# Total catch an order of magnitude above officially reported landings for a red-listed marine species

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**Abstract:** Accurate information on total catch and effort is essential for successful fishery management. However, officially reported landings might be underestimates of true catches in the fishery. We investigated the fishery of the national red-listed European lobster (*Homarus gammarus*) in south-eastern Norway by combining estimates of Effort (E) from probability-based strip transect surveys and Catch Per Unit Effort (CPUE) data obtained independently from volunteer catch diaries, phone interviews and questionnaires. We estimated that recreational catch account for 65 % of the total catch in the study area. Moreover, our study show that only a small proportion (23 %) of the commercial lobster landings are sold through the legal market and documented. In total, the estimated catch of lobster is found to be nearly 14 times higher than the officially reported landings. Our study highlights the need for appropriate data collection of catch in coastal areas and is a warning sign to management authorities of the consequences of ignoring coastal illegal, unreported and unregulated (IUU) fisheries and the potential impact of recreational fisheries.

## Introduction

Fisheries management depend on accurate estimates of total fishing effort and mortality (Pollock et al. 1994, Pitcher et al. 2002; McCluskey and Lewison 2008). However, Pauly (2009) argues that official catch statistics available generally are biased downward because they often do not account for small-scale and recreational fisheries. When unreported catches are indeed studied, they tend to be significant (Pitcher et al. 2002; Ainsworth and Pitcher 2005; Varkey et al. 2010; Agnew et al. 2009; King and Sutinen 2010). Assuming that unreported catches are zero when they are in fact not, may thwart sustainability of the resources concerned (Sumaila et al. 2006; Agnew et al. 2009).

Recently, there has been an increased focus on illegal, unregulated and unreported (IUU) fishing (Pitcher et al. 2002; Le Gallic and Cox 2006; Sumaila et al. 2006; Agnew et al. 2009; Gavin et al. 2010). IUU fishing comprises a range of different legal and illegal activities, spanning from high seas to coastal areas. Legal IUU activities can include recreational fisheries without catch statistics and commercial catches that agencies are not mandated to record, while illegal activities might involve fishing in protected areas, non-compliance with regulations and underreporting (Pitcher et al. 2002). In general, IUU catches are difficult to estimate, and Catch Per Unit Effort (CPUE) from other fisheries, anecdotal information, and interviews are often used for the estimates (McCluskey and Lewison 2008).

Evidently, recreational fisheries can lead to a decline of fish populations (Lewin et al. 2006). For certain fisheries, recreational catch can actually be higher than commercial catch (McPhee et al. 2002; Schroeder and Love 2002; Coleman et al. 2004). In addition, catches dominated by recreational fishers tend to include a large portion of overfished species (Schroeder and Love 2002; Coleman et al. 2004). Recreational fishers are a diverse group with different motivations for fishing (Holland and Ditton 1992; Arlinghaus 2006) and their catches are challenging to estimate (NRC 2006). It is expected that the CPUE in recreational fisheries will have a higher variation than for commercial fisheries, since recreational fishers generally do not expect profit from the fishery (McCluskey and Lewison 2008).

The fishery for European lobster (*Homarus gammarus*) serves as an example fishery for investigating IUU fishing along the Norwegian coast. Lobster is a high priced species targeted by both recreational and commercial fishers which in this fishery have to follow the same regulations (except maximum number of traps) within a short season (October-

November). Commercial CPUE has been decreasing to what can be termed historically low levels (Pettersen et al. 2009) and the lobster is now listed on the national red list as near threatened (Oug et al. 2006). Available catch statistics in Norway are provided through mandatory official landings reports from the commercial fishing sector, where all commercial fishers are obliged to report. The fishery for lobster in Norway has no license requirements and is open access (neither quota nor total effort regulations apply) both for commercial and recreational fishers. Therefore, no information is available on the number of participants in the fishery from official records. Neither the potential unreported commercial lobster catches nor recreational catches in the Norwegian lobster fishery have ever been estimated before this study. We combine probability-based effort estimates (Kleiven et al. in prep) and CPUE data in order to estimate total catches in the commercial and recreational fishery within season. Further, we compare the results with the official reported landings in the lobster fishery.

**Material and methods**

The study area was the Agder counties at the south-eastern Skagerrak coast of Norway (excluding areas west of the south cape, Lindesnes) (Fig. 1), with a total coastal area between zero and 40 meters depth of 471.2 $km^2$ (Kleiven et al. in prep). In these counties, people live scattered along the coast and on islands, with boats docked on private properties and small harbours. The coastal municipalities in the study area have a total population of nearly 200,000 (SSB 2010), and in addition represents one of the most popular tourist destinations in the country.

*Estimates of lobster fishing effort.* Probability-based strip transect surveys were used to estimate effort (number of traps per week) in the 2008 lobstering season (method is described in Kleiven et al. in prep) for the study area. The transect surveys provided estimates of weekly effort for both recreational and commercial fishers throughout the season. We estimated that recreational fishers contributed to 66-70 % of total effort the first three weeks of the lobster season. Later in the season recreational effort decreased compared to commercial effort (Fig 2).

*Recreational catch diaries.* Estimates of catch per unit effort were obtained based on data provided by volunteer recreational fishers recruited by phone and public meetings. Participants were asked to fill out a catch diary throughout the lobster season. A pilot survey was conducted in the 2007 lobster season (October-December), where 15 recreational fishers

were recruited to fill out catch diaries. The feedback from the pilot study led to the design of diaries applied in 2008. The diaries were printed on water resistant paper. For every lobstering trip, the fishers were requested to fill out information on soak time (the number of days the fishing gear had been out), number of legal (≥25 cm total length) and sublegal sized lobsters and number of released egg-bearing females (which are protected) captured for each trap. Fishers who did not return the diary after the end of season were contacted by phone and asked if they had fished for lobster, and if so, encouraged to send in the diary. If they had not completed the diary, the fishers were asked additional question in order to know if they had fished without filling out the diary or that they had not participated in the fishing season. Recreational fishers that filled out diaries were not randomly selected. Hence, it was necessary to test if this group was indeed representative for the lobster fishing population in the study area. As part of the strip transect survey, Kleiven et al. (in prep) collected a random sample of buoys with fisher's information in field. A phone interview regarding CPUE of these fishers were conducted for Aust-Agder (eastern county representing approximately 50 % of the total study area) after the first week of the lobster season. At the end of the two month season, a mail based questionnaire was sent to all recreational fishers randomly selected in field (Kleiven et al. in prep) and were asked about i) fishing period, ii) number of traps fished, iii) catch number iv) how often they hauled the traps and v) profiling information, such as age and experience (years of lobster fishing). The same information was gathered from those who filled out catch diaries.

We used a standard method to test if the mean CPUE (legal sized lobsters per trap day$^{-1}$) for the first week and the whole season of diarists and the random selection of fishers were significantly different (Schenker and Gentleman 2001):

$$(\overline{X} - \overline{Y}) \pm 1.96\sqrt{\text{var}(\overline{X}) + \text{var}(\overline{Y})}\,, \qquad \text{equation } i$$

where $\overline{X}$ and $\overline{Y}$ is the mean CPUE for the sample populations. CPUE for each respondent is calculated as a point estimate from which the mean and SE is calculated for the whole group. CPUE are significantly different if the interval does not overlap zero.

*Commercial fisheries.* Selected panels of commercial fishers has collaborated with the Institute of Marine Research (IMR) since 1928, providing CPUE data for the whole season (Pettersen et al. 2009). The CPUE data collected from commercial fishers are for scientific

use only and personal reports provided by commercial fishers are treated confidentially and not shared with the management authorities. The long collaboration between IMR and the commercial fishers has built up trust and the data are considered as reliable. These data provides only the mean CPUE (number of traps used, fishing time and catch of legal sized lobsters) for the whole season. Therefore, data for the whole season was used to compare CPUE between recreational and commercial fishers. We estimated CPUE for each commercial and recreational fisher as

$$CPUE = \frac{C}{E}, \qquad \text{equation } ii$$

where C is total number of legal sized lobsters caught in the season, and E is total number of trap days for each fisher for the whole season. We had only reports of CPUE from seven commercial fishers in the study area. We therefore compared the CPUE of commercial fishers (n = 21) and recreational fishers writing catch diaries (n = 95) over a larger area (Norwegian part of Skagerrak). We used the standard method (Schenker and Gentleman 2001) to test for significant difference in CPUE between these groups (equation *i*).

Commercial fishers are obliged by law to report their landings of lobster (NDF 1995). The landing statistics are collected by the fishers own sales organization (Skagerakfisk), which are registered as the official landings. We acquired the landing statistics from Skagerakfisk, where we could extract landing data (in kilos) from each official landing facility in the study area. Further, in collaboration with a selection of commercial fishers, we collected length data of lobsters landed in the 2008 lobstering season. Additionally, historical data on length-weight relationship has been collected. We used these data to estimate the mean weight of lobsters measured in the 2008 lobster fishing season. We transformed reported landings from kilos to number of lobsters in order to make the data comparable to the recreational and commercial CPUE data which was collected as number of lobsters.

*Estimates of total catch of lobster*. Total catch was estimated as the product of CPUE and E, which were estimated from independent studies. Estimates of weekly catches are represented by the mean CPUE as lobsters per trap week$^{-1}$. The first week was defined as the seven days following the opening of the lobster season. Let $\overline{X}$ and $\overline{Y}$ denote mean CPUE and E, respectively. An estimator of total catch is then the product

$C = X \times Y$ , equation *ii*

Since CPUE and E were estimated in separate studies, X and Y can be considered as independent variables. Hence, an unbiased estimator for the variance of $C$ is given as (Goodman 1960):

$\text{var}(\hat{C}) = \overline{X}^2 s_Y^2 + \overline{Y}^2 s_X^2 - s_X^2 s_Y^2$, equation *iii*

where $s_X^2$ and $s_Y^2$ are the variances of the mean CPUE and E, respectively.

**Results**

In all, 106 catch diaries were sent to individual recruited fishers and 77 were returned. Follow up phone interviews revealed that nine persons had not participated in the lobster fishery, while 20 persons had participated in the lobster fishery without reporting catches in the diary. Response rate of lobster diaries, from those fishers that took part in the lobster fishery, were therefore estimated to be 79 %. CPUE for the whole season for those who filled out lobster diaries (n = 77) was estimated at 0.064 (SE = 0.005). Eighty percent (n = 66) of those who returned a catch diary filled out an additional questionnaire regarding their age and experience.

We tested the assumption that the recreational fishers who participated in the diary survey could be considered a representative sample from all lobster fishers in the area. Estimated mean CPUE for the whole season for those who filled out lobster diary with questionnaire (n = 62) were 0.064 (SE = 0.006), while the mean CPUE for the random sample (n = 37) of fishers was 0.06 (SE = 0.005). There were no significant difference between those who filled out catch diaries and the random sample of recreational fishers identified from field observations of buoys with respect to their age, experience (years of lobster fishing), number of active fishing days or time between trap hauls (table 1). Moreover, we did not find a significant difference in CPUE between the random selection of fishers registered in field (n = 24, CPUE = 0.118, SE = 0.017) and those who filled out catch diaries (n = 35, CPUE = 0.112, SE = 0.015) for the first week of the season in the eastern half of the study area. We therefore conclude that the fishers recruited to fill out diaries can reasonably be considered as a representative selection of the recreational lobster fishing population, and that the diaries provide representative estimates of CPUE that can be used in conjunction with effort estimates to estimate total recreational catches.

We tested if weekly mean CPUE from catch diaries provided by recreational fishers could be considered representative of the mean CPUE in the commercial fishery (table 1). CPUE for the whole season was therefore tested between the recreational lobster diarists and the reported commercial CPUE for the study area. The CPUE for the small sample of commercial fishers (n = 7) in the study area was 0.069 (SE = 0.015). Mean fishing days for commercial fishers were 33.6 days for the study area, while the recreational fishers had a mean of 34.1.In order to test the general assumption that it is no difference in CPUE between commercial and recreational fishers, we compared all recreational lobster diarists from the Norwegian part of Skagerrak (n = 95, CPUE = 0.066, SE = 0.005) with the commercial catch rate for the same region (n = 21, CPUE = 0.070, SE = 0.008). Even though commercial catch rates have a tendency of being slightly higher than recreational fishers, the difference between the groups was not significant. We conclude that mean CPUEs from recreational catch diaries could be combined with independent effort estimates for commercial fishers to estimate total commercial catches. The resulting catch estimates would be expected to be slightly biased downwards if commercial fishers have higher catch rates than recreational fishers.

*Weight-length relationships and reported landings.* Mean weight of legal lobsters measured (n=837) in the season was estimated to be 653 (SE=7) grams. Total official commercial landings for the study area were 1813 kilo (Skagerakfisk landing statistics 2009).

*Total catch in the fishery.* CPUE was highest the first week of the season, decreasing by nearly 50% in the second week (figure 3). CPUE decreases through season and in the last week of the season CPUE is only 17 % of the first week. The catches were highest in the first week of the season accounting for 46 % of the total estimated landings. Seventy-seven percent of the lobsters were landed in the three first weeks of the season (fig. 4). Recreational catch account for 65 % of the total catch, while the commercial part is 31 % (table 2). Four percent of the catch could not be allocated to recreational nor commercial sector, since the traps were unmarked or unreadable (Kleiven et al. in prep).

**Discussion**

We found that official landings represent just 23 % of the total commercial landings. For the combined commercial and recreational fisheries, our estimates of catches are nearly 14 times higher than the officially reported landings. Commercial fishers are by law obliged to report

their lobster catches and not doing so can be considered as IUU fishing in terms of underreporting or not reporting catches at all. The unreported catches outnumber the official landings to such a degree that official landing statistics appears totally untrustworthy. This implies that official landing statistics of lobsters should not be used for stock assessment and to set management target by management authorities.

To our knowledge, this study is the first attempt to account for unreported catches from commercial and recreational fisheries in order to estimate the total catch in a Norwegian coastal fishery.

Norway has scored high when it comes to implementing ecosystem based management and following up the FAO code of conducts for responsible fisheries (Pitcher et al. 2009a, b). Considerable Norwegian resources have been used to combat IUU fishing on shared international fish stocks (Stokke 2009). The Norwegian Ministry of Fisheries and Coastal Affairs (NMFCA 2010) states that: "Illegal, unreported and unregulated fishing (IUU fishing) is one of the most serious problems currently facing the management of the world's fisheries. Both legal harvest as well as marine ecosystems are threatened. Fighting this crime is the highest priority of Norwegian fisheries management". It can be argued that national coastal fisheries, such as the fishery for European lobster, have not been part of the IUU strategy at the same level. Further, IUU fishing could be a significant part of the total catches for other coastal species under the same management regime. Our results show that even the most advanced fishery nations might have serious challenges when it comes to controlling and managing the use of coastal resources. When total catches of a red listed species appear to be an order of magnitude higher than official landings, it is a clear need to evaluate the landing data collection, management and surveillance practices in coastal Norway.

The recreational fishers contribute to significant effort and catches in the lobster fishery, as found in Australia (Lyle et al. 2005), the US (Muller et al. 2000) and South Africa (Cockcroft and Mackenzie 1997). To our knowledge, our findings represent the highest proportion of recreational outtake in any lobster fishery described to date, with a recreational catch that is twice the commercial catch. However, our survey covered only a part of the Norwegian coast where lobster fishing activities occur. Our findings cannot be extrapolated to unsampled areas.

Our findings are another example of recreational catch domination of overfished species, as observed by Schroeder and Love (2002) and Coleman et al. (2004). Commercial fishers need to profit from the fishery in order to cover cost and secure an income for the crew. It is therefore expected that commercial effort would decrease if stocks decline. A decrease in effort can be hampered if fish prices rise due to increased demand or the fishery is subsidised (Sumaila et al. 2007). Recreational fishers on the other hand are not dependent on profit. A recreational lobster fisher using 10 traps would expect a mean catch of 0.7 lobsters per day for the season. Even in the first week, when the catch rate and effort is the highest, mean daily catch for 10 traps were only 1.1 lobsters. However, recreational fishers are not dependent on economic revenue from the fishery and can choose to continue as long as the experience value of the activity is high. The driving forces behind such a self-subsidised fishery (Kleiven et al. in prep) have the potential to withheld high fishing effort on overfished and economically extinct stocks. This might be the case for the lobster fishery in Norway. While commercial fishers have left the fishery or started selling the catch on the black market in order to increase the revenue, recreational fishers can withhold the high fishing effort without fear of bankruptcy.

Catch rates of commercial and recreational fishers were comparable. CPUE of commercial fishers estimated from the standardised long term time series collected by IMR is not necessarily representative since the panel of fishers were randomly selected. This could cause bias since the fishers reporting their catch rates to IMR may not be representative for the whole commercial lobster fishing sector in the area. However, the insignificance in catch rates between the groups studied (both recreational and commercial fishers) and the low variation between fishers within these groups indicate that this bias expectedly is low. The questionnaires sent out to all commercial fishers observed in field were anonymous. The anonymity was used because many of the potential respondents expectedly underreport their catches to the management authorities. A follow up survey of non-respondents was therefore not conducted. However, the information gathered from the questionnaire was related to additional information about number of traps per buoy and other gear used in the lobster fishing season and was not used to estimate CPUE from this sector.

Our total catch estimate might be conservative. Kleiven et al. (in prep) calculated that the proportion of traps deeper than 40 meters represented 2.8 % of the total effort. The fishing effort by these traps were not included in the total effort estimate and subsequently not

included in the total catch estimate. Further, Kleiven et al. (in prep) argue that the effort estimates form the strip transects surveys can be an underestimate in the beginning of the season and an overestimate at the end. The reason for this is that we used a standardised transect width calculated by calibration studies even though mean transect width appeared to increase slightly through the survey period. This could lead to an underestimate of the total catch since the highest effort and catch rate was in the beginning of the season. In addition, a small proportion (4%) of the traps were attached to buoys with markings that were either unreadable or they were not marked. This effort is included in the total catch estimate, but not assigned to neither commercial nor recreational fishers. Including these observations as either recreational or commercial could be considered as a bias if one of the groups has a higher frequency of wrongly marking their buoys. Our estimate relate to the lobsters caught within the legal fishing season. It is suspected that lobsters are poached outside the legal season (NDF 2009). However, these numbers are still unexplored. Lobster fishing mortality outside the legal fishing season would increase the total IUU catch further.

By using probability-based strip transects to estimate effort and catch diaries to estimate CPUE, we achieved a high precision on the total catch estimate. However, the method is time consuming, costly and weather dependent. In one season, personnel of two were only able to cover a fraction of the total area of lobster fishing activities in Norway. The method would be highly costly if aiming at a yearly catch estimate in the Norwegian lobster fishery. A license system for recreational fisheries, as in Australia (Lyle et al. 2005), the US (Muller et al. 2000) and South-Africa (Cockcroft and Mackenzie 1997) would reduce the cost and be more effective in order to estimate recreational landings.

The lack of total effort and/or catch regulations might hinder a recovery of the lobster population, even when other regulations have been implemented. A small increase in CPUE may lead to more people participating in the fishery, which in turn has the potential to counteract the rebuilding of the lobster population. Our results indicate that there is a race to fish, where both CPUE and effort is the highest in the first days of the season. The fishery has the potential to fish out a high proportion of the catchable lobsters in a very few days, and appear to be more like a depletion experiment rather than a sustainable fishery.

## Concluding remarks

While the catches in the off-shore areas more often are dominated by larger commercial vessels, the coastal fishery consist of recreational and small-scale commercial fishers. Due to this complexity, the catches in coastal fisheries are challenging to estimate and more often ignored by the management authorities (Pauly 1995). The collection of reliable total catch data is therefore essential for the management authorities. This should include securing that commercial landings are reported, which would require more effort on controlling compliance and traceability of lobsters on the market. Further, it has to be developed a data collection framework for recreational fisheries. Moreover, total effort or total catch regulation in the fishery is needed in order to rebuild the red-listed European lobster in Norway. In addition, a network of lobster reserves would have the potential to protect fractions of the lobster population from the high fishing pressure (Moland 2010). However, it is obvious that the lobster fishery is a small activity compared to other coastal fisheries. It is therefore an urgent need to evaluate the IUU catches and recreational fisheries for a number of other coastal species, such as cod (*Gadus morhua*), halibut (*Hippoglossus hippoglossus*), ling (*Molva molva*), European eel (*Anguilla anguilla*) and Norway lobster (*Nephros norvegicus*) which are expected to be other popular recreational target species. Our results presented herein highlights the need for appropriate data collection of catch in coastal areas and is a warning sign to management authorities of the consequences of ignoring coastal IUU fisheries and the potential impact of recreational fisheries.

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**Figure legends**

**Figure 1.** Study area and distribution of fishing area for volunteer recreational fishers (red rings) that filled out catch diaries along Agder (Southern Skagerrak coast) in the 2008 fishing season. Angled lines indicate study area.

**Figure 2.** Number of traps/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 these weeks is estimated as a mean of the week before and after the lacking week (Kleiven et al. in prep).

**Figure 3.** Mean CPUE (lobster trap-1 day-1) for each week through the lobster season from catch diaries. Error bars indicate SE of mean. n = number of catch diaries for the given week.

**Figure 4.** Total weekly catch (number of lobsters) in the lobster fishery 2008 in the study area. Error bars indicate 95% CI. The catch is highest in the first week of the season.

**Table 1.** Test of the representativity of volunteer recreational catch diaries as i) between recreational diarists and a random sample of recreational fishers and ii) between recreational diarists and commercial fishers. CPUE is lobsters trap$^{-1}$ day$^{-1}$. Mean year born (YB), years of lobster fishing experience (FY), fishing days (FD) and time between each trap haul (TH), incl. mean S.E. for the test sample and recruited diary reporters. The first week of the season (Aust-Agder, eastern part of the survey area) and for mean of season (whole study area) for diary and a random selection of fishers registered in field. If the interval for the difference contains zero, it is no significant difference (Schenker and Gentleman 2001).

| | | Diary | | Test pop | | | |
|---|---|---|---|---|---|---|---|
| | | Mean | SE | Mean | SE | Interval | Sig |
| i) Whole season Diary and random questionnaire within study area | CPUE | 0.064 | 0.006 | 0.060 | 0.005 | 0.02, -0.01 | no |
| | YB | 1953.8 | 1.7 | 1952.2 | 2.5 | 6.7, -5.1 | no |
| | FY | 24.5 | 2.0 | 23.9 | 2.9 | 8.4, -5.4 | no |
| | FD | 34.1 | 2.1 | 30.9 | 2.8 | 10.1, -3.7 | no |
| | TH | 2.17 | 0.09 | 2.21 | 0.19 | 0.4, -0.5 | no |
| i) First week, diary and random phone interview Aust-Agder | | 0.112 | 0.007 | 0.118 | 0.017 | 0.03, -0.04 | no |
| *ii)* Whole season, Diary and commercial fishers within study area | | 0.064 | 0.006 | 0.069 | 0.020 | 0.04, -0.05 | no |
| *ii*) Whole season. Dairy and commercial fishers in Skagerrak | | 0.066 | 0.005 | 0.070 | 0.009 | 0.02, -0.02 | no |

**Table 2.** Total estimated landings of lobster in numbers and kilos for recreational, commercial and official landings. Unknown catch is lobster caught by fishing gear that could not be allocated to recreational nor commercial sector, since the buoys were unmarked or unreadable.

| | # of lobsters | Kilo |
|---|---|---|
| Total recreational catch | 25400 | 16600 |
| Total commercial catch | 12100 | 7900 |
| Unknown | 1400 | 900 |
| Official commercial landings | 2803 | 1831 |
| Total catch | 38900 | 25400 |

**Figure 1**

**Figure 2**

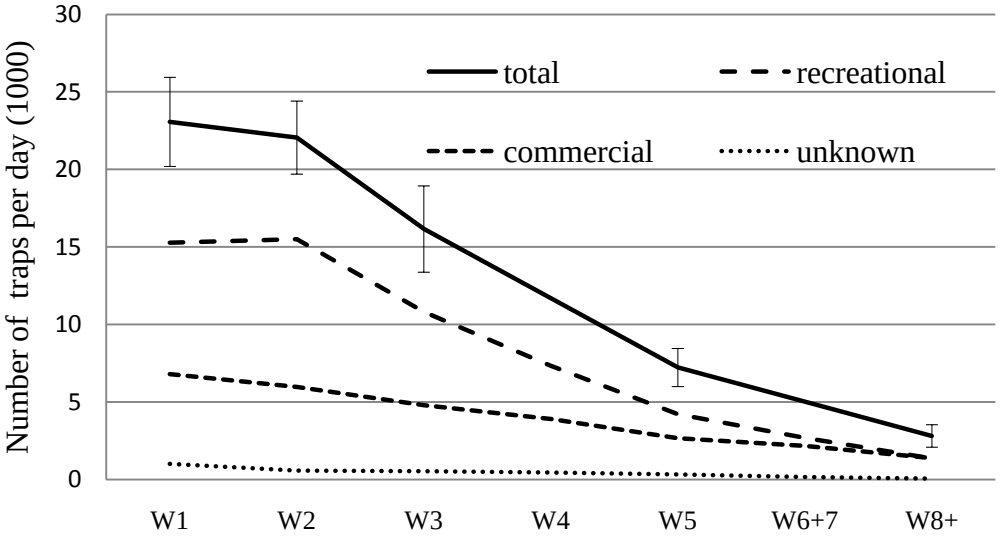


**Figure 3**

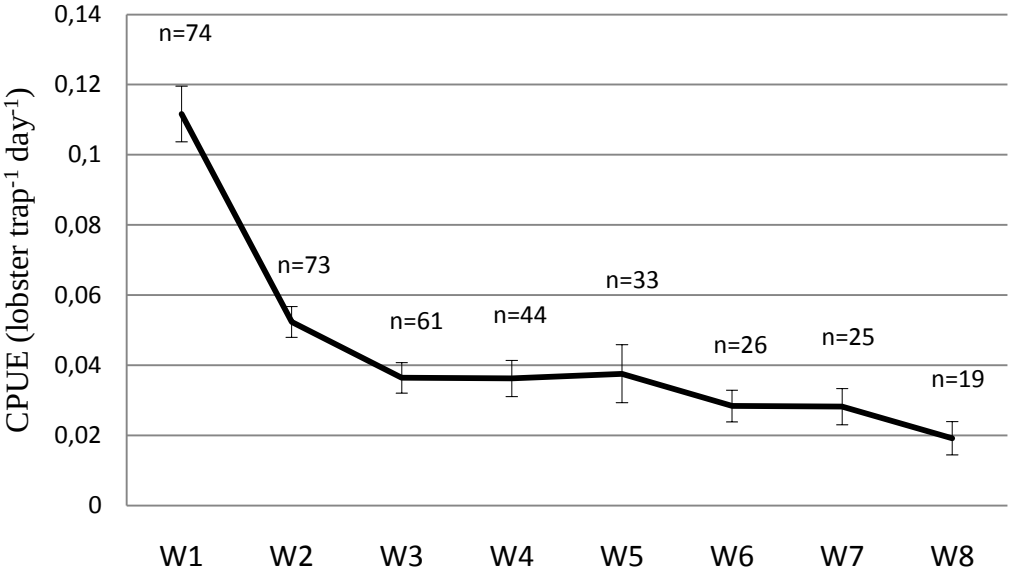
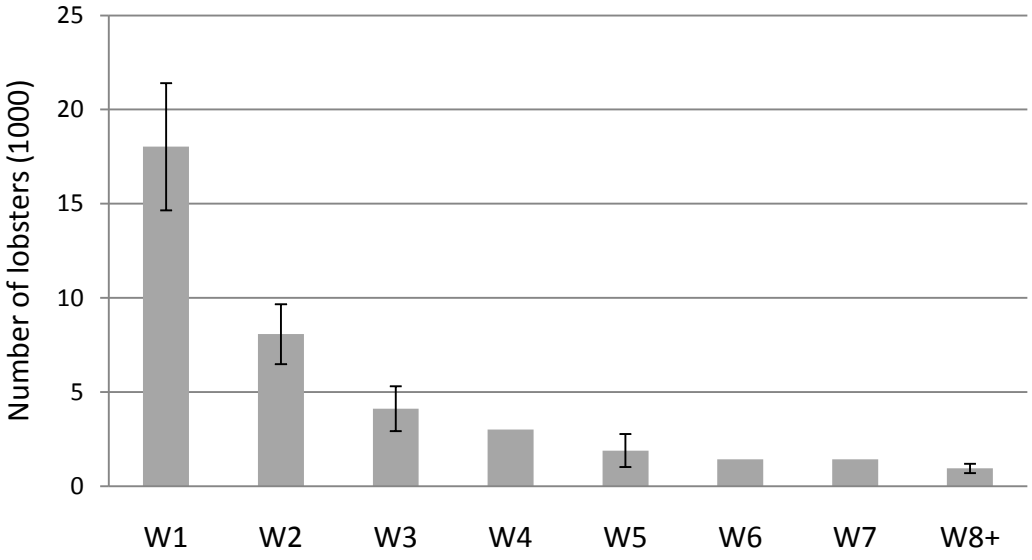
**Figure 4**