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Recreational sea fishing in Europe in a global context—Participation rates, fishing effort, expenditure, and implications for monitoring and assessment

Kieran Hyder[1] | Marc Simon Weltersbach[2] | Mike Armstrong[1] | Keno Ferter[3] | Bryony Townhill[1] | Anssi Ahvonen[4] | Robert Arlinghaus[5,6] | Andrei Baikov[7] | Manuel Bellanger[8] | Janis Birzaks[9] | Trude Borch[10] | Giulia Cambie[1,11] | Martin de Graaf[12] | Hugo M C Diogo[13] | Łukasz Dziemian[14] | Ana Gordoa[15] | Ryszard Grzebielec[14] | Bruce Hartill[16] | Anders Kagervall[17] | Kostas Kapiris[18] | Martin Karlsson[19] | Alf Ring Kleiven[20] | Adam M Lejk[14] | Harold Levrel[21] | Sabrina Lovell[22] | Jeremy Lyle[23] | Pentti Moilanen[4] | Graham Monkman[11] | Beatriz Morales-Nin[24] | Estanis Mugerza[25] | Roi Martinez[1] | Paul O'Reilly[26] | Hans Jakob Olesen[27] | Anastasios Papadopoulos[28] | Pablo Pita[29] | Zachary Radford[1] | Krzysztof Radtke[14] | William Roche[26] | Delphine Rocklin[30] | Jon Ruiz[25] | Callum Scougal[1] | Roberto Silvestri[31] | Christian Skov[32] | Scott Steinback[33] | Andreas Sundelöf[34] | Arvydas Svagzdys[35] | David Turnbull[36] | Tessa van der Hammen[12] | David van Voorhees[22] | Frankwin van Winsen[37] | Thomas Verleye[38] | Pedro Veiga[39] | Jon-Helge Vølstad[3] | Lucia Zarauz[25] | Tomas Zolubas[35] | Harry V Strehlow[2]

[1]Centre for Environment, Fisheries & Aquaculture Science, Lowestoft, Suffolk, UK

[2]Thünen Institute of Baltic Sea Fisheries, Rostock, Germany

[3]Institute of Marine Research, Bergen, Norway

[4]Natural Resources Institute Finland (Luke), Helsinki, Finland

[5]Department of Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany

[6]Division of Integrative Fisheries Management, Faculty of Life Sciences, Albrecht-Daniel-Thaer-Institute of Agriculture and Horticulture, Humboldt-Universität zu Berlin, Berlin, Germany

[7]Fisheries Resources Department, Ministry of Environment, Tallinn, Estonia

[8]Ifremer, UMR AMURE, Unité d'Economie Maritime, Plouzané, France

[9]Institute of Food Safety, Animal Health and Environment, Riga, Latvia

[10]Akvaplan-niva AS, Fram Centre, Tromsø, Norway

[11]School of Ocean Sciences, Bangor University, Menai Bridge, Anglesey, UK

[12]Wageningen Marine Research, IJmuiden, The Netherlands

[13]Marine and Environmental Sciences Centre, Universidade dos Açores, Departamento de Oceanografia e Pescas, Horta, Açores, Portugal

[14]National Marine Fisheries Research Institute (NMFRI), Gdynia, Poland

[15]Department of Marine Ecology, Centre d'Estudis Avançats de Blanes (CEAB-CSIC), Blanes, Spain

[16]NIWA, Auckland, New Zealand

[17]Institute of Freshwater Research, Swedish University for Agricultural Sciences, Drottningholm, Sweden

[18]Hellenic Centre for Marine Research, Institute of Marine Biological Resources and Inland Waters, Anavissos, Greece

[19]Department of Aquatic Resources, Institute of Coastal Research, Öregrund, Sweden

[20]Institute of Marine Research, Flødevigen Marine Research Station, His, Norway

[21]UMR CIRED, Nogent-sur-Marne Cedex, Paris, France

[22]NOAA Fisheries, Silver Spring, MD, USA

[23]Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Australia

[24]Mediterranean Institute of Advanced Studies (CSIC/UIB), Esporles, Mallorca, Iles Balears, Spain

[25]AZTI-Tecnalia, Sukarrieta, Bizkaia, Spain

[26]Inland Fisheries Ireland, Dublin, Ireland

[27]Technical University of Denmark, National Institute of Aquatic Resources (DTU Aqua), Lyngby, Denmark

[28]Fisheries Research Institute, Nea Peramos, Greece

[29]Department of Applied Economics, Faculty of Economics and Business Administration, University of Santiago de Compostela, Santiago de Compostela, Spain

[30]Department of Geography, Memorial University of Newfoundland, St. John's, NL, Canada

[31]C.I.B.M. Centro Interuniversitario di Biologia Marina ed Ecologia Applicata, Livorno, Italy

[32]DTU AQUA, Section of Inland Fisheries and Ecology, Technical University of Denmark, Silkeborg, Denmark

[33]NOAA Fisheries, Woods Hole, MA, USA

[34]Institute of Marine Research, Swedish University of Agricultural Sciences, Lysekil, Sweden

[35]Ministry of Agriculture, Fisheries Service, Klaipeda, Lithuania

[36]Marine Scotland, Scottish Government, Edinburgh, UK

[37]Institute for Agricultural and Fisheries Research (ILVO), Oostende, Belgium

[38]Vlaams Instituut voor de Zee (VLIZ), Flanders Marine Institute, Oostende, Belgium

[39]Centre of Marine Sciences (CCMAR), FCT-7, University of Algarve, Faro, Portugal

Correspondence
Kieran Hyder, Centre for Environment, Fisheries & Aquaculture Science (Cefas), Lowestoft Laboratory, Lowestoft, UK.
Email: kieran.hyder@cefas.co.uk

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Abstract

Marine recreational fishing (MRF) is a high-participation activity with large economic value and social benefits globally, and it impacts on some fish stocks. Although reporting MRF catches is a European Union legislative requirement, estimates are only available for some countries. Here, data on numbers of fishers, participation rates, days fished, expenditures, and catches of two widely targeted species were synthesized to provide European estimates of MRF and placed in the global context. Uncertainty assessment was not possible due to incomplete knowledge of error distributions; instead, a semi-quantitative bias assessment was made. There were an estimated 8.7 million European recreational sea fishers corresponding to a participation rate of 1.6%. An estimated 77.6 million days were fished, and expenditure was €5.9 billion annually. There were higher participation, numbers of fishers, days fished and expenditure in the Atlantic than the Mediterranean, but the Mediterranean estimates were generally less robust. Comparisons with other regions showed that European MRF participation rates and expenditure were in the mid-range, with higher participation in Oceania and the United States, higher expenditure in the United States, and lower participation and expenditure in South America and Africa. For both northern European sea bass (*Dicentrarchus labrax*, Moronidae) and western Baltic cod (*Gadus morhua*, Gadidae) stocks, MRF represented 27% of the total removals. This study highlights the importance of MRF and the need for bespoke, regular and statistically sound data collection to underpin European fisheries management. Solutions are proposed for future MRF data collection in Europe and other regions to support sustainable fisheries management.

KEYWORDS
European marine recreational fisheries, fisheries assessment and management, fishing effort and expenditure, participation, surveys and monitoring of marine recreational fisheries

1 | INTRODUCTION

Recreational fishing has been shown to be an important component of fishing mortality across the globe (Coleman, Figueira, Ueland, & Crowder, 2004; Cooke & Cowx, 2004, 2006; Ihde, Wilberg, Loewensteiner, Secor, & Miller, 2011; Lewin, Arlinghaus, & Mehner, 2006; McPhee, Leadbitter, & Skilleter, 2002; Post et al., 2002), generating significant economic (e.g. Arlinghaus & Cooke, 2009; Cisneros-Montemayor & Sumaila, 2010; Cowx, 2002; Toivonen et al., 2004) and social benefits (e.g. Arlinghaus, Mehner, & Cowx, 2002; Griffiths, Bryant, Raymond, & Newcombe, 2017; Lynch et al., 2016; Parkkila et al., 2010). In some parts of the world, data on marine recreational fishing (MRF) removals are included in stock assessments, and separate quota allocations are made for commercial and recreational fisheries for certain stocks (Ryan, Trinnie, Jones, Hart, & Wise, 2016). The economic value of the recreational fishery is in some cases recognized and taken into account in allocation decisions between sectors (e.g. Lee, Steinback, & Wallmo, 2017; Steinback, 1999; Steinback, Gentner, & Castle, 2004), and specific government policies supporting and promoting MRF have been developed (e.g. USA—NOAA, 2015). In Europe, a lack of reliable estimates of recreational catches has resulted in MRF being excluded from stock assessments and allocations for many years (Pawson, Tingley, & Padda, 2007). This can be problematic for some widely targeted species such as Atlantic cod (*Gadus morhua*, Gadidae), as it may undermine our ability to manage fish stocks to maximum sustainable yield (Hyder, Armstrong, Ferter, & Strehlow, 2014) as required by the Common Fisheries Policy (EU, 2013) and Marine Strategy Framework Directive (EU, 2008b). Widely held views that removals and socioeconomic impact of MRF are low have been challenged in Europe. Recent studies in Europe have demonstrated the biological impact (e.g. Armstrong et al., 2013; Ferter et al., 2013; van der Hammen, de Graaf, & Lyle, 2016; Herfaut, Levrel, Thébaud, & Véron, 2013; Morales-Nin et al., 2005; Sparrevohn & Storr-Paulsen, 2012; Strehlow, Schultz, Zimmermann, & Hammer, 2012; Veiga, Ribeiro, Gonçalves, & Erzini, 2010; Vølstad et al., 2011), economic impact (e.g. Armstrong et al., 2013; Borch, Moilanen, & Olsen, 2011; Herfaut et al., 2013; Monkman et al., 2015) and social benefits (e.g. Armstrong et al., 2013).

Recognizing the need for data to support implementation of the Common Fisheries Policy (EU, 2013), the European Commission introduced a Data Collection Framework (DCF) in 2001 placing a legal requirement for Member States to collect specified types of data, including estimates of recreational catches and releases for selected species (EU, 2001). The requirements were altered slightly in the subsequent EU DCF regulations (EU, 2008a, 2010, 2016a) that specify a multiannual programme for the collection, management and use of data in the fisheries sector. The DCF requires estimates of annual recreational catches and releases of Atlantic cod, European sea bass (*Dicentrarchus labrax*, Moronidae), European eel (*Anguilla anguilla*, Anguillidae), Atlantic bluefin tuna (*Thunnus thynnus*, Scombridae), Atlantic salmon (*Salmo salar*, Salmonidae) and all elasmobranchs, with species requirements varying across regions (EU, 2010; Figure 1). These requirements have been replaced by the EU Multiannual Programme (EU-MAP) for the period 2017–2019 for listed species and/or species identified at marine regional scales needed for fisheries management purposes, for example sea trout (*Salmo trutta*, Salmonidae) and pollack (*Pollachius pollachius*, Gadidae) (EU, 2016a; Figure 1). Despite the EU data collection requirements, it has taken time for European countries to develop and implement suitable survey methods for MRF and build scientific expertise. However, data sets of catches are becoming available, and MRF removals have recently been included in stock assessments (e.g. western Baltic cod—Eero, Strehlow, Adams, & Vinther (2014), European sea bass—ICES (2012a, 2015a)).

MRF in Europe involves many different methods including both active (e.g. rod and line, spear and hand-gathering) and passive (e.g. nets, traps, pots, and set-lines) approaches (Table 1). A broad range of species are targeted, including finfish (e.g. gadoids, European sea bass, mackerels (Scombridae), flatfish, seabreams (Sparidae)), shellfish (e.g. scallops (Pectinidae), mussels) and crustaceans (e.g. crabs, European lobster (*Homarus gammarus*, Nephropidae)), with the mix of species varying between countries (for full details, see Supporting Information). For those species defined under the DCF (EU, 2008a, 2010) or EU-MAP (EU, 2016a) (hereafter termed DCF), Atlantic cod, European eel, Atlantic salmon and sea trout are the main targets in the Baltic Sea; Atlantic cod, European eel, European sea bass, Atlantic salmon, pollack, and elasmobranchs in the North Sea, Eastern Arctic, and North Atlantic; and European sea bass, European eel, elasmobranchs and Atlantic bluefin tuna in the Mediterranean and Black Seas (Table 1). Many more species are targeted by MRF than are included on the list of species reported under the DCF, so there are numerous other marine species where recreational catches may be a significant or even dominant component of total fishing mortality (e.g. European lobster—Kleiven, Olsen, & Vølstad (2012)).

Even though recreational fishing is thought to have significant impacts on many fish stocks (Arlinghaus & Cooke, 2005), impacts on the marine environment are difficult to assess as global assessments of recreational fishing generally do not distinguish between freshwater and marine fisheries (e.g. Arlinghaus, Tillner, & Bork, 2015; Cooke & Cowx, 2004). There are a number of regional estimates of MRF globally; however, for Europe, available data are either limited or outdated. There have been several national estimates of MRF participation, effort and expenditure for European countries

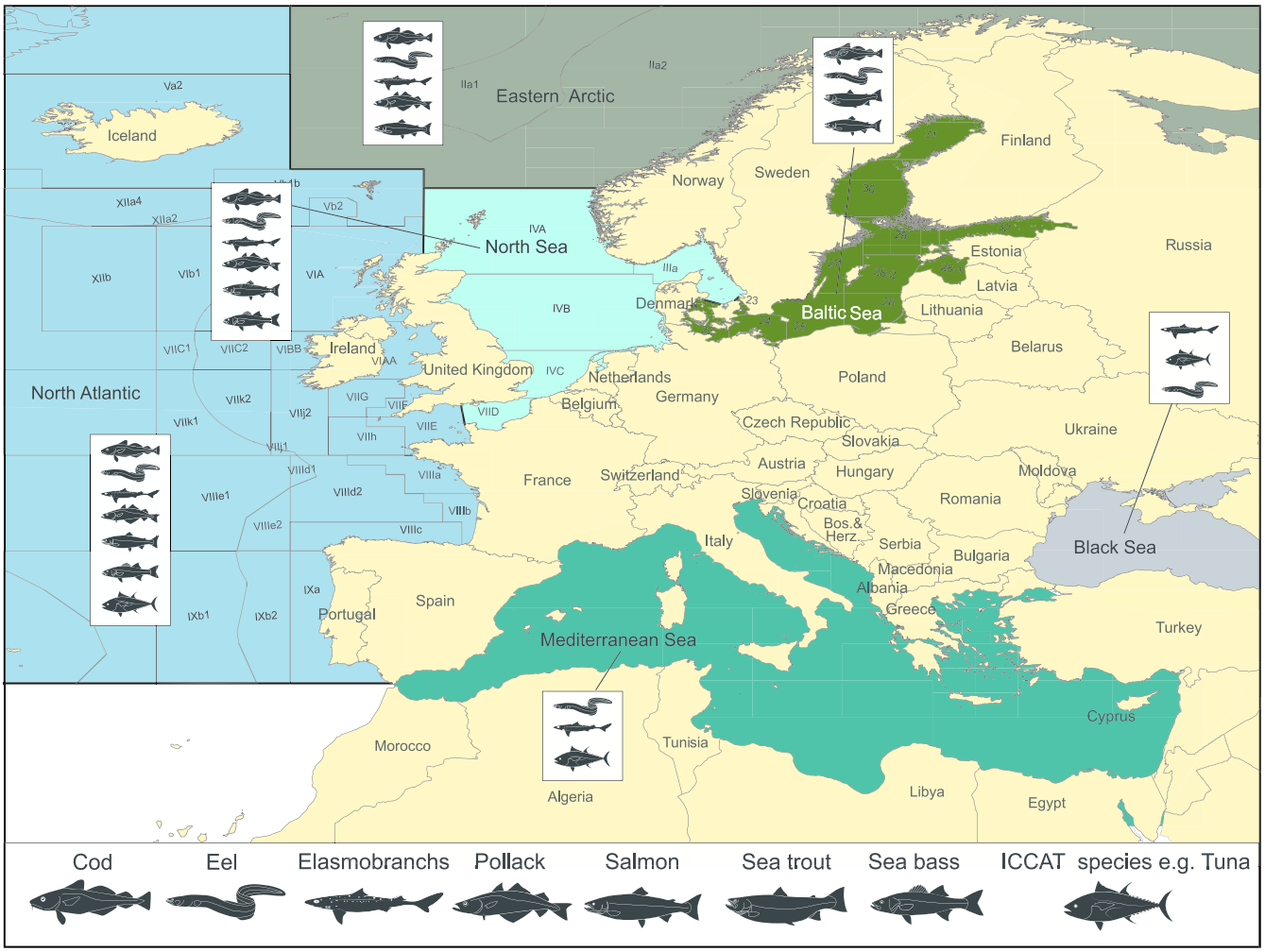

FIGURE 1 Map of ICES areas and subdivisions of the European marine waters, alongside the region-specific species for which marine recreational fisheries data collection is required for Member States under the EU-MAP (EU, 2016a)

(e.g. UK—Armstrong et al., 2013; the Netherlands—van der Hammen et al., 2016; Germany—Strehlow et al., 2012; France—Rocklin, Levrel, Drogou, Herfaut, & Veron, 2014) covering various methods (e.g. angling—Veiga et al. (2010), nets and pots—Sparrevohn & Storr-Paulsen (2012), and spearfishing—Zarauz et al. (2015)). However, no attempt has been made to synthesize these data to generate a robust assessment of MRF in Europe or address the challenges associated with the underlying data and associated biases.

The objectives of this study were to assess the importance of MRF in Europe, highlight key knowledge gaps, make proposals of how to fill these gaps and evaluate the implications of these gaps for fisheries monitoring and assessment. To achieve these objectives, estimates are derived of the total number of fishers, participation rates, days fished and expenditure of MRF in Europe. The contribution of MRF to total fishing mortality is exemplified using western Baltic cod (Figure 1) and European sea bass (ICES areas IVb,c and VIIa,d-h; Figure 1) as case-studies. Results are discussed in the context of global MRF, the implications for fisheries management, and proposals are made of how to address the challenges of monitoring and assessment of MRF in Europe and other regions.

2 | METHODS

2.1 | Collection and selection of MRF data

The collection and selection of MRF data are summarized in this section, but due to the complexity, the full description and justification are provided for each country in the Supporting Information. Data are available from MRF surveys for some countries in Europe, many of which are published in the grey literature and in local languages. Each year the ICES Working Group on Recreational Fisheries Surveys (ICES WGRFS) brings together experts from across Europe and compiles the latest MRF estimates for species where statutory data collection is required (ICES, 2012b, 2013, 2014, 2015b, 2017). Here, available literature was compiled for 27 countries within Europe that had a coastline on the Atlantic Ocean, North Sea, Baltic Sea, Mediterranean Sea, and Black Sea. The only exception was Bosnia and Herzegovina, which has a very limited coastline (see Table 1 for full list of countries). For each country, the population size for 2014 was downloaded (Eurostat, 2016a) and 2014 per capita GDP was sourced (IMF, 2016). The extent of fishing opportunities was

TABLE 1 Marine recreational fishing sectors and target species by regions for Europe

	Baltic Sea		North Sea & Eastern Arctic		North Atlantic		Mediterranean & Black Sea	
Country	Target species	Sector	Target species	Sector	Target species	Sector	Target species	Sector
Albania	–	–	–	–	–	–	E, Sh	S, P, Ch, Pt, Sp
Belgium	–	–	C, B, E, P	S, P, Ch, L, N	–	–	–	–
Bulgaria	–	–	–	–	–	–	E, Sh	S, P, Ch, Pt, Sp
Croatia	–	–	–	–	–	–	B, E, Sh, T	S, P, Ch, Pt, Sp
Cyprus	–	–	–	–	–	–	B, E, Sh, T	S, P, Ch, Pt, Sp
Denmark	C, E, S, St	S, P, Ch, N, Pt, Sp	C, B, E, St, P, Sh	S, P, Ch, N, Pt, Sp	–	–	–	–
Estonia	C, E, S, St	S, P, Ch, N, Pt, Sp	–	–	–	–	–	–
Finland	C, E, S, St	S, P, Ch, N, Pt, Sp	–	–	–	–	–	–
France	–	–	C, B, E, P, Sh	S, P, Ch, N, Pt, Sp	B, E, P, Sh, T	S, P, Ch, N, Pt, Sp	B, E, Sh, T	S, P, Ch, N, Pt, Sp
Germany	C, E, S, St	S, P, Ch, N, Pt	C, B, E, P, Sh	S, P, Ch, N, Pt	–	–	–	–
Greece	–	–	–	–	–	–	B, Sh, T	S, P, Ch, L, Pt, Sp
Iceland	–	–	–	–	C, Sh	S, P, Ch, N, Pt		
Ireland	–	–	–	–	C, B, E, P, Sh	S, P, Ch, Pt, Sp	–	–
Italy	–	–	–	–	–	–	B, E, Sh, T	S, P, Ch, Pt, Sp
Latvia	C, E, S, St	S, P, Ch, N, Pt, Sp	–	–	–	–	–	–
Lithuania	C, E, S, St	S, P, Ch, Sp	–	–	–	–	–	–
Malta	–	–	–	–	–	–	B, E, Sh, T	S, P, Ch, Pt, Sp
Montenegro	–	–	–	–	–	–	B, E, Sh, T	S, P, Ch, Pt, Sp
Netherlands	–	–	C, B, E, P, Sh	S, P, Ch, N	–	–	–	–
Norway	–	–	C, B, E, S, St, P, Sh	S, P, Ch, L, N, Pt, Sp	–	–	–	–
Poland	C, E, S, St	S, P, Ch, Sp	–	–	–	–	–	–
Portugal	–	–	–	–	B, E, Sh, T	S, P, Ch, Sp	–	–
Romania	–	–	–	–	–	–	E, S, Sh	S, P, Ch, Pt, Sp
Slovenia	–	–	–	–	–	–	B, E, Sh, T	S, P, Ch, Pt, Sp
Spain	–	–	–	–	B, E, P, Sh, T	S, P, Ch, N, Pt, Sp	B, E, Sh, T	S, P, Ch, Pt, Sp
Sweden	C, E, S, St	S, P, Ch, N, Pt	C, B, E, St, P, Sh	S, P, Ch, N, Pt	–	–	–	–
UK	–	–	C, B, E, P, Sh	S, P, Ch, N, Pt, Sp	C, B, E, P, S, Sh	S, P, Ch, N, Pt, Sp	–	–

Sectors are defined as fishing platforms where S, shore angling; P, private boat angling; Ch, charter boat angling; L, longlining; N, net fishing; Pt, pot fishing; Sp, spearfishing. Potential target species relates to species where data must be collected in Europe following the Data Collection Framework (EU, 2008a, 2010, 2016a), where B, European sea bass; C, Atlantic cod; E, European eel; P, pollack; S, Atlantic salmon; Sh, elasmobranchs; St, sea trout; T, tuna. Regions are defined following the Data Collection Framework (EU, 2008a, 2010, 2016a).

characterized for each country, fishing modes and gears, and target species were identified where there are requirements for catches to be reported under the DCF (EU, 2008a, 2010, 2016a).

A list of studies was compiled for each country that included estimates of number of fishers, participation rates, effort (total days, days per fisher) and expenditure (total expenditure, expenditure per fisher) (see Table 2 and Supporting Information for a full description of derivation of data from studies). For some countries (e.g. Spain and Portugal) or groups of countries (e.g. UK), data were pooled from constituent states or regions to provide national estimates (see Table 2 and Supporting Information). Calculations from national data were made where estimates were not provided in survey reports (e.g. only participation rate, but no estimate of numbers). Estimates of participation for France were partitioned between Atlantic and Mediterranean regions using the relative split of sea fishing effort between regions (i.e. 60:40 split) (see Table 2 and Supporting Information).

2.2 | Estimating numbers of fishers, participation rates, fishing effort and expenditure

Estimates of numbers of recreational sea fishers, participation rates, fishing effort (total days, days per fisher) and expenditure (total, per fisher) were generated for countries bordering the Atlantic (including the Baltic Sea) and the Mediterranean, and all of Europe combined (see Table 2 for a detailed list of countries).

The numbers and participation rates of MRF were used for countries with existing data. The relationship between participation rate and GDP was examined using correlation analysis comparing arcsine transformed participation rate and per capita GDP (following Arlinghaus et al., 2015). For countries with no data, participation rates were extrapolated to the "recipient country" from the most relevant country identified by national experts, hereafter termed "donor country" (see Table 2 and Supporting Information), and used with population size to estimate numbers of fishers. This assumed that the same proportion of the population was engaged in recreational sea fishing in both recipient and donor countries. The numbers of fishers were then summed for the Atlantic, Mediterranean and the whole of Europe, and used to derive participation rates based on the total population size. To ensure reproducibility of the calculations, the equations are provided below. If F_r is the number of fishers in region r, f_i is the number of fishers in country i, m countries are in region r, p_j is the participation rate in donor country j used for extrapolation, P_r is the participation rate in region r and x_i is the population of country i, then the following equations were used to estimate numbers of fishers:

$$F_r = \sum_{i=1}^{m} f_i \tag{1}$$

$$\text{where } f_i = \begin{cases} f_i, & \text{country data exist} \\ p_j x_i, & \text{extrapolation needed} \end{cases} \tag{2}$$

$$\text{and } P_r = F_r / \sum_{i=1}^{m} x_i \tag{3}$$

A similar procedure was used to derive estimates of effort, with extrapolations based on the average annual fishing days per recreational sea fisher. This assumed that, on average, recreational sea fishers in the recipient country fished the same number of days per year as in the donor country. The average days fished per year was multiplied by the numbers of recreational sea fishers in the country to derive the total effort. The total effort was then summed for Atlantic, Mediterranean and the whole of Europe and the days per fisher derived from the total population size.

For expenditure, a similar method was used with the exception that expenditures were first converted to 2015 prices using Harmonised Consumer Price Index (Eurostat, 2016b), and a correction was made for the difference in per capita GDP (IMF, 2016). This assumed that the same proportion of overall wealth is spent on MRF in the donor.

If E_r is the total expenditure of marine recreational fishers in region r, e_i is the per fisher amount spent in country i, e_j is the per fisher amount spent in donor country j used for extrapolation, and g_i and g_j are the per capita GDP in country i and country j respectively, then fisher expenditure was estimated as follows:

$$E_r = \sum_{i=1}^{m} e_i f_i \tag{4}$$

$$\text{where } e_i = \begin{cases} e_i, & \text{country data exist} \\ e_j g_i / g_j, & \text{extrapolation needed} \end{cases} \tag{5}$$

An assessment of data quality based on expert judgement was used to select specific studies for the analysis, and a semi-quantitative measure was developed to show the potential bias associated with each survey estimate. This semi-quantitative assessment of bias is similar to approaches used to provide indications of uncertainty in other fields (e.g. food safety—EFSA Scientific Committee (2015)). Each individual country value was assessed for the magnitude and the direction of bias (b_i) which was rated on a 7-point scale, ranging between highly overestimated (+3), negligible bias (0), and highly underestimated (−3), taking into account known sources of survey bias that might affect the accuracy of the estimates including coverage, non-response, recall and avidity biases (see Pollock, Jones, & Brown (1994); ICES (2010) for general reviews). It was necessary to weight the contribution of the bias in each country (w_i), so that, for example, a large error in a small estimate did not have as much influence on the overall bias as a small bias in a large value for a country. Hence to calculate the relative bias in region r (B_r), the following equation was used:

$$B_r = \sum_{i=1}^{m} b_i w_i / \sum_{i=1}^{m} w_i \tag{6}$$

where w_i was the individual country value for number, effort and expenditure, and b_i was assumed to be the same for the donor and recipient countries (see Supporting Information in Table S1). The relative bias in the overall estimates was a ratio, so it was categorized by sign to indicate direction of bias (positive—overestimates, negative—underestimate) and on a categorical logarithmic scale (negligible < 0.2; 0.2 ≤ minimal < 0.4;

TABLE 2 Data compiled for each country on recreational sea fishing numbers, participation, activity (average effort per fisher (days) and total days fished per year), average spend per fisher and total expenditure (euro; not corrected for inflation), and country information including basin (AT – Atlantic, MED – Mediterranean and Black Sea) the Gross Domestic Product (GDP – thousands of USD per capita) and population size compiled from Eurostat (Eurostat 2016a, b)

	Country attributes			MRF Information					
Country	Basin	Population (thousand)	Per capital GDP	Participation rate (%)	N° fishers (thousand)	Effort per fisher (days)	Total days fished (thousand)	Fisher annual spend (euro)	Expenditure (million euro)
Albania	MED	2,896	11,377	Greece	Greece	Italy	Italy	Italy	Italy
Belgium	AT	11,204	42,973	0.22*	24	1.05*	26	1,372	33*
Bulgaria	MED	7,246	17,860	Greece	Greece	Italy	Italy	Italy	Italy
Croatia	MED	4,247	20,889	Greece	Greece	Italy	Italy	Italy	Italy
Cyprus	MED	858	30,769	Greece	Greece	Italy	Italy	Italy	Italy
Denmark	AT	5,627	44,343	6.90*	386	6.15*	2,370	543	210*
Estonia	AT	1,316	26,999	1.48*	20	Latvia	Latvia	275	5*
Finland	AT	5,451	40,347	5.50*	300	10.70	3,200	Sweden	Sweden
France	AT & MED	63,929	40,375	2.06*	1,319	6.79*	8,960	Germany	Germany
Germany	AT	80,767	45,888	0.22	174	7.84	1,365	676	118*
Greece	MED	10,904	25,859	2.70	300	France	France	Italy	Italy
Iceland	AT	326	43,637	31.50	103	Norway	Norway	Denmark	Denmark
Ireland	AT	4,606	49,195	2.13*	77	8.28	634	1,641	126
Italy	MED	60,783	35,486	1.32*	800	6.00	4,800*	300	240*
Latvia	AT	2,001	23,707	2.04*	41	37.30	34	Estonia	Estonia
Lithuania	AT	2,943	27,051	Latvia	Latvia	Latvia	Latvia	Estonia	Estonia
Malta	MED	425	33,216	Greece	Greece	Italy	Italy	Italy	Italy
Montenegro	MED	622	14,996	Greece	Greece	Italy	Italy	Italy	Italy
Netherlands	AT	16,829	47,355	3.20	504*	3.60	1,823	275	139*
Norway	AT	5,108	66,937	33.00	1,285*‡	11.50*‡	14,779*‡	Denmark	Denmark
Romania	MED	19,947	19,711	Greece	Greece	Italy	Italy	Italy	Italy
Poland	AT	38,018	25,105	Germany	Germany	1.74*	143	Estonia	Estonia
Portugal■	AT	10,427	26,975	1.67	175	36.83	6,431	796*●	139*●
Slovenia	MED	2,061	29,658	Italy	Italy	Italy	Italy	Italy	Italy
Spain (AT)■	AT	24,483	33,711	0.67*	165	29.64	4,889	672	111*
Spain (MED)■	MED	22,029	33,711	0.61*	133	33.00	4,399	Spain (AT)	Spain (AT)
Sweden	AT	9,645	45,986	5.74*	566*	7.90	4,471	395*♦	223*♦
UK■	AT	64,308	39,511	1.79	1,150	6.15*	7,074	1,664†	1,914†

*Indicates calculation of figure using survey data. Where data were not available or of insufficient quality to be used, the extrapolation country is indicated. Constant exchange rates assumed of 1.25 euro to GBP (†) and 0.11 euro to Swedish Krona (♦). ■indicates compilation of total from different regions; ●correction to 2015 prices; and ‡based on the Norwegian population between 16 and 79 years in 2014.

0.4 ≤ small < 0.8; 0.8 ≤ moderate < 1.6; and 1.6 ≤ large). The relative bias ranged between −3 and +3, representing the situation where the estimates for all individual countries were highly underestimated (−3) or highly overestimated (+3) in relation to the likely actual value.

2.3 | Comparison with other regions globally

Estimates of numbers, effort and expenditure were compiled from other regions across the world from the published literature including global analyses (Cisneros-Montemayor & Sumaila, 2010), regional assessments (Pawson et al., 2007; Pawson, Glenn, & Padda, 2008) and national surveys for the United States (NMFS, 2015), Canada (Brownscombe et al., 2014; Fisheries & Oceans Canada, 2012), Australia (Henry & Lyle, 2003) and New Zealand (Wynne-Jones, Gray, Hill, & Heinemann, 2014). Numbers of recreational sea fishers in Canada were derived from the total effort and days fished per fisher, and related to the 2010 population (http://www.statcan.gc.ca/) to give participation rate, and expenditure was estimated based on partitioning by effort between freshwater and marine fishing (Fisheries & Oceans Canada, 2012). Estimates of direct expenditure were corrected for inflation to 2015 prices using the World Bank annual regional inflation in

consumer prices (http://databank.worldbank.org/) and converted into euros.

The regions in the global analysis of expenditure (Cisneros-Montemayor & Sumaila, 2010) were not identical to those used by the World Bank, so the region for 28 countries of the European Union was used for Europe, all development states in Latin America and the Caribbean used for the Caribbean, Central America and South America, and Australia used for Oceania. Comparisons were then made between the estimates developed in this synthesis and other regions globally for participation rate, effort and expenditure, and used to assess the importance of the sector in Europe. Cisneros-Montemayor and Sumaila (2010) split Europe into four areas, but did not provide details of the countries in each area, so comparisons were made with north and south regions of Europe.

2.4 | Removals by MRF and comparisons with commercial fisheries

Despite the European requirement for recreational catches and releases to be reported for several species (EU, 2008a), only stock assessments for western Baltic cod (ICES subdivisions 22–24—Eero et al., 2014; ICES, 2016b), Atlantic salmon in the Baltic Sea (ICES subdivisions 22–32—ICES, 2015c), and European sea bass (ICES areas IVb-c and VIIa,d-h—ICES, 2015a) (Figure 1) included MRF catches. Comparisons of the recreational and commercial removals were made between reconstructed recreational removals and commercial catches.

The derivation of recreational removals for western Baltic cod (Strehlow et al., 2012) and subsequent inclusion in the stock assessment are well described (Eero et al., 2014). At present, only recreational removals from Germany have been included in the stock assessment (Strehlow et al., 2012), but data were available for Denmark (Sparrevohn & Storr-Paulsen, 2012) and Sweden (ICES, 2015b). Here, total recreational removals (catches and dead releases) were estimated using catches and releases multiplied by post-release mortality for all countries with MRF for western Baltic cod. Available data were grouped into sea-based (boat angling, charter boat angling, trolling) and land-based (shore angling, wading) fishing modes. Post-release mortality of cod was assumed to be 100% for shore-based releases (precautionary approach), and a mortality rate of 11.2% was applied to boat-based releases (ICES, 2016b; Weltersbach & Strehlow, 2013).

For European sea bass, estimates have been compiled and used in ICES stock assessments for ICES areas IVb-c and VIIa,d-h (Figure 1), and a full description of methodology has been published in ICES reports (ICES, 2012a, 2015a). Estimates of European sea bass removals by recreational fishers have been made for England (Armstrong et al., 2013), France (Herfaut et al., 2013; Levrel, Bellanger, Le Goff, & Drogou, 2013; Rocklin et al., 2014), Belgium (ICES, 2012a) and the Netherlands (van der Hammen & de Graaf, 2015). The methods for collection of data varied (see Supporting Information for description of surveys), and there was no single year for which recreational estimates were available for all countries. Hence, estimates for several years were combined to give an average value that was allocated to 2012 for the purposes of the ICES stock assessment and are presented here.

3 | RESULTS

3.1 | Numbers of fishers, participation rates, fishing effort and expenditure

The total number of European recreational sea fishers was estimated to be approximately 8.7 million, with 5.9 million and 2.8 million in Atlantic and Mediterranean regions, respectively (Figure 2, Table 3). Around 13% of the total estimate was based on extrapolation between countries, with a greater proportion of the Mediterranean region estimates subjected to extrapolation (Table 4). The highest numbers of recreational sea fishers were from Norway and the UK in the Atlantic region, whereas the greatest numbers of fishers in the Mediterranean were from Italy (Figure 2, Table 3). The overall participation rate for the whole of Europe was 1.6%. In the Atlantic region, participation rates ranged between 33% (Norway) and 0.22% (Germany). In the Mediterranean, Greece (2.7%) had the highest and Spain (0.61%) had the lowest participation rate, but there was considerable uncertainty about participation rates in many of the other countries (Figure 2, Table 3). The semi-quantitative assessment of bias indicated that the estimate of the numbers of people fishing recreationally in the Atlantic region was reasonable with only a small underestimate likely, but there was potential for a large underestimate for the Mediterranean and a moderate underestimate of numbers for the whole of Europe (Table 4). Individual country surveys were generally categorized as negatively biased due to coverage issues. There was a significant positive correlation between per capita GDP and participation rate ($r = 0.56$, $n = 19$, $p < 0.05$), but this was driven by a single value for Norway. Removal of Norway from the analysis led to a non-significant positive relationship ($r = 0.24$, $n = 18$, $p > 0.05$), so more data would be needed to characterize this relationship.

The total MRF effort in Europe was estimated at 77.6 million sea fishing days, with the majority (73%) carried out in the Atlantic (56.8 million fishing days) compared to the Mediterranean (20.9 million fishing days) (Figure 3, Tables 3 and 4). Over 5 million days in total were fished each year in Norway, UK, Portugal, France and Spain (Figure 3, Table 3). This equated to on average 9.0 sea fishing days per recreational fisher in Europe, with more than 10 days fished per year in Estonia, Finland, Iceland, Latvia, Lithuania, Norway, Portugal, and Spain (Figure 3, Table 3). About 16% of the fishing effort estimate was based on extrapolation between countries, with a much higher proportion extrapolated in the Mediterranean (Table 4). Overall, the semi-quantitative assessment of bias indicated that effort estimates were reasonable for the Atlantic region and the whole of Europe (minimal and small underestimation, respectively), but there was a moderate underestimate of participation for the Mediterranean generally due to under-coverage of fishing methods (Table 4).

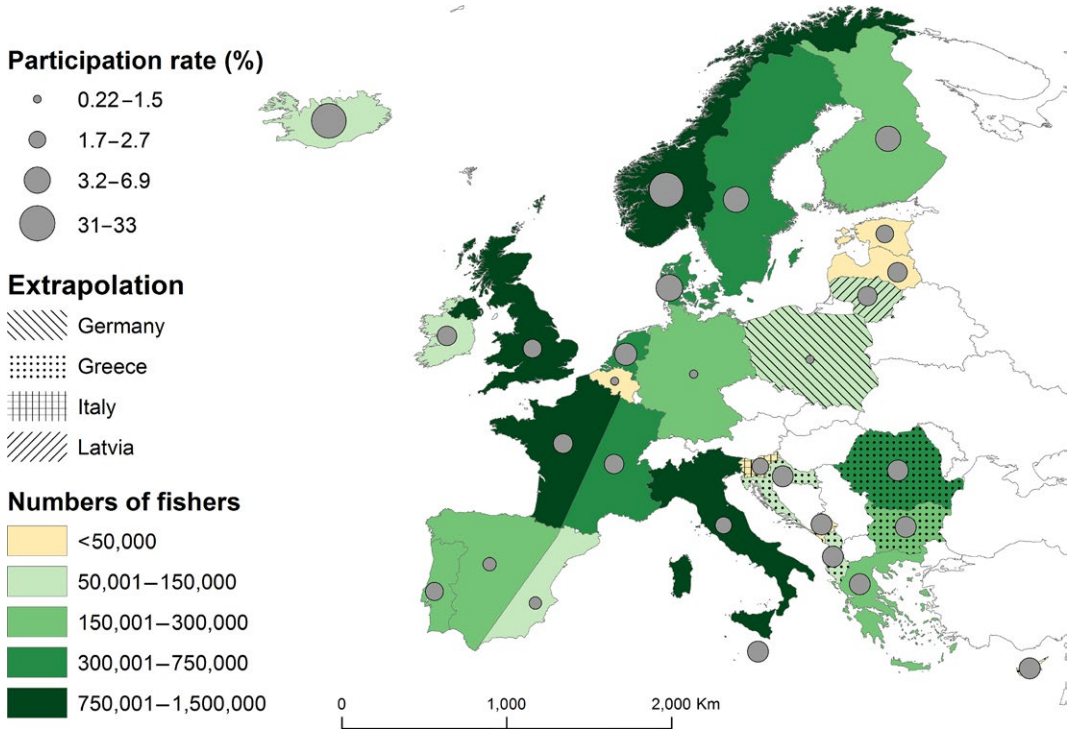

FIGURE 2 Estimated number of recreational sea fishers and the proportion of population that had been sea fishing in the last 12 months. Cross-hatching indicates the country used to extrapolate where no data existed. France and Spain were divided between the Atlantic and the Mediterranean region which is indicated by the dividing line (see Methods and Supporting Information for details)

The expenditure by recreational sea fishers was estimated to be €5.89 billion in Europe, with around €4.97 and €0.92 billion spent in the Atlantic and Mediterranean regions, respectively (Tables 3 and 4). The UK and Norway accounted for 53% of this expenditure, with the UK having the highest annual average expenditure per recreational sea fisher at €1,732 (Figure 4, Table 3). On average, European recreational sea fishers spend €680 annually. In total, 42% of the expenditure estimate for Europe was based on extrapolations between countries (Table 4). Overall, the semi-quantitative assessment of bias indicated that expenditure estimates were reasonable for the Atlantic region and the whole of Europe, but were moderately underestimated for the Mediterranean (Table 4). There was no significant correlation between per capita GDP and expenditure (r = 0.25, n = 11, p > 0.05), but this was based on a small sample size, and the overall trend was positive.

3.2 | Comparison with other regions globally

European regional comparisons were possible with angling (European Anglers Alliance as cited in Pawson et al. (2008)) and sea fishing (Pawson et al., 2007) with similar estimates of numbers, but higher expenditure than estimated in this study (Table 5). Direct comparison at a European level with a global analysis of participation and expenditure in MRF (Cisneros-Montemayor & Sumaila, 2010) suggested a higher participation rate of 3.7% which was driven by much higher participation rates in northern Europe (6.21%), but a lower per fisher spend of €465 than this study. There was also a different pattern in expenditure, with a higher spend in southern than northern Europe (Table 5). Comparison with other regions of the world showed that participation rates were highest in Australia (19.5%), followed by the United States (3.26%), Africa (0.28%) and Asia (0.18%) (Table 5). Days fished per recreational sea fisher were generally similar across all regions, but estimates were only present for the United States (6.5), Canada (9.1), Australia (6.1) and New Zealand (5.1) (Table 5). Previous estimates of average annual expenditure by recreational sea fishers for Oceania and Europe were similar to this study, and were generally much higher than Africa and Asia, with the United States and Central America having a much greater expenditure than other regions (Table 5).

3.3 | Removals by MRF and comparisons with commercial fisheries

MRF removals accounted for a significant component of the total removals (recreational and commercial) for both western Baltic cod (ICES subdivisions 22–24; Figure 1) and northern European sea bass stock (ICES areas IVb-c and VIIa, d–h; Figure 1). The total commercial and recreational landings of western Baltic cod by Germany, Denmark, and Sweden were 17,306 t, of which, 27% was estimated to be from MRF (Table 6). For western Baltic cod, Germany had the highest proportion of total cod removals by recreational fishers (52%), and Sweden the lowest (9%). Release proportions (based on released fish in numbers) ranged between 32% and 48% of the total recreational catch depending on country (overall release proportion 35%). For European sea bass, recreational fishing was estimated to be responsible for 27% of the total removals of 5,401 t in 2012 for countries where survey estimates were available (Table 7).

TABLE 3 Numbers of recreational sea fishers, days fished, and expenditure (presented in constant 2015 prices) by countries in Europe. Where data were not available, data have been imputed from the % fishers (numbers) or total days fished (effort) and corrected for population size

		Participation			Effort (days)			Expenditure (€)		
Region	Country	% fishers	N° fishers (thousand)	Bias	Per fisher	Total fished (thousand)	Bias	Per fisher	Total spend (million)	Bias
Atlantic	Belgium	0.22■	24	−−−	1.05■	26	−−−	1,372	33■	−
	Denmark	6.90■	386	+/−	6.15■	2,370	+/−	595	230■	+
	Estonia	1.48■	20	−	37.30◆	727◆	+++	276	5	+
	Finland	5.50■	300	+/−	10.70	3,200	+/−	350◆	105◆	−−
	France⅄	2.06■	791	+/−	6.79■	5,376	+/−	595◆	471◆	+/−
	Germany	0.22■	174	+/−	7.84	1,365	+/−	677	118■	+/−
	Iceland	31.50	103	+/−	11.50◆	1,180◆	−	586◆	60◆	+
	Ireland	2.13■	77	+/−	8.28	634	+/−	1,654	127	+/−
	Latvia	2.04■	41	−−−	37.30	34	+++	243◆	10◆	+
	Lithuania	2.04◆	60◆	−−−	37.30◆	2,244◆	+++	277◆	17◆	+
	Netherlands	3.20	504■	+/−	3.60	1,823	+/−	284	143■	−−
	Norway	33.00■	1,285■●	−−	11.50■●	14,779■●	−	899◆	1,155◆●	+
	Poland	0.24◆	82◆	+/−	1.74■	143	−−	257◆	21◆	+
	Portugal	1.67	175	−	36.83	6,431	+	796■	139■	−
	Spain	0.67■	165	−	29.64	4,889	−	729	120■	−
	Sweden	5.74■	566■	−−	7.90	4,471	−−	399■	225■	−−
	UK	1.79	1,150	+/−	6.15■	7,074	+/−	1,732	1,991	+/−
	Total	**1.70**	**5,902**	**NA**	**9.62**	**56,765**	**NA**	**842**	**4,971**	**NA**
Mediterranean	Albania	2.70◆	78◆	−−−	6.00◆	469◆	−−	104◆	8◆	−−
	Bulgaria	2.70◆	196◆	−−−	6.00◆	1,174◆	−−	163◆	32◆	−−
	Croatia	2.70◆	115◆	−−−	6.00◆	688◆	−−	191◆	22◆	−−
	Cyprus	2.70◆	23◆	−−−	6.00◆	139◆	−−	281◆	7◆	−−
	France⅄	2.06■⅄	528	+/−	6.79■	3,584	+/−	595◆	314◆	+/−
	Greece	2.70	300	−−−	6.79◆	2,038◆	+/−	236◆	71◆	−−
	Italy	1.32■	800	−−	6.00	4,800■	−−	324	259	−−
	Malta	2.70◆	12◆	−−−	6.00◆	69◆	−−	303◆	3◆	−−
	Montenegro	2.70◆	17◆	−−−	6.00◆	101◆	−−	137◆	2◆	−−
	Romania	2.70◆	539◆	−−−	6.00◆	3,231◆	−−	180◆	97◆	−−
	Slovenia	1.32◆	27◆	−−	6.00◆	163◆	−−	271◆	7◆	−−
	Spain	0.61■	133	−−	33.00	4,399	−−	729◆	97◆	−
	Total	**1.41**	**2,767**	**NA**	**7.54**	**20,855**	**NA**	**332**	**920**	**NA**
All	Total	**1.60**	**8,669**	**NA**	**8.95**	**77,619**	**NA**	**680**	**5,891**	**NA**

Indicative levels of bias are shown using a semi-quantitative scale ranging from +++ (high overestimate) to −−− (high underestimate). ◆represents an extrapolation; ■indicates that figures are calculated using survey data; ●based on the Norwegian population between 16 and 79 years in 2014; NA indicates not applicable as this was assessed using semi-quantitative approach; ⅄estimates for the Atlantic and Mediterranean were derived using the split of sea fishing effort for France (full details in Supporting Information).

The proportion varied between countries, with the highest proportion of recreational removals in Belgium (53%), reflecting the low commercial catch for that country (Table 7). High release proportions (based on released fish in numbers) were observed ranging from 44% to 66% (overall release proportion 55%). Overall, the assessments of bias suggested that the recreational cod and sea bass harvest, release and removal estimates were small underestimates.

4 | DISCUSSION

4.1 | Robustness of estimates of numbers, participation rate, effort and expenditure

This study provides for the first time a robust synthesis of survey data across Europe selected by in-country experts, to characterize the

TABLE 4 Estimates of magnitude and direction of known sources of bias in estimates for each region. The relative bias ranged between −3 and +3, representing the situation where the estimates for all the individual countries were highly underestimated (−3) or highly overestimated (+3) in relation to the likely actual value, and were categorized as negligible <0.2; 0.2 ≤ minimal < 0.4; 0.4 ≤ small < 0.8; 0.8 ≤ moderate < 1.6; and 1.6 ≤ large

Category	Atlantic	Mediterranean	Total
Numbers of fishers	5,902,000	2,767,000	8,668,000
Proportion extrapolated	0.02	0.36	0.13
Relative Bias	−0.75	−2.08	−1.18
Magnitude	Small	Large	Moderate
Direction	Under	Under	Under
Fishing effort (days)	56,765,000	20,855,000	77,619,000
Proportion extrapolated	0.07	0.39	0.16
Relative Bias	−0.26	−1.46	−0.58
Magnitude	Minimal	Moderate	Small
Direction	Under	Under	Under
Spend on fishing (euro)	4,970,852,000	919,728,000	5,890,579,000
Proportion extrapolated	0.37	0.72	0.42
Relative Bias	0.05	−1.21	−0.15
Magnitude	Negligible	Moderate	Negligible
Direction	Over	Under	Under

numbers, participation rates, fishing effort and expenditure by MRF. The data used to represent the most comprehensive compilation of surveys undertaken, to date, were supported by in-depth knowledge of the strengths and shortcomings of individual studies, and included extrapolation to countries without data (see Table 2 and Supporting Information). Extrapolation assumptions were agreed by a group of over 50 experts in MRF as being appropriate and valid. For these reasons, alongside recent improvements in the extent and quality of surveys, and the explicit assessment of potential biases, this study represents more defensible estimates for Europe than previous assessments (e.g. Cisneros-Montemayor & Sumaila, 2010; Pawson et al., 2007, 2008).

The uncertainty in the estimates of participation, effort and expenditure arises from two sources: measurement error (precision) and biases (issues with design and implementation of each survey and methods used for extrapolation). Uncertainty could be estimated by combining the standard errors of the individual surveys or through the use of bootstrapping. However, the standard error was not reported for many individual country surveys, meaning that imputation of many errors alongside numerous assumptions would be needed to derive estimates of uncertainty. In addition, precision is likely to be much less important than bias, as it is the outcome of the levels of sampling and can be improved simply by increasing sampling effort in each country. Implementing either analytical or bootstrap approaches would require a best estimate of bias, the range of uncertainty in each country with survey estimates and an error distribution for each extrapolation. Hence, despite the ease of implementing either analytical approaches combing errors or bootstrapping, it would give a false indication of the level of precision and our knowledge of the form and magnitude of the uncertainty. National experts were able to provide a robust assessment of the direction and magnitude of bias, where there were clear causes (e.g. incomplete coverage, recall bias). As a result, the most appropriate approach with the data available was to separate precision and bias, and focus on bias using a semi-quantitative method as it has the largest impact on the uncertainty. Hence, potential biases and the impact of bias on the robustness of the estimates are discussed in more detail in the rest of this section.

Different surveys incorporating specific issues regarding survey design, coverage, non-response and recall biases, and variability in data specifications have been included in this synthesis. For example, some surveys have issues with coverage of gears, fishing modes, or demographic groups, or recall periods, and most have not accounted for non-response (see Supporting Information for details). The target population for national surveys also varied due to issues with sampling children (e.g. under 16 years), but this bias was likely to be trivial compared to other sources (e.g. under-coverage). Expenditure data represented a specific challenge as there was a lack of consistency in the range of goods and service elements included in the various surveys. Where possible, however, only expenditure was used to reduce this issue, and in most cases, expenditure referred to trip data (e.g. transportation, accommodation, food, boat and gear rentals) and durable goods (e.g. boat, fishing tackle, fishing licences, clothing), with proportionate expenditure excluded (e.g. vehicles, second homes). The assessments of bias at a country level have been estimated by the Member State experts who run the surveys using approaches developed by ICES for assessing the quality of MRF surveys (ICES, 2013, 2014, 2015b, 2017). As a result, we are confident that this approach has provided realistic assessments of magnitude and direction of bias in individual country surveys.

The assessment of bias in combination with the proportion of the overall estimate based on extrapolation gave a good representation of the robustness of the estimates at a regional level. However, as effort and expenditure tended to be derived from extrapolations of recreational sea fisher numbers, there was additional uncertainty in these estimates. Imputations accounted for just 13% of the total estimate of recreational sea fisher numbers in Europe, suggesting that this represented a relatively minor bias overall, but has the potential

to have a larger effect in the Mediterranean region where a greater proportion (36%) of the estimate was based on imputation. The combination of the weighted bias assessment and imputed proportions indicated the estimates for the Atlantic were more robust than for the Mediterranean, with the results for the Atlantic and the whole of Europe considered reasonably robust and Mediterranean estimates less certain. However, the weighted bias for expenditure was mainly driven by Norway, which compensated for less robust estimates from the Mediterranean (Tables 3 and 4). The use of per capita GDP to correct for differences in expenditure was a potential additional uncertainty, as the relationship between expenditure and GDP is unclear. Previous studies indicated no clear trends with per capita GDP (Cisneros-Montemayor & Sumaila, 2010) or a decline with increasing population density and GDP (Arlinghaus et al., 2015). Here, positive but non-significant correlations between per capita GDP and expenditure were found. However, per capita GDP was only used to correct between pairs of similar countries, so was likely to be a reasonable approach for this purpose.

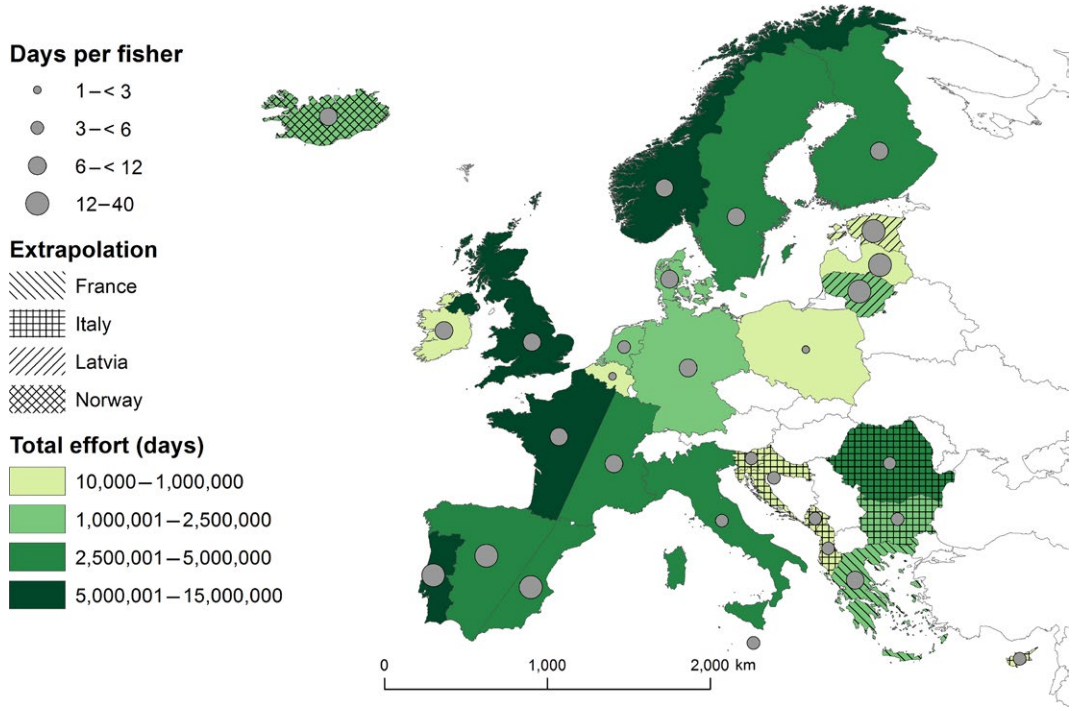

FIGURE 3 Estimated annual effort of recreational sea fishers (average days fished per fisher and total effort) in Europe where cross-hatching indicates the country used to extrapolate where no data existed. France and Spain were divided between the Atlantic and the Mediterranean region which is indicated by the dividing line (see Methods and Supporting Information for details)

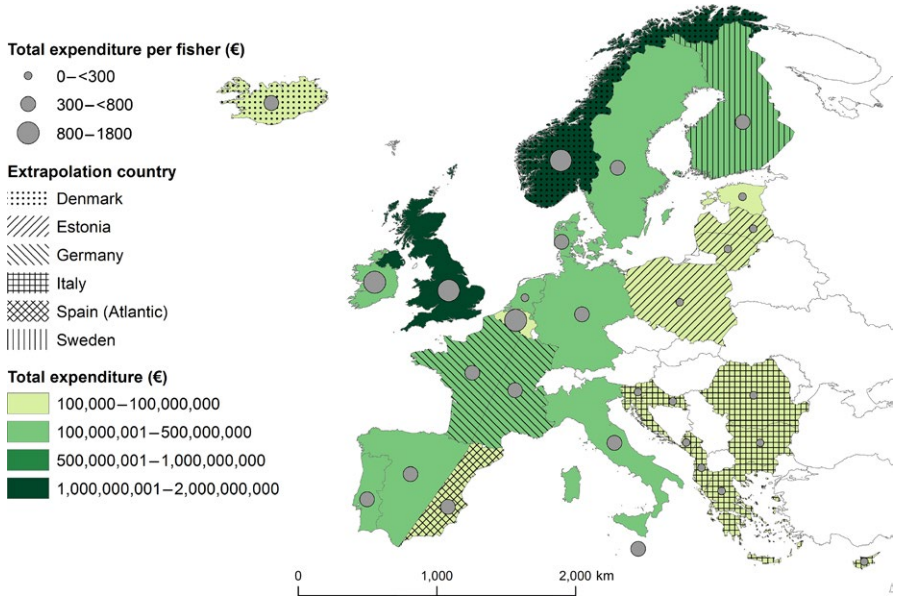

FIGURE 4 Estimated annual expenditure of recreational sea fishers (average expenditure per fisher and total expenditures) in Europe where cross-hatching indicates the country used to extrapolate where no data existed. France and Spain were divided between the Atlantic and the Mediterranean region which is indicated by the dividing line (see Methods and Supporting Information for details)

TABLE 5 Total numbers of recreational sea fishers, participation, days fished (total and on average per fisher), and expenditure (total and on average per fisher) by region

		Participation		Effort (days)		Expenditure (euro)		
Region	Part	Percentage	Number (million)	Per fisher	Total (million)	Per fisher	Total (billion)	Source
Africa	All	0.28	–	–	–	378*	–	Cisneros-Montemayor & Sumaila (2010)
Americas	All	1.83	–	–	–	1,017*	–	Cisneros-Montemayor & Sumaila (2010)
	North	4.71	–	–	–	1,139*	–	Cisneros-Montemayor & Sumaila (2010)
	Caribbean	0.23	–	–	–	806*	–	Cisneros-Montemayor & Sumaila (2010)
	Central	1.13	–	–	–	2,279*	–	Cisneros-Montemayor & Sumaila (2010)
	South	0.78	–	–	–	75*	–	Cisneros-Montemayor & Sumaila (2010)
	USA	3.26	10.5	6.47	68.0	2,783*	29.2 *	NMFS (2015, 2016)
	Canada	1.03+	0.35+	9.10	3.21	396+	0.14+	Fisheries & Oceans Canada (2012)
Asia	All	0.18	–	–	–	906*	–	Cisneros-Montemayor & Sumaila (2010)
Europe	All	3.73	–	–	–	465*	–	Cisneros-Montemayor & Sumaila (2010)
	Northern	6.21	–	–	–	313*	–	Cisneros-Montemayor & Sumaila (2010)
	Southern	1.43	–	–	–	627*	–	Cisneros-Montemayor & Sumaila (2010)
	All	–	8–10	–	–	–	9–12	As cited in Pawson *et al.* (2008)
	All	–	9.50	–	–	–	–	Pawson *et al.* (2007)
	All	1.60	8.67	8.95	77.6	678	5.89	This study
	Northern	1.70	5.90	9.62	56.8	842	4.97	This study
	Southern	1.41	2.77	7.54	20.9	332	0.92	This study
Oceania	Australia	19.5	3.36	6.10	20.6●	560†	1.85†	Henry & Lyle (2003)
	New Zealand	17.0	0.60	5.14	2.45	900	0.86	Wynne-Jones *et al.* (2014); Holdsworth *et al.* (2016)
	Oceania	17.7	–	–	–	633†	–	Cisneros-Montemayor & Sumaila (2010)

*Indicates conversion from US dollars to euro using a conversion rate of 0.89 euro; †is CPI adjusted to 2015, and converted from AU dollars to euros using a conversion rate of 0.69 euro; ●80% of total effort occurred in marine waters; and +estimated from Fisheries & Oceans Canada (2012). All estimates were converted to 2015 equivalents using the compounded regional and country annual inflation rates from the World Bank.

TABLE 6 Most recent estimates of biomass (tonnes) and/or numbers of western Baltic cod (ICES subdivision 22–24) harvested and released by recreational fishers, total removals (tonnes) by recreational and landings by commercial fisheries. The percentage of recreational removals is based on total removals

		Harvest			Release			Removals (tonnes)			
Country	Year	Biomass	Numbers ('000)	Bias	Biomass	Numbers ('000s)	Bias	Recreational	Commercial	% Recreational	Bias
Germany	2015	3,032	2,430	+/−	410	1,139	+/−	3,161	2,915	52	+/−
Denmark	2015	1,272	978	+	220	657	+	1,297	7,361	15	+
Sweden	2015	215	165	−−	51	153	−−−	221	2,351	9	−−
Total*	2015	4,519	3,573	−	681	1,949	−	4,679	12,627*	27	−

Levels of bias are indicated using a semi-quantitative scale ranging from +++ (large overestimate) to −−− (large underestimate). Commercial landings are from 2015.
*The commercial values (landings) refer to western Baltic cod only using a mixing ratio of eastern and western Baltic cod commercial catch in ICES subdivision 24 of 2.36 (ICES 2016a). Recreational cod catches in the western Baltic management area (subdivisions 22–24) are considered to consist exclusively of western Baltic cod.

TABLE 7 Annual biomass (tonnes) and numbers of European sea bass (ICES areas IVb-c and VIIa,d-h) harvested and released by recreational fishers, total removals (tonnes) by recreational and landings by commercial fisheries as used by ICES for stock assessment. The percentage of recreational removals is based on total removals

		Harvest			Release			Removals (tonnes)			
Country	Year	Biomass	Numbers ('000)	Bias	Biomass	Numbers ('000)	Bias	Recreational	Commercial	% Recreational	Bias
Belgium	2011	60	51	−−	25	59	−−	60	55	53	−−
France	2009–11	940	781	+/−	332	904	+/−	940	2740	26	+/−
Netherlands	2010–13	183	284	+/−	97	232	+/−	183	395	32	+/−
England	2012	285	243	+/−	197	467	+/−	285	743	28	+/−
Total	2012	1,468	1,359	−	650	1,662	−	1,468	3,933	27	−

Levels of bias are indicated using a semi-quantitative scale ranging from +++ (large overestimate) to −−− (large underestimate). Commercial landings are as reported by vessels registered in the country shown, irrespective of country of landing.

4.2 | Participation, effort and expenditure in a global context

The current estimate of participation in MRF in Europe (1.6%) was about half that reported previously (3.73%) (Cisneros-Montemayor & Sumaila, 2010). This difference may be explained by the present synthesis focussing on MRF surveys that were not available at the time of the previous estimates rather than a decline in participation (compare Supporting Information with Cisneros-Montemayor & Sumaila (2010)). Globally, the highest participation at a regional level in MRF occurred in Oceania (Henry & Lyle, 2003; Wynne-Jones et al., 2014), with participation rates in Australia (19.5%) and New Zealand (17.0%) about an order of magnitude greater than in Europe as a whole. Norway and Iceland had higher individual country participation rates (>30%), highlighting the variability across Europe. While the overall participation in MRF for the Americas (1.83%) (Cisneros-Montemayor & Sumaila, 2010) was comparable to Europe, the participation rate in the United States (3.26%—NMFS, 2015, 2016) was double that of Europe. The lowest participation rates globally have been estimated for Africa and Asia (Cisneros-Montemayor & Sumaila, 2010). Many factors have been shown to influence participation in MRF (e.g. population size, population density—Edwards, 1989; Heberlein, Ericsson, & Wollscheid, 2002; Arlinghaus et al., 2015), but it is likely that complex interactions between factors drive differences in participation rate and vary between countries, making differences difficult to interpret. However, lower participation rates in Europe than Oceania and the United States could be related to past urbanization trends, as access to coast was not a significant predictor of total recreational marine and freshwater fishing rates in previous studies (Arlinghaus et al., 2015), or could also be due to increasing costs or decreasing catch rates. Despite variability in global participation rates, there was general similarity in the average days fished, ranging between 5 and 10 days per fisher each year. This suggests that the time that fishers dedicate to MRF may be driven by common elements despite the variation in environment and target species between countries and within regions.

There were differences between the expenditure for the Atlantic and the Mediterranean regions with higher expenditure in the Atlantic region being contrary to the pattern reported by Cisneros-Montemayor & Sumaila (2010). Summation of the real adjusted gross disposable income of households per capita for Atlantic and Mediterranean European countries in 2014 (Eurostat, 2016c) showed that disposable income was higher in the Atlantic, indicating that individuals were likely to have more disposable income and thus likely to spend more on recreational pursuits than in European countries bordering the Mediterranean. Average expenditure per angler in the United States (NMFS, 2015, 2016) and Canada (Fisheries & Oceans Canada, 2012) was much higher than observed for Europe, mainly due to a larger proportion of durable goods expenditure (e.g. boats) and differences in the expenditure categories used (e.g. expenditure related to second homes and inclusion of value-added impacts—Fisheries & Oceans Canada, 2012; Brownscombe et al., 2014; NMFS, 2015). Average expenditure in Australia and New Zealand (Henry & Lyle, 2003; Holdsworth, Rea, & Southwick, 2016) was comparable to Europe, although more recent Australian surveys suggest that average expenditure may be higher than previously estimated (Lyle, Stark, & Tracey, 2014; West, Lyle, Matthews, Stark, & Steffe, 2012). Due to sampling challenges, recreational fisheries are undervalued and so recognizing the value is a large step in considering the benefits of MRF in comparison with commercial fisheries (Lynch et al., 2016).

4.3 | Implications for monitoring and assessment of MRF

4.3.1 | Monitoring

Regular data collection is required to improve both the understanding and the management of MRF (ICES, 2013). In some countries, analysis of annual recreational fisheries monitoring has thrown light on the factors influencing the social, economic and biological dynamics (e.g. Arlinghaus et al., 2015; Brownscombe et al., 2014), and have been used to support MRF development. However, these are not available for MRF in many countries affecting the ability to develop and increase the impact on the economy (e.g. Europe—ICES, 2013). A lack of the expertise required to carry out these complex surveys and the generally held belief that MRF has minimal impact on fish stocks has slowed the start of data collection in many regions including Europe (Pawson et al., 2007). In Europe, differences in national fisheries research priorities impeded MRF data collection in some countries, resulting in large differences in MRF data quality, and highlight the importance of common data collection regulations such as the DCF. In fact, the requirement to carry out MRF pilot studies within 2 years of the implementation of the new EU-MAP (EU, 2016a), the need for evidence to underpin derogation from delivery of national MRF data, and the provision for fisheries managers to define additional species, where required, may lead to broader monitoring in future to fill data gaps in Europe.

The frequencies of monitoring surveys vary globally, with surveys carried out every 5 years in Canada (Brownscombe et al., 2014; Fisheries & Oceans Canada, 2012), 2 years in the Netherlands (van der Hammen et al., 2016) and annually in the United States (NMFS, 2015). However, time series of MRF catches show large variation in catch-per-unit-effort and catches between years (Strehlow et al., 2012). These variations underline the importance to collect annual estimates of catches for inclusion in stock assessments, otherwise assumptions are required to generate times series from data from either a single year (e.g. sea bass—ICES, 2012a, 2015a) or to deal with intermittent data (ICES, 2013). MRF effort is not directly related to stock size (e.g. Strehlow et al., 2012), anglers behave in different ways (e.g. Post et al., 2002), and improvements in gear or technology can improve catch rates (e.g. Brownscombe et al., 2014) even when stocks are declining. Thus, management measures used to control recreational fisheries, for example bag limits or closed seasons may not have the desired and predicted outcome. Consequently, MRF monitoring needs to be established before problems are identified to build the evidence base

needed to address these problems and support informed decision-making. Generally, annual multispecies surveys of MRF should be carried out unless evidence shows that the impact is minimal and, even where this evidence exists, regular pilot studies should be performed every 5 years to assess whether the situation has changed (STECF, 2016).

The introduction of national recreational fishers registries or licences would facilitate MRF data collection by providing representative sampling frames at low costs (Ashford, Jones, & Fegley, 2009; ICES, 2013), but may face opposition from recreational fishers and require enforcement to be a useful tool. Recreational fishers logbook smartphone applications ("apps") could provide an alternative means of collecting data to support existing monitoring programmes and deliver broader spatial data sets in real time, but only once a good understanding of the biases in app data is available, and appropriate standards are developed (Venturelli, Hyder, & Skov, 2017). Recreational fishing tourism is rarely covered by national recreational fisheries surveys mainly due to non-coverage issues, particular when using off-site methods for data collection. Therefore, national pilot studies are needed to evaluate this important part of MRF. The use of on-site creel surveys and better collaboration between countries at a regional scale would help to close this important gap.

Due to the varying nature of MRF characteristics across countries (e.g. species, platforms, gears, cultural background), experience in Europe has shown that it is not sensible to develop a single design for all countries, for example in the United States (NMFS, 2016; NOAA, 2015) or Canada (Fisheries & Oceans Canada, 2012). This is because the large variation in MRF characteristics would lead to inefficiency in data collection. Instead, in Europe, the focus has been on the development of statistically sound surveys of known quality that can be combined to produce overall estimates (ICES, 2012b, 2013, 2014). This means that different countries develop monitoring programmes that provide robust data at a national level in the most efficient manner, rather than following a prescriptive survey design (e.g. on-site roving creel, diary panel). This is likely to provide a more robust and pragmatic approach in regions with shared stocks where cultural differences may impact on the reaction and response to different survey methods.

At a global level, it is important to have studies of MRF as the impact can be very large, especially in countries where the main motivation is to catch fish for consumption (e.g. in many African countries). Ideally, statically sound, robust, annual MRF data with minimal bias and good coverage would be available for all countries. However practically, the need for data in many countries and the appropriate sampling depends on the assessment methodology, the quality of commercial data and the capability of local experts. For example, it does not make sense to collect "gold standard" MRF data where simple risk-based or trend-based stock assessment approaches are used. Hence, it is not sensible to prescribe a single programme for all countries. Instead, the MRF monitoring should be implemented on a case-by-case basis, underpinned by statically sound sampling and an understanding of the biases (ICES, 2013). The experience at a European level of the collection of MRF data by multiple countries may help other countries and regions to develop sound MRF monitoring programmes.

4.3.2 | Assessment

MRF catches are routinely included in stock assessments and management in some countries (e.g. USA—Lee et al. (2017), Australia—Ryan et al. (2016)). However, this is not the case in many countries, and global fish catches have been estimated to be 14% higher if recreational fishing was included alongside commercial catches (Cooke & Cowx, 2004). Hence, inclusion of MRF in total fishing mortality is important due to the widespread and popular nature meaning that catches can be large for certain species or stocks (Coleman et al., 2004; Cooke & Cowx, 2004, 2006; Ihde et al., 2011; Lewin et al., 2006; McPhee et al., 2002; Post et al., 2002).

Even where MRF data exist, there are significant challenges in including MRF catches in stocks assessments due to the irregular collection and changing survey methodologies. Europe provides a good example of this, with MRF only included in assessments of Baltic salmon (ICES, 2015c), western Baltic cod (Eero et al., 2014; ICES, 2016b) and European sea bass (ICES, 2015a). Significant assumptions have been made to include the estimated MRF removals of European sea bass of 1,500 t for 2012 from the northern stock, with MRF mortality assumed to be constant to generate a time series for the assessment (ICES, 2015a). This excluded the potential post-release mortality (Ferter et al., 2013) and countries that lacked data (e.g. Wales, Scotland, Northern Ireland, Channel Islands) (ICES, 2015a). Even in the case of western Baltic cod, assumptions were necessary despite the length of the time series (Strehlow et al., 2012) and good understanding of post-release mortality (Capizzano et al., 2016; Ferter et al., 2015a,b; Weltersbach & Strehlow, 2013). In other regions, these challenges are even greater with lack of data leading to reconstructions made based on data from other fisheries (e.g. Pauly & Zeller, 2016) or unconventional sources (e.g. Belhabib et al., 2016), and little information on release rates or post-release mortality (e.g. Ferter et al., 2013). However, comparison of novel data sources with existing surveys in Europe to understand the implications of their use (Venturelli et al., 2017), alongside the further development of the value of individual data points in data-rich situations (ICES, 2016c), will help inform development of MRF monitoring across the world.

MRF management measures have been implemented in Europe that will affect catches in the future (e.g. bag limits and seasonal closures for European sea bass (EU, 2015) and bag limits for western Baltic cod (EU, 2016b)). However, assumptions made (e.g. post-release mortality, times series) or exclusion of MRF catches from stock assessment may lead to bias in stock estimates, and a failure of stocks to respond as expected to management measures (Eero et al., 2014; Hyder et al., 2014; Ryan et al., 2016). Hence, robust methods that account for MRF removals in stock assessments and allocation decisions need to be developed even for data-poor assessments, alongside a better understanding of release rates and post-release mortality (Hyder et al., 2014).

5 | CONCLUSION

This synthesis showed that MRF is an important activity in Europe with significant participation rate, substantial effort, large economic impact,

and important impacts on certain fish stocks. There are still significant data gaps that affect understanding, assessment, management and development of MRF within Europe (e.g. ICES, 2016b), but a large-scale single survey is not appropriate due to the diverse nature of the sector and cultural difference. The EU-MAP (EU, 2016a) provides a mechanism that will address some of the data gaps, but robust regular multispecies surveys of MRF in all countries across Europe are needed. The European situation is mirrored in many other regions with even fewer data available, so pragmatic solutions that may include novel methods for data collection need to be considered. A combination of MRF monitoring with studies on post-release mortality and the development of new methods for the reconstruction and assessment of recreational catches will lead to the routine inclusion of MRF in stock assessments, fisheries management, and catch allocations. The development of the MRF data collection in Europe can help other regions to establish sound data collections, especially in terms of using pragmatic bespoke approaches and experiences of merging data from different surveys. Thus, increasing our ability to manage global marine fish stocks sustainably.

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ORCID

Kieran Hyder http://orcid.org/0000-0003-1428-5679

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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