

**Assessing impact of fishing on growth of corkwing
wrasse (*Symphodus melops*) and goldsinny wrasse
(*Ctenolabrus rupestris*)**

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Abstract

Corkwing wrasse (*Symphodus melops*) and goldsinny wrasse (*Ctenolabrus rupestris*) are two temperate wrasse (*Labridae*) species who are targeted by commercial fishery due to their ability to reduce sea-lice infections. The scientific community have raised concerns regarding the long-term sustainability of the wrasse fisheries, as these two species are extensively harvested along the Norwegian coast. Studies on a wrasse fishery impact in wild populations of corkwing and goldsinny wrasse are therefore needed. Addressing whether harvesting impacts on the growth rate in these two species can provide a better understanding on how wild populations of wrasse are affected. Giving a better basis for future regulations and directions to maintain a sustainable wrasse fishery.

In this study I analyzed five years of catch-mark-recapture (CMR) data on individual growth collected in a marine protected area (MPA) on the west coast of Norway. A before-after control-impact (BACI) approach on two adjacent islands (fished and control (MPA)) allowed me to assess the possible effect of a replicated wrasse fishery on growth rates in wild populations of corkwing and goldsinny wrasse. A total of 8855 of corkwing and 4993 of goldsinny were tagged over thirteen sampling periods between 2017 and 2021. In total 1890 corkwing and 733 goldsinny were recaptured. My results showed a significant difference in growth rate between fished area and control area for male corkwing wrasse. Males in the fished area had a faster growth after fishing started compared to before. This could indicate that fishing had a clear effect on male corkwing growth. In the long run, this may be a positive sign for the fished population since males growing larger quicker could lead to earlier maturation, better male parental care, and better population productivity. Female corkwing wrasse did not show significant differences in growth rate between the areas, neither before nor after fishing started. Earlier maturation could be a possible explanation, with more investment towards gonad growth instead of growth. For goldsinny there were little difference in growth between fished and control area, neither before nor after fishing started. A possible explanation could be that both sexes of goldsinny grow slower than corkwing, meaning that it could take longer time to detect any differences in growth. Based on my results, there is reasons to believe that a wrasse fishery will have a greater impact on corkwing compared to goldsinny. As corkwing showed more difference between the two areas. Goldsinny did not have the same growth variation between the areas. This could indicate that fishing can have less negative effect than anticipated, especially if faster growing males provide better parental care.

Sammendrag

Grønngylt (*Symphodus melops*) og bergnebb (*Ctenolabrus rupestris*) er to av tre tempererte leppefisk (*Labridae*) arter som blir målrettet fisket for å bruke i oppdrettsanlegg, på grunn av deres evne til å begrense lakseluspåslag. Forskningsmiljøet har uttrykt bekymring angående den langsiktige bærekraften til leppefiskeriene, ettersom fiske på disse to artene er omfattende langs norskekysten. Flere studier på hvordan leppefiske påvirker ville populasjoner av grønngylt og bergnebb er derfor nødvendig. Ved å adressere mulige påvirkninger fiskeri har på vekst rate for disse to artene, kan føre til en bedre forståelse for hvordan ville populasjoner av leppefisk blir påvirket. Noe som fører til et bedre fundament for fremtidige reguleringer og direktiver for å opprettholde et bærekraftig leppefiske.

I dette studiet brukte jeg fem år med fangst-merking-gjenfangst data fra et marint verneområde på vestkysten av Norge. På to nærliggende øyer (fisket og kontroll (marint verneområde)) ble det brukt en før-etter tilnærming for å se på effektene av et etterlignet leppefiske på individuell vekstrate i populasjoner av grønngylt og bergnebb. Totalt 8855 grønngylt og 4993 bergnebb ble merket over tretten perioder mellom 2017 og 2021. Hvorav totalt 1890 grønngylt og 733 bergnebb ble fanget om igjen. Mine resultater indikerte at det var en signifikant forskjell i vekst rate mellom fisket og kontroll område for grønngylt hanner. Hanner i fisket område hadde raskere vekst etter at fiske startet sammenlignet med før fiske. Dette kan indikere at fiske hadde en klar effekt på vekst for grønngylt hanner. Lenger fremme i tid kan dette være et positivt tegn for den fiskede populasjonen ettersom raskere vekst for hanner kan føre til tidligere modning, bedre foreldreomsorg, og bedre produktivitet i populasjonen. Grønngylt hunner hadde ikke en signifikant forskjell i vekst rate mellom områdene, og heller ikke før eller etter fiske startet. Tidligere modning kan være en mulig forklaring, med mer investering i gonadevekst istedenfor vekst. For bergnebb var lite forskjell mellom vekst i fisket område og kontroll område og heller ikke før og etter fiske startet. En mulig forklaring kan være at begge kjønnene vokser saktere enn grønngylt, som betyr at det kan ta lenger tid å se forskjeller i vekst. Basert på mine resultater, så er det grunner til å tro at leppefiske vil ha en større effekt på grønngylt enn bergnebb. Ettersom grønngylt viste mer variasjon i vekst mellom de to områdene, med klare forskjeller mellom kjønnene. Bergnebb hadde ikke den samme variasjonen i vekst mellom områdene. Forvaltning av disse artene kan by på utfordringer ettersom de blir fisket opp i store mengder for å bli brukt som rensefisk i lakseoppdrett.

Preface

First, I'd like to express my deepest thanks to my supervisors Tonje Knutsen Sjørdalen and Kim Halvorsen for their incredible support, guidance, and feedback throughout the project. I would not have made it without you and could have not asked for better supervisors! Your knowledge and positivity truly made this project inspiring and fun to work with. I would also like to thank Kim Halvorsen and Torkel Larsen for sharing their experience and helping me in field work with identifications of wrasse, throwing and hauling fyke nets. In addition, I would also thank Reidun Bjelland and Anne Berit Skiftesvik on the Institute of Marine Research on Austevoll for their contribution on data sampling in the field work. I'd also like to thank previous contributors from earlier sampling years for their collection of valuable data.

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1. Introduction

1.1 Marine fisheries and its impacts

Commercially and recreationally fisheries are important to local and national economies, and contributes to substantial economic benefits (Arlinghaus *et al.*, 2002; Hilborn *et al.*, 2003). However, the sustainability of fisheries has been questioned, and remains as a major problem worldwide (Sparholt *et al.*, 2021). Overfishing of the spawning biomass of a population, recruitment overfishing, can reduce its ability to replenish and can consequently lead to population collapse (Pauly, 1994; Ben-Hasan *et al.*, 2021) which the collapse of north western Atlantic Cod (*Gadus morhua*) is a good example of (Walters and Maguire, 1996).

Although fish stocks may adapt to fishing through evolution in the long run, fishing operations are still deliberately selective (Pauli *et al.*, 2015) not only as a result of regulations enacted to protect smaller individuals, but also by fishermen targeting commercially profitable and available species (Salas *et al.*, 2004; Andersen *et al.*, 2012). When it comes to selectivity, population productivity may negatively be affected by the size selectivity (i.e., removal of large individuals) and mortality that is imposed by many commercial and recreational fisheries (Uusi-Heikkilä *et al.*, 2015b). Earlier studies have suggested that smaller individuals (subjected to low fishing mortality) will typically have low fecundity and reproductive success (Shelton, 2006; Uusi-Heikkilä *et al.*, 2015a). Large males that are more dominant in male-male competition and have a high resource-holding potential are often preferred by the large females (van den Berghe and Gross, 1989; Sjørdalen *et al.*, 2018). In systems where body size is a sexually selected trait, a reduction in size variability can be expected to disrupt the choice of mate and competition within the species. Given that a size variability is present in a exploited population as a result of size-selective harvesting (Hutchings and Baum, 2005; Nusslé *et al.*, 2017).

Changes in abundance and size structure because of fisheries can have indirect (and often negative) effects on other ecosystem components. Removal of predators high in the food web can completely restructuring the food web in ecosystems, and possibly resulting in cascading effects through the trophic levels below (Frank *et al.*, 2005; Norderhaug and Moland, 2021), ultimately affecting nontargeted species (Wood *et al.*, 2018; Perälä and Kuparinen, 2020). In a longer timeframe, fish stocks may adapt to fishing through evolution (Roos *et al.*, 2006). Most typically, overexploiting harvesting practises tend to select for earlier maturation at smaller size causing higher reproductive investment for the individuals in the exploited stock (Reznick *et*

al., 1990; Conover and Munch, 2002; Hutchings and Baum, 2005; De Roos *et al.*, 2006; Jørgensen *et al.*, 2007; Hočevár and Kuparinen, 2021). Traits connected to maturation timing can change faster than other life-history traits, and therefore may be more responsive to fisheries induced evolution (FIE) (Audzijonyte *et al.*, 2013).

Precautionary approaches to promote rebuilding and limit the risk of fish collapse under sustained fishing pressure have been supplemented with a reference point for management called maximum sustainable yield (MSY) (UNCLOS, 1982). Long-term predictions of yield and sustainability generally assume density dependence in the abundance of incoming recruits by incorporating a negative relationship between recruitment and spawning stock biomass (Cadigan 2013).

1.2 Density dependent growth

The removal of fish from a population will potentially ease the competition of space and food, leaving more resources for the remaining individuals in the populations to increase their growth rate. This concept in population ecology is called density dependent, and occurs when population growth rates or survival are regulated by the density of a population (Ricker, 1954; Beverton and Holt, 2012). When the number of individuals in a population becomes high, the mortality could increase with higher intra-specific competition for limited resources such as food and habitat. In addition, diseases, parasites and predators are other mechanisms for density dependent mortality (Hixon and Webster, 2002; Stige *et al.*, 2019). High density would also increase competition for spawning territories and mates, which could reduce fertility (Anderson and May, 1978; Pulliam, 1988; Sinclair *et al.*, 2003). The opposite would be the case when population size is low. Mortality rates during the juvenile (pre-recruit) phase is typically very high and predation is thought to be the main cause (Cushing, 1974; Sogard, 1992). Therefore, it is believed that fish populations are mainly regulated by density-dependent growth in the juvenile phase (Lorenzen and Enberg, 2002). Increase of food availability due to low competition could therefore be particularly advantageous for juvenile individuals that are dependent on rapid growth in an early, vulnerable life stage (Andersen *et al.*, 2017). Rapid growth makes it possible for a newly settled juvenile to leave the most vulnerable size classes quicker, resulting in an advantage over slower growing individuals (Sogard, 1992). Density regulations can be challenging to detect since populations can fluctuate widely, without showing signs of density regulations, this has caused debate regarding how regulations can be

detected and whether it is important at all (Turchin, 1995; Hixon and Webster, 2002; Brook and Bradshaw, 2006). Fish growth is believed to be an important key in regulating fish populations (Lorenzen and Enberg, 2002). Fish species tend to grow indeterminately (somatic growth), with very few exceptions, which means fish grow their whole life. This somatic growth can have an impact on survival, sexual maturity and productiveness (Rose *et al.*, 2001; Vincenzi *et al.*, 2014; Korman *et al.*, 2021). Some strategies to avoid juvenile mortality are rapid growth and early sexual maturity, which is expected to give better fitness and incur predation risks (Bacon *et al.*, 2005).

1.3 Marine protected areas

The density of populations can be increased by conservation efforts, such as establishing no-take areas or marine protected areas (MPAs), areas partially or completely closed for fishing. It is documented that MPAs create areas with higher fish biomass and size distributions compared to unprotected fished areas, if designed correctly (Halpern *et al.*, 2010; Edgar *et al.*, 2014; Baskett and Barnett, 2015). Support from fishers is still limited, even though MPA advocates suggests that these protected areas not only protect the exploited species, but also provides “spillover” effects where fish or larvae leave the MPA and are eventually caught (McClanahan and Mangi, 2000; Hilborn, 2018). Hoping that spillover from a high biomass area within a MPA can offset the assumed loss of catch associated with their establishment (Gell and Roberts, 2003; Grorud-Colvert *et al.*, 2014; Marshall *et al.*, 2019).

For the fished areas, there is reasonable to believe that removal of individuals will have a positive effect on population growth, as more food resources are distributed on fewer individuals in the population. However, the opposite may be the case inside the MPA as fish abundance can affect population growth in a negative way, having more competition on limited food resources, leading to overall smaller individuals with slower growth rates over time (Gårdmark *et al.*, 1999; Post *et al.*, 1999; Lorenzen and Enberg, 2002; Beverton and Holt, 2012). It therefore has been hypothesized that MPAs can lead to slowed growth of exploited species, reducing its usefulness as a fisheries management tool (Claudet *et al.*, 2006; Gårdmark *et al.*, 2006; Marshall *et al.*, 2019).

1.4 Wrasse fishery

MPAs are well suited to protect and manage sedentary fish and crustacean species in shallow waters (Knutsen *et al.*, 2022). In Norway, small MPAs have been proven to increase size and abundance of two species of wrasse, the corkwing wrasse (*Symphodus melops*) and goldsinny wrasse (*Ctenolabrus rupestris*) (Halvorsen *et al.*, 2017a). These two species have become commercially important in Scandinavia and on the British Isles, where they are used as cleaner fish in Salmon Aquaculture (Halvorsen *et al.*, 2021a). Since starting farming on Atlantic salmon (*Salmo salar* Linnaeus, 1758) in Norway in the 1970`s, removal of ectoparasitic salmon lice (*Lepeophtheirus salmonis* Krøyer, 1837 and *Caligus elongatus* Nordmann, 1832) have been challenging (Heuch *et al.*, 2005). In addition to economic losses, the salmon lice also cause damage and stress when attached to the skin of the fish and could potentially cause a threat to nearby ecosystems (Costello, 2006; Krkošek *et al.*, 2006). After Bjordal (1988) described the symbiosis between Atlantic salmon and wrasse (*Labridae* Cuvier, 1816), harvesting of wrasse as a biological delousing tool in the aquaculture industry started (Espeland *et al.*, 2010). The demand for wild caught wrasse increased rapidly in the late 2000`s as salmon lice developed resilience towards commonly used chemical pesticides (Besnier *et al.*, 2014; Skiftesvik *et al.*, 2014). Mechanical and thermal delousing methods are now largely replacing chemical pesticides in Norway. However, both farmed and wild caught wrasse are still extensively used, with corkwing and goldsinny as the most commonly used wild cleaner fish (Faust *et al.*, 2018; Overton *et al.*, 2019). Several limitations have been imposed in order to avoid overfishing, currently the fishery is managed by seasonal closure from mid-July to mid-October, minimum species-specific size limits; 11 cm for goldsinny, rock cook (*Centrolabrus exoletus*) and cuckoo (*Labrus mixtus*), 12 cm for corkwing and between 22-28 cm for ballan wrasse (*Labrus bergylta*)(Forskrift om regulering av fisket etter leppefisk i 2022, 2021.§8). To avoid overfishing it is important to monitor fisheries and investigate how local populations may be affected by fishing pressure, since depletion of local populations can occur (Halvorsen *et al.*, 2017b).

In this study, I explored the impact of fishing on adult growth in two wrasse species. Of these, sexual size dimorphism is strongly male-biased in the corkwing wrasse, while male and females goldsinny wrasse are more similar. In many species the form and strength of selection on body size or correlated traits is rarely identical between the sexes, resulting in sexual size dimorphism (SSD) (Parker, 1992; Fairbairn *et al.*, 2007; Halvorsen *et al.*, 2016). Nesting males of corkwing

wrasse is a good example, as they are fiercely territorial during nesting season, leading to aggressive confrontations, often won by large individuals (Potts, 1974a, 1985). For different reasons, sexual size dimorphism is often overlooked when assessing the management of commercial fisheries. Size selective harvesting on sexually dimorphic populations would likely be sex-selective, which makes the neglect in the management assessment unfortunate (Rowe and Hutchings, 2003; Fenberg and Roy, 2008; Hanson *et al.*, 2008; Zhou *et al.*, 2010; Kendall and Quinn, 2013; Halvorsen *et al.*, 2016). Moreover, the corkwing wrasse grow generally faster and has shorter life span than the goldsinny (Halvorsen *et al.*, 2017a). Thus, the growth response to fishing may differ between and within these two species.

The objective with this study was to compare growth in corkwing and goldsinny wrasse populations between a MPA and an adjacent fished area. Based on five years of capture-mark-recapture (CMR) data from 13 sampling periods, I use linear models to investigate if a simulated wrasse fishery has an impact on body growth rates. The models for corkwing are separated between females and males because of the known differences in growth between the sexes. Goldsinny males and females were presented in the same model because both sexes have similar growth rates and fewer CMR data. I hypothesize that corkwing individuals in the fished area will have faster growth rate based on theories suggesting there will be more space and food available for the remaining individuals after larger fish is removed due to fishing. For goldsinny I hypothesize that the results will present less difference in growth rates and fishing will have a smaller impact compared to corkwing. I imagine goldsinny are more effected by other local factors such as density, predation, and habitat.

2. Methods

2.1. Study area

The study was conducted inside an experimental marine protected area (MPA) nearby the field station of Institute of Marine Research in Austevoll, outside of Bergen in Western Norway. Three islands are located within the MPA (Fig 1) where commercial fishing for wrasse has been prohibited since 2017. The surrounding waters of two of the islands, Bleikjo and Saltskjærholmane, was used as the study area. With the southeastern side of the islands facing Huftarøy being more sheltered to Bjørnafjorden compared to the east side. The two islands were divided into multiple zones. Bleikjo into 4 zones (1-4) and Saltskjærholmane into 12 zones (1-12) (Aasen, 2019). At low tide the average length of the shoreline at each zone is 79.8 at Bleikjo and 141.3 at Saltskjærholmane. The distance between the islands are 80 meters and with a maximum water depth of about 25 meters. The surrounding habitats mostly consist of hardbottom covered by a variety of kelp, which is a suitable habitat for wrasse fishes (Skiftesvik *et al.*, 2014). In a before-after control-impact (BACI) approach the smallest island of the two, Bleikjo, was chosen as the site for the experimental fishery, called fished area from now on. Saltskjærholmane, the unfished site, will be referred to as control area.

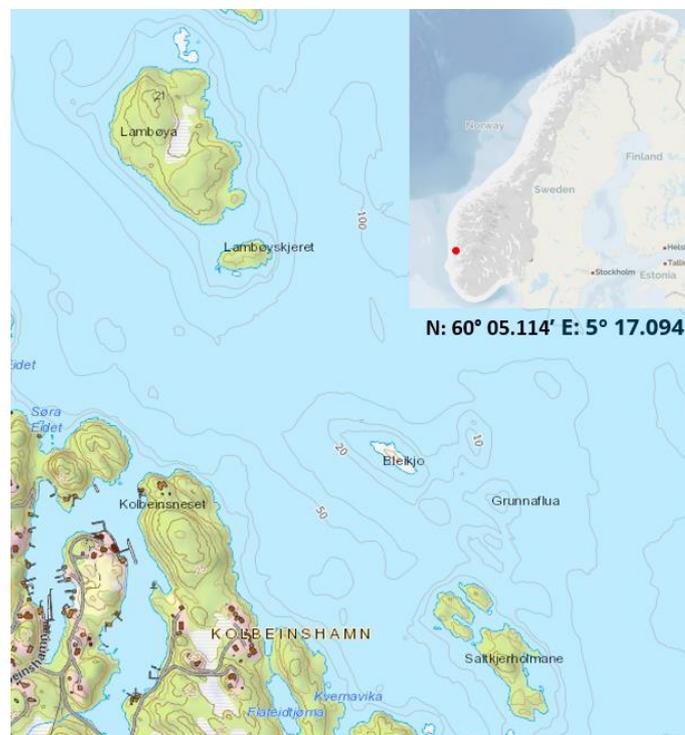


Figure 1: Overview map of the geographic positions of Bleikjo and Saltskjærholmane, at Austevoll in Hordaland. Location in Norway are marked with a red dot in the top right corner. Saltskjærholmane, Bleikjo and Lambøya/Lambøyskjeret are all a part of the MPA. Map are obtained from <https://kart.fiskeridir.no/fiskeri> and <https://www.norgeskart.no>

2.2. BACI-design

Before-after control-impact (BACI) are suggested to be statistical powerful designs in environmental impacts assessment studies (Smokorowski and Randall, 2017). Even in the early days of marine conservation science discipline, the BACI design was suggested (Jones *et al.*, 1993). An important tool in environmental impact assessment is to detect changes in a site before the impact happened and after, and compare this to a control location, where the impact persists. A BACI approach will give the unequivocal detection of change between these sites, which strengthens this approach (Moland *et al.*, 2021). Wrasse harvesting in an ecosystem is an example of an anthropogenic disturbance, in a marine conservation setting. Removal of one or part of these anthropogenic disturbances in this setting will be represented the “impact”.

2.3. Study species

Corkwing and goldsinny both belong to the family *Labridae* which includes more than 500 described species worldwide (Parenti and Randall, 2000; Jansson *et al.*, 2020). These are two of six wrasse species inhabiting the Norwegian coast and are the two most abundant cleaner wrasse species used in Atlantic salmon farming industry in Norway (Blanco Gonzalez and de Boer, 2017). Corkwing functions as intermediate predators in the ecosystem and prey on different invertebrates (Helfman *et al.*, 2009; Skiftesvik *et al.*, 2014). In turn, they are preyed upon by other larger fishes and piscivorous birds (Svåsand *et al.*, 2000; Nedreaas *et al.*, 2008; Dehnhard *et al.*, 2021). Corkwing can reach sizes up to 200-300 millimeters and prefer to inhabit shallow coastal areas (<5 meters depth) filled with a rocks and eelgrass, however they can occur in depths of 15-18 meters as well. Algae is important in corkwing habitats, both as a nest building material and habitats for small crustaceans, gastropods, and bivalves which corkwing feed on (Potts, 1974a, 1985; Costello, 1991a; Sayer *et al.*, 1996). Therefore, they are typically found in areas with high algal cover, e.g., kelp forests and eelgrass beds, within the 5 meters depth (Quignard and Pras, 1986; Gibson, 1993; Skiftesvik *et al.*, 2014). The spawning period of both corkwing and goldsinny starts in May and end late July, with June as the most active month (Costello, 1991a; Skiftesvik *et al.*, 2015).

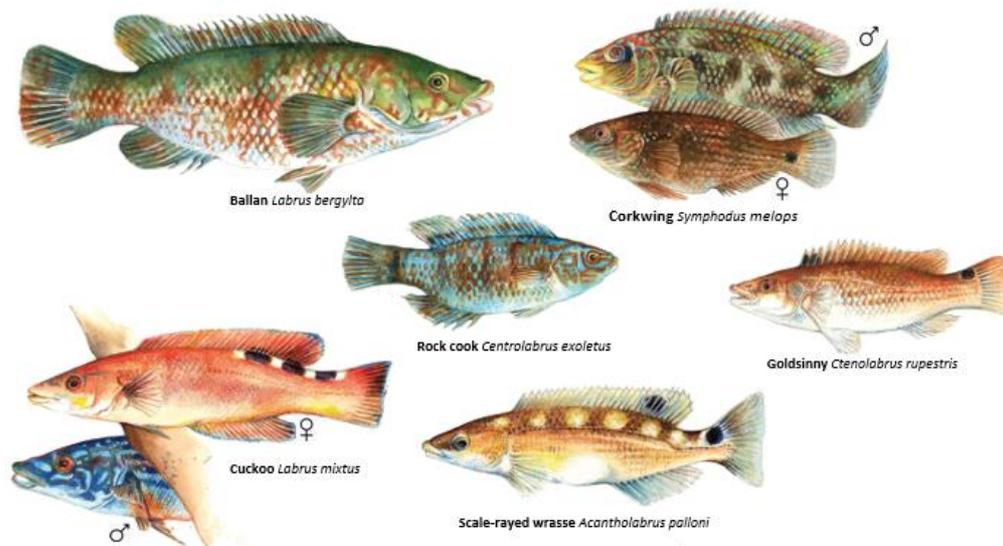


Figure 2: The wrasses of Norway. Upper left: Ballan wrasse. Upper left: Corkwing wrasse, larger male in the back and female in the front. Center: Rock cook wrasse, females are similar, but less blue. Bottom left: Cuckoo wrasse, red female in the front and blue male in the back. Bottom center: the rarer Scale-rayed wrasse. Bottom right: Goldsinny wrasse. Illustration by Stein Mortensen. Modified with English names and gender signs, with permission from Stein Mortensen

During sexual maturation, corkwing undergoes morphological changes with strong coloration in males that lasts through the spawning season. (Potts, 1974a). Reproductive corkwing males are dimorphic, with one male morph being distinctively blue and green colored, and one male morph employing female mimics (sneaker male). Sneaker males have less distinctive colors and possess a papilla which resembles that of females. This imitation and alternative reproductive tactic (ART) may increase the chance to be tolerated by territorial dominant males of the same species, leading to a higher likelihood for participating in matings initiated by these males (Gross, 1982; van den Berghe and Gross, 1989; Uglem *et al.*, 2000; Uglem and Rosenqvist, 2002). On average, most corkwing matures when reaching 2-3 years, with a mean length of 100mm. However, size and age at which fish mature can vary between populations (Potts, 1974b; Costello, 1991b; Darwall *et al.*, 1992; Halvorsen *et al.*, 2016). Corkwing can attain a total length of 28 cm and maximum age of nine years (Darwall *et al.*, 1992; Sayer *et al.*, 1996). While goldsinny may reach a body length of 18cm and 20 years of age (Darwall *et al.*, 1992; Sayer *et al.*, 1995).

Goldsinny inhabits the same inshore, rocky, and algal habitats as corkwing (Hilldén, 1981; Sundt and Jørstad, 1998; Jansson *et al.*, 2020). However, it is assumed that corkwing in general prefers deeper water and are the least abundant of the two (Halvorsen *et al.*, 2020). Females and males can often be visually distinguishable, as females have rib shaped patterns and males may have orange horizontal stripes on the lower part of their abdomen (Hilldén, 1981). While the nesting corkwing males are brightly colored in green, blue, and orange, the females are plainer with mostly a yellowish or brown color, and also a dark urogenital papilla (Potts, 1974a). Goldsinny males have a red coloration on the abdomen, which separates them from the females (Hilldén, 1981).

2.4 Data collection

Data from thirteen sampling periods spread over 5 years of sampling was used to calculate growth (Table 1). For sampling of fish, we used fyke nets with 7.8 m single leader, 70 cm entrance ring and leader mesh size of 11 mm. During a period of six days, eight fyke nets were placed out per day. The fyke nets were placed out in the afternoon and left overnight, which resulted in a soak time between 15-20 hours approximately. Placement of the fyke nets alternated between the zones (n=16), each zone was sampled for a total of three times every other day per sampling period. Fyke nets were placed near the shoreline in a perpendicular position, attempting not to place it too deep. The leader net extended towards the surface which would lead most of the passing individuals that move along the bottom into the chambers of the fyke net.

Table 1: Overview of the sampling periods for the standardized fyke-net survey. 2017 had three smaller sampling periods.

Year	Period	Date (dd.mm/yy)
2017	1	02.08 - 08.09/ 2017
2018	2	11.05 - 18.05/ 2018
	3	02.07 - 09.07/ 2018
	4	04.09 - 11.09/ 2018
2019	5	16.05 -23.05/ 2019
	6	09.07 - 14.07/ 2019
	7	03.09 - 08.09/ 2019
2020	8	04.05 - 09.05/ 2020
	9	27.06 - 02.07/ 2020
	10	26.08 - 31.08/ 2020
2021	11	06.05 - 11.05/ 2021
	12	28.06 - 03.07/ 2021
	13	23.08 - 28.08/ 2021

Individuals caught was determined to species level and measured for total length to the nearest millimeter. Further, light pressure was applied on the abdomen to gather information about the sex and spawning state (female, male or sneaker), based on sexual products extruded. When there were no sexual products present, sex was determined by looking at phenotype for goldsinny and corkwing wrasse. Sneaker males were only distinguishable in the mating season when sexual products where extruded, because of their female phenotype. After each fyke, we gently released all catch at the same location as capture.

2.5 PIT-tagging

Passive Integrated Transponder (PIT) tags were used to monitor the fate of the wrasse individuals. These are glass-encapsulated passive transponders that are sealed in biocompatible glass to protect the electronics and prevent tissue irritation (Gibbons and Andrews, 2004). For corkwing, PIT-tags have been used previously to estimate fishing mortality (Halvorsen *et al.*, 2017c), and the use of PIT-tags are well-documented for wrasse and as an identification method for studies on fish (PRENTICE and F., 1990; Bolland *et al.*, 2009).

For this study, we used half duplex PIT-tags (2,12 x 12 mm; RFID Solutions Stavanger, Norway). Every wrasse species in the catch were scanned (HPR lite-from Biomark Inc. USA) to check for presence of a PIT-tag from earlier tagging periods. For previously tagged individuals, PIT-tag ID numbers were also noted in addition to the method described above. Individuals of ballan, goldsinny and corkwing wrasse >100 mm that were not previously tagged were anesthetized prior to tagging in 50-100 mg l⁻¹ tricaine methanesulfonate (MS-222) in 8-10 l of seawater until loss of equilibrium. The loss of equilibrium occurred differently depending on size and species, most of the individuals were ready for tagging within 1-3 minutes. A tag injector with a needle fitted were used to inject a PIT-tag into the body cavity. Between each tag injection, the tag injector was cleaned in 96% ethanol and the needle was replaced after tagging approximately 20-40 individuals. After tagging, scales were collected from corkwing with a tweezer and put into an empty Eppendorf tube for further processing. Fin clippings on the caudal fin were collected by using a small scissor for future DNA analysis.

2.6 Data analysis

Statistical analyses were carried out using the R software, version 4.0.2 (R Core Team, 2018). The ggplot2 package was used to create all graphics (Wickham, 2016). Linear models were used to test for fishing impact on individual growth. All data was modelled with a gaussian error distribution using the function `lm()`. A series of assumptions such as independence, normality, homogeneity, fixed X, and correct model specifications ((Zuur *et al.*, 2009). A model validation process is necessary when applying a linear model to your data, to verify these assumptions. By following instructions I: 1) plotted the residuals vs fitted values to check for homogeneity of variance, 2) plotted a QQ plot to check for normality, and 3) plotted the residuals against each explanatory variable to check for independence (Zuur *et al.*, 2009). The growth models were fitted separately for each species and corkwing was also divided between females and males. The response variable in the models included growth (mm per month),

length (mm), and CPUE (number of individuals caught in fyke net). Area (fished and control) and sampling year are the explanatory variables.

To detect if there is an impact of fishing on growth a significant interaction between area and year is needed. The reason for this is that I assume that there is a difference between areas (fished, control). However, to conclude that the difference in growth is directly related to fishing, a significant interaction between area and year is needed. I therefore chose two models including one with an interaction effect and one with only an additive effect: A likelihood ratio test (LRT) was used on each growth model for corkwing female, corkwing male and goldsinny.

$$\textit{Growth rate} = \textit{Previous length} + \textit{Area} + \textit{Year}$$

$$\textit{Growth rate} = \textit{Previous length} + \textit{Area} * \textit{Year}$$

3. Results

3.1. Overview

Overall, 16 471 individuals of corkwing (n=10 745) and goldsinny (n=5726) was captured (>100mm). From these, 8 855 corkwing and 4 993 goldsinny was tagged with a total recapture of 1890 and 733 individuals respectively.

Table 2: Total number of tagged individuals of corkwing and goldsinny between the last tagging period every year (fall) and the following spring + summer following year.

Sampling intervals	Fall-Spring	Fall-Summer	Total (Fall – Spring + Summer)
Corkwing			
2017-2018	89	58	147
2018-2019	64	27	91
2019-2020	20	59	79
2020-2021	38	41	79
Goldsinny			
2017-2018	20	13	33
2018-2019	21	16	37
2019-2020	10	17	27
2020-2021	17	13	30

3.2. Mean CPUE and length

Mean CPUE indicates that there were some variations for both goldsinny wrasse (2.4-12.5) and corkwing wrasse (4.9-17.5) between 2018 and 2021 (Fig 3). Goldsinny indicated relatively similar CPUE between the areas, with a high top in September of 2018 and a smaller one in September of 2020. Corkwing had overall higher CPUE compared to goldsinny and indicated that there was more variation in CPUE between the sampling periods, with the highest value from the fished area in May of 2019. There seems to be a trend with higher CPUE values in the fished area compared to control for both species before fishing started. After fishing, the control area seems to have a higher CPUE than fished area for both species. In addition, overall CPUE values for goldsinny seems to follow each other more compared to corkwing.

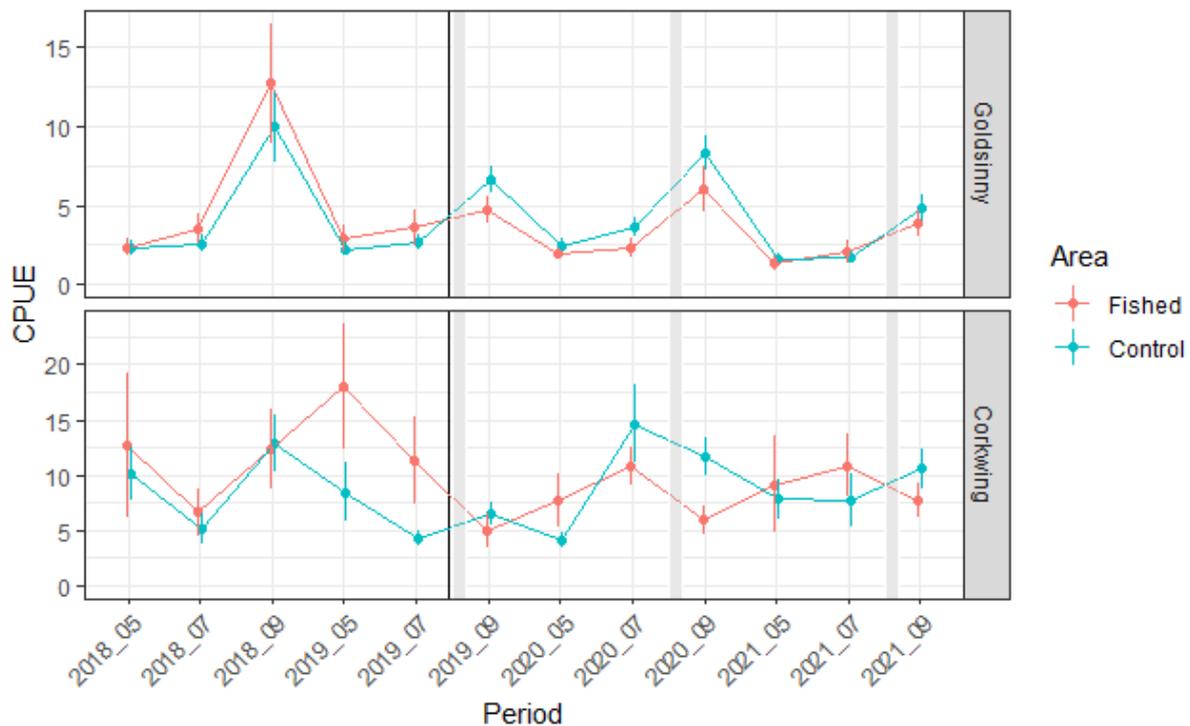


Figure 3: Mean CPUE for tagged individuals of corkwing and goldsinny in the control and fished area between the first period in 2018 and last period in 2021. Black vertical line indicates when the replicated wrasse fishery on Bleikjo was started, August 2019. Grey vertical lines highlight the continuation of harvesting in the fished area in August every year until 2021.

Findings showed some trends with variations in mean length for corkwing (141-147mm) and goldsimny (115.6- 119mm) between area and year (Fig 4). Corkwing indicated a relatively stable mean length for fished and control area from 2017 to 2018, with slightly higher mean length in control area. While goldsimny had more variations, with a lower mean length in control overall. The mean length also seemed to increase after fishing was started in the fished area, which could indicate a possible effect of fishing. The opposite was for goldsimny in control area, which resulted in decreasing mean length after fishing started.

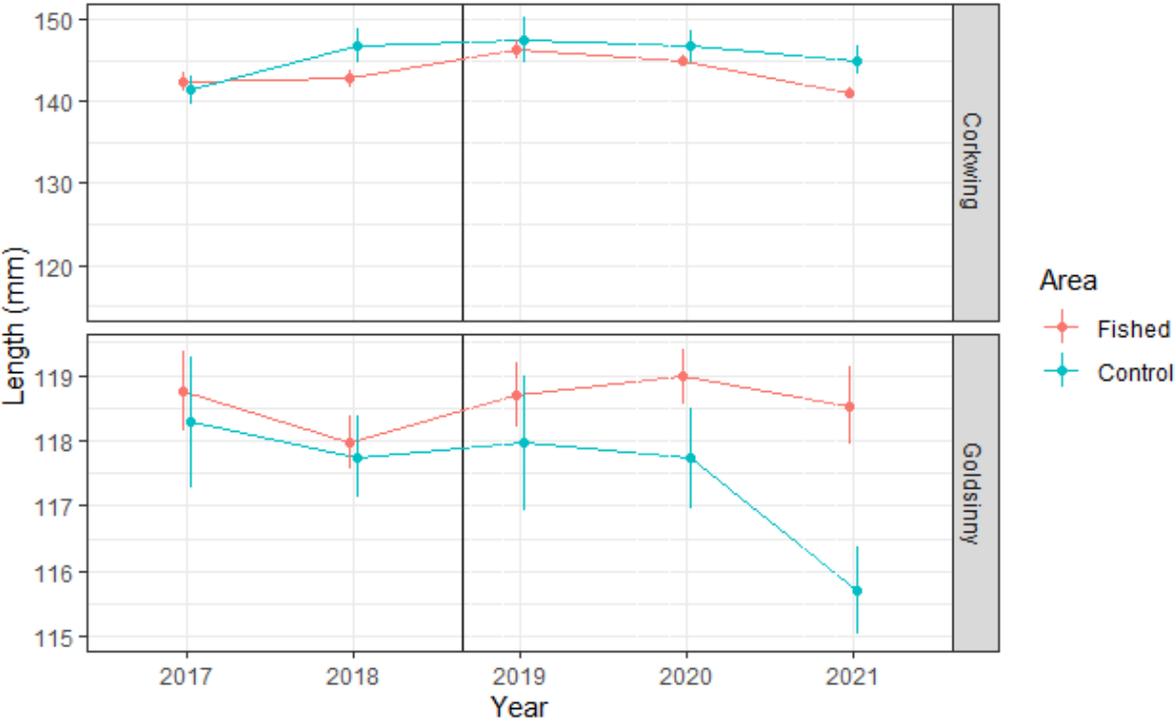


Figure 4: Mean length for individuals of corkwing and goldsimny in fished and control area over all sampling years. Year markers are placed in the last sampling period for each year. Black vertical line shows when the replicated wrasse fishery was started on Bleikjo, August 2019.

3.3. Growth rate analysis

3.3.1. Corkwing

For female corkwing, there were no significant differences in between fished and control area, neither before nor after the fishery (lm; area x year effect, likelihood ratio test $L = -16.165$, d.f. = 7, $P = 0.4369$) (Fig 5, table 3). Growth rates for female corkwing indicated that the smallest fish had the highest growth rate, before growth declined with increased length. There were some variations in growth rate between the sampling years, with a span around 0-2 mm monthly overall. Length varied between 100 (minimum size limit for tagging) and 180 mm. The recaptured individuals caught in the tagging periods in 2019 and 2020 had an overall higher estimated growth per month. The lowest growth was observed in 2020-2021, approximately three years after the first experimental fishing was conducted for the first time in the fished area.

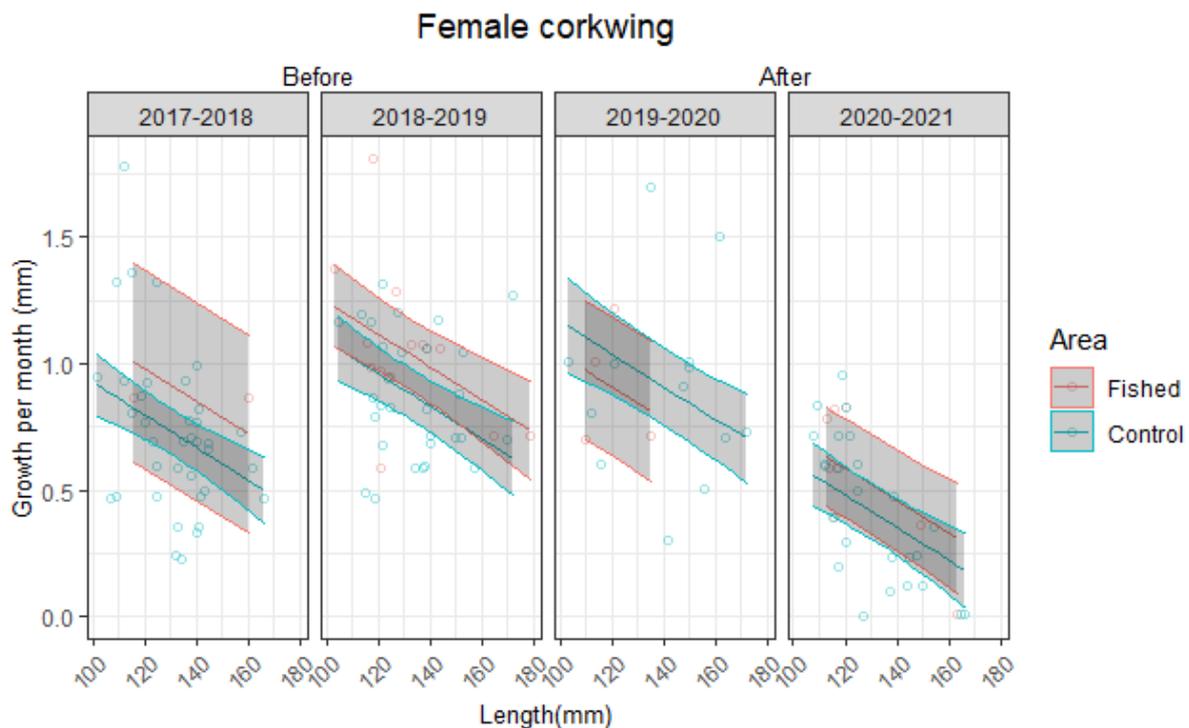


Figure 5: Estimated growth per month (mm) of recaptured female corkwing individuals from both areas in the survey. Figure are based on the total number of recaps for every tagging period (May, July, and September) between 2018 and 2021, where every point represents a recaptured individual. Shaded areas present the upper and lower confidence interval for the estimated growth. Before refers to the two first sampling periods before the simulated fishery was started. After refers to the two periods after.

Table 3: Summary of linear model on female corkwing growth rates between year and area. The table shows response variable, coefficients, estimate, standard error (SE), T value and P value. Significant terms are illustrated with a p-value in bold.

Response	Coefficients	Estimate	SE	T value	P value
Growth	(Intercept)	1.753	0.279	6.290	<0.0001
	length at capture	-0.006	0.001	-4.533	<0.0001
	year 2019	0.139	0.211	0.657	0.512
	year 2020	-0.069	0.243	-0.283	0.778
	year 2021	-0.393	0.222	-1.772	0.079
	area (control)	-0.180	0.203	-0.887	0.378
	year 2019: area (control)	0.024	0.222	0.108	0.914
	year 2020: area (control)	0.310	0.262	1.186	0.238
	year 2021: area (control)	0.076	0.233	0.327	0.744

For male corkwing there were a significant difference between the fished and control area, from before and after the fishery (lm; area x year effect, likelihood ratio test $L=-130.83$, d.f. = 7, $P<0.001$) (Fig 6, table 4). In the fished area, male corkwing grew slower before fishing and faster after fishing (started August 2019). These interesting results could indicate that fishing had a positive effect on male corkwing growth rate in the fished area. In addition, male corkwing showed similar trends as female corkwing with highest growth for smaller fish, declining with increased length. The growth per month span from around 0 mm to just below 4 mm monthly overall. Length varied between 100 -190mm.

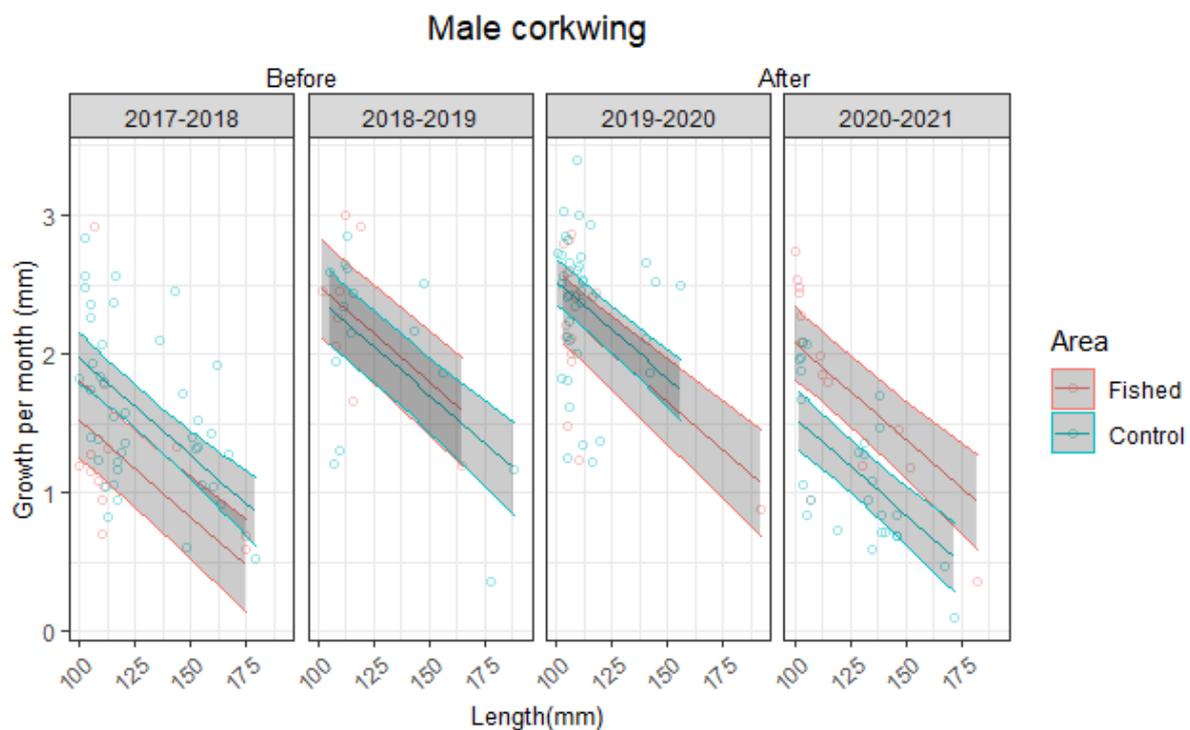


Figure 6: Estimated growth per month (mm) of recaptured male corkwing individuals from both fished and control area. Figure are based on the total number of recaps for every tagging period (May, July, and September) between 2018 and 2021, where every point represents a recaptured individual. Shaded areas present the upper and lower confidence interval for the estimated growth. Before refers to the two first sampling periods before the simulated fishery was started. After refers to the two periods after

Table 4: Summary of linear model on male corkwing growth rates between year and area. The table shows response variable, coefficients, estimate, standard error (SE), T value and P value. Significant terms are illustrated with a p-value in bold.

Response	Coefficients	Estimate	SE	T value	P value
Growth	(Intercept)	2.920	0.262	11.163	<0.0001
	length at capture	-0.014	0.002	-7.620	<0.0001
	year 2019	0.966	0.226	4.281	<0.0001
	year 2020	0.828	0.189	4.400	<0.0001
	year 2021	0.551	0.190	2.896	0.004
	area (control)	0.441	0.160	2.755	0.007
	year 2019: area (control)	-0.530	0.272	-1.952	0.053
	year 2020: area (control)	-0.271	0.219	-1.236	0.218
	year 2021: area (control)	-0.978	0.229	-4.284	<0.0001

3.3.2. Goldsinny

As for corkwing, goldsinny did not show any significant difference in growth before or after fishery in the fished and control area (lm; area x year effect, likelihood ratio test $L=31,70$, d.f. = 7, $P=0.4774$) (Fig 7, table 5). Individuals had also faster growth for smaller fish, which declined at increased length. Length varied between 100-130mm. Overall, the growth per month was lower for goldsinny compared to corkwing, with approximately 0-0.6 mm per month, independent of year, areas, and length. Results indicated relatively similar growth rates between sampling periods from 2017 to 2020 in both areas, where 2017-2018 and 2018-2019 was sampling periods before simulated wrasse fishery started. 2020-2021 had the slowest growth rates, but also resulted in many zero values in growth, that may explain the reason for this.

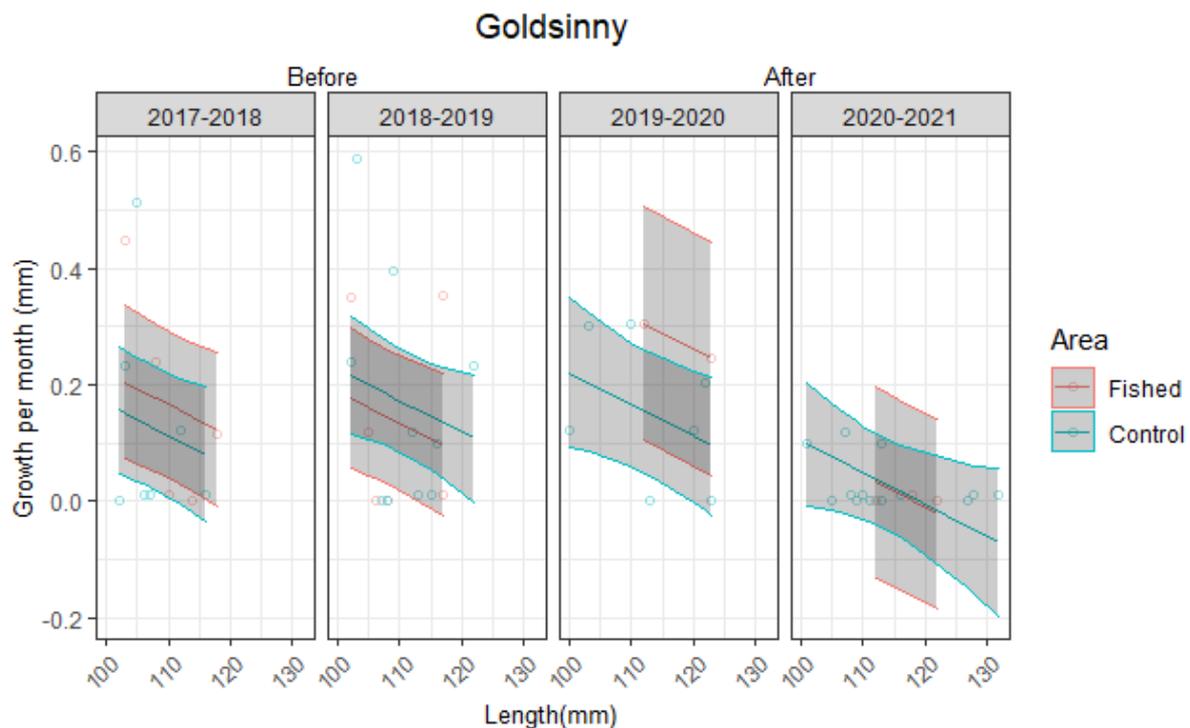


Figure 7: Estimated growth per month (mm) of recaptured goldsinny individuals (males and females) from both areas in the survey. Figure are based on the total number of recaps for every tagging period (May, July and September) between 2018 and 2021, where every point represents a recaptured individual. Shaded areas present the upper and lower confidence interval for the estimated growth. Before refers to the two first sampling periods before the simulated fishery was started. After refers to the two periods after

Table 5: Summary of linear model on goldsinny wrasse growth rates between year and area. The table shows response variable, coefficients, estimate, standard error (SE), T value and P value. Significant terms are illustrated with a p-value in bold.

Response	Coefficients	Estimate	SE	T value	P value
Growth	(Intercept)	0.767	0.320	2.394	0.021
	length at capture	-0.005	0.003	-1.924	0.06
	year 2019	-0.032	0.086	-0.369	0.714
	year 2020	0.150	0.121	1.237	0.223
	year 2021	-0.122	0.106	-1.155	0.254
	area (control)	-0.053	0.084	-0.626	0.534
	year 2019: area (control)	0.091	0.112	0.814	0.420
	year 2020: area (control)	-0.097	0.142	-0.684	0.498
	year 2021: area (control)	0.058	0.124	0.470	0.640

4. Discussion

The aim of this study was to assess the effects of wrasse fishery on individual growth in wild wrasse populations. By using a before-after control-impact (BACI) approach, and several years of data, I estimated the monthly growth rate for corkwing and goldsinny wrasse from two different sites, a fished area, and inside a MPA established by the IMR (Institute of Marine Research) as control. The main findings were that there was a significant difference in male corkwing growth rate per month between fished and control area. Male corkwing grew faster in the fished area after fishing started, which supports my initial hypothesis where I suggested that corkwing would grow faster in fished area. Therefore, it is reasonable to believe that fishing had a positive effect on this population, with males attaining larger size quicker. The population could benefit from having quick growing males as they provide important parental care for offspring, and removal of the caring sex could have direct consequences for offspring survival (Suski *et al.*, 2003; Sutter *et al.*, 2012). In addition, achieving large sizes quickly can also bring benefits regarding mating opportunities and mate selection by females (Robertson and Hoffman, 1977). Even though my findings suggest that fishing could have a positive effect on male growth rates there are previous studies that suggesting that size selective harvesting of large individuals could reduce body size and age structures within a population (Swain *et al.*, 2007; Fenberg and Roy, 2008). This makes for an interesting contradiction. As fisheries is expected to catch fast growing individuals, but at the same time increase growth for the remaining individuals when density is reduced. Where density dependent seems to affect corkwing males the most. In addition, a previous study in the same MPA did find that the capture probability was negatively correlated with body size (Ruud, 2020). Female corkwing did not show any significant differences in growth rate between the two areas, neither before nor after fishing started. For both areas, estimated growth per month was between 0 - 2 mm. Females do not provide the same parental care as the males. Investment of more energy towards gonad growth instead of growth and achieving greater reproductive output by earlier maturation could be a possible explanation.

Findings did also indicate clear differences between corkwing sexes, however, it is worth mentioning that this was not tested for in this study. Males grew faster than females, which is also supported by a recent study on factors affecting growth in corkwing in the same area (Vik, 2019). Faster growth for male fish have also been presented in other studies (Treasurer, 1994; Sayer *et al.*, 1995). A possible explanation for slower growth on female corkwing attributed slower female growth to earlier maturation and not the same intrasexual competition as the male-male competition for females will cause (Treasurer, 1994). On the other hand, previous research has suggested that attaining large sizes quickly could be beneficial as large females in general tend to have better fecundity from spawning over longer time periods, higher production of eggs, and create larger sized eggs (Wright and Trippel, 2009; Halvorsen *et al.*, 2016).

For goldsinny sexes were presented in the same model as differences in growth between male and females are negligible. My initial hypothesis was that the smaller-sized goldsinny would have increased growth rate over time, having benefits from being in the fished area where traditional minimum size limit management tool is applied (Halvorsen *et al.*, 2017a). However, my results did not find any significant difference in growth rate between the areas, neither before nor after fishing started. Estimated growth per month for goldsinny was 0 - 0.6 mm. During modelling, some individuals presented negative growth. Possible explanation for this could be human errors in manually plotting length, and written individual length is shorter compared to previous sampling of the same fish. These had to be corrected to zero growth as the correct length on these individuals are unknown.

In general, smaller fish had the fastest growth per month, and growth gradual declined with length. This result was expected beforehand as high growth rates in smaller individuals can be explained by the vulnerability of being small. Faster growing individuals will be more likely to survive compared to individuals that remain small over a longer time, because slower growth increases the chances for predation (Nilsson and Brönmark, 2000). The reason for that is because most predators are gape-size limited, they are dependent on small enough prey that can fit into their mouths (Post and Parkinson, 2001). Based on adaption strategies among other fish species it is reasonable to believe that corkwing minimize the risk of predation by having high growth rates at small sizes (Tonn *et al.*, 1992; Persson *et al.*, 1996).

The growth predictions for both corkwing wrasse and goldsinny wrasse are based on the hypothesis that growth is density dependent, meaning that growth rates could increase in populations where the largest fish are regularly removed, leaving more food and space available for the remaining fish to grow faster. Density dependent growth have been shown on other fish species where growth opportunities was restricted because of limited food availability and reduced feeding success (Doherty, 1983; Victor, 1986; Jones, 1987; Forrester, 1990; Cowan *et al.*, 2000). Since corkwing and goldsinny have overlapping habitats requirements and depends on the same resources it is reasonable to believe that some sort of resource competition will occur (Costello, 1991a; Sayer *et al.*, 1996; Thangstad, 1999). No fish were removed in the control area, which could lead to a higher density of corkwing and goldsinny competing for the same resources. This might restrict the growth rate over time. Yearly variations in total captures (Appendix A) could be a result of slow growth, inactivity, and low metabolic rates. Studies on ballan wrasse showed that juveniles grow faster at temperatures over 16°C (Cavrois-Rogacki *et al.*, 2019). Larger individuals showed low metabolic rates and inactivity at low temperatures (5-10°C), while physiological performance increased at rising temperatures (Yuen *et al.*, 2019).

Habitat variations will most likely not play an important role in impacting wrasse growth in the two study areas. As a recent study in the same area did not find that variation in habitat influenced corkwing growth. However, the habitats could be too similar to provide differing growth rates (Vik, 2019). On the other hand, previous studies on bluehead wrasse (*Thalassa fasciotomy*) did find higher growth rates in sheltered inshore populations compared to high exposure populations, claiming that this difference in growth could be a result of different habitat qualities (Warner, 1995). Habitats on the two different islands and zones in this study was generally similar, moderately covered with algae growth with some variation dominating algae type, substrate, and degree of exposure. This has previously been documented as the preferred habitat for wrasse, were corkwing and goldsinny was typically found in sheltered or exposed rocky shores, mudflats and kelp forests, were they feed on slow-moving or sessile prey (Thangstad, 1999; Skiftesvik *et al.*, 2015). The fished area was the smallest and most exposed island of the two and would potentially have different habitats compared to control area, although some zones in the control area was also affected by exposure, mainly by waves. Growth rates should also be expected to be different between the two islands if the nature types have sufficient differences. For instance, places with a higher degree of exposure such as the fished area might provide less vegetation and scree for the fish to use as hiding places in

addition to less available nutrients, compared to the more sheltered control area. However, it might not be as one-sided as this, as corkwing could move between different habitats. Fish movement between the island in this study is limited because of the deeper waters (>20m) prevents this (Halvorsen *et al.*, 2021b). A previous study on inshore and offshore populations with many kilometers apart, showed that there was a great variation in exposure between the populations of bluehead wrasse (Schultz and Warner, 1991).

Catch per unit effort (CPUE) indicated little variation between the areas, although there were indications that CPUE had some higher values prior to when the simulated fishery was started in August 2019. Control and fished were the two adjacent islands within the MPA in this study. Estimated catch per unit effort (CPUE) between the two islands showed trends that there are differences between the species, as corkwing have a higher CPUE compared to goldsinny. Variations between sampling periods are also visible, which could be explained by changes in sea temperature in the different sampling periods, affecting fish movement (Deady and Fives, 1995). However, the differences in CPUE between fished area and control area were also relatively similar in 2021, at a point where fish over the minimum size limit (>100mm) had been removed annually from the fished area since 2018, when a simulated wrasse fishery started. This result was different compared to a similar study on corkwing and goldsinny (Halvorsen *et al.*, 2017a), which resulted in a higher CPUE for targeted species in MPAs, where corkwing was consistently larger and older inside MPAs. In the same study, goldsinny had less clear growth effects from harvesting. A higher CPUE inside the control area was predicted in advance, as increased density is an anticipated effect of MPAs (McCoy *et al.*, 2010). However, the results showed little differences between the areas. The CPUE estimates were based on tagged fish of corkwing and goldsinny and not total captures, for that reason it is reasonable to believe that limited data samples of these tagged fish could affect the CPUE estimates, even though it may take decades before increased density of a species inside a MPA are detectable (Nickols *et al.*, 2019).

My results indicated that fishing could have an impact on growth in fished populations, and there have been raised concerns on whether and how the Norwegian wrasse fishery impacts the wild populations of wrasse (Espeland *et al.*, 2010; Skiftesvik *et al.*, 2014; Halvorsen *et al.*, 2016). Species-specific size limits, establishments of regional quotas and shorter fishing seasons are some of the recent management regulations (Forskrift om regulering av fisket etter

leppesk i 2022, 2021. §§2,4,5,8). Still, the Norwegian wrasse fishery is sex- and size selective, with nesting males having higher growth rate, and reaching the minimum size limit before females and sneaker males, which could alter the sex ratios within populations. Previously suggested in corkwing populations on the west coast of Norway, with a strong male-biased dimorphism (Halvorsen *et al.*, 2016, 2017c). Other consequences could be changes in population structure, sex ratios and reproduction (Halvorsen *et al.*, 2016) Reduction and changes in size structure for corkwing and goldsinny populations have previously been connected to wrasse fisheries (Darwall *et al.*, 1992; Sayer *et al.*, 1996). Such depletion of corkwing and goldsinny densities from wrasse fishery may also have a wider consequence on the coastal ecosystems, as removal of wrasse densities can lead to cascade effects through altered predator-prey dynamics (Selden *et al.*, 2017). As a top-down effect mesograzers or as a bottom-up effect as a reduced food source for large piscivores (Kraufvelin *et al.*, 2020; Dehnhard *et al.*, 2021). Wrasse prey on a variety of small grazers in seaweed which could potentially contribute to reduce herbivory/grazing, and hence the community control that small-sized consumer species imposes. In turn, changes in numbers of mesopredatory fish (increase or decrease in abundance) could result in community changes (Norderhaug *et al.*, 2005; Kraufvelin *et al.*, 2020).

Data from this study is based on a catch-mark-recapture (CMR) analysis, which could potentially alter the results if errors occur. The potential for human errors in CMR studies are very much present as catch needs to be handled, tagged, and data are manually recorded in this study. In this study, the negative growth values for goldsinny could be an example of a potential human errors when manually noting the fish length in field. Passive integrated transponders (PIT) are being used to tag individuals, which could potentially lead to tag-loss and/or affect fish survival. Although, usage of PIT is well tested, with minimal chances of tag-loss and little effect on fish's survival (Peterson *et al.*, 1994; Achord *et al.*, 1996; Gries and Letcher, 2002; Halvorsen *et al.*, 2016). Based on previous testing, I assumed that PIT tags did not affect growth (Kimball and Mace, 2020)

For future research on growth rates for corkwing and goldsinny it would be interesting to continue the CMR-studies in the same area, to see if the fishing impacts on males persist in fished population and maybe affect females and goldsinny as well. Since this study is based on two relatively small islands inside an MPA, it would also be interesting to do more similar studies on other wild wrasse populations in other marine protected areas, to compare with my results. Not only in the western part of Norway, but also in Skagerrak where populations are being harvested and translocated (Skiftesvik *et al.*, 2014; Halvorsen *et al.*, 2017b).

5. Concluding remarks

In my thesis, I found a significant difference in growth rate for male corkwing wrasse in the fished area, with males growing faster after fishing was started. This matched with my initial hypothesis, that fish in the fished area would grow faster compared to control area. In addition, this indicated that fishing had an impact on growth rates in the fished population. For female corkwing wrasse there were no significant difference in growth rate between the areas, neither before nor after fishing started. I hypothesized that goldsinny would not have much difference in growth and not be impacted by fishing in the same way as corkwing. This turned out to also be the case, as goldsinny wrasse did not have any significant difference in growth rate between area, neither before nor after fishing. Smaller individuals grew fastest, and corkwing male was found to have the fastest growth per month independent from area. Secondly, the CPUE for corkwing and goldsinny had little variations between the fished area and the control area. Both species showed relatively similar values over several sampling periods.

Lastly, I conclude to say that the impact fishing seemed to have on male corkwing growth in the fished population could have a positive effect on the population. The findings from this study make contributions to future management of wrasse fisheries. As a result of the different impact fishing had on growth rates between males and female corkwing, they should be managed as two different populations in the Western Norway given the difference. Despite that goldsinny did not show any indications of fishing impact on growth rates, it is important with future research on both species to ensure sustainable harvesting.

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Appendix A

Table A.1: Total number of tagged and recaptured individuals of corkwing and goldsinny over the 5 years of sampling, with numbers from each year instead of each interval.

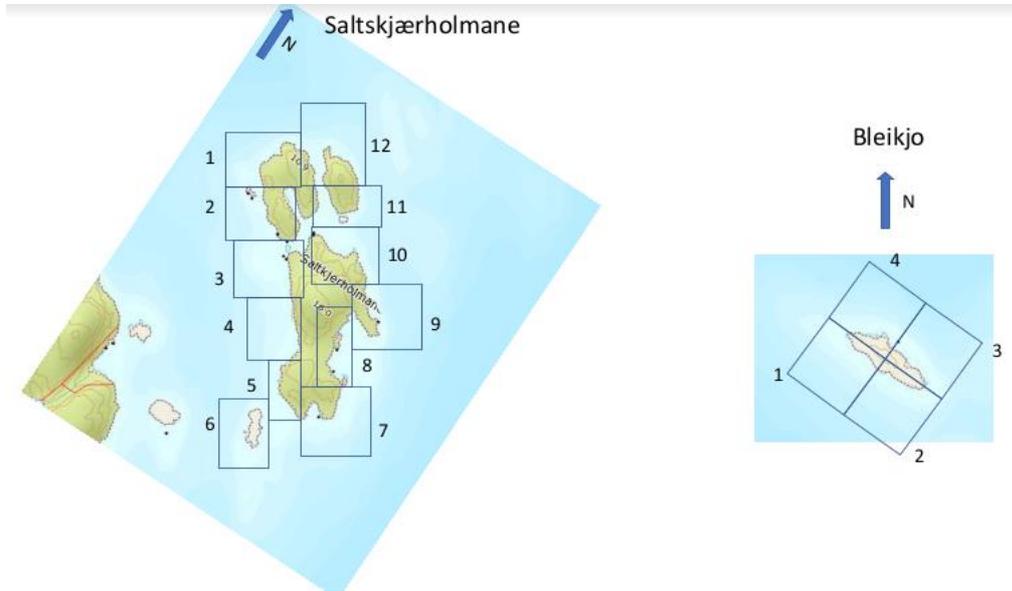
Sampling year	Total captures (>100mm)	Tagged individuals	Recap total	Recapture rate (in %)
Corkwing				
2017	2038	1804	234	11.5 %
2018	2852	2387	465	16.3 %
2019	1787	1399	388	21.7 %
2020	2171	1776	395	18.2 %
2021	1897	1489	408	21.5 %
Total	10745	8855	1890	17.8 % (mean)
Goldsinny				
2017	1285	1248	37	2.9
2018	1511	1366	145	9.6
2019	1094	908	186	17
2020	1142	920	222	19.4
2021	694	551	143	20.6
Total	5726	4993	733	13.9 % (mean)

Recapture rate: Using numbers of recaptures in relation to total number of captured individuals larger than 100mm.

Recap total/total captures) x 100

Appendix B

Table B.1: Overview of the numerated zone divisions in the control area (Saltskjærholmane) and fished area (Bleikjo). Blue arrows indicate norths direction. Illustration from (Aasen, 2019).



Coordinates for the marine protected area in Austevoll:

N 60° 05,514' Ø 005° 16,099

N 60° 05,638' Ø 005° 16,439

N 60° 04,877' Ø 005° 17,809

N 60° 04,736' Ø 005° 17,497