Canadian Science Publishing

ARTICLE

Inclusion of recreational fishing in data-limited stocks: a case study on Norway lobster (*Nephrops norvegicus*) in Norway

Fabian Zimmermann, Alf Ring Kleiven, Merete Vik Ottesen, and Guldborg Søvik

Abstract: Recreational and semi-subsistence fisheries are challenging to monitor but can act as precursors of developments in commercial fisheries, contributing information in data-limited situations. We compared trends in commercial landings of Norway lobster (*Nephrops norvegicus*) with data collected through a citizen science project by recreational fishers in Norway during a period that coincided with the onset of a commercial trap fishery. The results show that trap fishing for *Nephrops* emerged recently in Norway, with significant regional differences in size composition and catch rates. Comparable patterns in catch rates between regions were found in commercial landings during the same period, suggesting that landings per boat trip may provide a suitable abundance index in a severely data-limited fishery. Our study indicates that recreational fishing acted as trailblazer for a surge in fishing with lower-impact gear along the Norwegian coast, underscoring the fact that non-commercial fisheries may act as early indicators of emerging commercial fisheries. Collecting information through citizen science projects targeting non-commercial fishers can therefore provide baseline data, especially from the earliest, unmonitored stages of fisheries, and contribute to stock assessment.

Résumé : La surveillance des pêches sportives et de semi-subsistance est difficile, même si ces dernières peuvent être des précurseurs de nouveaux phénomènes dans les pêches commerciales, fournissant de l'information dans des situations de données limitées. Nous comparons les tendances des débarquements commerciaux de homards de Norvège (*Nephrops norvegicus*) à des données recueillies dans le cadre d'un projet de science citoyenne par des pêcheurs sportifs en Norvège durant une période coïncidant avec le début d'une pêche commerciale au casier. Les résultats montrent que la pêche au casier au homard de Norvège est un phénomène récent en Norvège qui présente des différences régionales significatives sur le plan de la composition par tailles et des taux de prise. Des motifs semblables des taux de prise entre régions sont observés dans les débarquements commerciaux au cours de la même période, donnant à penser que les débarquements par sortie pourraient constituer un indice d'abondance convenable dans une pêche caractérisée par un manque criant de données. L'étude indique que la pêche sportive constituait un signe avant-coureur d'une montée rapide de la pêche avec des engins à faible impact le long de la côte norvégienne, soulignant le fait que les pêches non commerciales peuvent être des d'indicateurs précoces de nouvelles pêches commerciales. La collecte d'information par l'entremise de projets de science participative visant des pêcheurs non commerciaux peut donc fournir des données de référence, notamment sur les toutes premières étapes non surveillées de nouvelles pêches et être utile pour l'évaluation de stocks. [Traduit par la Rédaction]

Introduction

Recreational and semi-subsistence fishing have high economic and cultural value (Hughes 2015), but can put substantial pressure on target populations and impact marine ecosystems. Although official statistics often only distinguish between commercial and recreational fisheries, the differences among small-scale commercial, subsistence, and recreational fishing are gradual and include intermediate, poorly defined forms such as semi-subsistence fishing (Hyder et al. 2017). Semi-subsistence fishing refers to fishing activities at the intersection of subsistence, commercial, and recreational fishing, such as people fishing with commercial equipment mostly for their own consumption, without depending on it for their main source of food or income. These types of fishers are not accurately represented by the dichotomous definition of fisheries as either commercial or recreational, even though they represent a common situation in coastal fisheries where the boundaries between (part-time) small-scale fishers and recreational activities may be blurred. Despite their relevance, non-commercial fisheries are typically understudied and severely data-limited, posing a major challenge for fisheries management (Hyder et al. 2018).

In Norway, a large coastal fleet consists of commercial and non-commercial fishers that are often active in the same areas and use largely identical gear and fishing strategies — especially in shellfish fisheries. Out of nearly 5200 active commercial vessels in the Norwegian coastal fleet in 2019, 94% of them were less than 15 m long. These small vessels are subject to less rigid reporting requirements than larger vessels (only landings registered, with electronic logbooks or automatic identification system (AIS) tracking not being mandatory). This fleet segment has substantial overlap with fishers that do not have a commercial registration and are thus considered recreational fishers despite the fact that the scope and scale of their fishing activities may go well beyond that typical of recreational fishing, such as pole-and-line sports fishing. The participation rate in non-commercial fishing is difficult to measure due to

Received 8 June 2021. Accepted 15 November 2021.

F. Zimmermann. Institute of Marine Research, Framsenteret, Postboks 6606, Langnes, Tromsø 9296, Norway.
A.R. Kleiven. Institute of Marine Research, Flødevigen Research Station, 4817 His, Norway.
M.V. Ottesen and G. Søvik. Institute of Marine Research, Postboks 1870, Nordnes, Bergen 5817, Norway.

Corresponding author: Fabian Zimmermann (email: fabian.zimmermann@hi.no).

 Published at www.cdnsciencepub.com/cjfas on 1 April 2022.

few or no restrictions on access through registration or license requirements. The Norwegian regulations for non-commercial fishing are stricter than those for commercial fishing, but can nonetheless be termed liberal. Fishers are allowed to fish with 210 m of gill net, 300 hooks on a longline, and up to 20 pots or traps, in addition to rods and lines. Non-commercial fishers are also allowed to sell their catch (maximum limits apply; Anonymous 2008). Thus, the key distinction between (registered) commercial small-scale fishers and non-commercial fishers in Norway is mainly the limit on the amount of passive gear allowed for non-commercial fishers. As a result of this low threshold to enter a fishery, non-commercial fishing on coastal resources can be considered an open-access fishery, with relevant impacts on a broad range of finfish and shellfish species.

While often considered to be a minor source of fishing mortality compared to commercial fisheries, removals of specific, often high-value species via non-commercial fishing can be of the same magnitude as those from commercial fishing or even be the dominant cause of fishing mortality (Radford et al. 2018). In the Norwegian part of Skagerrak, recreational fishers landed 65% of the total European lobster (*Homarus gammarus*) catches in 2008 (Kleiven et al. 2012) and dominated the catches of cod (*Gadus morhua*) in nearshore areas (Kleiven et al. 2016). Similar patterns are likely for a range of species and areas, both in Norway and internationally. This may be especially true along the southern and western coastlines of Norway, which have a high population density and substantial non-commercial fishing activity. There is no mandatory reporting for non-commercial landings in Norway unless catches are officially sold, nor has a data collection framework been implemented to systematically collect data from non-commercial fishing. Thus, a substantial knowledge gap exists for all coastal fisheries where non-commercial fishing plays a relevant role, which presumably applies to most commercially harvested coastal species in Norway. The problem is compounded by limitations in commercial data due to reduced reporting requirements for the small-scale fleet, the inaccessibility of many coastal species to standard scientific surveys, and unclear stock structures because of coastal topography. Consequently, a substantial proportion of coastal fish and shellfish populations in Norway can be considered data-limited and underregulated. The Norway lobster (*Nephrops norvegicus*, hereinafter *Nephrops*) provides an interesting case study because its fishery changed fundamentally within a decade, following drastic shifts in gear composition and the distribution of catches, as well as a large increase in fishing mortality caused by non-commercial activities. Therefore, *Nephrops* in Norway illustrates how changes in fishing patterns can alter the data needs for monitoring and management. In addition, this case study represents the globally common situation of severe data limitations in a fishery where recreational activities play a relevant role.

Nephrops sustains one of the most economically important fisheries in Europe. Total commercial landings steadily increased until the mid-2000s, peaking in 2007 at almost 76 000 tonnes (t) (Ungfors et al. 2013) before decreasing to around 49 000 t in 2018 (FAO 2021). In contrast, landings in Norway have increased over recent years to their highest level in 2020 at just above 400 t, even though this value remains comparatively low in a European context. Most *Nephrops* in Europe are caught by conventional trawls. This has also been the case in the Skagerrak (International Council of the Exploration of the Sea's (ICES) functional unit (FU) 3), where Denmark, Sweden, and Norway share the *Nephrops* resource (assessed and managed together with the Kattegat (FU 4); ICES 2020). However, trawlers in Sweden were excluded from near-coastal areas in the mid-1980s, resulting in a growing trap fishery that contributes a substantial share of the total landings (ICES 2020). A similar development has been observed in Norway in recent years, where *Nephrops* catches have traditionally been taken by trawls, mainly as by-catch in the shrimp fishery (Søvik et al. 2017). This began to change in 2001 when a trap fishery emerged, both in the Skagerrak and along the west coast of Norway (ICES 2020). New legislation in 2004 imposed a ban on *Nephrops* trawling (but not shrimp trawling) within 4 nautical miles (1 n.mi. = 1.852 km) of the baseline in Norwegian waters, except for in the Skagerrak area, and increased minimum mesh size in all large-mesh bottom trawls to 120 mm (Søvik et al. 2017). In contrast to the Skagerrak, where a targeted *Nephrops* trawl fishery is still allowed, these regulations contributed to substantially decreased trawl catches of *Nephrops* in the Norwegian zone of the North Sea (i.e., the area off West-Norway, ICES FU 32) after 2010 and may have provided an incentive for a trap fishery along the coast (ICES 2020; Søvik et al. 2017). Observations and anecdotal evidence suggest that development in the commercial trap fishery was preceded by an increased interest in recreational trap fishing for *Nephrops*. The accessibility of fishing grounds to small coastal boats, the high value of the product, and the absence of entry restrictions or other relevant regulations have created strong incentives for non-commercial and commercial fishers to enter the *Nephrops* trap fishery. The recent emergence of the fishery, in combination with few reporting requirements for small vessels, have restricted the availability of data and prevented the systematic monitoring of a stock with a patchy distribution. As a result, concerns have been raised about the sustainability of the fishery.

Most global fisheries can be categorized as data-limited (Costello et al. 2012), and data from the emergence of a fishery that can act as baseline for future developments are especially scarce. Information from recreational fisheries is rarely used in an assessment context, even when such fisheries contribute a significant proportion of the total catch. In this paper, we investigated how fisheries data voluntarily reported by recreational fishers acting as citizen scientists can support the development of monitoring processes for an emerging, data-limited fishery. To do so, we compared available commercial landing data with information obtained from a survey of recreational fishers. Our comparative analyses of catch rates and composition established a baseline on the seasonal and spatial fisheries dynamics and investigated whether landings data can provide a suitable stock index for a future stock assessment. Our results demonstrate how alternative data sources, and especially data collected by citizen scientists, can improve the monitoring of fish stocks in data-limited situations. Moreover, we show the importance of incorporating information from recreational and other non-commercial fishers in monitoring and assessment processes for fisheries where non-commercial catches constitute a relevant source of fishing mortality.

Methods

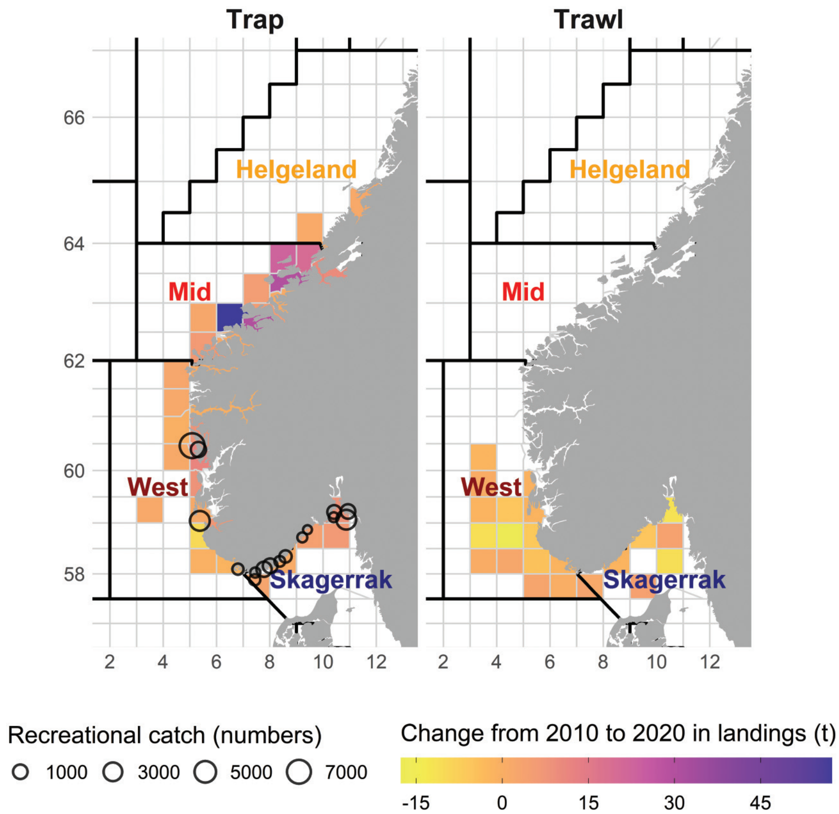
Study species

Throughout its distribution, *Nephrops* is limited to a muddy habitat where it excavates burrows 20–30 cm into the substrate (Johnson et al. 2013). In the Norwegian waters of the Skagerrak, *Nephrops* is limited to patches of muddy areas between rocky bottoms, in a narrow belt along the sharply descending coastline. Suitable habitat is found in large parts of the eastern Skagerrak and throughout the Norwegian part of the North Sea (ICES 2020), whereas the species distribution is more patchy in coastal areas and fjords.

Tagging experiments have shown that adult *Nephrops* only undertake small-scale movements (Aguzzi and Sardà 2008; Farmer 1975). Egg-laying takes place in early autumn (Farmer 1975; Powell and Eriksson 2013), and females carry the roe until hatching in the following year. Berried females remain within their burrows; therefore, catches are often dominated by males (ICES 2020).

There are no quota regulations or effort control of the Norwegian *Nephrops* fishery. The minimum landing size (MLS) in the Norwegian fishery is 130 mm total length (TL, measured from the tip of the rostrum to the posterior margin of the telson) or 40 mm carapace length (CL, measured from the eye socket to the back of

Fig. 1. Map of changes in quantity (tonnes, t) of *Nephrops* landed in Norway between 2010 and 2020 by statistical rectangle and gear type, and the location of *Nephrops* caught by recreational fishers as part of this study (black circles) scaled by the total number of samples (specimens). The colour scale indicates how much more or less *Nephrops* was landed in a specific statistical rectangle in 2020 compared to 2010, ranging from a decrease in landings (yellow) to a large increase in landings (purple). Only differences in landings in statistical rectangles with more than a total of 1 t landed in both years are shown. The study regions are delimited with black lines (borders correspond to the main areas in Norway's statistical grid, except for 08 and 28, which were merged into the West-Norway region). Map is shown in latitude–longitude with Mercator projection, with land polygon data obtained through the R package "marmap" (Becker and Wilks 1995) and the Norwegian statistical grid provided as shapefile by the Fisheries Directorate of Norway. [Colour online.]



the carapace). By contrast, since 2016 the Danish and Swedish fisheries in the Skagerrak and Kattegat have set an MLS of 32 mm CL. In the trap fishery, there is a maximum limit of 20 traps per recreational fisher and (or) boat, but there is no effort regulation on the number of traps in the commercial fishery. In the trawl fishery, regulations have been imposed mainly to protect fish stocks (Søvik et al. 2017).

Commercial data

Available commercial data were provided by the Fisheries Directorate of Norway and consist of sales notes registering all landings, with information on species, gear type used, and catch location within Norway's statistical grid. Each grid cell measures 1° longitude and 0.5° latitude and overlaps with ICES statistical rectangles. Before 2005, landings data were only provided on an aggregated basis. Data on individual landings are available from 2005, containing information on the identification and specification of the boat, as well as the first sale price. To avoid bias from minor registrations of *Nephrops* bycatches, only boats with more than one trip and more than 100 kg total annual landings were considered as active participants in the *Nephrops* fishery. Data from electronic logbooks only exist for boats larger than 15 m, which excludes almost the entire *Nephrops* fishing fleet. The main areas from the Norwegian statistical grid were used to define different regions (09 = Skagerrak, 08 and 28 = West-Norway, 07 = Mid-Norway, 06 = Helgeland Coast; see Fig. 1). Areas 08 and 28 were combined into one region because they correspond to *Nephrops* FU 32 as defined by ICES, being functionally linked in terms of fisheries.

Survey of recreational fishers

A survey was sent out to identified recreational European lobster fishers in 2011 (273 fishers) and 2014 (272 fishers). The questionnaire focused on three different trap fisheries: European lobster, brown crab (*Cancer pagurus*), and *Nephrops*. For each fishery, respondents were asked if they conducted the respective activity and, if so, for how long (in years). The respondents were also surveyed on their personal perceptions of catch and size developments in the five preceding years for each respective species (increased, stable, decreased). The fishers could agree, disagree, or have no opinion on the statement that more people have been fishing for a species in the last five years. In the 2011 survey, the fishers were also asked to volunteer in a citizen science project by collecting and reporting their catch and effort data. The respondents who indicated that they fished for *Nephrops*, and who were willing to participate in reporting, were contacted individually.

The first stage of catch data collection was conducted from April to December 2012. All volunteers were mailed a printed diary to make notes on their fishing activity and catches. The citizen scientists registered the day of trap haul, depth, trap soaking time, number of traps hauled, and total catch of *Nephrops*. They also noted the total numbers of individuals above and below the minimum legal CL size (MLS), sex, and whether females carried eggs. Data were either transmitted via a phone interview or e-mailed by the fisher using a standardized report scheme.

The second stage of the survey lasted from January 2013 to April 2014. In addition to the information collected during the first stage, the fishers were asked to conduct length measurements in January, May, and August. The volunteers were mailed a set of calipers, a detailed description of the measuring procedure, and a diary for length measurements. Carapace length of the first 25 *Nephrops* caught each fishing day was measured (in mm), and the sex was identified for each.

Statistical analysis

Registered commercial landings per boat trip were used as a proxy for catch rate (i.e., landings per unit effort). To achieve a representative subsample of consistent fishing activity over the 2012–2014 study period, landings data were filtered for boats that were active in one of three regions in all 3 years and landed in total a minimum of 1 t of *Nephrops*. A linear mixed-effect model was used to explore how landings per boat trip were linked to the following potential covariates: fishing region (Skagerrak, West-Norway, and Mid-Norway), season (quarter), year, and size category of the vessel (below 8, 8–11, 11–15, or above 15 m). Boat ID was included as a random intercept to absorb variance in landings linked to individual differences between fishers, notably the number of traps used, as follows:

$$L_{i,t} = \beta_0 + \beta_{1,i,t} + \beta_{2,i,t} + \beta_{3,i,t} + \beta_{4,i,t} + b_{0,i} + \varepsilon_{i,t} \tag{1}$$

with t as boat trip, i as individual boat, β_0 as general intercept, and $\beta_{1,i,t}$, $\beta_{2,i,t}$, $\beta_{3,i,t}$ and $\beta_{4,i,t}$ as categorical effects of region, season, year, and vessel size category, respectively. Individual boats were represented as a normally distributed random effect $b_{0,i} \sim \mathrm{N}(0, \sigma_I)$, and $\varepsilon_{i,t}$ as a normally distributed error term with a log-link function.

Catch rates of recreational fishers were analysed with a linear mixed-effect model using year, season (quarter), region (Skagerrak and West-Norway), numbers of traps, and soak time as potential covariates (fixed effects). Individual fishers were included as a random effect to account for potential clustering effects within fishers (i.e., between-fisher variation due to experience, fishing gear, location, or other effects associated with each fisher). Subsequently, the full model was specified as follows:

$$C_{i,s} = \beta_0 + \beta_{1,i,s} + \beta_{2,i,s} + \beta_{3,i,s} + \beta_{5,i,s}T_{i,s} + \beta_{6,i,s}S_{i,s} + b_{0,i} + \varepsilon_{i,s} \tag{2}$$

with s as fishing trip and i as individual fisher, β_0 as the general intercept, and $\beta_{1,i,t}$, $\beta_{2,i,t}$ and $\beta_{3,i,t}$ as categorical effects of region, season, and year, respectively. $\beta_{5,i,s}T_{i,s}$ and $\beta_{6,i,s}S_{i,s}$ represented the fixed effects of the number of traps and soak time, respectively, the data for both of which were continuous and log-transformed. Individual fishers were modelled as a normally distributed random intercept $b_{0,i} \sim \mathrm{N}(0, \sigma_J)$. The initial model was specified with a Poisson distribution, but was subsequently replaced with a negative binomial distribution due to overdispersion.

The sex ratio and proportion of egg-bearing females were modelled using region $\beta_{1,i,t}$ and season $\beta_{2,i,t}$ as fixed effects, as follows:

$$S_{i,s} = \beta_0 + \beta_{1,i,s} + \beta_{2,i,s} + \beta_{7,i,s} + b_{0,i} + \varepsilon_{i,s} \tag{3}$$

$$S_{i,s} = \beta_0 + \beta_{1,i,s} + \beta_{2,i,s} + b_{0,i} + \varepsilon_{i,s} \tag{4}$$

After initial inspection of the data, an interaction term $\beta_{7,i,s}$ between region and season was included in the model. Both the sex ratio and proportion of berried females were modelled with a beta distribution.

The biological length composition of the recreational data was analysed using a subsample of individual measurements n of *Nephrops*, using a linear mixed-effect model with sex $\beta_{8,i,n}$ as a categorical fixed effect, in addition to region $\beta_{1,i,t}$ and season $\beta_{2,i,t}$. Fishing depth was included as a continuous fixed effect $\beta_{9,i,n}D_{i,n}$:

$$L_{i,n} = \beta_0 + \beta_{1,i,n} + \beta_{2,i,n} + \beta_{8,i,n} + \beta_{9,i,n}D_{i,n} + b_{0,i} + \varepsilon_{i,s} \tag{5}$$

modelled with $\varepsilon_{i,n}$ as a normally distributed error term.

All model fits were validated through inspection for homogeneity and homoscedasticity, and the most parsimonious model for each case was determined through backward selection based on $\mathrm{AIC_c}$ (Hurvich and Tsai 1989). The relevance of the random effects (individual vessel or fisher) was determined through the intraclass correlation (ICC; i.e., the ratio of between-fisher variance to total variance, providing a measure of how observations were correlated within each fisher).

All analyses were conducted with R version 4.0.2 (R: Development Core Team 2021) using the tidyverse (Wickham et al. 2019), lme4 (Bates et al. 2015), glmmTMB (Brooks et al. 2017), and emmeans (Lenth et al. 2021) packages.

Results

Commercial fisheries

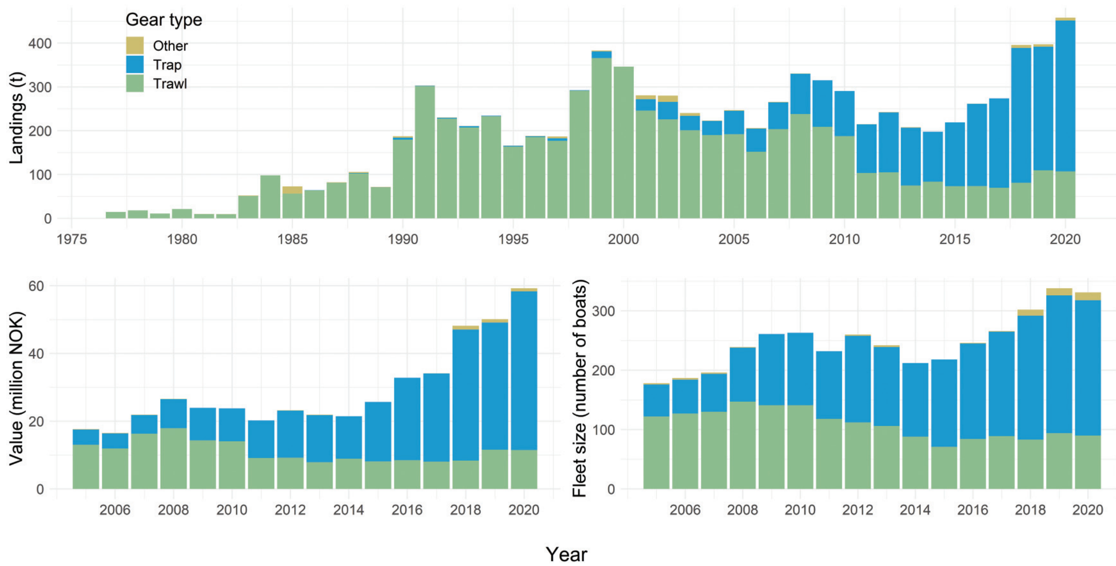
From 1977 to 2000, commercial landings of *Nephrops* in Norway showed a steady upward trend, from 14 t in 1977 to 346 t in 2000 (Fig. 2). During this period, the fishery was almost exclusively a trawl fishery, which contributed 98% of the total landings. In the early 2000s, total landings remained stable at a level below the peak in 1999–2000, with catches from traps providing a minor but gradually increasing share of total landings from 9% in 2001 to 35% in 2010. From 2011 onward, trap catches constituted the largest part of total landings, increasing from 52% in 2011 to 75% in 2020. After 2017, the increase in trap landings resulted in an overall increase of landings, reaching the highest observed quantity to date in 2020 at 458 t. This value represents an increase in total landings of 57% from 2010 to 2020, due to a tripling of trap landings. Trawl landings decreased by 43% over the same period.

The changes in landings were reflected in corresponding changes in the economic value of the fishery and the fleet size (Fig. 2). The strong increase in value has been exacerbated by the higher value of trap landings compared to trawl landings, on average fetching a price more than 60% higher in past years. The increase in price is mainly due to higher quality of *Nephrops* from trap landings. Because trap catches have constituted an increasing share of the landings, the combined effect has led to an over-proportional increase in value compared to landed quantities.

Increases in total landings and value, and a change in gear composition in the Norwegian *Nephrops* fishery, corresponded with a northward shift of the major fishing areas (Fig. 1). Trawling for *Nephrops* has always predominantly occurred in the Skagerrak, where the shrimp fishery is larger than in the west and where targeted trawling for *Nephrops* is still allowed. The shift towards trap fishing, which is more widespread in West- and Mid-Norway than in Skagerrak, therefore also resulted in a regional shift in fishing area. A second factor explaining the regional shift in the Norwegian *Nephrops* fishery is the availability of pristine fishing grounds (no trawling) in the fjords and coastal areas of West- and Mid-Norway, which has led to a northward expansion and intensification of fishing activity over the past ten years (see online Supplementary Fig. S1[1]). While landings from areas in southern Norway largely stagnated or even declined, landings from West- and Mid-Norway increased. Total landings from Mid-Norway have grown

[1]Supplementary data are available with the article at https://doi.org/10.1139/cjfas-2021-0152.

Fig. 2. Commercial landings (top) of *Nephrops* in Norway, their value (Norwegian krone, NOK; bottom left), and the fleet size (bottom right) over time by gear type used. Aggregated landings data were available from 1977 to 2020, while sales notes with more specific data on vessels and prices exist from 2005 onward. Other gear types refer to gear not explicitly registered as trap or bottom trawl, including unknown gear, fyke nets, gillnets, and others. Only boats landing at least 100 kg in a year were counted as part of the fleet. [Colour online.]



substantially in recent years, overtaking the Skagerrak as the main fishing region in 2017. In 2020, Mid-Norway produced more than double the total landings of the Skagerrak or West-Norway. In the most northern region where a *Nephrops* fishery occurs, the Helgeland Coast, the first year with relevant registered landings (close to 4 t) was 2020.

Between 2005 and 2020, the highest mean trap landings per boat trip were observed in Mid-Norway (Fig. 3). Although trap landings per boat trip in West-Norway reached levels comparable to those in Mid-Norway between 2012 and 2017, they declined in the following years. Landings per boat trip for trawl trended downward over almost the entire time series, but showed a clear increase in 2019 and 2020 (especially in West-Norway) that coincided with an increase in total landings. However, the comparability of gear types is limited because boats catching *Nephrops* with trawl are mostly not a targeted fishery (especially in West-Norway), and are fewer in number and larger in size, suggesting a higher fishing capacity.

Recreational fisheries

In addition to the responses of 131 and 143 recreational fishers to the survey administered in 2011 and 2014, 29 fishers volunteered to act as citizen scientists and provided information on their catch in 2012, 2013, and 2014. Of these, 28 were self-described recreational fishers and one was a retired professional fisher who still possessed a commercial license and could thus fish with more than 20 traps. Twenty-four of the participants were active in ten municipalities in the Skagerrak region, whereas five reported from three municipalities in West-Norway (Fig. 1 and Supplementary Fig. S2[1]). Total recreational catches in numbers per municipality throughout the study period ranged from 8 to 7898 *Nephrops*. A subset of *Nephrops* were individually measured for length in 2013.

Survey administered in 2011 and 2014

Response rates for the 2011 (n = 273) and 2014 (n = 272) surveys were 48% (n = 131) and 53% (n = 143), respectively (Supplementary Table S1[1]). The mean number of years of *Nephrops* fishing experience increased from 3.7 in 2011 to 7.1 in 2014. The mean number of years of lobster and crab fishing experience was significantly higher, ranging from 21.6 to 27.2 years in 2011 and 2014 (Supplementary Table S1[1]). The first reported year of participation in the *Nephrops* fishery among the respondents was 1995, with a boost in participation rate evident from 2008 (Fig. 4). The results indicate that participation in the recreational fishery for *Nephrops* roughly doubled from 2005 to 2010 and then again from 2010 to 2014.

In the 2011 survey, 6% of the respondents fishing for *Nephrops* expressed the opinion that catches had increased during the preceding 5 years, whereas 40% stated that they had decreased. In contrast, 11% and 12% of the respondents said catches of European lobster and brown crab, respectively, had decreased in the same period. The perception of catch development changed somewhat in the 2014 survey; 24% of the respondents stated that the *Nephrops* catches had decreased and 15% perceived an increase (Fig. 4). Further, 35% of the respondents fishing for *Nephrops* in 2014 stated that the mean size of *Nephrops* had decreased during the last 5 years, in contrast to European lobster (14%, n = 128) and brown crab (6%, n = 77). Sixty-eight percent and 61% of respondents agreed in 2011 and 2014, respectively, that more people had been participating in the *Nephrops* fishery in the last 5 years.

Length structure

A total of 285 individual *Nephrops* (caught by 5 fishers) were measured in the Skagerrak and 565 *Nephrops* (caught by 3 fishers) were measured in West-Norway. Of these, 2% and 6% were below the MLS of 40 mm CL in the Skagerrak and West-Norway, respectively. Variation in size was best described by region and sex, with both covariates showing statistically significant ($p < 0.05$) differences in CL (Supplementary Table S2[1]). *Nephrops* were smaller in West-Norway compared to the Skagerrak, and females were smaller than males (Fig. 5). Although the intraclass correlation for individual fishers was relatively low (0.14), there were relevant random effects linked to individual fishers (Supplementary Fig. S3[1]). This result indicates that there was variation in *Nephrops* catch size that was not explained by the covariates.

Catch composition: proportion of females and berried females

From a total of 813 registered fishing trips, the 29 citizen scientists provided information on the sex of all *Nephrops* caught on 481 fishing trips. Of all *Nephrops* that were sex-determined, a total of 5025 were females and 8071 were males. For 475 fishing trips,

Fig. 3. Mean landings of *Nephrops* per boat trip (lines) and corresponding 95% confidence intervals (shaded areas) per gear type between 2005 and 2020 for the three major *Nephrops* fishing areas along the Norwegian coast. Data include landings per trip registered in the sales notes of all boats in each year with more than one trip and more than 100 kg total landings per year. Only mean landings per boat trip of region–year combinations with more than one active boat are shown. [Colour online.]

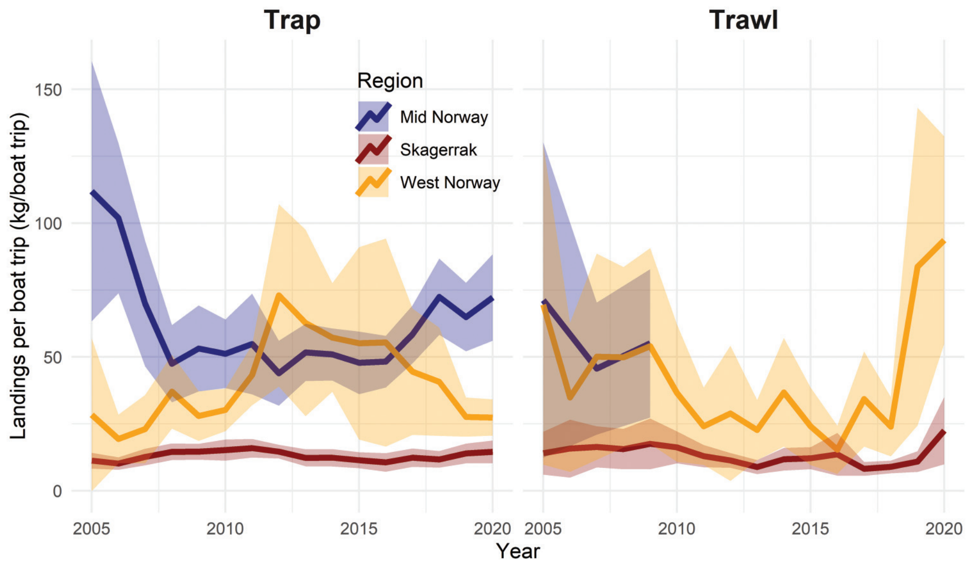
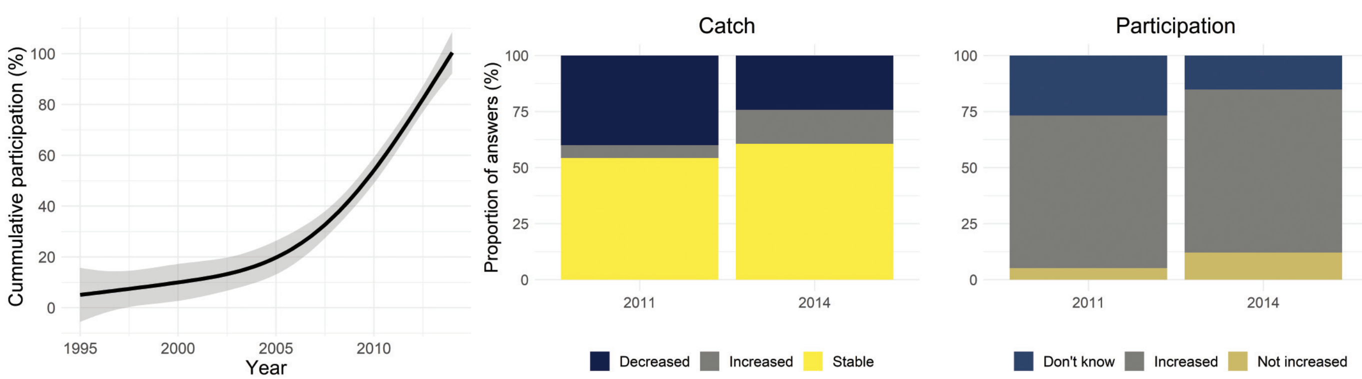


Fig. 4. Cumulative participation (left) in the *Nephrops* fishery among the survey participants in 2014 (n = 34), and their perceptions in 2011 and 2014 of how the catches (middle) and participation in the fishery (right) had changed over the preceding 5 years. Cumulative partipation is represented by a smoothed curve (GAM). The questions about how catches and participation had changed were as follows: (1) Did the catches increase, decrease, or remain stable over the past 5 years? (2) Do you agree that participation in the fishery has increased in the past five years? Results are shown as the proportion of total answers provided. [Colour online.]



information on whether berried females were caught was provided. On average, the proportion of females in the catch was higher in the Skagerrak (45%) than in West-Norway (27%), with the highest proportions (56% and 37%, respectively) in the third quarter. Similarly, the proportion of berried females was higher in the Skagerrak (21% of all females) than in West-Norway (9%) across all fishing trips and showed a seasonal pattern towards an increased proportion in the fourth quarter (33% and 20% of all females, respectively). However, there was substantial variation among fishing trips and, notably, in the average sex ratio and proportion of berried females reported by individual fishers. Model selection confirmed these observed patterns. We found that models reduced to region and season as fixed effects explained the proportions of females and berried females best (Supplementary Tables S3 and S4[1]), together with variation linked to individual fishers as a random effect (Supplementary Figs. S4 and S5[1]).

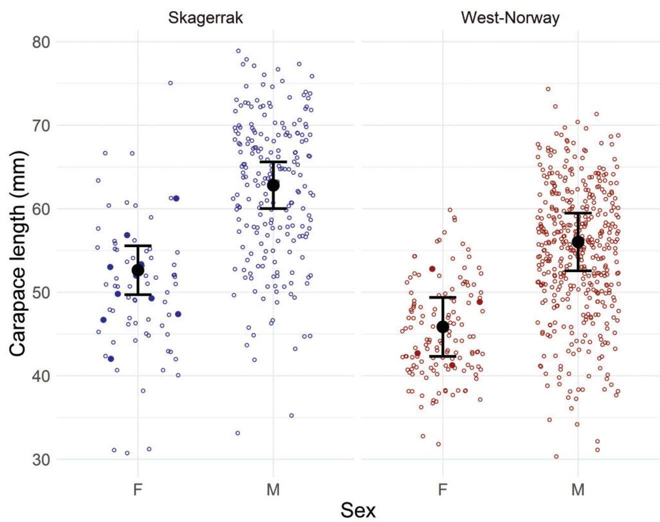
For the proportion of females, post-hoc pairwise comparisons showed only a marginally significant ($p < 0.07$) difference between regions, and a statistically significant ($p < 0.05$) difference between the second and third quarters. The low level of significance was linked to the large amount of variation in the data, especially in West-Norway, resulting in wide confidence intervals (Fig. 6). The conditional ICC was 0.63, confirming a substantial within-fisher correlation in observations.

Although the proportion of berried females in West-Norway tended to be lower than in Skagerrak (Fig. 6), post-hoc pairwise comparison showed that the effect was not statistically significant. The proportion of berried females was significantly ($p < 0.01$) elevated in the fourth quarter compared to the three other quarters. In contrast to the sex ratio, comparatively little variation was linked to the individual fishers, as indicated by a conditional ICC of 0.18.

Catch rates

For the citizen scientist fishers, catches and catches per trap day were clearly higher in West-Norway, with a mean of 42.5 *Nephrops* per trip and 0.57 *Nephrops* per trap day, compared to 17.5

Fig. 5. Size composition of recreational catches by region and sex, measured as carapace length. Shown are the means and 95% confidence intervals (black dots and error bars) estimated by a linear mixed-effect model, and each *Nephrops* caught in the Skagerrak (blue, left) or West-Norway (red, right). Full circles indicate berried females while empty circles are females without eggs or males. Individual data points are jittered for visualization purposes. [Colour online.]



and 0.21, respectively, in the Skagerrak. Our statistical analysis (Supplementary Table S5[1]) confirmed that catch rates were significantly ($p < 0.001$) different between the two regions, with a 3.29 times higher catch rate in West-Norway compared to the Skagerrak after accounting for the year, season, number of traps, soak time, and individual fisher effects (Supplementary Fig. S6[1]).

The number of traps and soak time showed significantly ($p < 0.01$) positive relationships with catches (Fig. 7). In both cases, a loglinear relationship between the continuous variables and the catch rate described the data best, reflecting the diminishing return of additional traps or days. However, the effect of the number of traps was much stronger than the effect of soak time and showed a clear increase up to the maximum observed number of traps (80). On the other hand, the effect of soak time levelled off after ∼5 days and remained essentially flat after ∼10 days. The uncertainty was higher for larger trap numbers or longer soak times due to the low number of registrations; for example, only one fisher used more than 20 traps and only 18 fishing trips lasted longer than 15 days. In addition, a substantial amount of variation was linked to the individual fisher (conditional ICC = 0.34), but without any spatial pattern.

There was relatively little variation over time in the catch rates of recreational fishers, both between and within years. Nevertheless, both year and season (quarters) were selected as statistically significant covariates in the final model explaining total catches, with stronger seasonal effects (Supplementary Fig. S7[1]). Most notably, the first quarter had significantly ($p < 0.05$) higher catches compared to the other three quarters. Among the years, 2012 showed slightly elevated catches compared to the other two years, with a significant contrast to 2013 but not 2014. The latter may be explained by the larger uncertainty in 2014 due to relatively limited data, with only 10% of the total registrations from that year.

Comparison between commercial and recreational catch rates

When comparing the predicted catch rates (landings per boat trip) from commercial trap landings in 2012–2014 with the predicted catch rates from recreational data, we found almost identical ratios for the Skagerrak and West-Norway (Fig. 8). Commercial catch rates were best explained by a model that included region, season, and year as fixed effects (Supplementary Table S6[1]) and individual fishing vessel as a random effect (Supplementary Fig. S8[1]). The ratio between predicted means for Skagerrak and West-Norway was 3.35, almost identical to the ratio of 3.29 found for recreational data. Catch rates from Mid-Norway were minimally lower than in West-Norway, but a post-hoc comparison showed no statistically significant contrast. This finding confirms that the catch rates were very similar during this period, as suggested by the mean landings per boat trip (Fig. 3). The commercial catch rates followed the same pattern as the recreational catch rates for year and season. We found a slight decrease in catch rate from 2012 to 2014 and a relatively clear, statistically significant seasonal pattern, with the highest catch rates in the first quarter and the lowest rates in the third quarter, comparable to that observed for the recreational fishers.

Discussion

Data limitations are a key challenge for stock assessment and, thus, sustainable fisheries management (Costello et al. 2012). In addition to limitations in data quantity or quality, this deficit includes a lack of historic baseline information (especially from the early stages of a fishery), and insufficient redundancy in data series to allow for cross-validation. Here, we show how surveys and self-reported data collected by volunteers in a citizen science project involving non-commercial shellfish fishers provide important baseline information from the onset of a *Nephrops* trap fishery in Norway. The results represent the first comprehensive overview of the regional stock composition, and confirm that readily available landings data may be a suitable proxy for changes in catch rate over time. These insights are valuable stepping stones towards an analytical stock assessment of an unassessed and largely unregulated stock.

The shift in gear composition in the Norwegian *Nephrops* fishery was the result of a combination of trawling restrictions in inshore areas (Søvik et al. 2017) and increasing demand for high-quality, live shellfish. Although the regulative changes were clearly an initial trigger for the emergence of the trap fishery, continued growth of the fishery over the past decade has likely been driven by changes in consumer attitude and economic incentives. Economic incentives linked to the size and quality of the catch are common in other fisheries (Zimmermann and Heino 2013) and have implications for management strategies (Zimmermann et al. 2011). Although *Nephrops* was largely seen as a bycatch species of the shrimp fishery in the past, public perception has aligned itself in recent years with international preferences for *Nephrops* as a high-value delicacy (Ungfors et al. 2013). Our interview survey reflects the past attitude through a clear difference between the interest of recreational fishers in *Nephrops* compared to European lobster and brown crab, two fisheries with a much longer tradition in Norway that are mostly targeted by the same recreational fishers (F. Zimmermann, unpublished data). This underscores the fact that fisheries, and thus fishing pressure on species, can change drastically in a relatively short timeframe in response to policies, economic incentives, consumer attitudes, new technologies, or a combination thereof.

Throughout its range, *Nephrops* has mostly been fished with bottom trawl, a gear with substantial impacts on bottom habitats as well as high rates of bycatch and discard (ICES 2021). Exemptions from landing obligations have been sought and, in some cases, granted for several *Nephrops* fisheries based on evidence of discard survival (Fox et al. 2020; Mérillet et al. 2018). Although empirical evidence is limited, trap fishing for *Nephrops* likely reduces bycatch and discard rates (Jansson 2008) and increases discard survival (Valentinsson and Nilsson 2015) due to better selectivity and less harmful handling. The shift from a trawl- to a trap-dominated *Nephrops* fishery in Norway has, therefore, improved

Fig. 6. Proportion of females of total catch (left) and proportion of berried females (right) in recreational catches. Shown are means and 95% confidence intervals (black dots and error bars) predicted by a linear mixed-effect model, and each *Nephrops* caught in the Skagerrak (blue) or West-Norway (red). Individual data points are jittered for visualization purposes. [Colour online.]

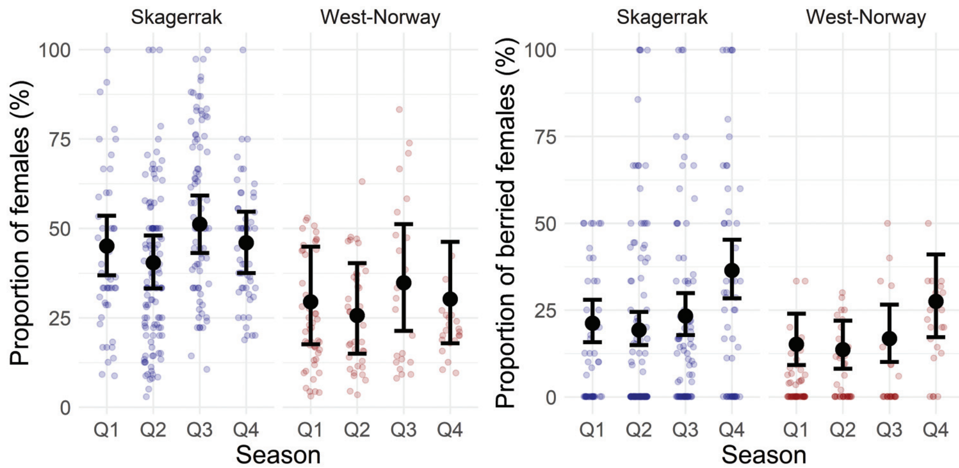
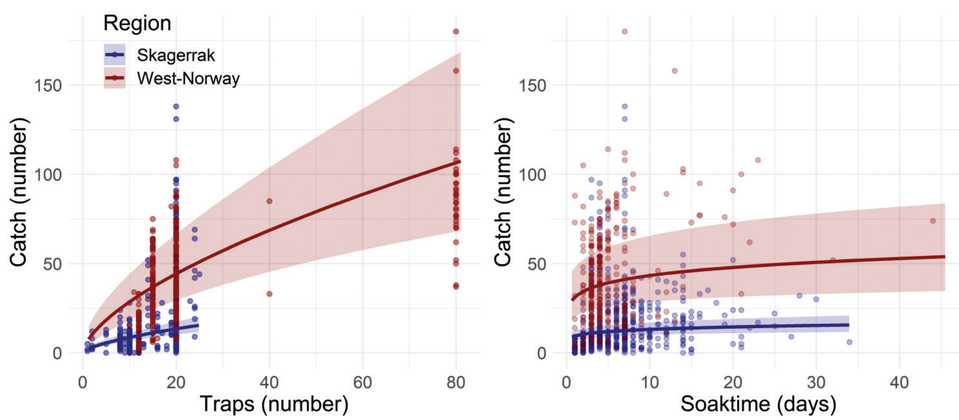


Fig. 7. Relationship between the number of *Nephrops* caught by recreational fishers and number of traps used (left) and the soak time (right) by region. Dots represent individual fishing trips, and lines and shaded areas are the means and 95% confidence intervals, respectively, predicted by the selected linear mixed-effect model. [Colour online.]



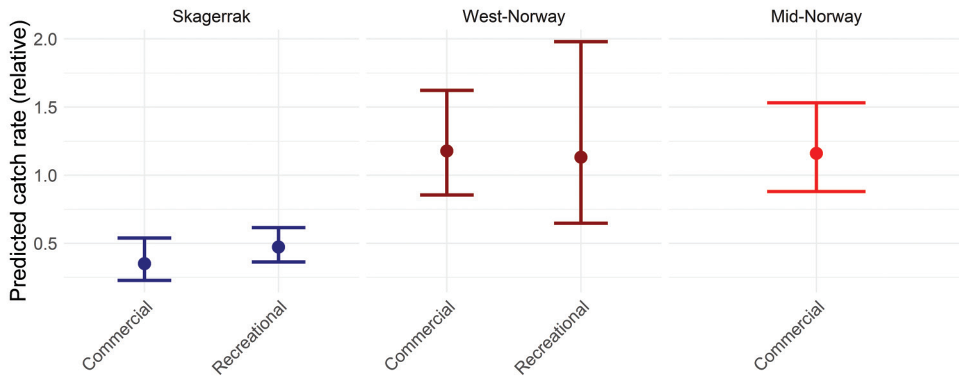
the sustainability of the fishery, and reduced impacts on coastal ecosystems. Despite the benefits of trap fishing, the expansion in commercial and non-commercial fishing activity in the absence of any regulation beyond minimum landing size remains a cause for concern. In addition, traps are often left permanently at sea and cover large areas, causing user conflicts and ghost fishing when lost (Kleiven et al. 2021; Macfadyen et al. 2009).

Most stock assessment methods rely on relative indices of abundance that are often based on fisheries data, which are available for most fish stocks (Maunder 2001). Although catch-only methods for assessing and managing fish stocks exist (Pons et al. 2020), they tend to perform poorly (Branch et al. 2011; Carruthers et al. 2014; Free et al. 2020). Therefore, a relative index of abundance from fisheries data can substantially increase the number of applicable assessment methods and quality of output. Our results revealed that standardized landings per boat trip from the Norwegian *Nephrops* fishery may reflect relative changes in the stock size, and thus provide an abundance index. This is a valuable conclusion because over the past decade, *Nephrops* in Norway has primarily been harvested by a small-scale trap fishery with limited reporting requirements, resulting in low-resolution landings data that lack more detailed effort information. In addition, landings data include the entire period encompassing the emergence and expansion of the trap fishery, providing a historic reference when reporting requirements are improved in the future. Because data collection often starts when a fishery is already mature or depleted, this historic perspective on long-term changes in fish stocks and ecosystems is often unavailable. Constructing indices that include the early stages of a fishery can therefore help to prevent a biased perception due to shifting baselines (Pauly 1995; Pinnegar and Engelhard 2008).

Our study showed that the trap fishery for *Nephrops* emerged relatively recently, gaining traction after 2010 to become the main source of *Nephrops* landings in Norway. Although the survey represents a limited snapshot of active recreational fishers in 2011 and 2014, the results suggest a clear correspondence between increased participation in the non-commercial fishery and commercial landings. There is strong overlap in Norwegian coastal fisheries among recreational, semi-subsistence, and commercial fishing (Aas and Kaltenborn 1995; Liu et al. 2019), and non-commercial activities may subsequently evolve into commercial ones given the right economic incentives. Thus, the shift towards a trap fishery on *Nephrops* has likely been facilitated by the increase in recreational trap fishing, which subsequently aligned fishing strategies between commercial and non-commercial fishing and increased the impact of non-commercial fishing on the *Nephrops* stock.

The *Nephrops* fishery in Norway provides a case study of how recreational fishing can become a major source of fishing mortality, while evading quantification because traditional monitoring

Fig. 8. Predicted catch rate (marginal effect) by region estimated by linear mixed-effect models fitted to commercial landings and recreational catch data, standardized to the respective mean landings and mean catches. Commercial catch rates were based on landings per boat trip of a subsample with high and consistent activity (vessels active in all years between 2012 and 2014, with minimum of 1 t of annual landings). Shown are the mean predicted catch rates (dot) and 95% confidence intervals (error bars). [Colour online.]



efforts do not capture non-commercial fishing activities. Given the impact of non-commercial fishing on other coastal shellfish species (Kleiven et al. 2012), non-commercial landings of *Nephrops* are likely of a magnitude comparable to commercial landings. The Norwegian *Nephrops* fishery therefore resembles a range of finfish and shellfish stocks in other regions with substantial non-commercial removals (Coleman et al. 2004; Herfaut et al. 2013; Radford et al. 2018). In a stock with a relevant share of non-commercial fishing, including information on these fishing activities in stock assessment has been recommended (Hyder et al. 2018; McPhee et al. 2002) to improve the accuracy of assessments and avoid biases. Because commonly used assessment models scale stock size with catches, significant unregistered catches will result in an underestimation of stock size. Furthermore, recreational fishing may target different components of a stock than commercial fishers, resulting in a different selectivity. Therefore, including non-commercial fishing in stock assessment may not only provide a complete account of total catches, but also a more accurate picture of how fishing mortality is distributed across size classes, areas, seasons, etc. To achieve an implementation in stock assessment, required data could be collected through reporting mandates or observer schemes, such as those used in commercial fisheries. However, the characteristics of recreational fishing have made the implementation and enforcement of traditional data collection programs challenging. Therefore, despite the potential benefits, recreational fishing data have rarely been used in stock assessment, except in a few cases (ICES 2021). Exceptions include seabass around the British Isles (recreational removals, including post-release mortality estimated within the assessment model through a survey-estimated fishing mortality multiplier) and western Baltic cod (recreational catches reported by Germany, Denmark, and Sweden included in total catches in stock assessment and management advice).

The collection and reporting of data by volunteer citizen scientists has been proposed as a cost-effective approach to increase data availability for stock assessment and management, supplementing or replacing costly and time-consuming data collection programs (Fairclough et al. 2014; Fulton et al. 2019). Typically associated with fisheries-independent data, the collection of fisheries-dependent data through observer programs can also bind a substantial amount of resources, most notably in smaller-scale fisheries with many active fishers but a limited total value. Although the costs and benefits of data collection are rarely quantified (Bentley and Stokes 2009), resource limitations often restrict the expansion of data collection programs to fisheries segments that are difficult to survey, such as recreational or semi-subsistence fishers. In Norway, no licenses or registrations are required for non-commercial fishers in most cases, preventing a comprehensive overview of fishing activity or reporting obligations. Currently, the only exception is an obligatory license for recreational European lobster fishing, which was recently introduced and led to a cost-effective data collection framework (Kleiven et al. 2019). In absence of mandates, well-designed citizen science projects may be suitable for filling data gaps and providing useful information (Gundelund et al. 2020; Hyder et al. 2015). Here, we showed that even a citizen science project with a modest scope can contribute relevant information for establishing a stock assessment in a data-limited situation. Because of the limited duration of and participation in the project, it remains unclear whether non-commercial and commercial fishing remained comparable during the subsequent development of the fishery. The results nevertheless underscore the potential value of self-reported data for monitoring effort and, thus, the need for future data collection through voluntary citizen science projects in the absence of more stringent reporting requirements for non-commercial fishing.

In conclusion, collecting data from a new fishery in its infancy provides an opportunity for the establishment of baseline information for future monitoring and for informing stock assessment. Here, we showed how, despite its limited scope, a citizen science project with non-commercial fishers provided useful information on the biology, composition, and catch rates of a *Nephrops* stock that would not have been available otherwise and allowed us to cross-validate a standardized index of catch efficiency as a potential proxy for abundance. These results incentivize continued data collection and monitoring efforts as the basis for future stock assessment and management advice.

Author contributions

FZ, AK and GS designed and wrote the study, MO and AK collected the data, FZ conducted the analysis, all authors read and edited the text.

Acknowledgements

The authors thank all the fishers for participating in the survey and contributing data. The work was funded through Interreg IVA, Öresund-Kattegat-Skagerrak, European Regional Development Fund (www.interreg-oks.eu), project ØBJ-FISK – Economically sustainable growth in the *Nephrops* fishery in the KASK region (2012–2014), and Research Council of Norway (project 267808, "Marinforsk"). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. We thank two anonymous reviewers for their feedback.

References

Aas, Ø., and Kaltenborn, B. 1995. Consumptive orientation of anglers in Engerdal, Norway. Environ. Manage. **19**: 751–761. doi:10.1007/BF02471957.

Aguzzi, J., and Sardà, F. 2008. A history of recent advancements on *Nephrops norvegicus* behavioral and physiological rhythms. Rev. Fish Biol. Fish. **18**(2): 235–248. doi:10.1007/s11160-007-9071-9.

Anonymous. 2008. Lov om forvaltning av viltlevande marine ressursar In LOV-2008-06-06-37. Ministry of Trade, Industry and Fisheries.

Bates, D., Mächler, M., Bolker, B., and Walker, S. 2015. Fitting linear mixed-effects models using {lme4}. J. Stat. Soft. **67**(1): 1–48. doi:10.18637/jss.v067.i01.

Becker, R.A., and Wilks, A.R. 1995. Constructing a geographical database. AT\&T Bell Laboratories Statistics Research Report [95.2].

Bentley, N., and Stokes, K. 2009. Moving fisheries from data-poor to data-sufficient: evaluating the costs of management versus the benefits of management. Mar. Coast. Fish. **1**(1): 378–390. doi:10.1577/C08-045.1.

Branch, T.A., Jensen, O.P., Ricard, D., Ye, Y., and Hilborn, R. 2011. Contrasting global trends in marine fishery status obtained from catches and from stock assessments. Conserv Biol. **25**(4): 777–786. doi:10.1111/j.1523-1739.2011.01687.x. PMID:21535149.

Brooks, M., Kristensen, K., van Benthem, K., Magnusson, A., Berg, C.W., Nielsen, A., et al. 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R J. **9**(2): 378–400. doi:10.32614/RJ-2017-066.

Carruthers, T.R., Punt, A.E., Walters, C.J., MacCall, A., McAllister, M.K., Dick, E.J., and Cope, J. 2014. Evaluating methods for setting catch limits in data-limited fisheries. Fish. Res. **153**: 48–68. doi:10.1016/j.fishres.2013.12.014.

Coleman, F.C., Figueira, W.F., Ueland, J.S., and Crowder, L.B. 2004. The impact of United States recreational fisheries on marine fish populations. Science, **305**(5692): 1958–1960. doi:10.1126/science.1100397. PMID:15331771.

Costello, C., Ovando, D., Hilborn, R., Gaines, S.D., Deschenes, O., and Lester, S.E. 2012. Status and solutions for the world's unassessed fisheries. Science, **338** (6106): 517–520. doi:10.1126/science.1223389. PMID:23019613.

Fairclough, D.V., Brown, J.I., Carlish, B.J., Crisafulli, B.M., and Keay, I.S. 2014. Breathing life into fisheries stock assessments with citizen science. Sci. Rep. **4**(1): 7249. doi:10.1038/srep07249. PMID:25431103.

FAO. 2021. Global Production Statistics 1950–2018. Available from http://www.fao.org/fishery/statistics/global-production/ [Accessed 29 March 2021].

Farmer, A. 1975. Synopsis of biological data on the Norway lobster *Nephrops norvegicus* (Linnaeus, 1758). FAO Fisheries Synopses (FAO) No. 112.

Fox, C.J., Albalat, A., Valentinsson, D., Nilsson, H.C., Armstrong, F., Randall, P., and Catchpole, T. 2020. Survival rates for *Nephrops norvegicus* discarded from Northern European trawl fisheries. ICES J. Mar. Sci. **77**(5): 1698–1710. doi:10.1093/icesjms/fsaa037.

Free, C.M., Jensen, O.P., Anderson, S.C., Gutierrez, N.L., Kleisner, K.M., Longo, C., et al. 2020. Blood from a stone: performance of catch-only methods in estimating stock biomass status. Fish. Res. **223**: 105452. doi:10.1016/j.fishres.2019.105452.

Fulton, S., López-Sagástegui, C., Weaver, A.H., Fitzmaurice-Cahluni, F., Galindo, C., Fernández-Rivera Melo, F., et al. 2019. Untapped potential of citizen science in Mexican small-scale fisheries. Front. Mar. Sci. **6**: 517. doi:10.3389/fmars.2019.00517.

Gundelund, C., Arlinghaus, R., Baktoft, H., Hyder, K., Venturelli, P., and Skov, C. 2020. Insights into the users of a citizen science platform for collecting recreational fisheries data. Fish. Res. **229**: 105597. doi:10.1016/j.fishres.2020.105597.

Herfaut, J., Levrel, H., Thébaud, O., and Véron, G. 2013. The nationwide assessment of marine recreational fishing: a French example. Ocean Coast. Manage. **78**: 121–131. doi:10.1016/j.ocecoaman.2013.02.026.

Hughes, R.M. 2015. Recreational fisheries in the USA: economics, management strategies, and ecological threats. Fish. Sci. **81**(1): 1–9. doi:10.1007/s12562-014-0815-x.

Hyder, K., Townhill, B., Anderson, L.G., Delany, J., and Pinnegar, J.K. 2015. Can citizen science contribute to the evidence-base that underpins marine policy? Mar Pol. **59**: 112–120. doi:10.1016/j.marpol.2015.04.022.

Hurvich, C.M., and Tsai, C.-L. 1989. Regression and time series model selection in small samples. Biometrika. **76**(2): 297–307. doi:10.1093/biomet/76.2.297.

Hyder, K., Radford, Z., Prellezo, R., Weltersbach, M., Lewin, W.-C., Zarauz, L., et al. 2017. Research for PECH Committee-Marine recreational and semi-subsistence fishing-its value and its impact on fish stocks. European Parliament, Policy Department for Structural and Cohesion Policies, Brussels, Belgium.

Hyder, K., Weltersbach, M.S., Armstrong, M., Ferter, K., Townhill, B., Ahvonen, A., et al. 2018. Recreational sea fishing in Europe in a global context—Participation rates, fishing effort, expenditure, and implications for monitoring and assessment. Fish Fish. **19**(2): 225–243. doi:10.1111/faf.12251.

ICES. 2020. Working Group on the Assessment of Dermersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Scientific Reports. ICES, Copenhagen.

ICES. 2021. Workshop on the Inclusion of Discard Survival in Stock Assessments (WKSURVIVE). ICES Scientific Reports. ICES, Copenhagen.

Jansson, T. 2008. Discards in the Swedish creel fishery for *Nephrops norvegicus*. M.Sc., Gothenburg University.

Johnson, M.P., Lordan, C., and Power, A.M. 2013. Habitat and ecology of *Nephrops norvegicus*. *In* Advances in Marine Biology. *Edited by* M.L. Johnson and M.P. Johnson. Academic Press. pp. 27–63.

Kleiven, A.R., Olsen, E.M., and Vølstad, J.H. 2012. Total catch of a red-listed marine species is an order of magnitude higher than official data. PLoS ONE, **7**(2): e31216. doi:10.1371/journal.pone.0031216. PMID:22363583.

Kleiven, A.R., Fernandez-Chacon, A., Nordahl, J.-H., Moland, E., Espeland, S.H., Knutsen, H., and Olsen, E.M. 2016. Harvest pressure on coastal Atlantic cod (*Gadus morhua*) from recreational fishing relative to commercial fishing assessed from tag-recovery data. PLoS ONE, **11**(3): e0149595. doi:10.1371/journal.pone.0149595. PMID:26959371.

Kleiven, A.R., Lyle, J., Ferter, K., Espeland, S.H., Kleiven, P.J.N., Christensen, L., and Vølstad, J.H. 2019. Hummerfisket 2017 og 2018: Innsats og fangst. Rapport fra Havforskningen. Institute of Marine Research, Bergen, Norway.

Kleiven, A.R., Thorbjørnsen, S.H., and Aslaksen, T. 2021. Tiltak mot spøkelsesfiske i Raet nasjonalpark. Rapport fra Havforskningen. Institute of Marine Research, Bergen, Norway.

Lenth, R., Singmann, H., Love, J., Buerkner, P., and Herve, M. 2021. Emmeans: estimated marginal means, aka least-squares means. Version 1.6.1. Available from https://CRAN.R-project.org/package=emmeans.

Liu, Y., Bailey, J.L., and Davidsen, J.G. 2019. Social–cultural ecosystem services of sea trout recreational fishing in Norway. Front. Mar. Sci. **6**: 178. doi:10.3389/fmars.2019.00178.

Macfadyen, G., Huntington, T., and Cappell, R. 2009. Abandoned, lost or otherwise discarded fishing gear. FAO Fisheries and Aquaculture Technical Paper 523.

Maunder, M.N. 2001. A general framework for integrating the standardization of catch per unit of effort into stock assessment models. Can. J. Fish. Aquat. Sci. **58**(4): 795–803. doi:10.1139/f01-029.

McPhee, D., Leadbitter, D., and Skilleter, G. 2002. Swallowing the bait: is recreational fishing in Australia ecologically sustainable? Pac. Conserv. Biol. **8**(1): 40–51. doi:10.1071/PC020040.

Mérillet, L., Méhault, S., Rimaud, T., Piton, C., Morandeau, F., Morfin, M., and Kopp, D. 2018. Survivability of discarded Norway lobster in the bottom trawl fishery of the Bay of Biscay. Fish. Res. **198**: 24–30. doi:10.1016/j.fishres.2017.10.019.

Pauly, D. 1995. Anecdotes and the shifting baseline syndrome of fisheries. Trends Ecol. Evol. **10**(10): 430. doi:10.1016/S0169-5347(00)89171-5. PMID:21237093.

Pinnegar, J.K., and Engelhard, G.H. 2008. The 'shifting baseline' phenomenon: a global perspective. Rev. Fish Biol. Fish. **18**(1): 1–16. doi:10.1007/s11160-007-9058-6.

Pons, M., Cope, J.M., and Kell, L.T. 2020. Comparing performance of catch-based and length-based stock assessment methods in data-limited fisheries. Can. J. Fish. Aquat. Sci. **77**(6): 1026–1037. doi:10.1139/cjfas-2019-0276.

Powell, A., and Eriksson, S.P. 2013. Chapter 6: Reproduction – life cycle, larvae and larviculture. *In* Advances in Marine Biology. *Edited by* M.L. Johnson and M.P. Johnson. Academic Press. pp. 201–245.

R: Development Core Team. 2021. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Radford, Z., Hyder, K., Zarauz, L., Mugerza, E., Ferter, K., Prellezo, R., et al. 2018. The impact of marine recreational fishing on key fish stocks in European waters. PLoS ONE, **13**(9): e0201666. doi:10.1371/journal.pone.0201666. PMID:30208030.

Søvik, G., Furevik, D., Jørgensen, T., Bakke, S., Larssen, W.E., Thangstad, T., and Woll, A.K. 2017. The Norwegian Nephrops fishery — history, exploitation and management. *In* Sustainable Bio-resources: Management, Product Development and Raw Material Quality. Orkana Forlag, Stamsund, Norway.

Ungfors, A., Bell, E., Johnson, M.L., Cowing, D., Dobson, N.C., Bublitz, R., and Sandell, J. 2013. Chapter 7: Nephrops fisheries in European waters. *In* Advances in Marine Biology. *Edited by* M.L. Johnson and M.P. Johnson. Academic Press. pp. 247–314.

Valentinsson, D., and Nilsson, H.C. 2015. Effects of gear and season on discard survivability in three Swedish fisheries for Norway lobster (*Nephrops norvegicus*). Swed. Univ. Agric. Sci. **2**: 1–11.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L.D.A., François, R., et al. 2019. Welcome to the Tidyverse. J. Open Source Soft. **4**(43): 1686. doi:10.21105/joss.01686.

Zimmermann, F., and Heino, M. 2013. Is size-dependent pricing prevalent in fisheries? The case of Norwegian demersal and pelagic fisheries. ICES J. Mar. Sci. **70**(7): 1389–1395. doi:10.1093/icesjms/fst121.

Zimmermann, F., Heino, M., and Steinshamn, S.I. 2011. Does size matter? A bioeconomic perspective on optimal harvesting when price is size-dependent. Can. J. Fish. Aquat. Sci. **68**(9): 1651–1659. doi:10.1139/f2011-093.