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 (October-November) along the Agder counties in southern Norway to estimate the number of deployed lobster traps over time. The survey covered a surface area of 471 km^2 of the coast with depths $\leq$ 40 meters. Surface buoys marking lobster traps were counted along strip transects placed representatively in the survey area in 5 different weeks from start to end of the lobstering season. Calibration studies were conducted to standardise transect width and to estimate and adjust for detection rates of buoys along transect strips. Mean number of lobster traps per km^2 and associated variance was estimated by a ratio-estimator using bootstrapping, with transects as primary sampling units. Post-stratification of the counts by depth (by 10 meter depths interval) combined with GIS 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 per km^2, decreasing steadily to 5.96 (SE 0.79) in the 8th (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 66 % of the total effort (number of traps) in the fishery. We show that strip transects are a suitable method 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.

Introduction

Recently, recreational fishing and its impacts on marine resources have gained increased attention in the US (Schroeder and Love 2002; Coleman et al. 2004), Australia (McPhee et al. 2002), 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 (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 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 fixed width. An important general assumption is that all objects within the strip transect are observed, which might 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 transect width. Strip transect surveys can be an appropriate method to estimate fishing effort by counting surface buoys within representatively selected transect lines. Transect surveys to count standing gear have the benefit that we can perform reliable calibration studies. However, 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 different countries. Studies conducted in South Africa (Cockcroft and Mackenzie 1997), Australia (Lyle et al. 2005) and US (Muller et al. 2000) show that recreational fishing for lobster can be a significant part of the total landings in these countries. These studies were able to take the advantage of license requirements in the respective lobster fisheries. Recreational fisheries are often more dispersed than commercial fisheries, making representative and cost-effective data collection more challenging. 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 with different participation level, numerous access points, and a large number of fishers (NRC 2006).

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).

Marine recreational fishing in general is a popular activity in Norway; A study conducted by Hallenstvedt and Wulff (2004) indicated that more than 40 % of the adult population fished in the sea in 2003. The study did not fully cover the population of recreational fishers, and new methods designed to estimate recreational effort representatively are needed. The lobster season in south-eastern Norway lasts for two months (October-November). Only traps are allowed for catching lobster, and the regulations (such as minimum size, protection of egg bearing females and 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, the same traps do as well catch edible crabs (*Cancer pagurus)*. The only defined difference between a crab trap and a lobster trap is the size difference of escape vents. Since lobster can only be caught legally using one type of gear (traps), during a short season, it is feasible to quantify a total effort in the legal fishery. More often, fishing practices are different between the recreational and commercial sector and it is more appropriate to compare catches, as conducted by Schroeder and Love (2002) and Coleman et al. (2004). Although recreational fishing for lobster is popular in Norway, this is the first comprehensive study to estimate effort by recreational fishers. Moreover, the official landings of lobster from the commercial fishing sector are likely biased due to potential underreporting. Official catches are therefore expected to be inaccurate estimates of the total removals of lobster. There is, furthermore, 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 is allowed to fish for lobster without informing the management authorities (open fishery). Estimates of participation and effort are therefore 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).

Here, we will present a strip transect method to estimate recreational and commercial effort in the Norwegian fishery for European lobster (*Homarus gammarus*) for the south-eastern Skagerrak coast. In addition, our strip transect method includes calibration of transect width and the use of depth stratification to increase the effective sample size for estimating effort.

Material and Methods

The southern coast of Norway is shaped by the glacial scouring, including small fjords, and submerged, semi-submerged glacial moraines, making it a suitable lobster habitat. People live scattered along the coast and on islands, with boats docked on private properties and small harbours. Agder is situated in the south-eastern Norway along the Skagerrak coast. 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 size between 80.000 (Kristiansand) and 6.000 (Tvedestrand), are found in the study area. A complex archipelago, 1-4 km wide, with approximately 1900 islands is placed between the mainland and the deep Norwegian trench (Fig 1).

Design of transect survey. The counties of Aust- and Vest-Agder were treated as two discrete study areas, and were surveyed by different field personnel. Our 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), as shown in fig. 1. A straight line was first drawn parallel to the coast on a low resolution computerized map (BlueChart Atlantic v2008 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 ten with the aim to conduct counts along three random transects within each group every survey period (weekly), totalling 60 transects per 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 meters. To reduce cost, we therefore decided to end transects when the depth exceeded 40 meters off shore, 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 meter 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 calibration study to estimate the transect width and detectability (see calibration below).

A stored 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. 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 (≤10 m, >10 to ≤20 m, >20 to ≤30 m and >30 to ≤40 m) along the transect line. Counts of buoys were then allocated to different depth strata as observed by an on board echo-sounder at the transect centre line.

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

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 zero 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 (DEM) and bathymetric data ("Marine primary data") from the Norwegian mapping authority. A GRID with cell-size of 10 by 10 meters was generated. From this GRID, the depth surface was then classified into four groups (≤10 m (151.5 km^2), >10 to ≤20 m (116.6 km^2), >20 to ≤30 m (122.1 km^2) and >30 to ≤40 m (81.0 km^2). Total area between zero and 40 meters 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. 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 meters 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 90^0 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 analysed and the actual distance from the transect line to the buoy was measured in MapSource© and compared to 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, totalling 16 transect runs and 530 potential buoy observations over 5 days. 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):

$$CAL = \frac{a+c+d}{a+b} \qquad \text{equation } i$$

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 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 we used the following formulae for each transect (equation *ii*):

$$Traps / km^2 = CAL * buoys / km^2 * (R_t * Rw_n + C_P * Cw_n + (\frac{R_t * Rw_n + C_t * Cw_n}{Rw_n + Cw_n}) * Uw_n) \ ,$$

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

Transect estimates of trap density. Let X_i be the estimated number of lobster traps within transect strip *i*, and let M_i be the area of the transect strip. A simple estimator for the mean number of lobster traps per km^2 is then (Cochran 1977, p.250)

$$\overline{x}_i = \frac{\sum_i^n x_i}{\sum_i^n M_i} , \qquad \text{equation } iii$$

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 that takes advantage of the accurate information of the depth surface in the survey area. Using MapSource©, each transect was divided into depth groups based on GPS plots from field observations. Let x_{ij} be the number of observations in each depth group j (depth ≤10 m, >10 to ≤20 m, >20 to ≤30 m and >30 to ≤40 m) inside transect i, and let 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 km^2 in depth group j is then

$$\bar{x}_j = \frac{\sum_{i=1}^{n} x_{ij}}{\sum_{i=1}^{n} M_{ij}}, \qquad \text{equation } iv$$

The overall mean density of lobster traps in the survey area (across depth groups) was estimated by post-stratification, using the postStratify function provided within the R package “survey” (Lumley 2004) and the variance was estimated by bootstrapping (Canty and Davidson 1999), using 1000 resamples of size *n*. The ratio estimator was used since strip transect area size (size of the PSUs) varied randomly.

In order to analyse 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 post-stratification 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” (D*eff*) is defined as the ratio of the two variances (see Kish 1965; 1995; 2003).

$$Deff = \frac{\mathrm{var}(\bar{x})_B}{\mathrm{var}(\bar{x})_A}, \qquad \text{equation v}$$

The “effective sample size” for estimating the mean density of lobster traps by post-stratification is defined as *n/Deff*, where *n* is the number of random transects. The effective sample size (ESS), hence, 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 post-stratification 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. Number of transects per week is given in Fig. 6.

Calibration study. The effective strip transect half-width (μ) was set as 70 meter, 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 meters intervals) from the line where as many objects were defined inside as outside (fig. 2). There were minor differences in effective strip size between the two independent researchers in the calibration study (fig. 3). Observer A had a detection rate of 0.92 within μ, while for observer B the detection rate was 0.95. The results from the two independent researchers was 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 (fig. 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 meters for the calibration study. Mean distance of the random buoys plotted in field ranged from 33.4 to 37.5 meters from transect centre line for the five different weeks, indicating that transect width did not change considerably between weeks.

From the calibration study (a) 78.1 % of the buoys were observed and correctly defined as inside, (b) 6.6 % were incorrectly defined as inside and (c) 9.2 % were incorrectly defined as outside. In addition, (d) 6 % of the buoys were undetected (see equation *i*). 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 offsite interviews indicated a total proportion of 0.095. Commercial fishers informed that 29 % of their traps were crab traps. The only difference between a commercial crab and lobster trap was that it was not required escape vents in crab traps. This was seen as a loop hole in the new regulations for the 2008 season, leading to inclusion of escape vents for crabs (70 mm) for the 2009 season (NMFCA 2009). We assumed that lobsters caught in crab traps 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 three first 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 (fig. 5). A small amount of the buoys were 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 two months lobstering season, we were able to map effort in a subset of five weeks. In week no. 3, only half (n=33) of transects were covered due to difficult weather conditions. Most of the traps were observed between > 10 and ≤ 30 meters depth (fig. 6). We estimated proportion of buoys deeper than 40 meters 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 the week 5 and 8 for week 6 and 7.

The highest total effort peaked the first week of the season, and then declined steadily in the consecutive weeks. In the first week of the lobster season, the mean number of traps was 48.95 (SE 3.11) per km^2 for the area found between zero and 40 meters. The density decreased to 5.96 (SE 0.79) per km^2 in the last week of the season (table 1). The use of post-stratification by depth improved the efficiency (lower design effect) of the effort estimation. The effective sample size (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 post stratification 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 post stratification.

Estimated total number of deployed traps in the first week of the lobstering season was 23 100 traps per day (SE 1500); 66 % of which were recreational traps (fig. 7). Total effort remained relatively stable for the first two 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 not able to allocate the gear to neither commercial nor recreational fishers.

Moreover, 64 % of the total effort was concentrated in the first three 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

The counting of buoys within depth intervals in each segment allowed us to employ post-stratification, based on accurate maps of depth in the study area. The 2007 pilot survey was conducted without depth group registration and the mean speed within transects was 4.9 knots. For the 2008 lobster season with depth group registration, mean speed was 4.3 knots in the same area as the 2007 pilot survey was conducted. In addition, transport time between transects would be the same for both methods. The gain of collecting depth data in field is therefore found to be higher than the cost of time.

The calibration study was an efficient way to standardise 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. From field data, we observed a small difference in mean distance of plotted buoys between weeks. The mean distance from the transect line of plotted buoys ranged between 33.4 and 35.3 meters in the three first weeks and increased to 37.5 and 36 meters 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 standardise and detect changes in surveyor behaviour. Further, the small difference in behaviour 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 crab (*Cancer pagurus*) 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 loop hole 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 loop hole, 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 to lobster gear. In the field study, the trained field researchers were experienced and able to distinguish buoys belonging to lobster traps compared to other fishing gear based on differences in type of buoys and knowledge of fishing behaviour. It was a small difference between the proportion of other standing gear observed in field (0.075) and the information gathered by offsite interviews (0.095). However, nets are for example used 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 zero and 40 meters. 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 meters. This is not included in the effort estimate, but indicate that the bias in estimated total effort caused by eliminating areas with depth greater than 40 m is negligible. Covering areas deeper than 40 meters 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 to 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 %, with no follow-up survey of non-respondents. The questionnaire sent out to commercial fishers was anonymous, making a follow-up survey more challenging. A future survey should follow up the non-respondents in order to see if their fishing habit corresponds with the respondents.

When investigating recreational fisheries effort, common methods are creel surveys and/or random phone interviews. 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 licences 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 two 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 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 south-eastern 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 mid 1990’s to 2002/2003. Since 1995, a telephone-diary survey conducted periodically has been undertaken to estimate the recreational catch of southern rock lobster (*Jasus edwardsii*) through time (Lyle et al. 2005). The same study found that the recreational catch had increased significantly through time and was in the 2002/2003 season 12 % of the total allowable commercial catch. Muller et al. (2000) estimated the recreational landings of 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.

Management implications

Dannevig (1936) discussed the function of exposed and inaccessible lobster habitats as “natural refugia” at his time. 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 km^2 for the first week was 49 for areas shallower than 40 meters, which means one lobster trap per 0.02 km^2. A behaviour 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 were 0,02 km^2 (Moland 2010). This indicate that for a single day of the first week of the lobstering season, the large number of traps have 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 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 (TARC)(Lyle, 2008). In order to reach a 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. However, monitoring and managing effort will remain highly problematic without license requirements for both commercial and recreational fishers.

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References

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers and L. Thomas, editors. 2001. Introduction to distance sampling: estimating abundance of biological populations: Oxford University Press, Oxford.

Canty, A. J. and A. C. Davidson. 1999. Resampling-based variance estimation for labour force studies. The Statistician 48:379-391.

Cochran, W. G. 1977. Sampling Techniques. 3rd Edition. John Wiley & Sons, New York. Cockcroft, A. C. and A. J. Mackenzie. 1997. The recreational fishery for West Coast rock lobster Jasus lalandii in South Africa. South African Journal of Marine Science-Suid-Afrikaanse Tydskrif Vir Seewetenskap 18:75-84.

Coleman, F. C., W. F. Figueira, J. S. Ueland and L. B. Crowder. 2004. The impact of United States recreational fisheries on marine fish populations. Science 305(5692):1958-1960. Cooke, S. J. and I. G. Cowx. 2004. The role of recreational fishing in global fish crisis. BioScience 54(9):857-859.

Dannevig, A. 1936. Hummer og Hummerkultur. Fiskeridirektoratets skrifter, Serie HavUndersøkelser (in Norwegian). Report on Norwegian Fishery and Marine Investigations 4(12):60.

Efron, B. 1982. The jackknife, the Bootstrap and Other Resampling Plans. Society for Industrial and Applied Mathematics, Philadelphia.

Hallenstvedt, A. and I. Wulff. 2004. Fritidsfiske i sjøen 2003 (in Norwegian). Norwegian College of Fisheries Science / University of Tromsø, Tromsø.

Kish, L. 1965. Survey Sampling. Wiley, New York.

Kish, L. 1995. Methods for design effect. Journal of Official Statistics 11:55-77.

Kish, L. 2003. Selected papers. John Wiley & Sons, New Jersey.

Lumley, T. 2004. Analysis of complex survey samples. Journal of Statistical Software 9:1-19.

Lyle, J. M., A. J. Morton and J. Forward. 2005. Characterisation of the recreational fishery for southern rock lobster, Jasus edwardsii, in Tasmania, Australia: implications for management. 39:703-713.

Lyle, J. 2008. Tasmanian recreational rock lobster and abalone fisheries – 2006/07 fishing season. Internal report. Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, Hobart. Pp. 32

NMFCA (Norwegian Ministry of Fisheries and Coastal Affairs). 2009. Forskrift om endring av forskrift om utøvelse av fisket i sjøen. FOR-2009-09-04-1154. Lovdata: Norwegian Government, Oslo.

McPhee, D. P., D. Leadbitter and G. A Skilleter. 2002. Swallowing the bait: Is recreational fishing in Australia ecologically sustainable? Pac. Conserv. Biol. 8:40-51.

Moland, E. 2010. Ecology of European lobster in a marine reserve context: Implications for conservation biology. Doctoral dissertation. University of Oslo.

Muller, R. G., W. C. Sharp, T. R. Matthews, R. Bertelsen and J. H. Hunt. 2000. The 2000 update of the stock assessment for spiny lobster, *Panulirus argus,* in the Florida Keys. Fish and Wildlife Conservation Commission, Florida Marine Research Institute.

NDF (Norwegian Directorate of Fisheries). 2007. Forvaltning av hummer i Norge. Rapport med forslag til revidert forvaltning av hummer fra arbeidsgruppe nedsatt av Fiskeridirektøren (eng: Management of lobster in Norway. Report with suggestions for a revised management plan for lobster from a working group initiated by the Director of Fisheries). 05.10.2007, Bergen.

NMFCA (Norwegian Ministry of Fisheries and Coastal Affairs). 2009. Forskrift om endring av forskrift om utøvelse av fisket i sjøen. FOR-2009-09-04-1154. Lovdata: Norwegian Government, Oslo.

NRC (National Research Council). 2006. Review of recreational fisheries survey methods. National Research Council of the National Academies. Washington D.C.

Oug, E., P. Djursvoll, K. Aagaard, T. Brattegaard, M. E. Christiansen, G. Halvorsen, W. Vader and B. Walseng. 2006. "Krepsdyr - Crustacea. Pages 197-206 in J. A. Kålås, Å. Viken and T. Bakken, editors. Norsk Rødliste 2006 - 2006 Norwegian Red List (in Norwegian). Artsdatabanken. Trondheim, Norway.

Pettersen, A.R., E. Moland, E. Moland Olsen and J.A. Knutsen. 2009. Lobster reserves in coastal Skagerrak - An integrated analysis of the implementation process. Pages 178-188 in E. Dahl, E. Moksness and J. Støttrup, editors. Coastal Zone Management. Wiley-Blackwell Publishing, London.

Potthoff, R.F., M.A. Woodbury and K.G. Manton. 1992. “Equivalent sample size” and “equivalent degrees of freedom” refinements for inference using survey weights under superpopulation models. Journal of American Statistical Association 87:383-396.

Rangel, M. O. and K. Erzini. 2007. An assessment of catches and harvest of recreational shore angling in the north of Portugal. Fisheries Management and Ecology 14(5):343-352.

Schroeder, D. M. and M. S. Love. 2002. Recreational fishing and marine fish populations in California. California Cooperative Oceanic Fisheries Investigations Reports 43:182-190.

Thomas, L., S.T. Buckland, K.P. Burnham, D.R. Anderson, J.L. Laake, D.L. Borchers and S. Strindberg. 2002. Distance Sampling. Pages 544-552 in A. H. El-Shaarawi and W. W. Piegorsch, editors. Encyclopedia of Environments. John Wiley & Sons, Chichester.

Figure legends

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

Figure 2. Results from transect calibration experiment. As proportion of all buoys within each distance group (10 meter). As 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 meters), Between zero to 30 meters, nearly all were detected and defined as inside, decreasing with the distance from the transect line, g(0). When g(0) were more than 70 meters from the transect line, most of the buoys were defined as outside or not detected.

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

Figure 5. Proportion of recreational (rec) and Commercial (comm) traps through the season (week 1 to week 8). Buoys that were unmarked or unreadable are recorded as unknown. The unsampled week 4 was estimated as the mean of week 3 and 5, while the grouped weeks of 6 and 7 is the mean of week 5 and 8.

Figure 7. Number of traps per day for the respective weeks for the study area with bars indicating 95 % CI. Number of traps for recreational, commercial and unknown. Surveys were not conducted for week 4, 6 and 7. Effort for the unsampled week 4 was estimated as the mean of week 3 and 5, while the grouped weeks of 6 and 7 is the mean of week 5 and 8.

Table 1. Mean traps/km^2 for the study area shallower than 40 meters and standard error (SE) of the mean for the surveyed weeks, where A is bootstrapped mean of transects without depth strata and area post stratification and B is bootstrapped mean of transects with depth strata and area post stratification. Bn is the sample size for B, DE is the design effect of depth strata and post stratification and ESS is the effective sample size for the needed number of transects for A to reach the same precision as B.

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

Figure 1

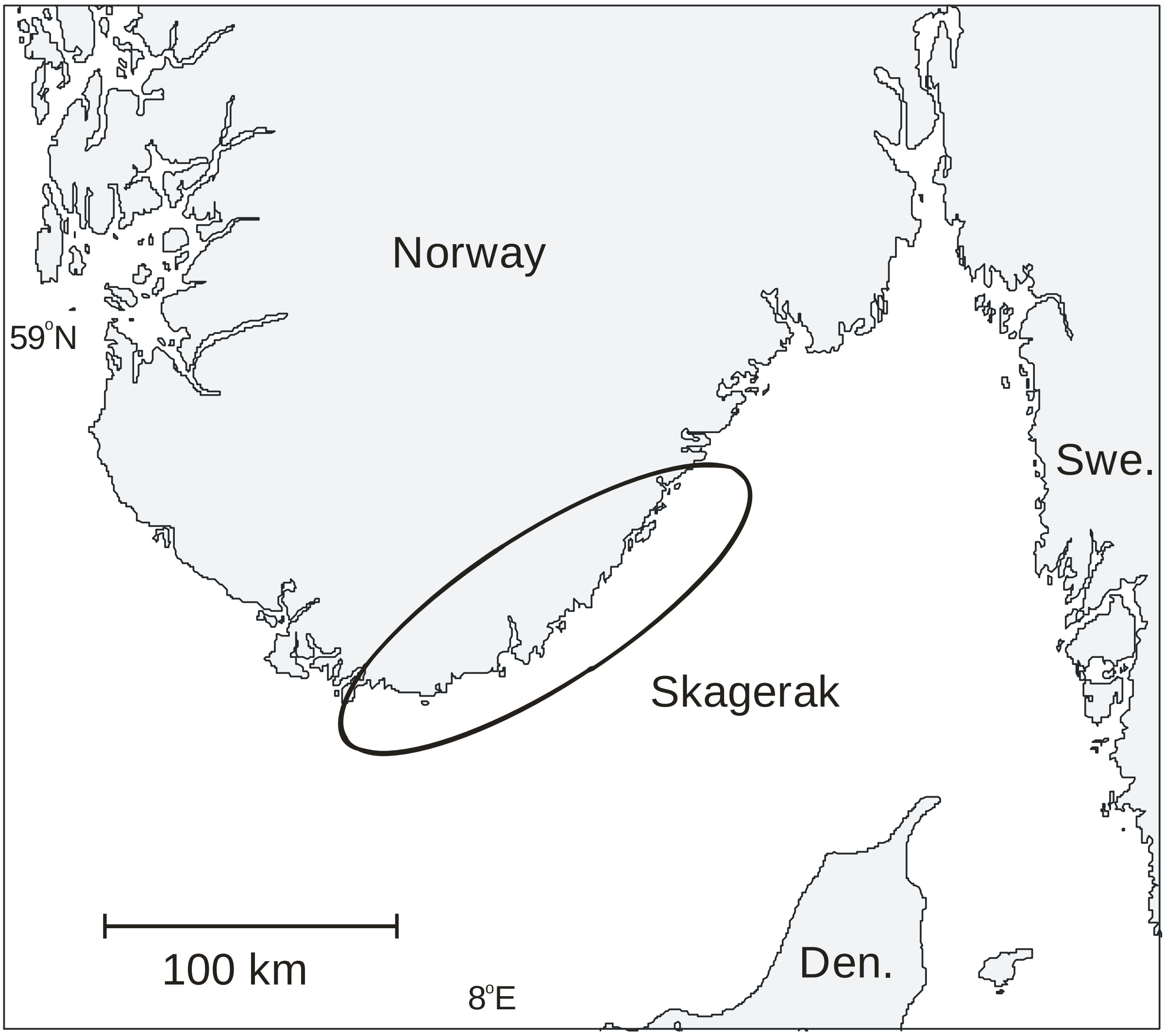
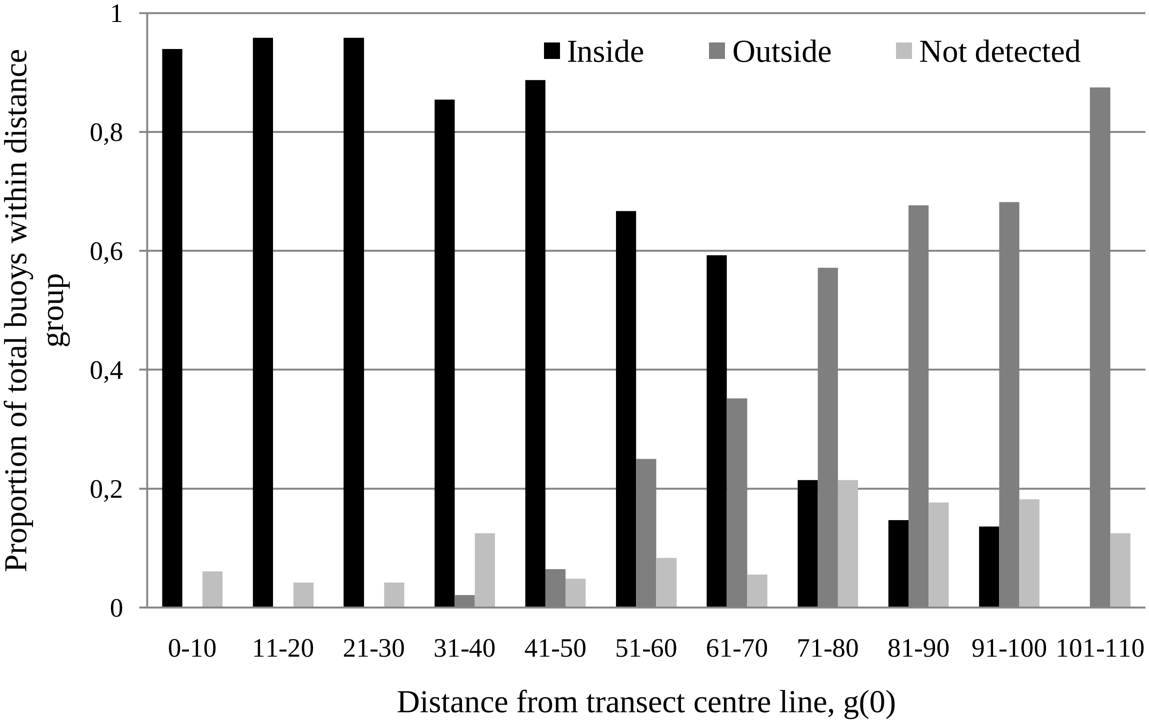


Figure 2



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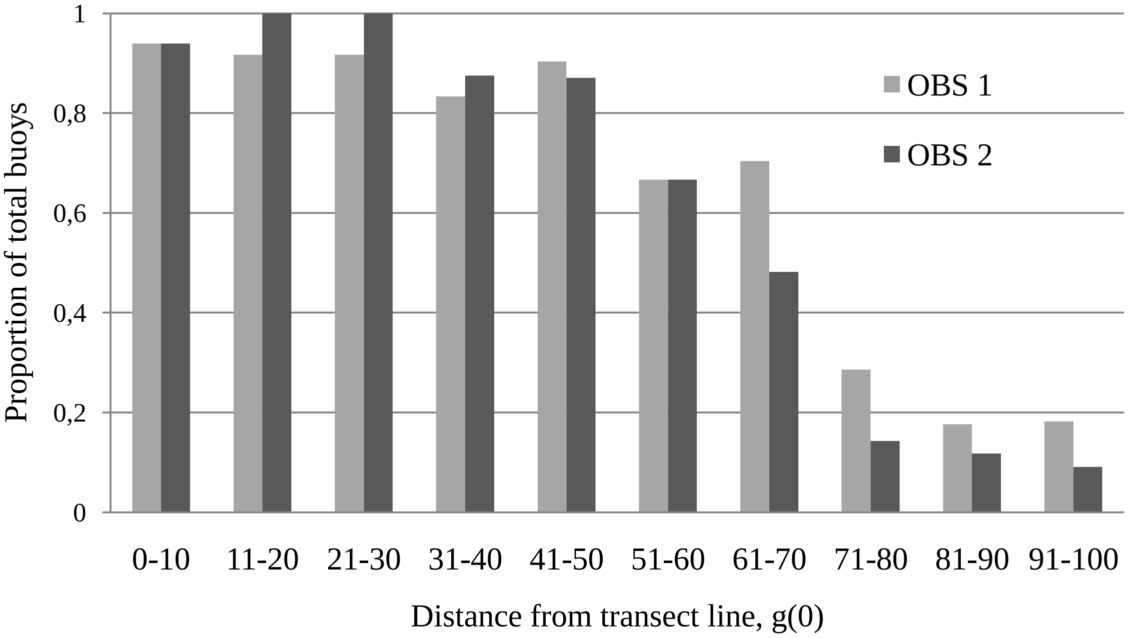

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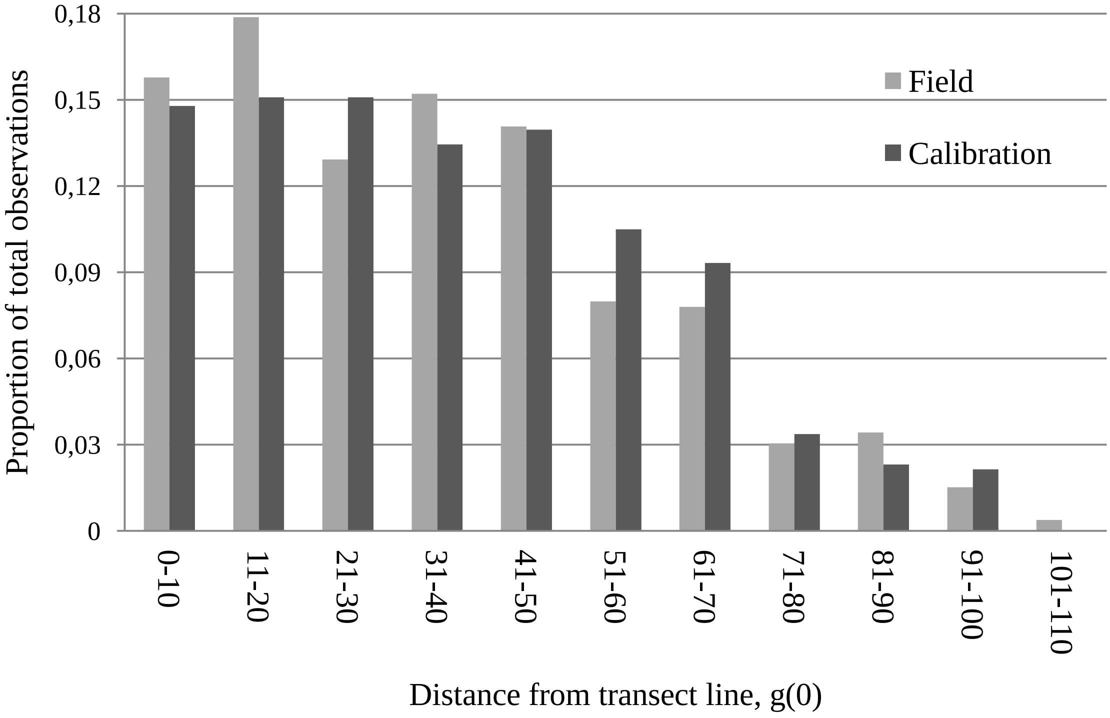

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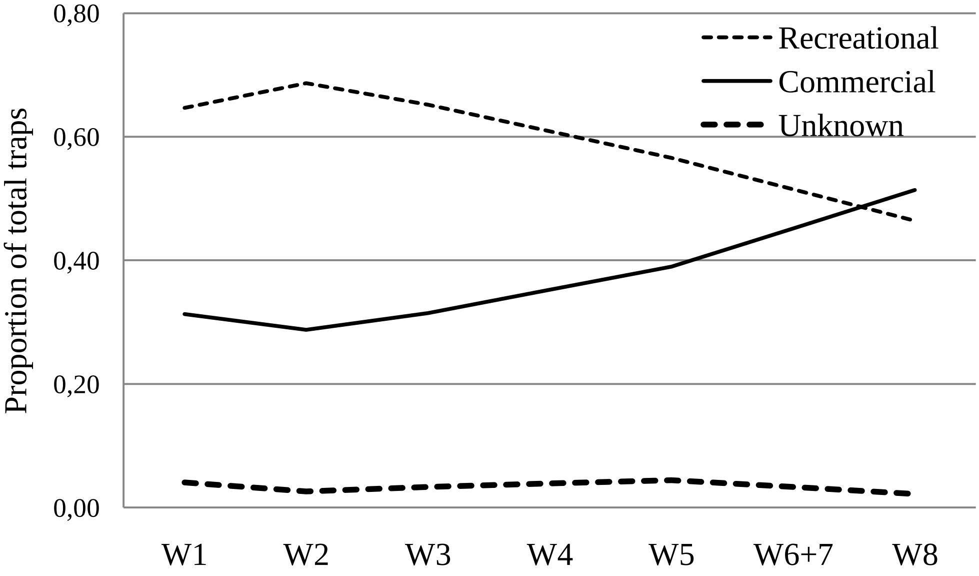

Figure 6

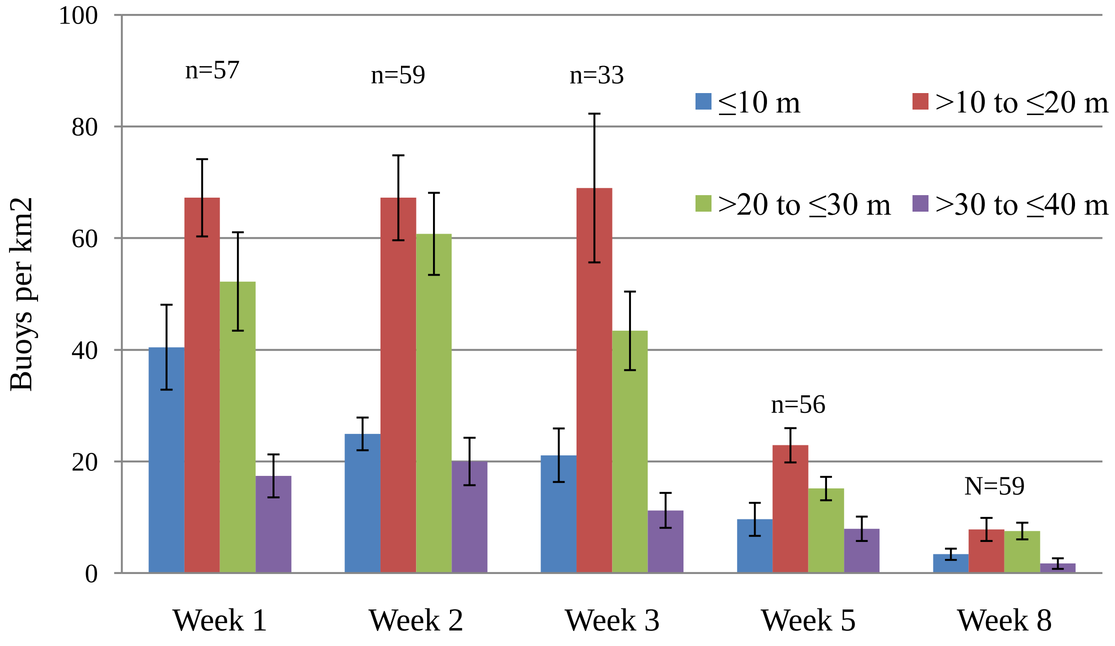

Figure 7