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Original Article

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Integrating complementary survey methods to estimate catches in Norway's complex marine recreational hook-and-line fishery

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Marine recreational fishing is popular in Norway, but current estimates of the catches by resident and tourist anglers are lacking due to several challenges, in particular Norway's long and intricate coastline with no defined access points and the large tourist fishery. To test methods for long-term monitoring of boat-based marine recreational anglers, estimate their catches, and characterize the fishery, we conducted a roving creel survey based on a novel spatial sampling frame and a survey of tourist fishing businesses in Troms and Hordaland County. These surveys showed that cod (*Gadus morhua*) and saithe (*Pollachius virens*) dominated the catches in Troms, while mackerel (*Scomber scombrus*) and saithe dominated the catches in Hordaland. The estimated total annual harvest of cod by all marine recreational anglers was 2 160 tonnes (relative standard error, or RSE 44%) in Troms and 73 tonnes (RSE 29%) in Hordaland, of which ∼40% (in weight) were landed in registered tourist fishing businesses, based on data from the tourist fishing survey. The results indicate that recreational anglers in Hordaland harvest more cod in coastal waters than commercial fishers. This study provides information for developing marine recreational fisheries monitoring in challenging survey situations to support science-based fisheries management.

Keywords: access point survey, catch estimation, Norwegian coastal cod, off-site survey, probabilistic surveys, recreational fishing, roving creel survey.

Introduction

The ecological impacts of marine recreational fisheries are increasingly recognized (Cooke and Cowx, 2004; Arlinghaus *et al.*, 2015; Hyder *et al.*, 2017; Hyder *et al.*, 2018; Radford *et al.*, 2018; Lewin *et al.*, 2019). Hyder *et al.* (2018) estimated that there are ∼8.7 million European marine recreational fishers. For some species, the catches by marine recreational fishers account for a significant part of the total catches in some countries and regions (Herfaut *et al.*, 2013; Kleiven *et al.*, 2016; Radford *et al.*, 2018). To ensure sustainable fisheries management, it is necessary to account for fishing mortality caused by recreational fishing (Cooke and Cowx, 2006). However, the lack of recreational fisheries time-series data for many fish stocks makes it difficult to include recreational catches, even when they may account for a significant part of the total catches (Radford *et al.*, 2018). So far, the recreational catches of western Baltic cod (*Gadus morhua*), Atlantic salmon (*Salmo salar*) in the Baltic Sea, and northern European sea bass (*Dicentrarchus labrax*) have been included in European stock assessments (Eero *et al.*, 2015; Radford *et al.*, 2018).

Handheld hook-and-line tackle (often referred to as angling) is the main fishing method used in many countries, although other methods such as long lines, spears, traps, and gill nets are also used (Pawson *et al.*, 2008). In some recreational fisheries, for example, in Norway, fishers are also allowed to sell their catch. This complexity and diversity of recreational fishing makes it difficult to define the activity. ICES (2013) defined recreational fishing as "the capture or attempted capture of living aquatic resources mainly for leisure and/or personal consumption. This covers active fishing methods including line, spear, and hand–gathering and passive fishing methods including nets, traps, pots, and set–lines".

In Norway, marine recreational fishing regulations are rather liberal, and a recreational fishing licence is generally not required in marine waters, with some exceptions, namely for targeted lobster (*Homarus gammarus*) fishing with traps, Atlantic salmon and sea trout fishing in estuaries, and Atlantic bluefin tuna (*Thunnus thynnus*) fishing. Resident marine recreational fishers are allowed to fish with hand-held fishing gear, jigging machines, gill nets, long lines, and traps. In addition, resident recreational fishers can sell their catches for

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up to 50 000 NOK (ca. 5 000 euros) per year through official landing sites. Fishing is conducted both from shore and from boat and is difficult to monitor or control due to Norway's long and intricate coastline with no defined access points for resident fishers, and the large tourist fishery. As there are no formal educational programmes for recreational fishers and since dissemination of management regulations cannot happen through licence sales, fisheries managers must rely on recreational fishers informing themselves about fishing regulations before they go fishing.

Compared to the resident marine recreational fishery, the Norwegian marine tourist fishery is more regulated. Foreign tourists are only allowed to fish with hand-held fishing gear and are not allowed to sell any of their catches. Since 2018, marine tourist fishing businesses have been obliged to register in a national database if they provide at least one rental or guiding boat for fishing and if they earn >50 000 NOK per year (NFD, 2017). Other tourist fishing businesses that do not meet the minimum income requirement can register voluntarily. Registered businesses are mandated to report the catches (including the number of released fish) of Atlantic cod, saithe (*Pollachius virens*), Atlantic halibut (*Hippoglossus hippoglossus*), redfish (*Sebastes sp.*), and Atlantic wolffish (*Anarhichas lupus*) per boat and trip to the Norwegian Directorate of Fisheries (NFD, 2018). Management regulations of marine fishing tourism were tightened in January 2021, as only angling tourists staying at registered tourist fishing businesses can export up to 18 kg of fillet or products of self-caught marine fish (Lovdata, 2021), and business owners are obliged to inform their guests about fishing regulations. Although tourist anglers fish both from boat and shore, the majority of marine tourist fishing effort is conducted from boat (Borch, 2004; Borch *et al*., 2011).

There are several previous studies that have estimated the impacts of marine recreational fishers in Norway (Hallenstvedt and Wulff, 2004; Kleiven *et al*., 2011; Vølstad *et al*., 2011; Ferter *et al*., 2013a; Kleiven *et al*., 2016; Jorde *et al*., 2018), but knowledge is limited about the impacts of recreational fisheries on the Norwegian cod stock in general and the coastal cod stock north of 62° in particular. The Norwegian coastal cod populations have been low for many years and are subject to rebuilding measures, including specifications of maximum catch limits (ICES, 2021). Following advice from a benchmark process, the Norwegian coastal cod population north of 62° has been assessed and managed as a northern and a southern stock since 2021, separated by 67° latitude (Institute of Marine Research, 2022). Furthermore, the bycatch of coastal cod in the commercial fishery targeting the northeast Arctic cod stock (which is considered to be in a healthy state) has recently caused concerns, as northeast Arctic cod that is caught within 12 nm off the coastal baseline has lost its Marine Stewardship Council accreditation due to this bycatch issue (MSC, 2021). As the impacts of recreational fisheries on the Norwegian cod stocks in general and the coastal cod stock north of 62° in particular are poorly documented, estimates of the contribution of recreational fisheries to cod fishing mortality are of major interest in Norway. There is no long-term monitoring of the marine recreational fishery in Norway, except for the recreational lobster fishery and the newly introduced mandatory catch reporting for some selected species caught in registered marine fishing tourist businesses. Reasons for this are related to the complexity of the fishery, logistical constraints, and high costs of conducting such surveys in Norway. There are many different types of recreational fishers (i.e. resident recreational fishers born inside and outside Norway and angling tourists staying in registered tourist fishing businesses or other accommodations), and their fishing effort (both from shore and boat) is widely spread out in space and time. The general lack of data has led to several stakeholder conflicts and public debate. In particular, the legitimacy and sustainability of the whole marine angling tourism fishery have been called into question (Borch, 2009).

A phone-diary survey was recently conducted to estimate the catch and effort of resident marine recreational fishers in all of Norway (Vølstad *et al*., 2019). However, Vølstad *et al*. (2019) found that this survey had a substantial undercoverage of resident recreational anglers who were born outside Norway. In addition, as that phone-diary survey was based on the Norwegian national registry of residents, it did not cover foreign marine angling tourists. The newly implemented registry for marine tourist fishing businesses provided the opportunity to access marine angling tourists staying at such businesses.

To collect information on all recreational fishers, including residents born outside Norway and tourist anglers not staying in registered businesses, we conducted a roving creel survey based on a novel spatial sampling frame combined with a probabilistic sample survey of 20 selected tourist fishing businesses in two study areas. The term creel survey is applied to sampling surveys that target recreational anglers. The name - widely used in the recreational fisheries survey literature - comes from the basket, or creel, that anglers use to keep captured fish while they continue fishing. We focused on boat-based angling, as investigating all fishing modes, including shore fishing and passive gear fishing, was outside the budget and scope of this study. The field surveying of marine recreational anglers is notoriously complex (National Research Council, 2006). The main aim of this study was to determine the feasibility of implementing a roving creel survey in the future to monitor the recreational fishery along a larger portion of the Norwegian coastline and to characterize the recreational fishers found in Norwegian waters (demographics, fishing behaviours, regulation knowledge). Another aim was to estimate boat-based catches (including species composition) for resident marine anglers and tourists in two selected counties and to identify some limitations of these catch estimates due to the survey implementation and logistical constraints. In addition, the present study contributes valuable information for the development of cost-effective monitoring of marine recreational fishing in challenging situations (e.g. the lack of a licence system and no defined access points), which can form the basis for a science-based sustainable recreational fisheries management.

Material and methods

Study area

Norway has a population of 5.3 million residents (2017; Statistics Norway) and a 100 915km long coastline (including fjords, estuaries, and islands). In this study, we chose two counties as study areas, one in western Norway ("Hordaland") and one in northern Norway ("Troms") (Figure 1a). These study areas were selected as they are popular tourist angling destinations, and represent a contrast in terms of

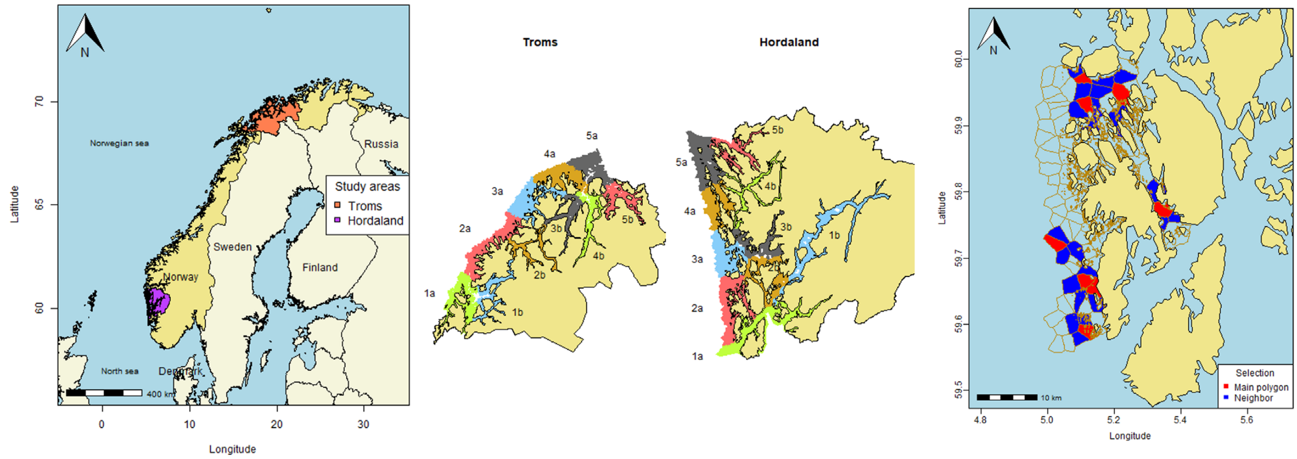

Figure 1. Overview of (left) the locations of the two study areas, Hordaland and Troms in Norway, (middle) the five outer "offshore" subareas (denoted "a") and five inner "inshore" subareas (denoted "b") within each of the two study areas (example for sampling in one quarter: Round 1 (starting with inshore subarea "b", northwards): 1b→2a→3b→4a→5b; Round 2 (must then start with an offshore subarea "a", going southwards in this case): 5a→4b→3a→2b→1a; and (right) one sampling day where eight major polygons (red) and up to three neighbours (blue) were selected in subarea 2a in Hordaland.

population density, available fishery resources and commercial fisheries landings (Table 1).

The project was registered and evaluated by the Norwegian Centre for Research Data (project number 58760; www.NSD.no), and all data collection and processing were done in accordance with the Norwegian privacy law.

Sampling design and procedure for the roving creel survey

Roving creel surveys (Pollock *et al.*, 1994) using spatial sampling frames were conducted in Hordaland and Troms (Figure 1a) between 1 April 2018 and 31 March 2019. These surveys were run in parallel with a phone-diary survey to allow for later comparison (Vølstad *et al.*, 2019). In Hordaland, the roving creel survey was continued after March 2019, but only fish length measurements were included from the period between March and December 2019 to increase sample sizes when converting catch in numbers to weight. The survey was conducted from a boat, and all active anglers intercepted were approached for an interview if at least one person of age 16+ was on board.

The study areas in Hordaland and Troms were defined as coastal waters within the coastal baseline (consisting of straight lines drawn between the outmost points of the entire Norwegian coast). Details on how the sampling frames were created can be found in Vølstad *et al.* (2019). In short, both study areas were divided into polygons with an average area of 4 km^2 using a Generalized Random-Tessalation Sampling design (Stevens Jr and Olsen, 1999; Stevens Jr and Olsen, 2004) for generating the centroids and Voronoi tessellation (with modifications) for creating the polygons. Polygons only containing depths >150 m (i.e. no locations that were shallower than 150 m in the entire polygon) were removed from the sampling frame (10% and 1% of the study areas in Troms and Hordaland, respectively), as fishing effort was assumed to be minimal in these polygons based on expert knowledge. All polygons included in the final sampling frame were imported to ArcGis® (ESRI, USA) so that they could be accessed via "Collector" (http://doc.arcgis.com/en/collector) using iPads (Apple, USA) in the field.

The survey sampling design and sampling procedures for the roving creel survey are thoroughly described in Vølstad *et al.* (2019). In short, each study area was divided into five outer "offshore" subareas and five inner "inshore" subareas (Figure 1b). The aim was to sample these ten subareas once per quarter by spending one day surveying each. The subareas were covered by sampling in a systematic way, starting either with an inshore or offshore subarea (randomly selected) and then alternating between inshore and offshore subareas in a southward or northward direction (also randomly selected). In this way, we covered all ten subareas in two 5-day periods. At the beginning of the study, the start-date of the first 5-day period was selected, and the following survey rounds were scheduled alternating six and seven weeks throughout the study period. Each 5-day period included three weekdays and both weekend days, and the start day was randomly selected between Wednesday and Saturday. The reason of oversampling weekend days was to increase the number of interviews as we expected higher fishing effort during the weekend. The original plan was to adjust for this imbalance using post-stratification, but we found that a slight change in estimated totals was offset by a substantial increase in the relative standard error (RSE) due to the low sample sizes of interviews within the domains. Hence, we chose not to employ post-stratification. The sampling frame for each subarea consisted of 52–126 polygons in Hordaland and 142–282 polygons in Troms. Each time a subarea was to be sampled, eight polygons were randomly selected, and together with up to three randomly selected direct neighbours, these formed clusters of up to four polygons that defined the primary sampling units (PSUs) (Figure 1c). These PSUs were surveyed based on the most efficient and shortest travel route by boat. Only boats with anglers actively fishing were approached for an interview. In some rare cases, not all boats within a polygon could be interviewed and sampled (e.g. when a boat drove away while we were interviewing another boat). These boats were recorded and noted as "observations" and included in the effort estimates. As the density of angling boats was expected to be low in Troms based on findings from a pilot study, we conducted transit interviews in Troms to gain additional data on

Table 1. Length of coastline, population, number of registered tourist fishing businesses, number of rental fishing boats, and reported commercial cod fishery landings (sales notes) of the two study areas between April 2018 and March 2019.

Parameter/County	Hordaland	Troms
Coastline (km)	8 741	6 020
Population (age 16+)	420 730	136 670
Registered tourist fishing businesses	161	110
Registered rental fishing boats	610	510
Officially reported commercial cod landings (in tonnes) from coastal waters (including recreational fishers)	43	20 545
Officially reported commercial cod landings (in tonnes) in coastal waters by recreational fishers	2	284

Official landings were restricted to catches taken within 12 nautical miles off the coastal baseline.

trip lengths, fish lengths, angler demography (e.g. residency), and accommodation type. These interviews were conducted while the research boat was in transit between any two PSUs for all observed boats where anglers were actively fishing. As the transit interviews were conducted outside the PSUs, the number of fish caught were not included in the analysis.

Before the interview was conducted, all persons onboard were informed about the survey, its aims, that participation was voluntary, and that the data collected would be treated confidentially. If the anglers on a boat refused to be interviewed, this was noted as a refusal. During the interview, the anglers were asked about their fishing effort, catch quantity (numbers landed and released by species), release reasons, knowledge of fishing regulations, demographics (age, gender, nationality, and country of residence), and accommodation type. The person with the most recent birthday in the angling party (only age 16+) was asked for contact information that we could use for post-trip interviews. The total length (TL) of landed fish was measured by project staff (up to 20 randomly selected individuals per species and boat). After each interview, anglers were informed that they would be contacted via phone within one or two days for a follow-up interview where they would be asked about when they stopped fishing and about their additional catch on this fishing trip. The post-trip telephone interview was conducted to get complete trip data on trip length and total catch per species (numbers landed and released by species). In some cases, this post-trip interview was conducted up to one week after the on-site interview due to initial non-contact. Moreover, some fishermen could not be reached, so imputations were necessary (see below). If field sampling could not be conducted due to adverse weather (usually winds >10–12 m s^{-1}, in which fishing practically was not possible due to waves and currents), the fishing effort in the selected area was assumed to be zero.

Sampling design and procedure for the tourist fishing business survey

An on-site survey combined with an off-site diary survey was conducted at 20 tourist fishing businesses (10 out of 161 businesses and 10 out of 110 businesses in Hordaland and Troms, respectively) from 1 April 2018 to the end of 2019. The number of boats included in the sample and the overall number of rental boats per municipality in the two counties are given in Figure 2. The businesses (PSUs) were sampled randomly from the national database of registered tourist fishing businesses provided by the Norwegian Directorate of Fisheries, where the probability p_i of business i being selected was proportional to the number of rental boats per business [Equation (1)]:

$$p_i = \frac{Number\ of\ rental\ boats\ at\ business\ i}{Total\ number\ of\ rental\ boats\ across\ all\ businesses\ within\ county}. \quad (1)$$

All selected businesses were visited by project staff one to three times during their rental season between April 2018 and March 2019 to interview angling tourists (same interview protocol as for the roving creel survey) and to length-measure the catch the same way as in the roving creel survey once the fishers had come to shore. Since the interview was on land at the landing site, all interviews were complete trips. In Hordaland, this on-site sampling was continued in the 2019 fishing season, but the only data used from this extra on-site sampling were length measurements. The date for the first visit was randomly selected between weeks 14 and 29, and the second visit was scheduled 16 weeks after the first visit, or earlier (i.e. on the last day with guests) if the fishing season was over on the selected date for the second visit. If there was no fishing activity due to a lack of guests or severe weather, the visit was rescheduled to the closest date with fishing activity. In some cases, adjustments had to be made to the sampling schedule due to logistical reasons.

In addition, the businesses were asked to report the catches (numbers landed and released by species) of their guests per trip directly to the Institute of Marine Research from 1 April 2018 to the end of 2019. In total, catch data were reported for the 12 most popular species using a paper-based catch diary filled out by the guests [Atlantic cod, saithe, Atlantic halibut, redfish, Atlantic wolffish, pollack (*Pollachius pollachius*), haddock (*Melanogrammus aeglefinus*), European hake (*Merluccius merluccius*), Atlantic mackerel (*Scomber scombrus*), tusk (*Brosme brosme*), common ling (*Molva molva*), and sea trout (*Salmo trutta*)]. However, five businesses in Troms and one in Hordaland used electronic reporting applications that only allowed for the reporting of the five species required by the Norwegian Directorate of Fisheries. The electronic reporting was conducted by the guests directly after the trip, either via a tablet that was available in the filleting room or via their own mobile phone. All 20 businesses were closely followed up by our research staff to ensure regular and thorough reporting; e.g. all business owners were asked to inform their guests that catch reporting should be done immediately after the fishing trip had finished to reduce recall bias.

Data analysis of roving creel survey data

General approach

In the roving creel survey, a census or subsample of boats with varying trip lengths was intercepted within PSUs (clusters of polygons), with varying numbers of fishers interviewed per boat. Therefore, we consider the interview of a boat as the secondary sampling unit within each PSU.

In the following, we assume that the PSUs are random snapshots in time and space (i.e. that each search within a PSU is "instantaneous") within an area. The support for assuming

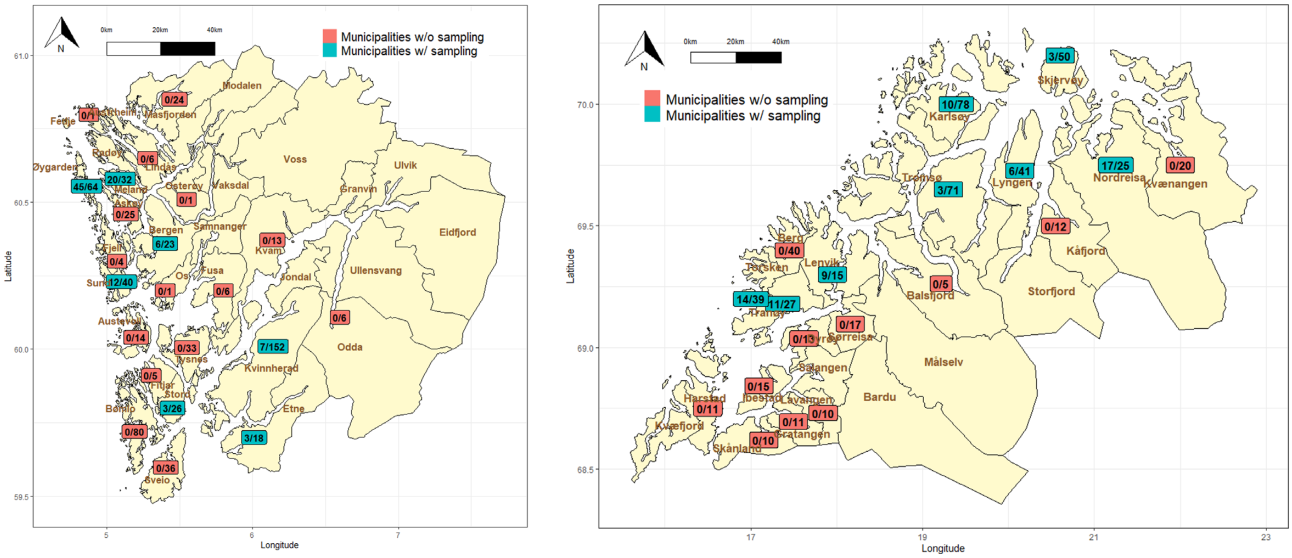

Figure 2. Overview of the number of rental boats in registered tourist fishing businesses per municipality in Hordaland (left) and Troms (right). The red boxes show the municipalities without sampling, and the blue boxes show the municipalities with sampling in this study (number of vessels at the randomly sampled tourist fishing businesses/total number of boats by municipality).

instantaneous counts and interviews is that when the crew enters a PSU, they search forward (i.e. they do not wait for a fixed time to interview all boats that enter a polygon). Calculations were performed first at the polygon level and then summarized at the PSU level (a cluster of up to four polygons). For each area, subarea, and quarter, the results from the PSUs were used to estimate the total number of fish caught and released per species. To be able to use all interviews in the analyses, not just the ones with follow-up telephone calls ("complete trips"), some imputations were performed (see the next section).

Once the imputations were performed, the analyses proceeded as follows for each species within each area, subarea, and quarter:

The total number of fish landed (t_i) per polygon i was calculated as the mean number of fish $\bar{y}_i$ per boat trip multiplied with the total number of trips (n) (interviewed + refused + observed) [Equation (2)]:

$$t_{i(j,a,s,q,f)} = \bar{y}_{i(j,\ a,s,q,f)} \times n_{i(j,a,s,q)}, \tag{2}$$

where i = polygon, j = PSU, a = area, s = subarea, q = quarter, and f = fish species. The notation $i(j, a, s, q, f)$ here denotes that polygon (i) is nested within the PSU (j), area (a), subarea (s), quarter (q), and fish species (f). In the following, we use the general notation c (b) to denote that c is nested within b.

For each PSU, the total number of fish was the sum of the estimated total fish landed per polygon [Equation (3)]:

$$t_{j(a,s,q,f)} = \sum_i t_{i(j,\ a,s,q,f)}. \tag{3}$$

Due to the unequal spatial areas of the PSUs, the estimated total number of fish/species landed were converted to a catch per unit area [CPUA; Equation (4)]:

$$CPUA_{j(a,s,q,f)} = t_{j(a,s,q,f)}/A_{j(a,s)}, \tag{4}$$

where $A_{j(a,s)}$ is the area in km^2 of the j^{th} PSU within subarea s in area a. For each species within each quarter, subarea, and area, the average $\overline{CPUA}_{a,s,q,f}$ among PSUs was calculated.

The total number of fish landed per day (from 9:00 a.m. to 8:00 p.m.) for a subarea within a quarter was calculated as [Equation (5)]:

$$t_{a,s,q,f} = (\overline{CPUA}_{a,s,q,f} \times A_{a,s})/p_a, \tag{5}$$

where $A_{a,s}$ is the spatial area (km^2) of the subarea (s) within the area (a), and p_a is the proportion of all boats operating on a given day in the area a in the survey period from 9:00 a.m. to 8:00 p.m. that were intercepted. This proportion, which is equivalent to an average detectability rate (Thompson, 1992), was estimated at 44% for Troms and 31% for Hordaland using data from all complete trips. To estimate p_a, we first pooled all complete trips within an area and considered their distribution in time of the day and trip length as the true fishing pattern for all days in the study (Figure 3). Second, we used slices of 1-min intervals from 9:00 a.m. to 8:00 p.m. (the period we covered with our sampling) and calculated the proportion of all trips that were intercepted in each 1-min interval. The ≪detectability≫ p_a was estimated as mean detectability across all 1-min intervals, and it was assumed to be fixed for the whole year in each area (Troms and Hordaland) in further analyses (Figure 3).

The SE of $t_{a,s,q,f}$ was calculated as the square root of the variance of the $CPUA$ values in the mean $\overline{CPUA}_{a,s,q,f}$ times $A_{a,s}/p_a$.

The total number of fish landed for an entire quarter $T_{a,s,q,f}$ was estimated by scaling up the mean number of fish landed per day to all days [Equation (6)],

$$T_{a,s,q,f} = t_{a,s,q,f} \times \left(\frac{365}{4}\right), \tag{6}$$

with $SE(T_{a,s,q,f}) = SE(t_{a,s,q,f}) \times (\frac{365}{4})$.

The total number of fish landed by species for an area a in the 12-month study period, $T_{a,f}$, across subareas and quarters

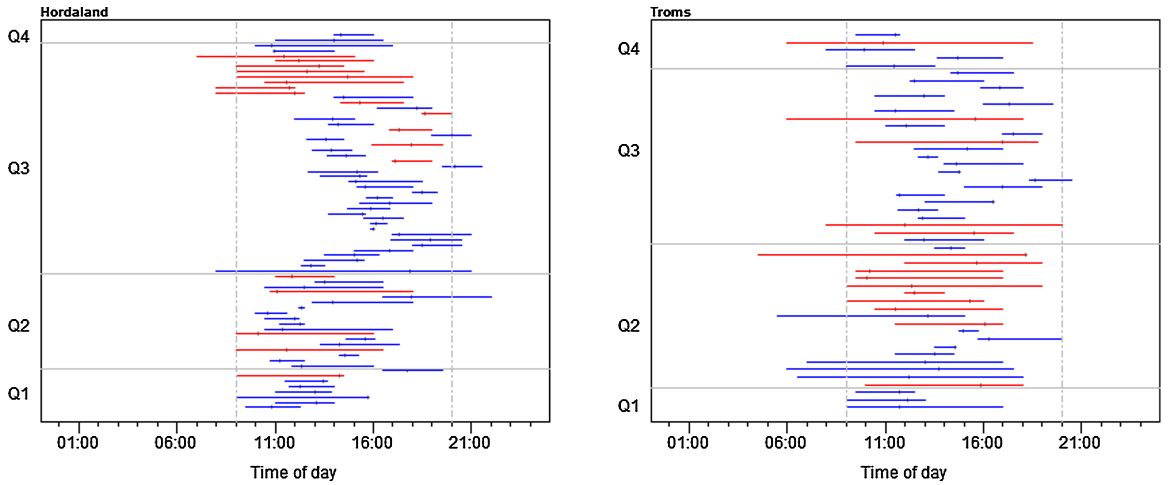

Figure 3. Overview of fishing trips in Hordaland (left) and Troms (right) for which complete-trip data were available. The lines show the duration of each fishing trip (red = tourist fishing, blue = others), and the marks on the lines are the time of interview. The roving creel surveys were conducted between 9:00 a.m. and 8:00 p.m., and the proportions of trips covered within this time window were estimated at 31% in Hordaland and 44% in Troms.

was calculated as [Equation (7)]:

$$T_{a,f} = \sum_{s,q} T_{a,s,q,f}\,, \tag{7}$$

with the RSE (Jessen, 1978) calculated as [Equation (8)]:

$$RSE\ =\ SE\left(T_{a,f}\right)/T_{a,f}, \tag{8}$$

where $SE(T_{a,f})$ is the square root of the sum of variances across subareas and quarters, $SE^2(T_{a,s,q,f})$.

The same estimators were used to estimate the total number of fish released.

Imputation for incomplete trips

For the trips where fishing continued after the on-site interview, we were dependent on the post-trip interview (usually by telephone) to collect catch data for the whole trip. We got complete trip data for 69% and 67% of the interviews in Hordaland and Troms, respectively. In cases where this was not possible (incomplete trips), the missing data were imputed consistent with other previous studies (e.g. Hoenig *et al.*, 1997; Pollock *et al.*, 1997). Before any analyses were performed, any on-site interview that was lacking complete-trip data was "made whole" by imputing the likely total number of fish landed and released per complete trip. Two approaches for imputing were used, depending on whether the boat had landed or released any fish of a species prior to the on-site interview or not.

(1) If the fishers in the boat had fished for at least 30 min and landed or released any catch of the species in question at the time of the on-site interview, the total catch of the trip per species was calculated as the boat's CPUE of this species at the on-site interview multiplied with the average trip length. The average trip length for each county relates to boats catching the same species.
(2) If the boat had not landed or released any fish of species relevant for this study at the time of the on-site interview, the trip was imputed to have the average number of fish of a species from complete trips that did not have any landings or releases of the species at the time of their on-site interview. The interviews used in the imputation were within the same sampling area.

Imputing missing strata

There were four combinations of subarea and quarter for which no data were collected due to logistical issues, namely, Hordaland, subarea 1b, in 18-Q4; Troms, subareas 1b and 2a, in quarter 18-Q3; and Troms, subarea 5a, in quarter 18-Q4. To estimate total landings for the entire area in each quarter, data for these missing strata were required. For Hordaland, subarea 1b, quarter 18-Q4, the imputed value was the mean total abundance for Hordaland in subareas 2b, 3b, 4b, and 5b, across quarters 18-Q4 and 19-Q1 ("winter"). For Troms, we imputed the value for subarea 1b in 18-Q3 with the mean for Troms subareas 2b, 3b, 4b, and 5b, across quarters 18-Q2 and 18-Q3 ("summer"). The missing value for subarea 2a in 18-Q3 was imputed with the mean for Troms subareas 1a, 3a, 4a, and 5a across quarters 18-Q2 and 18-Q3, and for subarea 5a in quarter 18-Q4, we used the mean for Troms subareas 1a, 2a, 3a, and 4a across quarters 18-Q4 and 19-Q1. As fishing effort and catches vary between seasons due to the number of foreign tourists (substantially less foreign tourists in winter), weather conditions (better weather during summer) and light conditions (substantially less light during winter), we assumed that season (summer/winter) across all respective outer or inner areas was a better predictor than mean total abundance from the same, respective subareas across the whole year.

Background information

Background information about the interviewed anglers was recorded and summarized over all interviews within the study frame and county using "naive" estimators under the assumption of simple random sampling of fishers. These descriptive statistics are therefore provided without variance estimates. This included the demography of the interviewed anglers, country of residence, accommodation type (i.e. anglers staying in registered tourist fishing businesses with obliged reporting or others) in Norway, knowledge of regulations, and average fishing trip length. Information about the knowledge of minimum landing size was obtained per angler party (i.e. for the whole group), but accommodation type in Norway was recorded per person. We assumed that all anglers within an angler party had the same knowledge status when calculating the proportion of anglers that knew the correct minimum landing size by accommodation type.

Data analysis of the tourist fishing business survey data

Catch estimation

The annual catch by registered tourist fishing businesses was based on the catch data collected in 2018 and 2019. Let $y_{i(j,a,f)}$ be the total number of fish reported landed (or released) by business i during week j in area a for species f. The total number of fish landed (or released) by all businesses in the sampling frame for week j is estimated using Equation (9):

$$\hat{\tau}_{j(a,f)} = \frac{1}{n} \sum_{n} \frac{y_{i(j,a,f)}}{p_i}, \tag{9}$$

(Hansen and Hurwitz, 1943) with variance estimated using Equation (10)

$$\widehat{var\left(\hat{\tau}_{j(a,f)}\right)} = \frac{1}{n(n-1)} \sum_{n} \left(\frac{y_{i(j,a,f)}}{p_i} - \hat{\tau}_{j(a,f)}\right)^2. \tag{10}$$

These estimators are based on the assumption of sampling with replacement, which is reasonable since the sampling fraction of businesses is <10% (Cochran, 1977).

We also assume independent sampling between weeks and estimate the total yearly catch $\hat{\tau}_{a,f}$ of species f and its variance by summing the weekly catches and their associated variances. The precision of yearly estimates of total catch $\hat{\tau}_{a,f}$ is expressed by the RSE [Equation (11); RSE; Jessen, 1978],

$$RSE = \frac{\sqrt{\widehat{var\left(\hat{\tau}_{a,f}\right)}}}{\hat{\tau}_{a,f}}. \tag{11}$$

Background information

The demography of the interviewed anglers, including the country of residence and knowledge of regulations was summarized with descriptive statistics as in the roving creel survey (see above).

Biomass estimation for estimated catch numbers

The biomass (in tonnes) was estimated for selected species where length data from at least 100 fish distributed over at least 20 sampled trips were available from the tourist fishing business and roving creel surveys combined. Estimates were based on scaling up estimated yearly catch numbers with estimated average weights $\bar{w}_{a,f}$ for species f using Equation (12):

$$\hat{B}_{a,f} = \hat{\tau}_{a,f} \times \bar{w}_{a,f}. \tag{12}$$

The variance of this product (Goodman, 1960) was calculated using Equation (13):

$$var\left(\hat{B}_{a,f}\right) = \hat{\tau}^2_{a,f} \times var(\bar{w}_{a,f}) + \bar{w}^2_{a,f} \times var(\hat{\tau}_{a,f}) - var\left(\hat{\tau}_{a,f}\right) \times var\left(\bar{w}_{a,f}\right), \tag{13}$$

where $var(\bar{w}_{a,f})$ was estimated by bootstrapping the trips with length-samples and using length–weight keys to estimate mean weight of fish per trip. The precision of $\hat{B}_{a,f}$ is expressed by the RSE.

Enough data to estimate biomass were available for cod and saithe in Troms and cod, saithe, pollack, ling, and mackerel in Hordaland (Table 1, Supplementary Material). Average weights were obtained from all length measurements made during the study (tourist fishing business and roving creel survey combined) using the length–weight relationships established by Fantoft Berg and Nedreaas (2021) based on data from Norwegian coastal gillnet fisheries.

Results

Roving creel survey

Response rates (i.e. the proportion of angler parties approached that were willing to participate in the survey) in the roving creel survey were very high, with 100% and 99% in Hordaland and Troms, respectively. In total, 106 boats (240 anglers) were interviewed in Hordaland and 76 boats (177 anglers) in Troms (including 31 transit interviews in Troms) between April 2018 and March 2019. Three boats in Troms and one in Hordaland were observed within polygons but not interviewed.

The species composition of the estimated annual landings was different between Hordaland and Troms. Cod (930 949, RSE 44%; 2 160 t, RSE 44%) and saithe (122 394, RSE 41%; 104 t, RSE 43%) dominated the boat-based landings in Troms, and mackerel (816 227, RSE 65%; 131 t, RSE 65%) and saithe (167 626, RSE 51%; 154 t, RSE 52%) dominated the boat-based landings in Hordaland (Table 2 and Figure 4). Cod landings in Hordaland (57 094, RSE 27%; 73 t, RSE 29%) were substantially lower than in Troms. No pollack, ling, or hake were recorded in Troms, and no wolffish was recorded in Hordaland.

For several species, substantial parts of the catch were released (Figure 4). The main reason for releasing fish was that the fish were "too small", both in Hordaland and Troms. For saithe, the release proportions (based on numbers) were 39% in Hordaland and 48% in Troms. For cod, the release proportions were 39% in Hordaland and 20% in Troms.

The average number of anglers per boat was higher for anglers staying in a registered tourist fishing business (2.7 anglers/boat in Hordaland and 3.3 anglers/boat in Troms) than the average number of anglers per boat when not staying in a tourist fishing business (i.e. resident anglers and non-registered tourists; 2.0 anglers/boat in Hordaland and 1.6 anglers/boat in Troms). The average trip length was longer for anglers staying in a registered tourist fishing business than for anglers not staying in a tourist fishing business both in Hordaland (5.1/3.1 h) and Troms (8.5/4.0 h), based on complete trip data.

Most anglers were male, both in Hordaland (81%) and in Troms (93%). In terms of accommodation type, 44% and 59% of the interviewed anglers stated that they stayed in registered tourist fishing businesses in Hordaland and Troms, respectively. Anglers staying in registered tourist fishing businesses were dominated by persons residing in Germany both in Hordaland (87%) and Troms (50%) (Figure 5). The anglers not staying in registered tourist fishing businesses (i.e. resident anglers and other tourists) were dominated by persons residing in Norway, both in Hordaland (76%) and Troms (92%).

Concerning knowledge of regulations, 47% and 31% of the interviewed anglers staying in registered tourist fishing businesses knew the correct minimum landing size for cod in Hordaland and Troms, respectively. In contrast, only 18% and 9% of the other anglers interviewed (i.e. resident anglers and tourists not fishing from a registered fishing tourism business)

Table 2. Estimated annual boat-based catch by marine recreational anglers (resident and tourist anglers combined) in Troms and Hordaland based on the roving creel survey between 1 April 2018 and 31 March 2019.

	Troms							Hordaland						
	Kept				Released			Kept				Released		
	Numbers		Biomass		Numbers		Proportion	Numbers		Biomass		Numbers		Proportion
	N	RSE (%)	Tonnes	RSE (%)	N	RSE (%)	% of total catch	N	RSE (%)	Tonnes	RSE (%)	N	RSE (%)	% of total catch
Cod	930 949	44	2 160	44	236 582	40	20	57 094	27	73	29	36 982	30	39
Haddock	*6 135*	39			*5 065*	*64*	*45*	*8 393*	42			*9 464*	*54*	*53*
Saithe	122 394	41	104	43	114 688	33	48	167 626	51	154	52	107 944	29	39
Pollack	*0*	-			*0*	-	-	45 668	26	66	27	11 132	41	20
Ling	*0*	-			*0*	-	-	40 572	33	86	35	8 824	54	18
Tusk	*21 972*	42			*38 475*	30	*64*	*3 650*	78			*0*	-	*0*
Hake	*0*	-			*0*	-	-	*19 115*	62			*1 072*	*100*	*5*
Redfish	50 933	36			*0*	-	0	*2 570*	*100*			*9 810*	*65*	*79*
Halibut	*10 727*	*41*			*2 666*	*67*	*20*	*0*	-			*1 417*	*62*	*100*
Wolffish	*19 132*	*46*			*4 752*	*67*	*20*	*0*	-			*0*	-	-
Mackerel	*8 166*	*73*			*17 853*	*88*	*69*	816 227	65	131	65	86 659	60	10

Estimates in italics are based on low number of fish registered and reported in the whole survey period (kept + release < 30 individuals).

knew the correct minimum landing size for cod in Hordaland and Troms, respectively.

Tourist fishing business survey

In total, 79 fishing parties (217 anglers) were interviewed in Hordaland and 77 fishing parties (240 anglers) in Troms between April 2018 and March 2019 during the tourist fishing business survey.

Both the tourist fishing business survey and the roving creel survey showed similar species compositions in the catches (Figure 4). Cod (365 549, RSE 6%; 848 t, RSE 9%) and saithe (85 738, RSE 6%; 73 t, RSE 15%) dominated the landings in Troms, and mackerel (114 308, RSE 8%; 18 t, RSE 9%) and saithe (123 529, RSE 6%; 114 t, RSE 13%) dominated the landings in Hordaland.

The estimated weekly catch varied substantially during the season in both Hordaland and Troms (Figure 6). Cod catches were generally higher at the beginning of the season, peaking at week 23 in Troms and week 18 in Hordaland. For saithe, the majority of catches were taken in the middle of the season in Troms (around week 30), but earlier in the season in Hordaland (week 22), with decreasing catches later in the season. Mackerel catches were rather low before week 30 and peaked between weeks 30 and 40 in both Hordaland and Troms.

As also found in the roving creel survey, substantial parts of the catch were released (Figure 4). The main reason for releasing fish was that the fish were "too small", both in Hordaland and Troms. In Troms, the release proportions were generally higher than in Hordaland (Table 3 and Figure 4). The release proportions for saithe (based on numbers of fish) were 29% in Hordaland and 54% in Troms. For tusk, this difference was even larger, with 8% of the catch released in Hordaland and 55% in Troms. For cod, the release proportions were similar between Hordaland (30%) and Troms (32%).

The majority of anglers stayed at the 20 collaborating businesses both in Hordaland (89%) and Troms (100%), and a low proportion of anglers were residents renting a boat for a day. The tourist anglers (i.e. those staying at the business) were dominated by persons residing in Germany both in Hordaland (86%) and Troms (44%), followed by persons residing in Norway (5%) and Russia (5%) in Hordaland, and persons residing in Russia (15%) and Estonia (9%) in Troms (Figure 5). Most tourist anglers were male, both in Hordaland (85%) and in Troms (95%). Twenty-three percent and 38% of the interviewed anglers who stayed at the tourist fishing businesses knew the correct minimum landing size for cod in Hordaland and Troms, respectively.

Discussion

This study shows that both resident and tourist anglers account for a considerable harvest of economically important fish species in the Norwegian marine coastal zone, both in Hordaland and Troms. When comparing the estimated landings in weight based on the tourist business survey with the estimated landings in weight of all marine recreational anglers based on the roving creel survey, the cod landings in tourist fishing businesses accounted for ∼40% of the total marine recreational angler cod landings both in Hordaland and Troms. While the catch estimates based on the tourist business survey were generally precise, the estimates based on the roving creel survey had larger uncertainties. Even though there

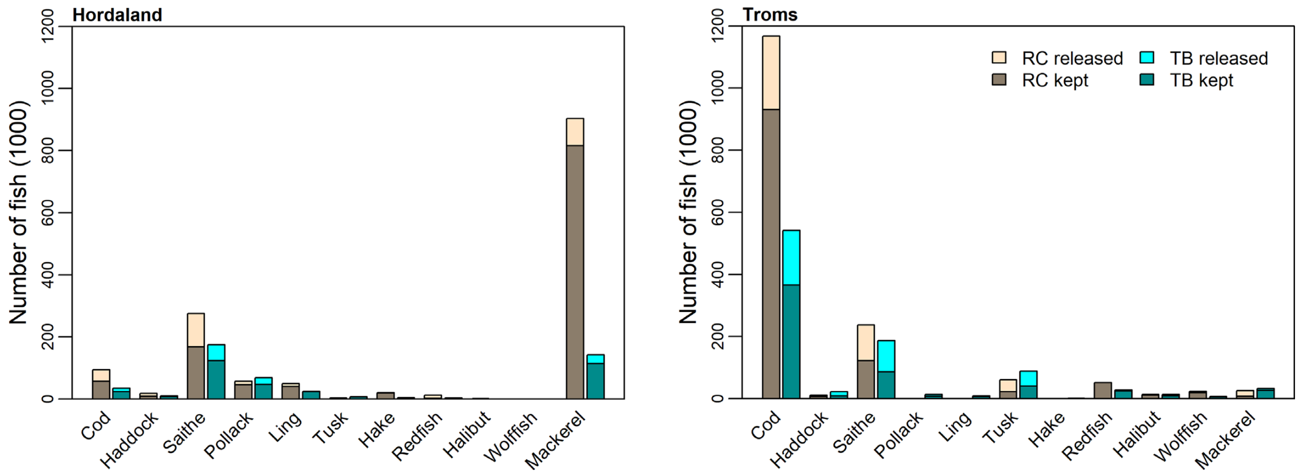

Figure 4. Estimated numbers of fish landed by recreational resident and tourist anglers from boat based on the roving creel survey (RC—brown colours), and numbers of fish landed in registered tourist fishing businesses based on the tourist fishing business survey (TB—blue colours).

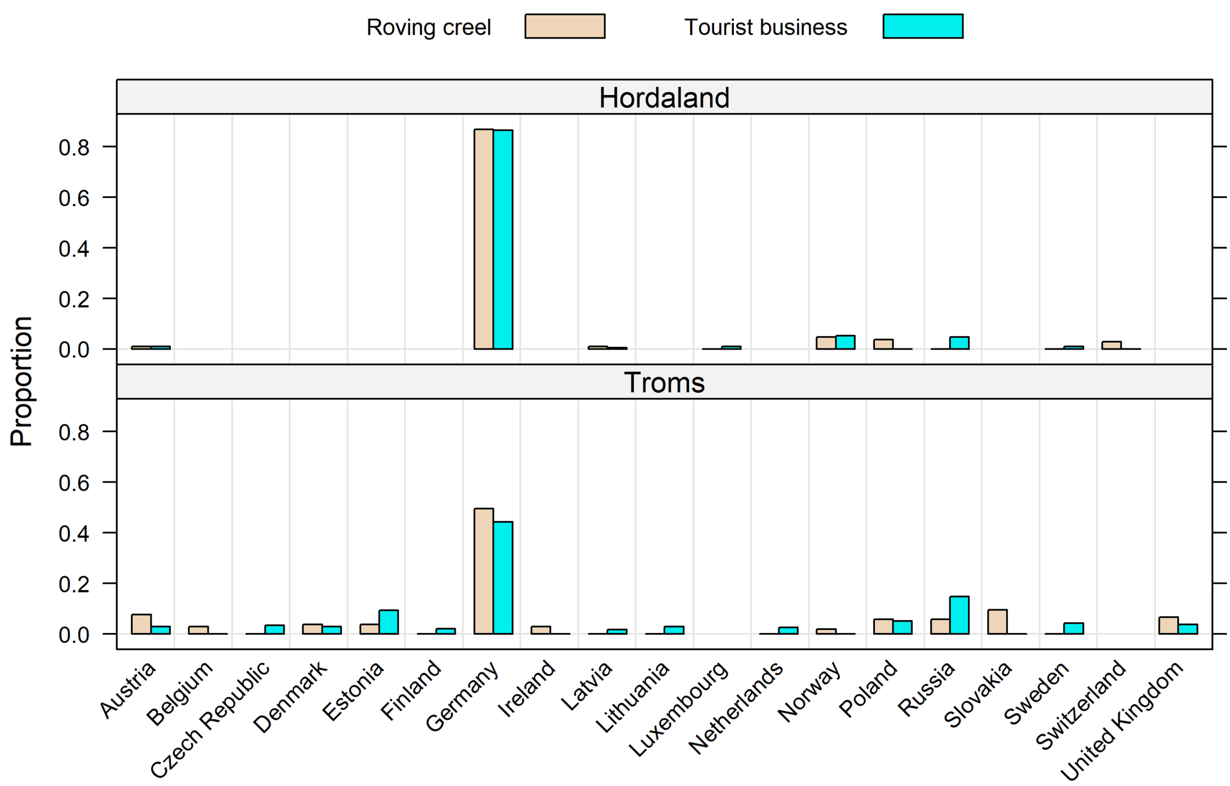

Figure 5. Distribution of residence countries of anglers staying in registered tourist fishing businesses in Hordaland and Troms based on the roving creel interviews and the interviews at registered tourist fishing businesses.

was an extra cost associated with running two surveys in parallel, this approach was the only way to evaluate how much tourists catch compared to resident recreational anglers. The roving creel survey alone did not allow for separate domain estimates for these two sectors due to the low sample size of interviews. By running both surveys in parallel, we were able to make informed judgements on the quality of our estimates from both surveys. Similar approaches have also been used in other studies on recreational fishery catches (e.g. Lai *et al.*, 2021; Lewin *et al.*, 2021; Taylor *et al.*, 2021). Compared to the commercial harvest, the harvest by recreational anglers was generally small in Troms, but nevertheless could have negative impacts on local fish populations if fishing effort is very high in relatively closed fjord systems. This conclusion is similar to the conclusions by Vølstad *et al.* (2011), who investigated the impacts of marine angling tourism on a national scale in Norway. However, in Hordaland, recreational anglers landed an estimated 73 tonnes (RSE 29%) of cod, which is more than the officially reported commercial cod catch (43 tonnes) in coastal waters during the survey period, so it is important to account for recreational fishing to ensure sustainable management of this resource. Based on our findings, we suggest implementing long-term monitoring of resident and tourist recreational fishers on a national scale to identify regions with high

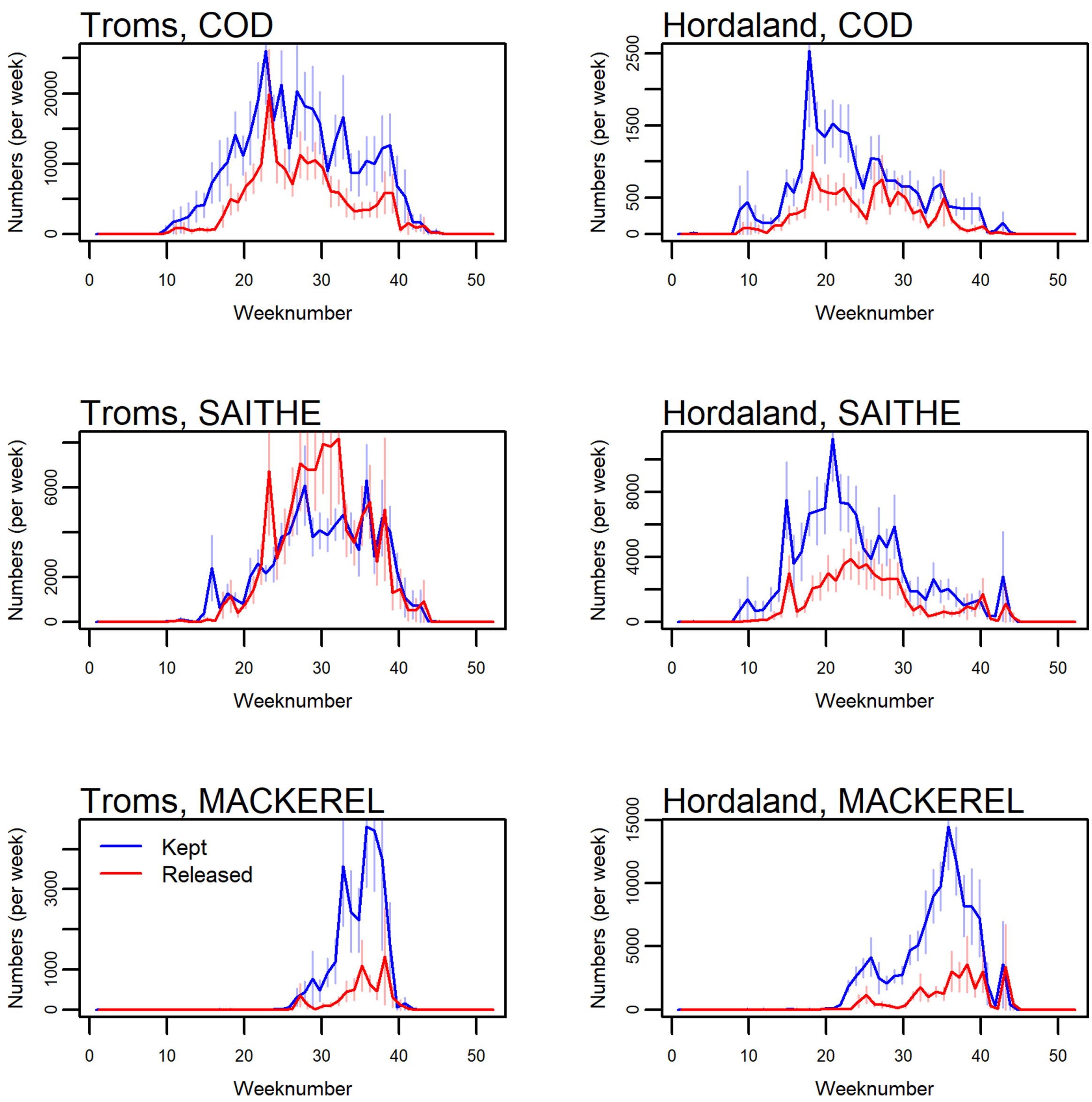

Figure 6. The estimated weekly catch of cod, saithe, and mackerel in registered tourist fishing businesses in Troms and Hordaland based on the tourist business survey in 2018–2019. The vertical lines indicate the SE.

recreational fishing effort and study potential impacts on local fish stocks (Hyder *et al.*, 2018). Furthermore, it is important to establish time series of recreational fisheries data that can be used in stock assessments for relevant stocks (Radford *et al.*, 2018; Hyder *et al.*, 2020).

Study limitations

The roving creel survey generally yielded substantially less precise catch estimates than the tourist fishing business survey. We found that the distribution of fishing effort at sea was highly patchy spatially, leading to high variability in our counts. Moreover, for some species, a very low number of individuals was recorded and reported in the field, and complete-trip data were lacking for some of those trips (e.g. ling in Troms). Higher effort was found in the proximity of fishing hot spots (e.g. reefs or places with a lot of current), fishing tourism businesses, and densely populated areas, which is in line with other studies (Parnell *et al.*, 2010; Smallwood and Beckley, 2012). On the other hand, very little or no fishing effort was recorded in the majority of the searched polygons. As a result, our sample sizes were not adequate to reduce variability as much as would be desired. The particularly low number of interviews completed in Troms also caused low precision in the data. For example, only interviews within randomly selected PSUs were included in the catch estimation, resulting in a total of 45 interviews across all four quarters. The ongoing application of the roving creel survey design developed for this study could be used to cumulatively characterize the relative spatial intensity of recreational fishing in Norwegian waters, leading to a more optimal allocation of survey effort and more precise harvest estimates in the future.

In the roving creel survey, we oversampled weekend days, as each survey round consisted of three weekdays and both weekend days. This would have led to a higher overall effort estimate if fishing effort had been higher during the weekend. However, we found that the fishing effort by angling tourists is less dependent on the day of the week. Instead, it appears that weather conditions play a major role in the daily effort dis-

Table 3. Estimated annual catch of the 12 most popular species in registered tourist fishing businesses in Troms and Hordaland based on the tourist fishing survey in 2018–2019.

	Troms Kept Numbers N	Troms Kept Numbers RSE (%)	Troms Kept Biomass Tonnes	Troms Kept Biomass RSE (%)	Troms Released Numbers N	Troms Released Numbers RSE (%)	Troms Released Proportion % of total catch	Hordaland Kept Numbers N	Hordaland Kept Numbers RSE (%)	Hordaland Kept Biomass Tonnes	Hordaland Kept Biomass RSE (%)	Hordaland Released Numbers N	Hordaland Released Numbers RSE (%)	Hordaland Released Proportion % of total catch
Cod*	365 549	6	848	9	175 505	7	32	24 016	7	31	12	10 473	9	30
Haddock	9 422	13			13 078	23	58	8 064	9			1 654	10	17
Saithe*	85 738	6	73	15	101 004	8	54	123 529	6	114	13	51 526	8	29
Pollack	7 359	31			5 529	29	43	47 285	7	69	11	21 003	8	31
Ling	6 263	11			2 971	14	32	22 975	6	49	14	1 617	12	7
Tusk	40 143	9			48 627	8	55	6 396	10			554	20	8
Hake	923	70			270	50	23	4 765	17			134	31	3
Redfish*	24 291	10			3 371	11	12	2 056	21			1 021	22	33
Halibut*	8 826	6			4 526	9	34	125	32			41	39	25
Wolffish*	5 981	9			881	16	13	59	24			10	74	14
Mackerel	27 032	15			5 916	25	18	114 308	8	18	9	28 177	18	20
Seatrout	70	49			58	65	45	60	79			71	55	54

*Species for which reporting is mandatory, and which were reported by all businesses including the ones that used electronic catch reporting.

tribution of recreational fishers (Fraidenburg and Bargmann, 1982; Townhill *et al.*, 2019). Using post-stratification, we estimated an 11% upward bias in effort for Hordaland and a 0% bias for Troms. Therefore, due to the small sample sizes within domains, we chose not to correct for this source of bias in estimates of total catches, since any reduction in bias would have been offset by increased variance due to the post-stratification.

The roving creel survey did not cover the whole day since our sampling was restricted to the time period from 9:00 a.m. to 8:00 p.m. Thus, trips starting after 8:00 p.m. and ending before 9:00 a.m. (i.e. pure night fishing) were not covered in this study, which may have led to some bias in total catch estimates (Diogo and Pereira, 2016; Sande *et al.*, 2022), especially in Troms during mid-summer when there is daylight for 24 h. Also, it is not possible to truly randomize the snapshot sampling of PSUs in time within the daily time period, which can cause bias in the estimates of daily trip coverage. This was not an issue in the tourist fishing business survey, as the catch estimates are based on catch reporting by the angling tourists, which covers the entire day.

The catch estimates in the tourist fishing business survey were based on self-reported data, which can have several bias issues like recall bias, non-reporting and/or prestige bias, and species identification bias (Pollock *et al.*, 1994; Page *et al.*, 2012; Lewin *et al.*, 2021). This was less of an issue in the on-site sampling in the roving creel survey, as the catch was inspected by research staff, but may have affected the complete-trip reports via telephone. Roving creel surveys are also affected by avidity bias, as the probability of intercepting anglers that stay out longer (and are likely more avid) is higher than for those that only fish shorter trips (and are likely less avid) (National Research Council, 2006). The relatively low number of interviews in the roving creel survey did not allow to assess this bias in more detail.

It was not possible to compute separate catch estimates for angling tourists and other anglers in the roving creel survey due to the relatively low number of interviews in the randomly selected PSUs. Thus, to determine the contribution of anglers fishing from registered tourist fishing businesses compared to the total angler catches in Hordaland and Troms, we compared the estimates from the two independent surveys. However, some caution is necessary because the daily sampling periods were different between the two surveys. As the sampling period per day was longer for the tourist fishing business survey compared to the roving creel survey, the catch share of tourists may therefore be slightly overestimated. For example, the point estimates of harvest for some species were occasionally even higher in the tourist fishing business survey than in the roving creel survey, e.g. tusk in Troms and pollack in Hordaland. However, this is likely due to the low precision of the roving creel estimates, and the absolute differences are not significantly different from zero ($p > 0.05$; Schenker and Gentleman, 2001). The main fishing effort also takes place during the day, which is why we assume that the difference in sampling periods has a limited impact on our conclusions. Notably, the distribution of country of residence for those staying in registered fishing businesses was very similar between both surveys (Figure 5).

The harvest estimates based on the roving creel survey also include catches that are landed and sold by resident recreational fishers through commercial fish landing sites and thus are also included in the officially reported commercial catches (Table 1). Due to low sample sizes, it was not possible to get separate estimates for private harvest and landings that are sold by recreational fishers. Therefore, there is a potential for double counting, but the proportion of cod that is officially landed by recreational fishermen compared to commercial fishermen is rather low (<5%; Table 1), and the officially landed recreational cod catches are within the uncertainty of our roving creel estimates.

Implications for science and management

This study shows that resident recreational fishers and angling tourists account for a substantial catch of some species in the coastal zones of Hordaland and Troms in Norway. Both coastal cod stocks north of 62° are of particular concern (ICES, 2021). We estimated that recreational anglers annually harvest around 2 000 tonnes of cod in Troms, and 70 tonnes in Hordaland. Despite the high uncertainties in these roving-creel estimates, our overall conclusions are supported by the complemented surveys. Although the harvest estimate in Hordaland is much lower than in Troms, recreational anglers contribute a higher proportion of the overall cod harvest in the coastal zone of Hordaland compared to Troms. The officially reported commercial cod landings taken within 12 nautical miles off the coastal baseline were 43 tonnes in Hordaland; thus, we estimate that recreational anglers harvested at least the same amount of cod within the same time period (73 t; RSE 29%). In Troms, the officially reported cod landings taken within 12 nautical miles off the coastal baseline (22 545 t) were around ten times higher than the recreational harvest on rod and line (2 160 t, RSE 44%). This difference in the relative contributions of recreational anglers to the total harvest between Hordaland and Troms can likely be explained by a relatively higher recreational fishing effort in Hordaland compared to Troms and a relatively higher commercial fishing effort in Troms compared to Hordaland. The human population in Hordaland is three times higher than in Troms, and there were also more registered tourist fishing businesses and boats in Hordaland than in Troms at the time of this study (Table 1).

An important next step is to evaluate the biological significance of the recreational fishing mortality (harvest + dead releases) in Hordaland and Troms to ensure sustainable fisheries management. Several other studies have shown that recreational fishing can have an impact on marine fish stocks, which is why this fishing sector should be accounted for in stock assessments and management (Eero *et al.*, 2015; Hyder *et al.*, 2018; Radford *et al.*, 2018; Lewin *et al.*, 2019). While some species are likely minimally impacted, e.g. mackerel, which is very abundant, the impact on other species, e.g. coastal cod, requires further investigations. It is important to investigate the relative impacts of all fisheries, i.e. commercial fishing, recreational fishing with standing gear, and recreational angling both from shore and boat, on the coastal cod stock in particular. This has been done regionally in Norway (Jorde *et al.*, 2018), but not on a national level, mainly due to the lack of data and biological samples from recreational landings. As cod catches in Norway consist of different stock components, these impacts can, for example, be studied by advanced DNA analyses (Dahle *et al.*, 2018; Jorde *et al.*, 2018; Johansen *et al.*, 2020). Before new management measures are implemented, it is also necessary to evaluate different management options to ensure effectiveness and avoid unintended socio-economic consequences for the recreational fishery (Haase *et al.*, 2022; Bronnmann *et al.*, in press).

Even though the management of marine recreational fishing in Norway has few regulations, the majority of the interviewed anglers did not know the correct minimum size limit for cod, which is one of the main target species. Interestingly, the proportion of those who knew the correct minimum landing size was higher for angling tourists than for residents. This can be explained by the fact that the owners of tourist fishing businesses usually inform their guests about fishing regulations upon arrival. Fisheries managers should put an increased effort on informing and educating resident marine recreational fishers about fishing regulations.

This study found that release proportions were substantial for some species. Approximately half of the catch was released for some species, which is in line with previous studies in Norway and other European countries (Ferter *et al.*, 2013a, b). Ferter *et al.* (2013a) showed that the main reason for releasing fish by marine angling tourists in Norway was that the fish were "too small", which is in line with the present study. One underlying assumption when releasing fish is that the fish will survive (Arlinghaus *et al.*, 2007). However, post-release survival is highly species-specific (Bartholomew and Bohnsack, 2005) and also depends on several other factors like capture depth, anatomical hooking location, and water temperature. In Norway, the post-release survival of cod and halibut has been thoroughly studied (Ferter *et al.*, 2015a, b, 2017). These studies show that the post-release survival of these species can be high if they do not have major hooking injuries and manage to submerge after release. For many other marine species in Norway, however, the post-release survival is largely unknown, even though release proportions are high, as shown in this study. High post-release mortalities in combination with high release rates need to be added to the total fishing mortality (Coggins *et al.*, 2007; Kerns *et al.*, 2012). To minimize the negative impacts of catch and release, it is important to study the post-release survival of other relevant marine species in Norway and to develop species-specific catch and release guidelines (Cooke and Suski, 2005; Brownscombe *et al.*, 2017).

Future studies and conclusions

The present study combined two different survey methods independently to investigate Norway's complex rod and line fishery in two diverse study regions. Based on these surveys, we have been able to estimate the boat-based recreational catches for several important species and found that the recreational harvest can be substantial for some species. The survey methods developed in this study can be applied on a national scale in Norway and be used for other countries with complex recreational fisheries and large coastlines with many islands. However, to decrease survey costs and/or increase precision, particularly for the roving creel survey, it would be advantageous to test the use of drones (Provost *et al.*, 2020), aerial surveys (Taylor *et al.*, 2021), and camera monitoring (Hartill *et al.*, 2020) to map spatial distributions of fishing effort. Such data could potentially be used to reduce the number of 0 observations in the roving creel survey by assigning higher probabilities for including polygons with expected high effort in the sample. In addition, the number of interviews could potentially be further increased by employing adaptive sampling (see e.g. Christman, 1997, 2009) for choosing neighbouring polygons within PSUs in the field in a manner that maintains probabilistic sampling of polygons. Such probability-based survey approaches may also be supplemented with new survey methods, such as using fishing apps (Venturelli *et al.*, 2017; Gundelund *et al.*, 2020; Skov *et al.*, 2021) to collect catch-per-unit-effort and other catch-specific information from anglers and to estimate fishing effort at a regional level.

To monitor recreational fisheries in large stretches of Norway's coastline, which is costly, we believe that the use of rotating surveys (e.g. Breidt and Fuller, 1999; Skaug *et al.*, 2004) could be the method of choice. Using such methods, coastal counties could each be surveyed in a single year, achieving full coverage of large stretches of the coastline over several years. If conducted on a rotating basis, this would provide the time series of catch and effort needed as input to stock assessments.

In conclusion, this study shows that the marine recreational catches of some species in Norway should be accounted for in stock assessments and management. Previous studies have shown that recreational fishers can account for a substantial proportion of the total harvest, e.g. coastal cod in the Skagerrak (Kleiven *et al.*, 2016), which is in line with some of the findings in the present study. To run stock assessments, it is necessary to establish time series data (Radford *et al.*, 2018). As recreational catches and effort may vary between years (Strehlow *et al.*, 2012), a continuous monitoring system for marine recreational fishing should be established. Such monitoring should also include recreational fishing from shore and fishing with standing gear, as these also have a significant effort in some regions. The results of the present study contribute to the sustainable management of Norwegian coastal fish resources and lay the basis for future marine recreational fishing surveys in Norway.

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Supplementary data

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

Conflict of interest

The authors declare no conflicts of interest.

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Author contributions

KF: conceptualization, planning, field work, data curation, data analysis, writing—original draft, writing—review and editing, project administration, funding acquisition; HO and MC: conceptualization, planning, data curation, data analysis, writing—original draft, writing—review and editing; ARK: conceptualization, planning, writing—review and editing, project administration, funding acquisition; SG, CD, and OB: planning, field work, data curation, writing—review and editing; MSW, BH, JL, and KH: conceptualization, planning, data analysis, writing—review and editing; TB: planning, field work, writing—review and editing, funding acquisition; JHV: conceptualization, planning, data analysis, writing—original draft, writing—review and editing, project administration, funding acquisition.

Data availability

The data underlying this article will be shared on reasonable request with the corresponding author.

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