ecologically, economically, and socially sustainable, and recommend that fisheries organisations urgently review HSs for marine fisheries with a recreational component to close the harvest strategy gap among sectors.

Keywords: fisheries management, fishing objectives, multi-sector fisheries, recreational experience, sectoral equitability, harvest strategy components

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1. Introduction

Recreational fishing (RF) is an important component of fisheries globally, particularly in high-income nations. While participation varies considerably among regions, approximately 10% of the developed world fishes recreationally (Arlinghaus et al., 2015, 2019). Retained catch by recreational fishers has been estimated at 17 billion fish per year or 12% of total global fisheries harvest by weight (Cooke and Cowx, 2004). For numerous stocks, recreational harvest represents a significant proportion of the total catch (Coleman et al., 2004; Cooke and Cowx, 2006; Ihde et al., 2011; Brown, 2016; Hyder et al., 2018; Radford et al., 2018; Lewin et al. 2006, 2019), highlighting the need to account for RF with respect to resource sustainability (McPhee et al., 2002; Post et al., 2002; Ihde et al., 2011; Radford et al., 2018). The socio-economic scale of RF is also substantial; ~190 billion USD is spent on RF per year (World Bank, 2012) with ~1 million jobs attributable to the activity worldwide (Arlinghaus et al., 2002; Steinback et al., 2004; Cisneros-Montemayor and Sumaila, 2010; Hyder et al., 2018).

Despite the significance of RF, governance of the activity is often limited relative to commercial fishing, especially in the marine realm. Many nations do not include RF in their fisheries policies or governance structures (Bower et al., 2020), and when the activity is included, management approaches are often unsuitable or poorly implemented (Arlinghaus et al., 2019; Potts et al., 2020), although the extent of this varies greatly among nations and regions. In a recent survey of fisheries experts from 28 nations, less than a quarter of respondents thought that RF was managed effectively, with most noting that management of industrial and small-scale fisheries was superior (Potts et al., 2020). In addition to increasing the risk of overfishing, the omission of RF from management processes decreases the likelihood of achieving desirable fishery performance for recreational fishers, while generating inequality and conflict among sectors. The need to develop management frameworks that integrate RF with other sectors has been repeatedly identified as important (Arlinghaus et al., 2019; Hyder et al., 2014, 2020; Fowler et al., 2022; Holder et al., 2020), but implementation has generally been slow.

Harvest strategies (HS) offer a means to integrate RF into the monitoring, assessment and management of fisheries that also include a commercial or small-scale sector (hereafter

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termed 'multi-sector fisheries'). Sometimes referred to as management strategies (Butterworth and Punt, 1999; Dichmont et al., 2020), HSs are increasingly being used to manage fisheries as they are an improvement on previous approaches that were associated with fishery collapses (Sainsbury et al., 2000; Dowling et al., 2020). HSs are a formal framework that specify fishery objectives and how they are to be achieved, via pre-determined monitoring, assessment and management rules that control fishing mortality by adjusting harvest, along with metrics that must be met for success (Sloan et al., 2014). Performance indicators, either empirical or arising from a model-based assessment, are compared to reference points that identify both a desirable fishery state (target reference point) and an unacceptable fishery state (limit reference point). Trigger reference points may also be used between the target and limit reference points to facilitate early intervention before the limit is reached (Table 1). By having pre-specified management controls that are explicitly linked to performance measures (the value of indicators relative to reference points) and drive a fishery towards its target, HSs are more likely to achieve desirable outcomes compared to previous management approaches (Froese et al., 2011; Dowling et al., 2015a). For example, modelling of biomass for North Sea herring (*Clupea harengus*) and blue whiting (*Micromesistius poutassou*) during a historical period indicated that application of a basic management control linking harvest levels to maximum sustainable yield (MSY) would have maintained stock biomass considerably closer to target than the actual stock at the time and may have prevented the collapse of the North Sea herring stock during the 1970s (Froese et al., 2011).

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To deliver effective outcomes across all fishery sectors, HSs must acknowledge and serve the objectives of all sectors that utilise the resource (Pascoe et al., 2019; Dichmont et al., 2020; Dowling et al., 2020). Involving all sectors in HS development is also important for identifying mutually-acceptable HS components, including reference points, monitoring methods, and management actions, and for identifying and addressing potential conflicts, to the extent possible within the scope of a HS (Hilborn, 2007). Given some inherent differences between sectors, the exclusion of one from HS development may result in reduced fishery performance for that group - in the worst-case scenario, systematically disadvantaging them and limiting information that can provide for the sustainable management of the resource. HSs have commonly been applied to fisheries with a large commercial sector that provides sufficient data to support model-based stock assessment (Dowling et al., 2015a). However, monitoring and assessment can also be achieved using empirical performance indicators such as catch-per-unit-effort (CPUE) (Dowling et al., 2015b), which are in many cases more readily available from RF data sources (Fowler et al., 2022). Multiple indicators, potentially from different sectors, can also be combined to jointly monitor fishery performance and inform management actions within a HS (Harford et al., 2021).

HSs also provide a partial means of managing the ‘human dimension’ of RF. Many objectives (or motivations) of recreational fishers are social (Arlinghaus, 2006; Magee et al., 2018; Fowler et al., 2022); for example, catching trophy fish or obtaining a family meal (Graefe, 1980; Pascoe et al., 2019). These types of objectives are rarely acknowledged explicitly in fisheries management, mirroring a broader challenge to directly address social objectives in institutional approaches for fisheries sustainability (Stephenson et al., 2018). However, due in part to the emergence of ecosystem-based fisheries management (EBFM, FAO, 2003; Pikitch et al., 2004), there is an increasing focus on social objectives and their inclusion in HSs alongside the more common ecological and economic objectives (termed the "triple-bottom-line" [TBL] HSs, Smith et al., 2007; Fletcher et al., 2016; Stephenson et al., 2017; Dichmont et al., 2020). HSs with different types of objectives can be challenging to implement due to the trade-offs between competing objectives and varying priorities among stakeholders, rights-holders, and other user groups. Yet, recent research indicates the potential for optimisation across numerous objectives within complex multi-sector fisheries (Dichmont et al., 2020; Dowling et al., 2020). HSs may therefore be used to address socio-economic aspects of multi-sector fisheries (including RF), alongside ecological objectives.

As HSs are increasingly applied to more complex multi-sector fisheries (Dichmont et al., 2020), there is a need to understand the nature and extent of RF inclusion in existing strategies, to define the current gap in inclusion between sectors and inform development of equitable strategies into the future. To address this, we examined RF inclusion in HSs for multi-sector marine fisheries in 15 regions of 11 nations. We focused on marine fisheries, because these more commonly involve multiple sectors, and on nations identified as having

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effective RF management (see Methods), because these are most likely to include RF in HSs when the sector is present. Specifically, we aimed to: 1) characterise the multi-sector marine fisheries that involve the RF sector with respect to: a) the other sectors involved, b) the environments fished, c) the gear types used, and d) whether RF occurs from shore or boat; 2) determine the elements specified for RF in HSs compared to those for other sectors, including performance indicators and management controls; and 3) identify the types of fishing objectives specified for RF and potential conflicts with other sectors. We discuss the risks associated with the observed exclusion of RF from HSs, both for achieving fishery performance for the sector and ensuring the sustainability of marine multi-sector fisheries.

2. Methods

Nations were selected on the basis of an “average” or “good” score regarding the efficacy of RF management, as determined by Potts et al. (2020), and the availability of suitable experts (see below). We focused on nations with relatively RF management because HSs from these nations are most likely to include RF where the sector is present within a multi-sector fishery. Canada was included despite a “poor” score being recorded for the province of British Columbia because of the explicit incorporation of RF in fisheries policy at multiple jurisdictional levels (Potts et al., 2020). Two additional inclusions were the UK and São Paulo state, south-eastern Brazil; the former provides a contrasting case study of emerging RF management in a high income country, while the latter provides a case study of high RF participation in a low or middle income country.

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Expert knowledge was used to obtain information on HSs, because these documents are often not publicly available, or are contained within ‘grey’ literature that is difficult to locate using internet searches. Terminology for the same HS components also varies among regions, which may be misinterpreted by external practitioners, and language barriers provide additional challenges to HS interpretation. An expert can be defined as anyone with relevant and extensive or in-depth knowledge of a topic of interest that is not widely held by others (Krueger et al., 2012; Martin et al., 2012). Experts for the current study were mostly identified from the primary literature on RF. Some of these individuals identified additional experts in their nation to assist with specific regions. Based on expert recommendation, two nations were divided into separate regions for analysis; the United States (U.S.) was divided into four regions (NW, NE, SW, SE) and Spain was divided into two regions (Atlantic and Mediterranean). Experts included fisheries scientists, managers, and economists with 6 - 36 years of experience within their nation, as well as some with extensive international experience in fisheries research. All had experience with RF, and most experts indicated additional experience with either commercial or small-scale fisheries.

We used a multiple-round expert elicitation process based on the approach outlined in Martin et al. (2012). A questionnaire was used to elicit knowledge in three main areas: 1) the characteristics of multi-sector marine fisheries that involve the RF sector in the expert's region or nation; 2) the elements of a HS that have typically been specified for each fishing sector; and 3) the types of RF objectives addressed by HSs and the nature of any stated conflicts between sectors. Three fishing 'sectors' were considered – recreational, commercial, and small-scale. Recreational fishing is defined as "fishing of aquatic animals (mainly fish) that do not constitute the individual's primary resource to meet basic nutritional needs and are not generally sold or otherwise traded on export, domestic or black markets" (FAO, 2012; Hyder et al., 2020). While it is acknowledged that small-scale fisheries are diverse and an all-encompassing definition is challenging (Kurien and Willman, 2009), for the purposes of this study we consider the small-scale 'sector' to encompass typically traditional fishing involving households (as opposed to commercial companies), using a relatively small amount of capital and energy, relatively small fishing vessels (if any), making short fishing trips, close to shore, and mainly for local consumption (FAO, 1999; Di Cintio et al., 2022). Small-scale fishing includes subsistence, cultural and artisanal activities, where catch from the latter may be sold but only in small quantities to local markets. Commercial fishing was considered to be any fishing activity where the catch is sold and the operation is more substantial in scale than that encompassed by our small-scale definition.

The HS elements evaluated were those identified by Sloan et al. (2014) and are outlined in Table 1. Both conceptual (qualitative) and operational (quantitative) objectives were examined, to distinguish between qualitative consideration of RF objectives and their explicit operationalisation within a HS framework. Management controls (decision rules) were specifically examined, to distinguish whether these were dynamic, that is, adjusted in

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response to assessment outcomes (e.g., increase and decrease of total allowable catch [TAC]), or merely statically applied (e.g., gear restrictions).

Following the initial elicitation round of the questionnaire, responses were screened for potential errors related to misinterpretation and experts were individually contacted to clarify their responses. Experts were then provided with the preliminary results and given an opportunity to modify their responses.

Responses to most questions were provided on an ordinal five-point scale; “almost never” (1), “rarely” (2), “often” (3), “mostly” (4), and “almost always” (5). This standardized the responses and facilitated direct comparison among sectors. Approximate proportional values were also assigned for each response category (e.g., mostly: ~75% of the time) to assist comprehension and reduce procedural variability among experts. A small number of responses were short-answer format. When answering questions, experts were asked to consider all HSs for multi-sector fisheries that involve the RF sector in their region or nation. HSs are not necessarily developed for all multi-sector fisheries, so the number of HSs in a region is a subset of the number of multi-sector fisheries.

To limit misinterpretation biases, experts were provided with a defined scope and instructions for completing the questionnaire, including definitions of terms and a worked example. To ensure a focus on true HS, experts were asked to avoid high-level management plans that provide only broad (conceptual) objectives, lack other HS components, are not stock-specific, and do not explicitly aim to control harvest. The questionnaire was distributed via email and completed remotely, rather than in a shared environment, reducing the influence of group-based biases, including dominant personalities, subset polarization, and ‘group-think’ (Martin et al., 2012). A comments section was provided, allowing experts to clarify responses if they thought it necessary.

Questionnaire data were explored using a combination of summary statistics and quantitative analyses. Medians and interquartile ranges were used to facilitate comparisons among groups based on ordinal scores. Permutational Multivariate ANOVA (PERMANOVA+, PRIMER-E) was used to test for differences in the suite of specified HS elements between

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sectors and principal coordinates analysis (PCO) was used to visualise the separation (Anderson et al., 2008). Permutations were based on a Euclidean distance matrix. Namibia was excluded from statistical analyses because only one HS has been developed for a multi-sector fishery that involves the RF sector.

3. Results

3.1 RF in marine multi-sector fisheries

The RF sector shares removals from marine stocks with both commercial and small-scale sectors in nearly all regions examined, but the relative extent varies considerably (Figure 1). In most regions, the RF sector shares stocks more often with the commercial sector than the small-scale sector. This is "almost always" the case in Spain - Atlantic, the UK, and Canada, and "mostly" the case in Japan, Australia and the eastern regions of the U.S. The opposite was reported in Germany, São Paulo - Brazil, Namibia and Spain - Mediterranean, where the RF sector more commonly shares marine stocks with the small-scale sector. In the Bahamas and Norway, the RF sector shares marine stocks equally with commercial and small-scale sectors.

RF, as a component of multi-sector marine fisheries, was reported to be more prevalent in the coastal nearshore environment and estuaries than offshore (Table 2). However, there were numerous exceptions; for example, RF in the Bahamas was more prevalent offshore and within estuaries than the coastal nearshore. Shore-based fishing was generally more prevalent than boat-based fishing, except in Canada and São Paulo - Brazil, where the opposite was reported. Both types were equally prevalent in Norway (Table 2).

As expected, the range of fishing gear types used by the RF sector within multi-sector fisheries was considerably narrower than other sectors (Figure 2). Hook-and-line was "almost always" used, with spear, pot or trap, and hand collection methods receiving median scores between "often" and "rarely" (2.0-2.5, Figure 2). The recreational use of mesh/gill nets, dip nets, and cast nets was reported from some regions.

3.2 HS elements specified for each fishing sector

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In total, experts considered 339 harvest strategies for marine multi-sector fisheries with a RF sector. Regions with the greatest number of HSs considered were the U.S. - SE, Norway, and Japan, while those with the fewest were Germany, São Paulo - Brazil, and Namibia (Figure 1).

The combined suite of HS elements specified for the RF sector differed to those from the commercial sector (pseudo-t = 2.638, p = 0.009) but was similar to those from the small-scale sector (pairwise PERMANOVA, pseudo-t = 1.674, p = 0.090; Figure 3). A breakdown of scores for individual HS elements (see definitions in Table 1) indicated that all elements were more frequently specified for the commercial sector than either the RF or small-scale sector (Figure 4). RF was "almost never" (1) or "rarely" (2) mentioned in HSs from 40% (6 out of 15) of regions. In contrast, the commercial sector was at least "often" (3) mentioned or "almost always" (5) mentioned in 73% (11 out of 15) of regions (Figure 4). Exceptions were the four U.S. regions, which reported identical inclusion of all HS elements for both the RF and commercial sectors. Excluding the U.S., the least frequently specified HS elements (scoring "almost never" [1]) for RF were the three types of reference points (Limit, Trigger and Target), followed by operational objectives and dynamic management controls. These elements relate to quantitative monitoring and management, the associated values of which can be challenging to specify for RF. These HS elements were also the least frequently specified for the small-scale sector. Target reference points and management controls were the least frequently specified elements for the commercial sector.

The lowest scores for the RF sector across all HS elements were reported from the two case study regions of the UK and São Paulo, Brazil (Appendix 1). Elements were "almost never" (1) specified for RF in HSs in these regions, with the exception of data collection in the UK, which was "almost always" (5) specified, and management controls in São Paulo, which were "rarely" (2) specified. These scores contrasted strongly with those for the commercial sector in the same regions, with HS elements "almost always" specified in the UK and "rarely" to "mostly" specified in São Paulo.

Despite the relatively infrequent inclusion of RF in HS, experts from 87% (13 out of 15) of regions reported that inclusion has increased through time. Two exceptions were Namibia,

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where inclusion has reportedly decreased, and the U.S. – SW, where RF inclusion has reportedly been stable for the past decade.

3.3 Types of objectives specified for the RF sector in HSs

Fishery sustainability was the most frequently specified objective for RF and was included in HSs from all regions that reported specific objectives for the sector (13 regions, Table 3). The next most frequently specified objectives were maintaining catches within the RF sector allocation, maximising RF value, and catching many fish. Few regions reported social objectives that were unrelated to catch, such as enhancing social networking and spending time with friends and family. Exceptions to this were Norway and Spain – Mediterranean, which indicated that the objective "enjoying the outdoors/communing with nature" was "almost always" (5) and "mostly" included in HSs from these regions, respectively. Norway also listed "spending time with friends and family" as "mostly" included.

The breadth of RF objectives included in HSs varied considerably among regions (Table 3). Spain – Mediterranean included all objectives for the sector at least "rarely" (2), with the exception of maximising bite (strike) rate. The U.S. – NE included all catch-related objectives but none of the non-catch-related objectives. Regions with fewer RF objectives focused on fisheries sustainability, maintaining catches within the RF sector allocation, maximising RF value, and catching many fish (e.g., Australia, UK).

3.4 Conflicts specified in HSs

The inclusion of known conflicts between sectors in HSs also varied considerably among regions (Figure 5a). Even within the U.S., conflicts were "almost always" included in HSs from the U.S. – NE and U.S. – SE but rarely in HSs from the U.S. – SW. Conflicts were mostly between the RF and commercial sectors, rather than the RF and small-scale sectors (Figure 5a). Conflicts with the RF sector were mostly related to competition for a limited resource, especially with respect to allocation of that resource (Figure 5b). Other conflicts included different regulations between sectors and perceptions of unfairness, access rights, and a lack of appreciation for subsistence fisheries. Note that many of these cannot be directly addressed within a HS, but an inclusive HS may mitigate these conflicts to some extent.

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4. Discussion

The limited inclusion of RF in HSs identified in the current study, together with the fact that RF plays a significant and often increasing role in the harvest of marine resources, raises uncertainty regarding the sustainability and management of marine multi-sector fisheries. Experts from numerous regions reported that RF was not even mentioned in HSs for fisheries where the activity was undertaken. The risks of not effectively including the RF sector in HSs are ecological, social and economic, stemming from: 1) reduced likelihood of achieving fishery performance for the RF sector, to the point of systematic disadvantage, 2) uncertainty regarding the impacts of RF on target stocks and the broader ecosystem, and 3) inequity among sectors, including reduced accountability of the RF sector for its contribution to fishing mortality. Given our focus on nations with relatively efficient RF governance (Potts et al., 2020), the issue is likely widespread and potentially more severe in nations with less effective policy and legislation regarding RF.

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Omitting or only partially including RF in HSs reduces the likelihood of delivering optimal fisheries performance because the processes required to achieve fishing objectives are not established. For HSs to function effectively, conceptual objectives must be translated into operational objectives, against which the performance of a fishery can be monitored using indicator metrics. Yet, operational objectives were one of the least frequently specified HS elements for the RF sector. Compounding this issue was the lack of reference points specified for the RF sector in many regions. Reference points provide both a target to aspire to and a limit below which fisheries performance is considered unacceptable. Without reference points, fishery performance cannot be explicitly assessed against the level required to achieve objectives. The risk of shifting baselines is also heightened because a reference of past performance is not formally retained (Pauly, 1995). Critically, the absence of a limit reference point for ecological objectives risks management inaction during a period when overfishing may be occurring (see Post et al. 2002, for example). While management decisions can be made *ad-hoc*, their pre-emptive development and automatic application at particular levels of fishery performance is a requirement of HSs that provides certainty for stakeholders, rights-holders, and user groups while also optimising resource protection. It also avoids the need to reactively develop socio-economically detrimental management measures during periods of poor fishery performance that could disproportionately penalize one sector.

As stated, the formal incorporation of RF objectives into HSs necessitates the translation of each conceptual recreational objective to an operational objective, associated with a quantitative performance indicator. These may be calculated either directly (empirically) measured, or analytically derived from a quantitative stock assessment. They can then either directly inform a harvest control rule, and the resultant adjustment of management measures, or they can be used to evaluate the performance of the HS. For example, a performance indicator of strike rate might be compared to a target and limit reference point value, and this performance measure combined with others to inform an adjustment to the total allowable catch (TAC), and hence, the recreational bag limit. On the other hand, a time-series of strike rate might not contribute to a harvest control rule, but be used to determine whether a HS is performing well against this objective. Operationalising RF objectives explicitly within a HS can directly address certain forms of inter-sectoral conflict, either qualitatively by enabling trade-offs to be explicitly identified and discussed, or quantitatively, by each sector weighting the performance indicators and having these contribute to a sector-specific objective function, where the management outcome is adjusted until a cross-sector overall optimum is achieved (Dowling et al., 2020).

We identified significant cross-sectoral inequities in HS development for multi-sector fisheries that may lead to inequities in fishery performance and resource accountability. The more frequent inclusion of HS components for the commercial sector relative to the RF and small-scale sectors delivers fishery performance in favour of the commercial sector. While some degree of fishery performance for other sectors is likely to be achieved with commercial objectives, this will depend on the overlap among sectors, and the scale of RF relative to commercial. For example, increasing stock biomass from a low level is likely to benefit all sectors initially, but some recreational fishers may desire a ‘trophy’ fishery with a high likelihood of encountering large fish and thus a higher stock biomass and age structure. However, the great diversity within the RF sector itself means the objectives of at least some RF groups will be met at a stock biomass consistent with achieving commercial objectives (see Fowler et al., 2022). Small-scale fishers may want more medium-sized fish to

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efficiently feed community groups, while commercial fishers for the same stock are likely to value catches that maximise profit which may be achieved at a lower stock biomass (Hilborn, 2007). The rates of fishing mortality required to achieve these objectives are different, hence a compromise (trade-off) on exploitation rates would likely be required to balance the objectives of all sectors. The more frequent inclusion of HS components for commercial fishing also places primary accountability for the resource on that sector, which may not appropriately reflect contributions to fishing mortality from other sectors.

The need for explicit compromise between commercial, small-scale and RF sectors is likely to increase for marine fisheries, given HSs are being applied to more complex multi-sector scenarios (Dichmont et al., 2020) and recreational fishers share many stocks with other sectors (Figure 1). Increasing consideration of triple-bottom-line objectives (ecological, economic, and social) within HSs will also likely increase explicit trade-offs with the RF sector, given that a large proportion of RF objectives are social (Fowler et al., 2022) and will likely conflict with other types of fishing objectives, particularly economic ones (Dowling et al., 2020). The limited inclusion of known sectoral conflicts in HSs from numerous regions suggests that objectives requiring compromise, and their implications for achieving equitable fishery performance, are likely not fully realised. While the most common source of conflict between recreational and commercial fishers – resource allocation – is outside of the scope of a HS, the maintenance of those sectoral allocations, once decided upon, can be achieved within a HS.

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The limited data collection specified for both recreational and small-scale fishing suggests uncertainty in the assessment of fishery performance and indicates that target stocks in numerous regions may be at increased risk of overexploitation. Sector-specific monitoring of retained catch is obviously required to understand total fishing mortality in multi-sector fisheries. Monitoring of each sector is also required to account for additional sources of mortality that are sector-specific, for example, discarding of undersized fish by the commercial sector and post-release mortality from the recreational sector, which can be substantial relative to retained catch. Underestimating mortality may lead to overestimation of future biomass in HSs that rely on model-based stock assessment. Knowledge of sector-specific harvest is required to specify effective management measures within HSs, to collectively reduce or increase fishing mortality in line with achieving fishery objectives. While the extent of these issues clearly depends on the relative magnitude of harvest among sectors, data on sector-specific harvest are at least initially required to make this determination. Although the collection of representative RF data is challenging, it is essential given that mortality from RF equals or exceeds that of commercial fishing in many marine fisheries (Coleman et al., 2004; Cooke and Cowx, 2006; Ihde et al., 2011; Brown, 2016; Hyder et al., 2018; Radford et al., 2018; Lewin et al., 2006, 2019).

In our analysis, we focused on federal fisheries in the U.S., which are all subject to the Magnuson-Stevens Fishery Conservation and Management Act (MSA, 2007). The equal inclusion of RF and commercial fishing in HSs in the U.S. is largely driven by the MSA. The MSA requires consideration of resource use for both sectors, operating under the premise that, "…fishery resources must be conserved and managed in such a way as to assure that an optimum supply of food and other fish products, and that recreational opportunities involving fishing are available on a continuing basis and that irreversible or long-term adverse effects on fishery resources are minimized" (Cloutier, 1996; Dell'Apa et al., 2012). Fisheries managers are also directed to achieve optimum yield for a fishery, defined in Section 3(33) as "the amount of fish which—(A) will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities…(B) is prescribed as such on the basis of the maximum sustainable yield from the fishery, as reduced by any relevant economic, social, or ecological factor…" However, other regions investigated in the current study also have legislation mandating consideration of RF opportunities (e.g., Australia), so it is unclear why such legislation has not resulted in greater inclusion of the RF sector within HSs in those regions, as it has in the U.S.

HSs in most U.S. regions also included a range of catch-related objectives likely to be of direct importance to the RF sector (e.g., catching many fish). While a number of these objectives may be indirectly achieved in other regions via more commonly applied ecological objectives related to stock biomass, their explicit inclusion in U.S. HSs, via the optimum yield mandate, at least facilitate some level of direct monitoring and assessment of success. Importantly, the focus on federal fisheries in the U.S. tends to depict the best cases for RF inclusion within HSs, as few coastal states have statutes similar to the MSA that

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guide fisheries management at the state level. Fisheries that primarily operate in state waters were included in some regions in the current study, but only fisheries that are managed through cooperative state/federal plans and, therefore, fall under MSA (e.g., summer flounder, black sea bass, and scup in the Northeast; salmon on the West Coast). Exclusion of most state-level fisheries likely increased the RF inclusion scores relative to a more exhaustive treatment of all U.S. fisheries.

Results from the two case-study regions of the UK and São Paulo (Brazil) indicate that poor inclusion of the RF sector in HSs can occur irrespective of the prominence of RF and developed governance structures. Although the per capita participation rate for marine RF in the UK is moderate relative to other European nations, the UK has the second highest number of recreational fishers and number of days fished per year in the Atlantic, as well as the highest annual average expenditure per marine recreational fisher in Europe (Hyder et al., 2018). Commercial fisheries governance in the UK is also well developed, as evidenced by our finding that HS components of the commercial sector are “almost always” included in HSs. The UK therefore provides a stark example of the HS gap that can develop between sectors, even where developed governance structures for fishing exist. This situation may have arisen through a common view in the UK that RF is a right, rather than an extractive activity to be regulated and managed alongside commercial fishing (Pawson et al., 2008). However, this situation is changing rapidly with the implementation of the UK Fisheries Act (2020), which has embedded recreational fisheries into the fisheries management process. Within this, there is the provision for the development of Fisheries Management Plans for many stocks that are co-designed by all sectors. This means that recreational fisheries are fully embedded and can engage in the fisheries management process. The process had not commenced when our initial survey was distributed, so these changes are not captured in the current analysis. At the time of writing, it was too early to identify outcomes from the development of Fisheries Management Plans, but early indications are positive with good engagement with recreational fishers (e.g. for European sea bass). In the state of São Paulo, Brazil, poor inclusion of RF in HSs likely stems from the limited capacity of fisheries management to keep pace with a rapidly growing sector (Barcellini et al., 2013; Arlinghaus et al., 2021). Catches for particular stocks in the state of São Paulo now already exceed those of the commercial sector, and small-scale fishers are transitioning to RF guiding

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services (Freire et al., 2016; Motta et al., 2016). Research and data collection for RF are also considerably lagging that for the commercial sector (Freire et al., 2016), presenting challenges for development of RF-specific HS components. The HS gap between the RF and commercial sectors was less severe in São Paulo than in the UK, due to only moderate inclusion of HS components for the commercial sector in São Paulo.

Identifying the cause(s) of limited RF inclusion in HSs is a critical first step toward addressing the issue. There are numerous potential and interrelated explanations, including: 1) a legacy of focusing on the historically more regulated commercial sector; 2) a lack of sectoral acknowledgement and thus lack of policy goals for RF in fisheries governance structures; 3) an assumption that the objectives of all sectors will be met by achieving those of the commercial sector; 4) a misconception that RF catch is insignificant and that catch-and-release has little or no impact; 5) challenges involved with regular and accurate monitoring of RF, together with limited ability to control total catch in response to assessment outcomes due largely to the open-access nature of most RF; 6) failure to address socio-economic aspects of sustainability; 7) a primarily harvest-based approach to decisions regarding the exclusion of sectors from HSs (e.g., prior resource allocation); and 8) limited organisation of the RF sector (e.g., lack of a ‘peak body’) and resulting challenges with representative engagement in management processes. Decisions to exclude a sector from a HS are often made via management processes that precede HS development and may be based on a limited range of criteria, most commonly an arbitrary threshold of harvest that is considered significant. Such an approach already fails to consider social and non-harvest-related economic aspects of sustainability, because the fishery objectives of the RF sector are often socio-economic and decoupled from retained catch. A continued focus on ecological sustainability in HSs, potentially at the expense of socio-economic considerations (Cevenini et al., 2023), is clear from the types of objectives specified for the RF sector in HSs considered in the current study (Table 3), although objectives regarding value for recreational and charter fishers were often included in numerous regions. The focus on ecological objectives for the RF sector likely mirrors a broader issue regarding limited implementation of the TBL to fishery HSs (Dowling et al., 2020), because articulating operational social objectives is challenging, as is relating economic objectives to the level of harvest.

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While all fisheries have unique characteristics that limit generalisations, knowledge of operational scenarios that commonly involve RF will assist planning for HSs applied to multi-sector fisheries. Unsurprisingly, our results indicate that RF is more likely a consideration in HSs for nearshore rather than offshore multi-sector fisheries, due to ease of access. However, this may not be the case for island nations with a relatively narrow continental shelf, such as the Bahamas in our study (Sahoo et al., 2019). In these circumstances, RF may be more prevalent in offshore areas and HSs may need to integrate the objectives and activities of the RF sector with those of large, valuable and often international commercial fleets. Development of such HSs would particularly benefit from pre-established resource allocation between sectors, with allocation based on factors beyond mere harvest fraction, particularly given the prevalence of catch-and-release in offshore game fisheries (Whitelaw, 2003).

The prominence of shore-based RF in most regions raises issues regarding the capacity to monitor and assess the sector within HSs, which may affect the achievement of fishing objectives. While RF is generally challenging to monitor, shore-based catch and effort are particularly difficult to quantify due to the large and often unknown number of access points and broad spatial scale of potential effort. The activity is therefore frequently overlooked or omitted from stock assessments and HSs (Hartill et al., 2012; Hyder et al., 2014; 2018; 2020; Smallwood et al., 2012; Tate et al., 2020). Remote monitoring methods, including cameras and drones, may offer cost-effective solutions for ongoing monitoring of shore-based effort, but not catch (Smallwood et al., 2012; Desfosses et al., 2019). Novel approaches using smartphone apps could also be used (Skov et al., 2021), but the issues around bias also need to be assessed (Venturelli et al., 2017). Offsite surveys are not affected by the number of access points, but data may not be precise enough to determine fishery performance relative to predetermined reference points, e.g. target or limit reference points. Ultimately, the type of RF monitoring required will be dictated by the objectives and performance indicators. Whole-of-stock monitoring and assessment are not necessarily required to achieve objectives within a HS and a relative comparison of metrics obtained from smaller-scale on-site surveys through time may be sufficient to monitor fishery performance and support management measures for the RF sector.

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The narrow range of gear types reported for RF in multi-sector fisheries suggests relative gear efficiency should be considered when attempting to achieve objectives for the sector within HSs. Common RF gear types, including hook-and-line and spear, are generally less efficient than nets and longlines that are more commonly used by the commercial sector. Such inefficiencies may result in poorer fishery performance for the RF sector relative to other sectors at the same level of stock biomass. For example, a stock at low biomass may still be viable for boat-based commercial fishers using nets, but too depleted to deliver an adequate strike rate for shore-based recreational fishers using hook-and-line (but see Kleiven et al., 2020). Differential management controls between sectors may exacerbate gear-based fisheries performance inequity, for example, lower minimum size limits for the commercial sector compared to the RF sector. Differential fishery performance among sectors may be addressed in HSs via a compromise on reference points; for example, adopting a higher limit reference point for stock biomass in the previous example, to ensure that unacceptable performance for the RF sector is not reached without substantial management intervention. Importantly, for the RF sector more than others, care must be taken when attempting to interpret fishery performance in relation to efficiency. Considerable fishery performance may be realised by recreational fishers at low efficiencies depending on other objectives that relate to the fishing experience (e.g., scenic beauty of the fishing location). In fact, primacy of non-catch-related objectives in some fisheries may drive continued RF effort at low stock biomass, maintaining RF satisfaction to the potential detriment of other sectors that rely on yield. Controlling total RF effort is challenging but likely essential for achieving fishery performance for, and accountability of, all sectors within multi-sector fisheries (Post et al., 2002).

The use of expert knowledge in the current study allowed an efficient international exploration of HSs, their elements, and the relative inclusion of the different fishing sectors. However, as with all elicitations of expert knowledge, our results were potentially influenced by respondent and procedural biases that cannot be fully accounted for (Martin et al., 2012). Although a range of bias control procedures was used (see Methods), only 1-3 experts could be engaged from each region and their responses may have been biased by their particular area of expertise and the completeness of their knowledge of HSs, among

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other things. Despite this, we believe it unlikely that biases substantially affected the findings of the current study, given the consistent results among most nations whose experts completed their questionnaires separately.

The substantial gap between sectors with respect to their inclusion in HSs risks the ecological and socio-economic sustainability of marine fisheries and we recommend it be addressed as a matter of urgency. RF stakeholder groups are becoming more engaged with fisheries management and are increasingly demanding such inclusion, recognizing that exclusion can lead to systemic disadvantage of the sector. Fisheries organisations should undertake a review of RF at the fishery level, to evaluate the magnitude of sustainability risk posed by the sector's partial or total exclusion from HSs. This may require establishment or improvement of RF data collection, both with respect to catch and effort, but also social and economic aspects. Consideration should also be given to management measures that can control total mortality arising from RF, something that cannot be achieved via the typical daily bag limits applied to open-access fisheries with a large number of recreational fishers that may engage in catch-and-release. In parallel, existing HSs should be revised with engagement of RF representatives, to ensure that the objectives of the sector are accurately captured and that suitable HS components and additional elements are established to achieve those objectives. To avoid future perpetuation of sectoral inequality in HSs, we recommend that nations establish legislation and policy that precisely specifies the requirements for inclusion of each sector within HSs, along with additional management policies, goals, and procedures that support the development of HSs, such as allocation policy and processes. The power imbalance between the RF and commercial sectors should also be acknowledged and controlled for during the HS development process, to ensure equitability of stakeholder input and the resulting outcome.

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Data availability statement

Data related to this publication are available from the corresponding author on reasonable request.

Conflict of interest statement

The authors have no conflicts of interest to declare.

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Table 1. Elements of a harvest strategy considered in the questionnaire, including fishing objectives and quantities enabling their achievement.

HS component	**Description**
Conceptual objective	A high-level objective that guides fisheries management in a manner consistent with overarching legislation. Conceptual objectives sit above operational objectives and are typically too broad to define specific measures of fishery performance.
Operational objective	A precise objective that has a direct and practical interpretation in the context of a fishery and against which performance can be directly measured. These are typically specified for individual stocks and should link to performance indicators, reference points, and management controls.
Performance indicator (PI)	A quantity that can be measured and used to track changes in the fishery with respect to achieving an operational objective.
Limit reference point (LRP)	The value of a performance indicator below which fishery performance is no longer considered acceptable.
Target reference point (TRP)	The value of a performance indicator that represents a desired level of fishery performance and should be aimed for.
Trigger reference point	A value between the LRP and TRP that triggers a management control designed to prevent further decline of the indicator toward the LRP
Management control	Also referred to as 'decision rules', these are pre-defined and specific management actions. Dynamic management controls vary according to the value of the PI relative to the reference points. This may be continuous, such that the level of management control is a function of the PI, or stepped, such that the management control is invoked when a specific value of the PI is reached; e.g. the LRP. Management controls may also be static, and implemented irrespective of the value of the PI.

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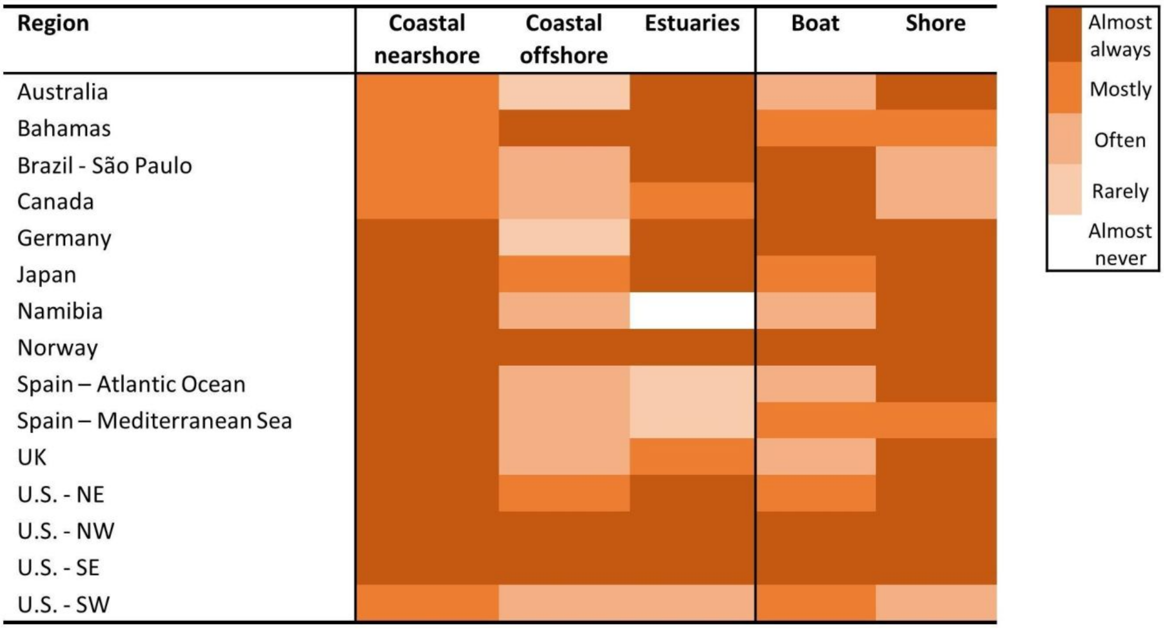
Table 2. Prevalence of RF by environment and fishing platform (boat vs shore) within multi-sector fisheries in each region. Colours indicate expert knowledge on the prevalence of RF in each environment and platform.



Region	Coastal nearshore	Coastal offshore	Estuaries	Boat	Shore
Australia	▓	░	■	▒	■
Bahamas	▓	■	■	▓	▓
Brazil - São Paulo	▓	▒	■	■	▒
Canada	▓	▒	▓	■	▒
Germany	■	░	■	■	■
Japan	■	▓	■	▓	■
Namibia	■	▒	□	▒	■
Norway	■	■	■	■	■
Spain – Atlantic Ocean	■	▒	░	▒	■
Spain – Mediterranean Sea	■	▒	░	▓	▓
UK	■	▒	▓	▒	■
U.S. - NE	■	▓	■	▓	■
U.S. - NW	■	■	■	■	■
U.S. - SE	■	■	■	■	■
U.S. - SW	▓	▒	▒	▓	▒

■	Almost always
▓	Mostly
▒	Often
░	Rarely
□	Almost never

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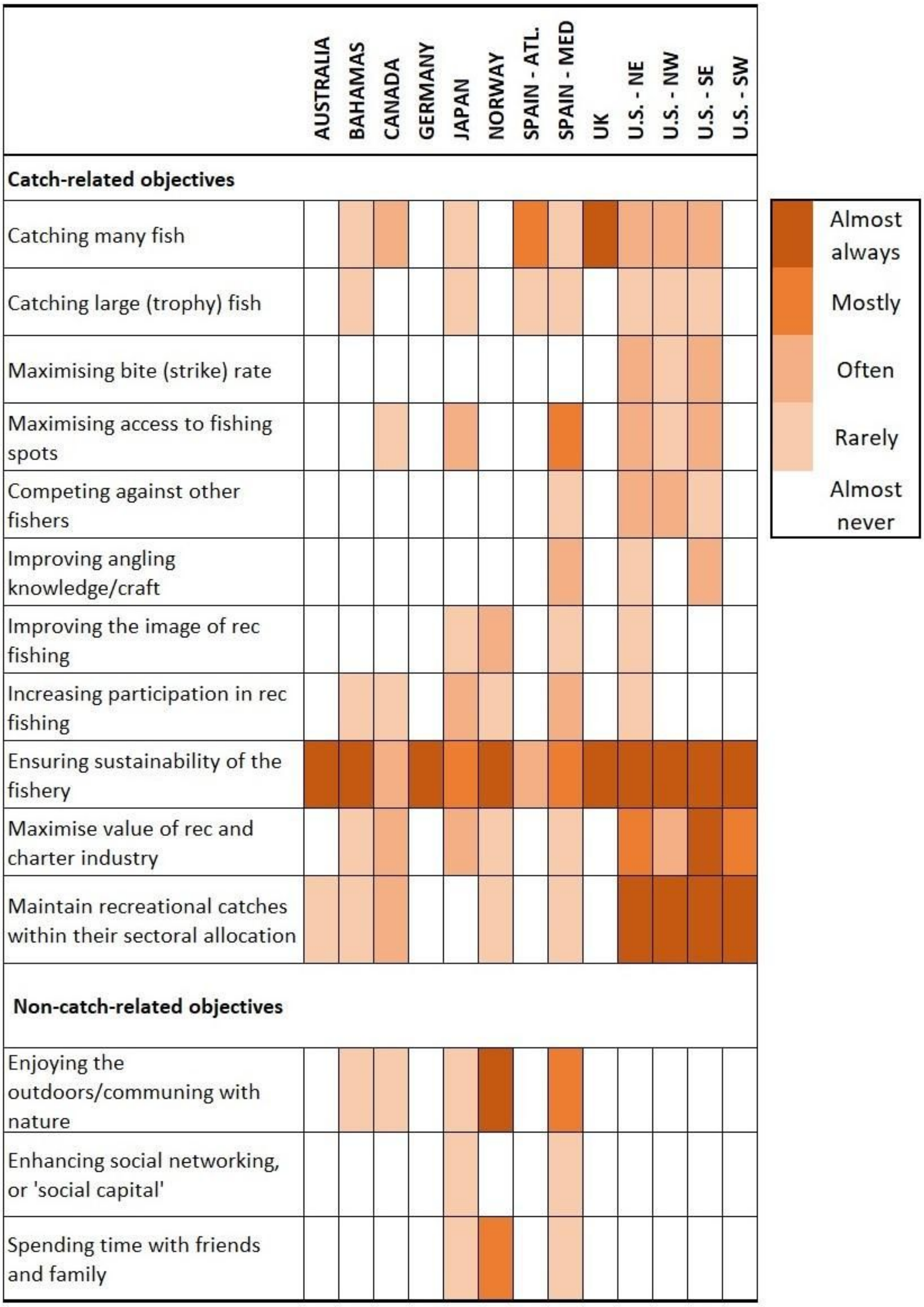
878 Table 3. Objectives specified for RF in HSs for marine multi-sector fisheries in 13 regions.
879 Colours indicate expert knowledge on the prevalence of each objective within HSs, ranging
880 from ‘almost always’ (dark orange) through to ‘almost never’ (white). The prevalence of
881 specific RF objectives were not reported for São Paulo, Brazil. Namibia was excluded
882 because only one HS was reported.



	AUSTRALIA	BAHAMAS	CANADA	GERMANY	JAPAN	NORWAY	SPAIN - ATL.	SPAIN - MED	UK	U.S. - NE	U.S. - NW	U.S. - SE	U.S. - SW
Catch-related objectives													
Catching many fish		░	▒		░		▓	░	█	▒	▒	▒	
Catching large (trophy) fish		░			░		░	░		░	░	░	
Maximising bite (strike) rate										▒	░	▒	
Maximising access to fishing spots			░		▒			▓		▒	░	▒	
Competing against other fishers								░		▒	▒	░	
Improving angling knowledge/craft								▒		░		▒	
Improving the image of rec fishing					░	▒		░		░			
Increasing participation in rec fishing		░	░		▒	░		▒		░			
Ensuring sustainability of the fishery	█	█	▒	█	▓	█	▒	▓	█	█	█	█	█
Maximise value of rec and charter industry		░	▒		▒	░		░		▓	▒	█	▓
Maintain recreational catches within their sectoral allocation	░	░	▒			░		░		█	█	█	█
Non-catch-related objectives													
Enjoying the outdoors/communing with nature		░	░		░	█		▓					
Enhancing social networking, or 'social capital'					░			░					
Spending time with friends and family					░	▓		░					

█	Almost always
▓	Mostly
▒	Often
░	Rarely
	Almost never

883
884

Figure captions

Figure 1. Regions included in the study (blue - abbreviated names for nations and regions fully described in Table 2).The colour scale indicates expert knowledge on the extent to which the RF sector is involved with marine fisheries that also include a commercial sector (left half of the circle) and the small-scale sector (right half of the circle) in each region. Numbers within circles indicate the approximate number of HSs considered, which is a subset of multi-sector fisheries in each region (see methods). Four regions are considered separately within the U.S. and two regions are considered separately within Spain (“SP”).

Figure 2. Types of fishing gear used by the RF (blue) and other (orange) sectors in marine multi-sector fisheries, expressed as a median score across 14 regions. Scores reflect expert knowledge on the prevalence of gear types used within each region, ranging from 5 (‘almost always’) through to 1 (‘almost never’). Error bars indicate third quartiles. Namibia was excluded from this analysis because only one HS for a multi-sector marine fishery was reported.

Figure 3. Principal coordinates analysis (PCO) comparing HS elements among sectors using expert scores on the extent to which each element was specified in the expert’s region. Scores ranged from 5 (“almost always”) through to 1 (“almost never”). Namibia was excluded from this analysis because only one HS for a multi-sector marine fishery was reported.

Figure 4. Expert scores indicating the degree to which each HS element was included for each fishing sector in 14 regions. Scores ranged from 5 (‘almost always’) through to 1 (‘almost never’). Blue: RF sector, orange: commercial sector, grey: small-scale sector. Namibia was excluded from this analysis because only one HS for a multi-sector marine fishery was reported.

Figure 5. Conflicts between RF objectives and those of other sectors in HSs for marine multi-sector fisheries: a) the extent to which known conflicts are explicitly stated in HSs and which sectors are involved in each region, and b) the frequency of specific types of conflicts, as reported by experts. Namibia was excluded because only one HS for a multi-sector marine fishery was reported.

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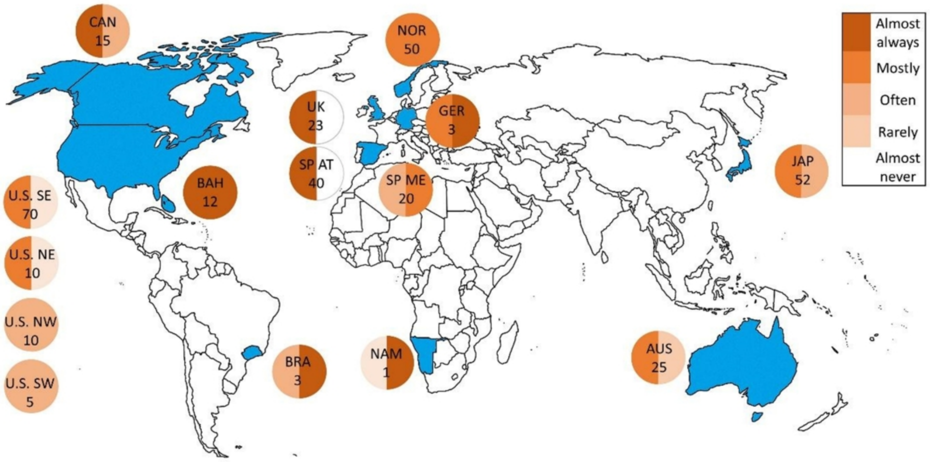
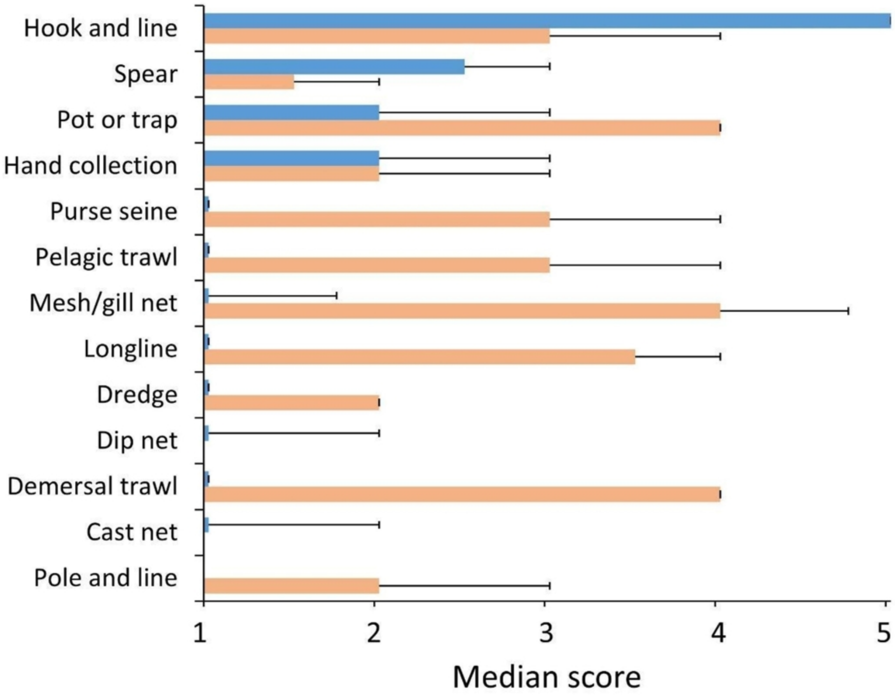


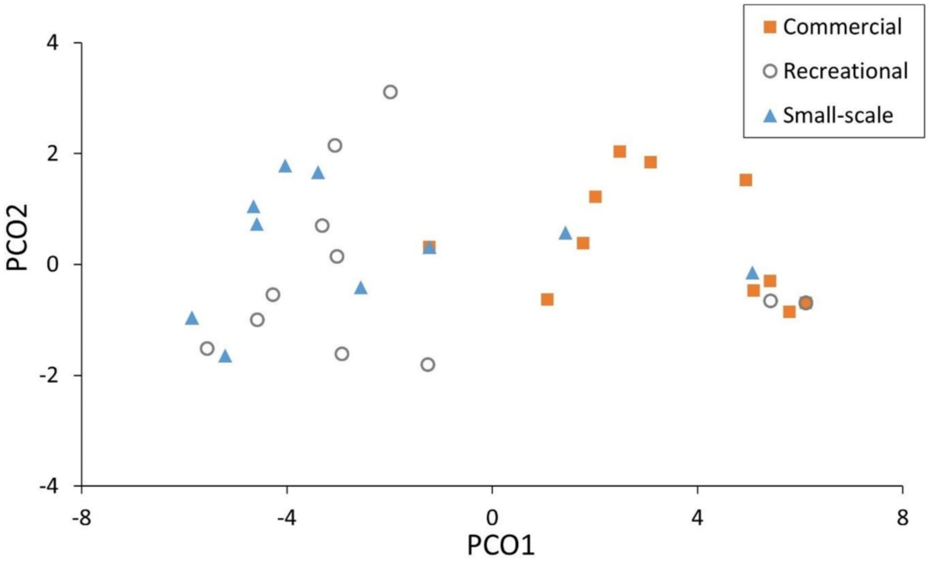
Regions included in the study (blue - abbreviated names for nations and regions fully described in Table 2). The colour scale indicates expert knowledge on the extent to which the RF sector shares marine fisheries with the commercial sector (left half of the circle) and the small-scale sector (right half of the circle) in each region. Numbers within circles indicate the approximate number of HSs considered, which is a subset of multi-sector fisheries in each region (see methods). Four regions are considered separately within the U.S. and two regions are considered separately within Spain ("SP").

338x190mm (307 x 307 DPI)



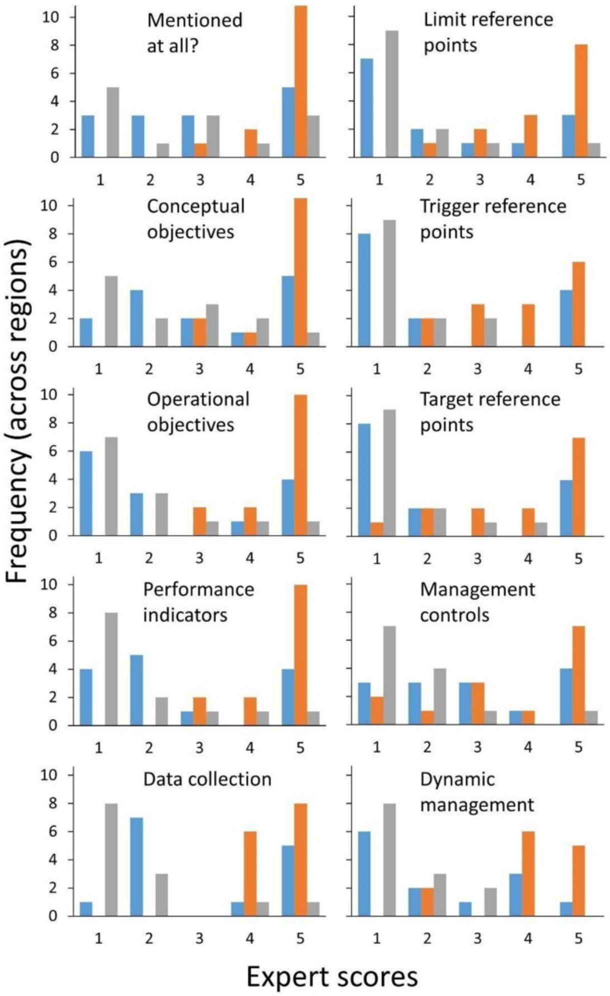
Types of fishing gear used by the RF (blue) and other (orange) sectors in marine multi-sector fisheries, expressed as a median score across 14 regions. Scores reflect expert knowledge on the prevalence of gear types used within each region, ranging from 5 (‘almost always’) through to 1 (‘almost never’). Error bars indicate third quartiles. Namibia was excluded from this analysis because only one HS for a multi-sector marine fishery was reported.

253x189mm (307 x 307 DPI)



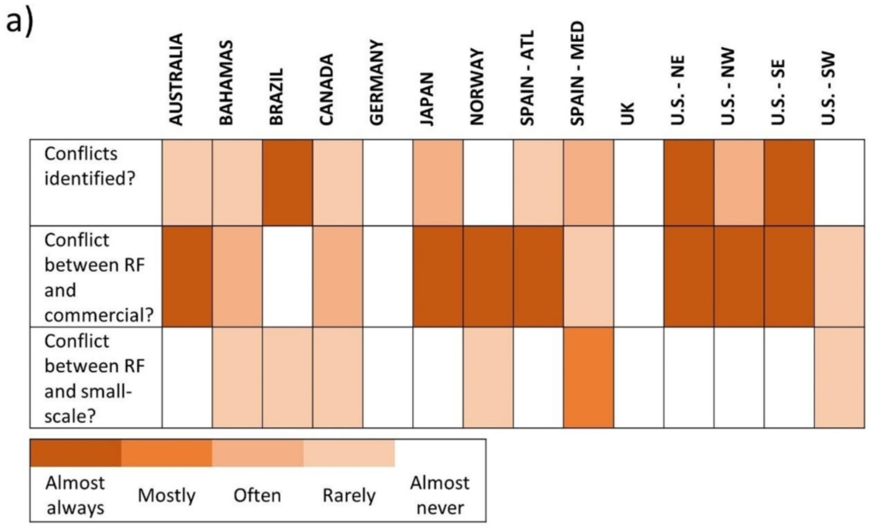
Principal coordinates analysis (PCO) comparing HS elements among sectors using expert scores on the extent to which each element was specified in the expert's region. Scores ranged from 5 ("almost always") through to 1 ("almost never"). Namibia was excluded from this analysis because only one HS for a multi-sector marine fishery was reported.

313x189mm (307 x 307 DPI)



Expert scores indicating the degree to which each HS element was included for each fishing sector in 14 regions. Scores ranged from 5 ('almost always') through to 1 ('almost never'). Blue: RF sector, orange: commercial sector, grey: small-scale sector. Namibia was excluded from this analysis because only one HS for a multi-sector marine fishery was reported.

190x338mm (307 x 307 DPI)



	AUSTRALIA	BAHAMAS	BRAZIL	CANADA	GERMANY	JAPAN	NORWAY	SPAIN - ATL	SPAIN - MED	UK	U.S. - NE	U.S. - NW	U.S. - SE	U.S. - SW
Conflicts identified?	Rarely	Rarely	Almost always	Rarely	Almost never	Often	Almost never	Rarely	Often	Almost never	Almost always	Often	Almost always	Almost never
Conflict between RF and commercial?	Almost always	Often	Almost never	Often	Almost never	Almost always	Almost always	Almost always	Rarely	Almost never	Almost always	Almost always	Almost always	Rarely
Conflict between RF and small-scale?	Almost never	Rarely	Rarely	Rarely	Almost never	Almost never	Rarely	Almost never	Mostly	Almost never	Almost never	Almost never	Almost never	Rarely

b)

Description of the conflict	**Frequency**
Competition for a limited resource especially with respect to allocation of that resource	11
Lack of appreciation for subsistence fisheries	2
Differential regulations and perceptions of unfairness	2
Restricted access to fishing areas	2
Inequity of size limit between sectors	2
Lack of knowledge of fisheries	1
Blurred lines between commercial and recreational	1

Conflicts between RF objectives and those of other sectors in HSs for marine multi-sector fisheries: a) the extent to which known conflicts are explicitly stated in HSs and which sectors are involved in each region, and b) the frequency of specific types of conflicts, as reported by experts. Namibia was excluded because only one HS for a multi-sector marine fishery was reported.

190x198mm (307 x 307 DPI)

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