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ARTICLE

Estimating Recreational and Commercial Fishing Effort for European Lobster *Homarus gammarus* by Strip Transect Sampling

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Abstract

Recreational fishing effort for coastal marine species can be significant but is often challenging to estimate. Here we present a case study where a probability-based strip transect survey is used to estimate effort in the Norwegian fishery for European lobster *Homarus gammarus*. This fishery is conducted by both recreational and commercial fishers, but reliable information on total fishing effort and total catch is lacking. In 2008, we conducted a strip transect sampling survey throughout the lobster fishing season in southern Norway to estimate the number of deployed lobster traps over time. Surface buoys marking lobster traps were counted along strip transects placed representatively in the survey area in five different weeks throughout the lobstering season. Calibration studies were conducted to standardize transect width and to estimate and adjust for detection rates of buoys along transect strips. Mean number of lobster traps per square kilometer and associated variance was estimated by a ratio estimator using bootstrapping, with transects as the primary sampling units. Poststratification of the counts by depth (by 10-m depth intervals) combined with geographical information systems mapping improved the precision of the estimated density of lobster traps and increased the effective sample size of transects by 22–44% per week. Estimated daily effort for the first week was 48.95 (SE = 3.11) traps/km^2, decreasing steadily to 5.96 (SE = 0.79) in the eighth (and last) week of the lobster season. Our study shows that lobster traps deployed by recreational fishers outnumber the ones deployed by commercial fishers, contributing to 65% of the total effort (number of traps) in the fishery. We show that strip transects are a suitable way to estimate effort in the Norwegian lobster fishery. We conclude that improved management efforts need to target recreational as well as commercial fishing activities in order to achieve effective management of the red-listed species.

Recently, recreational fishing and its impacts on marine resources have gained increased attention in the USA (Schroeder and Love 2002; Coleman et al. 2004), Australia (McPhee et al. 2002), and Portugal (Rangel and Erzini 2007) as well as globally (Cooke and Cowx 2004). It has been documented that for certain fish species, recreational catches exceed commercial catches

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(Coleman et al. 2004). Cooke and Cowx (2004) argue that a failure to recognize the potential effects of recreational fisheries could put ecologically and economically important resources at risk. A multitude of methods have been used worldwide to investigate effort and catch in recreational lobster fisheries, such as observation of changes in abundance, creel surveys, mail surveys, telephone surveys, diary surveys, and telephone diary surveys (Lyle et al. 2005). Strip transect surveys conducted using scuba gear, aircraft, and boats are widely used to estimate the abundance and biodiversity of wildlife (Thomas et al. 2002). In these surveys, each transect typically has a defined width. An important assumption is that all objects within the strip transect are observed, which can lead to the use of a narrow strip to minimize or avoid misdetection (Buckland et al. 2001). Calibration studies can be conducted to estimate detection rate and determine strip transect widths. Strip transect surveys can be an appropriate method to estimate fishing effort by counting surface buoys within selected transect lines. A benefit of transect surveys to count buoys attached to fixed gear is the ability to conduct reliable calibration studies to support the estimation of absolute number of standing gears in an area. To our knowledge, the use of strip transects to estimate fishing effort has not been described in the scientific literature.

Recreational fisheries for lobsters have been investigated in South Africa (Cockcroft and Mackenzie 1997), Australia (Lyle et al. 2005), and USA (Muller et al. 2000), and show that recreational fishing for lobster can be a significant part of the total landings. These studies were able to take advantage of license requirements in the respective lobster fisheries. While the commercial fishing sector is mostly registered and lands their catch at a limited number of locations, recreational fisheries are typically more diverse and dispersed, having different participation levels, numerous access points, and a large number of fishers (NRC 2006). The nature of recreational fishing makes representative and cost-effective data collection challenging.

People along the southern coast of Norway have been fishing European lobster *Homarus gammarus* for centuries. The fishery increased in the 1700s when the Dutch introduced traps to Norway and started exporting lobster to the European continent (Dannevig 1936). Until the 1950s, the reported annual commercial catch of lobster in Norway was one of the highest in Europe (NDF 2007). However, official landings and catch per unit effort (CPUE) have decreased steadily since the 1950s and are now at historically low levels (Pettersen et al. 2009). In 2006, European lobster in Norway was listed as "near threatened" in the national red list (Oug et al. 2006). New regulations were introduced prior to the 2008 lobster season. Additionally, four experimental lobster reserves were established in 2006 (Pettersen et al. 2009).

The lobster season in southeastern Norway lasts for 2 months (October–November). Traps are the only allowed fishing gear for catching lobster. Regulations, which also include minimum size, protection of egg bearing females and trap escape vents, are the same for both recreational and commercial fishers. However, commercial fishers are allowed to fish with up to 100 traps each, while the maximum number of traps for each recreational fisher is 10. While the main target species is lobster, these traps also catch edible crabs *Cancer pagurus*. The difference in the required size of escape vents for crab and lobster traps is the only factor that consistently would affect their respective catch efficiencies. In the 2008 season, commercial fishers were allowed to fish with an unlimited number of crab traps with no requirements on escape vents, while recreational fishers were required to have escape vents. In other words, a crab trap may be changed to a lobster trap by mounting two escape vents of 60 mm to the trap. There is no registry of recreational lobster fishers in Norway and no licensing requirements. Neither is the number of commercial lobster fishers known, since all registered commercial fishers with a registered boat are allowed to fish for lobster without informing the management authorities (open fishery). Although recreational fishing for lobster is popular in Norway, effort of recreational fishers has not been estimated and reported. Moreover, the official landings of lobster from the commercial fishing sector are potentially biased due to underreporting of catches. Since official catch statistics do not include recreational catches and is based on legally traded lobsters from the commercial sector, the total removals of lobster are likely to be underestimated. Estimates of effort are more challenging than in a fishery with license requirements for recreational fishers and quotas for commercial fishers, as, for example, southern rock lobster in Tasmania, Australia (Lyle et al. 2005). Since lobster can only be caught legally using one type of gear (traps), during a short season where the regulations are the same for commercial and recreational fishers, it is feasible to quantify a total effort in the legal fishery.

Here, we will present a strip transect survey method to estimate recreational and commercial effort in the Norwegian fishery for European lobster for the southwestern Skagerrak coast (Figure 1). In addition, our strip transect survey includes calibration of transect width and observation error as well as the use of depth stratification to increase the effective sample size for estimating effort.

METHODS

The southern coast of Norway was shaped by glacial scouring and includes small fjords and submerged or semisubmerged glacial moraines, making it a suitable lobster habitat. People live scattered along the coast and on islands, boats being docked on private properties and in small harbors. The two counties of Agder, with its main cities of Kristiansand (Vest-Agder) and Arendal (Aust-Agder), is situated in southeastern Norway on the Skagerrak coast (Figure 1). The study presented here covered all coastal sea areas of Agder except west of the south cape, Lindesnes (coastal baseline of 175 km). Seven coastal cities, with population sizes between 80,000 (Kristiansand) and 6,000 (Tvedestrand), are found in the study area. A complex archipelago measuring 1–4 km wide and containing approximately 1,900 islands is placed between the mainland and the deep Norwegian trench (Figure 1).

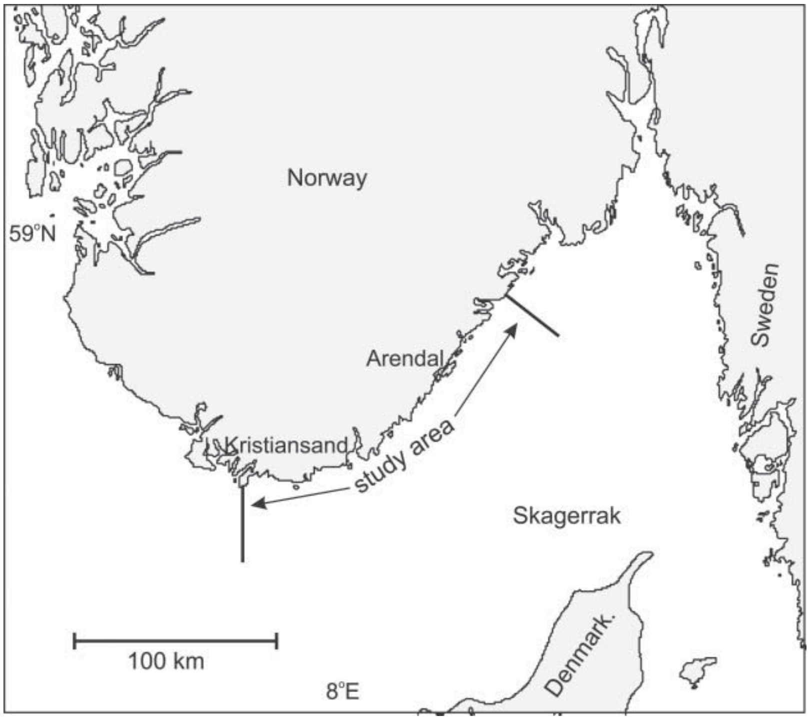

FIGURE 1. Map of the study area at the Norwegian south coast of Skagerrak. The study covered all coastal areas from 0 to 10–40 m in Agder, except west of the south cape, Lindesnes.

Design of transect survey.—The counties of Aust-Agder and Vest-Agder were surveyed by different field personnel. Our total target sampling effort was to count floating lobster buoys within 60 strip transects each week during the 2008 fishing season. We assumed that effort did not change significantly within each week and aimed at estimating weekly effort where transects could be conducted throughout the given week. Using the software MapSource, a systematic random sample of 100 transects perpendicular to the coastline were selected in each of the two areas (Aust-Agder and Vest-Agder to Lindesnes). A straight line was first drawn parallel to the coast on a low-resolution computerized map (BlueChart Atlantic version 2008 Tides and Marine Services) for each of the two bordering study areas. The starting point for the first transect in each study area was chosen randomly in the southern segment (random number for each study area). We then allocated 100 parallel transects perpendicular from the line at fixed distance (1.01 and 0.69 km for Aust-Agder and Vest-Agder, respectively) from the random starting point. These transects were divided into groups of 10, the aim being to conduct counts along three random transects within each group of then every survey period (weekly), totaling 60 transects/week. One randomly selected transect within each group was fixed for the whole survey season, while the other two were randomly selected and changed every survey period. During pilot surveys conducted in 2007, we found that 98% of the lobster traps were placed shallower than 40 m. To reduce cost, we therefore decided to end transects when the depth exceeded 40 m offshore, unless shallower areas were located further from shore, based on map studies.

The transect survey was conducted by a single researcher using a small, open 5-m boat for each of the two study areas. The field researchers were trained to estimate distances at sea in order to determine if a buoy were inside or outside the strip transect and to be consistent throughout the survey period. We aimed at a transect half-width (μ) of 70 m. However, it was not possible to determine accurately whether a buoy near the edge of transect was inside or outside the strip. We therefore conducted a calibration study to estimate the transect width and detectability (see below).

A stored Global Positioning System (GPS) position (way point) marked the start of each transect, and depth was recorded. Every buoy observed and defined as inside the strip transect by the researchers were counted. Every fifth observation was approached to record its GPS position, its depth, and the owners' registration as written on the buoy (random sample). Thus, we determined if the buoy belonged to a recreational or commercial fisher and its distance from the transect center line ($g[0]$). Based on the pilot study, we anticipated that the density of lobster traps were depth dependent. Within each transect, a GPS position was therefore recorded every time the boat crossed a new depth group ($\leq$10 m, $>$10 to $\leq$20 m, $>$20 to $\leq$30 m and $>$30 to $\leq$40 m) along the transect line. Counts of buoys were then allocated to different depth strata as observed by an onboard echo sounder at the transect center line.

The main study area was defined as the area within the 40-m depth. However, a small proportion of the buoys were registered deeper than 40 m. In order to test the potential bias of excluding areas deeper than 40 m in the estimate, we recorded the number of buoys observed within transect when $g(0)$ was deeper than 40 m and the plotted buoys (every fifth observation) recorded at depths deeper than 40 m.

Depth stratification.—In order to improve the precision of the transect estimates, we conducted a depth stratification by grouping observations according to four 10-m depth strata from 0- to 40-m depth. This method was tested against transects without depth strata in order to estimate the improved precision and effective sample size.

We estimated the total area of each depth stratum for the whole study area. This was mapped by interpolation, using the digital elevation model and bathymetric data ("marine primary data") from the Norwegian mapping authority. A grid with cell size of 10 × 10 m was generated. From this grid, the depth surface was then classified into four groups: $\leq$10 m (151.5 km^2), $>$10 to $\leq$20 m (116.6 km^2), $>$20 to $\leq$30 m (122.1 km^2), and $>$30 to $\leq$40 m (81.0 km^2). Total area between 0- and 40-m depth for the study area was 471.2 km^2.

Calibration of detectability and strip transect width.—A transect calibration study to estimate the mean transect width and buoy detectability was conducted after the 2008 field season. The calibration study was conducted within the same area and designed the same way as in the field study. Between 30 and 40 representative dummy buoys (diverse selection of buoys used in the lobster fishery) with rope and weight were placed along transects by independent field assistants within a maximum distance of 150 m from the transect line. The position of every buoy was recorded with a handheld GPS. The researchers then conducted a transect survey following the same protocol used in the field data collections. In the calibration experiment, the surveyor recorded each observed buoy with GPS when it was located at a 90° angle from the boat and recorded if it was inside or outside the strip transect. In this manner, we were able to estimate detection rate and errors in the defined transect width. Observations were analyzed, and the actual distance from the transect line to the buoy was measured in MapSource and compared with the field surveyors observation. Eight transects were randomly selected from 23 designed transects. Each transect was run independently by the same two researchers that conducted the field survey, totaling 16 transect runs and 530 potential buoy observations over 5 d. Transects covered both inshore and offshore areas. We were able to distinguish four types of observations and errors in order to calibrate for the true number of buoys inside transect (CAL), expressed as

$$\mathrm{CAL} = \frac{a + c + d}{a + b}, \tag{1}$$

taking into account buoys correctly defined as inside (a), buoys incorrectly defined as inside (b), buoys incorrectly defined as outside (c), and undetected buoys inside the transect (d). In order to test if the results from the calibration study were representative for the field survey, we compared the distance distribution of the random selection of buoys from field with those of the calibration study.

Converting counts of buoys to number of lobster traps.—Buoy observations in the strip transect had to be converted to traps, and the relationship between lobster gear and other fishing gear was estimated. Phone interviews with recreational fishers were conducted throughout the survey period. Individuals were selected randomly based on the fisher registrations recorded in the field sampling. Questions were asked to obtain the following information: number of traps in use, use of other types of fishing gear, and number of traps per buoy (if set as a chain of traps with a single surface buoy). All commercial fishers detected in the field received a mail questionnaire to report type of fishing gear used in the lobster season and number of traps per buoy as well as the number of buoys used for other types of fishing gear.

Based on the offsite interviews, we collected information on how many pots were represented by each buoy for both commercial and recreational fishers. In order to transform number of buoys to number of traps, the formula we used for each transect was

$$\mathrm{Traps}/km^2 = \mathrm{CAL} \cdot \mathrm{buoys}/km^2 \cdot \Bigg(R_t \cdot Rw_n + C_t \cdot Cw_n + \left(\frac{R_t \cdot Rw_n + C_t \cdot Cw_n}{Rw_n + Cw_n} \right) \cdot Uw_n \Bigg), \tag{2}$$

where CAL is the transect calibration factor, R_t and C_t are the number of traps per buoy for recreational and commercial fishers, respectively, and Rw_n, Cw_n, and Uw_n are the proportion of buoys belonging to recreational, commercial, and unknown fishers, respectively, for a given week, n. We assume that the observed proportional relationship between recreational and commercial buoys is representative of the unknown buoys for the given week.

Transect estimates of trap density.—If we let χ_i be the estimated number of lobster traps within transect strip i and M_i be the area of the transect strip, a simple estimator for the mean number of lobster traps per square kilometer is then (Cochran 1977:250)

$$\overline{\chi}_i = \frac{\sum_i^n \chi_i}{\sum_i^n \mathrm{M}_i} \tag{3}$$

where n is the number of transects in the sample. The variance of this ratio estimate was estimated by bootstrapping (Efron 1982) from the primary sample of transects.

We also derived an estimate of the mean density of lobster traps from the depth surface in the survey area. Using

MapSource, each transect was divided into depth groups based on GPS plots from field observations. If we let χ_{ij} be the number of observations in each depth group j (depth: $\leq$10 m, $>$10 to $\leq$20 m, $>$20 to $\leq$30 m, and $>$30 to $\leq$40 m) inside transect i and M_{ij} be the area of the portion of transect i in depth group j, an estimator for the mean number of lobster traps per square kilometer in depth group j is then

$$\overline{\chi}_j = \frac{\sum_{i=1}^{n} \chi_{ij}}{\sum_{i=1}^{n} M_{ij}} \tag{4}$$

The overall mean density of lobster traps in the survey area (across depth groups) was estimated by poststratification using the postStratify function provided within the R package "survey" (Lumley 2004), and the variance was estimated by bootstrapping (Canty and Davidson 1999) using 1,000 resamples of size n. The ratio estimator was used since strip transect area size (size of the PSUs) varied randomly.

In order to analyze the efficacy of including depth groups in the estimate, we compared the precision in estimates of mean density based on post stratification by depth-classes with the standard estimates. The efficiency of the poststratification was evaluated by comparing the respective variance of the estimated mean density of lobster traps (A) with the variance obtained by the standard estimator based on random transects (B). The "design effect" (Deff) is defined as the ratio of the two variances (see Kish 1965, 1995, 2003), given as

$$\text{Deff} = \frac{\text{var}(\overline{x})_B}{\text{var}(\overline{x})_A}. \tag{5}$$

The "effective sample size" (ESS) for estimating the mean density of lobster traps by poststratification is defined as n/Deff, where n is the number of random transects. Hence, ESS is the expected number of transects selected by simple random sampling and with no stratification that would be required to achieve the same precision as obtained using the poststratification by depth. Kish (1995) and Potthoff et al. (1992) provide a general discussion on the calculation of design effects and effective sample sizes.

RESULTS

Three weeks (4, 5, and 7) were not covered in the survey. Due to weather conditions and security considerations, some transects, or part of transects, had to be excluded at certain times for the surveyed weeks. Fifty-seven transects were covered in week 1, 59 in week 2, 33 in week 3, 56 in week 5, and 59 in week 8.

Calibration Study

While median wind strength in the survey period (all days in which transects were run) was 5.9 m/s, the median wind strength during the calibration study was 4.3 m/s. The effective strip transect half-width (μ) was set as 70 m, which is the distance from the transect line for which as many objects are detected beyond μ as are missed within μ (Thomas et al. 2002). In our survey, μ is the closest distance group (10-m intervals) from the line where as many objects were defined inside as outside (Figure 2). There were minor differences in effective strip size between the two independent researchers in the calibration study (Figure 3). Observer A had a detection rate of 0.92 within μ, while for observer B the detection rate was 0.95. The results

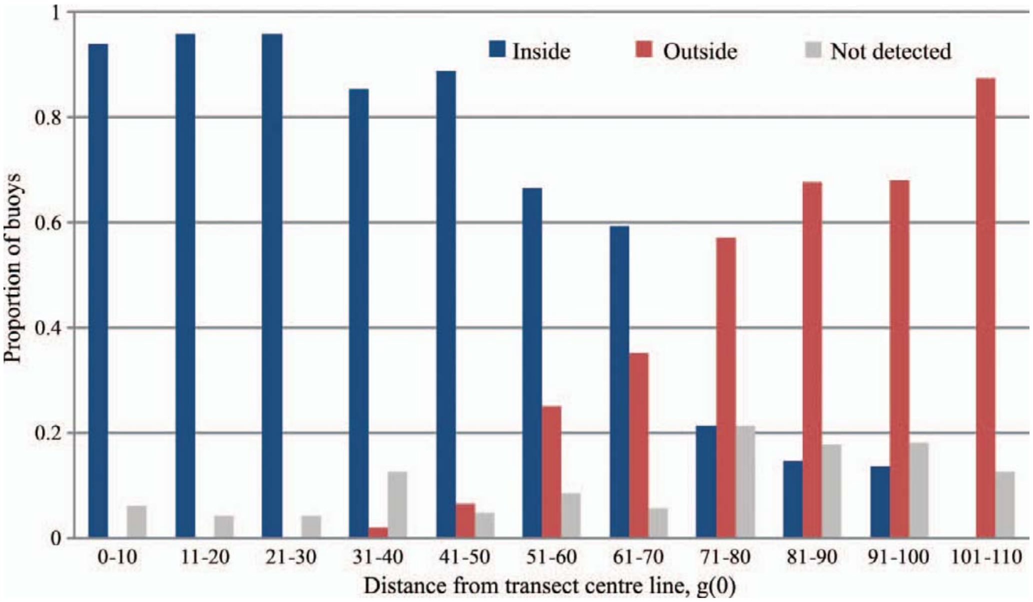

FIGURE 2. Results from transect calibration experiment as proportion of all buoys within each distance group (10 m), observed and defined as inside, observed and defined as outside, and not detected.

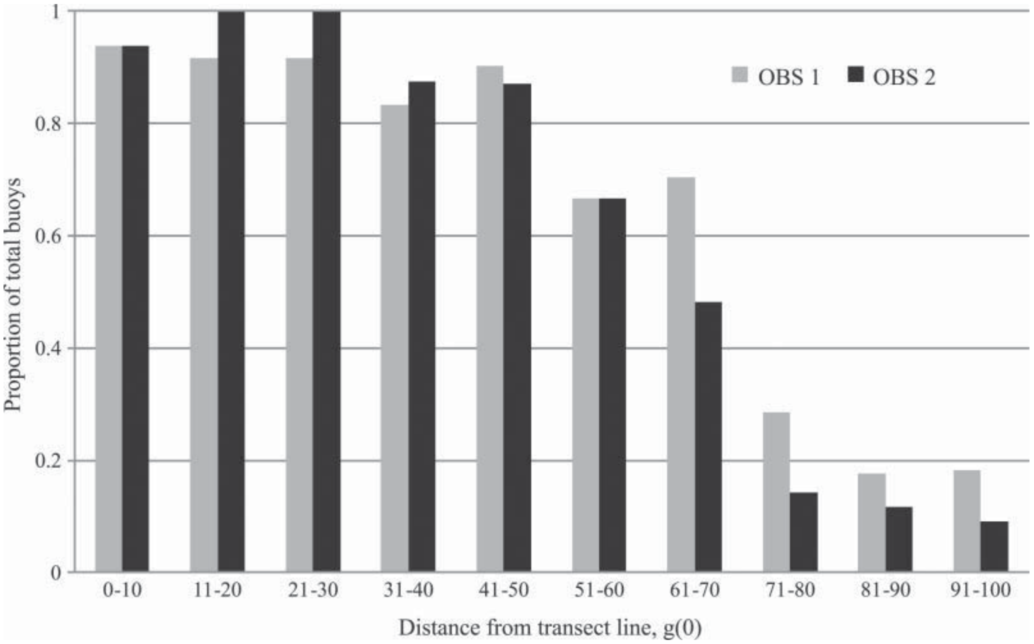

FIGURE 3. Comparison of buoys observed and defined as inside for the two observers (OBS 1 and 2) in the calibration study given as proportion of all potential buoys in each distance group (10 m), Between 0 and 30 m, nearly all were detected and defined as inside, decreasing with the distance from the transect line, *g*(0). When *g*(0) was more than 70 m from the transect line, most of the buoys were defined as outside or not detected.

from the two independent researchers were combined and used in the estimates.

A comparison of the random sample of buoys recorded in the field and the observations in the calibration study indicates that the calibration study is representative for the field conditions (Figure 4). There are some more observations close to transect line in the field than in the calibration study and a higher observation rate between 50 and 70 m for the calibration study. Mean distance of the random buoys plotted in field ranged from 33.4 to 37.5 m from transect center line for the five different weeks, indicating that transect width did not change considerably between weeks.

From the calibration study, we note that (1) 78.1% of the buoys were observed and correctly defined as inside, (2) 6.6%

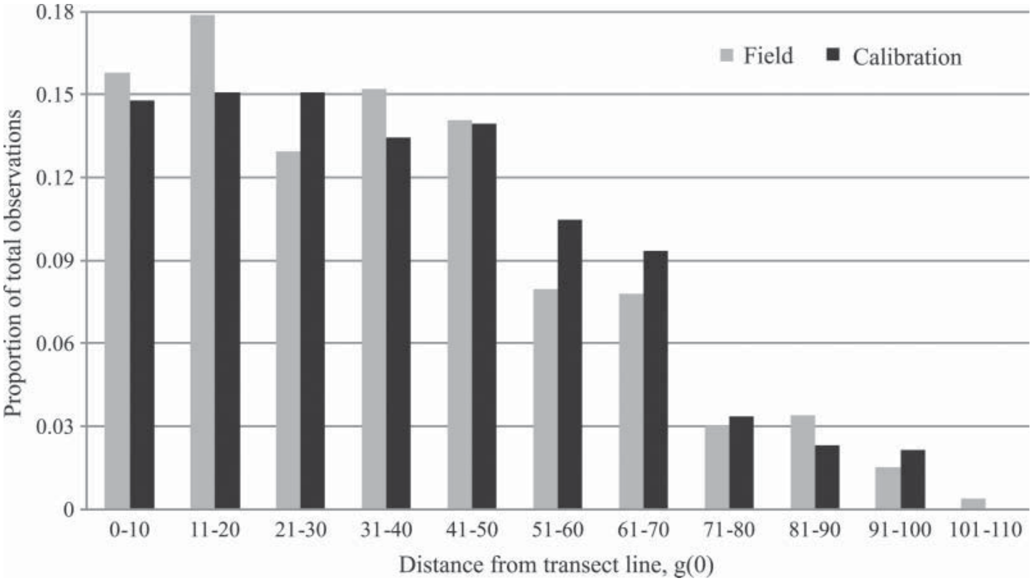

FIGURE 4. The observed buoys defined as inside the strip transect and their distance from transect center line, *g*(0), in meters from the calibration study and the random sample from field observations; given as a proportion of total observations.

were incorrectly defined as inside, and (3) 9.2% were incorrectly defined as outside. In addition, (4) 6% of the buoys were undetected (see equation 1). The transect calibration factor (CAL) was estimated to be 1.10.

Off-Site Interviews

Based on a random selection of recreational fishers interviewed by phone ($n = 61$, 5% rejection rate) throughout the lobster season, we estimated that these fishers use 1.069 (SE = 0.027) traps per buoy on average. Based on the questionnaire received from commercial fishers ($n = 25$, 42% response rate), we estimated that commercial fishers fished with a mean number of traps per buoy of 1.234 (SE = 0.081).

The same fishers also reported other type of standing fishing gear (nets and traps) used in the same period and area, targeting other species than lobster. For recreational and commercial fishers the proportion of other gear was 0.055 and 0.216, respectively. In week 2, we recorded gears other than lobster trap buoys counted in transects. The proportion of other gear observed in field was 0.075, while the off-site interviews indicated a total proportion of 0.095.

Commercial fishers informed us that 29% of their traps were crab traps. We assumed that lobsters caught in crab traps within the lobster season were kept by the commercial fishers.

Recreational fishers dominated the fishery in the beginning of the season, accounting for 66–70% of all the traps during the first 3 weeks of the season. Later in the season, the proportion of traps increased for commercial fishers, indicating that commercial fishers fished for a longer time of the season than recreational fishers (Figure 5). A small proportion (4%) of the buoys was either not marked or had unreadable markings, and we could therefore not determine if these belonged to recreational or commercial fishers.

Transect Estimates of Trap Density

Throughout the 2-month lobstering season, we were able to map effort in a subset of 5 weeks. In week 3, only half ($n = 33$) of transects were covered due to difficult weather conditions. Most of the traps were observed between a depth of more than 10 m and 30 m or less (Figure 6). We estimated proportion of buoys deeper than 40 m to be 0.028. Weeks 4, 6, and 7 were not surveyed. The mean effort for these weeks was estimated as the mean of the week before and after for week 4, and the mean of weeks 5 and 8 for weeks 6 and 7.

The highest total effort peaked the first week of the season and then declined in the consecutive weeks. In the first week of the lobster season, the mean number of traps was 48.95 (SE = 3.11) per square kilometer for the area found between 0 and 40 m. The density decreased to 5.96 (SE = 0.79) per square kilometer in the last week of the season (Table 1).

The use of poststratification by depth improved the efficiency (lower design effect) of the effort estimation. The ESS was increased by 22–44% for the different weeks by depth stratification (Table 1). As a mean for the survey period, a strip transect survey without area poststratification would need a 34% increase in the number of transects to reach the same precision level. We therefore based the final effort estimates on depth strata and area poststratification.

Estimated total number of deployed traps in the first week of the lobstering season was 23,100 traps/d (SE = 1,500); 66% of

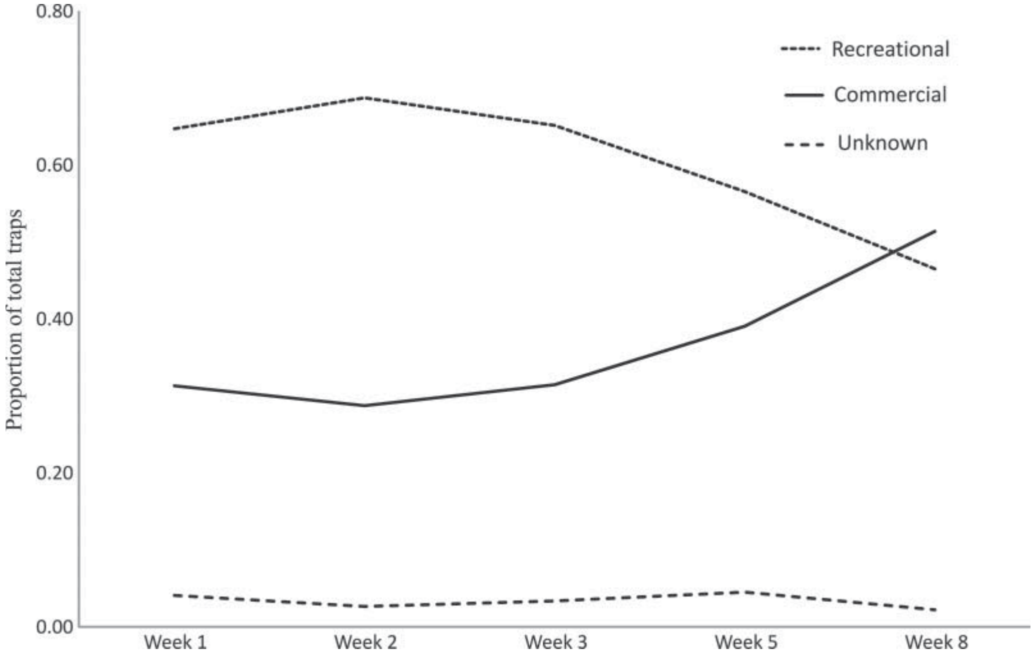

FIGURE 5. Proportion of recreational and commercial traps through the season (week 1 to week 8). Buoys that were unmarked or unreadable are recorded as unknown.

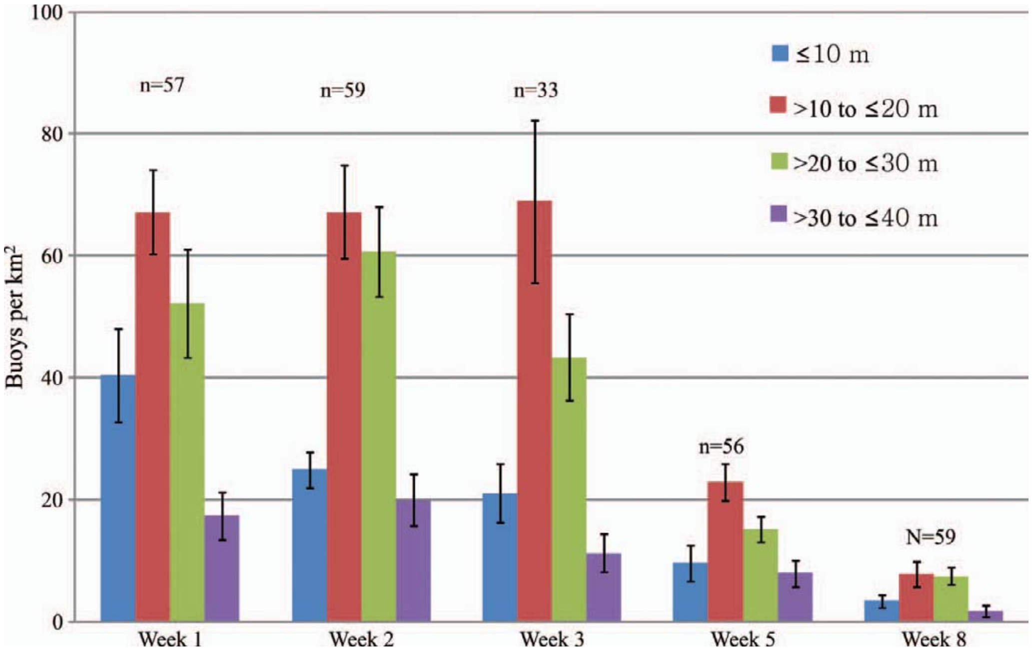

FIGURE 6. Density of traps (km^2) per depth group for the surveyed weeks. The highest density of traps is found between 10 to 30 meters.

which were recreational traps (Figure 7). Total effort remained relatively stable for the first 2 weeks. From the third week, effort decrease continuously through the season for both recreational and commercial fishers. In total, 65% of the effort (trap-days) was contributed by recreational fishers, while commercial fishing effort contributed 31% of the total effort. Additionally, 4% of the observed gear had an unknown owner, implying that we were unable to allocate the gear to either commercial or recreational fishers.

Moreover, 64% of the total effort was concentrated in the first 3 weeks of the lobstering season. In total, recreational fishers accounted for 424,000 trap-days for the whole season within the study area. Commercial fishers had a total effort of 215,000 trap-days.

DISCUSSION

Our study reveals that lobster traps deployed by recreational fishers outnumber the ones deployed by commercial fishers, contributing to 65% of the total effort in the fishery along the Norwegian Skagerrak coast. Strip transect sampling and counting of buoys within depth intervals in each segment allowed us to employ geographical information systems for poststratification, based on accurate maps of depth in the study area.

The calibration study was an efficient way to standardize the transect width and control for detection rate. Even though we aimed to use buoys for the calibration study that represent the diversity in the lobster fishery, an exact representation should not be expected. Calibration studies were only performed after the field season. The median wind strength in the survey was found to be slightly higher than for the calibration study. This could possibly affect the detection rate supposing that less wind increases the detection potential. However, due to the narrow strip used in the survey, the bias in detection rate is expected to be low. From field data, we observed a small difference in mean distance of plotted buoys between weeks. The mean distance

TABLE 1. Mean lobster traps per square kilometer for the study area shallower than 40 m and standard error (SE) of the mean for the surveyed weeks, where *A* is the bootstrapped mean of transects without depth strata and area poststratification, *B* is bootstrapped mean of transects with depth strata and area poststratification, *Bn* is the sample size for *B*, DE is the design effect of depth strata and poststratification, and ESS is the effective sample size for the needed number of transects for *A* to reach the same precision as *B*.

Week	*A*	SE	*B*	SE	*Bn*	DE	ESS
1	47.34	3.44	48.95	3.11	224	0.817	274
2	46.13	3.06	46.81	2.55	235	0.694	338
3	35.00	3.60	34.30	3.01	130	0.699	186
5	16.93	1.55	15.33	1.34	225	0.777	289
8	6.03	0.88	5.96	0.79	235	0.806	292

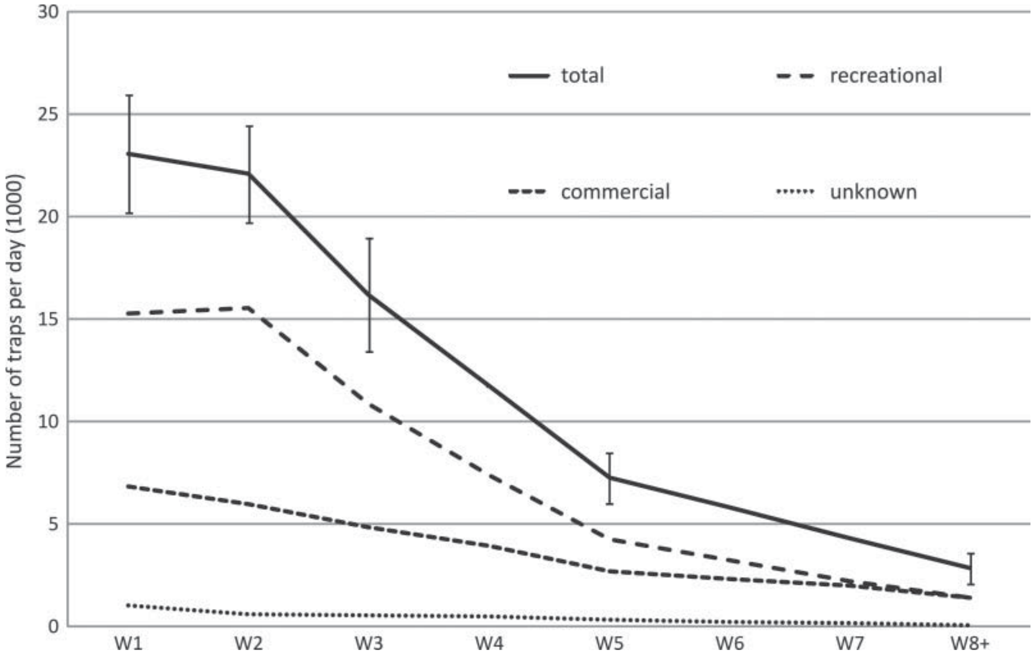

FIGURE 7. Number of traps (recreational, commercial, and unknown) per day for the respective weeks for the study area (bars indicating 95% confidence interval). Surveys were not conducted for weeks 4, 6, and 7.

from the transect line of plotted buoys ranged between 33.4 and 35.3 m in the first 3 weeks and increased to 37.5 and 36 m the two last survey periods, respectively. The increase in transect width at the end of the season may be due to a density effect, where transect width is slightly increased when the density of buoys decrease. This change may have resulted in an underestimate in the beginning of the survey period and an overestimate later in the season. Calibrations before field survey could have reduced this small variation in transect width. We recommend that calibration studies should be conducted both before and after the survey period in order to standardize and detect changes in surveyor behavior. Further, the small difference in behavior by the two independent researchers and the comparison between data from field and calibration confirm that the results from the calibration study should be considered as reliable, and that the data from main study is consistent.

We assume that lobsters caught in edible crab traps were kept by the commercial fishers. Crab traps amount to 29% of the total commercial traps. New regulations were introduced prior to the 2008 lobstering season, including escape vents in lobster traps. The fact that commercial fishers were allowed to use an unlimited number of identical traps without escape vents in the crab fishery, at the same time, represented a loophole in the regulation. Keeping a lobster fished by a crab trap is illegal. It is not expected that fishers follow this regulation, since the gear is used at the same time in the same area by the same fishers. In the 2009 season, new regulations came into force in order to close this loophole, where escape vents (70 mm) in commercial crab traps were introduced (NMFCA 2009).

Even though the lobster traps outnumbered other types of passive fishing gear in the lobstering season, some other fishing gear (mostly traps and nets) were present. However, phone-based interviews and mail questionnaires showed that other type of gear were low in number compared with lobster gear. In the field study, the trained field researchers were experienced and able to distinguish buoys belonging to lobster traps compared with other fishing gear based on differences in type of buoys and knowledge of fishing behavior. We found a small difference between the proportion of other standing gear observed in field (0.075) and the information gathered by off-site interviews (0.095). However, nets are used, for example, for a short period of time (overnight) and the gear might not be present at the time transects were run. We therefore assume that the field personnel have been able to distinguish other gear from lobster traps at an acceptable level.

The survey presented herein covered all sea areas between 0 and 40 m. However, a small proportion of lobster traps were found employed at greater depths (2.8% of total observed traps). This observation corresponds with the 2007 pilot survey, where 2% of the traps were found deeper than 40 m. This is not included in the effort estimate but indicates that the bias in estimated total effort caused by eliminating areas with depth greater than 40 m is negligible. Covering areas deeper than 40 m would increase the cost of the sampling effort significantly, while the gain would be quite limited due to the low proportion of traps employed at these depths compared with shallower areas.

While the response rate for phone interviews of recreational fishers were high (5% rejection rate), the response rate for mail-based questionnaires from commercial fishers was only 42%; there was no follow-up survey of nonrespondents. The questionnaire sent out to commercial fishers was anonymous, making a follow-up survey more challenging. A future survey should follow-up the nonrespondents in order to see if their fishing habit corresponds with that of the respondents.

When investigating recreational fisheries effort, common methods are creel surveys, random phone interviews, or both. These methods are complex and challenging, especially when targeting a small proportion of the population (NRC 2006), such as recreational lobster fishers, and when fishing licenses are not required. The present survey is not dependent on direct information from fishers apart from that provided through offsite interviews to determine information such as the ratio of buoys to traps. Two field personnel were able to cover a 170-km complex coastline weekly with a sampling level that achieved high precision in effort estimates. To reduce costs, future surveys could target the first 2 weeks of the season and calculate reduction in effort from phone surveys from a random selection of fishers registered in the field. We observed that nearly all fishers participate from the beginning of the season, reducing the risk of bias of fishers coming into the fishery at a later stage. Field work in October and November along the Norwegian coast is vulnerable to harsh weather conditions, which can hamper a field operator's work. Therefore, the method presented herein is weather dependent.

Our study demonstrates that recreational fishing effort dominated the lobster fishery in 2008 in southeastern Norway. Surveys from many countries indicate that recreational fishing effort and catch for lobster is growing. In South Africa, Cockcroft and Mackenzie (1997) used a multistage telephone interview of permit holders through season to estimate effort and catch for West Coast rock lobster *Jasus lalandii*. They found that recreational catch increased from 7% of total allowable commercial catch in 1992–1993 to 25% in 1995–1996. In Tasmania, Australia, the number of persons with lobster licenses increased by 80% from the mid-1990s to 2002–2003. Since 1995, a telephone diary survey conducted periodically has been undertaken to estimate the recreational catch of southern rock lobster *J. edwardsii* through time (Lyle et al. 2005). The same study found that the recreational catch had increased significantly through time and in the 2002–2003 season was 12% of the total allowable commercial catch. Muller et al. (2000) estimated the recreational landings of Caribbean spiny lobster *Panulirus argus* to be 23% of the total landings in the Florida Keys in the 1999–2000 season. The studies are based on lobster fisheries with a licensing system. To our knowledge, the method presented herein is the first time effort in a fishery is estimated by strip transects. The domination of recreational effort in the lobster fishery implies that the proportion of the recreational catches within our study area is much higher than the studies presented above. In order to follow fishing effort through time from year to year in the Norwegian lobster fishery, a fishing license system would make the data collection process cheaper, more efficient, and safer.

This study has estimated the total effort in the lobster fishery. Managing a fishery based solely on effort information may be challenging due to potential variations in catches between fishers, in different areas, and in time. In order to improve the management of the lobster fishery, there is a need to collect CPUE data to estimate the recreational and commercial catches in the fishery. Further work should aim at collecting real-time CPUE data from both recreational and commercial fishers throughout the lobster fishing season in order to get precise estimates of total catches.

MANAGEMENT IMPLICATIONS

At his time, Dannevig (1936) discussed the function of exposed and inaccessible lobster habitats as "natural refugia." Today, recreational and commercial fishers are equipped with high-technology, large boats and heavy fishing gear, making the new areas available for fishing. It is reasonable to assume that the old natural refugia are now being fished. Four experimental lobster reserves have been established along the Norwegian Skagerrak coast in order to understand how lobster responds to protection (Pettersen et al. 2009). Such reserves would at least be able to protect a fraction of the heavily fished, red-listed lobster population. Mean number of traps per square kilometer for the first week was 49 for areas shallower than 40 m, which means 1 lobster trap/0.02 km^2. A behavior study of European lobster in an experimental lobster reserve situated within the study area showed high site fidelity, where mean home range for the lobsters was 0.02 km^2 (Moland et al. 2011). This indicates that for a single day of the first week of the lobstering season, the large number of traps has the potential to cover all home ranges of all lobsters in the area.

To introduce sound management regulations in a fishery, it is important to know total effort and catch (NRC 2006). Our study highlights the need for managers to include recreational fishers in their management approach if the aim is to decrease overall lobstering effort and lobster fishing mortality. If management authorities want to reduce the effort in the lobster fishery, a shortening of the season would have low impact. If the season lasted for October only, the total effort would be reduced by around 23%. Obviously, a reduction in number of traps per fisher would have a higher impact. However, since there are currently no license requirements for the participants in the recreational fishery and it is time consuming for management authorities to control the number of traps per fisher under the fishery, a regulation of number of traps is a challenging task. In Tasmania, Australia, the management authorities have a management trigger level when recreational catch reaches 10% of total allowable catch (Lyle et al. 2005), which subsequently led to a total allowable recreational catch (Lyle 2008). To achieve sound management of the lobster fishery in Norway, management authorities should consider a limit on maximum effort in the fishery in order to rebuild the red-listed lobster stock. In order to improve management further, collecting catch data for both recreational and commercial fishers is needed. However, monitoring and managing effort and catch will remain highly problematic without license requirements for both commercial and recreational fishers.

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