UNIVERSITY OF OSLO
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Consequences of Selective Harvesting a Small Temperate Fish Species Displaying Strong Male Dimorphism, the Corkwing Wrasse (*Symphodus melops*).

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http://www.duo.uio.no/

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Symphodus melops

Abstract

The corkwing wrasse (*Symphodus melops*) is, together with other wrasse species, increasingly being harvested in the Norwegian wrasse fishery to support the Atlantic salmon farming industry as cleaner fish to combat sea lice infestations. There is limited knowledge about how the different wrasse species are being affected by the high fishing pressure. The life history of corkwing wrasse has been shown to be very variable throughout its range, but this is the first study investigating the link between the biology of corkwing wrasse and current management and fishing methods in Norwegian waters. In this thesis, I investigated how fishing processes and management regulations function and at the same time describe the distinct demography and life history of corkwing wrasse in South Norway. I describe that the two types of fishing gears employed in the fishery are significantly different in selectivity of targeted and non targeted species as well as on size and sex of corkwing wrasse, and show how this in conjunction with a passive management provide a low protection of corkwing wrasse. Potentially, this may result in depletion of local populations and ecological, evolutionary and socioeconomic consequences. Hopefully this study will provide the necessary base knowledge to be able to predict how corkwing wrasse populations might respond to high fishing pressure.

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1. Introduction

Approximately three quarters of the world fish stock are either fully exploited, overexploited, depleted or recovering from depletion (FAO, 2006). Fishing practices are also nearly never random (Law, 2000). Most fishing stocks will therefore face more challenges than a simple replenishment of the removed biomass. Size-selective harvesting of fish, where the largest individuals of a species are targeted, is very common in fisheries (Fenberg & Roy, 2008). Such harvesting practices are not only controlled by the demand of stakeholders (which might value larger fish higher), but are also mandated by the management plans through gear restrictions or minimum landing size (Conover & Munch, 2002; Fenberg & Roy, 2008). Minimum size restriction is likely the oldest (Herrington & Nesbit, 1943) and the most common (Coggins *et al*. 2007) conservation measure in fishery management. The intention is often to allow juveniles to reach spawning size before being targeted by the fishery and to provide some protection of the spawning stock to avoid recruitment overfishing.

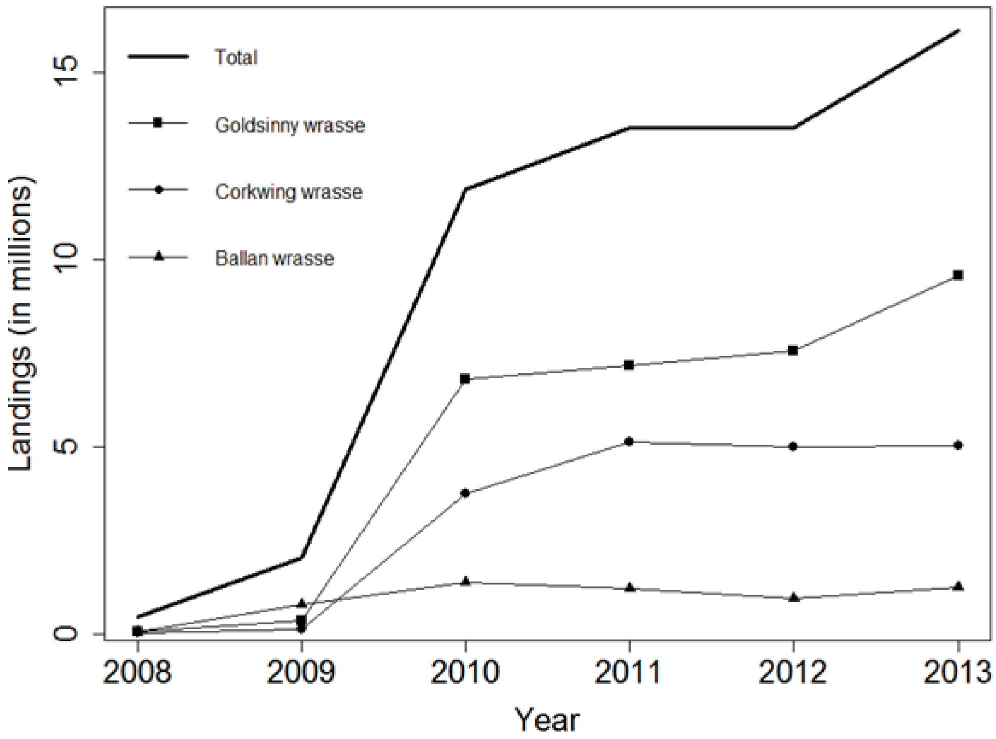
The size-selective harvest of fish is also achieved through the selectivity of commercial fishing gear. This selectivity is influenced by a number of technical (e.g. mesh size), environmental (e.g. oceanic topography) and biological (e.g. sexual dimorphism) factors (Stewart, 2001).

Therefore, there is usually substantial variation in size-based selectivity between different types of fishing gears, but also in catch per unit effort (CPUE) and species composition in the catch (Armstrong *et al.* 1990; Dalzell, 1996; McClanahan & Mangi, 2004). A common management goal is that the fishing gear should allow juveniles and non-target species to escape (Armstrong *et al.* 1990; McClanahan & Mangi, 2004). Besides selecting on body size, fishing gear might also be selective on traits affecting behavior in relation to fishing gear and catchability (Uusi-Heikkilä *et al.* 2008).

There is growing evidence that body size and age structure is reduced by size-selective harvesting the largest individuals (Swain *et al.* 2007; Fenberg & Roy, 2008). Reduction in body size is for example shown for Pacific salmon (*Oncorhynchus spp.*) (Ricker, 1981), bluegill (*Lepomis macrochirus*) (Beard Jr & Kampa, 1999), Atlantic silverside (*Menidia menidia*) (Conover & Munch, 2002), Atlantic cod (*Gadus morhua*) (Swain *et al.* 2007) and in several species of rockfish (*Sebastes spp.*) (Harvey *et al.* 2006). Fishery-induced selection may also act on alternative reproductive tactics (ARTs) by targeting different reproductive tactics unevenly. The bluegill is a species which exhibit male dimorphism, with dominant nest building males and smaller, female mimicking sneaker males. These morphs were maintained through frequency dependent selection (Gross, 1991). Later, Drake *et al.* (1997) found that the percentage of sneakers increased in lakes with higher fishing intensity.

The topic for this study is to assess the selectivity caused by fishing gear and size limits of a small temperate fish species displaying strong male dimorphism, the corkwing wrasse (*Symphodus melops*). Similar to the bluegill, the corkwing wrasse have dominant nest-building males and sneaker males (Uglem *et al. 2000*). Together with the goldsinny wrasse (*Ctenolabrus* rupestris) and the ballan wrasse (*Labrus bergylta*), the corkwing wrasse is harvested to support the Atlantic salmon (*Salmo salar*) farming industry as cleaner fish (Deady *et al.,* 1995), because of their ability to reduce the number of parasites on host fish (Potts, 1973). Sea lice (*Lepeophtheirus salmonis salmonis*) poses a major threat toward wild salmon stocks and other species, and authorities require that the salmon industry keep lice numbers at a minimum level (Torrissen *et al.* 2013). The usage of cleaner wrasse to control lice numbers has been prompted as an environmental friendly and sustainable alternative to chemical lice treatment (Kvenseth *et al.* 2003). Details about the how the Norwegian wrasse fishery is regulated and more about the target wrasse species are found in materials and methods.

The first attempts of using wrasses as cleaner fish were made in 1988 (Bjordal, 1988), and already in the early 1990s concerns were raised about the sustainability of the fishery from researchers on the British Islands (Sayer *et al.,* 1996a; Darwall *et al.,* 1992; Varian *et al.*, 1996). The wrasses appeared as a solution in times where the Norwegian salmon farming industry was criticized for being out of control regarding the usage of drugs (Grave *et al.*, 1999). When new regulations in 1992 restricted the prescription of drugs to farmed fish (Directorate of Health, 1992) a huge decrease in drug use was observed (Grave *et al.,* 1999). From then the wrasses gradually became the main solution to limit the parasites, and from 2009 the wrasses are experiencing a dramatic increase in fishing pressure (Figure 1).



<u>Figure 1</u>. Total landings (individuals; in millions) from 2008-2013 in the Norwegian wrasse fishery. The landings for each of the target species (goldsinny wrasse, corkwing wrasse and ballan wrasse) are shown individually (Directorate of Fisheries, landing statistics).

Since the concern were raised by British researchers the wrasse fishery have grown more than a ten-fold in Norway, landing over 15 million individuals in 2013 (Figure 1). The large growth in landings is due to a fast expansion of the salmon industry and because of an increased density of salmon louse (http://www.lusedata.no). Yet, there is limited knowledge about how the different wrasse species have been affected by the high fishing pressure, or how they will be affected in the future if it is maintained. More knowledge is clearly needed in order to avoid overfishing and unintended population effects, as recovery after such overfishing has proven to be slow or not happening at all after reduction or cessation of fisheries (Hutchings 2000; Hutchings & Reynolds 2004; Enberg *et al.* 2009).

The wrasses occupy an intermediate position in the food web, mainly feeding on molluscs and crustaceans (Deady & fives, 1995; Sayer & Treasurer, 1996), while being an important prey for many larger fish species such as the coastal cod (Nedreaas *et al.* 2008). If wrasse populations are reduced, the consequently reduction of the intermediate level in the food web may impact ecosystem functioning. It has been shown that populations of ballan wrasse (D'Arcy *et al.* 2013) and corkwing wrasse (Knutsen *et al.* 2013) are genetically differentiated along the Norwegian coast. If wrasse populations are spatially fine structured, local populations experiencing high fishing intensity might be overfished.

The main goal of this project is to increase our knowledge about how the wrasse fishery might impact local populations, with a special focus on the corkwing wrasse. Corkwing wrasse was chosen as the focal species for this study because it is, together with the goldsinny wrasse, the most used wrasse in terms of numbers. However, it might be more vulnerable to overfishing due to its complex reproduction involving nest building and parental care (Costello, 1991). In addition the goldsinny wrasse may reproduce at sizes not targeted by the fishery (Sayer *et al.*, 1996a) and may therefore be more resilient to overexploitation than the corkwing wrasse, which is maturing at larger sizes (Darwall *et al.* 1992). The fishery may mediate impact on the populations through the selectivity and efficiency of the fishing gear and/or through the regulation imposed by the management. I wanted to shed light on how the fishing process and management regulation are working, and how they interact. Specifically, I wanted to study how the two types of gear employed in the fishery could be selective on:

- Targeted and non-targeted species
- Size, sex and male reproductive tactic of the corkwing wrasse

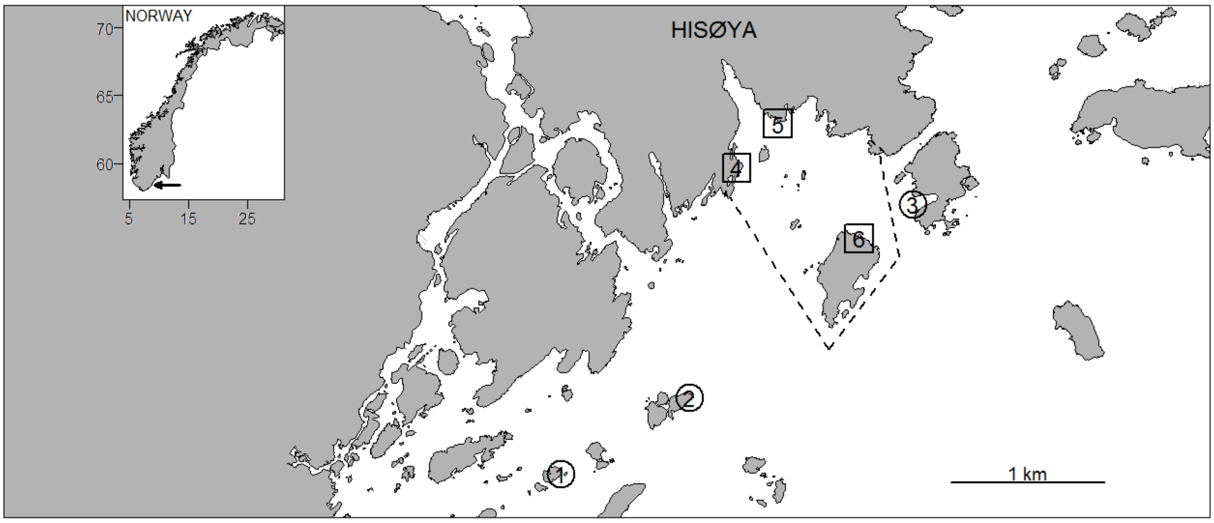
Further, I wanted to provide knowledge on the reproduction, demography and life history of the corkwing wrasse in our study area, and to compare the findings to the current regulations in the fishery.

To my knowledge, this is the only study of demography and life history of corkwing wrasse in South Norway. Hopefully this study will provide the necessary base knowledge to be able to predict how corkwing wrasse populations might respond to high fishing pressure.

2. Materials and methods

2.1 Study area

The study area (Figure 2) was located near Hisøya on the southeastern coast of Norway (58° 24'-25'N, 8° 43'-46'N). One out of four lobster (*Homarus gammarus*) reserves established in 2006 are located within this area. As lobsters, wrasses are only caught with passive gear such as fyke nets and pots. These types of gear are prohibited in the reserves. Therefore, even though the reserves aim at protecting the local lobster population, the reserve will also protect wrasses since the equipment used to catch them are banned. The area surrounding the reserve supports a relatively intensive wrasse fishery, making this area ideal for studying the effects of the wrasse fishery. For this study we selected three locations within the reserve and three locations outside (Figure 2). All of the sampling sites were selected after some days of test fishing and consultation of local fishermen. Details about sampling procedures can be found in the upcoming chapter about data collection (2.3).



<u>Figure 2</u>. Map of the study area; Norway and a detailed map of the coast outside of Hisøya. The lobster reserve is located inside of the dotted lines. The numbers on the map over the study area refer to the six sampling sites: Sven Johnsens holmer (1), Skjellbergholmene (2), Havsøy (3), West of Terneholmen (4), Gullpynt (5), Ærøy (6). Squares around the numbers indicate that these locations are located inside of the lobster reserve, while circles indicate locations outside the reserve.

The three sampling sites outside of the lobster reserve consisted of Sven Johnsens holmer, Skjellbergholmene and Havsøy. The latter is exposed from the south and is located on the eastern side of the lobster reserve. It has a large variety of habitats, from a rocky substrate to sandy *Zostera marina* beds. Skjellbergholmene lies on the western side of the reserve, and may be quite exposed by winds from the southeast. The habitat consisted of rocky substrate with a lot of brown algae and kelp. Sven Johnsens holmer is the most sheltered location located the furthest away from the reserve. A lot of the location was sandy and the presence of brown algae and kelp was low.

The three sampling sites inside of the lobster reserve consisted of Gullpynt, Ærøy and west of Terneholmen. The latter is exposed from the south and lies on Hisøya, near the eastern border of the reserve. Most of the habitat consists of rocky substrate with brown algae, but at the northern part it is more sandy. Ærøy is a big island located in the outer part of the reserve. The eastern part was used as a location as it was easily accessible and most parts consisted of rocky substrate with a lot of brown algae and kelp. Gullpynt lies on Hisøya, in between Flødevigen and Stølsvigen. It is located the furthest inside of the lobster reserve, but may still be exposed if there are harsh winds from the southeast.

2.2 Target wrasse species

The total landings in the Norwegian wrasse fishery passed 15 millions in 2013 (Figure 1). The species being targeted by the fishery are all members of the Labridae family: corkwing wrasse, goldsinny wrasse, ballan wrasse and rock cook (*Centrolabrus exoletus*). The rock cook is of minimal interest in the fishery and will therefore not be included when referring to target species from now on. The goldsinny wrasse is a slow-growing small wrasse species with pelagic eggs, while the ballan wrasse is a protogynous hermaphrodite with male parental care (Costello, 1991). They will get some attention in this study, but most of the focus will be on the corkwing wrasse.

The corkwing wrasse is a widespread and ecologically important species in European coastal waters (Sayer & Treasurer 1996; Varian *et al.* 1996), distributed along a temperate gradient from the North African coast to Mid-Norway, and reaching into the Mediterranean and Baltic (Quignard & Pras, 1986). The corkwing wrasse may maximally reach 25-30 cm and 8-9 years

(Sayer *et al.* 1996b). Spawning occurs in shallow near-shore waters, and involves a benthic egg stage and a pelagic larval phase lasting less than 20 days (Costello, 1991; Sayer *et al.* 1994). Males shows parental care for its eggs which are laid in large and complex nests (Potts, 1984; Potts, 1985). A total of 3-20 % of males have been reported to exhibit female-mimicry, using a "sneaker" tactic to fertilize the eggs laid in nests made and guarded by territorial males (Uglem *et al.* 2000). The sneaker male has slower growth than both females and territorial males, but have significantly higher gonadosomatic index in the spawning season (Uglem *et al.*, 2001).

2.2.1 Regulation of the Norwegian wrasse fishery

Because of the increased interest in wrasses (Figure 1) the Directorate of Fisheries introduced management measures for the fishery from 2011. Two important measures set by the Directorate of Fisheries are to determine the minimum length and when the fishery should be opened. In the study area the opening of the fishery has been late May for all years (30 - 27 May) since 2011. This is proposed even though the Institute of Marine Research every year have suggested to open the fishery later (Directorate of Fisheries, 2014). The minimum length has been 11 cm every year and for all species. Both measures will also apply for the upcoming 2014 season (Directorate of Fisheries, 2014). The measures are supposed to protect the wrasse populations by securing that some wrasses spawn before they are exposed to the fishery.

The Norwegian wrasse fishery functions differently along the coastline, but can be divided into two simple layouts (Figure 3). There are no fish farms in Southern Norway and the fishermen is therefore selling their fish to wrasse supplier companies that will transport the fish to the fish farms. When selling the fish to the wrasse suppliers, the fishermen are met with other minimum lengths than the ones set by the Directorate of Fisheries. This is because salmon of different sizes need specific sizes of wrasse for efficient delousing. The requirements are likely to vary between regions and companies. In the study area there are two separate wrasse suppliers with their own requirements based on preferences from the fish farms (Table 1). Therefore, even if the official minimum length (OML) is 11 cm, there are other functional minimum sizes (FML) affecting the populations. From now on 14 cm is used as the FML for corkwing wrasse and ballan wrasse, and 11 cm as the FML for goldsinny wrasse. It is also common for the wrasse suppliers to have other requirements, such as not buying corkwing wrasse in the start of the fishing season or only buying territorial males (pers. obs.).

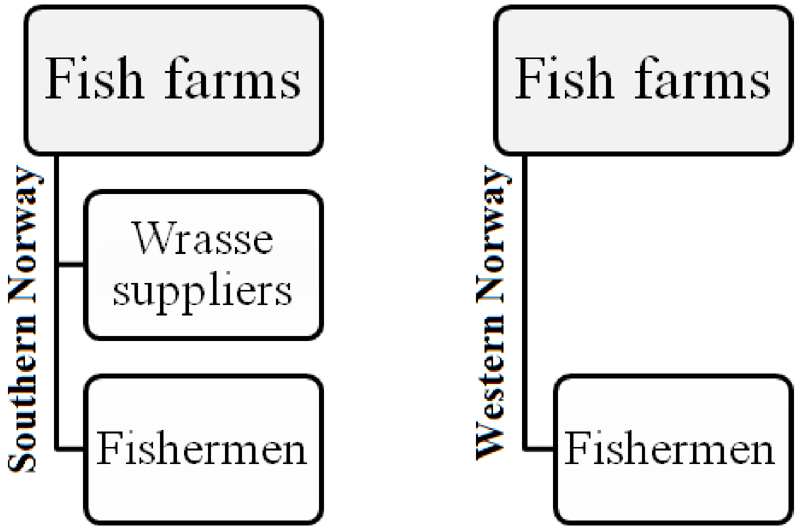


Figure 3. How the Norwegian wrasse fishery is organized. In Southern Norway, the fish farms will use wrasse suppliers to collect wrasses along the coast, while in Western Norway the fishermen sell the wrasses directly to the fish farms. The wrasse suppliers are only buying wrasses that fulfills the requirements set by the fish farms.

Table 1. Official minimum length (OML) set by the Directorate of Fisheries and two functional minimum lengths (FMLs) set by two wrasse suppliers for the target species in our study area during the 2013 fishing season. One of the wrasse suppliers in our study area raised the minimum size for ballan wrasse and corkwing wrasse at the end of the fishing season.

Target species	OML	FML 1	FML 2
Goldsinny wrasse *Ctenolabrus rupestris*	11 cm	11 cm	11 cm
Ballan wrasse *Labrus bergylta*	11 cm	14 cm	14 cm - 15 cm
Corkwing wrasse *Symphodus melops*	11 cm	14 cm	13 cm - 15 cm

(Directorate of Fisheries, 2014)

2.3 Data collection

The sampling took place from June to September 2013, and was separated into five sampling sessions. Table 2 presents the dates of each sampling session and information about the number of fishing gear used at each sampling site. We lowered the number of pots throughout the sampling sessions because high catches of goldsinny wrasse extended our time at sea by hours. With corkwing wrasse being the focal species we chose to avoid spending too much time measuring goldsinny wrasses. In sampling session 2 we added two new sampling sites, one inside of the lobster reserve (Gullpynt) and one outside the reserve (Havsøy).

Table 2. During five sampling session we sampled with both pot and fyke nets. It was sampled at four sampling sites during the first sampling session, and at six sites during session 2-5. The total number of fishing gear used throughout the sampling sessions will show the fishing effort for each sampling site.

	Sampling sessions					
	1	2	3	4	5	
Sampling sites	(11/6 - 16/6)	(30/6 - 5/7)	(20/7 - 25/7)	(9/8 - 14/8)	(30/8 - 3/9)	**Effort**
(1) Sven Johnsens holmer						
Pot	8	18	15	12	10	63
Fyke net	8	18	18	18	15	77
						140
(2) Skjellbergholmene						
Pot	12	18	15	12	10	67
Fyke net	10	18	18	18	15	79
						146
(3) Havsøy						
Pot	-	18	15	12	10	55
Fyke net	-	18	18	18	15	69
						124
(4) West of Terneholmen						
Pot	12	18	15	12	10	67
Fyke net	11	18	18	18	15	80
						147
(5) Gullpynt						
Pot	-	18	15	12	10	55
Fyke net	-	18	18	18	15	69
						124
(6) Ærøy						
Pot	12	18	15	12	10	67
Fyke net	12	18	18	18	15	81
						148

During the first four sampling sessions we released all the fish back to where they were caught after identifying them to species and measuring their length (to nearest mm). Both sexes and male morphs of the corkwing wrasse were identified by morphology and with a gentle pressure to their abdomen to see if they release eggs or sperm. The pressure revealed if the fish was reproductively active and at the same time revealed sneaker males.

During the fifth sampling session the corkwing wrasse was euthanized using an overdose of clove oil and frozen for later examination in the laboratory. The study was part of a mark-recapture study on population size, movement and growth (Halvorsen, unpublished) where corkwing wrasses were tagged and recaptured by the use of passive integrated transponders (PIT-tags). Tagging data was not used in the study, with the exception of information about spawning status and exclusion of pseudoreplicates when calculating sex ratios.

2.3.1 Fishing gear

The fish was sampled with either pots or fyke nets (Appendix 1). Table 2 show when, where and the number of fishing gear that was used throughout the sampling sessions.

All the pots that were used belong to the same model measuring 70 x 40 x 29 cm and weighing 3 kg. The pots have two circular entrances (75 mm diameter), a bait bag at the top and trap the fish by having a self-closable entrance into a separate room. A hatch is located on the long side of the trap, shut by two plastic hooks. One of the hooks also shut the bait bag. The pots are covered with small-meshed eel netting (15 mm) without knots. The pots were mainly baited with shrimps, but occasionally with crushed crabs. They were never placed deeper than 6-7 meters and was placed on both flat and sloped bottom. The pots were placed on or close to rocky substrate with brown algae and kelp.

All the fyke nets that were used belong to the same model, but some were older than others. It is the same model that was used in the past eel fishery and they have a mesh size of 30mm. The entrance (55 cm diameter) is followed by three trap doors and a continuous shrinking of size until the end (30 cm diameter). The fyke nets are placed by releasing the bottom part in the water first and then pull the net slowly towards land. Most of the times they were pulled all the way to the shoreline so that the start of the leader almost breaks the surface water. The fyke nets were never placed deeper than 6-7 meters, but only on sloped bottoms. The fyke nets were placed on or close to rocky substrate with brown algae and kelp. Fyke nets catch all types of fish trying to pass the leader.

At each sampling site the fishing gear was randomly placed at spots with suitable depth and substrate. The fishing gear was placed during the morning and afternoon and pulled the next day. For a given day the fishing gear will fish for an unequal period of time. However, I assumed that this will not alter the results of this study noticeably as the order of the sampling sites were randomly selected every day. Keeping the same order every day would make the fishing gear fish for almost the same amount of time at each sampling site, but they would also consistently fish at different times of day.

2.4 Laboratory work

In the laboratory the fish were weighed, and sex was determined by internal examination of gonads. The fish was opened by inserting a small scissor into the anus and cutting up over the peritoneum, before cutting up and backwards in a circular manner, ending up at the anus again. Then the intestine was removed with tweezers. A picture of the gonads was taken to aid in sex determination. The territorial males can be identified from the morphology alone, having a brighter coloration and lacking a blue genital papillae. But to distinguish between females and sneaker males is difficult. The female gonads are a bit larger, and are often darker with more visible veins. To make the determination more certain, all the gonads were examined under a low magnification stereo microscope. The gonads were removed from the fish using tweezers and a scalpel, and put in a small petri dish filled with water. By gently tearing the gonads apart in water, the sexes are usually easily distinguished. The gonads of sneaker males being more flat, firm and rubber-like, while the female gonads are thick, loose and more pillow-like. In addition when you tear the female gonad apart small clusters of papillae-like structures appear.

Finally the otoliths were extracted for age determination. When extracted they are put in water for some hours before gently dried by a finger or piece of paper. The otolith were stored dry until reading. Before reading they were placed in 96 % ethanol with a black background. In this study a setup with Leica microscope (MZ 16 A) and camera (DFC425 C) was used to take pictures of each otolith at 20 times magnification. Each hyaline ring (the black zone: Figure 4) represents a winter. The otoliths were read by two different people and then compared. If the two readings did not match (n = 4), the otoliths were read a third time and agreed upon.

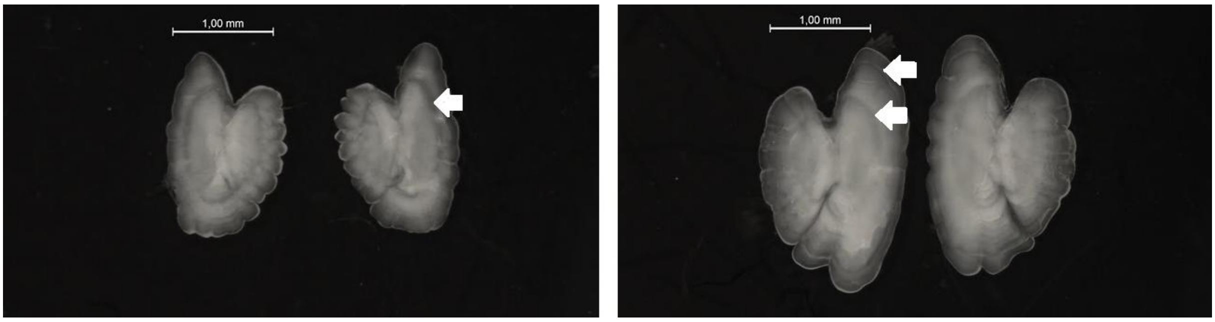


Figure 4. Illustrations of the corkwing wrasse (*Symphodus melops*) otoliths. The left otolith show a one year old male (TL: 137mm) and the right otolith show a two year old female (TL: 152mm). The arrows indicate winter zones. Total length (TL).

2.5 Statistical analyses

R software (version 3.0.2; The R foundation for Statistical Computing 2013) and RStudio were used when performing all the statistical analyses in this study.

In this study catch per unit effort (CPUE) refers to the number of fish per fishing gear per night. When comparing the CPUE of fishing gear we had four estimates (sampling sites) for each gear in sampling session 1 and six estimates in sampling session 2-5. When comparing the CPUE inside of the lobster reserve with the outside of the reserve we had two estimates (sampling sites) for each in sampling session 1 and three estimates each in sampling session 2-5. The mean CPUE of the estimates is plotted in the figures and standard deviation is included to present the spread between the estimates. A standard *t*-test was used to test for differences in CPUE for each sampling session.

Standard chi-squared tests (X^2) were used to test if observed sex ratios differed from an expected 1:1 sex ratio. I also used a simple proportion test (X^2; Test of equal or given proportions) to test for differences in age structure.

In length-frequency histograms all the sampling sessions (1-5) and sexes are pooled together and shaded bars are used to illustrate fish under the functional minimum length (FML). As the data were not normally distributed, the non-parametric Wilcoxon signed-rank test was used to compare length-frequency distributions.

3. Results

3.1 The fish community

A total of 11 718 individual fish belonging to 15 families was captured during five sampling sessions at the 6 sampling sites (Table 3). Species in the families Labridae and Gadidae were most common in the samples. In general, more fish were caught in pots (7504 individuals) than in fyke nets (4214 individuals), while more fish species were caught in fyke nets (28 species) than in pots (18 species). There was large variation in CPUE through the season for the pots, less so for the fyke nets. Outside of the lobster reserve (Figure 5), the CPUE for pots increased through all sampling sessions. Inside of the lobster reserve, the CPUE for pots increased through the first four sampling sessions, and decreased again at sampling session 5. Overall, CPUE was lower for fyke nets than for pots.

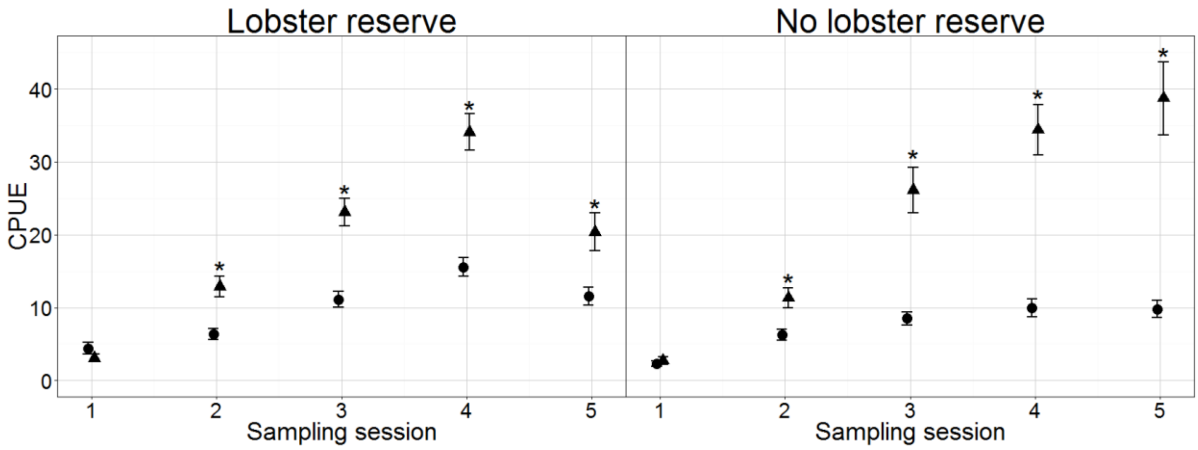


Figure 5. Mean catch per unit effort (CPUE; ± SD) for all species caught in fyke net (●) and pot (▲) inside and outside of the lobster reserve. The asterisk (*) indicates that the CPUE for fyke nets and pots for a given sampling session is significantly different. Standard *t*-test was used to test for the differences, and details can be found in Appendix 2.

Table 3. **Total catch during five sampling sessions at six sampling sites off the east coast of Norway. The table shows the number of individuals caught in fyke net and pot for each species and the mean total length (cm; ± SD). Target wrasse species are highlighted in bold.**

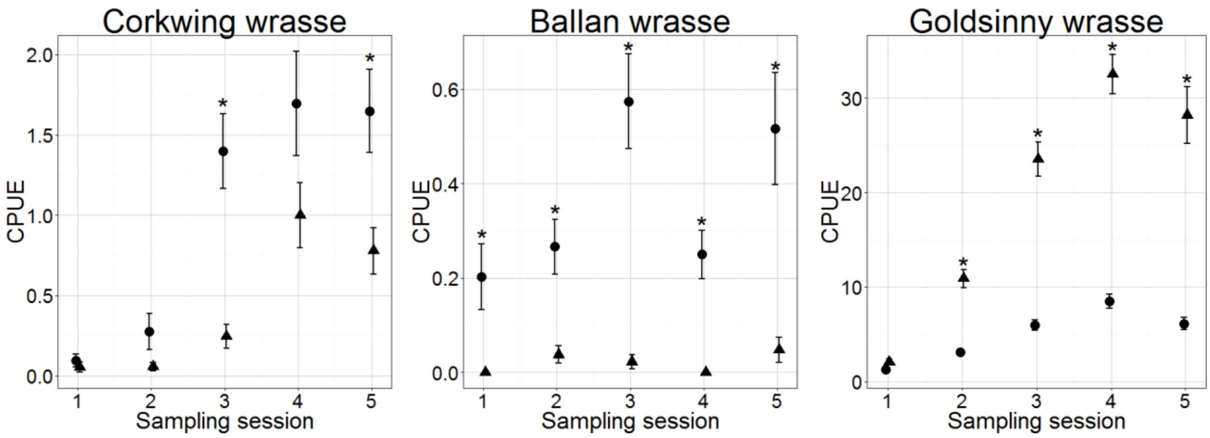
		Pot		**Fyke net**	
Family/species	Common name	mean length (cm) ± SD	n	mean length (cm) ± SD	n
Ammodytidae					
Hyperoplus lanceolatus	Great sandeel	-	0	20.0	1
Anguillidae					
Anguilla anguilla	European eel	-	25	-	307
Belonidae					
Belone belone	Garfish	-	0	73.0 ± 4.2	2
Clupeidae					
Clupea harengus	Atlantic herring	-	0	18.0	1
Cottidae					
Myoxocephalus scorpius	Short-spined sea scorpion	18.3 ± 4.5	18	17.2 ± 5.2	27
Taurulus bubalis	Long-spined sea scorpion	10.9 ± 1.9	83	11.2 ± 1.5	51
Gadidae					
Gadus morhua	Atlantic cod	33.0 ± 5.5	81	36.7 ± 10.5	257
Merlangius merlangus	Whiting	-	0	10.2 ± 3.5	6
Pollachius pollachius	Atlantic pollock	18.8 ± 8.8	10	18.7 ± 8.6	159
Pollachius virens	Saithe	-	0	24.0 ± 3.6	32
Raniceps raninus	Tadpole fish	26.2 ± 3.8	3	24.6 ± 6.8	6
Trisopterus minutus	Poor cod	20.7 ± 8.2	3	17.7 ± 3.0	21
Gobiidae					
Gobiusculus flavescens	Two-spotted goby	-	0	5.0	1
Pomatoschistus sp.		10.4 ± 1.5	11	10.8 ± 1.3	56
Labridae					
Centrolabrus exoletus	Rock cook	12.4 ± 4.7	2	11.7 ± 1.6	70
Ctenolabrus rupestris	**Goldsinny wrasse**	**10.2 ± 1.4**	**7068**	**11.1 ± 1.5**	**2456**
Labrus bergylta	**Ballan wrasse**	**23.5 ± 6.2**	**9**	**19.7 ± 7.9**	**179**
Labrus mixtus	Cuckoo wrasse	24.5 ± 1.4	2	20.5 ± 5.0	17
Symphodus melops	**Corkwing wrasse**	**15.4 ± 3.1**	**153**	**13.9 ± 2.7**	**517**
Pholididae					
Pholis gunnellus	Rock gunnel	15.9 ± 2.1	7	16.8 ± 2.4	3
Phycidae					
Ciliata mustela	Fivebeard rockling	21.2 ± 4.7	26	24.5 ± 2.7	10

Table 3.
(Continued)

Pleuronectidae					
Microstomus kitt	Lemon sole	-	0	28.0 ± 1.9	6
Platichthys flesus	European flounder	-	0	23.2 ± 7.1	22
Pleuronectus platessa	Plaice	-	0	23.3 ± 3.9	2
Solea solea	Common sole	-	0	37.5	1
Salmonidae					
Salmo trutta trutta	Sea trout	-	0	22.5	1
Scophtalmidae					
Zeugopterus punctatus	Topknot	12.1	1	-	0
Syngnathidae					
Syngnathus acus	Greater pipefish	-	0	43.0	1
Syngnathus typhle	Broadnosed pipefish	25.0	1	-	0
Zoarcidae					
Zoarces viviparus	Eelpout	24.0	1	26.5 ± 4.9	2
			7504		**4214**

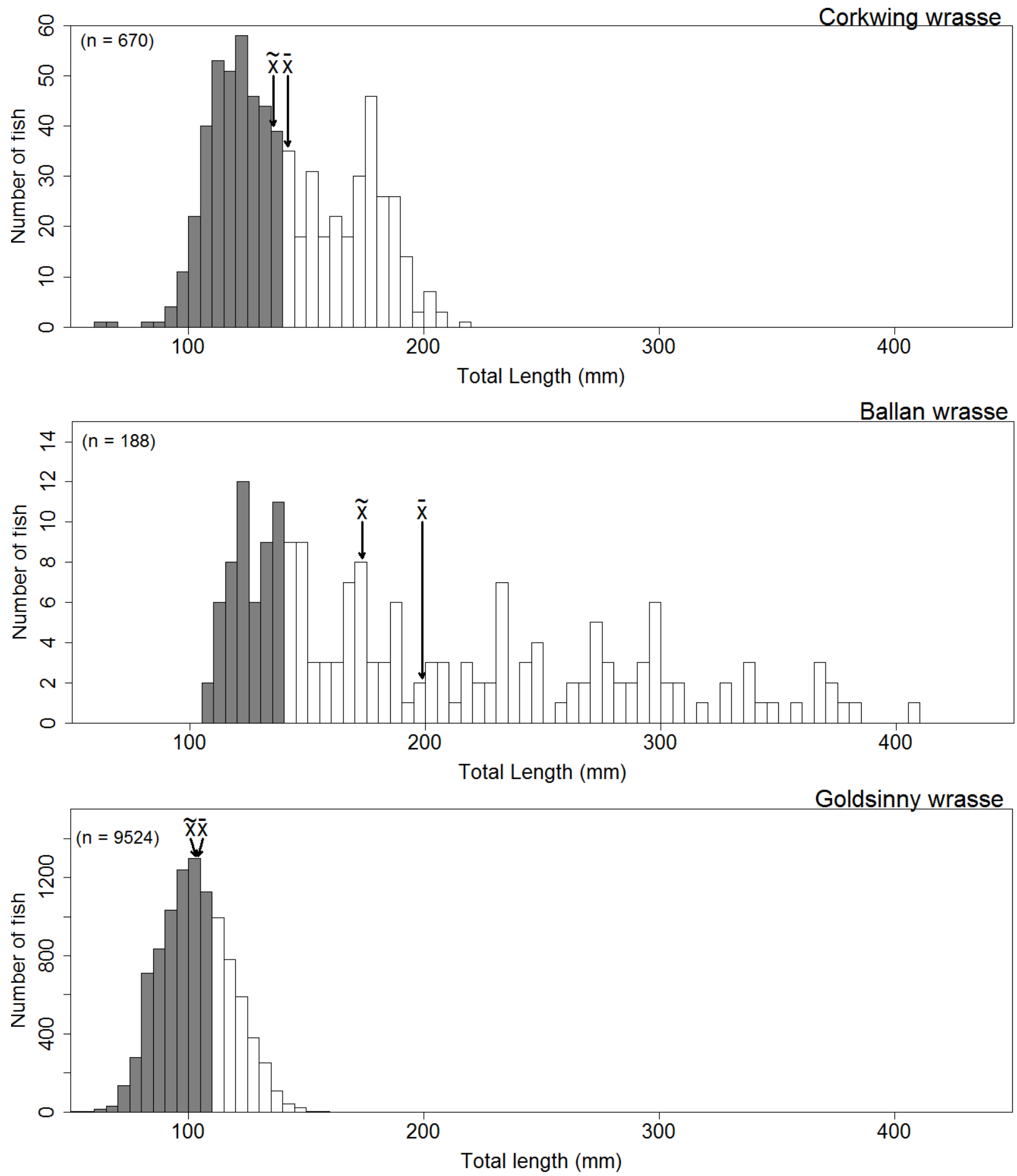
3.2 The target wrasse species

A total of 670 corkwing wrasse, 188 ballan wrasse and 9524 goldsinny wrasse was captured during five sampling sessions at the six sampling sites. Figure 6 show the CPUE of the three target species throughout the five sampling sessions. The corkwing and ballan wrasse were generally less abundant than the goldsinny wrasse. Overall, their CPUE was lower for pots than for fyke nets, but for the goldsinny wrasse the CPUE was lower for fyke nets than for pots. For the corkwing wrasse the CPUE for the fyke nets increase a lot from the second to third sampling session. However, the pots have their largest increase in CPUE from the third to fourth sampling session. For the goldsinny wrasse the CPUE for the pots and fyke nets increase more steadily through the first four sampling sessions, and decreased slightly again at sampling session 5. For the ballan wrasse the CPUE for the pots and fyke nets was generally very low through all five sampling sessions and show no clear patterns.



<u>Figure 6</u>. Mean catch per unit effort (CPUE; ± SD) for fyke net (●) and pot (▲) is shown for each sampling session and for each of the target wrasse species. The asterisk (*) indicates that the CPUE for fyke nets and pots for a given sampling session is significantly different. Standard *t*-test was used to test for the differences, and details can be found in Appendix 3. Notice that the y-axis are different.

The length distribution for each of the target species caught was either normally distributed or skewed to the right (Figure 7). The mean total length (TL) for corkwing wrasse was 142 mm and 56% of the catch was below the functional minimum length (FML). The mean TL for ballan wrasse was 198 mm and 30% of the catch was below the FML. The mean TL for goldsinny wrasse was 104 mm and 68% of the catch was below the FML. In the samples of this study the corkwing wrasse reached a maximum size of 219 mm, while the ballan wrasse and goldsinny wrasse reached 410 mm and 157 mm, respectively.



<u>Figure 7</u>. Length-frequency distribution for each of the target wrasse species caught throughout five sampling sessions in the study area (n = number of fish measured). Fish below the functional minimum length (FML; see table 1) are indicated by shaded bars. The arrows indicate mean ($\bar{X}$) and -median ($\tilde{X}$) sizes. Notice that the y-axis are different.

3.3 Corkwing wrasse (*Symphodus melops*)

During the five sampling sessions, in total 371 territorial males, 252 females and 44 sneaker males were caught. Three corkwing wrasse were too small to be sexed. The overall sex ratio between females and territorial males was constantly biased towards the males (Table 4), but the sex ratio for corkwing wrasse above the functional minimum size (see table 1) did not differ from 1:1 outside of the lobster reserve or in fyke nets (Table 5).

Being part of the mark-recapture study allowed our sex ratios not to be biased from recaptures. By not recognizing recaptures the sex ratio would have been more biased towards territorial males because of differences in CPUE (Figure 8). The CPUE for territorial males was higher than for females in both fishing gears.

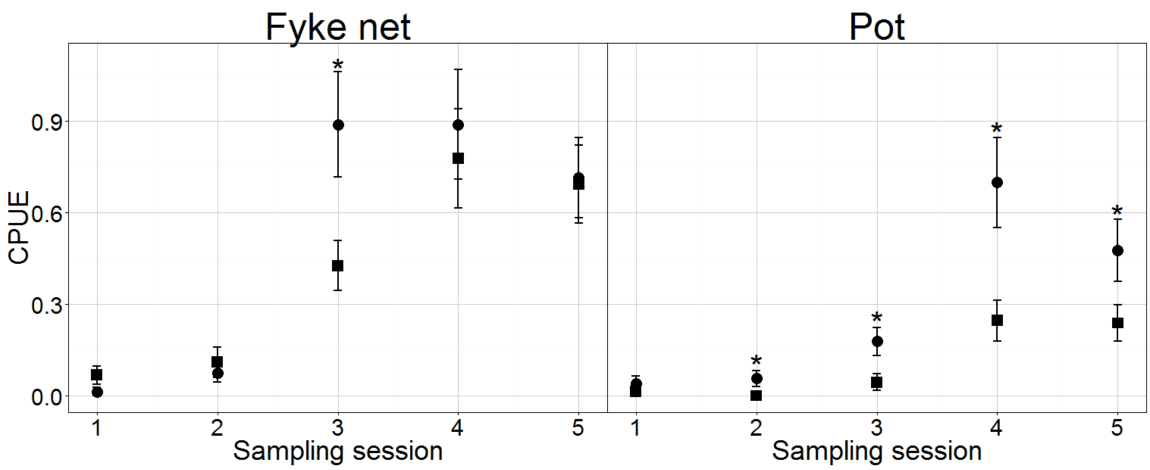


Figure 8. Mean catch per unit effort (CPUE; ± SD) for both females (■) and territorial males (●) is shown for each sampling session and for each fishing gear. The asterisk (*) indicates that the CPUE for females and territorial males for a given sampling session is significantly different. Standard *t*-test was used to test for the differences, and details can be found in Appendix 4.

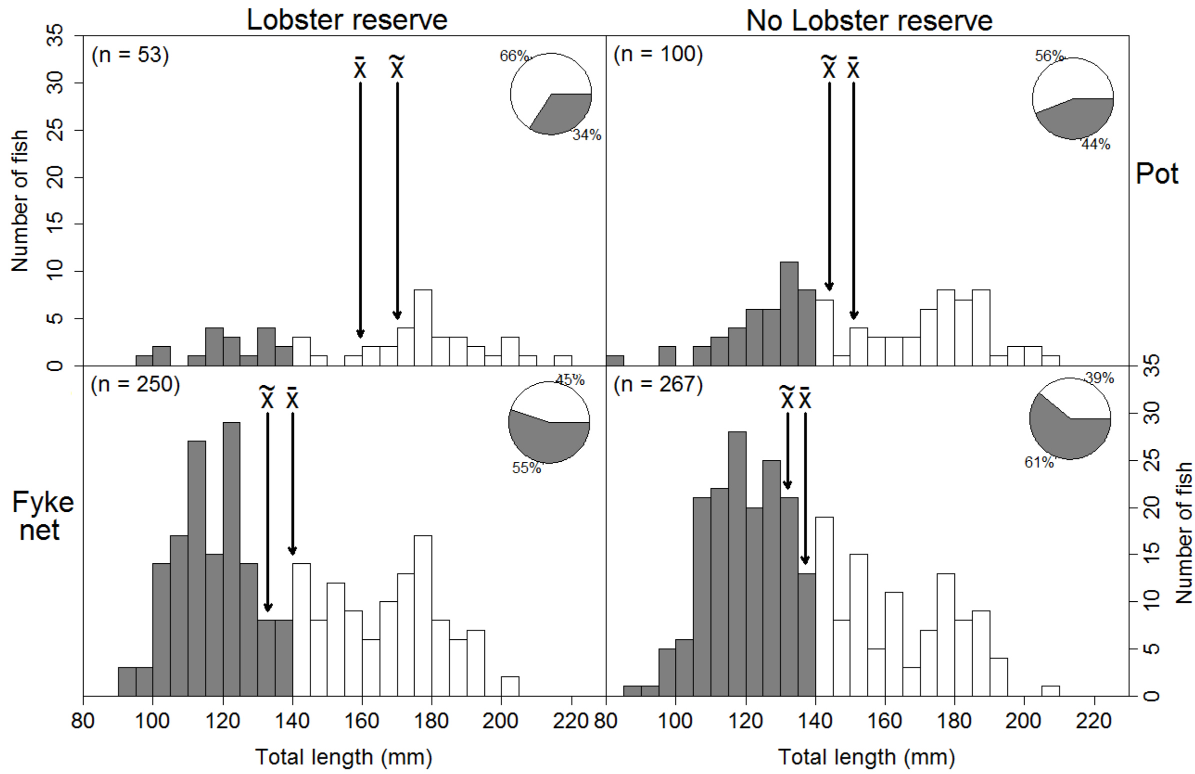
Table 4. Sex ratio between all individual females and territorial males of corkwing wrasse caught inside or outside of the lobster reserve, and caught with fyke net or pot. Chi-squared tests (X^2) were used to see if the observed sex ratios differed from an expected 1:1 ratio. The number of sneaker males are listed in bold behind the number of territorial males, but were not included in the X^2 test. Recaptures were excluded from the X^2 test.

	Females	Males	Sex ratio	df	X^2	p-value
Lobster reserve	99	144 (**20**)	1 : 1.5	1	8	0.004
No lobster reserve	128	181 (**15**)	1 : 1.4	1	9	0.003
Fyke net	192	234 (**32**)	1 : 1.2	1	4	0.042
Pot	35	91 (**3**)	1 : 2.6	1	25	< 0.001

Table 5. Sex ratio between all individual females and territorial males of corkwing wrasse above the functional minimum size (see table 1) caught inside or outside of the lobster reserve, and caught with fyke net or pot. Chi-squared tests (X^2) were used to see if the observed sex ratios differed from an expected 1:1 ratio. The number of sneaker males are listed in bold behind the number of territorial males, but were not included in the X^2 test. Recaptures were excluded from the X^2 test.

	Females	Males	Sex ratio	df	X^2	p-value
Lobster reserve	49	74(**1**)	1 : 1.5	1	5	0.024
No lobster reserve	63	70(**6**)	1 : 1.1	1	0.4	0.544
Fyke net	93	89(**5**)	1 : 1	1	0.1	0.767
Pot	19	55(**2**)	1 : 2.9	1	18	< 0.001

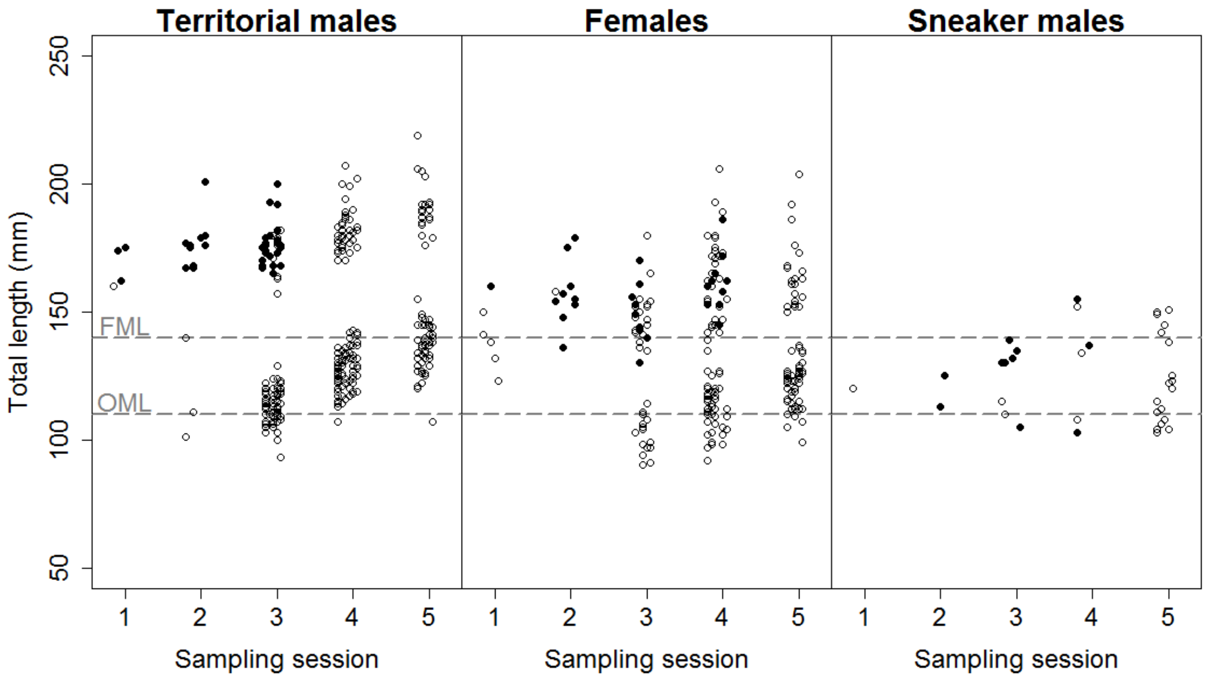
The length distribution for corkwing wrasse caught in pot or fyke net inside or outside of the lobster reserve was bimodal and skewed to either the right or left (Figure 9). The length distribution of corkwing wrasse caught in pots differed from the distribution of corkwing wrasse caught in fyke nets, both inside ($W = 9032$, $p < 0.001$) and outside of the lobster reserve ($W = 9374$, $p < 0.001$). The length distribution of corkwing wrasse caught inside of the lobster reserve did not differ from the distribution of corkwing wrasse caught outside of the reserve, neither in pots ($W = 3014$, $p = 0.163$) or fyke nets ($W = 34449$, $p = 0.527$).



<u>Figure 9</u>. Length-frequency distribution for corkwing wrasse caught with pots inside and outside the lobster reserve, and caught with fyke nets inside and outside of the lobster reserve. Fish below the functional minimum length (FML; see table 1) are indicated by shaded bars and the pie charts show the percentage of fish above and below the FML. The arrows indicate mean ($\bar{X}$) and -median ($\tilde{X}$) sizes.

The composition of the corkwing wrasse catch changed throughout the season (Figure 10). Almost all of the territorial males and females caught in the two first sampling sessions were larger than the functional minimum length (FML). But from the third sampling session the catch started to consist of many corkwing wrasse under the FML. From the third to the fifth sampling session the majority of this new group of corkwing wrasse was below the FML, but above the official minimum length (OML).

In the earlier sampling sessions reproductively active corkwing wrasse was a common part of the catch (Figure 10). During the first three sampling sessions we caught reproductively active territorial males, while reproductively active females and sneakers were caught during the first four sampling sessions. A total of 94 reproductively active corkwing wrasse was caught during the sampling. In general, more corkwing wrasse was caught outside of the lobster reserve than inside (364 to 303), but inside of the lobster reserve it was captured more corkwing wrasse that was reproductively active (61 to 33).



<u>Figure 10</u>. Total length (mm) for territorial males, females and sneaker males captured throughout five sampling sessions, with closed dots representing reproductively active individuals. The dashed lines presents the official and functional -minimum length (OML & FML; see table 1). Non-reproductively active sneaker males caught in sampling session 1-4 was determined by being recaptured in sampling session 5.

A total of 200 individual corkwing wrasse from sampling session 5 was aged (Figure 11). The samples from the fifth session mainly consisted of one- and two-year olds with the oldest corkwing wrasse being a four-year old male captured in a pot inside of the lobster reserve. The age determination showed that the group of females and territorial males that entered the fishery from sampling session 3 onwards (Figure 10) likely consisted of one year old fish (Figure 11). There were no reproductively active females or territorial males in that age-class (Figure 10). However, sneaker males were found to be reproductively active as one year olds.

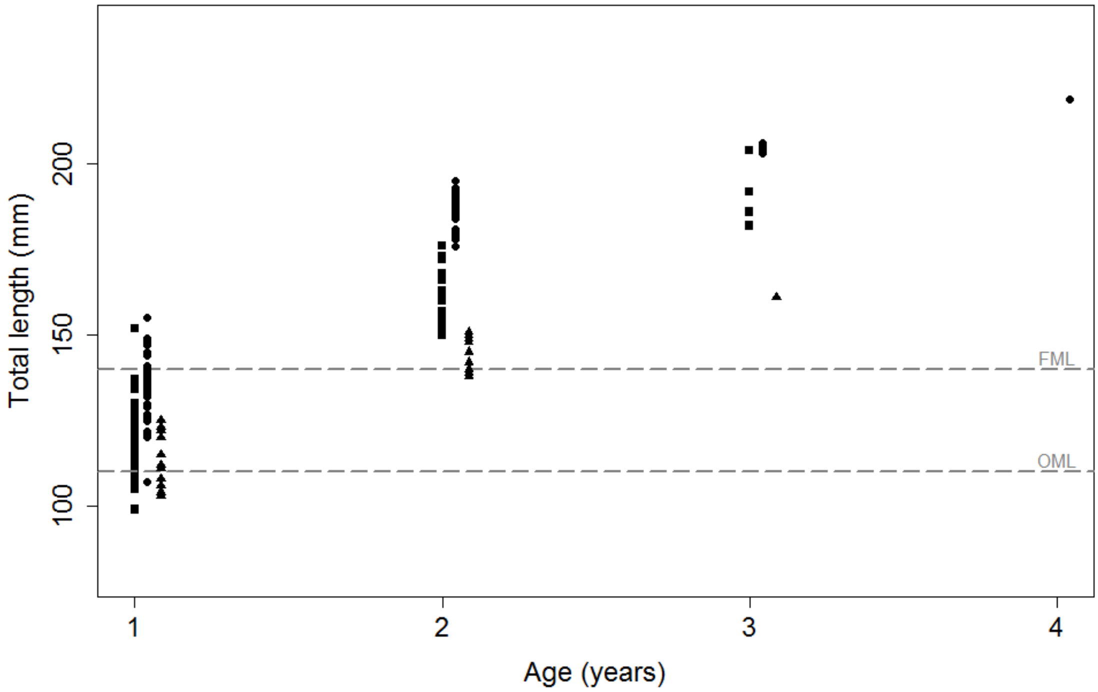
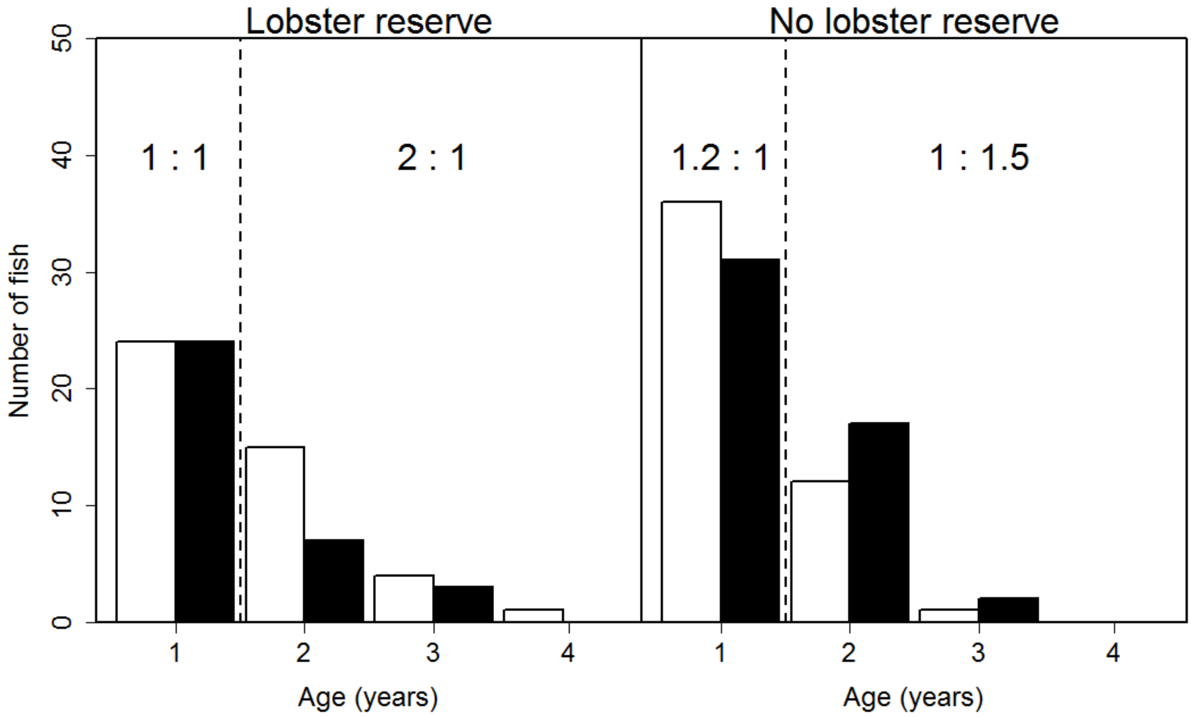


Figure 11. Total length (mm) for aged females (■), territorial males (●) and sneaker males (▲), captured during the fifth sampling session. The dashed lines presents the official and functional -minimum length (OML & FML; see table 1).

The total age distribution for territorial males and females (Figure 12) showed that the sex ratio changed with age, both inside and outside of the lobster reserve. The sex ratio for juvenile fish (1 years) did not differ from 1:1. The sex ratio for older fish (≥ 2 years) differed inside of the lobster reserve (2 : 1, $X^2 = 4$, df = 1, p = 0.041), but did not differ outside of the lobster reserve (1 : 1.5, $X^2 = 1$, df = 1, p = 0.289). However, significantly less older territorial males (≥ 2 years) was caught outside of the lobster reserve compared to the inside of the lobster reserve ($X^2 = 11$, df = 1, p < 0.001).



<u>Figure 12</u>. Sex specific age-frequency distribution for females and territorial males caught inside and outside of the lobster reserve during the fifth sampling session (open bars, territorial males; black bars, females). The sex ratio is shown for one year olds and for older fish (≥ 2 years).

4. Discussion

As being the first study linking the biology of corkwing wrasse to management and fishing methods in Norwegian waters, it has revealed that two types of fishing gears used in the fishery have different catch properties which might have implications for both targeted species and non targeted species. To understand selectivity and efficiency of the fishing gear is a natural starting point for evaluating the effects of new fisheries. Furthermore, we found that reproductively active individuals received very low protection by current management regulations, as well as from the minimum size enforced by the industry itself. I will discuss the selectivity of gear and regulations and see them in conjunction to discuss potential consequences of the current fishing practices.

4.1 Gear selectivity for species

The fishing gears had an 'opposite' selection for the target species, with corkwing wrasse and ballan wrasse being frequently caught in fyke nets while goldsinny wrasse was mostly caught in pots (Figure 6). The high selectivity of pots towards the goldsinny wrasse helps explain why the overall catch per unit effort (CPUE) was higher in pots than in fyke nets (Figure 5). The CPUE did not increase throughout the season for the ballan wrasse (Figure 6). These results coincide with how some fishermen target the ballan wrasse with fyke nets early in the fishing season and then move on to target the goldsinny wrasse with pots later in the season (Directorate of Fisheries, 2014; pers. obs.). Fyke nets are less selective and will likely catch a more realistic part of fish communities (Table 3). But by being less selective, it also results in bycatch of more valuable non-target species such as Atlantic cod and the conserved European eel (*Anguilla anguilla*) (Table 3). The bycatch is discarded by the fishermen and might therefore not be an issue as long as the fish is unharmed and released in proximity of where it was caught. However, the sorting of bycatch might happen at deeper depth (pers. obs.), and especially smaller fish might be easy prey for larger fish as they try to return to shallow waters.

Overexploitation of wrasse may create ecological effects and alter ecosystem functioning in fish communities of near-shore waters. Predicting potential consequences are complicated, but it may result in cascading effects, completely restructuring the food web (Frank *et al.* 2005). As the wrasses possess a intermediate position in the food web, a reduction may negatively impact their predators (e.g. Atlantic cod) and positively impact their prey (e.g. molluscs, crustaceans and epiphytes). Depletion of species can increase the likelihood of creating regime shifts in an ecosystem (Folke *et al.,* 2004). Such shift can create alternative stable states that may persist for decades to centuries (Scheffer and Carpenter, 2003; Mumby, 2009).

4.2 Gear selectivity for sex and size of the corkwing wrasse

Both fishing gears had a male-biased sex ratio (Table 4) as the catch per unit effort (CPUE) was higher for territorial males than females (Figure 8). Because territorial males are larger than both females and sneaker males (Figure 11; Uglem *et al.,* 2000), the male-bias in fyke nets might be a result of gear retention (e.g. mesh size). However, for larger corkwing wrasse there is still a male-bias in pots (Table 5). Pots catch significantly larger corkwing wrasse than fyke nets (Figure 9). As opposite of fyke nets, pots are baited, and are therefore depending on foraging behavior to be efficient (Løkkeborg *et al.,* 1989). Reproduction is likely to affect such behavior (Hoffman, 1983), which can explain why only two reproductively active females where caught in traps, whereas 16 territorial males with running milt was caught. Pots and fyke nets does also differ in that the entrance and container of caught fish is separate in fyke nets, but not in pots. Territorial males are known to be aggressive towards conspecifics (Potts, 1974), and it is therefore plausible that other corking wrasses may avoid a pot with a territorial male already present. Further, Wasslavik (1999) found that females prefer more active territorial males, while territorial males have no preference towards active females. If this is seen in conjunction with that territorial males, during nest building, is observed to search for coralline algae over areas of several hundred feet (Potts, 1985), the likelihood of encountering fishing gears might increase.

4.3 Corkwing wrasse biology and implications of current management

The fishery had already been open for two weeks when our sampling started in the middle of June. Still, the catch was dominated by reproductively active corkwing wrasse for over a month (Figure 10). The functional minimum size (FML; see table 1) protect reproductively active sneaker males and a few females (6%), but all reproductively active territorial males we observed where unprotected by the size regulations (Figure 10). Reproductively active females are rejected by most wrasse suppliers (Directorate of Fisheries, 2014; pers. obs.), but not necessarily the reproductively active territorial males. Meaning that in the beginning of the fishery, almost exclusively reproductively active territorial males are targeted. Current fishing practices could reduce the reproductive capacity of harvested corkwing wrasse populations and negatively affect recruitment by not allowing the reproductive cycle to end. The spawning events for corkwing wrasse depend on territorial males that build and guard nests. Selectively harvesting territorial males that are reproductively active will consequently lower the number nests, but may also create crowding implications at the nests made by territorial males that succeed in escaping the fishery. Increased densities of sneaker males have been shown to have negative impact on both females and territorial males of the closely related ocellated wrasse (*Symphodus ocellatus*). The ocellated wrasse has similar reproductive tactics and it is shown how both females (Alonzo & Warner, 2000) and territorial males (Alonzo & Warner, 1999) were not willing to spawn at nests in the presence of sneaker males. Additionally, McCormick (2006) depicts how the density of females, through stress-related mechanisms, can negatively influence the quality of larvae produced. For the corkwing wrasse it has been observed behavior of how both female and territorial male show aggression towards sneaker males and redundant females (pers. obs.). By not securing recruitment and by selectively targeting one sex may destabilize dynamics and promote population collapse (Boukal *et al.* 2008). Depletion of local populations have likely already occurred (Directorate of Fisheries, 2014) and recovery of depleted stocks is still a poorly understood process, it can take years or even decades, and during this time catches may be dramatically reduced (Worm *et al.* 2009).

With the mean total length (TL) being 142 mm, more than half of corkwing wrasse catch fell below the functional minimum size (see table 1; Figure 7). This was a result of large number of one year olds (Figure 11) entering the fishery from the third sampling session (Figure 10).

The minimum sizes allow the fishery to target two year old females, the largest two year old sneakers and the largest one year old territorial males (Figure 11). Interestingly, we found the corkwing wrasse in our study area to be different from other described populations of corkwing wrasse in terms of age and size of maturation and life expectancy. Uglem *et al.* (2000) described that corkwing wrasse on the Swedish west coast have a short lifespan of maximum four years, in agreement with our study, but territorial males mature their first summer, which is in contrast to our findings where they seem to mature their second summer. Skiftesvik *et al.* (2014) found that corkwing wrasse studied on the west coast of Norway mature as one year olds and have a lifespan of maximum 14 years, both of which is in contrast to our findings. Knutsen *et al.* (2013) found little genetic differentiation among Sweden and Norway, so it is likely that environmental factors are influencing age at maturity. Further, Darwall *et al.* (1992) found that corkwing wrasse studied in the UK mature as two year old, in agreement with our study, but they have a lifespan of maximum six years, which is in contrast to our findings. All this contrasting results reflect the need of more understanding of geographical differences in the life-history of corkwing wrasse and what underlying mechanisms that may control it. Additionally, as the size-selective harvesting favors the sneaker males, knowledge about what underlying mechanisms that control sex determination is also needed. The sneaker morph is most likely fixed for life (Uglem *et al.,* 2000), so if sneaker males are genetically predisposed it might lead to evolutionary changes in the probability of maturing as a territorial male or sneaker male. The spatial distinctiveness of corkwing wrasse populations will be under evolutionary threat from the high fishing pressure.

The age structure of corkwing wrasse outside of the lobster reserve is truncated and has significantly fewer territorial males compared to inside of the lobster reserve (Figure 12). This is expected as a size-selective fishery likely will change the level and size dependence of mortality compared to non-harvested populations. Life-history theory predicts that fish adapt to these changes through evolutionary alterations in their life histories, and experiments and models predict that such fisheries-induced evolution is potentially fast (Heino & Dieckmann, 2009). Size selective harvesting the largest individuals will lower the number of fish exceeding the minimum size as genotypes with slower growth, earlier age at maturation and smaller size will be favored (Kuparinen & Merilä, 2007; Zhou *et al.,* 2010). Fishery-induced earlier maturation has been shown for several fish species (e.g. cod (Olsen *et al*., 2004), guppies (*Poecilia reticulata*) (Reznick & Ghalambor, 2005), and North sea plaice (Rijnsdorp, 1993)). Earlier maturation and loss of old-growth structure might reduce the spawning potential as there are evidence of older fish producing larvae of higher quality (Berkeley, 2004; Birkeland & Dayton, 2005), but may consequently also create negative socioeconomic consequences for the stakeholders. The Norwegian wrasse fishery differs from most fisheries by being a live-fish fishery. The size of the wrasses (Figure 7) determines their role in the aquaculture, as only larger wrasse, as large corkwing and ballan wrasse, are being used to delouse larger salmon (Directorate of Fisheries, 2014). Smaller wrasse, predominantly goldsinny wrasse, are abundant and the need from the industry is met by the catches (Figure 6). On the other hand, the fishermen have not been able to meet the demand of wrasse that can be stocked with medium and large salmon. On the long-term, current fishing practices may therefore create difficulties of providing the salmon farms with corkwing wrasse large enough to delouse medium-sized salmon.

4.4 Conservation incentives and concluding remarks

The actions of the Directorate of Fisheries are questionable regarding provisions in the Marine Resources Act (Havressursloven, 2009). The purpose of the act is to ensure a sustainable and socioeconomic profitable conservation of marine resources and their genetic diversity (§1). When conserving harvested species, emphasis shall be on a precautionary and ecosystem-based approaches (§7). However, utilization of marine resources shall also be adapted to stakeholders and local employment (§7).

Current management measures does not achieve their objectives. That has been illustrated for the corkwing wrasse in this study, and the Directorate of Fisheries have pointed out several flaws themselves (Directorate of Fisheries, 2014), but still showing limited willingness of renewal of their measures. Realistically, there are often conflicts between stakeholders, and all interest should be incorporated in the process of conservation efforts (Lundquist & Granek, 2005). But it is likely that interest from some stakeholders outweighs the interest from others. The management measures fit the salmon industry better than it fits the wrasse populations. For instance, fish farmers want access to wrasses as early as possible to avoid chemical delousing (Directorate of Fisheries, 2014), and the low official minimum size (OML; see table 1) allow the salmon industry to control the harvesting after their own demand. The corkwing wrasse is in reality regulated by the salmon industry and not the Directorate of Fisheries, and their regulation will instead function as 'makeup' of what seems to be more or less an open access fishery. Further, there are fish farms and fishermen that are skeptic to current conservation. All fish farmers and fishermen in the Hardangerfjord have organized a voluntary management for sustainable harvesting of the wrasse species (http://www.kvamvet.no). Such local involvement emphasize even more how current management measures need renewal.

Fortunately, the cooperation between the Directorate of Fisheries and the Institute of Marine Research constantly increase. Technical modifications of fyke nets that reduces bycatch of other species and the catch of undersized wrasse is currently being tested (Directorate of Fisheries, 2014; pers. obs.). This will likely provide valuable knowledge, and may be able to solve some unfavorable selectivity. If fyke nets can be technical modified to not retain unwanted age-classes and to decrease the bycatch of other species (Table 3), it may appear to be the best fishing gear enabling sustainable harvesting of corkwing wrasse. However, such gear-based management need to be combined with enforcement of stricter regulations, preferably implementing species-specific management measures that allow the wrasses to spawn.

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Appendix 1

<u>Figure 13</u>. The type of pot (left) and fyke net (right) that was used in data collection throughout five sampling sessions in the study area (Figure 2).

Appendix 2

<u>Table 6</u>. Results from standard *t*-tests used to test for differences in the catch per unit effort (CPUE) for fyke nets and pots inside and outside of the lobster reserve and for a given sampling session (Figure 5). Significant differences are highlighted in bold.

	Sampling session	n	df	*t*-statistic	p-value
Lobster reserve	1	263	62	1.4	0.1662
	2	1134	80	4.1	**< 0.001**
	3	1714	71	5.4	**< 0.001**
	4	2187	52	6.6	**< 0.001**
	5	1256	44	3.1	**0.0038**
No lobster reserve	1	145	69	0.7	0.5011
	2	1060	85	3.3	**0.0016**
	3	1861	52	5.4	**< 0.001**
	4	1924	45	6.7	**< 0.001**
	5	1661	34	5.6	**< 0.001**

Appendix 3

<u>Table 7</u>. **Results from standard *t*-tests used to test for differences in the catch per unit effort (CPUE) for fyke nets and pots for each of the target wrasse species and for a given sampling session (Figure 6). Significant differences are highlighted in bold.**

	Sampling session	n	df	*t*-statistic	p-value
Corkwing wrasse	1	11	141	0.8	0.4292
	2	27	120	1.9	0.0591
	3	173	128	4.7	< **0.001**
	4	257	168	1.8	0.0709
	5	202	135	2.9	**0.0039**
Ballan wrasse	1	14	73	2.9	**0.0046**
	2	33	130	3.8	**< 0.001**
	3	64	112	5.4	< **0.001**
	4	27	107	4.9	**< 0.001**
	5	50	99	3.8	< **0.001**
Goldsinny wrasse	1	152	138	1.8	0.0723
	2	1493	133	7.7	< **0.001**
	3	2818	105	9.3	< **0.001**
	4	3257	90	10.9	< **0.001**
	5	2162	68	7.1	< **0.001**

Appendix 4

<u>Table 8</u>. **Results from standard *t*-tests used to test for differences in the catch per unit effort (CPUE) for females and territorial males of the corkwing wrasse caught in fyke net and pot for a given sampling session (Figure 8). Significant differences are highlighted in bold.**

	Sampling session	n	df	*t*-statistic	p-value
	1	6	103	1.7	0.0977
	2	19	172	0.6	0.5197
Fyke net	3	142	153	2.4	**0.0159**
	4	180	212	0.5	0.6477
	5	132	180	0.1	0.9045
	1	4	118	1.0	0.3144
	2	6	106	2.2	**0.0333**
Pot	3	20	143	2.5	**0.0139**
	4	70	100	2.8	**0.0065**
	5	44	100	2.0	**0.0439**