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Contribution to the Themed Section: '*Marine recreational fisheries – current state and future opportunities*'

Original Article

Field surveying of marine recreational fisheries in Norway using a novel spatial sampling frame reveals striking under-coverage of alternative sampling frames

Jon Helge Vølstad [1]*, Mary Christman [2], Keno Ferter[1], Alf Ring Kleiven[1], Håkon Otterå[1], Øystein Aas[3,4], Robert Arlinghaus [5,6], Trude Borch[7], Jonathan Colman[4], Bruce Hartill[8], Thrond O. Haugen[4], Kieran Hyder [9,10], Jeremy M. Lyle[11], Martin Junker Ohldieck[1], Christian Skov[12], Harry V. Strehlow[13], Dave van Voorhees[14], Marc Simon Weltersbach [13], and Edward D. Weber[15]

[1]*Institute of Marine Research, Nordnes PO Box 1870, 5817 Bergen, Norway*
[2]*MCC Statistical Consulting, LLC, 2219 NW 23rd Terrace, Gainesville, FL 32605, USA*
[3]*Norwegian Institute for Nature Research (NINA), Fakkelgarden, N-2624 Lillehammer, Norway*
[4]*Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences, NO-1432 Ås, Norway*
[5]*Department of Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 12587 Berlin, Germany*
[6]*Division of Integrative Fisheries Management, Faculty of Life Sciences, Albrecht-Daniel-Thaer-Institute of Agriculture and Horticulture Humboldt-Universität zu Berlin, Philippstrasse 13, 10115 Berlin, Germany*
[7]*Akvaplan-niva AS, The Fram Centre, PO Box 6606, 9296 Tromsø, Norway*
[8]*NIWA, 41 Market Place Viaduct Harbour, Auckland Central 1010, New Zealand*
[9]*Centre for Environment, Fisheries and Aquaculture Science (Cefas), Pakefiled Road, Lowestoft, Suffolk NR33 0HT, UK*
[10]*School of Environmental Sciences, University of East Anglia Norwich Research Park, Norwich, Norfolk NR4 7TJ, UK*
[11]*Institute for Marine and Antarctic Studies, University of Tasmania, Private Bag 49, Hobart, TAS 7001, Australia*
[12]*DTU AQUA, Section of Inland Fisheries and Ecology, Technical University of Denmark, Vejlsøvej 39, 8600 Silkeborg, Denmark*
[13]*Thünen Institute of Baltic Sea Fisheries, Alter Hafen Süd 2, 18069 Rostock, Germany*
[14]*NOAA Fisheries, 1315 East-West Highway, Silver Spring, MD 20910, USA*
[15]*NOAA Southwest Fisheries Science Center, 8901 La Jolla Shores Drive, La Jolla, CA 92037-1509, USA*

Corresponding author: tel: +47 55 23 85 00; e-mail: jonhelge@hi.no.

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Norway has the highest participation rate in marine recreational fisheries (MRF) in Europe, and is popular among marine tourist anglers. Fishing licences are not required for marine recreational anglers, and the complex and long coastline makes on-site surveys a challenge. A novel approach for spatial sampling was developed and tested in on-site surveys, as part of a National study of MRF using multiple sampling frames including a telephone screening survey based on the national telephone directory. Field surveys were conducted in Troms and Hordaland Counties, and in the Oslofjord. We created spatial sampling frames of modified Voronoi polygons with continuous sea-surface area, with clusters of polygons as primary sampling units (PSUs). Interviews of intercepted anglers were obtained quarterly from a stratified sample of PSUs searched by boat. Many anglers interviewed in Troms (63%) and Hordaland (53%) were non-residents, of which 92 and 66% stayed in registered tourist fishing camps, respectively. Most anglers in the Oslofjord were residents, and in the inner Oslofjord, 63% of the resident anglers interviewed on-site were born outside Norway, which was not reflected in the telephone survey. Thus, if only off-site methods were used to map Norwegian MRF, this could lead to biased results in some regions.

Keywords: angler fishery, cluster sampling, fishing tourism, marine recreational fisheries, probability-based survey, spatial sampling frame, tourist fishing, Voronoi polygons, water-distance

Introduction

Many coastal nations have focused their fishery research and management on commercial fisheries (Pauly, 2009). However, during the last decade, there has been an increased research and management focus on marine recreational fisheries (MRF; McPhee *et al.*, 2002; Coleman *et al.*, 2004; Cooke and Cowx, 2004; NRC, 2006; Aas, 2008; Ferter *et al.*, 2013; Arlinghaus *et al.*, 2015; Kleiven *et al.*, 2016; Hyder *et al.*, 2018; Lewin *et al.*, 2019). Norway has the highest participation rate of recreational sea fishers in Europe (Hyder *et al.*, 2018), and marine recreational fishing is one of the most popular outdoor leisure activities in the country, with an estimated participation rate of 33% in 2014 (Vaage, 2015). Norway is also an increasingly popular tourist destination for recreational fishing, and the marine angling tourism industry is increasing (Borch, 2004; Borch *et al.*, 2011).

There is growing evidence that recreational fishing can significantly impact fish stocks (Lewin *et al.*, 2006; Lewin *et al.*, 2019) and that recreational fish catches can equal or even exceed catches in the commercial sector (McPhee *et al.*, 2002; Schroeder and Love, 2002; Coleman *et al.*, 2004; Kleiven *et al.*, 2012; Herfaut et al., 2013; Kleiven *et al.*, 2016; Radford *et al.*, 2018). A recent study showed that marine recreational landings were between 2 and 43% of the total landings for some fish stocks in Europe, but data were not available for most stocks (Radford *et al.*, 2018). Research conducted on the lobster (*Homarus gammarus*) fishery in the Agder counties (southern Norway) concluded that the recreational landings were twice as high as the commercial landings (Kleiven *et al.*, 2011; Kleiven *et al.*, 2012). Moreover, a mark-recapture study along the Skagerrak coast in Southern Norway estimated that resident recreational fishers accounted for 68% of the total Atlantic cod (*Gadus morhua*) landings in coastal areas (Kleiven *et al.*, 2016). However, a survey to estimate landings and effort in the recreational tourist fishing sector using a sampling frame of 445 tourist fishing businesses, suggested that this sector alone contributed little to the total fishing mortality of coastal stocks in Norway (Vølstad *et al.*, 2011). In 2018, the Norwegian Directorate of Fisheries established a registry for tourist fishing businesses, and more than 1000 businesses had registered by the end of 2018, suggesting a substantial increase in effort over the last 10 years. Further studies on the impact of this sector are therefore required.

MRF create significant economic impact to coastal communities as well as a variety of cultural and provisional ecosystem services such as health, well-being, and food (Fedler and Ditton, 1994; Parkkila *et al.*, 2010; Lynch *et al.*, 2016; Griffiths *et al.*, 2017; Cooke *et al.*, 2018; Hyder *et al.*, 2018). Fishery management is therefore not only about securing high yields and sustainable fish stocks but also about maximizing the socio-cultural and economic values generated from the utilization of these stocks in a leisure setting (Johnston *et al.*, 2010). Providing knowledge of the social and economic dimensions, and the ecosystem services that a fishing activity provides is important when allocating quotas between sectors and in resolving stakeholder conflicts (Salz *et al.*, 2001; Borch, 2010). The study of these dimensions of MRF relies on sufficient understanding of fisher motivations, preferences, and behaviour (FAO, 2012; Arlinghaus *et al.*, 2019). The benefits anglers desire from recreational fishing are often about more than catching fish (Fedler and Ditton, 1994; Arlinghaus, 2006; Beardmore *et al.*, 2011; Arlinghaus *et al.*, 2019). To secure a balance between economical sustainable yields and social benefits, fishery managers require accurate effort and catch estimates and knowledge of socio-economic benefits for all fishery sectors, including MRF (Pollock et al., 1994; Pitcher *et al.*, 2002; McCluskey and Lewison, 2008; Parkkila *et al.*, 2010). Ignoring the recreational fisheries sectors may lead to poor management with possibly severe consequences for fish stocks, as well as undermining important societal values at different scales (Cooke and Cowx, 2004; Sumaila *et al.*, 2006; Agnew *et al.*, 2009; Arlinghaus *et al.*, 2019). For Norway, and other European countries, it must be emphasized that the European Common Fisheries Policy (CFP) states that economic and social considerations must be taken into account in fisheries management [Regulation (EU) No 1380/2013]. Recreational fisheries should therefore be surveyed and managed in a manner that supports these CFP goals. At the international level, the International Council for the Exploration of the Sea (ICES) advises that data on different dimensions of MRF are needed to inform fisheries management strategies, and to support marine spatial planning (ICES Advisory Committee, 2015). In response, ICES has established a Working Group on Recreational Fisheries Surveys (WGRFS). This group has documented the European knowledge status in terms of participation rates, fishing effort, and expenditure in different recreational fisheries sectors (Hyder *et al.*, 2018). There is also an increasing focus on recreational fisheries monitoring and research in the European Union (EU). Through the EU Data Collection Framework (EC Reg. 199/2008 and EC Decision 2008/949/EC), EU Member States have committed themselves to establish monitoring programmes to map recreational catches (numbers kept and released) and describe economic dimensions for selected species, e.g. Atlantic cod and European sea bass (*Dicentrarchus labrax*). Estimates of MRF catches are included in the stock assessment of e.g. western Baltic cod (Strehlow *et al.*, 2012; Eero *et al.*, 2015) and for sea bass (ICES, 2018) where results have led to daily bag limits and/or closed seasons to reduce fishing mortality from MRF. Such actions have seen abundant angler opposition in some countries, motivating improved monitoring methods and novel approach that equitably distribute fish stocks among the various fishing sectors co-exploiting a common stock (Arlinghaus *et al.*, 2019).

Norway has the largest commercial fisheries landings in Europe (FAO, 2018), and commercial fisheries in the country are strictly monitored and well regulated (Gullestad *et al.*, 2014, 2015). Commercial vessels and fish dealers are obliged by law to register and report catches through logbooks, trip tickets, and sales slips (Alder and Pauly, 2008; Pitcher *et al.*, 2009). In contrast, the MRF sectors are poorly documented and regulations are liberal. Resident recreational fishers in Norway are allowed to use gillnets, pots, traps, longline, and even a jigging machine in addition to hand-held (rod and/or line) fishing gear (Kleiven *et al.*, 2016). Non-commercial fishers are also allowed to sell some of their catch through official landing sites. Non-resident recreational fishers are only allowed to fish with hand-held (rod and/or line) fishing gear and may not sell their catch. Despite the importance and expected magnitude of MRF in Norway, the level of available research funding to characterize and quantify these sectors has been limited, with only small aspects of the national MRF studied to date. There is therefore no reliable up-to-date knowledge on catch and effort nor on important socio-economic dimensions for all sectors of MRF in Norway. These limitations hold for much of Europe and the rest of the world (Post *et al.*, 2002; Arlinghaus *et al.*, 2019).

The Norwegian MRF are generally open access with no requirement for a fishing licence. The public right of access ("Allemannsretten") to pursue recreational activities has a very strong standing in Norway. The public have legal access to virtually all coastal waters, most of the coastline and to non-cultured land, and even can access cultured land when frozen for recreational purposes. Recreational fishing from shore can occur from nearly anywhere, even from privately owned land. This makes it difficult to survey this fishing using on-site methods. Comprehensive sampling frames (Cochran, 1977; Fuller, 2009) built on registry-databases of recreational fishers (see NRC, 2006) or indirect sampling frames (see Lavallée, 2007), such as a complete registry of recreational boats, are generally not available in Norway. Exceptions include the recreational trap fishery for lobster, where a licence and mandatory registration is required, and the registry of tourist fishing businesses, which is mandatory for enterprises with an income of more than 50 000 NOK per year. Both registries were established by the Directorate of Fisheries in 2017 and 2018, respectively. Resident recreational fishers who use standing gears are required by law to mark their buoys with contact information, and for lobster traps, also with a licence number. These buoys, if marked, can be surveyed by on-site methods and provide an indirect sampling frame to contact and interview recreational fishers that use standing gears.

Resident recreational fishers can be contacted for off-site surveys through a sampling frame based on the National Registry of residents (Statistics Norway), coupled with the Norwegian phone directory. This sampling frame will have known and expected under-coverage of foreign fishers such as foreign tourists and guest—and migratory workers, as well as refugees and immigrants. The latter groups will generally be residents and included in the National Registry, and many may have a Norwegian phone number. The foreign tourists will clearly not be listed in the National Registry. Nevertheless, they can be difficult to reach in phone surveys because of language barriers. In addition, the MRF in Norway are widely spread out in time and space, and the heterogeneous population of fishers cannot be representatively sampled on-site (and intercepted in person) from a finite list of access-points along the coast. This precludes the use of many of the cost-effective probability-based on-site methods applied for example in the US NOAA Marine Recreational Information Programme (MRIP; see http://www.st.nmfs.noaa.gov/recreational-fisheries/). To increase our knowledge on the different MRF sectors in Norway, and to evaluate their relative biological and socio-economic importance, we therefore developed and implemented alternative probability-based survey methods in collaboration with a team of international and national experts, and with input from the ICES expert group WGRFS.

To develop comprehensive methods to estimate effort, catches and socio-economic values in the Norwegian MRF, we saw the need to test complementary on-site and off-site methods using multiple sampling frames. In this paper, we present the sampling frames employed in a national survey of MRF conducted in 2018–2019. We then provide a detailed description of an on-site survey component and a novel approach to develop a spatial sampling frame. This on-site survey is used to evaluate the sampling coverage of the off-site sampling frames. Based on field interviews from on-site surveys conducted in two 5-day periods per quarter in each of three sampling regions in Norway (April–December 2018), we describe differences in angler demographics and accommodation type used by non-resident anglers. We apply this to assess the coverage of non-resident anglers using a list-frame based on the national registry of tourist fishing businesses established in 2018. We also discuss how on-site sampling can compensate for potential biases in off-site sampling frames of Norwegian residents.

Material and methods

Study area

Norway has the world's second longest coastline (after Canada) and a population of around 5.3 million people (2017; Statistics Norway). The coastline including fjords, inlets, and 239 057 registered islands is 100 915 km long (www.SNL.no). Three regions were chosen for in-depth studies in the survey: Troms county (north), Hordaland county (west), and the Oslofjord (southeast), consisting of the counties Østfold, Akershus, Oslo, Buskerud, and Vestfold (Figure 1).

The three regions differ in expected fishing effort, demographics of recreational fishers, and as indicated by official commercial landings reported for these coastal areas, they also differ in available fisheries resources (Table 1; Supplementary Figure S1). Troms county has a widely scattered population with only 6.4 inhabitants per km^2, and 106 registered tourist fishing businesses. This county also has large coastal commercial fisheries and is a popular destination for tourist anglers because of the potential for high catch rates of cod, as well as the opportunity of catching big cod and halibut (*Hippoglossus hippoglossus*) as well as other popular species. Hordaland has a medium population density (33.8 inhabitants per km^2), and 147 registered tourist fishing businesses. The Oslofjord region is relatively densely populated (79.4 inhabitants per km^2) and has few registered tourist fishing businesses.

Sampling frames used in the national survey of MRF

We grouped the MRF in Norway into categories that allowed us to identify suitable sampling frames for on-site and off-site

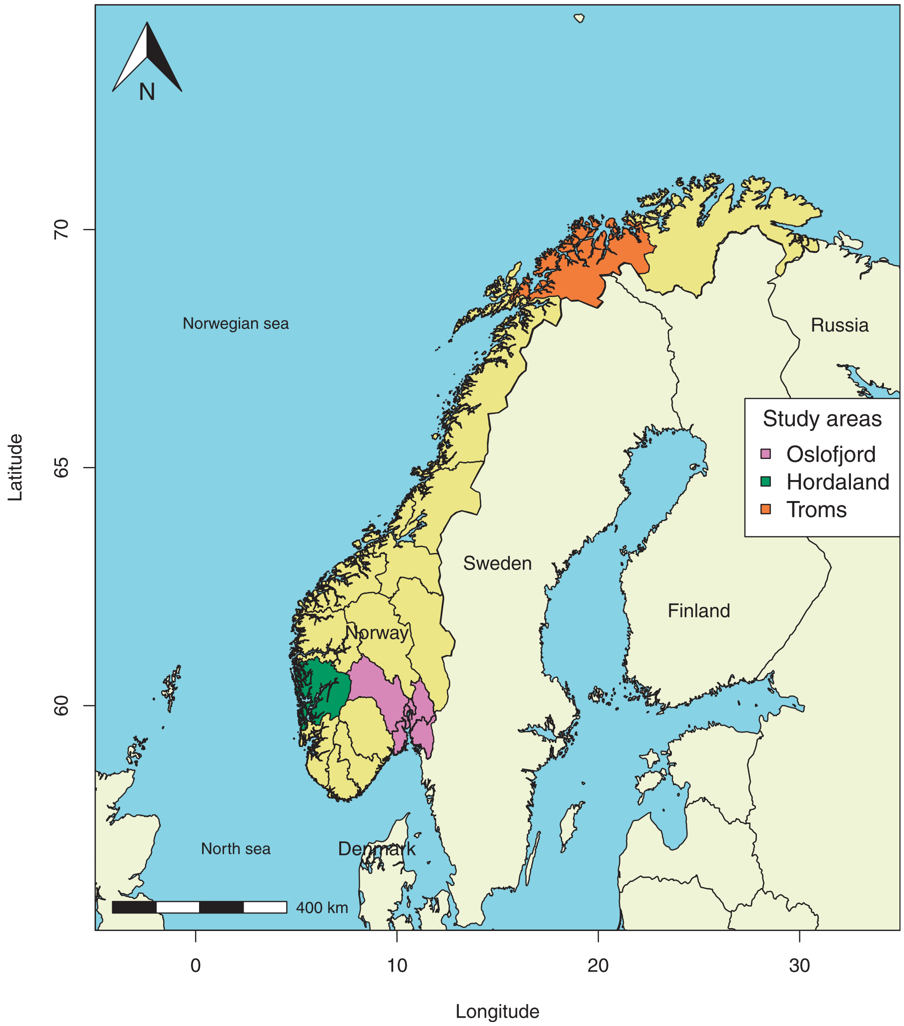

Figure 1. Map of Norway with the three regions for in-depth field studies highlighted (Oslofjord, Hordaland County, Troms County).

Table 1. Some key parameters for Norway and for the three regions where we conduct in-depth field studies.

Parameter/county	Norway	Oslofjord[a]	Hordaland	Troms
Land area[b] (km^2)	323 808	26 688	15 437	25 872
Sea area[c] (km^2)	145 458	3126	7250	15 261
Coastline[d] (km)	100 915	3091	8741	6020
Population (age 16+)[e]	4 295 331	1 714 745	420 730	136 670
Cottages[e]	431 028	96 806	30 443	12 755
RegisteredTourist fishing businesses[f]	1030	20	147	106
Boats for hire[f]	5632	86	626	502

Data are from year 2017 if not otherwise stated.
[a]Includes the counties Østfold, Akershus, Oslo, Buskerud, and Vestfold.
[b]Mainland and islands excluding Jan Mayen and Svalbard. Source: The Norwegian Mapping Authority.
[c]Within 12 nm of mainland (Source: The Norwegian Mapping Authority).
[d]Mainland and islands. Source: Statistics Norway.
[e]Source: Statistics Norway.
[f]Source: Norwegian Directorate of Fisheries (per 6 January 2019).

surveys (Figure 2). The 2018–2019 national study of recreational fisheries (RecFish 2018–2019) included three complementary surveys (Figure 3):

(1) an off-site survey of resident fishers (age 16+) using a sampling frame based on the National Registry, coupled with the phone registry including both landline and mobile phone numbers (most Norwegian residents of age 16+ have mobile phones);
(2) an on-site and off-site study of the formal tourist fisheries in Hordaland and Troms counties, using a sampling frame based on the registry of tourist fishing businesses from the Norwegian Directorate of Fisheries;

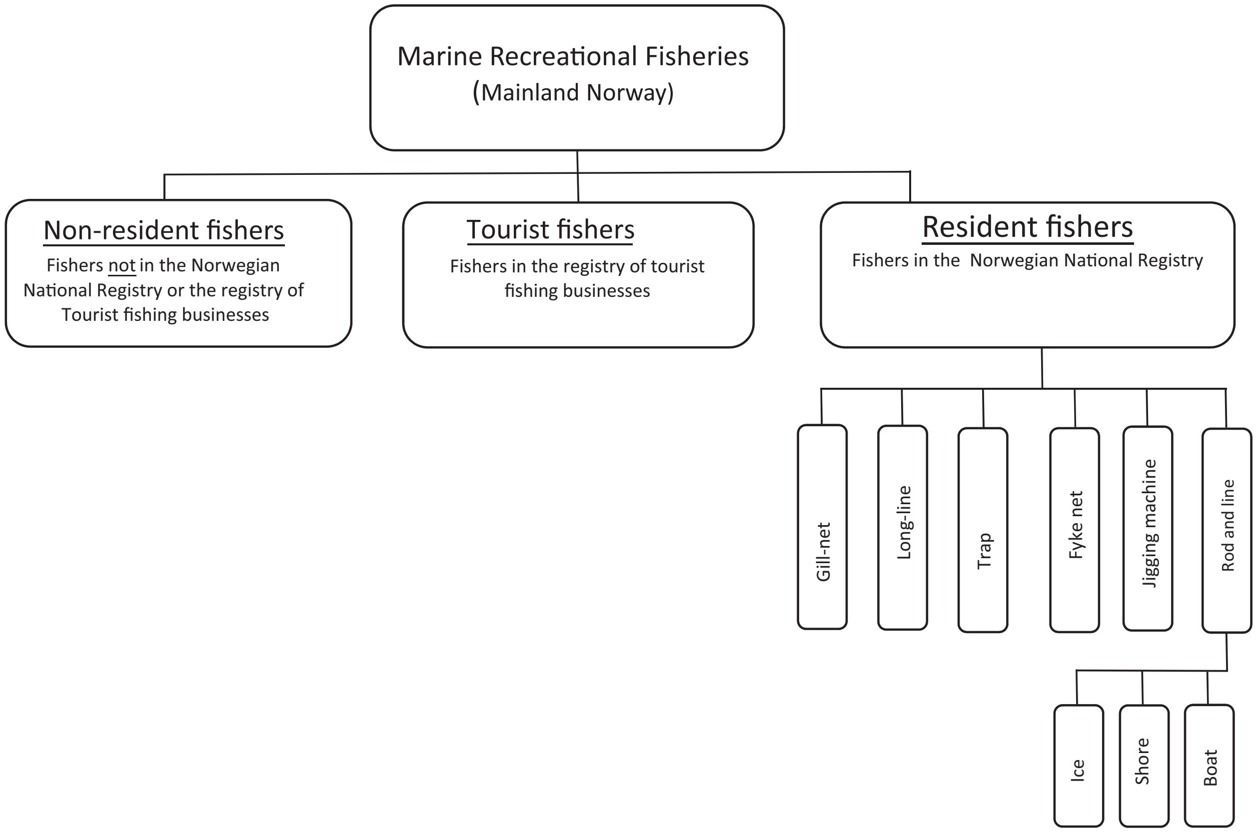

Figure 2. Marine recreational fisheries grouped into categories based on sampling frames. Resident recreational fishers can be covered in off-site surveys using Norway's National Registry coupled with the National Phone Directory. The tourist fishing sector can be surveyed using the official Registry of tourist fishing businesses as a sampling frame, with businesses as primary sampling units (PSUs) and days as secondary sampling units. This sampling frame provides indirect access to interview anglers and sample their landings. The non-resident fishers are guest workers, tourists that stay in private accommodation, and other anglers that cannot be covered through the registry of tourist fishing businesses.

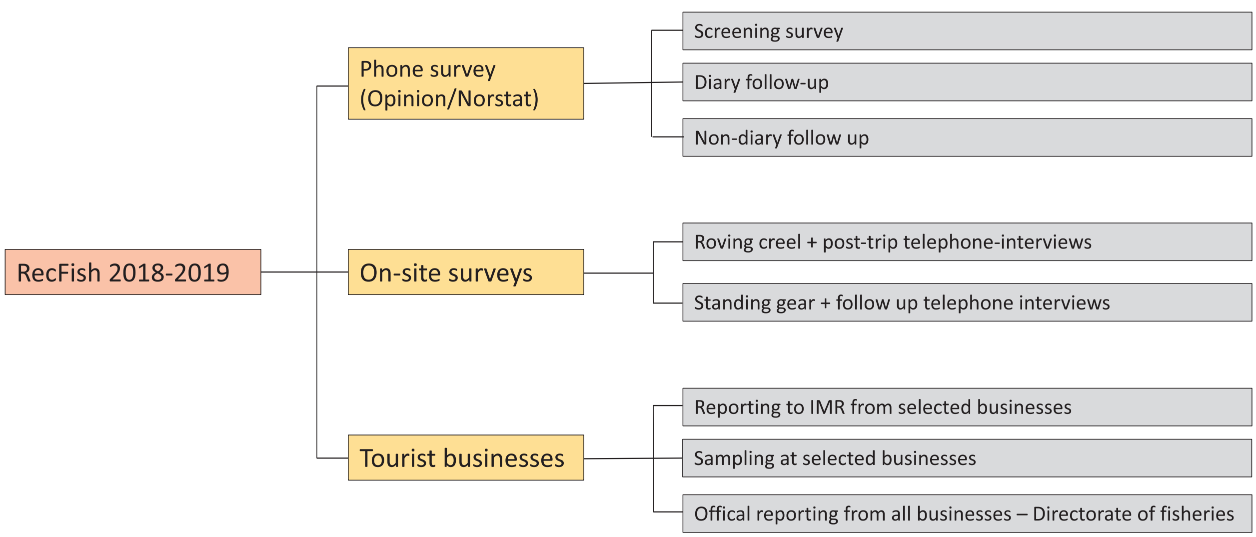

Figure 3. Survey sampling components in the current national survey of marine recreational fisheries in Norway (RecFish 2018–2019).

(3) an on-site intercept survey of anglers by boat in three regions (Oslofjord, Hordaland county, and Troms county) using spatial sampling frames (on-site interviews of fishers intercepted in the field and length measurements of fish coupled with post-trip interviews).

In this paper, we focus on the comparison of sampling frames to cover one segment of MRF, namely marine recreational angling, i.e. fishing with rod-and-line or another hand-held hook and line tackle. The interviews and data handling for all survey components are conducted according to a protocol approved by the Norwegian Centre for Research Data (Project reference 58760) to securely handle personal data.

Off-site telephone survey

The sampling frame for the off-site screening survey by phone was based on the National Registry of residents (age 16+), coupled with the phone directory, with individual persons as sampling units. An important aim of the screening survey was to recruit fishers to report their catches by trip in catch diaries over a 12 months period. In order to have a cost efficient screening survey, male fishers were over-sampled. The background for this was that the pilot surveys indicated that males dominate Norwegian MRF in terms of annual participation rate and number of fishing trips. A stratified random sample of 100 000 people (Table 2) was selected from the National Registry spread evenly among four spatial strata: (i) Troms County, (ii) Hordaland County, (iii) Oslofjord, and (iv) Rest of Norway, and by gender (2/3 men, 1/3 female). These National Registry records that included information on demographics and country of birth were coupled with the Norwegian phone directory by Bring (a Norwegian postal and logistics company operating in the Nordic countries). In total, 72 275 people could be linked to a phone number and this was used as a list-frame in the telephone screening survey (Table 2). The phone screening survey was conducted in February–March 2018 by the commercial survey companies Opinion and Norstat. In this survey, we mapped participation rates in MRF, and recruited fishers to report their catch for fishing trips between 1 April 2018 and 31 March 2019, in a catch diary provided by the Institute of Marine Research (IMR). A random sample of 38 470 people (age 16+) stratified by region and gender was called up by phone. A summary of the screening survey is provided in Table 2.

Off-site and on-site surveys of the marine tourist fishery

In Hordaland and Troms counties, complementary off-site and on-site surveys of the marine tourist sector were conducted using a list-frame based on the registry of tourist fishing businesses that were established by the Directorate of Fisheries in 2018. We used the individual businesses in this list as the primary sampling units (PSUs; Design class D, ICES, 2014). This registry provides comprehensive coverage of tourist fishing businesses and provides an effective sampling frame for studying the tourist fishery sector. All businesses with more than 50 000 NOK in gross income per year are mandated to register and many other small businesses with rental boats have registered voluntarily. The tourist fishing businesses in the registry mainly attract foreign anglers, providing accommodation and boat rental. Each guest visiting a registered business is allowed to export 20 kg of fish fillets, compared to 10 kg for anglers buying their services from unregistered tourist facilities. This provides an incentive for small businesses to register. Over 1000 tourist fishing businesses are currently registered, with more than 5000 boats for hire. The businesses in the registry are mandated to provide monthly reports on catch per trip of selected species (in number of fish landed and released) to the Directorate of Fisheries.

We selected a random sample of 10 businesses (PSUs) from this registry in each of Troms and Hordaland counties, with probability of selection for PSUs being proportional to their number of rental boats. These tourist fishing businesses report effort and catches by trip for the guests staying at their facilities directly to IMR and are exempt from mandatory reporting to the Directorate of Fisheries during the project period. IMR staff were in close contact with these businesses, which they visited on randomly selected days (secondary sampling units) throughout the project period, to interview fishers and sample their landed catches to obtain length-data of catches by species (an information letter is provided in the Supplementary Material). In this paper, we assess this sampling frame by comparing demographics of anglers interviewed at these tourist fishing businesses with the demographics of tourist anglers interviewed in the on-site field survey (see below).

Table 2. Percentage of people (age 16+) born outside Norway by region and gender (M = male; F = female) for the sample of people in each sampling stage for the telephone screening survey.

		% Born outside Norway							
		Troms		Hordaland		Oslofjord		Other	
Sampling stage	Sample size (n)	F	M	F	M	F	M	F	M
National Registry	100 000	11	13	14	16	22	23	13	14
Phone list	72 275	9	10	11	13	18	21	10	11
Phone calls	38 740	9	9	9	12	17	18	9	10
Interviewed	6728	8	6	6	6	15	12	7	6
MRF—all	2477	3	4	5	4	1	9	4	4
MRF—angling	2313	3	4	5	3	1	9	5	4

Be aware that the sample size (*n*) is the total sample size and is not equally spread between regions and gender. Note also that this table reports % born outside Norway for the sample of people, and not population estimates.

On-site field intercept surveys by boat

The study area in each region was defined as all coastal areas within the coastal baseline (as defined by the Norwegian mapping authority https://www.kartverket.no/en/). Sampling frames for each region were created using a Generalized Random-Tessellation Sampling design (GRTS; Stevens and Olsen, 1999, 2004) and a modified approach for constructing Voronoi polygons (cf. Okabe *et al.*, 2000) of approximate equal area.

The GRTS procedure was used to construct a set of random point locations within each study region (Figure 4a). Selection of the point locations was performed using the "grts" function of the package "spsurvey," version 3.3 (Kincaid and Olsen, 2016) in the R statistical environment version 3.3 (R Core Team, 2017). The number of points selected in each spatial sampling frame were 3053 for Troms, 1460 for Hordaland, and 626 for Oslofjord, to obtain spatial sampling units (i.e. the polygons surrounding points) with an average area of about 4 km^2.

Modified Voronoi polygons were then created using the GRTS points as seed locations and a rasterized "heat" map of water-distance from these points (Figure 4b). Each polygon consisted of all points in the plane, which were closest in travel distance by boat (e.g. around islands and peninsulas) to a particular GRTS point. We constructed the polygons using the QGIS Geographical Information System (QGIS Development Team, 2018) to call functions from the GRASS GIS system version 7.2 (GRASS Development Team, 2017), Saga GIS version 2.3.2 (Conrad *et al.*, 2015), and GDAL geospatial data abstraction library version 2.2.3 (GDAL, 2017). The shapefile for each spatial sampling frame was converted to a rasterized map with resolution of 5 m^2 using the

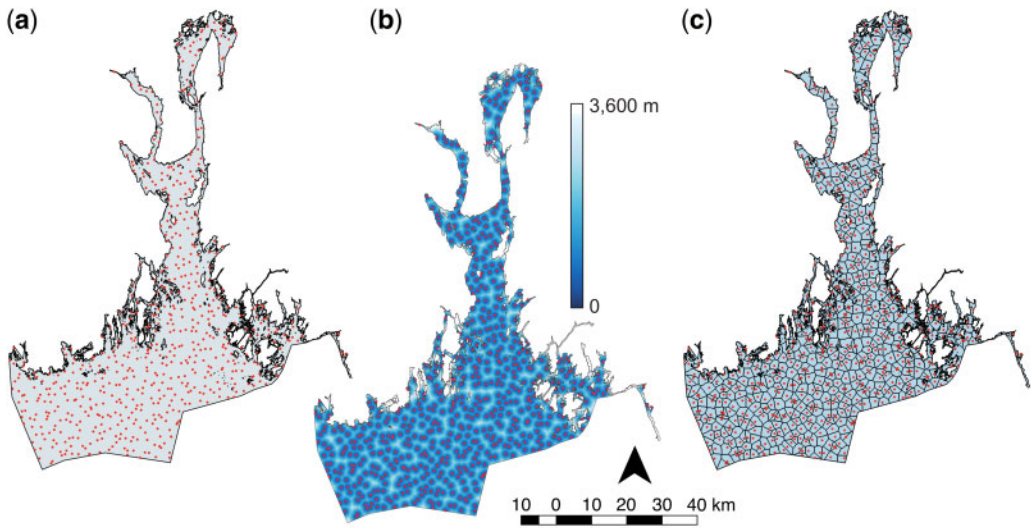

Figure 4. Example of spatial sampling frame development for the Oslofjord coastal areas in three steps: (a) Random points are selected using generalized random-tessellation sampling (GRTS), (b) the map is rasterized and sea-travel distance to each point is calculated, and finally (c) pixels were aggregated back into Voronoi polygons by assigning pixels to the nearest GRTS point by sea distance to create continuous water surface.

GRASS GIS "v.to.rast.value" function. In a few cases, sample points located very close to the shoreline were included in land pixels during rasterization. These points were manually moved a few metres back into the nearest water pixel. We then called the Saga GIS "accumulated cost" tool using the nearest-neighbour resampling method to assign each pixel in the sampling frame to the sampling point to which it was nearest by sea-travel distance. Finally, we called the GDAL "gdal_polygonize" function to construct polygons (sampling units) from groups of pixels that were associated with each point (Figure 4c).

After the entire area of each study region was tessellated, we removed any polygon with depths >150 m everywhere (i.e. no locations with depths <150 m within the polygon) from the sampling frame because recreational fishing activity is likely to be minor in these polygons. This assumption was based on pilot studies, extensive recreational fishing experience of team members, and on the fact that these deeper areas in these regions typically have muddy bottom and would not contain typical angling spots. The polygons excluded from the sampling frame represented 10, 1, and 3% of the area in the Troms, Hordaland, and Oslofjord study regions, respectively. Coastline was included in 41 out of 42 polygons in the sampling frame for inner Oslofjord, and in 241 out of 353 polygons in the outer Oslofjord.

The final polygons that defined the sampling frame were imported to ArcGis where surveys were designed and executed in the field with iPads through "Collector" (http://doc.arcgis.com/en/collector/).

Survey sampling design for the on-site field surveys by boat

Field surveying using boats to intercept anglers at representative locations at sea is expensive because of the large geographic areas to be covered in Norway. The choice of methods therefore had to be a pragmatic balance between randomization and cost-effective survey procedures. The study areas for Troms (15 261 km^2) and Hordaland (7 250 km^2) are larger than for the Oslofjord (3126 km^2). We therefore divided Troms and Hordaland into five main geographic strata, each divided into two substrata representing the outer and the inner coast. Oslofjord is close to the Norwegian capital, and the 2016–2017 pilot surveys showed a high density of recreational anglers in the inner area of the fjord. The Oslofjord was therefore first stratified into the inner and outer Oslofjord, and the latter stratum was sub-stratified into five geographic areas that each could be covered in one field-day (Supplementary Figure S2). Based on our experience from the pilot survey, we planned to conduct sampling surveys in two 5-day rounds per quarter in each of Troms and Hordaland counties, and in the inner and outer Oslofjord. We decided to conduct a census of all polygons in the inner Oslofjord during each 5-day survey period because of the small area and high density of anglers.

The 2016–2017 pilot surveys showed a large difference in recreational angler effort between midweek days and weekends. We therefore covered three midweek days and two weekend days (Saturday and Sunday) in each 5-day survey period in all regions. The start day of the survey was randomly selected with the requirement that Saturday and Sunday were included in the 5-day period. The start day of the first survey period in each region was randomly selected, then the following periods were scheduled alternating 6 and 7 weeks between each consecutive survey period. Some periods were rescheduled for logistical reasons (staff and boat availability).

For Troms and Hordaland counties, we generally alternated starting the survey in north or south of the survey area in each 5-day field sampling period, with a random start. The substrata to start the sampling in Troms and Hordaland were randomly selected, then the inner and outer subareas were systematically covered. In the inner Oslofjord, where all polygons were searched, the start of the route (north or south) was randomly drawn. In the outer Oslofjord, the first stratum for the survey in each 5-day period was randomly drawn (Supplementary Figure S2), from which a logistically effective route was determined.

Within each region and quarter, a stratified random sample of eight main polygons from each subarea was selected in the first stage for the roving creel survey of anglers. PSUs for field surveys were clusters of polygons created by including the two (for Oslofjord) or three (for Troms and Hordaland) closest neighbours for each randomly selected main polygon (Supplementary Figure S3). The chronological coverage of PSUs for each field day was chosen based on shortest and most efficient field cruise tracks. Time was recorded when a new sampling polygon was both entered and left. In Troms, where the density of anglers generally is very low, we also intercepted boats that were observed within the cruise-track during transit from one polygon cluster to the next, to cost-effectively increase the number of interviews.

Sampling procedures for the on-site field surveys by boat

Surveys of anglers were conducted by boats ranging from 22 to 50 foot, with potential cruising speed (weather and area dependent) between PSUs of more than 20 knots. In Troms and Hordaland, the spatial sampling was restricted to boat anglers, because the rough terrain along the coast precluded safe access to interview anglers fishing from the shoreline. Also, angling from the shore is very dispersed in these counties because of the complexity of the coastline. In the Oslofjord, where the shoreline generally is accessible from a boat, we also interviewed anglers fishing from shore in PSUs that bordered the shoreline, when considered safe to do so.

All angler parties that were actively fishing from boat in the selected PSUs were generally approached for an interview. For some PSUs in the Oslofjord where there were large numbers of boats, a random subsample of boats was intercepted and the others were counted. The entire party of anglers in each intercepted boat was interviewed. Onshore anglers in the Oslofjord often also fished in groups of family members or friends and were then interviewed as a group. In PSUs with large number of anglers fishing from shore, a subsample of anglers, and angler groups were interviewed, and the others were counted. Anglers that were intercepted were informed about the project and asked to participate in an interview.

A standardized interview protocol was followed, and refusals were recorded. The interview and data collections for fishing parties intercepted had four main components (the interview form is provided in the Supplementary Material):

(1) The fishing trip: ID, date, time of interview, time started fishing, fishing mode (boat/land, gear, trolling), number of fishers, catches and releases, reason for releases, and respondent guestimates of the largest cod and/or sea trout released.

(2) Demographics of all fishers in the party were covered by the interview: Gender, age, number of days fished previous 12 months, accommodation last night, country of residency, country of birth, and whether the fishers had been interviewed in the field or by phone before.

(3) Biological samples: If any catch was recorded, length measurements were conducted. If large catches, the survey clerks were instructed to measure a minimum of 20 randomly selected samples of each species, dependent on time schedule. Tissue samples and otoliths were collected for cod. For sea trout, tissue samples and fish scales were collected.

(4) Follow-up: Interviewed anglers were asked to participate in a follow-up study. If a group of fishers was interviewed, a contact person was selected by asking for the person with the most recent birthday. Subject to permission, this person provided his/her phone number and was contacted and interviewed by phone within a short time to obtain complete trip data (time stopped fishing and total catch and release). In addition, the contact person was asked to participate in a socio-economic online survey. If positive, the e-mail address was collected in addition to name and phone number.

Results

Off-site telephone survey and tourist fishery survey

In Table 2, the percentage of legal residents (age 16+) born outside of Norway is provided by region for the multistage sample of people in the off-site telephone screening survey. In total, 2313 individuals who were interviewed by phone in 2018 reported angling for recreation during the last 12 months. The phone directory covers a slightly smaller portion of legal residents born outside Norway than found in the National Registry (Table 2). The sample of people interviewed in each region had low to poor coverage of residents born outside Norway. In the Oslofjord region, for example, 23% of the male residents in the National Registry were born outside Norway, but in the sample of people that were successfully interviewed this group only represented 12%.

In total, 201 and 243 tourist anglers from a variety of nationalities were interviewed during quarterly visits to the 10 randomly selected tourist fishing businesses in Troms and Hordaland counties in 2018, respectively. All tourist anglers interviewed in Troms and the majority (94%) in Hordaland were non-residents. Thus, there appears to be little overlap between the two off-site sampling frames.

On-site field survey by boat

We obtained data on demographics and catch and effort through interviews of 1204 (86% male) anglers intercepted from April to December in 2018. The number of anglers intercepted and interviewed varied greatly by region and quarter (Figure 5), with data gathered from 176 marine anglers in Troms (92% male) and 224 marine anglers in Hordaland (82% male). Data on anglers fishing from shore or boat were obtained from 534 anglers in the inner Oslofjord (87% men), and from 270 anglers in outer Oslofjord (81% men). In Troms and Hordaland, the interviews suggest that 40–50-year-old anglers are most active, whereas 30–40-year-old anglers are most active in the Oslofjord. In some cases, information from anglers younger than 16 years was obtained from accompanying adults.

Angling from shore dominated in the inner Oslofjord (71% of interviews) and accounted for 44% in the outer Oslofjord (Figure 6). Most fishing effort from boat in the inner Oslofjord occurred in the second and third quarter. A small portion of the anglers approached for an interview in the inner (11%) and outer (7%) Oslofjord could not be interviewed (Figure 6), mainly because of language problems. We achieved complete trip data through post-trip phone interviews from 65% of anglers in Troms, 69% in Hordaland, 50% in the inner Oslofjord, and 77% in the outer Oslofjord (Figure 6).

Based on data from the on-site surveys in 2018, a large portion of anglers interviewed in Troms (63%) and Hordaland (53%) was non-residents, while only 11% of anglers interviewed in the inner Oslofjord and 6% in outer Oslofjord were non-residents (Figure 7). Most non-resident anglers interviewed in Troms (92%) and a large percentage in Hordaland (66%) rented

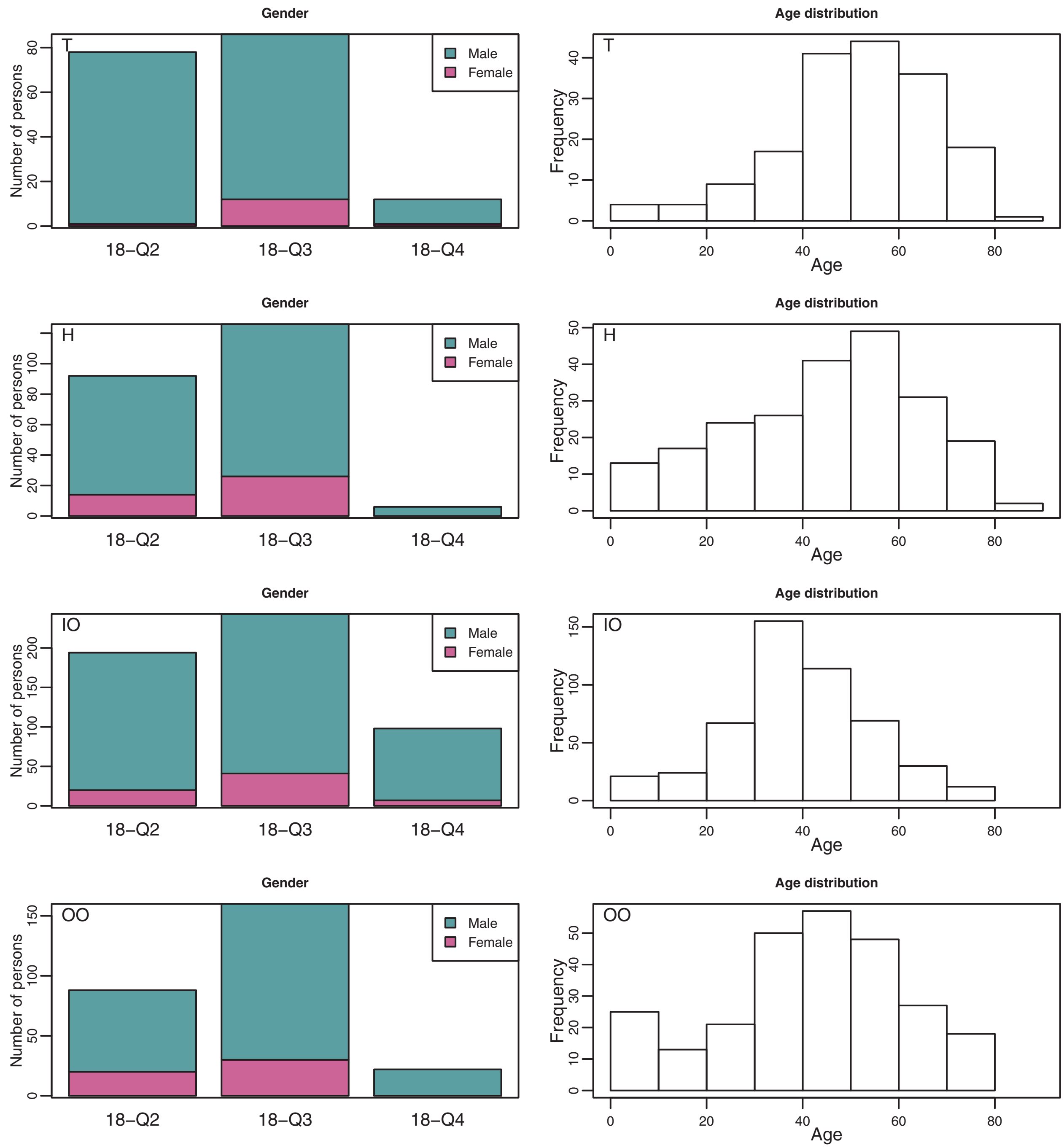

Figure 5. Demographics of the fishers interviewed in the field survey by boat in Troms (T), Hordaland (H), Inner Oslofjord (IO), and Outer Oslofjord (OO) by quarter during 2018. Anglers younger than 16 years old were fishing with their family.

accommodation and boats from registered tourist fishing businesses. Few anglers interviewed in the inner and outer Oslofjord (14 and 0%, respectively) reported that they rented accommodation and boats from registered tourist fishing businesses. The regional difference in participation rates of foreign-born residents in marine recreational angling was striking (Figure 7). Of all resident anglers intercepted, 8% in Troms, 15% in Hordaland, 63% in inner Oslofjord, and 15% in outer Oslofjord reported that they were born outside Norway. Norway has become a more heterogeneous country in recent years, and immigrants in Norway accounted for 14% of the population as of 1 January 2018 (Statistics Norway). In the counties bordering the Oslofjord, nearly 23% of the population in the National Registry are born outside Norway (Table 2).

Discussion

On-site and off-site surveys are widely used to characterize and quantify recreational fisheries. Results in this study demonstrate that the entire MRF in Norway cannot be surveyed solely using off-site methods based on the National Registry/phone directory.

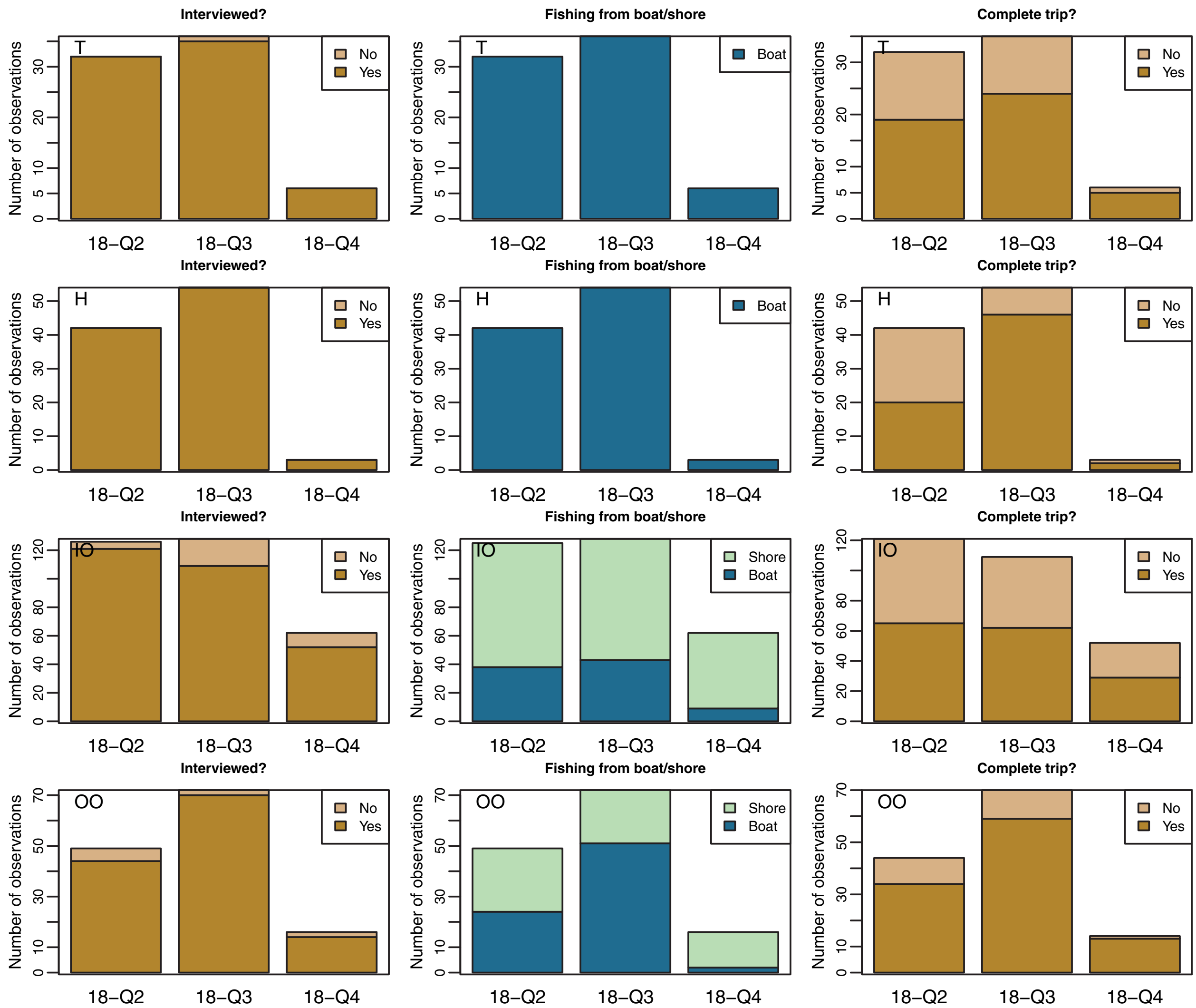

Figure 6. Number of fishers observed and number interviewed quarterly in the field survey conducted by boat in Troms (T), Hordaland (H), Inner Oslofjord (IO), and Outer Oslofjord (OO) during 2018. Angling from shore was only covered in the Oslofjord. In PSUs with large number of fishers all were counted and a random subsample of fishers were interviewed.

A substantial portion of anglers born outside Norway is not representatively covered in the telephone screening survey, and non-resident anglers dominate in some regions. Although the registry of tourist fishing businesses provides good coverage of the tourist fishing segment of MRF, some non-resident fishers do not access the fishery via these enterprises but organize their fishing on their own, for example by renting private cottages and boats, or staying with friends. In some parts of Norway, the on-site survey shows that angling fisheries are dominated by anglers born outside Norway, which was not reflected in the off-site telephone screening survey. Thus, if only off-site methods were used to map the entire Norwegian MRF, this could lead to bias in some regions.

The phone directory did not cover all persons (age 16+) in the National Registry. One reason could be that many young people living at home are listed under one of the parent's phone numbers, and another reason is that some people have blocked phone numbers. Some residents that recently have moved to Norway, may still use cell phones registered in other countries, especially because there are no roaming fees among European countries. Also, the lower response rates for residents born outside Norway in the phone surveys may be because of language barriers. The non-response rates and also avidity of marine recreational fishers related to demography will be an important topic in the analysis of the phone-survey and diary data for the National survey. Preliminary results based on interviews conducted in the on-site field surveys indicate that in the inner Oslofjord, resident fishers born outside Norway reported a mean of 28 fishing trips per year, compared to 17 fishing trips for Norwegian born residents (based on 12 months recall). This may explain some of the differences between off-site and on-site studies; residents born outside of Norway appear to fish more frequently and therefore have a higher chance of being interviewed during on-site surveys. We note that these 12 months recall data could be biased (Fisher *et al.*, 1991; Tarrant *et al.*, 1993; Connelly and Brown, 1995).

The establishment of the registry of tourist fishing businesses is a major step towards increased knowledge of the tourist fishing segment of the MRF in Norway, facilitating cost-effective monitoring of the tourist fisheries using off-site and on-site methods.

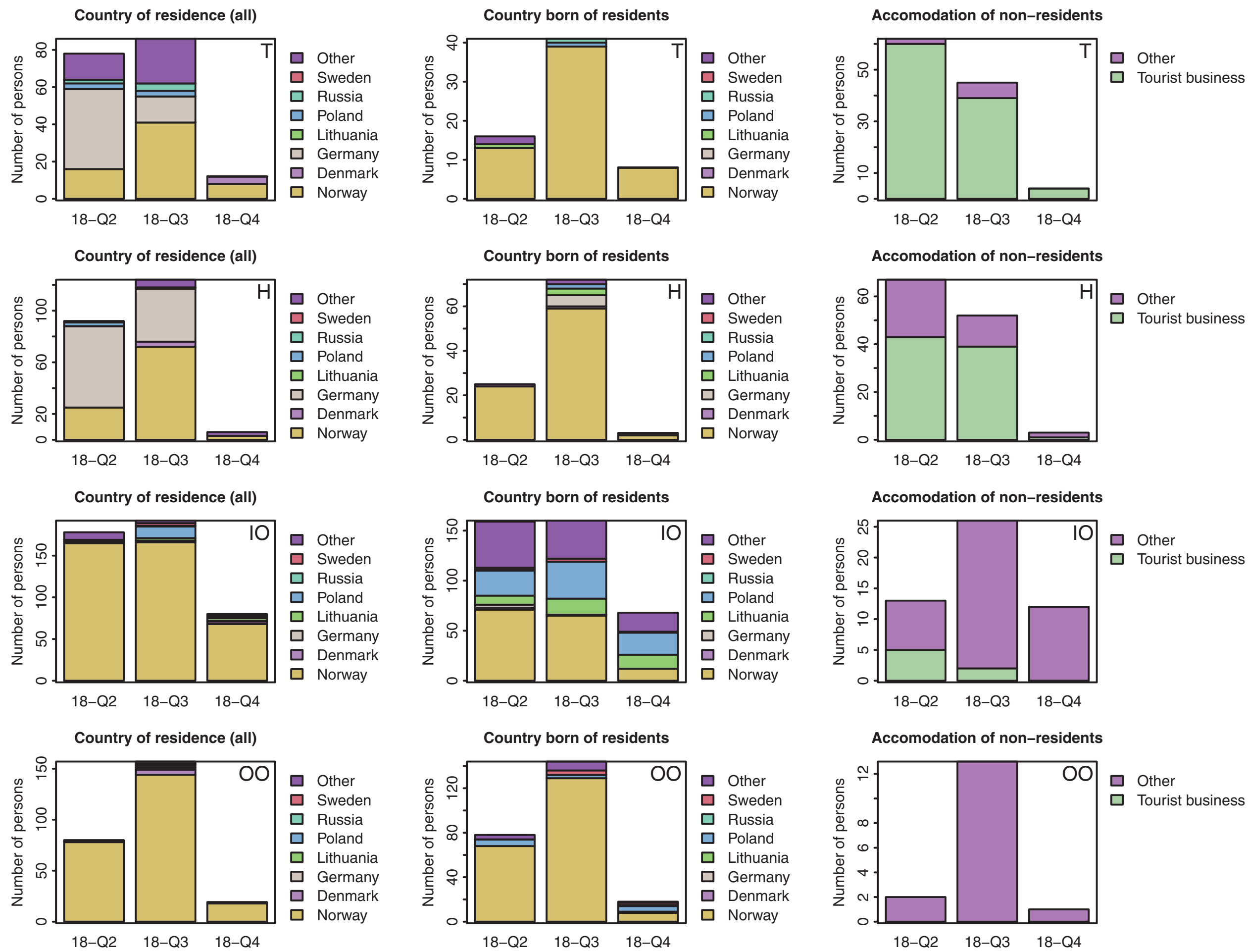

Figure 7. Demographics of all recreational anglers interviewed in the on-site field surveys in Troms (T), Hordaland (H), Inner Oslofjord (IO), and Outer Oslofjord (OO) during 2018. Country of residence (left panel), country of birth for fishers that are residents in Norway (middle panel), and accomodation of non-residents (right panel).

This study suggests that the registry covers a substantial portion of tourist anglers in the regions we investigated. Nevertheless, in Hordaland, around 30% of non-resident anglers were renting a private cottage/second home, and a small number were visiting family or friends (residents) in their home or second home. Some Norwegian citizens or legal residents that mainly fish with rod and reel or hand-held tackle also rent accommodation and boats from registered tourist fishing businesses. This also has to be considered when results from all study components (Figure 3) are combined to estimate catch and effort. Although outside the scope for this paper, the survey of the tourist sector in our national study of the MRF aims to evaluate the accuracy of mandatory reporting by tourist fishing businesses of catch by trip for selected species. This will serve as Supplementary Material to the catch reports that the registered businesses have to deliver to the Directorate of Fisheries.

Although costly and demanding, our study shows that on-site surveys will be necessary to representatively characterize all marine anglers in Norway. In the inner Oslofjord, resident anglers born outside Norway accounted for a large proportion of the effort observed, but would be poorly covered if only the telephone screening survey was conducted. A relatively large proportion of residents born outside Norway was not listed in the telephone directory, and even fewer were successfully interviewed compared to people born in Norway. In the Troms and Hordaland counties the on-site survey did not cover angling from shore for logistical reasons. Recreational fishing from shore is also popular in these regions and may also have higher participation rates of residents born outside Norway. Future on-site surveys of this segment will require mapping of popular spots for shore angling along the coast to build a sampling frame.

The field sampling provides an effective and robust method to cover non-resident recreational anglers, which cannot be covered by alternative sampling frames. The spatial sampling frames developed in our study are suitable for probabilistic field surveys in complex coastal areas where many islands and inlets obstruct travel by boat. We are currently testing this method to map buoys for standing gears, as an alternative to line transect or other distance sampling methods (Buckland *et al.*, 2001). An adapted strip transect survey method was used successfully to estimate effort in the Norwegian fisheries for European lobster (*H. gammarus*) in the southern counties of Aust-Agder and Vest-Agder (Kleiven *et al.*, 2011). In these counties there are few obstructions. The many islands in the regions covered in this study pose challenges when using transects as PSUs in an on-site survey. The spatial sampling frame of modified Voronoi polygons with continuous water surface presented in this study proved to be practical and effective for field studies of marine recreational anglers.

Refusal rates during intercepts in the roving creel survey were near zero for resident anglers born in Norway, while some resident anglers born outside Norway could not be interviewed because of language barriers. It was hard to communicate the goals of the project when anglers did not understand the language used by staff (Norwegian, English, or German). Some anglers expressed fear and could not be interviewed, and others expressed concern that the results would be used by control-authorities. In Norway, people generally trust the government and governmental research institutes, but this may not be the case for people coming from other nations. Loss of post-trip interviews was mostly because of no-contact and language problems. For anglers interviewed in the field, we could register and measure catches, and staff also used Google translator to assist some interviews. Reasons for non-response in the field surveys were noted in interview response reports, and non-response because of language issues (rather than simple refusal) can be quantified. This may be an important issue moving forward to quantify catch and effort, and will be evaluated in a forthcoming article.

Design-based methods (e.g. the Horvitz–Thompson estimator; see for example Cochran, 1977) and model-based methods will be used to estimate catch (kept and released) and length-compositions of fish kept by marine anglers by region from the on-site surveys. These results, combined with results from the phone-diary and tourist fishing business surveys, will provide regional estimates of catch (numbers kept and released) for selected species and total fish biomass landed. This is outside the scope for this paper and will be presented in a forthcoming paper.

The results of the present study in conjunction with results from the complementary surveys will be used to identify a cost-effective survey method for Norwegian marine recreational fisheries. This paper highlights the benefits and weaknesses of off-and on-site surveys. It also illustrates how off-and on-site surveys can be used in tandem to characterize and quantify multifaceted recreational fisheries with few solid list-frames, as it is the case in Norway.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

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