Size selectivity of standardized lobster traps used in long-term monitoring and their ability to catch large European lobsters (*Homarus gammarus*).

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Abstract

Harvesting the resources of the ocean has been an integral part of both human settlement and advancements for millennia. In later years, the effects of unsustainable harvesting have become clearer, and several management regulations have been sanctioned to preserve populations that are being threatened by overfishing. One of these management regulations is Marine protected areas (MPAs). In Norway, the Flødevigen lobster reserve was established in 2006 to study the effect of protection on the local European lobster (*Homarus gammarus*) population. The population has since increased in both numbers and size, but lately the maximum observed body size of lobsters within the reserve has been stagnating at around 400 millimeters (mm). In this study, the sampling method used in Norwegian lobster reserves was tested and evaluated. This was done to see whether the standard traps used to survey lobsters have been under-sampling the larger individuals through gear selectivity. This was done by introducing 10 collapsible fish traps with a substantially larger entrance funnel (270mm) to each day of sampling. The results show that there was an up to 10% difference in the body size of the lobsters caught in the standard traps compared to the larger fish traps. The large fish traps also caught 50% of the lobsters over 400 mm. This strongly suggests that the standard traps used in monitoring are size selective against large lobsters, and that traps with a larger funnel are better than smaller funnels at catching large lobsters. Testing revealed that the fish trap was more effective at catching the largest male lobsters, especially those with larger claws, which the standard traps mostly failed to catch. The presence of these large individuals may offer new perspectives on the effectiveness of the protection of European lobsters in Norway. This study demonstrates the importance of precise sampling methods when studying effects of conservation.

Sammendrag

Høstingen av havets ressurser har vært svært viktig i menneskets bosetting og utvikling i årtusener. I senere år har effektene av ikke-bærekraftig høsting av havets ressurser blitt tydeligere, og flere forvaltningsforskrifter har blitt innført for å bevare fiskebestandene som er truet av fiskepress. En av disse reguleringene er innføringen av marine verneområder (MPA) i kystnære områder. Flødevigen marine verneområde i Agder ble etablert i 2006 med hensikt å studere effekten av beskyttelse på den lokale bestanden av Europeisk hummer (Homarus gammarus). Hummerbestanden har siden det økt i både antall og størrelse, men nylig har den maksimale observerte kroppsstørrelsen for hummer i reservatet stagnert rundt 400millimeter (mm). I dette studiet ble prøvetakningsmetoden brukt i norske hummerreservater testet. Dette ble gjort for å undersøke om teinene under-representerer de større individene i populasjonen gjennom utstyr-selektivitet på kroppsstørrelse. For å teste dette ble 10 sammenleggbare fisketeiner med en stor åpning inkludert til hver prøvetakningsdag. Resultatene viser at det var en opptil 10% økning i gjennomsnittlig kroppsstørrelse mellom standard teinene og fisketeinene. De store fisketeinene fanget 50% av hummerne over 400mm. Dette tyder sterkt på at standardteinene som blir brukt til prøvetakning er størrelses-selektive mot store hummer, og at en teine med større åpning fanger større hummer mer effektivt enn teiner med smalere åpning. Resultatene viste også at fisketeinene var mer effektive til å fange de største hannene i populasjonen, spesielt de med store klør, noe standardteinene for det meste ikke klarte å fange. Tilstedeværelsen av disse store individene kan gi nye perspektiver på effektiviteten til beskyttelse av Europeisk hummer i Norge. Dette studiet demonstrerer viktigheten av presis prøvetakning når man studerer effektene av bevaring.

Table of contents

Preface

First and foremost, this endeavor would not have been possible without my incredible supervisors, Even Moland, Esben Moland Olsen and Tonje Knutsen Sørdalen from IMR and UiA. It has been an honor working with the three of you on this project, and your vast knowledge and patience have been unparalleled in the last year. I am also grateful for the opportunity to be a part of the fieldwork, and I would like to thank Sebastian Bosgraaf, chief engineer at IMR, for patiently guiding a rookie through lobster-fishing with bad jokes and knot lessons. Thanks should also go to Hege Monica Andreassen and Hanne Sannæs at IMR for great help during the field work.

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Last but certainly not least, I would like to thank my husband, Peter Nikolai! You have been my rock during this adventure. You have been there for me on the good days and the times when I have not seen the end, and for that I am eternally grateful.

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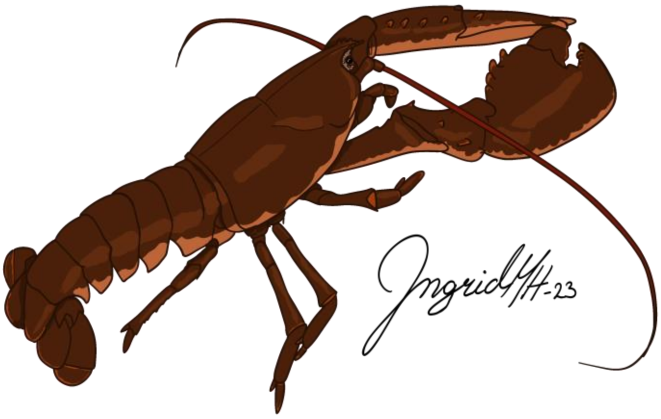
Ingrid Marie Helms



1. Introduction

1.1 Harvesting in a changing world

Dating back two million years, early ancestors of *Homo sapiens* practiced a hunter-gatherer culture, where they depended on nature's resources to sustain life (Ember, 2020). Even though humans settled in coastal areas early, and relied on shallow water mammals, fish or shellfish for food and tools (Marean et al., 2007; O'Connor et al., 2011; Spanier et al., 2015), they did not start with pelagic fishing until around 40 000 years ago (O'Connor et al., 2011). In the beginning, fishing was mostly used for food purposes (Hart & Reynolds, 2008), and early humans used hooks made from shellfish and fiber-based lines (O'Connor et al., 2011). Since then, fishing gear has been tailored to catch larger quantities and to catch specific species, fishing also grew to be a popular recreational activity (Hart & Reynolds, 2008). The efficiency of the fishery skyrocketed during the industrial revolution when most of the modern equipment was created (Smith, 2000). One reason for the increase in efficiency was that equipment that was driven by wind and manpower before, could now be managed with machinery (Caddy & Cochrane, 2001; Knauss, 2005). Since then, there have been two main categories of fishing gear: active gear and passive gear. All equipment that must be actively utilized by people, such as hook-and-line or harpoons, or that must be dragged by a boat, such as a trawl, is considered active gear. Equipment like pots, fyke nets, and gill nets that are stationed on the ocean floor is considered passive equipment (Karlsen & Simonsen, 1989).

The improvements to fishing gear is an ongoing evolution, and it is estimated that due to technological developments, there is a 3.2% increase in overall catchability every year (Eigaard et al., 2014). For instance, skewed hooks and swivel line has increased the catchability of haddock (*Melanogrammus aeglefinus*) with Faroese long line with 51% (Eigaard et al., 2011). As the fishing techniques and gear continue to evolve, the pressure on the populations in the sea increases (Jackson et al., 2001). For instance, the catchability of Snow crabs can be increased by 77% by adding white LED lights to baited traps (Nguyen et al., 2017), and the fishing power of fishing vessels was increased by 12% after using GPS and plotters for three years (Robins et al., 1998). Fishing for lobster also went from lowering a net repeatedly to the introduction of a baited trap that could be deployed from boats that could be left on the seabed till retrieval (Coull, 1997). A study on technological advancements of lobster traps presented that the mean catch rate of old lobster traps (cylindrical traps) was 0.22 lobster per trap, while a modern synthetic two-chambered trap had a catch rate of 0.88 lobster per trap (Kleiven et al., 2022).

Fishing gear has been adapted to match management requirements in an effort to preserve vulnerable populations and to reduce by-catch (Caddy & Cochrane, 2001; Watson & Kerstetter, 2006). This has been done by adding different mesh sizes to nets, different funnel sizes, or escape valves to traps (Melvin et al., 1999; Zhang et al., 2021). Although this has been viewed as an effective management strategy for protecting juveniles, recent research has revealed that this has resulted in additional selection pressure. A pressure that is directly caused by the efficiency of these measures, such as unintentionally targeting body shape, behavior and secondary characteristics (Zhou et al., 2010). For instance, economically important species such as the Atlantic cod (*Gadus morhua*) is shown to be affected by an ongoing harvest-induced selection by doubling the natural mortality and changing the behavioral composition of the populations (Fernández-Chacón et al., 2021; Olsen et al., 2012; Olsen & Moland, 2011). The same goes for the highly sought after European Lobster (*Homarus gammarus*), where traits such as behavior, phenotypic variability and mating behavior are under pressure from harvest selection (Sørdalen et al., 2018; 2020; 2022; Moland et al., 2019). The reduction of sexually selected male crusher claw size (Sørdalen et al., 2022), could potentially cause a weakening of sexual selection (Sørdalen et al., 2018). Harvest selection is also affecting home range, as there is a more frequent capture of lobsters with reduced home ranges compared to the ones with large home ranges (Moland et al., 2019).

Overfishing in Norway has significantly reduced European lobster populations, limiting their potential to reach older ages and larger sizes (Sørdalen et al., 2018). According to earlier research, between the 1950s and the 2000s, the lobster Catch-per-unit-effort (CPUE) declined by 65% in Norway (Pettersen et al., 2009). In a more recent study, the technological advancement of lobster traps was taken into account when calculating the decline in CPUE, and the results revealed that the European lobster landings in Norway had in reality decreased by 92% when accounting for ‘technological creep’ (Kleiven et al., 2022). This was due to modern lobster fishing gear, such as two-chambered traps (parlor traps), are three times more effective than its predecessor, the one-chambered wooden traps and cylindrical traps (Kleiven et al., 2022). Recently, there has been a lot of focus on ways to protect the phenotypic and behavioral traits that are being selected against by the fishing industry (Olsen et al., 2012; Sørdalen et al., 2020). The establishment of sanctuaries, which lessen human impact on the local ecosystems, is one of these strategies.

1.2 Marine protected areas

There is currently a global trend to establish marine no-take zones (MPAs) all around the world (Convention on biological Diversity (CBD), 2022), and has been referred to as key components when working towards global conservation of ecosystems (Woodcock et al., 2017). Studies show that MPAs where the fishing effort has been removed or reduced can lead to an increase in biomass, diversity, size and density of the protected species within (Fenberg et al., 2012; Fernández-Chacón et al., 2020). MPAs are known to assist the restoration of age- and size structures of exploited species, which again can stabilize fluctuations in population dynamics caused by fishing pressure (Babcock et al., 2010; Taylor & McIlwain, 2010).

In 2006 three lobster reserves were established as a pilot project along the Norwegian Skagerrak coast, with the intent to learn more about how the local lobster populations change in response to human influence (Pettersen et al., 2009). The reserves along with the adjacent control areas have been the subject of a yearly standardized lobster survey since 2006. In the initial four years following protection, the CPUE increased by 245% within the reserve, as compared to an increase of 87% in the control area (Moland et al., 2013). Since their initial scientific documentation, more than 50 MPAs have been established as lobster reserves by coastal municipalities (Knutsen et al., 2022). In the annually collected monitoring data, it has been observed a stagnation in the overall size increase of lobsters inhabiting the lobster reserve, as the lobsters appear to not grow beyond a total length of approximately 400 millimeters (mm) (Fernández-Chacón et al., 2021; Thorbjørnsen et al., 2018) (Table 5). There have also been signs of a flattening of the abundance increase in the reserves in the last decade (Sørdalen et al., 2022; Sørdalen et al., 2020). However, density has not been found to affect body growth and individual growth rate is actually higher inside the reserves compared to fished areas (Sørdalen et al., 2022).

Since 2006, the MPAs have been sampled with standard parlor traps (120mm entrances), with inclusion of a subset of larger parlor traps (180mm entrances) since 2016 for the purpose of tracking the size increase. It may be reasonable then to suspect that since the time of inclusion of larger traps in 2016, and the known body size potential of the species, the traps currently used for sampling might once again represent a limiting factor in tracking the actual size increase that has occurred in the protected populations. A study conducted in a Swedish lobster reserve documented that compared to diving, the parlor trap (120mm entrance) used there was selective when it came to size and especially on large males (Øresland et al., 2018). As the protected lobsters continue to increase in body size, the largest lobsters may not be able to enter the traps, rendering them unobservable. This might lead to observations that do not represent the populations and might miss out on the real changes in the size dynamics as the reserves age. An opposing hypothesis is that the traps are catching a representative sample of the population, and that the lobsters either have not grown any larger than approx. 400mm in 17 years, or, that the large individuals move out of the reserve due to 'demographic diffusion' and the increased competition that comes with an increase in abundance and population density (Steneck, 2006). Demographic diffusion take place when an identifiable part of a population shifts from an area with high population density to another area with lower population density (Steneck, 2006). In this case the part of the population that is suspected to relocate is the larger lobsters in the population. To better sample the populations of European lobster, the use of the right sampling equipment is important. If the gear used is size selective and only capable of sampling parts of the populations, the results may become skewed – and not representative of the whole population.

1.3 Research questions

The aim of this thesis was to determine whether the standard sampling traps for lobster do capture the true population size distribution in the Flødevigen reserve. The inclusion of larger fish traps alongside the standard traps can serve as a means of verifying whether standard traps are size selective towards smaller lobsters when sampling the lobster population. If the standard traps are indeed capable of capturing the whole size demographic in equal proportions (H0), there should be no difference between the sizes caught in standard traps and the fish trap. However, if the fish trap catches the largest individuals in the population better than the standard traps (H1), it can be confirmed that the standard traps are under-sampling certain size classes.

The objectives of this study are to determine whether large European lobster are currently being under-sampled in the Flødevigen reserve by including 10 large fish traps per sampling day. As well as, identifying the 'real' and potentially unobserved lobster body size. Lastly, the efficiency and size selectivity of the large fish traps will be evaluated, and whether the traps should be included in further studying.

2. Materials and methods

2.1 Study species

The European lobster is a decapod crustacean which has been an important part of the Norwegian commercial and recreational fisheries since the 1600s, when Dutch traders assisted with the development of the lobster fisheries (Knutsen et al., 2022; Knutsen et al., 2009). The European lobster prefers rocky habitats adjacent to sedimentary bottom and live at least down to 60 meters (Galparsoro et al., 2009). They show high site-fidelity and have relatively small home ranges (Moland et al., 2019). Although most individuals display high site-fidelity, some individuals can be found to migrate several kilometers (Huserbråten et al., 2013). Male and female lobsters are sexually dimorphic in the way that males grow faster and bigger than females (Debuse et al., 2001; Lizárraga-Cubedo et al., 2003; Sheehy et al., 1999), as well as the claws of male lobsters growing larger, especially the crusher claws (Elner & Campbell, 1981). As lobsters mature and grow large, females produce larger and more eggs than their smaller counterparts (Agnalt, 2007; Birkeland & Dayton, 2005; Tully et al., 2001). One of the largest lobsters recorded was an accidental catch in Denmark when during trawling a large claw was discovered, the claw was 360mm long and it was estimated that the lobster must have had a body size of 650mm (Wolff, 1978). Of large (150-170mm carapace length) male and female lobsters, the average age has been estimated to be 31 and 54 years, respectively (Sheehy et al., 1999).

In southern Norway, lobster fishing is only legal between October 1st and November 30th (December 31st in the north), and since 2008 it has been prohibited to harvest lobsters under 250mm. In 2017 a maximum size of harvested lobsters was introduced in southern Norway (320mm) to protect the larger individuals and strengthen the population (Regulation on the harvesting of lobsters, 2021, §8-10). Furthermore, the European lobster's status on the Norwegian Red List for Threatened Species was changed in 2021 from Least Concern (LC) to Vulnerable (Vu), when new research revealed that the condition of the population was worse than anticipated (Trandberg et al., 2021). Even with these regulations, there is still an intense trap-fishery on the European lobster in Skagerrak, where recreational fishers dominate with 65% of traps deployed (Kleiven et al., 2012).

High fishing pressure affects the lobster populations in different ways, for instance fishing lowers the abundance of lobsters (Fernández-Chacón et al., 2021; Nillos Kleiven et al., 2019), as well as lowering the mean body size (Fernández-Chacón et al., 2020; Moland et al., 2013;

Thorbjørnsen et al., 2018). The lowering of the mean body size of lobsters makes it more difficult for lobsters to find a suitable mate, since females prefer to mate with larger males (Sørdalen et al., 2018). Furthermore, since the female survival goes up when the body size increases (Fernández-Chacón et al., 2021), they risk “outgrowing” the available males. Which as mentioned before, might decrease the breeding success.

2.2 Study site

The study was conducted in the Flødevigen lobster reserve located on the Skagerrak coast in south-eastern Norway (58°25’N,8°45’E, Figure 1) and extends over an area of around 1km^2. The lobster reserve was established in 2006 in an effort to generate knowledge about the effects of protection on European lobster (Pettersen et al., 2009). All use of passive gear is prohibited, and the only legal fishing method is hook-and-line fishing (Pettersen et al., 2009; Regulation on protected areas for lobsters, 2006, § 1). Within the reserve the depth ranges from 0 to 32 m, except for a steep slope that goes down to 40-50 m on the southeastern edge of the MPA. The bottom terrain is dominated by rock faces and boulder fields, except for some flat soft bottom areas (Pettersen et al., 2009).

2.3 Sampling design

The experiment was divided into two sampling campaigns, with the difference being the sampling gear (Figure 1). Overall, three types of traps were used in the survey, the two standard traps; a small parlor trap (90x45x38cm, 120mm opening) and a large parlor trap (120x58x52cm, 180mm opening), and a large collapsible fish trap (130x80x120cm, 270mm opening - fully expanded), hereafter referred to as ‘small’, ‘medium’ and ‘large’ traps, respectively (Figure 2, Figure 3). The traps had a soak time of 24 hours and were hauled four times per campaign. The first campaign took place between August 29th and September 2nd. This first campaign was the annual standardized lobster survey. Here 20 small traps and 5 medium traps were evenly distributed daily, in total 80 small traps and 20 medium traps were hauled during the four days. The second campaign took place from September 5th to September 9th. In this survey the small traps were excluded, while the large traps were included. Here, 10 medium traps and 10 large traps were evenly dispersed through the MPA, resulting in a total of 40 hauls of the medium traps and 40 hauls of the large traps (Figure 5).

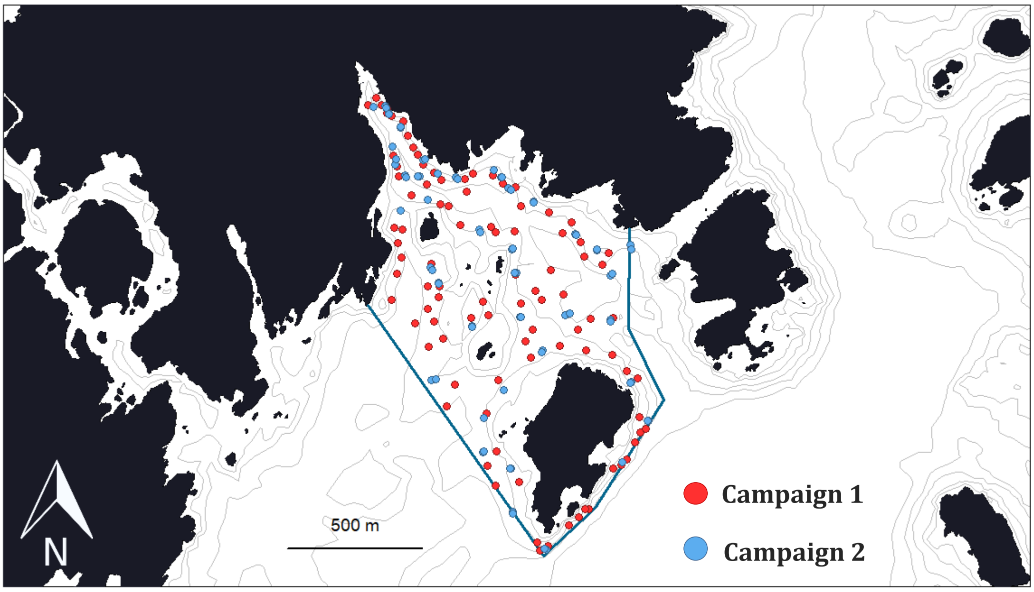


Figure 1: Map of the Flødevigen MPA (58°25'N,8°45'E) with all sampling sites separated into the two campaigns. Red = 29 August – 2 September, Blue = 5 - 9 September. Map created with the R package 'ggmap', version 3.0.1 (Kahle & Wickham, 2013).

Figure 2: The three trap types used in the study; a) Small parlor trap (90x45x38cm, 120mm opening), b) Large parlor trap (120x58x52cm, 180mm opening), c) Collapsible fish trap (130x80x120cm, 270mm opening).

Figure 3: Entrance size of the three trap types a) Small trap entrance (120mm), b) Medium trap entrance (180mm) and c) large trap entrance (270mm, fully expanded)

In both surveys the traps were baited with frozen mackerel (*Scomber scombrus)* and was affixed to a rope with a buoy that had a number unique to each trap. All the traps had closed escape vents to prevent smaller individuals from escaping. A winch (Hobbyfisher e150) mounted on the boat was used to retrieve the traps. The lobsters were thereafter tagged (T-bar tag anchor tags with unique serial numbers) in the ventral musculature in between the cephalothorax and abdomen, to protect it from releasing during molting. The sex of the lobster was determined by whether the first pair of pleopods were bony (male) or flexible (female). The body size (Total length) was measured from the tip of the rostrum to the edge of the telson to the nearest mm, while the claw size (Claw width) was measured at the broadest part of the crusher claw to the nearest mm (Figure 4). At each haul site the depth, time and location were recorded with the onboard GPS (Figure 5).

Figure 4: Measuring and tagging European lobster, on the left; a) Illustration of the body size (TL) measurement, b) Illustration of the claw size (CW) measurement. On the right; Tagging procedure of individual lobsters.

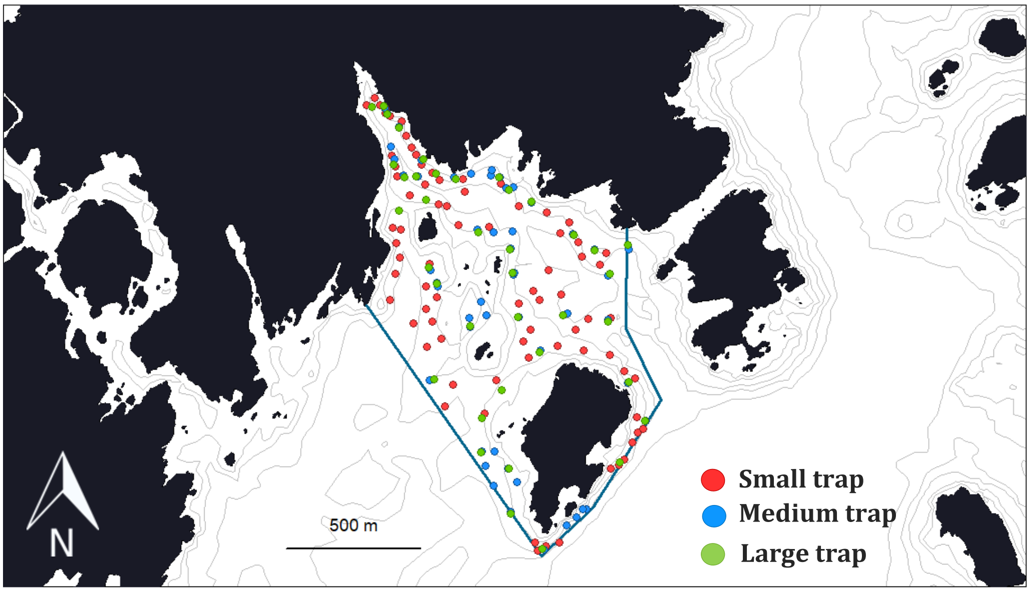


Figure 5: Map of the Flødevigen MPA (58°25'N,8°45'E) with all sampling sites separated into the traps used on the sites. Red = Small trap, Blue = Medium trap, Green = Large trap. Map created with the R package 'ggmap', version 3.0.1 (Kahle & Wickham, 2013).

2.4 Data analysis

Statistical analysis was done by using the statistical software R, version 4.2.2 (R Core Team, 2022). The ggplot2 package was used for most visualization (Wickham, 2016). The lobsters with either one or all claws missing were excluded from further analysis to prevent claw loss from affecting the results since it might affect the ability into smaller traps. Before combining the two sampling weeks, a linear regression model was used to see if "week" affected the trapping. Since no such interactions was found, the two datasets were combined in further analysis. Since the aim was to see if the traps affected the size of the lobsters caught, a linear model was used to test the effect of body size on gear. The test allowed the interaction to differ between males and females. The interactions in the linear regression models were visualized using the R package, sjPlot (Lüdecke, 2022). To see the differences between the mean body size caught in the traps a two-sample t-test was performed to see the differences between mean body size in the traps and between sexes. All the variable means was fitted with a Standard Error (SE) calculation. The same procedures were done with claw size. All models were validated and verified according to a set of assumptions for the best model fit (Zuur et al., 2009). This procedure included 1) potting of residuals vs fitted values to look for homoscedasticity, 2) a Q-Q normality plot, 3) Checked for independence by plotting the residuals and each explanatory variable against each other (Appendix A).

3. Results

After a combined total of 180 trap hauls, a total of 322 lobsters were caught between the August 30th and September 9th. After excluding the lobsters with claw loss, 308 lobsters were kept for further analysis. Of the lobsters caught, 145 (47%) were caught in the small trap, 106 (34%) in the medium traps and 57 (19%) in the large trap. 51% lobsters were within the legal size-limit, while 35% were over the legal size and 14% were below the legal size (Table 1). The lobsters were caught at a mean depth of 16.7m (±0.46), with the shallowest haul at 7m and the deepest haul at 32m (Appendix D).

Table 1: Summary of the European lobsters (Homarus Gammarus) caught in Flødevigen during the project.

		Sample size	% of total	Min TL	Max TL	Mean TL	SE TL	Min CW	Max CW	Mean CW	SE CW
Total catch		308	100	197	450	304	2,78	29	114	55	0,81
Campaign	*1.*	189	61	197	430	297	3,29	29	100	54	0,91
	2.	119	39	215	450	315	4,78	36	114	58	1,48
Gear	*Small*	145	47	197	405	293	3,54	30	96	53	0,95
	Medium	106	34	211	450	308	4,91	29	110	56	1,36
	Large	57	19	235	438	322	7,04	38	114	61	2,45
Sex	*Female*	150	49	197	438	305	3,94	29	70	49	0,70
	Male	158	51	205	450	302	3,92	35	114	61	1,26
Size regulations	*Under*	42	14	197	248	234	1,77	30	49	40	0,58
	Legal	157	51	250	320	285	1,62	29	74	51	0,63
	Over	109	35	322	450	357	2,81	37	114	68	1,33

Abbreviations: TL = Body size (mm), CW = Claw size (mm), Under = <250mm TL, Legal = 250-320mm TL, Over = >320mm TL, Small = Small Parlor trap (120mm opening), Medium = Large parlor trap (180mm opening), Large = Large collapsible fish trap (270mm opening), SE = Standard Error

3.1 Body size

The largest lobster caught was a male with a body size of 450mm and the smallest lobster was a female at 197mm, while the mean body size in the whole study was 304mm (±2.78 SE) (Table 1). The large traps had the highest mean body size at 322mm (±7.04 SE). The sex-specific body size mean for males and females was 302mm (±3.92 SE) and 305mm (±3.94 SE), respectively. There was a significant difference in mean body size between the sexes in the large traps (Table 2).

Table 2: Body size (TL) p-values of T-tests performed on all traps and both sexes. Significant p-values marked in bold.

Sex	Gear	Small	Medium	Large	Opposite sex
Male	*Small*	-	**0.0182**	**<0.001**	0.0561
	Medium	**0.0182**	-	**0.0024**	0.4786
	Large	**<0.001**	**0.0024**	-	**0.0063**
Female	*Small*	-	0.1724	0.6431	0.0561
	Medium	0.1724	-	0.5231	0.4786
	Large	0.6431	0.5231	-	**0.0063**

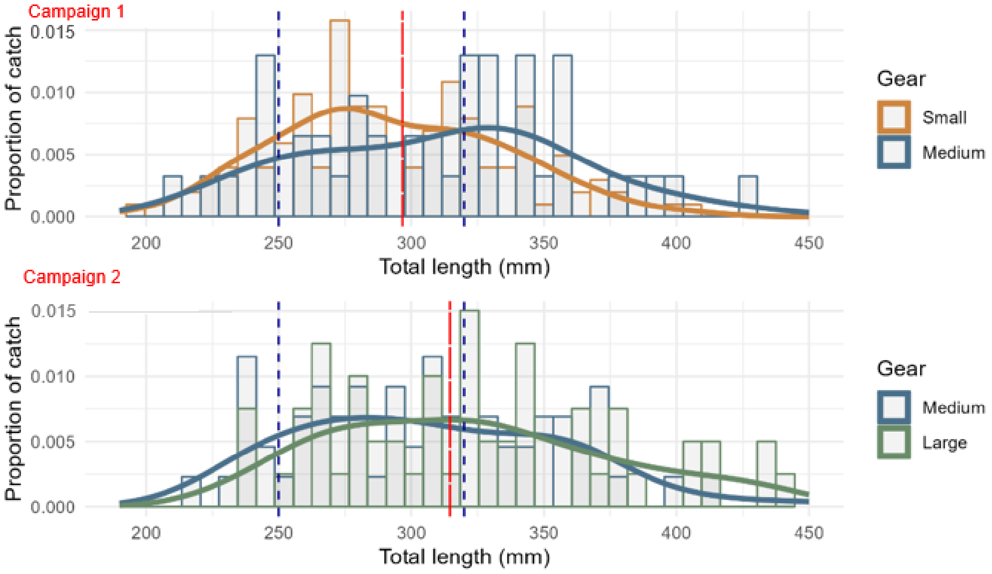


Figure 6: Body size (mm) density distribution of lobsters (n=308) in the first and second campaigns. The trap types are separated into colors. The dashed blue lines indicate the legal size-slots (<250mm, 250-320mm, >320mm), the red lines are the mean body sizes in both campaigns (297mm and 315mm, respectively).

The traps seemed to catch uniformly in the middle size range, but when it came to the largest (>400mm) and smallest lobsters (<230mm) there was a difference between the large trap and the two standard traps (Figure 6). For instance, of the largest lobsters, 50% were caught in the large traps, the medium traps caught 36%, and the small traps caught 14% of the lobsters (Table 3). Conversely, the large traps only caught 5% of the smallest lobsters, while the medium traps caught 26% and the small traps caught 62% (Table 3). Overall, a total of 150 female and 158 male lobsters were caught, and they were distributed throughout most of the size structure (Table 1) (Appendix B). For females, there was no significant difference among the mean body size between the three traps. However, males had a difference in mean body size among all trap sizes (Table 2). There was also a significant interaction between large male lobsters and the largest traps with a p-value <0.001 (Appendix C) (Figure 7).

Table 3: The largest (>400mm) and smallest (<235mm) lobsters in the study and in what trap they were caught, with percentage.

Selected size	Sample size	Gear	Lobsters caught	% of sample
Large lobsters *>400mm*	14	0	2	14 %
		1	5	36 %
		2	7	50 %
Small Lobsters *<235mm*	19	0	13	68 %
		1	5	26 %
		2	1	5 %

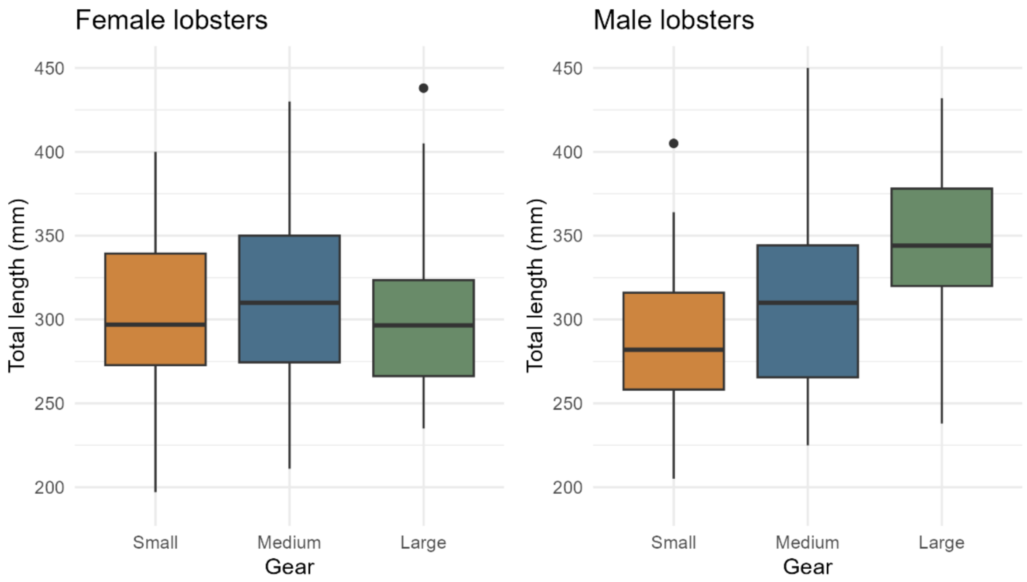


Figure 7: Boxplots visualizing the body size in each trap, separated into male and female lobsters. For each trap, the thick horizontal line is the median, while the margins of the boxplot represent the first and third quartiles.

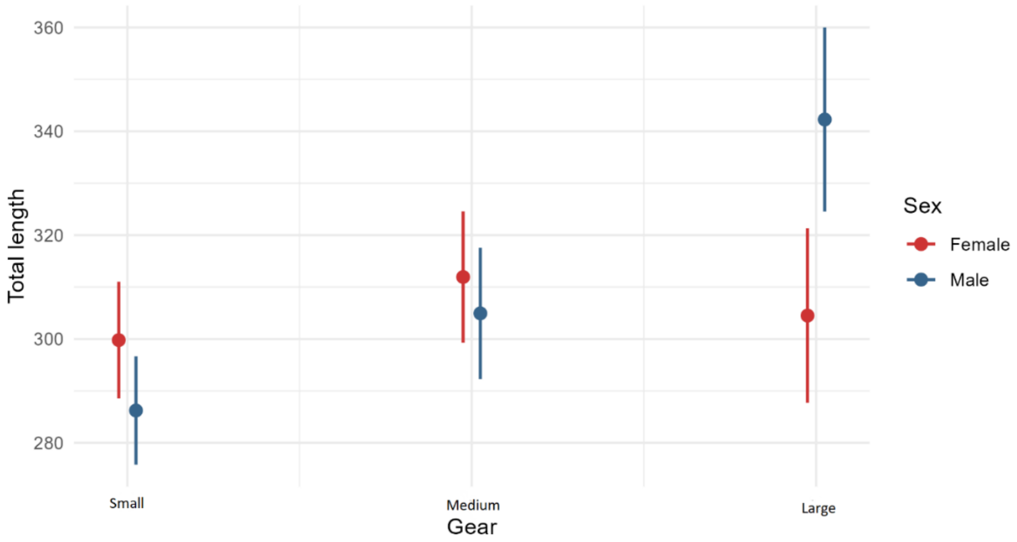


Figure 8: Predicted values of a linear regression model with Body size as the dependent variable and trap (Gear) and Sex as independent variables. (Slope: 51.317, t-value: 3.503), with a significant interaction between males and the large trap (p-value: <0.001).

3.2 Claw size

The claw size was mostly centered around ~50mm, with some claws over 80mm (Figure 9). The mean claw size of all lobsters caught was 55mm (± 0.81 SE) (Table 1). Most of the claws over 80mm (n=20) were caught with the largest traps (45%). As with body size, the largest traps had the highest mean claw size at 61mm (±2.45 SE), while small and medium traps had 53mm (±0.95 SE) and 56mm (±1.36 SE), respectively. The mean sex-specific claw size for males and females was 61mm (±1.26 SE) and 49mm (±0.70 SE), respectively (Table 1). There were more males with larger claws compared to females (Appendix B – Figure 15). Further, there was a significant difference in mean claw size between the sexes in all three traps (Table 4).

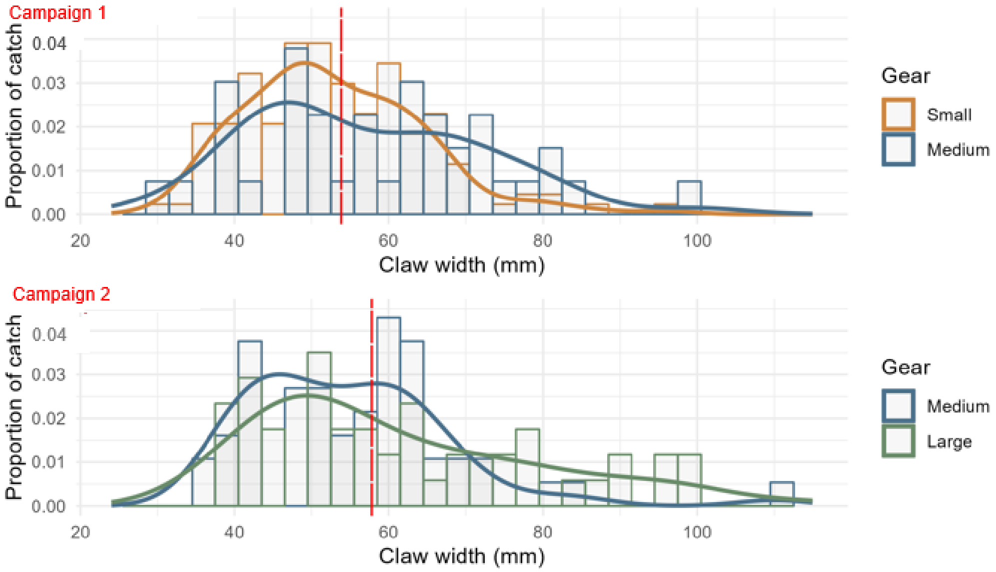


Figure 9: Claw size (mm) distribution of lobsters (n=308) in the first and second campaign. The red lines are the mean claw size of the first and second campaigns (54mm and 58mm, respectively)

Table 4: Claw size (CW) p-values of T-tests performed on all traps and both sexes, significant p-values marked in bold.

Sex	Gear	Small	Medium	Large	Opposite sex
Male	*Small*	-	0.0633	**<0.001**	**<0.001**
	Medium	0.0633	-	**0.0014**	**<0.001**
	Large	**<0.001**	**0.0014**	-	**<0.001**
Female	*Small*	-	0.3226	0.4872	**<0.001**
	Medium	0.3226	-	0.8644	**<0.001**
	Large	0.4872	0.8644	-	**<0.001**

The female claw size did not differ between the traps (Table 4). The male mean claw size was significantly different between the medium traps compared to the large trap, and between the largest traps and the small traps (Table 4 and Figure 10). There was also a strong significant interaction between big male lobsters and the largest traps (Appendix C) (Figure 11).

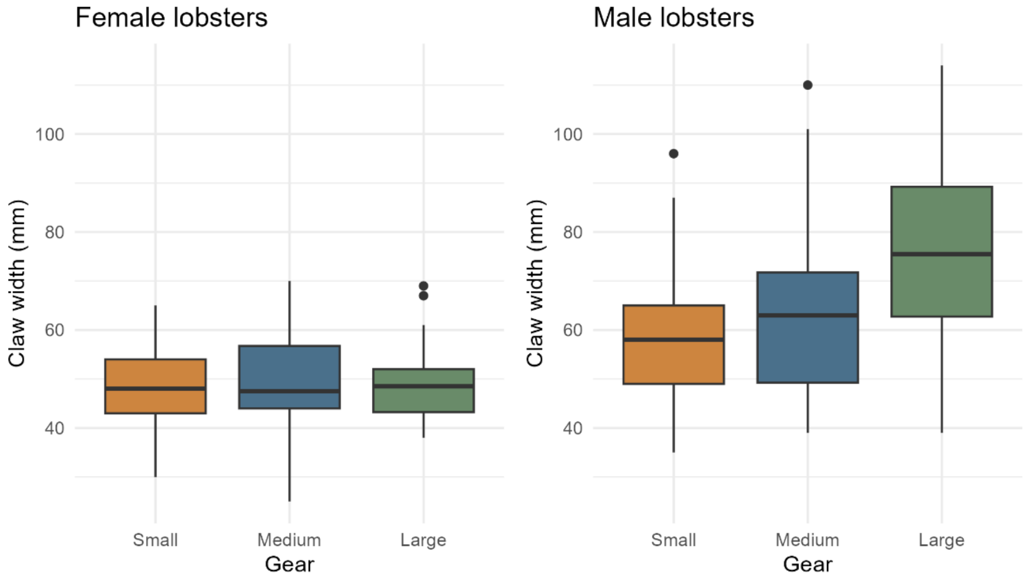


Figure 10: Boxplots visualizing the claw size in each trap, separated into male and female lobsters. For each trap, the thick horizontal line is the median, while the margins of the boxplot represent the first and third quartiles.

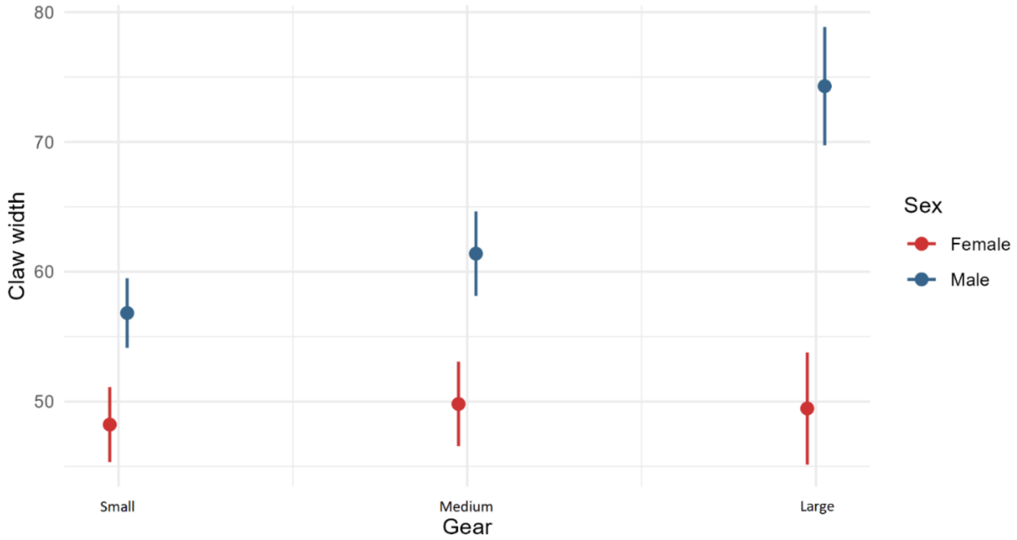


Figure 11: Predicted values of a linear regression model with claw size (CW) as the dependent variable and Gear and Sex as independent variables. (Slope: 16.769, t-value: 4.394), with a significant interaction between males and the large trap (p-value: <0.001).

4. Discussion

The objective of this study was to assess the standard set of parlor traps used in the annual survey in Norwegian lobster reserves. The purpose was to investigate whether the traps were size selective and if the traps are catching a size structure representative of the population. This was done by the inclusion of collapsible fish traps with a much larger and flexible entrances. The results showed significant differences in the mean size of lobsters caught in the standard parlor traps in comparison to the large fish trap. Further, the large traps seemed to catch the larger component of the population, this supports the hypothesis that the three gear types are size selective and catch different parts of the population size range. The large traps caught 50% of lobsters over 400mm, which further supports the hypothesis that large traps are more efficient at catching the larger lobsters. The potential factors explaining these results will be discussed further below, accompanied with what the different traps could mean for the understanding and future monitoring of marine reserves.

4.1 Changes in size structure

As mentioned, the results strongly suggests that the standard traps do not catch the whole size structure, and that the small parlor traps select against larger lobsters. This size-selectivity by the smaller traps can be further supported by a study that compared a similar trap to the small trap in this study (120mm opening) with sampling by diving. The study showed that the trap was size-selective in comparison to diving (Øresland et al., 2018). By comparing these new results with previous work in the same area using only the standard traps, a marked difference in body size was observed between new and old results. When looking at the overall mean body size there was a 9% and 11% increase compared to the present study (Fernández-Chacón et al., 2020; Thorbjørnsen et al., 2018) (Table 5). This study portrays a 5% increase in mean male body size compared to a recent study (Sørdalen et al., 2020) (Table 5). The increase in mean and maximum body size compared to previous findings reiterate that larger traps are capable of sampling a part of the lobster population, previously overlooked. This may be due to insufficient sampling gear.

Table 5: A summary of the mean and maximum lobster sizes (mm) from earlier articles from the Flødevigen MPA, using the two standardized trap types compared to the mean and maximum sizes found in the present study.

Article	Sample Year	Measurement	Result (mm)	Present study (mm)	% increase
(Sørdalen et al., 2020)	*2017-2019*	*Mean TL Female*	294	305	4 %
		Mean TL Male	288	302	5 %
		Max TL Female	395	438	11 %
		Max TL Male	414	450	9 %
(Thorbjørnsen et al., 2018)	*2014*	*Mean TL*	278	304	9 %
(Moland et al., 2019)	*2011-2012*	*Mean TL Male*	276	302	10 %
		Max TL Male	395	450	14 %
		Mean CW Male	53	61	16 %
(Fernández-Chacón et al., 2020)	*2004-2015*	*Mean TL*	275	304	11 %
		Max TL Female	422	438	4 %
		Max TL Male	425	450	6 %

Abbreviations: TL = Body size (mm), CW = claw size

The presence of larger lobsters, especially females, is considered crucial due to their heightened fecundity and spawning frequency compared to smaller lobsters (Agnalt, 2007; Birkeland & Dayton, 2005; Tully et al., 2001). Large claws are also seen as a sign of dominance between lobsters, and the males with the largest claws are better at defending themself and removing rivals (Elner & Campbell, 1981; Snedden, 1990; van der Meeren & Uksnøy, 2000). In a simulated study in tanks, lobsters in the same size class were observed to maintain dominance through highly aggressive fights (Skog, 2009). Aggression is typically initiated with claw displays, and if an aggressor has substantially larger claws than the opponent the interaction is concluded with this difference confirmed in the display, and the submissive individual withdraws. Large males are also documented to initiate the agonistic interactions and attempt to extend their territory to include more shelters for breeding (Karnofsky & Price, 1989). It has been suspected that larger individuals migrate out of the reserves through 'demographic diffusion' due to the increased lobster abundance and thus density (Moland et al., 2011; Steneck, 2006). However, the observation of larger males in the reserve (this study) can suggest there might not be as much 'demographic diffusion', since the males that were believed to have left the Flødevigen reserve were simply undetected by the traps currently in use. This does not mean that 'demographic diffusion' will not take effect in the reserves, rather that the lobster density might not yet have increased enough to trigger the large lobsters to move away from high population density.

4.2 Gear-selectivity on sex and claw size

There was no significant difference in size between females caught in the three traps, neither in body size nor claw size. The lack of relationship between female size (TL and CW) and the traps suggests that the standard traps are not as size selective on the female lobsters. Males grow faster and larger than females (Debuse et al., 2001; Lizárraga-Cubedo et al., 2003), thus the female lobsters may not be as affected by size selectivity of the standard traps as the males - as the females might not have had the time to grow large enough to be selected against by the traps. Since males also have larger claws than females (Debuse et al., 2001; Elner & Campbell, 1981), it might be easier for large females to pass through the smaller rigid funnels of the standard traps. After all, claw size showed the strongest relationship with the large traps (Figure 11).

Male lobsters with large claws will have difficulty entering the smallest traps due to the relationship between the size of the entrance and the width of their claws. The small traps had 120mm openings, thus males such as the one with a 114mm crusher claw would have trouble getting both claws in through the opening. To go through narrow entrances the lobsters enter with both claws first and have been observed to place one claw over the other to enter narrow openings (IMR escape vent trial video, unpublished). Still, the width of the claws will determine the size of the entrance they can use for practical purposes. In addition to the size of the entrance, the small and medium traps had rigid openings, thus if a large lobster was to get through and the funnel could not be flexed to fit the larger claws. This would be possible in traps with a flexible opening such as the fish trap. Large male lobsters are under high pressure from fisheries, especially lobsters with large claws (Sørdalen et al., 2020). Therefore, the presence of the larger males can further support MPAs in improving body growth by shielding populations from slow-growth selection (Sørdalen et al., 2022). Sørdalen et al. (2022) demonstrated the effect of protection on male growth was less clear than with females but attributed to the males' investment in larger claws. Considering the present results, the inclusion of larger traps in future studies can contribute to representing the whole size structure of the lobster population.

4.3 Advantages and disadvantages of implementing new equipment

As previously stated, the larger traps showed a significant difference in the mean body size and claw size of male lobsters in comparison to the standard traps. Additionally, a significant interaction was observed between body size of male lobsters and the large trap, as well as a more prominent significant interaction between the claw size of male lobsters and the large trap. These results confirm that the larger fish traps capture a portion of the size structure that the standard traps fail to catch. Moreover, the fish traps successfully caught larger males with even larger claws, which the standard traps failed to represent.

MPAs can be efficient in reestablishing size- and age structures that have been depleted by unsustainable fisheries (Taylor & McIlwain, 2010). The restoration of age and size structures in exploited species is vital for the recovery of fecundity in populations by increasing the amount of older and larger residents in the MPAs (Jack & Wing, 2010; Sørdalen et al., 2018; Taylor & McIlwain, 2010). This has the potential to benefit fisheries through increasing possible contributions to the region's larval pool (Jack & Wing, 2010). Future monitoring of lobsters in the Flødevigen reserve may require the implementation of larger traps to fully sample changes in size- and age structure.

Incorporating a larger trap, either the fish trap or a trap of similar caliber, in the annual lobster survey could offer valuable insight into the reserves as well as fished areas. A larger trap can help researchers gain greater insight into demographic diffusion and the spillover of lobsters from reserves. For instance, if the large lobsters from the reserve migrate to the fished area, they will most likely be overlooked with the current traps. The inclusion of a few larger traps when surveying fished areas it can increase the likelihood of sampling larger lobsters. However, this approach may not be as efficient in fished areas as in the reserve since the lobsters do not grow to be as large in the fished areas compared to protected areas (Fernández-Chacón et al., 2020; Sørdalen et al., 2022). Still, with the maximum size limit (>320mm) there is a possibility for lobsters to become permanently protected in fished areas as well, by surviving long enough to outgrow the maximum size limit. Larger traps can then be useful to study these large specimens that can reside safely in fished areas.

Including new sampling gear may incur complications. Future studies must consider that the new data must be standardized to match the ongoing time series and previous results (Maunder & Punt, 2004). This has been done before with the inclusion of the medium traps in 2016, and while researching fishery data and taking changes in gear into consideration (Kleiven et al., 2022). While the large traps were efficient in sampling the larger component of the population, it was not as efficient in capturing the smaller lobsters (5% of lobsters <235mm). Incorporating the larger traps into the standardized method, should however not exclude the small traps. The exclusion of the smallest traps would presumably result in under-sampling of the smaller component of the population. Thus, working against the goal of sampling the whole population. For this reason, if the large traps are to be included, both standard traps should also be kept.

4.4 Management implications

According to the present study, there is a relationship between the size of the lobsters and the size of the trap entrance. This information could be useful for protecting lobsters in the future and for boosting the productivity of fished populations. Considering that the mean body size of the large and medium traps were either over or close to the maximum legal size of 320mm, it seems to be inefficient for fishing legal-sized lobsters. Concomitantly, the lobsters caught in the small traps were well within the legal size-slots and the presence of escape vents can release under legal-sized lobsters. Thus, a fisher with the intention to catch predominantly legal lobsters can use the small traps (120mm opening) to avoid the lobsters that are too large. However, for educational purposes the two larger traps (>180mm opening) can be used to observe the larger lobsters. The establishment of MPAs are typically a slow process, as stated by Sørdalen et al. (2020). Therefore, more traditional fishing regulations may be a temporary option to reduce fishing pressure and restore some of the negatively impacted traits when MPAs are less accessible. If fishers mainly use the small trap, some of the disturbance of the large lobsters may be eased, and the risk of accidental deaths or claw loss caused by fishing might be reduced. Thereupon increasing the chance of survival to the size that permanently protects the lobsters (>320mm).

Since, this study has demonstrated that the traps in the standard lobster survey are underestimating the larger part of the size structure, a logical step is to consider other sampling methods to survey lobsters. Trap surveys can be intrusive on wildlife, a less invasive method is to implement photogrammetry or video monitoring (Jack & Wing, 2010; Steen & Ski, 2014). The application of machine learning, or even artificial intelligence in image recognition, called machine vision, can be an effective supplement to process data and monitor lobster (Li et al., 2022). Video monitoring could further assist with observing the agonistic interaction between the larger lobsters (>400mm) and the semi-large lobsters (~400mm) in the wild. This can contribute to better monitoring the effects of a full size structure on populations, and the full effect of protection on threatened species. And as Moland et al (2021) stated; It is a worthwhile priority to invest in long-term monitoring of MPAs and the effects of protection on the protected ecosystems.

4.5 Conclusion

In summary, there are clear indications of size selectivity in the standardized parlor traps used for the annual survey in Norwegian lobster reserves. If the intention of future studies is to observe and track the whole size structure in the lobster populations, the traps should be adapted to include larger entrances, or larger traps should be included. The inclusion of such traps can contribute to further monitoring of the effects of protection, and the extent of 'demographic diffusion' as the abundance of lobsters increases within the reserves. Simultaneously, the larger opening can further contribute to research on the changes in age and size structures as the lobsters grow large and the traits are selected against continue to be restored. From a fishery perspective the use of small traps with a narrow entrance can be efficient when fishing for lobsters within the legal size-slot. Which then can ease the disturbance of the largest lobsters in fished areas.

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List of figures and tables

Figures

Tables

Appendix

Appendix A

All models were visually inspected and validated by 1) potting of residuals vs fitted values to look for homoscedasticity, 2) a Q-Q normality plot, 3) Checked for independence by plotting the residuals and each explanatory variable against each other.

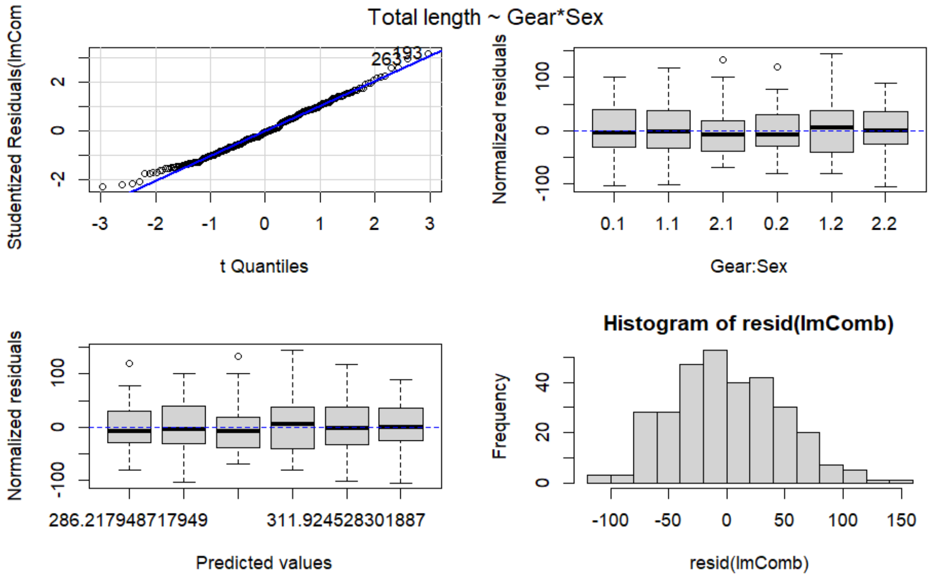

Figure 12: Model diagnostics for the linear regression model with body size (TL), all assumptions was validated, and the model kept.

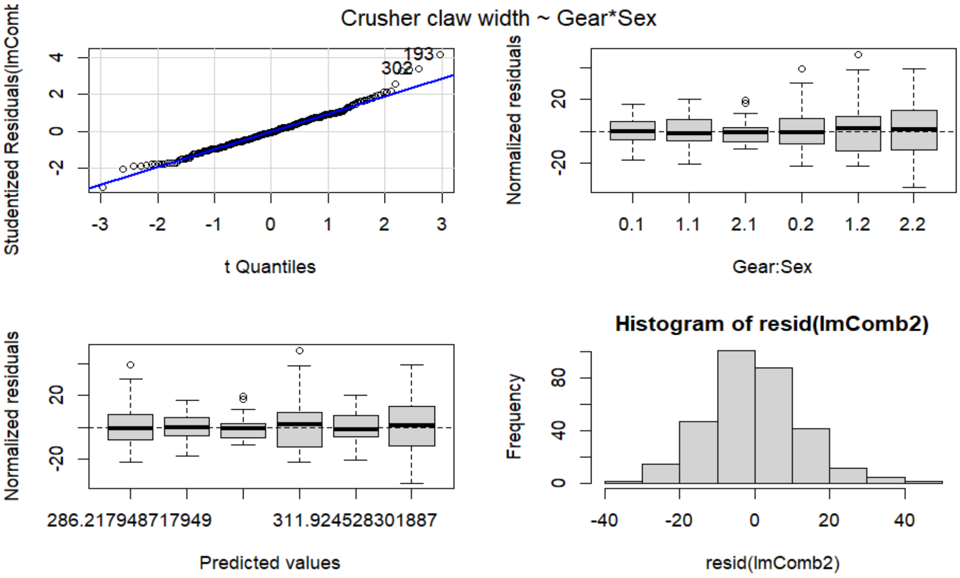

Figure 13: Model diagnostics for the linear regression model with claw size (CW), all assumptions was validated, and the model kept.

Appendix B

Distribution of male and female lobsters based on body size (TL) and claw size (CW) separated into Campaigns. Campaign 1 was between August 29th and September 2nd and Campaign 2 was between September 5th and September 9th.

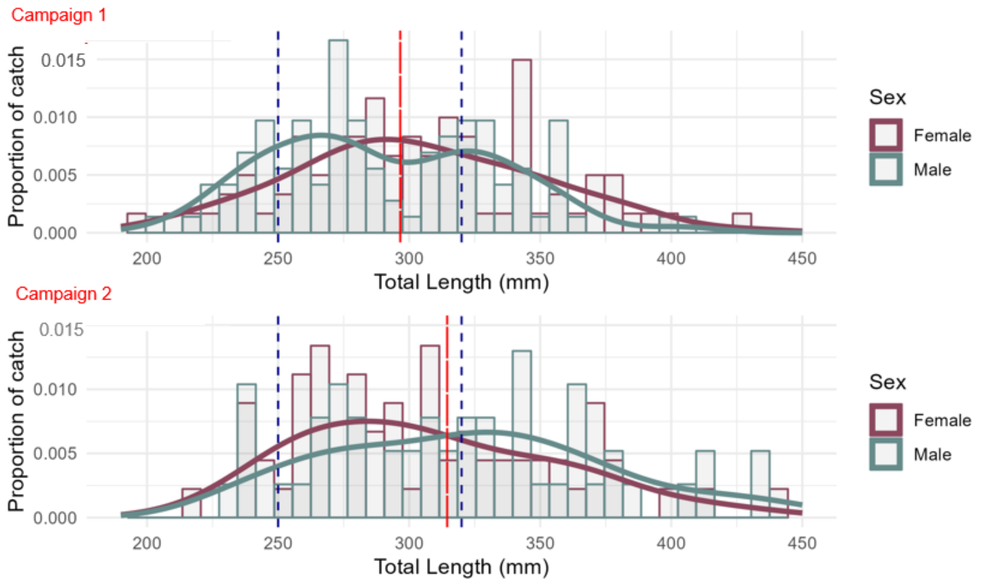

Figure 14: Body size (mm) distribution of male and female lobsters (n=308) in the first and second campaign. The dashed blue lines indicate the legal size-limits (<250mm, 250-320mm, >320mm), while the red lines are the mean TL of the first and second campaign (297mm and 315mm), respectively)

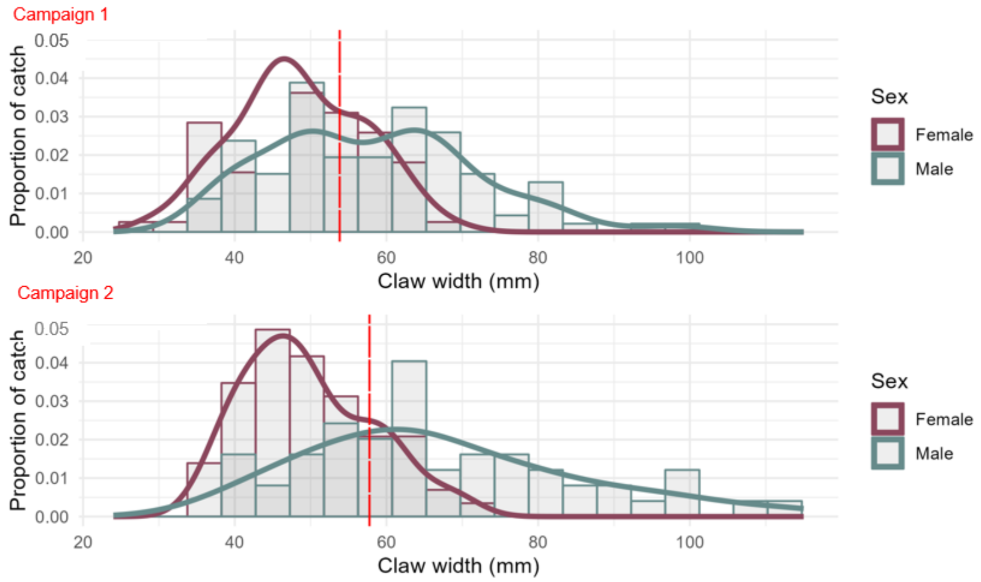

Figure 15: Claw size (mm) distribution of lobsters (n=308) in the first and second campaign with the density indicator of both males and females. The red lines are the mean claw size of the first and second campaign (53.83mm (±0.911 SE) and 57.76mm (±1.483 SE), respectively)

Appendix C

Tables with the coefficients from the linear models on body size and claw size.

Table 6: Coefficients of the linear regression model with body size as the dependent variable and Gear and Sex as independent variables. Significant P-values marked in bold.

	Variable	Estimate	Std. Error	T value	P - value
Body size	**Intercept**	299.776	5.714	52.463	**<2e-16**
	Gear 1	12.148	8.598	1.413	0.15870
	Gear 2	4.724	10.275	0.460	0.64602
	Sex 2	-13.558	7.791	-1.740	0.08283
	Gear 1: Sex 2	6.558	11.968	0.548	0.58413
	Gear 2: Sex 2	51.317	14.650	3.503	**0.00053**

Abbreviations: Gear 1 = Medium parlor trap, Gear 2 = Large fish trap, Sex 2 = Male

Table 7: Coefficients of the linear regression model with claw size as the dependent variable and Gear and Sex as independent variables. Significant P-values marked in bold.

	Variable	Estimate	Std. Error	T value	P - value
Claw size	**Intercept**	48.171	1.475	32.666	**<2e-16**
	Gear 1	1.180	2.235	0.528	0.598
	Gear 2	1.295	2.692	0.481	0.631
	Sex 2	9.051	2.013	0.495	**9.82e-06**
	Gear 1: Sex 2	3.727	3.113	1.197	0.232
	Gear 2: Sex2	16.768	3.816	4.394	**1.53e-05**

Abbreviations: Gear 1 = Medium parlor trap, Gear 2 = Large fish trap, Sex 2 = Male

Appendix D

When sampling, the depth of each haul was registered with GPS. The table below summarizes the depths of all traps, and the three trap types.

Table 8: Summary of the depth of the traps including mean and Standard error (SE).

Depth (m)	**Min**	**Max**	**Mean**	**SE**
All traps	7,1	32,4	16,7	0,45
Small trap	7,1	32,4	1,7	0,67
Medium trap	8,8	30,2	15,5	0,84
Large trap	8,8	29,9	16,4	0,88