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Responses of European lobster (*Homarus gammarus)* and lobster fishers to protective management

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Summary

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Marint bevaringsområder (MPA) er kjent for sine fordeler for høstede arter innenfor vernede grenser, men mulige fordeler til omkringliggende fiskeområder er lite kjent. Dette studiet kvantifiserer hvordan reagerer den Europeiske hummer (*Homarus gammarus*) og dets fiskeri til etablering av et lite (5.2 km^2) MPA i Skagerrak. Tallrikhet og fangstvekt var beregnet fra resultater av prøvefiske bade inne og ute av MPA, før (2010-2011) og etter (2012-2016) etablering. Hummer tallrikhet og fangstvekt ble beregnet som tall av fangst per-enhet-innsats ($CPUE_N$) og vekt av fangst per-enhet-innsats ($CPUE_W$), henholdsvis. Ved bruk av før/etter metoden ble hummerfiske-press kartlagt med opplysninger fra frivillige fiskere og telling av teiner i studieområdet.

Etter 4 år med bevaring har gradienter for tallrikhet og fangstvekt utviklet seg på tvers av MPA grenser, men fordeler til fiskeområder grunnet bevaring er begrenset. Innenfor MPA har $CPUE_N$ verdier økt fra 0.748 hummer/teine/dag før etablering til 1.93 hummer/teine/dag etter etablering. Fangstvekt ($CPUE_w$) har økt fra 1.29 kg/teine/dag til 1.54 kg/teine/dag i samme periode. Det var litt økning i $CPUE_W$ i fiskeområder nær grensene, men ikke for $CPUE_N$. I fiskeområder 2-3 km unna grensene, var $CPUE_N$ verdier stabil, men $CPUE_w$ har økt betydelig. Alt dette tyder på at fiskere får større men ikke mer hummer rundt MPA. Høyere vekt av fangst i fiskeområder er sannsynligvis på grunn av minsket dødelighet av rognhummer grunnet regulering. Fiskepress fra både fritidsfiskere og yrkesfiskere har økt mest rett utenfor MPA grensene. Resultat fra dette studiet viser at sammenhenger med fiskeriet må bli tatt i betraktning når man skal se på fordeler av bevaringsområder.

Nøkkelord: hummer, *Homarus gammarus*, bevaringsområdet, hummer fangst per enhet innsats, fritidsfiske, fiskepress

Abstract

Marine protected areas (MPAs) are valued for their conservation benefits to harvested species. However, potential benefits of MPAs to neighboring fisheries are less well-understood. This study quantifies how the European lobster (*Homarus gammarus)* and the fishery for this valued catch respond to the establishment of a relatively small (5.2 km^2) MPA on the Norwegian Skagerrak coast. A series of yearly standardized trap surveys was conducted to estimate lobster abundance and catch weights both inside and outside the MPA before (2010-2011) and after the MPA was established (2012-2016). Lobster abundance and catch weights were determined as number of catch per unit effort ($CPUE_N$) and weight of catch per unit effort ($CPUE_w$), respectively. Using a similar before-after study design, the lobster fishery was described from fishery diaries and by counting all lobster traps in the study area.

After 4 years of protection, gradients for abundance and catch weights across the MPA boundaries have developed, but the export of benefits to neighboring fishing areas are limited. Inside the MPA, $CPUE_N$ values increased from 0.748 lobsters/trap/day before protection to 1.93 lobsters/trap/day after protection. Catch weights have also increased from 1.29 kg/trap/day to 1.54 kg/trap/day in the same period. Slight increases in $CPUE_w$ were observed in the fished areas near the boundary, but not for $CPUE_N$. At fished areas 2-3 km away from the boundaries, $CPUE_N$ values were stable, and catch weights have increased. This suggests that fishers around the MPA are catching larger, but not more lobsters around the MPA. Increased catch weights in the fished areas are attributed to the protection of berried female lobsters from fishing mortality. Fishing pressure, mostly from recreational fishers, is increasing the most outside MPA boundaries, resulting in lowered $CPUE_N$ and catch weight values. Results from the study indicate that determining conservation and fishery benefits of an MPA should always be considered in context of existing and changing fishing pressure in order to effectively utilize MPAs as a fishery management tool.

Keywords: European lobster, *Homarus gammarus,* MPA benefits to fisheries, lobster CPUE, recreational fisheries

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1. Introduction

Marine protected areas (MPAs)--defined here as areas where harvesting of target marine species are prohibited--have been established in many areas around the world primarily with the objectives of species conservation and management of fishery resources in mind (Gell & Roberts, 2003; Roberts, Hawkins & Gell, 2005; McClanahan, Marnane, Cinner & Kiene, 2006). Evidence from many studies indicate that organisms targeted by fisheries respond positively in terms of increased abundance and increased sizes inside MPAs as a direct result of protection (Cole, Ayling & Creese, 1990; McClanahan & Kaunda-Arara, 1996; Davidson, Villouta, Cole & Barrier, 2002; Harmelin-Vivien, *et al.,* 2008; Shears, Grace, Usmar, Kerr & Babcock, 2006; Sainte-Marie, Hoskin, Coleman, von Carlhausen & Davis, 2011). Protection benefits an area by eliminating fishing mortality, and these allow for target organisms to recover, and eventually increase their numbers over time within that area (Gell & Roberts, 2003). This population growth inside the MPA, combined with the fishing mortality in the adjacent fished area, typically builds a gradient of size and abundance across the boundary, with higher values inside and a steady decline towards the boundary and fished areas (Kellner, Tetreault, Gaines, & Nisbet, 2007; Perez-Ruzafa, *et al.,* 2008).

For an MPA to be effective as a fishery management tool, these benefits of increased abundance and larger sizes inside the MPA must be exported to fished areas outside. One mechanism is through spillover, or the net export of adult biomass across the MPA boundary to fished areas outside. Another mechanism is through the enhanced production of egg and larvae (recruitment), which also benefits fished areas. The effect of spillover to local fisheries is often considered small compared to the enhanced recruitment effect, but it plays an important role in ensuring support of the MPA among the local stakeholders (Abesamis & Russ, 2005; Abesamis, Alcala & Russ, 2006; Russ, Alcala, Maypa, Calumpong & White, 2004).

Spillover of target species from MPAs to adjacent fished areas are potentially mediated by both density-dependent and density-independent movements (Kellner*,* Nisbet & Gaines, 2008). Density-independent movements may occur due to the random movements of target species that have home-ranges in the boundary. Density-dependent spillover may occur when the population density of target species increases inside the reserve, leading to competitive interactions and eventually causing more movement of individuals to low density areas near the boundaries and outside the reserve (Abesamis, *et al.,* 2006). When these displaced individuals are captured by fishers, the spillover benefit of MPAs to fisheries is realized. Such a spillover effect can be estimated as the increase in number of catch per-unit-effort ($CPUE_N$) and weight of catch per-unit-effort ($CPUE_w$) in fished areas around the MPA.

Results from a modelling study suggest that biological responses inside MPAs develop quickly (1-5-year period); population abundance is always higher inside the protected area especially where there is strong fishing pressure outside (Perez-Ruzafa, *et al.* 2008). This has been validated by many empirical studies; increased abundance and sizes of target species in fished areas near the boundary compared to areas further away are often considered as evidence for spillover (McClanahan & Mangi, 2000; Russ, Alcala & Maypa, 2003; Stobart, *et al.*, 2009; Follesa, *et al*., 2011; Weeks, Russ, Alcala & White, 2009). Species that have limited movements (whose home-ranges fall within an MPA) and are subjected to relatively high fishing pressure, such as the European lobster (*Homarus gammarus)* are expected to show the strongest response to protection (Kelly & MacDiarmid, 2003).

The European lobster is an important but diminishing fishery resource in Norway. It used to be economically important, but it has been exploited so heavily that populations all around the country, and especially in the Skagerrak coast, have been experiencing a steady decline since the late 1950´s (Pettersen, Moland, Olsen & Knutsen, 2009). The population crashed in the 1960´s (Agnalt, *et al.,* 2004) and has not shown signs of recovery ever since. Today, it is more valued as a recreational resource with limited commercial value (Kleiven, Olsen & Vølstad, 2012). The European lobster was on the Norwegian Red List of Threatened Species; it was removed from the list only in 2015.[1] Heavy pressure from recreational fishing is believed to have contributed to the continued low numbers. It has been estimated that the fishing effort from recreational lobster fishing is 3 times higher than commercial fishing for lobster in the Norwegian Skagerrak coast (Kleiven, Olsen & Vølstad, 2011). Furthermore, it was estimated that the total catch in the fishery is nearly 14 times higher than reported landings, and that as much as 76% of the catches from commercial fishing is unreported (Kleiven, *et al.* 2012). In 2014, the official landing statistics were at 52 tons, with an estimated economic value of 10.1 million NOK.[2]

Currently, the lobster fisheries in Norway is highly regulated with the imposition of gear number limits, minimum size limits, and restricted fishing periods, but its steady decline over the decades indicate that better management should be implemented to restore this important fishery resource. It was this impetus that drove the establishment of several MPAs with the aim to protect and perhaps enhance the lobster populations along the Skagerrak in the early 2000´s (Pettersen, *et al.*, 2009).

In many areas where MPAs have been set up for the management of crustacean fisheries, often dramatic increases in abundance and sizes can be observed within a protected area after several years of protection. This has been documented for the spiny lobster *Palinurus elephas* in the Mediterranean (Goñi, Quetglas & Renoñes, 2006; Follesa, *et al.* 2008; Goñi, *et al.*, 2008), the American lobster *Homarus americanus* (Rowe, 2001), the spiny lobster *Jasus edwardsii* (Cole, *et al.,* 1990; Davidson, *et al.*, 2002), and the European lobster *Homarus gammarus* (Huserbråten, *et al.*, 2013; Moland, *et al.,* 2013a; Hoskin, *et al.*, 2011). However, studies that quantify the effects of these MPAs on the adjacent fished areas are relatively few (see Goñi, *et al.*, 2008; Goñi, Hilborn, Diaz, Maloll & Adlerstein, 2010; Follesa, *et al.*, 2011).

[1] http://data.artsdatabanken.no/Rodliste2015/rodliste2015/Norge/16523
[2] source: Fiskeridirektoratet

Goñi, *et al.* (2006) demonstrated that spiny lobster export from a 12-year-old MPA (Columbretes Island Marine Reserve in the Mediterranean) was sufficient to maintain stable commercial catches up to 1500 m from the boundary. Commercial catch-per-unit-effort gradients for spiny lobster were also highest near the boundary of this MPA (Follesa, *et al.,* 2011). The Mediterranean studies, however, did not have before-data prior to protection.

The impact of an intervention is best determined by gathering data before and after such intervention in the same site, and preferably with replicates. This before-and-after approach for quantifying fishery effects are few and far-in-between, because of the logistic challenges such studies require (Francini-Filho & Moura, 2008; Russ, *et al.*, 2003; Moland, *et al.*, 2013a). The dynamics of how gradients develop across the boundary are also logistically difficult to document. Although several studies have focused on gradients for both density and size across reserve boundaries (Harmelin-Vivien, *et al.*, 2008; Willis, Millar & Babcock, 2003; Chapman & Kramer, 1999; Halpern, Lester & Kellner, 2010; Abesamis & Russ, 2005; Forcada, Bayle-Sempere, Valle & Sanchez-Jerez, 2008), these are all on fish, and to the best of the author´s knowledge, none has been published on before-after data for lobsters.

This study aims to fill in a part of this information gap by determining the effects of protective management for the European lobster to nearby fisheries. This was done by looking into gradients of abundance and sizes for lobsters as indexed by $CPUE_N$ values and catch weights ($CPUE_{w}$), respectively, in and around the MPA. The effects of management to fisheries are also determined by looking at the changes in fishing patterns and fishing pressure around the boundaries 4 years after MPA establishment. Finally, this study documents, in fine spatial scale, the impact that intensive fishing can have to fished areas near the boundaries of a newly established protected area.

2. Study Objectives

A typical lobster MPA on the Norwegian Skagerrak coast is a well-defined area where stationary fishing gears such as traps, pots, and nets are prohibited, but where hook and line fishing for species other than lobsters are allowed (Moland, *et al.,* 2011). The biological effects of protection (increased size and abundance) inside the MPA boundaries coupled with the high mortality due to fishing immediately outside the MPA will expectedly create gradients of size and abundance across the boundary, with the highest values inside and progressively decreasing with increasing distance away from the boundaries. These gradients can be determined by measuring number catch-per-unit-effort ($CPUE_N$) as an index for abundance, and catch weights ($CPUE_W$) for as an index for size. Increased values for both $CPUE_N$ and catch weights near the border can be considered as evidence of exported benefits to fisheries.

This study aims to determine the effect of protective management of a relatively new and small lobster MPA in southern Norway to nearby fisheries. Specifically, it aims to answer the following questions:

1) How has lobstet abundance, measured in terms numbers caught per-unit-effort ($CPUE_N$), developed over time across the MPA boundaries?
2) How has the catch weight, measured in terms of weight per catch-unit-effort ($CPUE_w$) developed over time across the MPA boundaries?
3) Is there a change in the location and intensity of fishing effort relative to the MPA boundaries over time?

3. Methods

3.1 Subject species and study site

3.1.1 The subject species

The European lobster (hereafter called "lobster") is a long-lived decapod that has a traditional importance to coastal communities in southern Norway. Its preferred habitats are rocky bottoms with small outcrops where it can find and build a network of tunnels with several entrances (Cooper & Uzmann, 1980). It can reach sizes of up to 50 cm, and attains sexual maturity at a total length (TL) of 22-25 cm (Tully, Roantree & Robinson, 2001). Movement studies have indicated that lobsters have a limited mean home range of <1 km^2 (Moland, *et al.*, 2011; Wiig, Moland, Haugen & Olsen, 2013; Skerritt, Robertson, Mill, Polunin & Fitzsimmons, 2015). Earlier studies on wild lobster movement in the United Kingdom indicated that majority of lobsters moved <3.8 km from their original release positions (Smith, Jensen, Collins & Mattey, 2001). These studies indicate that lobsters do not require large MPAs to have adequate protection from fishing (Moland, *et al.*, 2011) and their limited movement makes them ideal candidates for detecting an early response to protection (Kelly & MacDiarmid, 2003).

3.1.2 Study site

The site for this study encompasses a 52.44 km^2 area in the outer skerries of Tvedestrand fjord, with the MPA covering about 4.9 km^2 in the center (9° 8′ 0" E, 58° 36′3 0" N) (**Fig. 1**). This MPA was established in an area with suitable habitats (Haugland, 2011), in what used to be a preferred fishing ground for lobsters by the locals. It was established in 2012 after a series of consultations, hearings and discussions involving the municipal government of Tvedestrand, local organizations and scientists from the Institute of Marine Research (Havforskningsinstituttet) in Flødevigen (Celius, 2014). In contrast to the many small community-based MPAs in other countries, the Tvedestrand lobster MPA was set up primarily with a research objective in mind: to provide knowledge of the effects of small-scale closures on lobster population development.

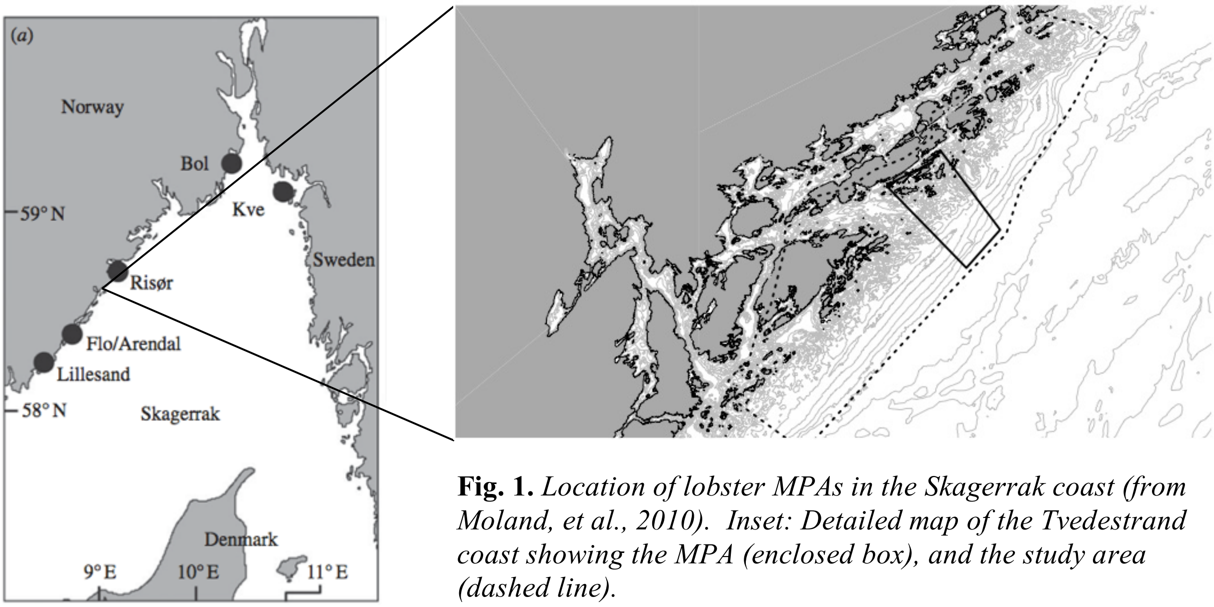


Fig. 1. *Location of lobster MPAs in the Skagerrak coast (from Moland, et al., 2010). Inset: Detailed map of the Tvedestrand coast showing the MPA (enclosed box), and the study area (dashed line).*

3.2 Data Collection Methods

To determine the presence of gradients, three different methods were used for the duration of this study: 1) Test fishing to determine gradients in $CPUE_N$ and catch weights, 2) Analysis of catch data compiled by recreational fishers during the lobster fishing season ("lobster diaries") to determine preferred fishing spots and estimate recreational catches, and 3) Lobster trap surveys to estimate fishing pressure in the area during the open season for lobster fishing. Details on these are provided in the sections that follow.

3.2.1 Method 1: Test fishing

Test fishing was conducted within the study area from 2010-2016 (**Fig. 1**). Sampling was done at around the same period every year (last week of August to first week of September), a month before the start of the open season for recreational lobster fishing. Standard modern parlour traps were used (**Fig. 2**). Sampling effort was varied from year to year; the actual number of traps deployed per year are given in **Table 1** below. Traps were left on the bottom for about 24 hours before retrieval.

Trap locations inside and around the MPA were selected at random during the first year of survey (2010). From 2011 onwards, the sampling regime was modified slightly using topography data to maximize sampling efficiency. Sampling was limited to only those areas that 1) have a rocky bottom, 2) have a slope between 5-20 degrees and maximum depth of 30 m from the surface, and 3) situated inside the study area (within 3.5 km northeast and southwest of the boundaries**,** see **Fig. 1**). No test fishing was done in the very deep areas southeast of the MPA border outside the study area.

Table 1. *Test fishing effort in the study area from 2010-2016.*

No. of traps deployed	2010	2011	2012	2013	2014	2015	2016
Outside	110	104	127	89	203	191	353
Inside	17	39	60	55	139	88	182
Total	127	143	187	144	342	279	535

Fig. 2. *The modified two-chambered 12 kg parlour trap (dimensions: 35 cm H x 66 cm W x 40 cm D) with two entrances and modifications to reduce ghost fishing. The frame is made of steel and covered with a synthetic net.*

The lobster trap

The traps used for this study have closed escape vents to prevent the escape of smaller lobsters, thereby minimizing sampling bias. The traps were also modified with an escape gash sewed up by cotton thread to prevent "ghost fishing"; if the trap is not recovered, the cotton thread eventually dissolves in seawater after several weeks, allowing lobsters and other animals to escape. The traps were baited with chopped-up mackerel (*Scomber scombrus)* before deployment and attached to a marker buoy with a 40-45m length rope. Marker buoys for each trap were individually numbered and indicated information about the test fishing activity**.**

<u>Catch location, measurement and tagging</u>

The traps were hauled up with the help of a hydraulic winch attached to side of a boat. The location of each haul was recorded using a GPS receiver. Each sampling point (a haul) also had a corresponding value for depth that was determined *in situ* by an echo sounder. Lobsters were measured for total length (TL) and carapace length (CL). Their sex was determined and they were individually tagged for a separate mark-recapture study (using T-bar anchor tags). Lobster ID from tagging was used in this study to exclude multiple catches of the same individual for the same season.

3.2.2 Method 2: "Lobster Diary" Forms

Data on preferred fishing spots, as well as data on catch numbers during the open season for lobster fishing were obtained from forms completed by recreational lobster fishers (see **Appendix 5** for examples). The forms were designed to collect information on the number of traps deployed per fisher, trap soak time, number of lobsters caught, biological information on lobster catch (i.e., below or above the legal size of 25cm TL, sex, and reproductive status), and trap locations. Trap locations were indicated by fishers on a map with a grid system (grid resolution of 500 m x 500 m, see **Appendix 5**). Checking by researchers in the field indicated that most of the fishers can confidently estimate the locations of their traps on the map using known landmarks. Data were also checked by researchers for completeness and validity before inclusion in the analysis. Trap locations were converted to the cartesian geographic coordinates of the center of each grid. These coordinates were then used for the analysis of spatial data.

3.2.3 Method 3: Lobster Trap Counts

Fishing effort around the MPA was estimated by conducting boat-based total counts of all lobster traps in the study area. The counts were done in the opening week of the lobster fishing seasons in 2009, 2014, 2015, and 2016. All lobster traps (marked by buoys) in the area were counted, and their numbers and coordinates (determined using a GPS receiver) were recorded**.** The coordinates were then plotted on a map to determine the density of lobster traps in a certain location on the same grid system for the given time frame (one week) in the area.

3.3 Data Preparation and Analysis

Data clean-up, analysis and generation of figures and maps were done primarily in the R environment for statistical computing (http://www.r-project.org) using the following packages: *mgcv* (Wood, 2011)*, pscl* (Jackman, *et al.*, 2017), *spdep* (Bivand & Piras, 2015), *sp* (Pebesma & Bivand*,* 2005), *splancs* (Rowlingson, Diggle, Bivand, Petris, & Eglen, 2013), *rgeos* (Bivand, Rundel, Pebesma, Suetz & Hufthammer, 2017b).

3.3.1 Clean-up, preparation, and analysis of data from test fishing

Clean-up

For the test fishing data, trap soak time was standardized to 24 hours so that catch-per-unit-effort (CPUE) can be computed as the number or weight of lobsters caught in a trap for one day. Data from the following were excluded from the analysis:

- Traps that had a soak time of more than 24 hours (which resulted from researchers not being able to retrieve the traps due to unfavorable sea conditions);
- Data from lobsters that were recaptured twice or more during the same field season (considered as “trap happy” lobsters).

Preparation of spatial data

The location of the traps (longitude and latitude), were converted into UTM units for use in data analysis and mapping in R. Spatial and temporal correlation was checked using auto correlation tests (ACF), to confirm that the data was neither spatially or temporally correlated before proceeding with the analysis.

The distance from the boundary (Dist) for each trap was calculated automatically *(rgeos* package in R) using the MPA edges as the reference polygon. To aid interpretation, the boundary line was designated as 0. Distance from the boundary was negative inside the MPA and positive outside the MPA.

Data analysis for $CPUE_N$

There were two possible statistic models that could be used for the analysis of $CPUE_N$ data from test fishing: generalized linear models (GLM) or generalized additive models (GAM) (Wood & Wood, 2017). Models for both can tackle data sets with many zero observations (zero-inflated), but GAMs are considered more appropriate for ecological data since the regression technique is not restricted by linear relationships, and it is flexible with regards to the statistical distribution of the data (Zuur, 2012). For $CPUE_N$ analysis, generalized additive model analysis using the zero-inflated Poisson (ziP) family (hereafter called ZIGAM) was used where the data was treated into two groups: the group with positive observations and zeroes that are expected from a Poisson distribution and the group with the excess zeroes (see Wood, 2011 for details).

The suitability of using a zero-inflated model was confirmed after stimulation studies using maximum likelihood methods with GLMs (after Zuur & Ieno, 2016) showed that the ordinary Poisson linear models could not cope with the large number of zeroes in the $CPUE_N$ data set. Although the results observed can be obtained with a GLM, it was highly unlikely (see **Appendix 4**, Fig. A4.1). A maximum likelihood simulation of the zero-inflated model, however, indicated that the model can cope with the test fishing data, which had about 65% zero observations (**Appendix 4**, Fig. A4.2). A further check of the $CPUE_N$ response in these simulations also showed a very good fit with our actual observations.

The most parsimonious generalized additive model describing the relationship between $CPUE_N$ and three covariates--distance from boundary, years of protection and depth--is as follows:

$$CPUE_N \sim s(\text{Distance x (yr.pr.}_{(i)})) + s(\text{depth}) \qquad \text{(Formula 1)}$$

where *s*(Distance) is a regression spline that denotes the function of distance of the trap from the boundary, yr.pr.(*i*) is a non-ordered variable that denotes the number of years of protection (0 before protection, and a range of 1-4 years after protection), and *s*(depth) denotes the function of the approximate depth of the trap from the surface. The interaction between distance to boundary and years of protection was included to allow different forms for the splines among the different sampling years. The fitted values of the model were obtained using the *predict.gam* command.

Determination of lobster weights

The weight of individual lobsters caught during test fishing was estimated from total length (TL), sex, and reproductive status using a predictive length-weight relationship. This relationship was determined using a GAM and the *predict.gam* function, with actual measurements of lobster total length and weights taken from 1921 to 1966 as inputs (see **Appendix 3** for details). The length-weight relationship was exponential but varied according to reproductive status (female, male, or female with eggs), with the largest males being the heaviest.

Data analysis for lobster weights

Due to the nature of the data from the traps (many zero values, and a few very large continuous numbers that have a positively skewed distribution, **Fig. 3**), a two part zero-adjusted generalized additive model using a gamma distribution (hereafter called ZAGA model) was used to determine trends in catch weights. This approach divides the data set into two groups: the group that has zero observations (presence-absence), and the group that has non-zero values (weights). A binomial distribution was used to model the first group, and an altered gamma distribution was used for the second group.

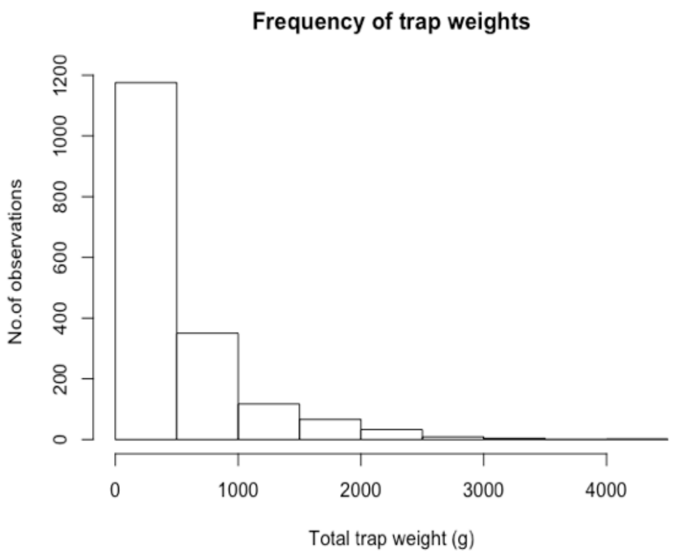


Fig. 3. *Histogram of haul weight observations.*

The analysis was implemented using the *mgcv* package (Wood & Wood, 2017). A parsimonious ZAGA model was obtained, and the following formula was used to model the catch weight response:

$$CPUE_W \sim s(Distance, by=factor(yr.pr.)) + s(depth) \quad \text{(Formula 2)}$$

where s(*Distance)* is a function of the location of the hauled trap relative to the border, *yr.pr.* is non-ordered variable indicating number of years of protection, s(*depth)* is a function of the depth of the trap the surface.

3.3.2 Preparation and analysis of reported recreational CPUE data

Data from forms submitted by recreational fishers from 2010-2016 were used, but only trap hauls that were inside the study area were included in the analysis. Their locations were indicated as a cell in the gridded map they were provided (**Appendix 5**). This cell has an area of 500 x 500 m. Each trap haul of every fisher was assigned a coordinate, which fell on the center of the grid cell for his location (ex. M22 is assigned 9^0 6´0¨ E, 58^0 36´0¨N). The distances of these grid coordinates to the boundary were then determined by using the *rgeos* package in R.

Data for recreational CPUE did not fulfill the assumptions for parametric tests, hence analyses were conducted using non-parametric tests. Wilcoxon rank test was used to determine if mean distance of preferred fishing spots from the MPA boundary differed across years. Post-hoc analysis was done by conducting a Dunn pairwise rank sum test. Reported recreational CPUE values and size of lobsters caught outside the MPA boundary before and after protection were compared using the non-parametric Chi Square and Wilcoxon rank sum tests.

3.3.3 Preparation and analysis of fishing gear survey data

Locations of fishing gear in the study area consisted of GPS coordinates; these were categorized into commercial or recreational lobster traps. The Euclidean distances of these points to the boundary were determined by using the same method (gDistance from the package *rgeos*). Mean distances to the boundary were determined for each category for different years. Areas of high fishing intensity (hotspots) were determined by generating a density map for each year with the use of the density analysis function for planar point pattern data.

3.3.4 Model selection and validation

The model selection process for all models was done by backwards selection using Akaike´s Information Criterion (AIC) scores. Validation for the optimal model is done by inspection of residual plots. Pearson residuals were used for validation of the the zero-inflated models (see **Appendices 1 & 2**).

4. Results

4.1 Number of catch per-unit-effort ($CPUE_N$)

4.1.1 Test fishing CPUE

Preliminary data analysis using the mean values for $CPUE_N$ for every year indicated that the trend is different inside and outside the MPA. While values outside the MPA have remained below 0.5 lobsters/trap/day since 2010, values inside the MPA have increased dramatically since protection began in 2012 **(Fig. 4).**

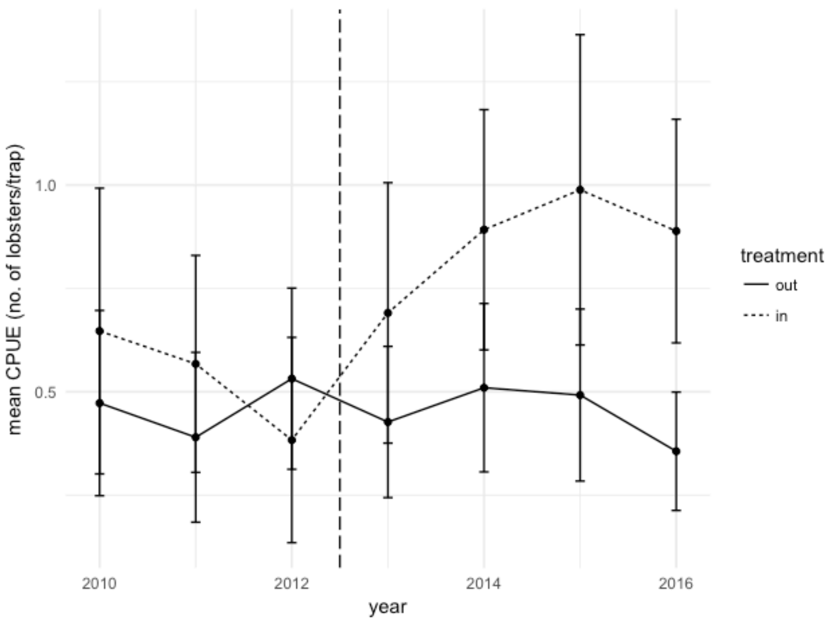


Fig. 4. *Preliminary CPUE trends inside and outside the boundary from 2010 to 2016. Dashed vertical line indicates when the MPA was established.*

The optimal ZIGAM result indicates that depth, as well as the combined effect of distance from the boundary after the second year of protection, are significantly associated with the $CPUE_N$ response (**Table 2**). Each year has a differing trend. The $CPUE_N$ values inside the MPA increased immediately after protection, while these values remained relatively low outside. Also, traps that were hauled from around 20m had the most number of lobsters. The

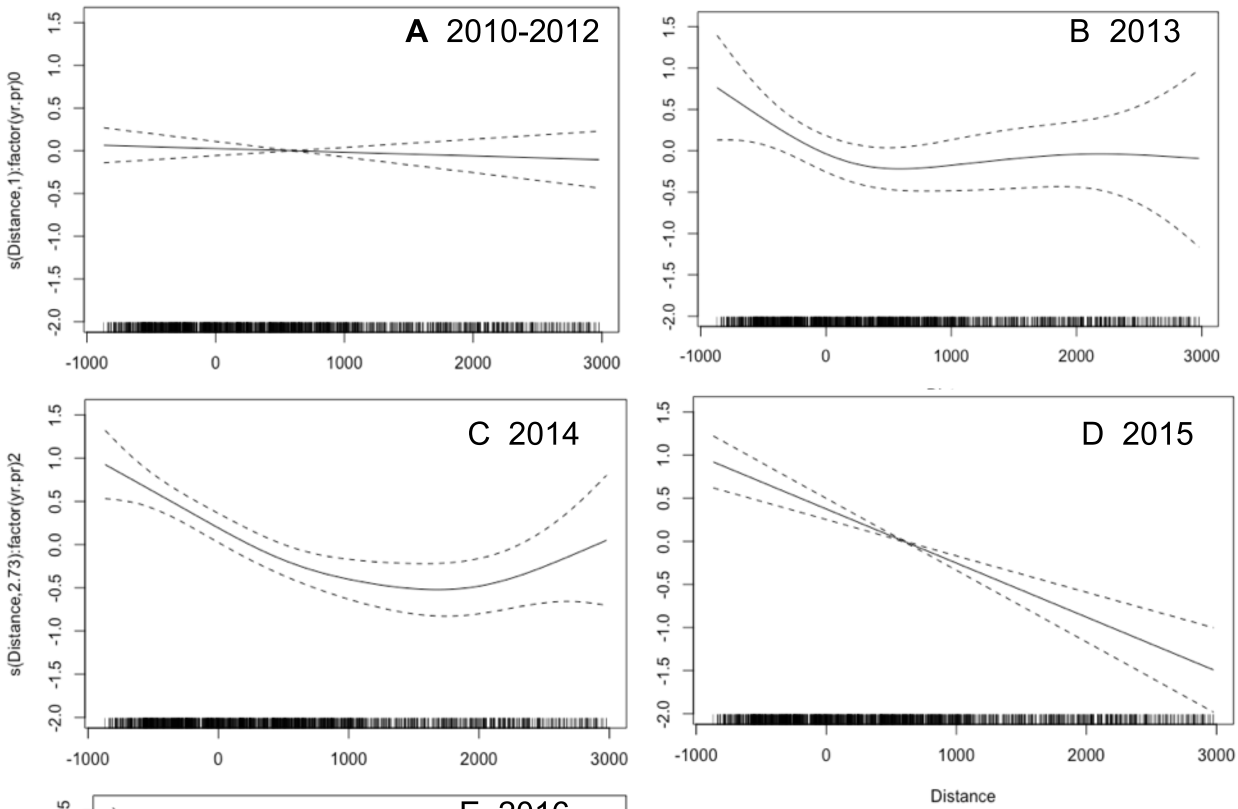
GAM results indicate, for example, that traps hauled from 20m depth inside the boundaries in 2016 have the highest $CPUE_N$ values (**Fig. 5A-5E** and **Fig. 5F**). The predictive model explains 27.4% of the variation observed in the data set.

Table 2. *Final model results for test fishing $CPUE_N$.*

Smooth terms	Edf[1]	p- value
s(distance x yr.pr.0)	0.3744	0.230
s(distance x yr.pr.1)	0.8926	0.186
s(distance x yr.pr.2)	2.3265	3.83×10^{-8} ***
s(distance x yr.pr.3)	0.9741	2.76×10^{-9} ***
s(distance x yr.pr.4)	3.3205	2×10^{-16} ***
s(depth)	3.2881	7.99×10^{-10} ***

[1]estimated degrees of freedom R^2= 0.274
***Significance level: 0.0001 n= 1745

The combined effect of distance from the boundary and years of protection indicate increasing $CPUE_N$ inside the MPA with increased years of protection compared to the fished areas outside. The predictive model indicates that at the optimum depth of 20m, the $CPUE_N$ inside the MPA has increased, from a $CPUE_N$ of 0.748 lobsters/trap/day prior to protection, to 1.93 lobsters/trap/day 4 years after (**Fig. 6**). This represents a 2.5-fold increase in the number of lobsters caught in traps inside the MPA. However, $CPUE_N$ did not increase in fished areas adjacent to the MPA boundary; $CPUE_N$ values in 2016 in these areas (between 0 to ~ 1.5 km) were lower than the $CPUE_N$ values before protection. $CPUE_N$ values farther away remained stable.



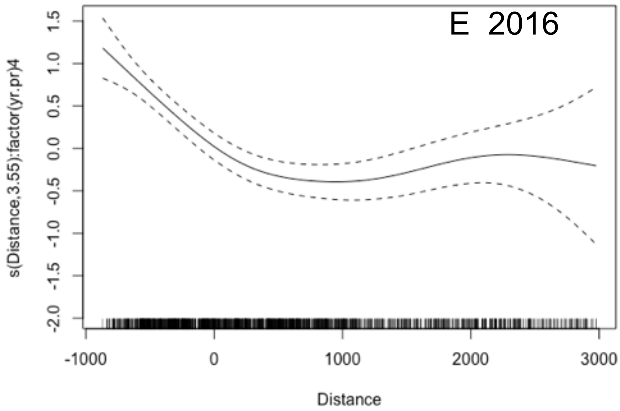


Fig. 5 A-E. *The combined effect of distance from the boundary and years of protection to the $CPUE_N$ response of lobsters A) before protection, B) 1 yr after protection C) 2 yrs after D) 3yrs after and E) 4 yrs after. Dotted lines are 95% confidence intervals.*

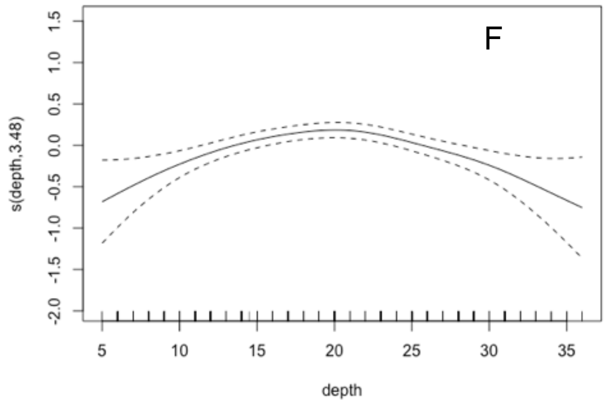


Figure 5-F. *Additive effect of depth to $CPUE_N$.*

Note: The notation *s(depth,3.48)* indicates the estimated degrees of freedom(edf) for the spline that describes the $CPUE_N$ response in relation to depth.

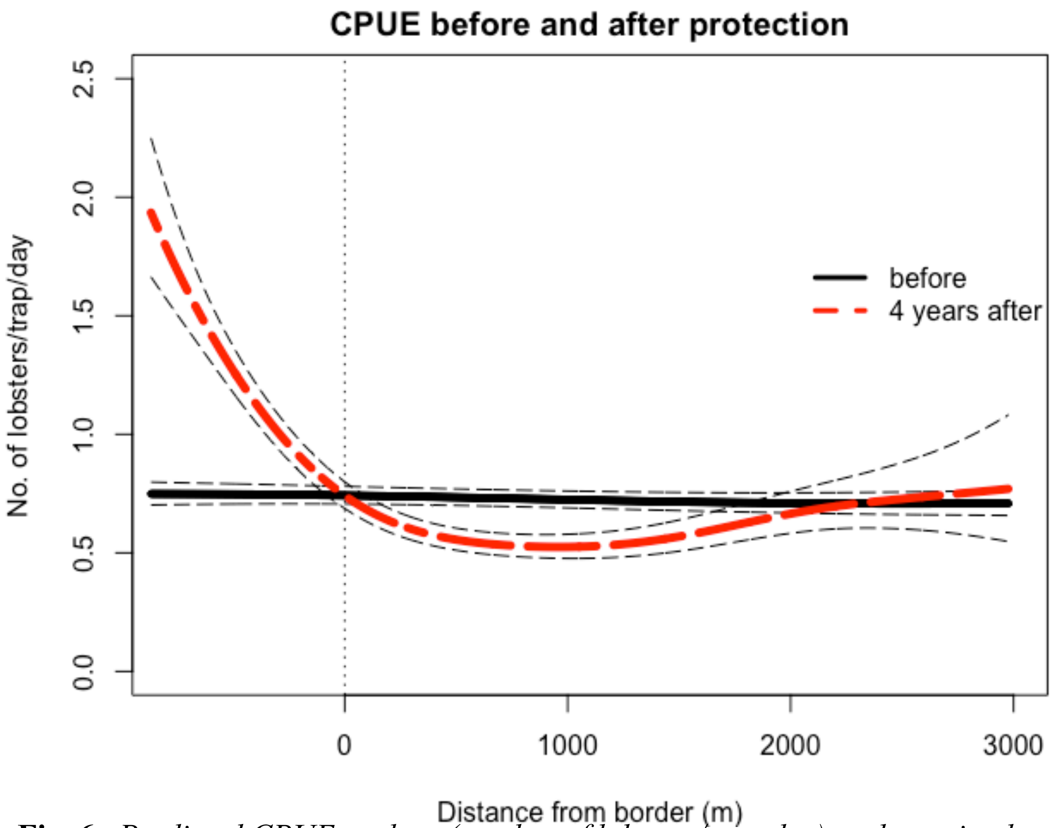


Fig. 6. *Predicted $CPUE_N$ values (number of lobsters/trap-day) at the optimal depth (20 m below the surface) prior to (black solid line) and 4 years after protection (red dashed line). Intervening years were omitted for the sake of clarity. Vertical dotted line indicates MPA boundary. Black dashed lines are 95% confidence intervals around the prediction line.*

4.1.2 Reported Recreational CPUE

Data obtained from recreational fishers was limited and variable; there were between 10-12 reporters for each year out of the many fishers in the area. There was a total of 7 196 trap hauls in total, but the number of hauls reported for each year varied (**Table 3**). Majority of these hauls contained no lobster catch.

Table 3. *No. of recreational fishing hauls within the study site per year from submitted forms.*

	2010	2011	2012	2013	2014	2015	2016
n=	1962	629	843	855	507	1 146	1 254
					TOTAL		7 196

Distance of traps from the boundary

The locations of fishing spots for each fisher were consistent on a year-to-year basis, indicating that each one had a preferred fishing area. Fishers who had fishing spots in the area that became the MPA relocated their activities to areas adjacent to the MPA.

Trap hauls reported from recreational fishers were significantly closer to the boundaries after protection (2507.94 m) compared to before protection (2864.9 m) ($p = 2.2 \times 10^{-16}$, Wilcoxon rank test with continuity correction).

The mean recreational CPUE for all the reported fishing spots outside the boundaries decreased from 0.185 lobsters/trap/day prior to protection to 0.164 lobsters/trap/day after the MPA was established, but this decrease was not statistically significant ($p=0.129$, Wilcoxon rank test). Furthermore, recreational CPUE in the north-eastern part of the MPA was also consistently higher compared to the south-western part, both before and after protection (**Fig. 7 A-B**).

The size composition of the reported catch (lobsters with TL> 25cm, and those that are under the legal size) was analyzed. Approximately 12% of the catch was under the legal size prior to 2012, and this decreased to 9.9% percent between 2013-2016. No significant differences in the size composition were detected before and after protection (Chi Square test, df=5, $X^{2\ crit} > X^{2obs}$).

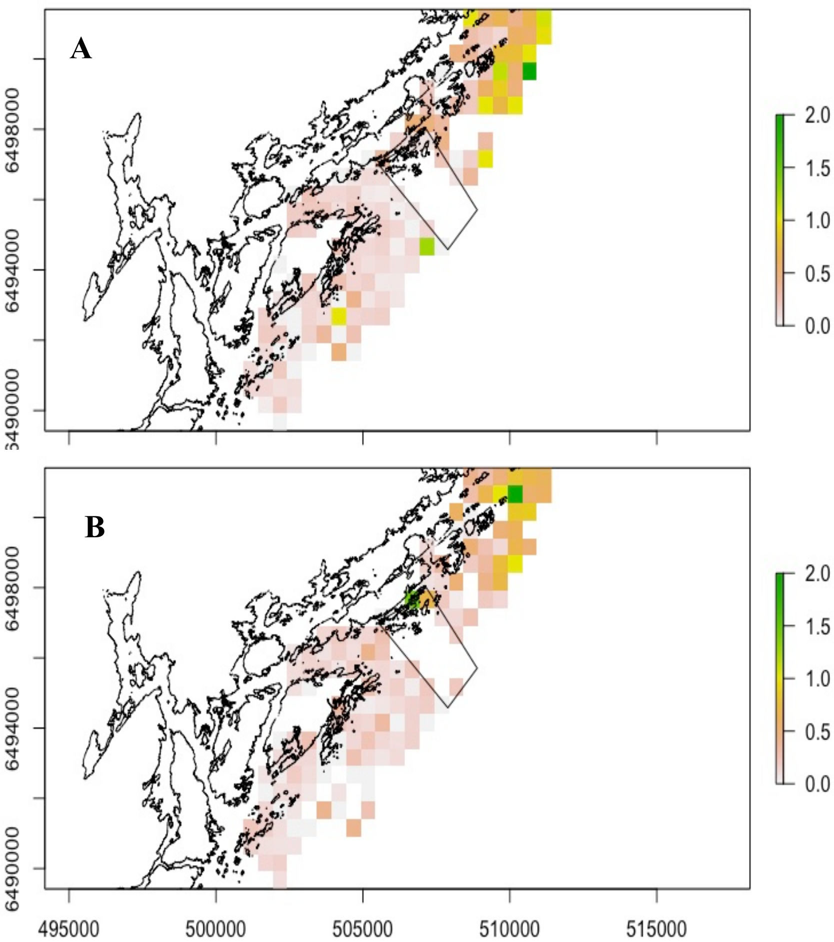
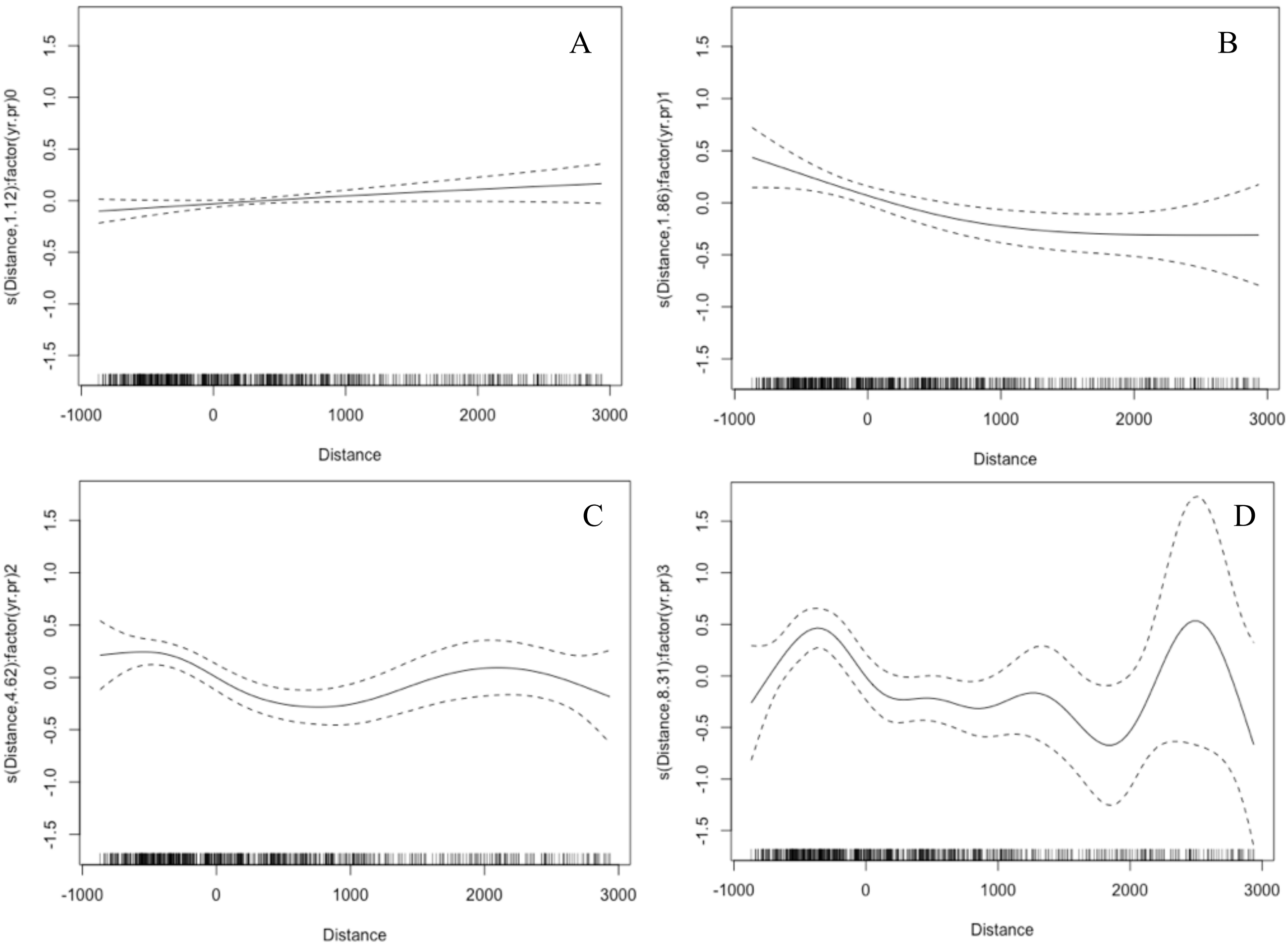


Fig. 7. *Mean reported CPUE for different areas around the MPA (A) before (2010-2012), and (B) after (2013-2016) protection.*

4.2 Catch weights ($CPUE_w$)

Results from the zero-altered GAM indicate a non-linear but significant change of catch weights with distance from the boundary and years of protection (**Table 4**). Catch weights inside the MPA increased immediately, and a gradient has formed as early as the year after protection (**Fig. 8B**). Responses in the succeeding years were varied, but there is a consistent trend of a decreasing catch weight gradient from the center of the MPA towards the boundaries. In 2015, the second peak for catch weights reflected the unusually large lobsters that were hauled up in the fished areas north-east of the MPA (**Fig. 8D**). Depth has a marginally small but significant effect to catch weights (**Fig. 8E**).



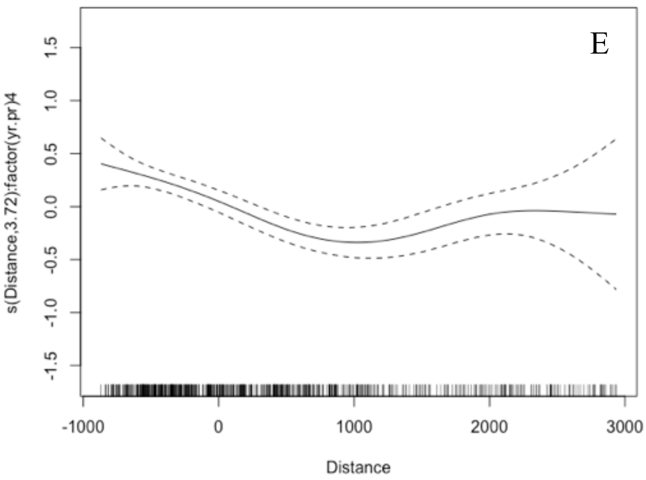


Fig. 8A-E. *Combined effects of distance to the boundary and years of protection on the catch weights ($CPUE_W$) of lobsters A) before protection, B) 1 yr after protection C) 2 yrs after D) 3yrs after and E) 4 yrs after. Dotted lines are 95% confidence intervals.*

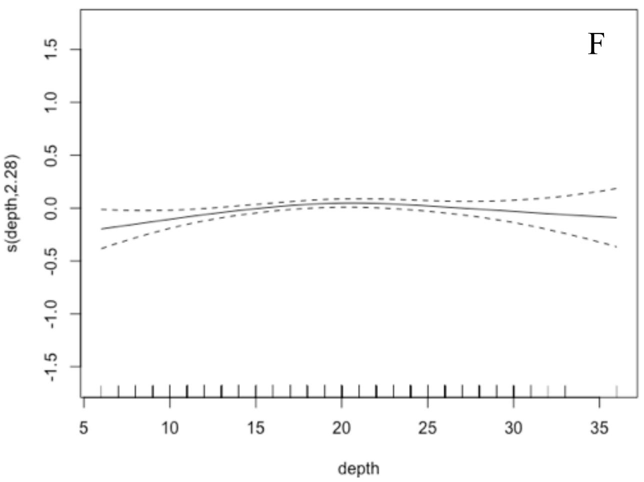


Fig. 8F. *Additive effect of depth to catch weights.*

Note: The notation *s(depth,2.28)* on the y axis indicates the estimated degrees of freedom(edf) for the spline that describes the $CPUE_W$ response in relation to depth.

Table 4. *Final model results for catch weights (zero-altered GAM).*

Smooth terms	Edf[1]	p- value
s(distance x yr.pr.0)	1.123	0.0807
s(distance x yr.pr.1)	1.855	0.000981***
s(distance x yr.pr.2)	4.617	0.000650***
s(distance x yr.pr.3)	8.314	2.35 x 10^{-5}***
s(distance x yr.pr.4)	3.720	1.17 x 10^{-8} ***
s(depth)	2.284	0.049210*

Significance level: 0.0001= *** 0.001= ** 0.01= *

[1]Estimated degrees of freedom R^2 (adjusted)= 0.203

The model predicted $CPUE_w$ results suggest that although $CPUE_w$ values 4 year after protection are higher in the whole study area, there is a different trend for weight increase inside and outside the boundary. Catch weights have increased by 16.23% (from 1.29 kg/trap/day to 1.54 kg/trap/day) inside the MPA, while these have increased by 36.45% (from 0.61 kg/trap/day to 0.96 kg/trap/day) in the farthest fishing area. This increase is lowest at around 800m-1200m away from the boundary (**Fig. 9**). The model explains 25.3% of the variance observed.

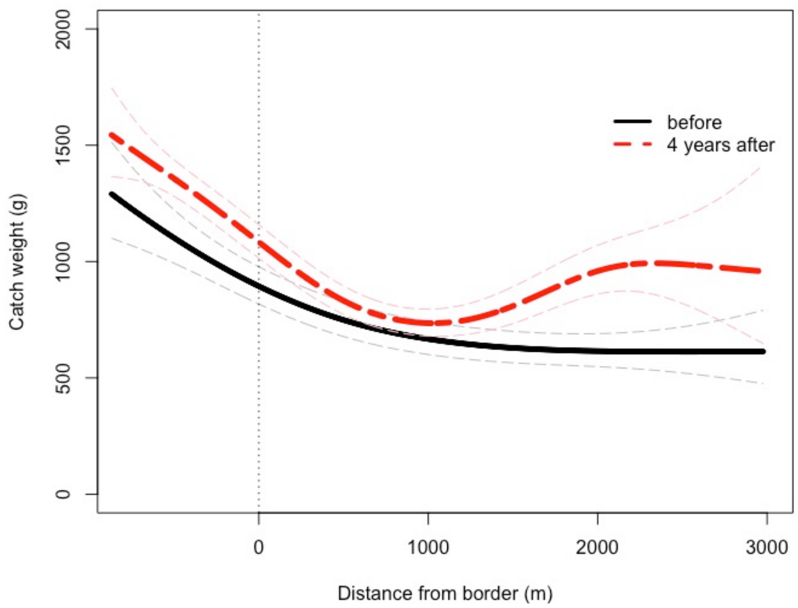


Fig. 9. *Predicted values for catch weights across the boundary before (black solid line) and 4 years after protection (red dashed line). 95% confidence intervals are in grey (before) and pink (4 years after). Dotted vertical line represents the MPA boundary.*

4.2 Fishing Intensity

The number of lobster fishing traps observed in the study area increased from 478 traps in 2009 to 966 traps in 2016 (**Table 5**), an increase of 248%. Recreational lobster traps comprised a majority the of traps observed. Fishing "hotspots" have appeared and seem to be intensifying over time (**Fig. 10**).

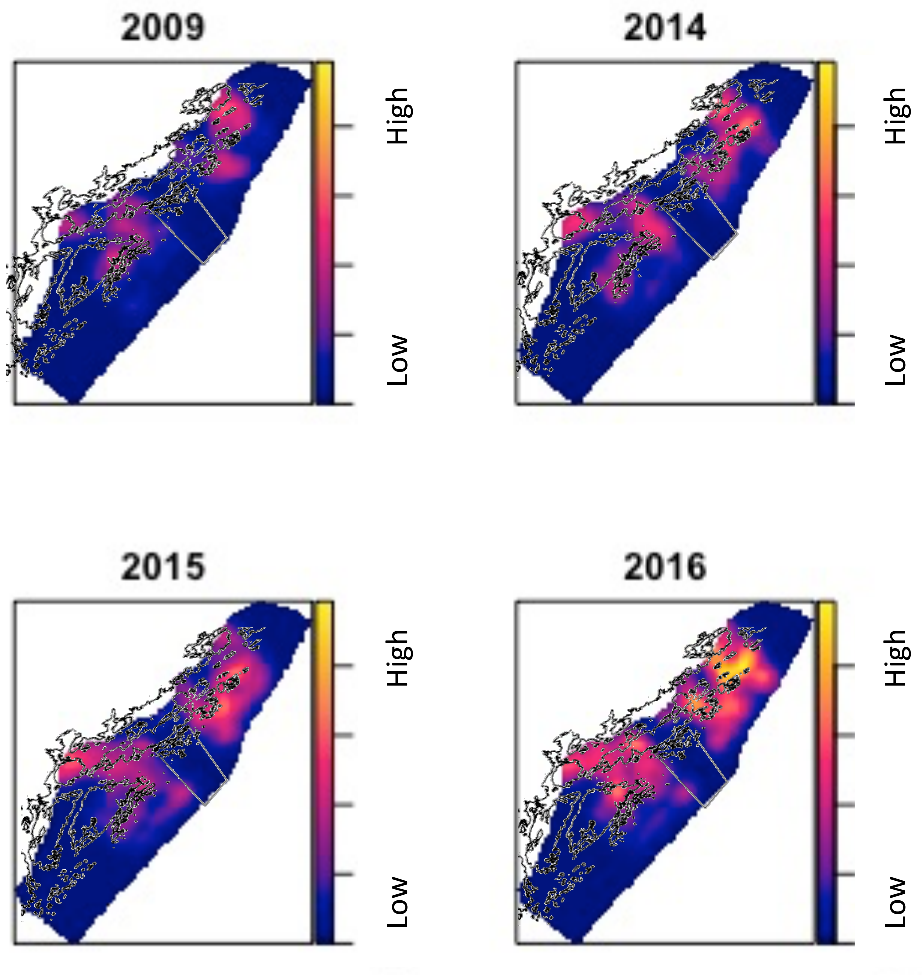


Fig. 10. *Relative intensity of traps and location and of lobster fishing hotspots (yellow areas) in the study area during the first week of the open season from 2009-2016. Scale indicates relative intensity of traps: blue areas= low intensity, yellow areas= high intensity.*

While the number of recreational fishing traps are increasing rapidly, the number of commercial fishing traps seems to be stable in the study area. However, the mean distance of traps from the boundary has shifted over time; both recreational and commercial fishers are fishing closer to the boundary in 2016 than they did in 2009 (**Fig. 11**), and this trend is being driven by recreational fishers (**Fig. 12**).

Table 5. *Total number of traps by fishery type and year observed in the study area.*

	2009	*2014*	*2015*	*2016*
Recreational	356	535	619	847
Commercial	122	118	115	119
Total	478	653	734	966

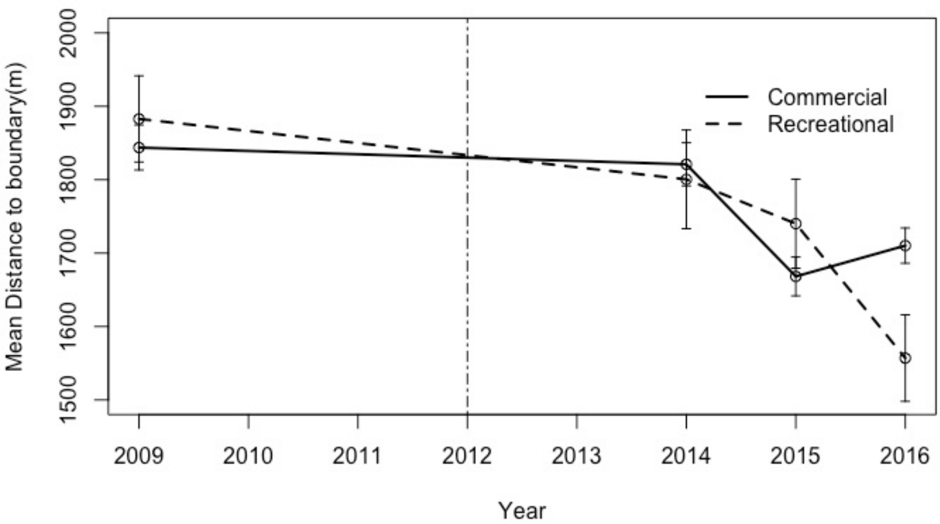


Fig. 11. *Mean distances of lobster traps by fishery type to the boundary from 2009 to 2016. Stippled vertical line indicates start of protection. No data is available from 2010-2013.*

A cursory analysis of standardized histograms of distances of traps to the border in years where data is available (**Fig. 13 A-D**) indicate that fishing effort density within 500m of the boundary increased immediately after MPA establishment and has remained high ever since.

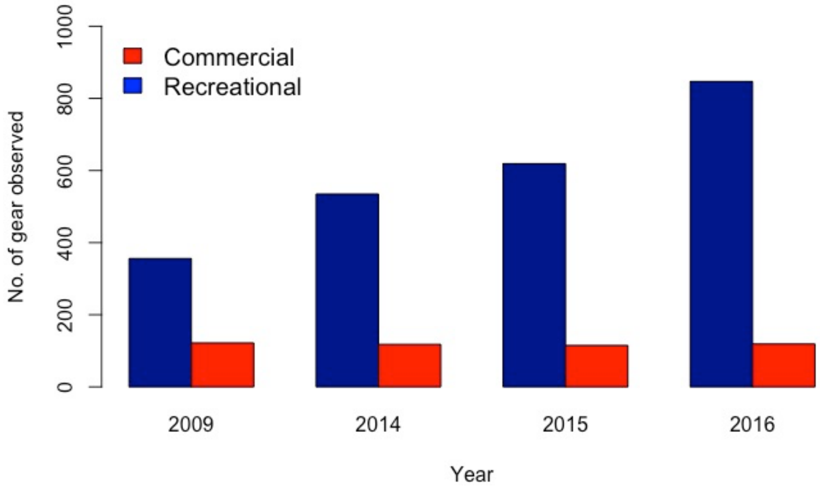


Fig. 12. *Total number of observed gear by fishery type in the study area from 2009-2016.*

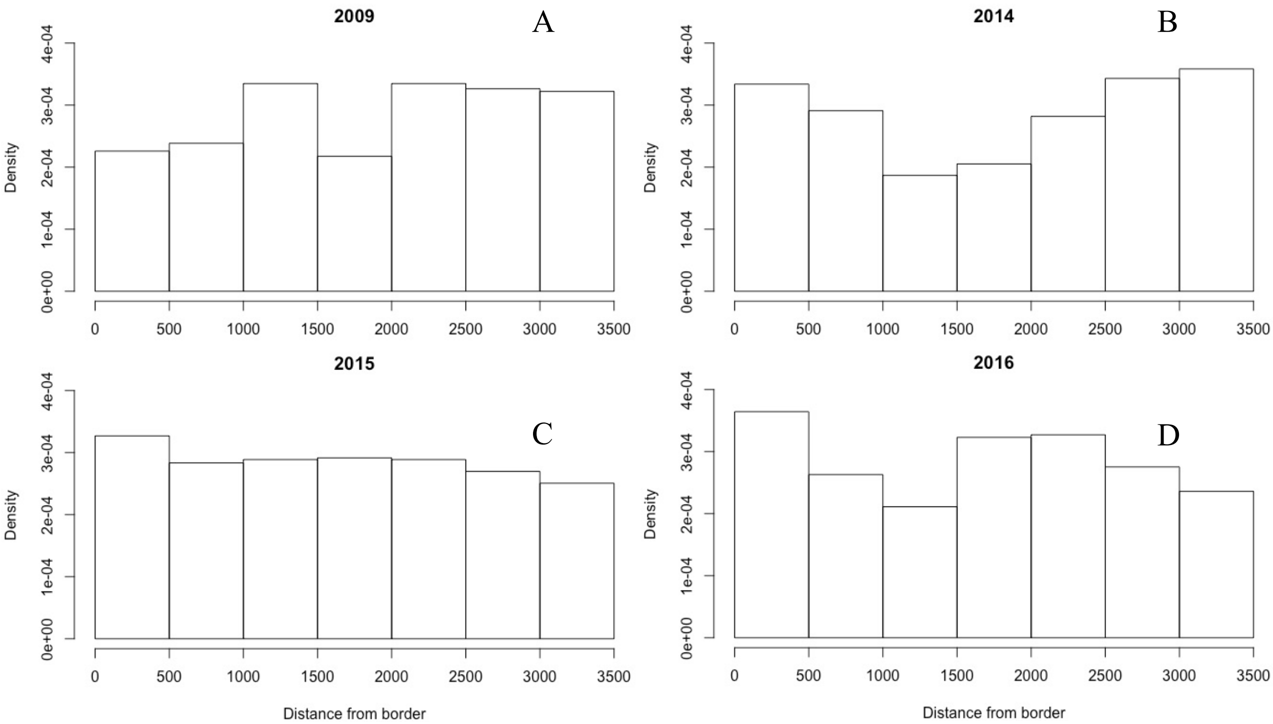


Fig. 13 A-D. *Relative density of lobster traps along given distances from the border before (A) and after (B,C,D) MPA establishment.*

5. Discussion

Results from this study indicate that the MPA for lobsters in Tvedestrand has exported limited benefits to adjacent fished areas after 4 years of protection. Estimated abundance and catch weights show a decreasing gradient from the center of the MPA towards the boundaries. However, only the abundance of lobsters inside the reserve have increased following protection, while increased $CPUE_N$ has not been detected in fished areas around the MPA. Catch weights in the entire study site have increased by 16%-35% since protection, with the highest increase in catch weights observed in the fished areas more than 2 km away from the boundaries. Fishing pressure in the areas around the MPA are increasing, but seem to be concentrating near the boundaries. These findings indicate that protective management has both biological and fishery-related components that should be considered at the same time.

Catch per unit effort ($CPUE_N$)

Protective management has an immediate effect on the $CPUE_N$ of lobsters inside the MPA; a gradient is visible after only one year, and $CPUE_N$ values inside the MPA have almost tripled after 4 years of protection. This rapid response of lobsters to protection in general has been noted in earlier studies. Hoskin, *et al.* (2011) noted the rapid increase in abundance of *H. gammarus* at the Lundy no-take reserve after only 4 years of protection, although these authors did not look at gradients relative to the boundary. Davidson, *et al.* (2000) recorded a 22% increase in rock lobster (*J. edwardsii)* numbers inside the Tonga Island Marine reserve 5 years after establishment. Follesa, *et al*. (2008) recorded a 200% increase in *P. elephas* abundance after 4 years of protection in the Mediterranean.

Some authors, however, are skeptical of the rapid response in abundance of species with slow life histories in small reserves. Jennings (2001) points out that patterns of abundance in small reserves may be driven by the spatial dynamics of a population: movement in and out of the MPA and fished areas. Eggleston & Parsons (2008) suggest that disturbance due to sport fishing can induce movement into reserves presumably through conspecific attraction where lobsters follow chemical cues to undisturbed sites. This “spill-in” effect, a behavioral response to protection (the lack of fishing disturbance), can result to higher densities inside the MPA because of the net emigration into the reserve in the early stages of protection.

$CPUE_N$, in a strict sense, does not equal abundance, as it only represents the subset of the catchable lobster population. But, it works as a good index of the number of lobsters that are available to the fisheries (but see Richards & Schnute, 1986). The observed steep $CPUE_N$ gradient towards the boundary can attributed to fishing mortality (or the lack thereof). Long–term protection is associated with a decrease in natural mortality for lobsters (Moland, *et al.,* 2013b), which results to bigger sizes and higher abundance inside an MPA, while fishing outside the boundary significantly reduces the population of catchable lobsters (Wiig, *et al.* 2013). Heavily fished areas around the MPA will therefore have lower abundances compared to areas without or with less fishing pressure.

The $CPUE_N$ pattern observed for this study is very similar to the CPUE pattern observed for *P. elephas* (Goñi, *et al*. 2006), although the methods are not comparable, and the reserve was older and much bigger at 44 km^2. This pattern has also been predicted by Hilborn, *et al.* (2006), in scenarios where stock was rebuilding from overexploitation before marine protected area implementation. Goñi, *et al*. (2006) attributed this pattern (a plateau followed by a depression before stabilizing) to concentrated fishing pressure around the boundary.

Catch Weights

The higher catch weights for lobster traps 4 years after protection indicate that the fishermen are getting larger lobsters in the fishing areas around the MPA, even if they are not getting more. This increase in catch weights inside the MPA can be attributed to protection, as recovery in biomass following reserve establishment is a consequence of reduced mortality rates and greater survivalship at age (Jennings, 2001). The depression near the border in the catch weight trend that was observed for 2016 is similar to the $CPUE_N$ trend, and it might be due to the same factors (heavier fishing pressure and increased mortality due to fishing).

Interestingly, catch weights have increased the most in areas more than 1500m from the boundary. The sex composition of the catch here (50.38% females) is slightly different compared to inside the MPA (where only 41.2% of the catch are females). Since Norwegian law mandates that berried females are to be released if caught during the open season for lobster fishing, female lobsters have a higher life expectancy outside the MPA, and they can thus grow larger. The larger sizes of female lobsters in the traps from fished areas, most likely due to protective regulations, has been documented in the Skagerrak (Kleiven, *et al.,* 2017). Around the Tvedestrand MPA, larger sizes and the slightly higher number of females might account for the different trend in catch weight values observed outside the MPA. This trend of bigger females (mean TL for females= 273.33 mm compared to 264.3 mm for males) is apparent even in the fished area near the boundary, which had generally smaller individuals compared to other areas outside the MPA.

Goni, *et al*. (2010) attributed the higher weight of lobster catches by commercial fishermen in areas around the Columbretes lobster MPA to protection, and estimated that although the number of lobsters caught annually did not quite make up for the loss of their fishing ground, the increased weight of their catches more than compensated for this loss. It will be interesting to see if this trend will also be observed in the Tvedestrand MPA after a decade or more of protection.

<u>Movement</u>

The gradients in CPUE and catch weights observed in this study can be attributed to the combined effects of protection and fishing pressure. However, movement might also play a crucial part in these results. Male lobsters are known to be aggressive and territorial (Karnofsky & Price, 1989). Movement of larger (and generally more aggressive) lobsters into the MPA can result to higher aggressive interactions, and thus the eventual displacement of smaller lobsters to the border areas. This will produce a similar gradient in catch weights, and further reinforce the existing gradients due to protection and fishing mortality.

Spill-over to fisheries requires a net movement of lobsters out of the MPA. A recent study by Thorbjørnsen, *et al*. (*in prep.)* has documented that lobsters moved in and out of three other MPAs in the Skagerrak, but about the same number were moving in both directions. The median distance covered by lobsters inside these MPAs was 75m. Similar preliminary results were observed in recapture data from the Tvedestrand MPA; lobsters moved in and out of the boundary, but this can be attributed to short-range movement within their home range. Majority of recaptured lobsters inside the Tvedestrand MPA (62%) stayed within the MPA, and they were recaptured within 100m of the location they were tagged in.

Interestingly, Thorbjørnsen, *et al.* (*in prep.)* documented in their study that although there was no net movement from the MPA, the sizes of lobsters moving out of the MPA are slightly bigger compared to those that are moving in. This will provide bigger but not more lobsters to the fished area, which concurs with the results observed in this study.

<u>Fishing pressure</u>

Many fishers are aware that protection yields benefits; there will be more and bigger lobsters inside the MPA—and consequently—at the boundary, compared to the fished areas. This results in a phenomenon called "fishing the line" (Kellner, *et al.*, 2007), where the boundary area becomes a preferred fishing site, and the fishing pressure here increases more. Concentrated fishing effort around the MPA boundaries have been noted in many other MPAs in Europe (Stelzenmüller, *et al.* 2008). The decreasing distance of traps to the boundary over time, as well as the relatively higher frequencies of traps here compared to other areas indicate that this trend is also occurring in the Tvedestrand MPA.

Could such a shift in the fishing pattern imply that the MPA is effective in the recreational fisher´s view, because majority now prefer areas that are nearer the boundary in 2016 compared to back in 2014? Also, could the eventual move of traps closer to the boundaries after 4 years of protection be due to the fishers´ expectations of bigger and better catches here? Only a survey of recreational fishers´ view could provide the answers to these questions. The author was unfortunately not able to reach any of the recreational fishers who participated in this study for comments, despite repeated attempts. Interestingly, the mean distance of commercial fishers´ traps to the boundary are significantly lower compared to recreational fishers in the first two years after the MPA was established. If the assumption holds that commercial fishers will choose to fish only in areas that have good potential yields, this implies that they have always considered the fishing area around the MPA as a prime fishing area.

The MPA in Tvedestrand was established to determine how MPAs for lobsters can function as a fishery management tool. This study looked into the effects of protective management to fisheries around the MPA. After 4 years of protection, the benefits exported to fisheries seem to be limited. This does not imply, however, that the MPA is not effective as a fishery management tool, because evidence from older lobster MPAs around the world indicate that it takes time, perhaps decades, before density-dependent spillover due to protection takes effect (Shears, *et al.*, 2006; Babcock, *et al.*, 2010; Abesamis & Russ, 2005). Furthermore, the shift in the fishing pattern around the Tvedestrand MPA makes it difficult to ascertain if the export of benefits to the fished area is happening, because fishing pressure has the effect of increasing the slope of the expected gradient (e.g. decreased abundance and sizes) in the fished areas adjacent to the MPA. The data on fishing intensity around the MPA is a snap shot of the fisheries in the area, and effectively shows that fishing pressure is increasing over time around the MPA. This trend is expected to continue and probably intensify in the coming years, unless some regulations on recreational fishing pressure are put in place.

6. Conclusions and Recommendations

To conclude, protection over several years has resulted in increased abundance and catch weights of lobsters inside the MPA studied here, but the effects to nearby fished areas are limited. Gradients have developed, but the high fishing pressure in the areas around the MPA and the relatively young age of the MPA should be taken into consideration in interpreting these results. Although the protective regulations on berried females can produce only limited increases in the catch yield for lobster fishers in the area, their importance in sustaining the population cannot be emphasized enough—especially when the high fishing pressure in the area is taken into consideration. Furthermore, the increasing fishing pressure in the study area makes it difficult to detect the effects of protection around the MPA.

Lobsters are a long-lived species, and it could take many years before any significant positive effects of protection for this species is realized in the fishing areas around the MPA. Indeed, this effect of protection might never develop in the neighboring fished areas if the trend towards increased fishing pressure continues.

"Fishing the line" is a phenomenon that reflects the expectations of fishers, and not exactly the actual available fishery resource in the boundary area. More than anything, it reflects the fishermen´s belief that protection is working. Since it takes many years before density-dependent spillover for lobsters (and thereby exported benefits for fished areas) can occur, this expectation must be managed. If fishing pressure is not abated, its negative effects might eventually extend into the boundaries of the MPA, eroding potential spillover benefits even before it can be felt in the fisheries.

The author recommends several measures that can be taken to support a healthy lobster fishery along the Norwegian Skagerak coast:

1) Continued protection of the MPA, as it requires a long time for the benefits of protection to be felt in the fisheries. More MPAs should be established to create better connectivity among the network of existing MPAs in the Skagerrak area.

2) Consider the prospect of reducing fishing pressure by regulating the number of traps that each recreational fisher can use during the open season (see Kleiven, *et al.* (2017) for details on other suggested measures for regulations).

Also, it is recommended that data collection for this study be extended, so that the long-term benefits of MPAs for adjacent fished areas can be determined. Indications of the potential benefits to fisheries have been observed, but only a long-term study can show this effectively. To establish if spillover is happening, a larger data set on both movement and size gradients is needed a few years from now.

As a final note, MPAs by itself are probably not the magic bullet that will address the problem of declining lobster fisheries in Norway. They are spatial management tools that should be included in the fisheries management toolbox, and be implemented sensibly together with existing regulations. Currently, the lobster MPA in Tvedestrand is part of a network of small, experimental MPAs in the Skagerrak coast that extends from Lindesnes to near the Swedish border. Additional regulations have been recently put in place; as of the time of writing, recreational fishers are now required to register in the national data base if they are participating in the yearly open season for lobster fishing. A maximum size limit has also been imposed: all lobsters having a total length of 32 cm are to be released. All these new regulations are steps in the right direction towards maintaining a healthy, sustainable lobster fishery in Norway for the coming years.

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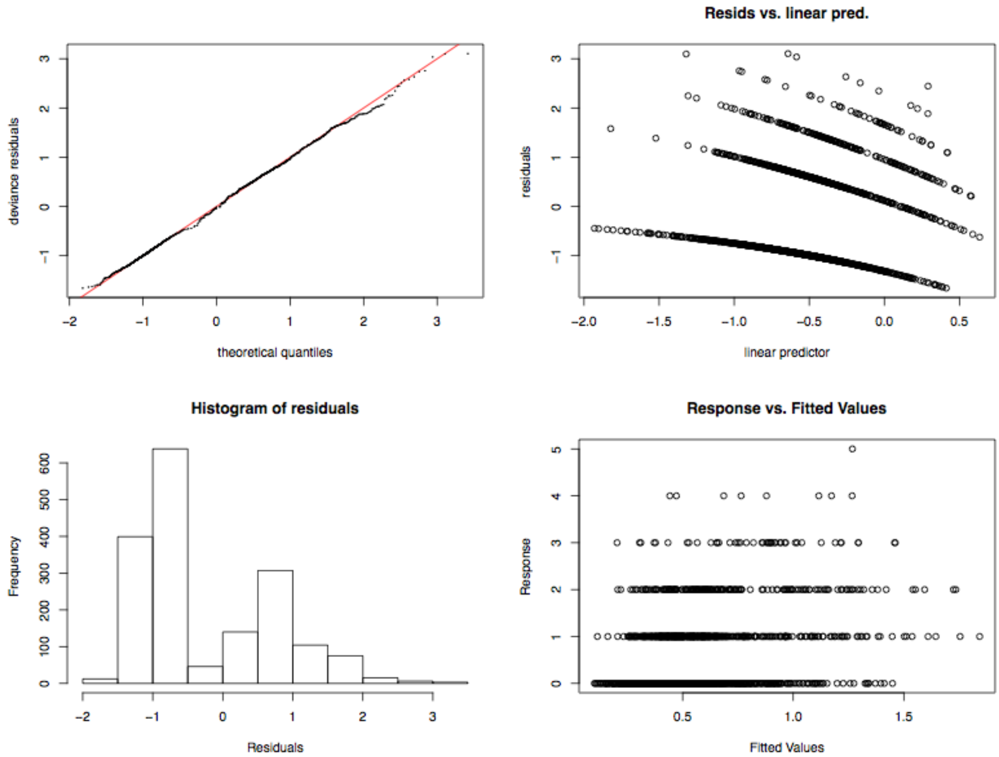
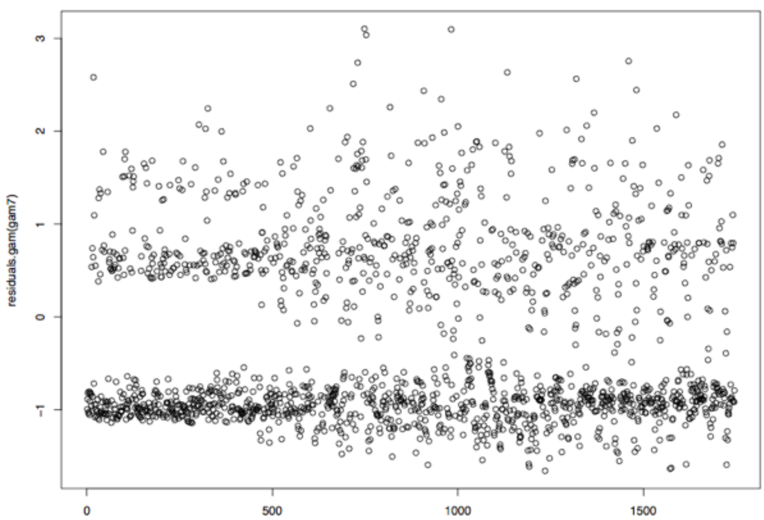
Appendix 1: Residual plots for zero-inflated GAM

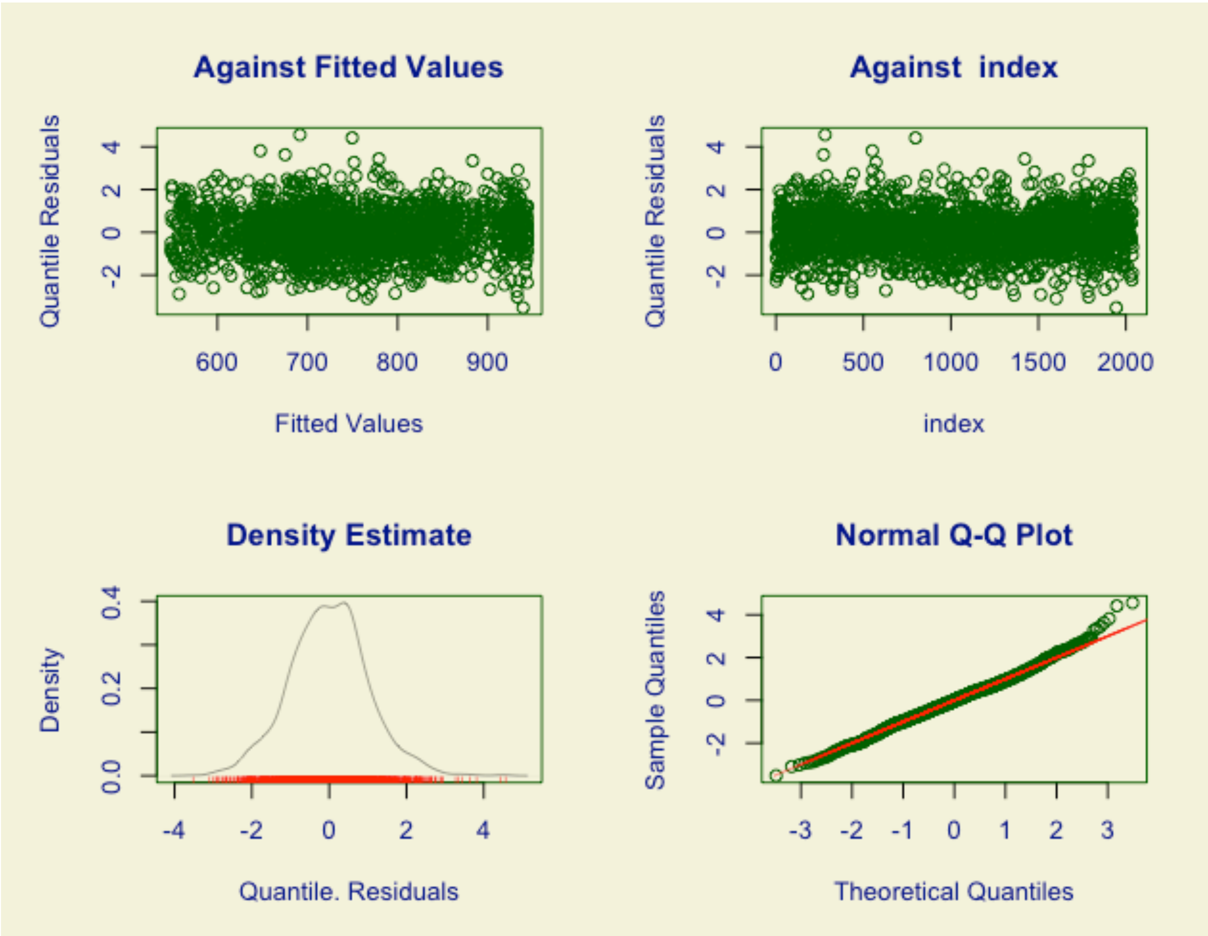
Residual plots (see Fig. 1-4 below) indicate that although the model can explain only 29.9% of the deviance observed, the fit of the predicted values to the actual value is good (Residual vs predicted values plot, upper right). Banding patterns are expected when the response are discrete numbers, as with a Poisson distribution (CPUE).



The residual plot (fitted values on the x axis and residuals on the y axis).



Appendix 2: Residual plots for zero-altered GAM



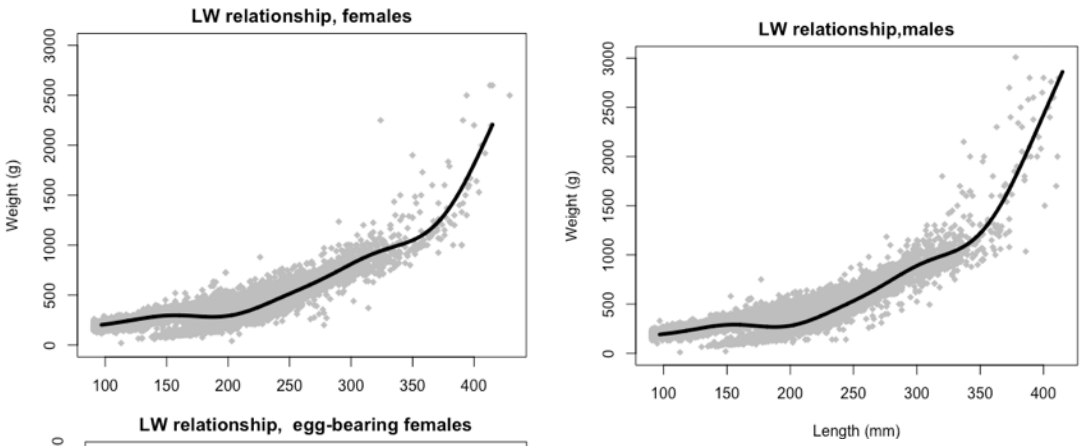
Appendix 3: Determining the length-weight relationship of lobsters

Historical data from 1921-1966 containing approximately 143,125 observations on length, weight, gender, and other variables was used to determine the length-weight relationship of lobsters. A generalized additive model (GAM) with the following variables was run:

Vekt.gr ~ s(Lengde,by=factor(Sex))

The command *predict.gam* was used to determine the fitted values of biomass for all the individual lengths from 2010-2016 that are presented in the graphs below.

GAM was used instead of GLM to accurately model the non-linear increase in biomass for all groups. Comparisons with models using quadratic relationships in GLM were made, and the additive model had a better pseudo R^2 value compared to a linear model. The results indicate that the growth curve is similar for all groups, but that beyond a certain size (roughly above 350mm), male lobsters tend to be much heavier compared to a similar-sized female. This result is confirmed by field observations that the biggest males tend to have the heaviest claws.



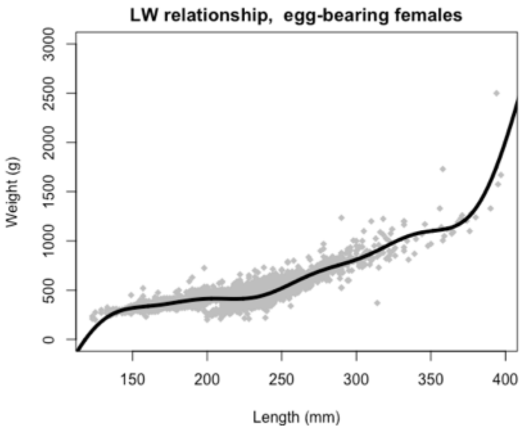


Figure A3.1- A.3.3 Length-weight relationship of females (upper left), males (upper right), and egg-bearing females (lower left). Gray points are actual observations from 1921 to 1966.

Appendix 4: Simulation of the GLM and ZIP models for CPUE data

The results of the maximum likelihood simulation study indicate that although the Poisson GLM can cope with the number of zeroes in the data set, the results are unlikely. The ZIP model however, can adequately simulate data sets that have as much as 65% zeroes.

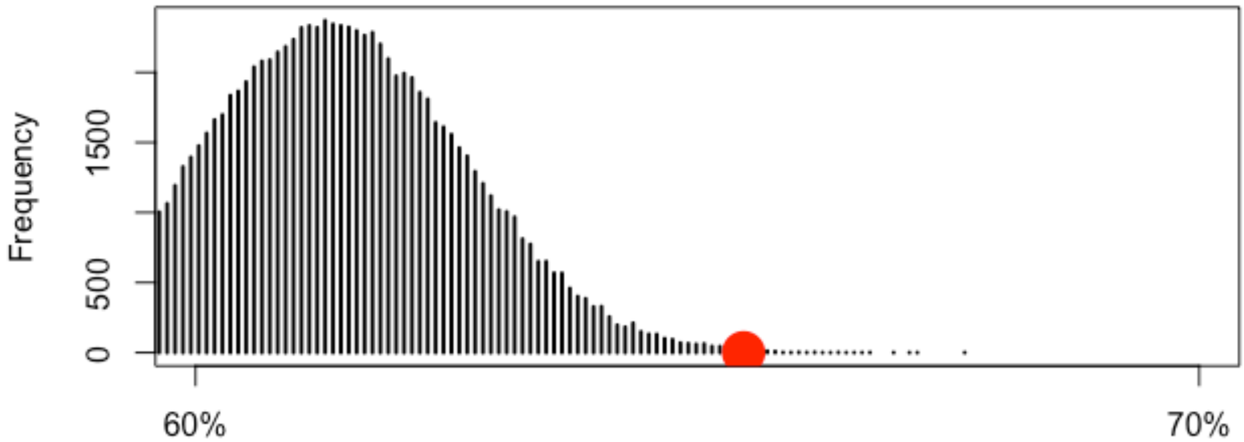


Figure A4.1 Frequency table for the percentage of zeroes in 100,000 simulated data sets from the fitted Poisson GLM model for the test fishing CPUE. The red dot represents the percentage of zeroes in the observed data.

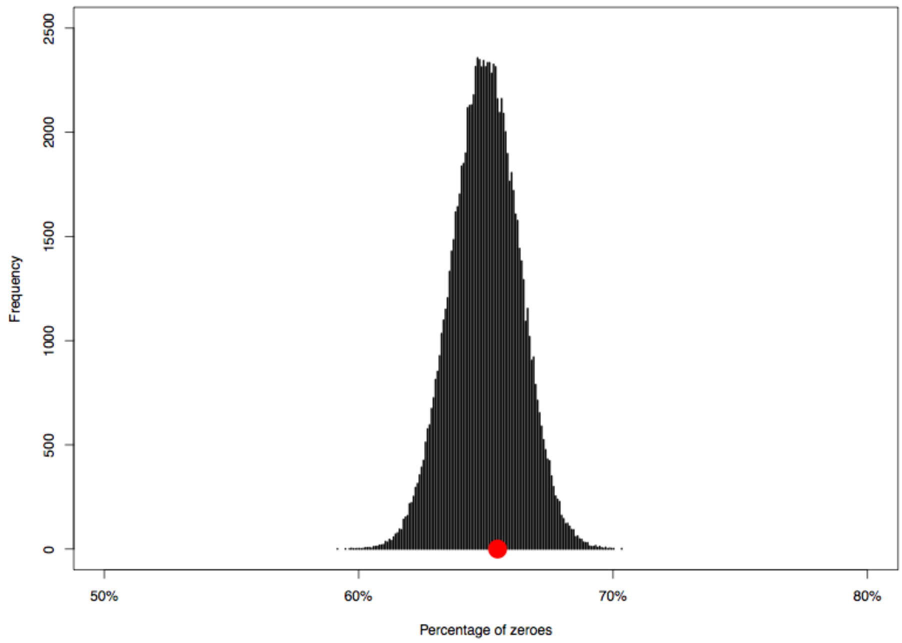
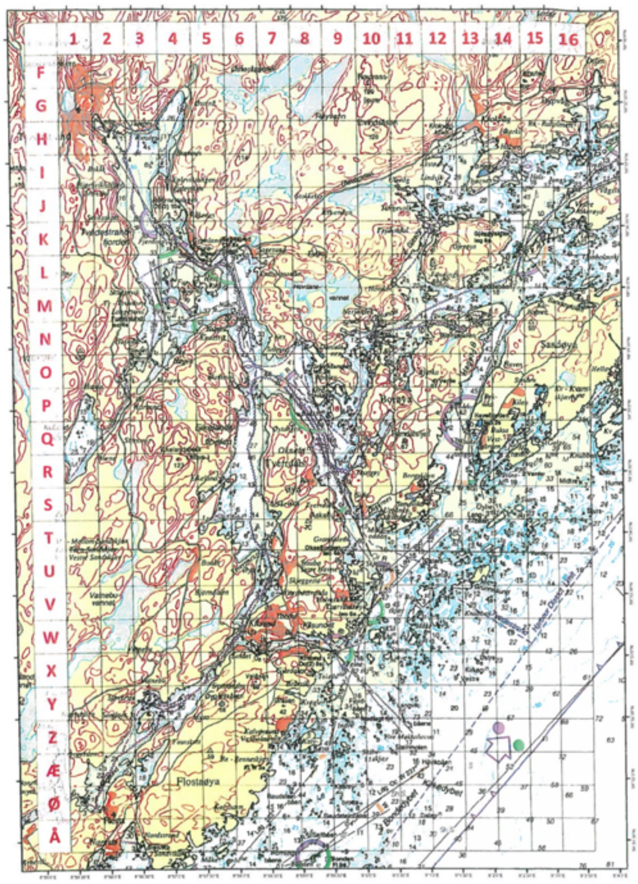
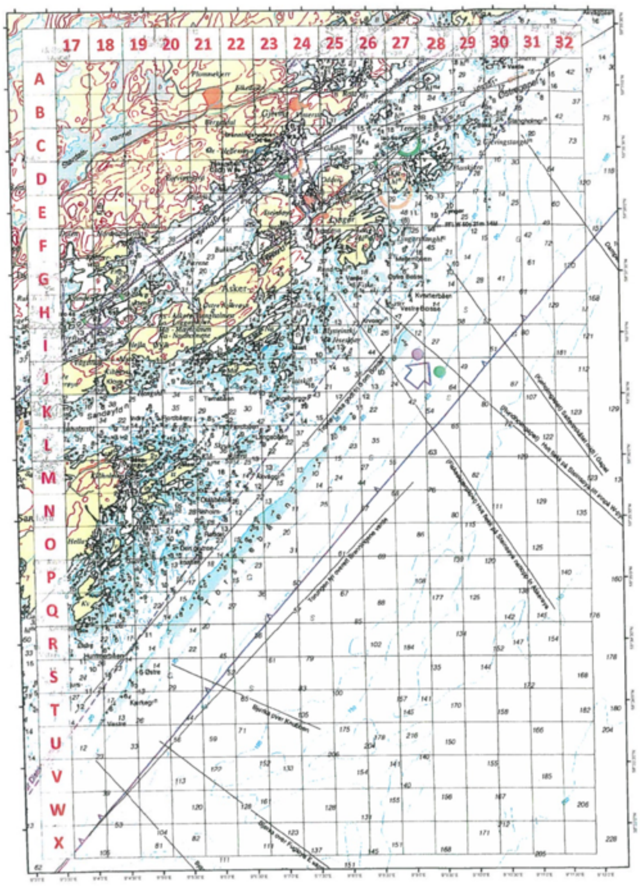


Figure A4.2. Frequency table for the percentage of zeroes in 100,000 simulated data sets from the fitted ZIP model for test fishing CPUE. The red dot is the percentage of zeroes in the observed data.

Appendix 5: Lobster diary form (filled out example)





Hummerfisket 2016
Fangstdagbok

HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH

Navn [redacted]

Dato 6. oktober
Sted Tvedestrand Kommune

Teine	1	2	3	4	5	6	7	8	9	10
Døgn ute	1	1	1	1	1	1	1	1	1	1
Kartområde	G24	G24	G25	G25	G25	H25	H25	H25	I27	I27
Totalt antall hummer	0	0	1	0	0	1	0	0	1	0
Over (≥25) minstemål (ikke rognhummer)			1						1	
Under (<25) minstemål (ikke rognhummer)										
Antall rognhummer						1				
Kommentarer. Mistet teine? Skriv inn hvor mange, trolig årsak og hvilket kartområde										

Dato 8. oktober
Sted Tvedestrand Kommune

Teine	1	2	3	4	5	6	7	8	9	10
Døgn ute	2	2	2	2	2	2	2	2	2	2
Kartområde	G24	G24	G25	G25	G25	H25	H25	H25	I27	I27
Totalt antall hummer	1	0	0	0	0	0	0	0	0	0
Over (≥25) minstemål (ikke rognhummer)	1									
Under (<25) minstemål (ikke rognhummer)										
Antall rognhummer										
Kommentarer. Mistet teine? Skriv inn hvor mange, trolig årsak og hvilket kartområde										