

Factors affecting growth in corkwing wrasse (*Symphodus melops*)

A study from the west coast of Norway

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IV

Abstract

Due to their ability to remove salmon lice, corkwing wrasse (*Symphodus melops*) has been increasingly applied in salmon farms. This sudden demand and catch of corkwing might have a negative impact on their natural growth, and is therefore a topic in need of research.

In this thesis, I performed five periods of mark-recapture experiments on corkwing wrasse over the course of one year at three islands situated near the Institute of Marine Research at Austevoll, on the west coast of Norway. The objective of this study was to examine how size, age, sex, habitat, and seasonal variation affect corkwing growth. I also performed an experiment to test the reliability of corkwing scales for age determination, by comparing scale age with otolith age.

My results show that growth rate was better explained by body size (length) than age, where smaller individuals had higher growth rates compared to larger corkwings. This might be an adaptation to increase the likelihood of survival and reproductive output, whereas larger corkwing may rather invest more energy in reproduction activities and gonad development. I assume an age reading error of 13 % from scales, which might be the reason why age was not the most explaining factor in this research. Male corkwing had higher growth rates than females, and this might be caused by intrasexual competition and intersexual selection, where larger males attain better territories and are more inclined to be selected as mates. Females do not provide parental care, and might achieve greater reproductive output by earlier maturation and investing more energy in gonad development than growth. There was a higher growth rate in spring and summer compared to fall and winter. Temperature increase in spring and summer lead to higher activity levels, greater food availability, and faster metabolism. My results showed goldsinny density could explain corkwing growth better than corkwing density. Corkwing had reduced growth in high goldsinny densities, which could be caused by high resource competition. Males were more affected than females, possibly due to males' territorial behavior and offspring investment. Variation of habitat showed no effect on corkwing growth. However, the habitats examined could have been too similar to provide differing growth rates, or results could be biased if subjects moved between different habitat types. Lastly, my results showed that corkwing scales were well suited for age determination. Further research on this topic is needed to achieve greater understanding of corkwing growth, hopefully developing a sustainable fishing industry.

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1. Introduction

Parasites in aquaculture have long been difficult to eliminate because they thrive and efficiently reproduce in such environments. For instance, it has been proven difficult to reduce the extent of salmon lice (*Lepeophtheirus salmonis*) in salmon farms. New remedies are continuously being produced to reduce abundance of ectoparasitic copepods in fish farms, but they quickly become immune (Jones, Sommerville & Wootten, 1992; Espedal, Glover, Horsberg & Nilsen, 2013; Jones, Hammell, Gettinby & Revie, 2013; Besnier et al., 2014). These parasites are reduced when wrasse (*Labridae*) fish, such as goldsinny (*Ctenolabrus rupestris*), rock cook (*Centrolabrus exoletus*), ballan wrasse (*Labrus bergylta*), and corkwing (*Symphodus melops*), are introduced in the salmon cages, because of their ability to cleanse off parasites on salmon. This has led to an increased interest for wrasse in fish farms since 2008 (Espeland et al., 2010). They are desired in aquaculture particularly because they reduce the need to continuously create new chemical substances designed to eradicate salmon lice (Deady, Varian & Fives, 1995). On the other hand, extensive catch of wrasse could potentially create negative effects on their population. Little research has been performed on them, meaning that there is limited knowledge on how wrasse populations will or already have responded to fishing pressure. It has recently come to public attention that more research on wrasse is necessary for a sustainable fishery.

Wrasse growth is one of many life-history traits that affect population dynamics, and they are likely to be vulnerable to size-selective fishing (Halvorsen et al., 2017). For instance, growth greatly influence length, which is generally important for predator avoidance abilities (Tonn & Paszkowski, 1992; Persson, Andersson, Wahlström & Eklöv, 1996; Nilsson & Brönmark, 2000; Post & Parkinson, 2001), reproductive success (Potts, 1974; Hilledén, 1984; Warner & Schultz, 1992), and winter survival (Post & Parkinson, 2001; Fullerton, Garvey, Wright & Stein, 2000). Therefore, size-selective fishing that targets predominately larger and fast growing individuals will probably result in a remaining population of vulnerable smaller sized individuals.

There is limited knowledge of factors affecting wrasse growth. It is therefore a topic in need of research, especially since growth has major impact on population dynamics. The corkwing is one of the wrasse species in need of more attention because of its frequent use in aquaculture (Halvorsen et al., 2016).

Fish growth mainly depends on age (Papageorgiou, 1979; Roff, 1983), size (Ross, 1984; Buesa, 1987; McKenzie et al., 2014), and sex (Wohlschlag, 1962; Imsland, Folkvord, Grung, Stefansson & Taranger, 1997), where older and larger individuals tend to have lower growth rates than in earlier stages of their development.

Some studies have shown age-dependent growth in corkwing (Treasurer, 1994; Sayer, Gibson & Atkinson, 1996), but length and age are strongly correlated, and it is therefore possible that body size is the main factor causing growth rate differences over time, rather than age.

There is reason to expect large growth rate differences between male- and female corkwing, due to their particular biology where territorial males generally are bigger (Potts, 1974; Dipper, 1976; Dipper, Bridges & Menz, 1977; Dipper & Pullin, 1979; Sayer et al., 1995; Halvorsen, 2016) and have higher growth rates than females (Dipper, 1976; Halvorsen, 2016). Females lay eggs in nests built and guarded by territorial males, for him to fertilize and protect against conspecific males that might try to sneak fertilize the eggs (Potts, 1974). Sexual dimorphism between males and females (figure 1.1) is therefore thought to be a result of intersexual selection and intrasexual competition, where larger males attract mates more easily and are more able to dominate territories and protect nests, thus increasing reproductive success for large sized males (Potts, 1974; Hilldén, 1984; Warner & Schultz, 1992). Certain males develop as sneaker males that possess similar size, growth rate, and phenotype as females (Dipper & Pullin, 1979). It is believed that they have evolved a female appearance as a strategy for stealing fertilizations from territorial nesting males (Uglem, Rosenqvist & Wasslavik, 2000; Halvorsen et al., 2016).



Figure 1.1: Three corkwing wrasse; male (upper position), female (middle position), and sneaker male (bottom position). Photo: Tonje K. Sjørdalen

In many temperate marine fishes, growth also tend to vary with season (McKenzie et al., 2014), habitat (Schultz & Warner, 1991), and density (Cowan, Rose & DeVries, 2000; Victor, 1986; Doherty, 1983; Jones, 1987; Forrester, 1990; Halvorsen, 2016), as these factors affect food availability and intraspecific competition, such as competition over nesting territories.

Corkwing inhabit shallow coastal areas and prefer stone- and vegetation structure for hiding and nest building, and are therefore often found at rocky reefs, lagoons, eel-grass-, and algal beds (Costello, 1991). Growth could be expected to vary among these habitat types, since they likely have different availability of food and shelter. Lower quality habitats have previously been documented to impact growth negatively in bluehead wrasse *Thalassoma bifasciatum* (Schultz & Warner, 1991). It is therefore reasonable to believe that corkwing growth rate varies among different habitat types. However, there is no study on how corkwing growth varies with habitat type.

There is also no documentation of density-dependent corkwing growth. However, previous research on other fish species commonly find density dependent growth rates, where growth decreases with higher population densities (Doherty, 1983; Jones, 1987; Forrester, 1990; Halvorsen, 2016). Based on these results, there is reason to believe that corkwing might have

reduced growth rates if densities increase sufficiently. Besides, densities of other species could also have impact on corkwing growth. Corkwing and goldsinny are found in the same habitat and feed on similar prey (Thangstad, 1999). It is therefore possible that corkwing growth also depends on goldsinny density, since they compete for the same resources.

The objective of this study was to examine how different factors affect corkwing growth. I have performed a mark-recapture study over the course of a year to attain individual growth data on corkwing males, females, and sneaker males. I also tested the reliability of corkwing scales for age determination, by comparing scale age with otolith age. Based on previous studies presented above, I assume that growth rate decline with individual age and/or length, males have higher growth rates than females, and higher growth rate during the summer and spring seasons. I tested if corkwing growth rates depend on habitat type, and whether growth rate depends on corkwing - and/or goldsinny densities.

2. Material & Method

2.1 Fishing Area & Period

Data sampling and capture-recapture experiments were executed on the three islands, Lambøya, Bleikjo, and Saltskjærholmane, located near the Institute of Marine Research in Austevoll, Hordaland, as shown in figure 2.1. Our research area was selected because they are protected areas, and because of its proximity to the Institute of Marine Research in Austevoll. The three islands were temporarily protected from wrasse fishing between August 2017 and September 2018 because of our research. These islands were divided into different zones of similar size. Lambøya was parted in 16 zones, Bleikjo in four, and Salskjærholmane in 12 (Figure 2.2). The average shore line lengths (at low tide) per zone on each island was 141.8 m on Lambøya, 79.8m on Bleikjo, and 141.3m on Saltskjærholmane, with a combined average zone length of 133.9m. We fished during five periods between August 2017 and September 2018 (table 2.1). There was one fishing period in September 2017, while another four took place in 2018.

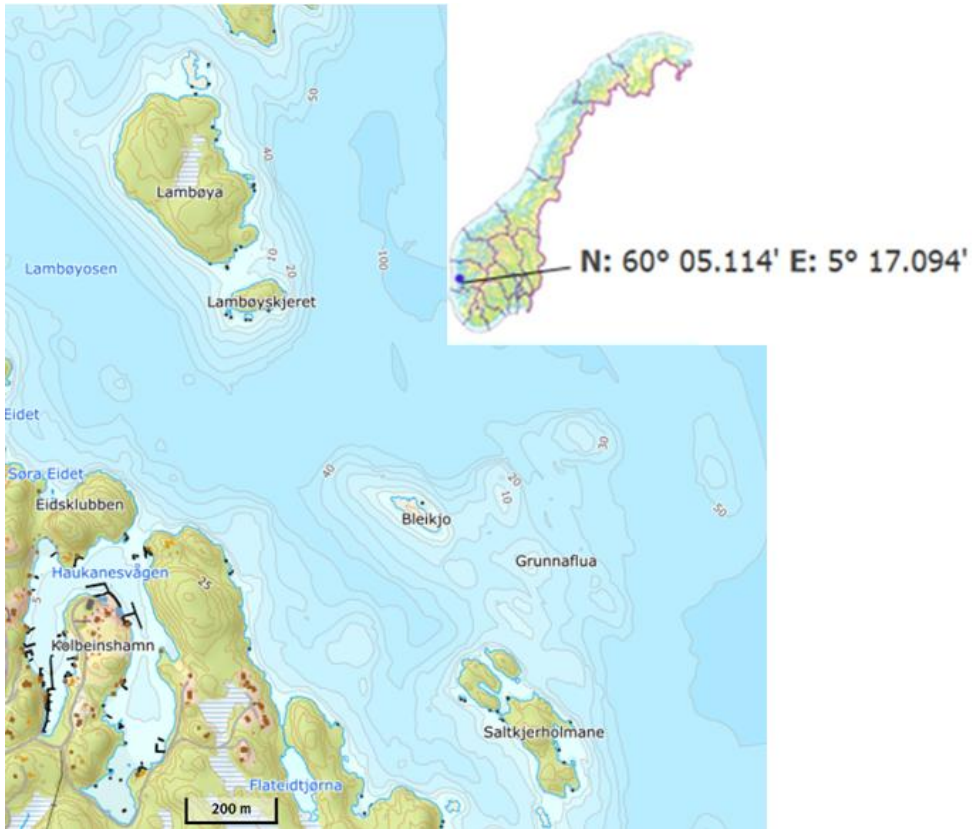


Figure 2.1: The geographic positions of Lambøya, Bleikjo, and Saltkjærholmane, positioned at Austevoll in Hordaland. Their location in Norway is marked with a blue dot. Map collected from <http://kart.fiskeridir.no>

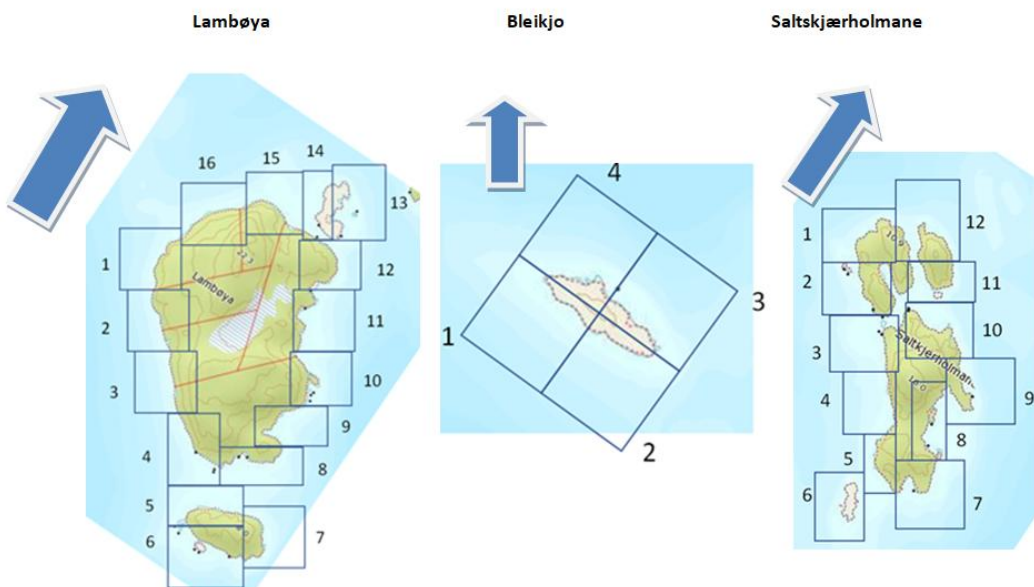


Figure 2.2: The numerated zone divisions of Lambøya, Bleikjo, and Saltkjærholmane. The blue arrows in figure 2.2 indicate north's direction. Map collected from <http://kart.fiskeridir.no>.

Table 2.1: Dates of our five fish periods performed between August 2017 and September 2018.

Fish period	Date
P1	02.08.2017-8.09.2017
P2	10.05.2018-18.05.2018
P3	02.07.2018-09.07.2018
P4	04.09.2018-11.09.2018
P5	24.09.2018-27.09.2018

2.2 Data Collecting & Sampling

A team of three people performed the field work together, doing the capture-recapture experiments, measuring lengths, and collecting scale samples of wrasse. Eight fyke nets were used in each zone and time period (see figure 2.4 and 2.5). Fyke nets are cylindrical-shaped fish traps, with multiple funnel formed entrances. These openings are easy to swim into, but challenging to exit. The end of the fyke net is closed with a string, which can be opened to release catch out of the net. This end has a heavy stone attached to make it sink when thrown in the water. Fyke nets also have a vertical leader net, stretching from the first and largest opening and outwards. One edge of the leader floats in the water, while the other is weighted with heavy lead, and sinks. This creates a barrier for passing fish, and leads them into the net (Lake, 2013). The fyke nets were 3.5 m long, with a leader net of 7.8 m and an 11 mm mesh size. Equal fishing effort was performed on every zone on all three islands for all five fishing periods, with the exception of two extra fyke nets hauled every day between 11th-15th of May 2018, set at Saltskjærholmane in zone 10, 11, and 12.



Figure 2.4: One of eight cylindrical shaped fyke nets used in the field. The funnel shaped openings can be seen on the inside of the net, a little part of the leader can be seen on the right, and the end where fish is to be released is seen on the left. Photo: Ylva K. Vik



Figure 2.5: One of the fyke nets seen from the first and largest opening. The leader lies flat in front of the fyke net opening. Photo: Ylva K. Vik

Fyke nets were placed by throwing one fyke opening over board at a time, starting with the bottom ring, and lastly attaching the leader net to the shore. It was important that the fyke net was placed straight and untangled. We hauled the fyke nets slowly to prevent the catch from getting decompression sickness. Fyke content was placed into a bucket filled with fresh sea water and some kelp to minimize stress.

The following procedure was to examine and PIT- tag (Passive Integrated Transmitter) the catch. PIT-tags are small transponders enclosed in glass, which are to be implanted in the abdominal cavity, and are proven to be well suited for identification studies of fish (Bolland, Cowx & Lucas, 2009). Each PIT-tag contains a unique code allowing us to distinguish between different individuals. These tags have little effect on survival, making them ideal for capture-recapture experiments (Gries & Letcher, 2002). I utilized full duplex PIT-tags (12.0 mm x 2.12 mm, RFID solutions). Individuals smaller than 100 mm were length measured (see figure 2.6) and categorized to species and gender but not tagged. Wrasse individuals longer than 100 mm were examined with a PIT-tag reader (shown in figure 2.6) to check whether the individual was already tagged. Already tagged wrasse were length measured, and species and gender were determined. Untagged wrasses of 100mm or longer were placed in a solution of 50-100 mg x l⁻¹ tricaine methanesulfonate (MS-222) in a volume of 8-10 L of seawater, as well as some kelp for stress relief. MS-222 is a harmless sedative when used correctly, and is often used to relieve certain fish from potential pain inflicted on them during research, as well as keep them still during examination (Hill, Davison & Forster, 2002; Barreto et al., 2007). A few scales were sampled from their abdomen with tweezers, and a PIT-tag was injected into their abdominal cavity with a PIT-tag injector (see figure 2.7). They were released at the same place they were caught after they had recovered for five minutes from the sedative. All sneaker males were categorized as females, since they are hard to distinguish from each other, especially outside the spawning season.



Figure 2.6: A corkwing being length measured with an edged measuring device. PIT-tag detector is in the top right corner. Photo: Tonje K. Sjørdalen



Figure 2.7: PIT-tagging of a corkwing male using a PIT-tag injector. Photo: Tonje K. Sjørdalen

2.3 Habitat Classification

It was necessary to classify habitats to test their effects on corkwing growth. Two days in September 2018 was spent filming underwater, using a GoPro Hero 6 black. Three transects were recorded in each zone, and were taken as far apart as possible. The videos were made by dropping the camera into the water approximately 20-30 m from land. The camera was lowered until I had a clear vision of the bottom. I adjusted the camera to varying inclinations as we slowly moved towards land, and hauled the camera back into the boat when land was reached. This procedure was done for all zones on all three islands. These video tapes were later analyzed and habitat categorized into different habitat types.

Five types of habitat categories were documented from Lambøya, Bleikjo, and Salskjærholmane for this research; “Area”, “Sheltered/Exposed”, “Habitat”, “Kelp-/thread algae”, and ”HabitatZone2”.

- “Area”

Habitat category “Area” consists of the three islands where data sampling was executed. These islands are Lambøya, Bleikjo, and Salskjærholmane.

- “Sheltered/Exposed”

Category “Sheltered/Exposed” involves sheltered and exposed habitat. Sheltered areas are without direct contact with the open ocean, and are protected from strong ocean currents and high speed wind, while exposed areas face the open ocean and are unprotected.

- “Habitat”

Habitat category “Habitat” is divided into four types (A, B, C, and D) according to biomass coverage of algae, dominating algae, and substrate type.

Habitat A had high biomass coverage with large abundance of kelp species. Most dominating species were sugar kelp (*Saccharina latissima*), oarweed (*Laminaria digitata*), and tangle (*Laminaria hyperborea*). A great diversity of seaweed and green-, red-, and brown algae occupied habitat A also. Substrate consisted of bedrock and large rocks.

Habitat B had medium algae coverage and scattered growth, where areas occasionally were barren. Green sea fingers (*Codium fragile*), green-, red-, and brown thread algae were

dominating species. Sugar kelp (*Saccharina latissima*) was present in smaller quantities deeper in the water. Littoral furoids were observed at surface level. Substrate included round rocks and bedrock at the surface water level.

Habitat C had low/medium and scattered biomass coverage, with partly barren substrate. This habitat was dominated by 10-50 cm long green-, red-, and brown thread algae. Different littoral furoid species were found at surface levels. Substrate was sandy bottom and bedrock near land.

Habitat D had medium biomass coverage with no distinct dominating algae species. Existing seaweed, kelp, and green-, red-, and brown thread algae were evenly distributed. Furoid species were found in the littoral zone. Substrate included bedrock, sand bottom, and rocks.

- “*Kelp-/Thread Algae*”

Category “Kelp-/Thread Algae” define habitats based on kelp- or thread algae domination. This category was tested since habitats were mostly dominated by either kelp- or thread algae.

- “*HabitatZone2*”

Habitat “HabitatZone2” is a new zone division, separating the areas into 11 zones. This is based on the first zone division, which was random and created as a system to sample evenly along the islands. The old zones have been redefined in an attempt to create new zones in a manner where similar- and neighboring zones with same exposure, algae composition, biomass coverage, and substrate are combined.

2.4 Scale- & Otolith Analyses

Growth zones in otoliths and scales are formed annually, and reflect periods of limited growth opportunity, for instance during winter when food is scarce and temperature low (Busacker, Adelman & Goolish, 1990). It is possible and common to estimate individual fish age by counting these growth zones (Bagenal & Tesch, 1978; Casselman, 1983). Otoliths have clear visible opaque growth lines which are easy to read (Casselman, 1983; Uglem et al., 2000). Casselman (1983) states that scales have similar translucent lines, but are less suited for age determination due to fake growth zones created because of slow growth. He claims this can result in growth zones that line up close to each other which make them indistinguishable, or when there is no detectable growth, no growth zones are produced, which is often the case in

older individuals. Otoliths from corkwing have been shown to be much more suitable for age determinations (Casselman, 1983; Donnelly, 1992; Halvorsen et al., 2016). Corkwing scales credibility for age determination is still unknown, as there is no research on this. However, scales have been proven successful for the congener *Symphodus tinca* (Boughamou, Derbal & Kara, 2014), and may therefore be potentially successful in corkwing as well. Consequently, I have made a test to evaluate to what degree scales are useful for ageing corkwing wrasse.

Firstly, I compared scales and otoliths from corkwing sampled at Austevoll during September 2017. Scales and otoliths from the same individuals were analyzed and compared. I assume that age determined by otolith readings were correct for this test. Secondly, I read scales from recaptured corkwing wrasse from our field work in 2018 for age determination.

Both lab procedures and age determination for scales sampled from the 2017 sample and the mark-recapture corkwing were more or less the same, with exception of a few details. From the 2017 sample, I had many scales and therefore had to choose 10 random scales from each individual, and then picked five of the most readable scales for subsequent age determination. From recaptured corkwing, I had usually less than five scales to work with, and therefore examined all. Further, several scales used for scale age testing were taken from the same individuals, but age determination for each scale was done independently. Scale age determination from recaptured corkwing was not random, since I needed to compare scales from the same individuals in an attempt to get correct age.

All scales were contained in Eppendorf tubes, where one Eppendorf tube contained several scales from one individual corkwing. Examination was done applying a Wild M3B stereo microscope. I chose the least damaged scales from each Eppendorf tube to be placed together between microscope slides. Applicable scales were individually cleaned by dipping them into regular dish soap water and then gently scraping off dirt and fish skin residuals. The scales had to be dried between paper towels to avoid decay after being cleaned. When dry, the scales were arranged between two microscope slides. I checked whether the scales had folded between these slides or if there was any extra noticeable water or filth on the scales when examining through the stereo microscope. I taped microscope slides together when I was content with the result. This procedure was repeated for all samples.

Photographs were taken of every scale and associating otoliths, as well as scales from recaptured individuals with an IS 1000 microscope camera, using software IS capture.

Otoliths were stored dry before being put in black multicelled trays with 96% ethanol and photographed with 20x enhancement. Scales were photographed with 10x enhancement.

Age determination of scales and otoliths was done by looking at the photographs. Figure 2.8 shows an example of a scale next to its associated otoliths.

Scale analyses for testing the scale method were done by three people individually, and otolith age analyses were done by me. Otoliths and associating scales were analyzed separately to avoid otolith age influencing scale age assessments. Scales from the same individuals were also analyzed separately and independently. Scales were shuffled and given new random names with a random name generator prior to age analysis to ensure independent analysis. Original and random names were saved in separate folders to keep track of scale identity when comparing with otolith age later. Scale- and otolith age was compared after their separate analyses. Otolith analyses are assumed to be correct.

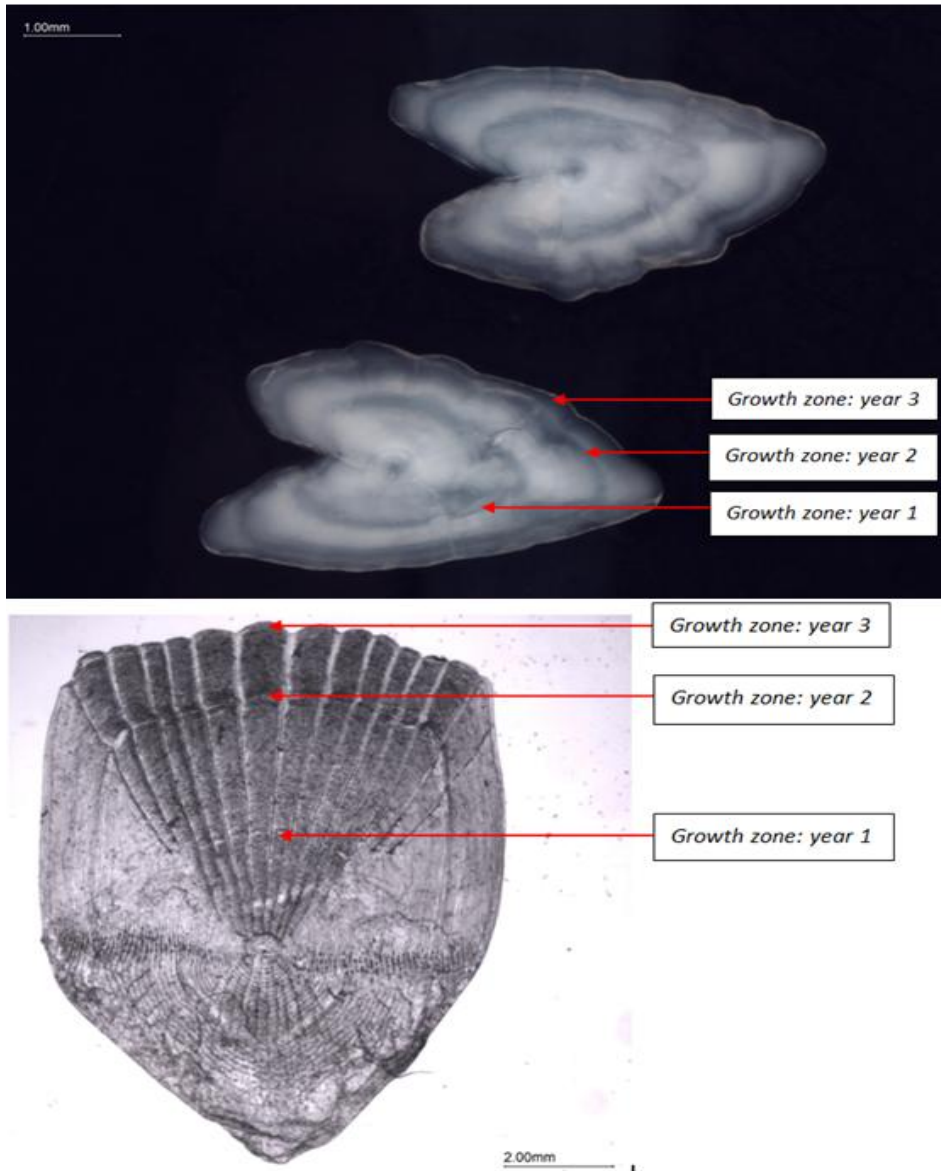


Figure 2.8: A corkwing scale (lower picture) and associated otoliths (upper picture), where the scale had random name 940-21142-29559.jpg, and original name 287_3. Growth zones can be seen stretching around the scale and otoliths, and are marked with red arrows. This individual appears to be three years of age, which is verified by the otoliths. Scale picture includes a 2.00mm line for scale, and otolith picture includes a 1.00mm line for scale. Photo, otolith: Torkel Larsen. Photo, scale: Ylva K. Vik.

2.5 Corkwing Growth

I estimated specific growth rate (Busacker et al., 1990) as my growth estimate and the response variable in my model.

Specific growth rate: $(\log_e(L_2) - \log_e(L_1)) / (t_2 - t_1)$

This thesis intends to examine whether there is a difference in specific growth rate between seasons (capture interval 1-2 (August/September-May), 2-3 (May-July), 3-4 (July-September), and 4-5 (early September-late September)). Since I want to examine growth from these seasons, I will only use data from individual corkwing captured between interval 1-2, 2-3, 3-4, or 4-5. The reason why specific growth rate has been used is because corkwing growth is exponential over time, where growth gradually decreases with increasing length size (Treasurer, 1994; Sayer et al., 1996). Growth should be expressed as a specific rate when it is exponential, because it allows fish with different length size bases to be compared, since the scale is changed from length growth to a proportion of growth.

All models have specific growth rate (specg) modulated by length at first capture (Length1) and “Season” as an additive effect. “Length1” is included in all test models since larger individuals are known to grow less than small individuals (Treasurer, 1994; Sayer et al., 1996). Capture interval is included in all test models, because of the large variation in food availability and temperature with different seasons. I only look at additive effects of “Season”, and no interaction effects, since I assume the seasonal effect on growth rate is independent of body size.

I found the best model describing variation in growth by performing several steps. I use Rstudio for my analyses (Rstudio team, 2016):

1) Choice of explanatory variables to model corkwing growth

I have to consider which explanatory variables that might be relevant for my hypotheses and include them to my model equation and test these with AIC (Akaike Information Criterion) to find the best fitted model. Lowest AIC value has best fit, meaning that the combination of factor variables with lowest AIC best explains how growth is affected by seasonal variation. Additional variables I need to analyze besides length and season, is age, sex, habitat type, and corkwing- and goldsinny density. In the following, I account for what these factor variables are called in my model equations, what they are, and the reason why they are important to include in my model equation tests:

- “Age”

“Age” is the age determined from first capture (since there were only sampled scales from first captures). I have set the models to include all cases where corkwing individuals have a

determined age in order to keep all data in the different equations consistent. Not all marked corkwing individuals have aged, because some individuals had unreadable scales. Age must be tested as a contributing factor variable, since there is a possibility for it to be of significant importance to growth, for instance if older individuals have a slower growth than younger.

- “Sex”

“Sex” includes male and female corkwing. Sneaker-males have been assorted to the female gender, since they are hard to distinguish from each other, especially outside the spawning season. Besides, females and sneaker males have been reported to have similar growth patterns (Dipper & Pullin, 1979). Sex is tested to see if there is a significant difference in growth between males and females.

- *Habitat Categories: “Area”, “Habitat”, “Kelp-/Thread Algae”, “Sheltered/Exposed”, and “HabitatZone2”*

There are five different categories of habitat. These categories have to be tested separately in order to find their individual effects on growth. The first is “Area”, which divides habitats by islands; Bleikjo, Saltskjærholmane and Lambøya. The second is “Habitat”, which divides habitat into four categories focusing on biomass coverage, algae composition, and substrate type; A, B, C, and D. The third is “Kelp-/Thread Algae”, which divides habitat by kelp or thread, depending on what is dominating at one specific area. The fourth is “Sheltered/Exposed”, dividing habitat into two categories of whether it is sheltered from high speed wind and waves (side turning towards land) or if it is exposed to high speed wind and waves (towards the open sea). The fifth is “HabitatZone2”, which is divided into 11 zones, where similar nature types have been combined.

I will first test for best model without habitat. When best primary model has been found, I will then proceed to find the model including the habitat with the lowest AIC value. Habitat is necessary to include when testing models, since there are possible differences in growth in different habitats due to for instance different food compositions or productivity.

- *Density of corkwing and goldsinny (Catch Per Unit Effort)*

Catch Per Unit Effort (number of fish per fyke net haul) is used as a proxy for density. I have three different Catch Per Unit of Effort-values, all measured in the same manner: it is the median catch value per fyke per “HabitatZone2” (“HabitatZone2” is described in section 2.3

Habitat Classification) of corkwing, goldsinny, and both combined. I will examine whether corkwing-, goldsinny-, or combined densities have significant impact on specific growth rate of corkwing.

2) Find best model type

I have chosen linear model (lm) to create my model (Rstudio team, 2016). “Normal Q-Q”-plots of best primary model (Appendix A, Figure A.1), best secondary model (Appendix A, Figure A.2), and best final model (Appendix A, Figure A.3) appears to be normally distributed, with residuals following the straight line. “Residuals Vs Leverage” – plots of best primary model (Appendix B, Figure B.1), best secondary model (Appendix B, Figure B.2), and best final model (Appendix B, Figure B.3) shows no influential cases, with all points within cooks distance, meaning there are no points which are influential against the regression line. These plots suggest lm to be a well fit model for this analysis, and will therefore be used here.

3) Test for best primary model with “Sex” and “Age”

I have performed four AIC-test in Rstudio (Rstudio team, 2016) to find best primary model to explain corkwing growth. The model with lowest AIC value is the best to describe variation in specific growth rate, and will be considered the best model to explain the results. I also include Δ AIC in my results, which shows the difference in AIC from the model with lowest value. I tested “sex” as an additive effect on specific growth rate, additive effects of “sex” and “age” on specific growth rate, “sex” and “age” as interactive effects with each other on specific growth rate, and lastly “age” as an additive effect on specific growth rate. I did not test to see if “sex” or “age” has interaction effect with season, since I assume there is no variation in gender- or age effects over time.

Age has not been determined in all individuals. For this reason, I have specified that I must only use data where age is determined to make sure all four model tests contain the same data set. This reduces data quantity from 155 to 83 individuals.

Data can be changed to include the whole dataset if my results show that the model with lowest AIC-value excludes “age”.

4) Test for best secondary model with different habitat categories

I have performed five AIC-tests to find the best secondary model to explain corkwing growth. The best fit primary model is tested with the four different habitat factor variables separately, to see if any of the habitat types reduce the AIC value of my model. The habitat with lowest AIC value will be included in my final model, if it has an AIC value of $-2 \Delta AIC$ or lower from the primary model with the lowest AIC. I will only test for additive effects of the different habitats, because I assume habitat effects are independent from the other factor variables. However, habitat type is known to change according to season, but this will not be tested since we only have available information of habitat type from September 2018 on the three islands, therefore excluding interaction effects.

5) Test for best fit final model with corkwing- and goldsinny densities

I have performed six AIC-tests to find best fit final model to explain corkwing growth. The best final model tests include corkwing density as additive effect, goldsinny density as additive effect, corkwing and goldsinny densities combined as additive- and interaction effects, and corkwing – and goldsinny density as interacting effects with sex. It is necessary to test interaction effects of the two densities with sex, because the behavioral differences between males and females might be affected by density. One of the models will be concluded to be the best final model if it has $-2 \Delta AIC$ or lower from the primary model with lowest AIC.

Additionally, I performed a test to see if there was a correlation between goldsinny – and corkwing density. A linear regression analysis based on densities from habitat category HabitatZone2 (Appendix C, Table C.1), shows there was a small and positive correlation between the densities of corkwing and goldsinny ($r=0.334$, $p<0.001$).

3. Results

3.1 Scale Evaluation

Scale analyses were performed by three independent readers with a total of 392 scales analyzed by each person. These three analyses tests combined had few incorrect readings of 13.18 % (assuming age determined from otoliths are correct). The highest error rate for a reader was 74 out of 392 (18.9%) (figure 3.1.1). All three readers were well coordinated as well, since correct age readings were often for the same scales (see figure 3.1.2). There were few situations where all three readings were incorrect (figure 3.1.2). However, scales from individuals 6-7 years of age were more often read wrong (figure 3.1.2), indicating a tendency for higher error rates with increasing otolith age. Further, all three reading regression lines are below the black reference line after age 3, which means scale age was underestimated by all readers and degree of underestimation increased with increasing age after age 3 (see figure 3.1.3). Deviation from correct age was usually only one year for all three readers. Despite increasing error percentage with increasing age, my regression analyses (table 3.1.1) for the three readers show high r-values of 0.795, 0.920, and 0.898, and indicate that scales are well suited for age determination.

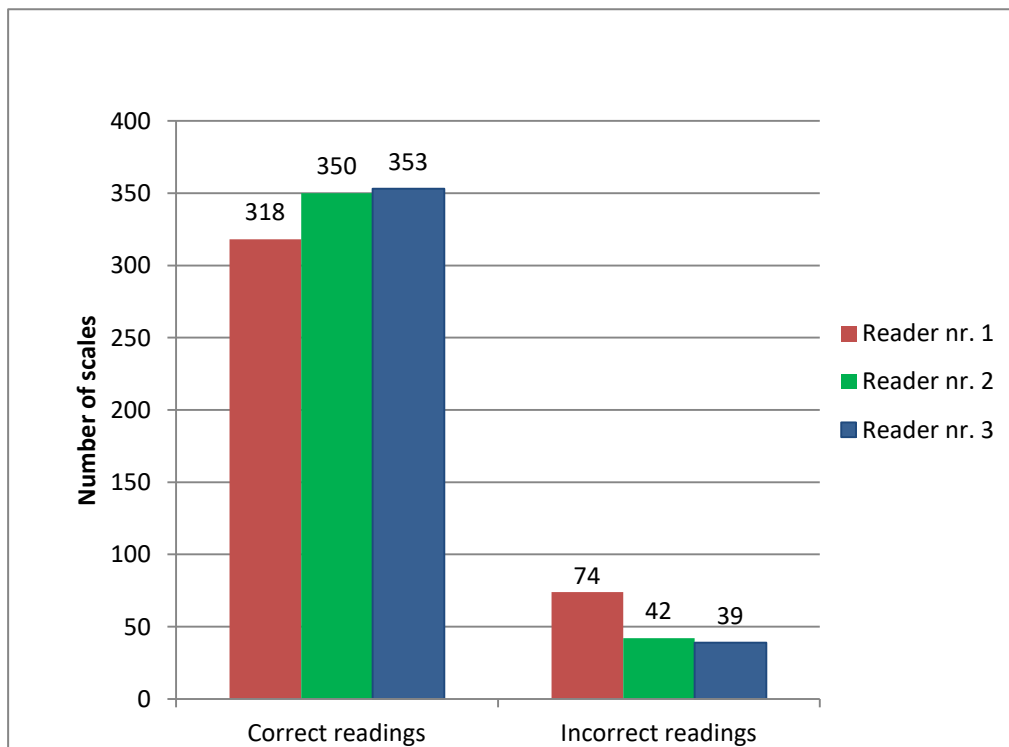


Figure 3.1.1: Number of correct- and incorrect scale age readings done by three readers independently. Age estimated for otoliths are assumed correct.

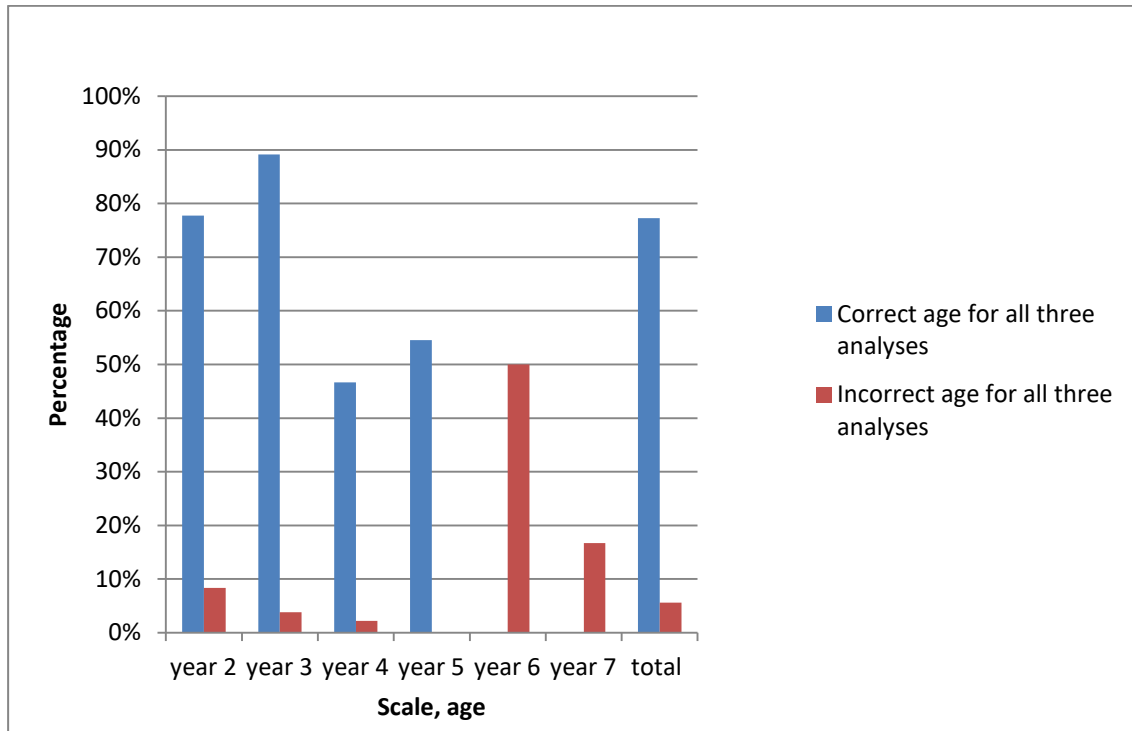


Figure 3.1.2: The percentage of correct scale age readings where all three are similar to otolith age, and percentage of incorrect scale age readings where all three are different from otolith age (not necessarily same incorrect age for all three readers).

Table 3.1.1: Relationship between otolith age and scale age readings done by the three independent readers.

Coefficients:	Estimate	Std. Error	t-value	P-value
Reader 1; $r=0.795$				
Intercept	0.515	0.096	5.365	<0.001
Scale age1	0.797	0.031	25.847	<0.001
Reader 2; $r=0.920$				
Intercept	0.191	0.061	3.137	0.002
Scale age2	0.934	0.020	46.303	<0.001
Reader 3; $r=0.898$				
Intercept	0.193	0.070	2.758	0.006
Scale age3	0.919	0.023	40.285	<0.001

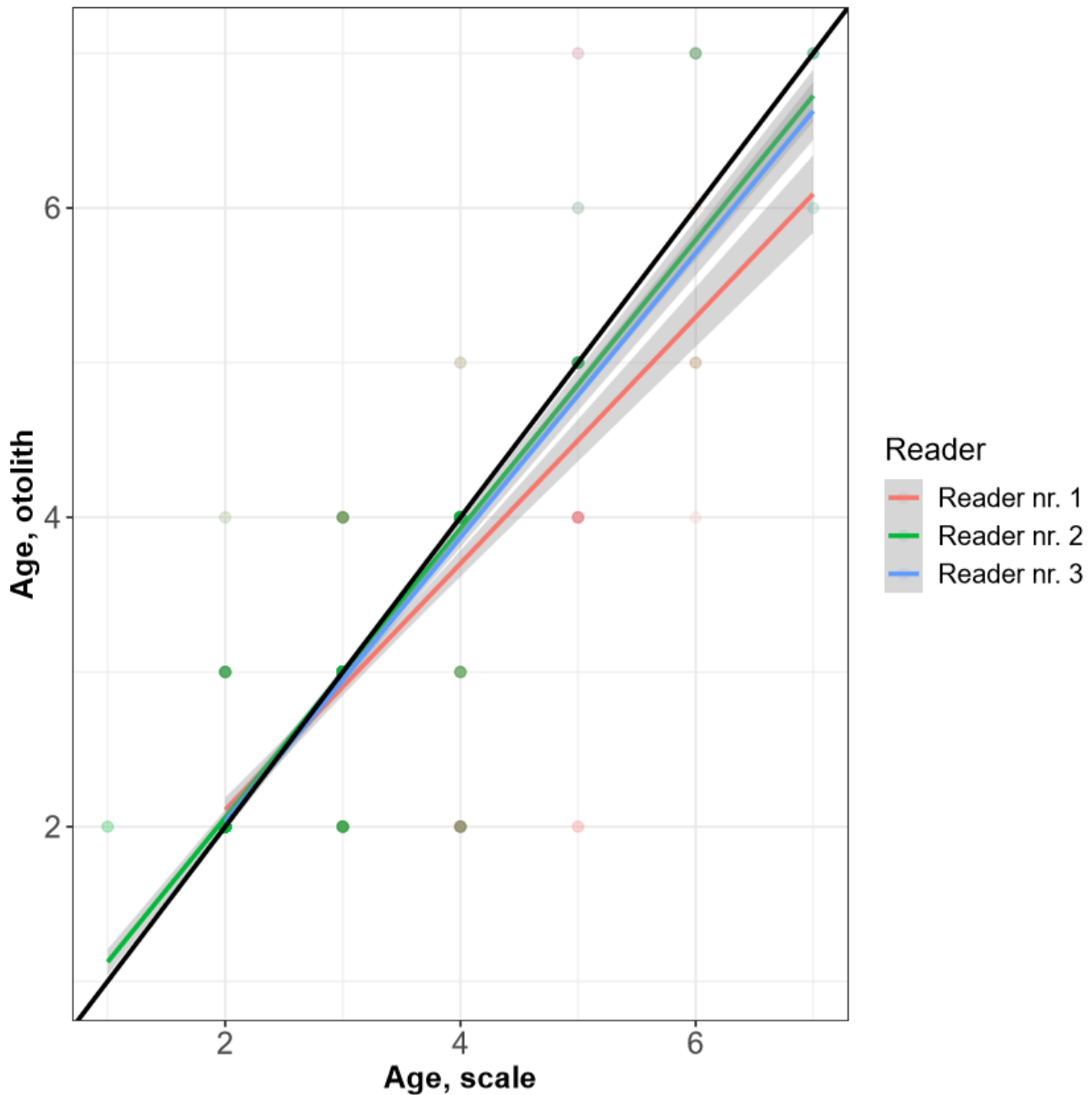


Figure 3.1.3: Relationship (with confidence envelopes) between scale age and otolith age. Regression lines for the three independent age readings as well as a black reference line showing where scale age equals otolith age are included. Each point may represent several observations, and points with high transparency represent fewer observations than less transparent points ($N=392$ pr. reader).

3.2 Corkwing Growth

During the sampling period a total of 6394 corkwings were captured. Of these, 3953 individuals were tagged, and of these 306 were recaptured. In this thesis, I use data from 155 of these recaptured corkwings, since these individuals have remained within the same habitats

from first to second capture, and are captured within season 1-2, 2-3, 3-4, or 4-5. I combined sneaker males with females, as these are hard to distinguish from each other. There was a decrease in number of corkwing with increasing length among the total material of 3953 tagged individuals (figure 3.2.1) and for the 155 individuals used in this thesis (figure 3.2.2). This means that most individuals used for my analyses are relatively small. Age was determined for 83 out of the 155 recaptured corkwings used for analyses, and a similar trend is seen with age, where there is a gradual decline in number of corkwing with increasing age (figure 3.2.3.).

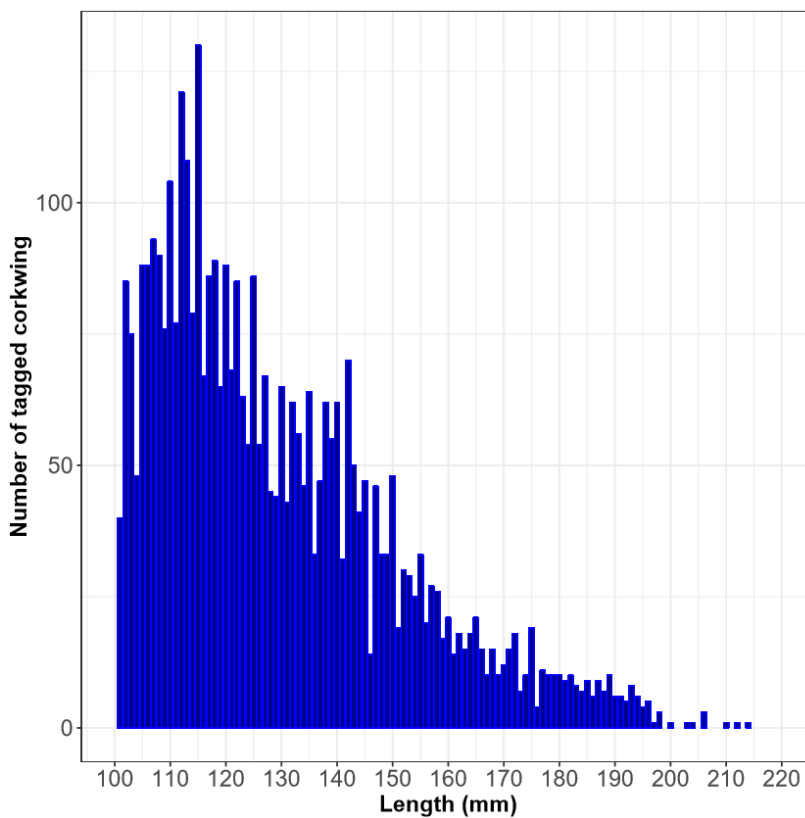


Figure 3.2.1: Length distribution of all corkwing individuals tagged ($N = 3953$).

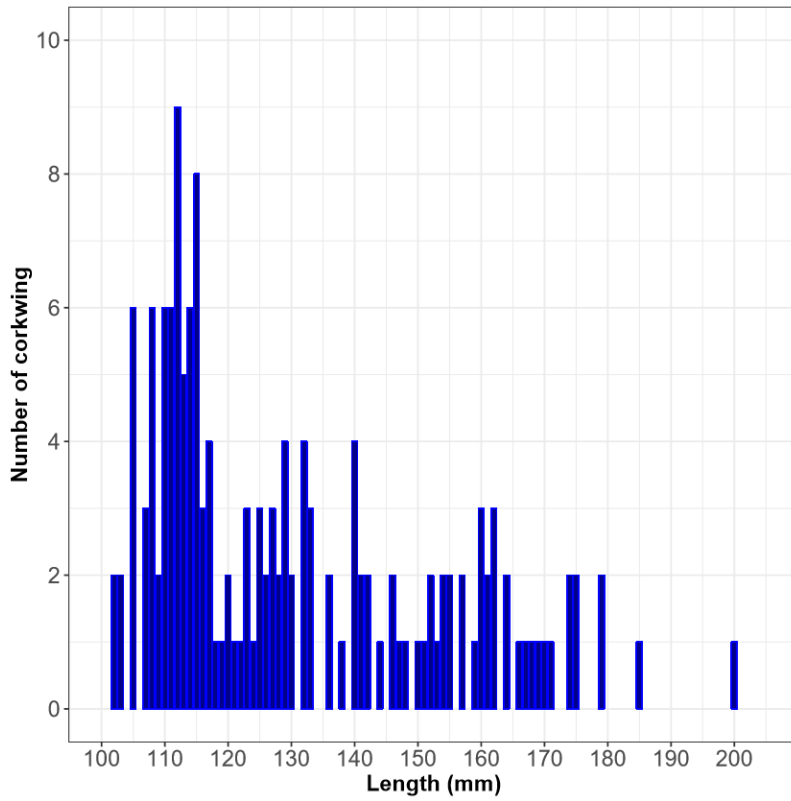


Figure 3.2.2: Length distribution of corkwing used for growth analyses ($N=155$).

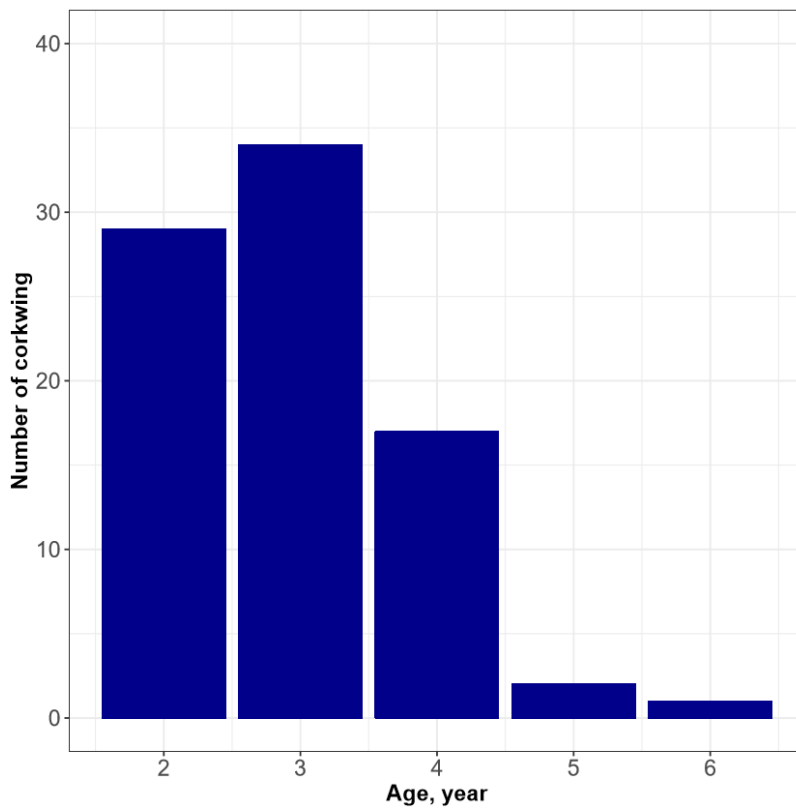


Figure 3.2.3: Age distribution of corkwing wrasse ($N=83$).

3.3 Growth Model Analyses

3.3.1 Age & Sex

I initially tested for the effect of age and sex on variation in specific growth. For all tests, length at first capture and seasons was included as factors. These tested models are limited to data where age was available (83 individuals). The results show that sex as an additive effect had the lowest AIC-value (-987.521), with a Δ AIC difference to the second-best model of -4.585. This can therefore be considered the best primary model (table 3.3.1). Our primary model can therefore be changed to include data for all individuals (155 individuals).

Table 3.3.1: AIC- and Δ AIC- values of the model including “sex” as an additive effect, “sex” and “age” as additive effects, the additive effect of “sex” and “age” as interacting effects with each other, and lastly “age” as an additive effect.

Variables	AIC	Δ AIC
+sex	-987.521	0
+sex+age	-982.936	4.585
+sex*age	-978.950	8.571
+age	-978.097	9.424

In the best fit primary model, males grew faster than females, there was a great variation in seasonal growth, where corkwing grew more in spring and summer than fall and winter, and larger individuals grew slower than smaller individuals (table 3.3.2, figure 3.3.1). The model including sex as an additive effect will be used for further tests in finding best secondary model.

Table 3.3.2: parameter estimates of the best primary model including sex as an additive effect on corkwing growth. This model has an AIC value of -1852.355, and will be used further to test for secondary best fit model.

Coefficients:	Estimate	Std. Error	t value	p value
(Intercept)	1.724e-03	2.420e-04	7.125	<0.001
Length1	-1.170e-05	1.755e-06	-6.664	<0.001
Season2_3	6.644e-04	1.246e-04	5.333	<0.001
Season3_4	1.320e-03	9.973e-05	13.231	<0.001
Season4_5	-1.046e-04	9.753e-05	-1.072	0.285
sexMale	3.280e-04	7.829e-05	4.189	<0.001

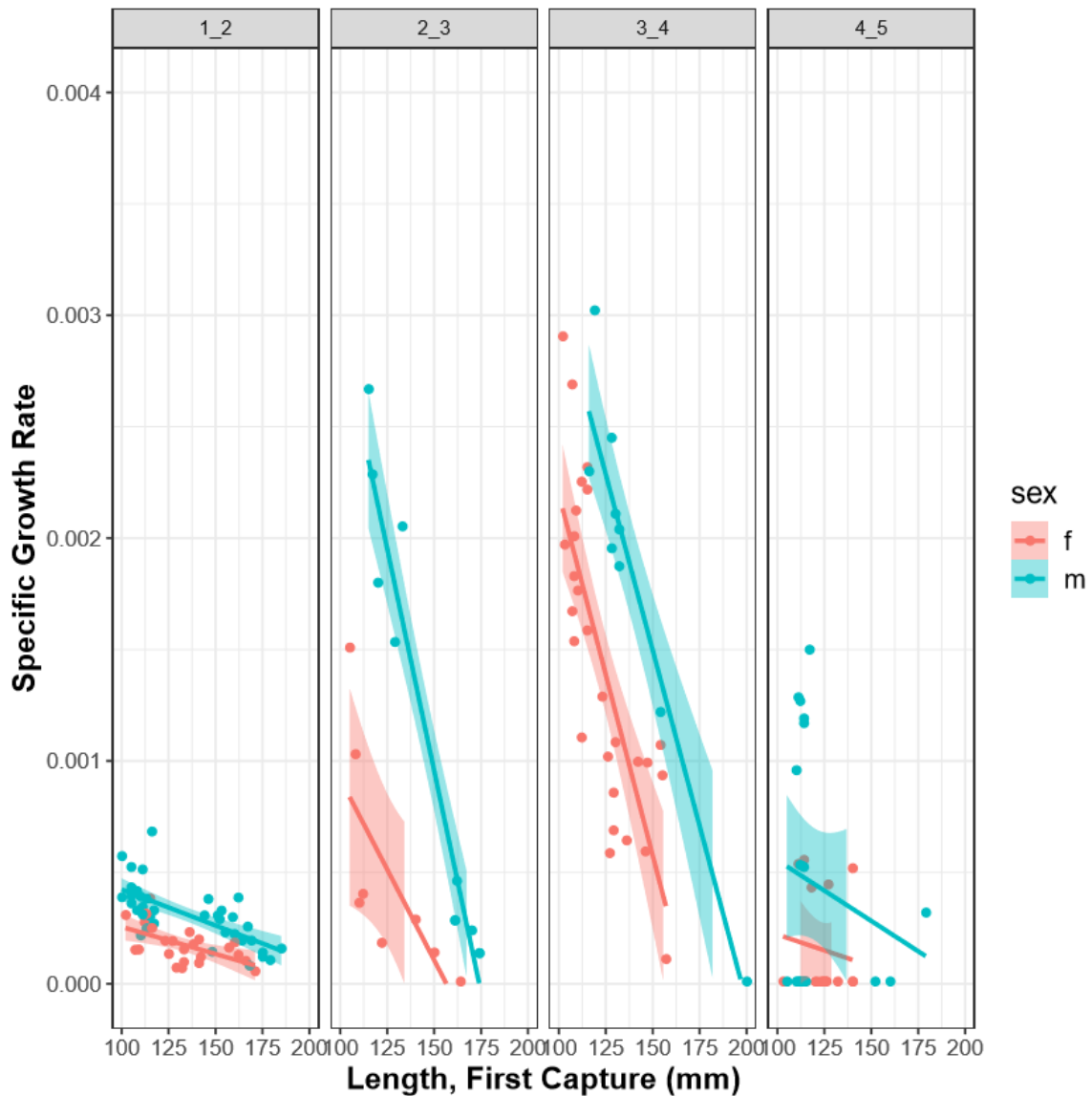


Figure 3.3.1: Changes in specific growth rate with length from first capture during different seasons (1_2 is September-May, 2_3 is May-July, 3_4 is July-September, and 4_5 is early September- late September) for female (pink color) and male (blue color) corkwing. Included are individual regression lines and confidence intervals.

3.3.2 Habitat

Using the best model from the above exercises (see table 3.3.2.), I tested whether habitat could explain variation in growth. I performed five AIC-tests to find the best secondary model to explain corkwing growth. These models were tested with the different habitat variables, and included all data (155 individuals). The model with “Area” had the lowest AIC value of the habitat-models (-1851.955), but had a slightly higher AIC-value compared to the model without habitat included (table 3.3.3).

Table 3.3.3: AIC- and Δ AIC- values of the model including Area, Sheltered_Exposed, Habitat, Kelp-/Thread Algae and HabitatZone2 as separate additive effects.

Variables	AIC	Δ AIC
+sex	-1852.355	0
+sex+Area	-1851.955	0.4
+sex+Sheltered_Exposed	-1850.426	1.929
+sex+Habitat	-1848.375	3.98
+sex+Kelp-/Thread Algae	-1851.144	1.211
+sex+Zone	-1842.408	9.947

The best habitat model (Appendix D, Table D.1) showed that Saltskjærholmane and Lambøya had high p values (p value > 0.05), which indicated that the area had no significant effect on specific growth rate. Further, males had a significantly higher growth rate than females, spring and summer had significantly increased growth compared to winter, fall had no difference in growth rate compared to winter, and larger individuals had lower growth rates than smaller individuals. The second best model's AIC value (-1851.955) was higher than best primary model including sex as factor variable (-1852.355). I therefore proceeded with the simplest model (excluding habitat) to continued analyses.

3.3.3 Density

Density of corkwing, goldsinny, and both combined (additive and interaction effects) were tested to see whether they affect corkwing growth. Also, I tested interaction effects of the two densities with sex. The model including an interaction effects between goldsinny density and sex, had the lowest AIC-value= -1952.182, with a Δ AIC-value= -99.645 (Table 3.3.4). This is lower than -2 AIC-values from the best fit primary model, making it the best model overall.

Table 3.3.4: AIC- and Δ AIC- values of the model including best primary model including sex, and various model tests including corkwing- and goldsinny densities.

Variables	AIC	Δ AIC
+sex	-1852.355	0
+sex+corkwing density	-1851.317	1.038
+sex+goldsinny density	-1855.392	-3.037
+sex+combined densities	-1945.804	-93.449
+sex*combined densities	-1948.508	-96.153
+sex*corkwing density	-1943.263	-90.908
+sex*goldsinny density	-1952.182	-99.645

From the best final model, higher goldsinny densities reduced male growth, male corkwing had higher growth rates than females, and there were higher growth rates in spring and summer compared to fall and winter (table 3.3.5, figure 3.3.2). Males grew much faster than females under low densities, but they grew equally fast under high densities, and there was little difference in growth between the sexes in winter. This is the best model to explain corkwing growth.

Table 3.3.5: The best final model including additive effect of goldsinny density and sex as interacting effects on corkwing growth. This model had lowest AIC-value of -1952.182.

Coefficients:	Estimate	Std. Error	t value	p value
(Intercept)	1.718e-03	2.687e-04	6.395	<0.001
Length	-1.216e-05	1.631e-06	-7.455	<0.001
Season2_3	5.418e-04	1.169e-04	4.636	<0.001
Season3_4	1.322e-03	9.643e-05	13.712	<0.001
Season4_5	-1.178e-04	9.344e-05	-1.261	0.2092
sexMale	8.764e-04	2.423e-04	3.617	<0.001
Goldsinny density	-2.302e-06	1.656e-05	-0.139	0.8896
sexM:goldsinny density	-5.216e-05	2.291e-05	-2.277	0.0242

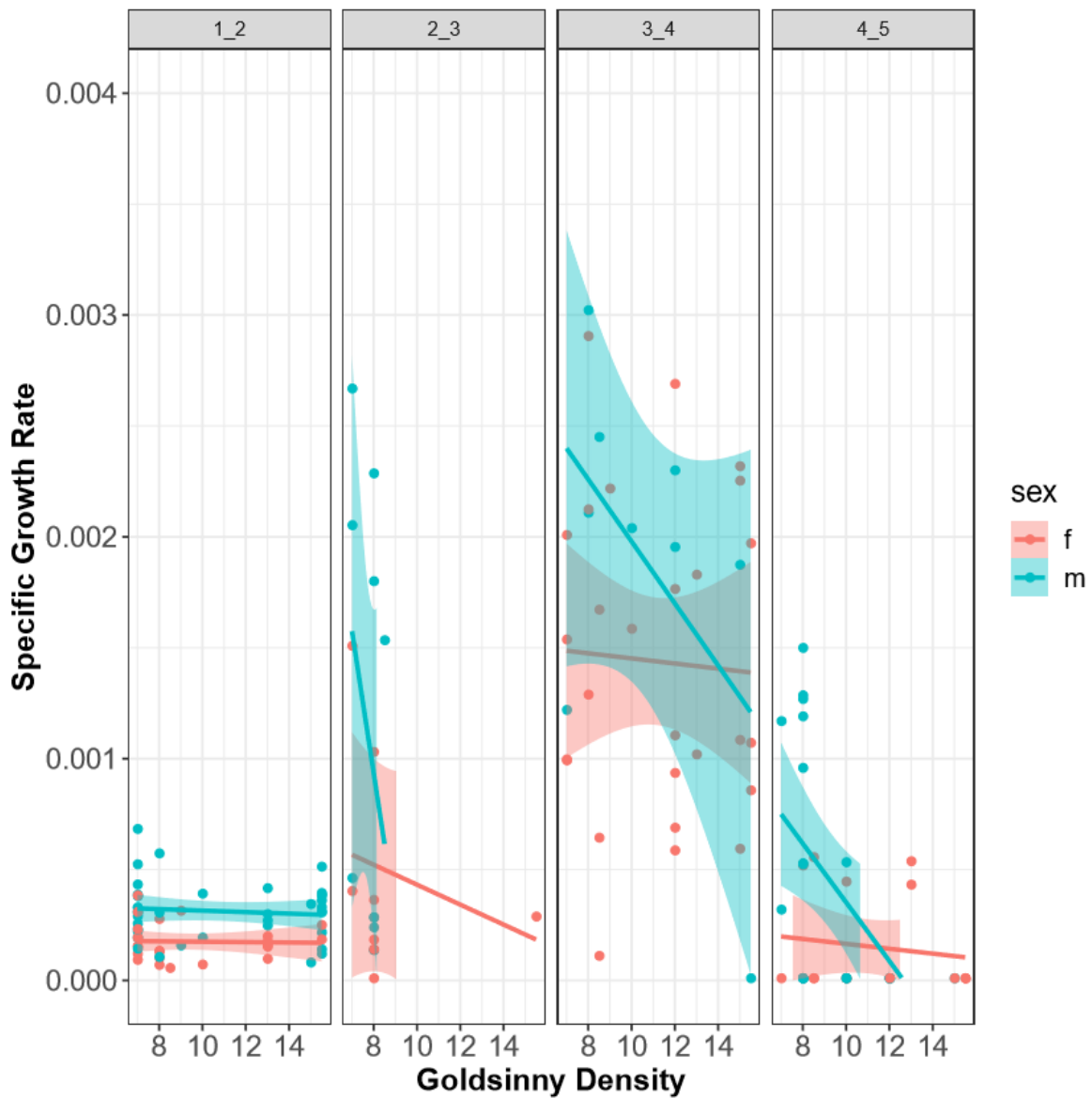


Figure 3.3.2: Changes in specific growth rate with goldsinny density in the different seasons (1_2=September-May, 2_3=May-July, 3_4=July-September, and 4_5=early September – late September) for female (pink) and male (blue) corkwing. Individual linear regressions on observed data and confidence intervals are shown.

4. Discussion

According to my results, specific growth rate was better explained with body size (length) rather than age, indicated by comparing AIC values, where longer individuals had lower growth rates than shorter individuals. However, previous studies have claimed that higher growth rates in younger corkwings were caused by their age (Treasurer, 1994; Sayer et al., 1996). In my research, I assume an age reading error of 13 %, which might be the reason why age was not the most explaining factor in this research.

Higher growth rates in smaller individuals can be explained by the vulnerability of being small, where individuals that remain small over longer time periods are more likely to become victims of predation. Individuals with high growth rates reduce the period when they are highly vulnerable for predation, and are therefore more likely to survive (Nilsson & Brönmark, 2000). This is because most predators are gape-size limited, and depend on prey small enough to fit into their mouths (Post & Parkinson, 2001). A corkwing which has reached a size protecting them from most predators, may allocate energy towards activities such as nest building, aggressive territorial behaviors, gonad development, and reproduction rather than growth, which might explain the gradual growth rate decline with length. High growth rates in small individuals in order to avoid predation risks are shown to be a common adaptation strategy among many fish species (Tonn & Paszkowski, 1992; Persson et al., 1996). It is reasonable to believe that corkwing minimize high predation risk by having high growth rates at small sizes.

Another explanation is that relatively short corkwing need to grow fast to increase reproductive output. For instance, small corkwing males that achieve large sizes quickly may have higher reproductive success because they are able to compete with conspecific males for mating opportunities. Being a large and dominating male is a concept generally accepted as an adaptation among many animals for increasing reproductive output (Trivers, 1972; Warner, 1982), and it can be assumed to apply for corkwing as well. Large corkwing males are often dominant and territorial over algae nests they make for their eggs, and are quickly able to ward off conspecifics who might attempt to fertilize the eggs (Potts, 1974). Attaining large sizes fast will therefore increase male reproductive output by increasing time spent on reproductive behavior, and by increasing his ability to drive away other competing males

from his nest. Further, attaining large sizes quickly for males might be beneficial when it comes to female's choice, given that females search for large dominating males who can defend a territory and her offspring eggs. This form of mate selection has been observed in tropical bluehead wrasse (*Thalassoma bifasciatum*) females, where they often choose large mates who are likely to possess and dominate the best spawning areas (Robertson & Hoffman, 1977). Previous research on the other hand has shown female corkwing choose mates regardless of male size (Uglem & Rosenqvist, 2002). However, the researchers explained that indifferent mate selection could be caused by unavailability of other males present, which means females had to select the one available male regardless of his size if she was to reproduce at all. Females may also have reproductive benefits from quickly attaining large sizes, considering large fish females in general tend to have greater fecundity by spawning over longer time periods, having higher egg production, and create larger sized eggs (Kjesbu, 1994; Berkeley, Chapman & Sogard, 2004; Wright & Trippel, 2009; Halvorsen, 2016). This adaptation might increase post-hatching survival, and thereby increase her reproductive output.

My results show that corkwing males grew faster than females. This sex differentiation could be a result of intrasexual competition, where male-male competition for females during mating season has a great evolutionary driving force, particularly in large populations (Halvorsen et al., 2016). In corkwing, it is the largest and most dominant individuals among territorial males that have greatest reproductive success, which is why there is generally a selection for large territorial males for many species (Trivers, 1972; Potts, 1974; Warner 1982; Hilledén, 1984; Warner & Schultz, 1992; Halvorsen et al., 2016). This is natural selection, where males of greater sizes are more able to defend their nest territories from competing males, and attain larger and higher quality nests, whereas females who are not driven by this competition, will not attain such large sizes.

Intersexual selection may also increase abundance of larger males, since females tend to choose males of greater sizes as mates (Halvorsen et al., 2016). Female sexual selection on male size is a common occurrence for various species, and has been observed for instance in the tropical bluehead wrasse (Robertson & Hoffman, 1977). Larger males have higher capability to defend against intruders (Halvorsen et al., 2016; Potts, 1974). Females may therefore prefer larger males if she bases her mate choice on his ability to protect her eggs. Further, in tropical bluehead wrasse, large males have usually larger and higher quality

territories than small males, and females tend to choose a larger male's nest, as its quality might increase survival of her offspring (Robertson & Hoffman, 1977).

Female corkwing do not need to invest as much energy into growth in order to defend or protect her offspring eggs since this is done by males (Potts, 1974). Nor is there evidence suggesting that males prefer females of a certain size in corkwing. Instead, she may invest more energy into egg production and gonad development to increase her fecundity. For instance, female corkwing and other female wrasse species have been shown in previous studies to trade off growth with early maturation, thereby being able to reproduce sooner than males (Dipper, 1976; Sayer et al., 1996; Halvorsen, 2016; Halvorsen et al. 2016). This trait may increase her reproductive output, since she spends more of her lifespan on reproduction rather than growth. Some studies believe that earlier maturation is the main factor explaining the large differences in size-at-age between the sexes (Quignard, 1966; Treasurer, 1994). Quignard (1966) states that the female hormone estrogen promotes earlier maturation, and acts as a somatic development inhibitor, while the common male hormone testosterone delays maturation and also enhance growth augmentation. Sayer et al. (1996) opposes this, and claims that male- and female growth rate will equalize shortly after males mature. Sayer et al. (1996) states early maturation is more likely to be a contributing effect to growth rates, rather than the main factor. However, there are clear differences in growth rate between the sexes, which seem most likely to be caused by a trade off from growth to reproduction when females become sexually mature.

My results reveal that corkwing growth is affected by seasonal variation, where there are higher growth rates in spring and summer, and less in fall and winter. Temperature may affect activity levels that lead to reduced foraging, which again may affect growth. A study found that corkwing had lower activity levels and consumed less during winter months, which was claimed to be due to lower temperatures (Deady & Fives, 1995). Another research found that corkwing was less frequently captured during winter seasons, which they also argued to be caused by lowered activity levels when cold (Thangstad, 1999). On the other hand, corkwing has been observed to continue feeding and growing during winter months, which means that they don't stop moving completely (Sayer et al., 1996), as seen in other wrasse species. For instance, goldsinny enter a torpid state and completely stop feeding when surrounded by temperatures below 5 degrees Celsius (Hilldén, 1984).

Reduced activity and lower food intake seen in corkwing and other wrasse species could be explained by a change in their metabolic rate according to temperatures. Lowered temperatures lead to decreased metabolism in ectotherm species like corkwing, meaning that their relatively slow turnover rates from food to energy cause lower activity levels and reduced growth rates (Johnston & Dunn, 1987; Thangstad, 1999). This is argued to be a tactic to save energy storage during periods of limited food supply and to increase chances of survival (Johnston & Dunn, 1987). It may therefore seem that variation in food availability and temperature through a year in temperate regions together result in seasonal growth trends seen in corkwing.

Seasonal growth rates are also likely to be caused by great ocean productivity in spring and summer, where corkwing food increase in biomass, and result in increased corkwing growth, whereas low productivity in fall and winter results in less growth inclinations due to limited food availability. Qignard (1966) also revealed the same discontinuous growth through the seasons in corkwing, and concluded that summer favors higher growth rates. Further, previous studies have documented significantly lower food content in corkwing stomachs between November and March (Sayer, Cameron & Wilkinson, 1994; Deady & Fives, 1995), which likely reflect low food availability caused by reduced ocean productivity.

It may be particularly important for small young of the year (YOY) fish to have high growth rates during warmer periods with high food availability, in order to survive winter. There has previously been documented size-selective winter mortality in other fish species, where smaller individuals were more likely to succumb during cold periods (Fullerton et al., 2000; Schludermann, Keckeis & Nemeschkal, 2009). High initial growth rates in summer periods are probably a survival strategy for small corkwing individuals as well. However, this study does not include YOY corkwing, as they are too small for PIT-tag experiments done in this research.

My results showed that goldsinny density could explain corkwing growth better than corkwing density, and corkwing had reduced growth in high goldsinny densities, particularly in spring and summer. This indicates that goldsinny and corkwing depend on the same resources, thereby resulting in high resource competition. Other observations show that corkwing and goldsinny rely on the same resources and prefer the same habitats (Thangstad, 1999), meaning that resource competition among these two wrasse species seems likely to occur, especially with larger population sizes. Studies performed on other fish species have

shown that growth is density-dependent, where higher competition leads to limited food availability, reduced feeding success and restricted growth opportunities (Victor, 1986; Doherty, 1983; Jones, 1987; Forrester, 1990; Cowan et al., 2000; Halvorsen, 2016).

Males were more affected than females by high densities, and this could be due to their territorial behavior and offspring investment. Males might remain in their territories to protect offspring regardless of densities, while females who are not resident, might move to another location of lower densities where there is lower resource competition. Further, territorial behavior seen in males might require a great amount of energy and is likely to restrict feeding, thereby restricting growth. Higher densities might make corkwing males invest even more energy and time into protection of territory and eggs than feeding and growth, since there are more individuals to fend off than under lower densities.

None of the habitat types seemed to have any significant effect on growth rate. All islands and zones were highly or moderately covered with algae growth, with some variation in type of algae dominating, substrate, and degree of exposure. However, no distinction in growth rate between the habitat types could indicate too similar algae composition, algae coverage, substrate, and exposure. Differences in growth rates should be expected if differences in nature types were sufficiently great. For instance, there should potentially be a difference in growth rate in an area completely sheltered compared to an area with high exposure, where high exposure places might provide less vegetation, hiding opportunities in vegetation and scree, and available nutrients, thus leading to reduced growth rates. However, these results could be biased, since corkwings may move between different habitats, with exception between the islands where deeper waters (>20 m) prevented migration.

Previous studies have found that corkwing prefers rocky biotopes with algae cover, where scree and kelp act as refuge (Thangstad, 1999; Skiftesvik, Durif, Bjelland & Browman, 2015). No present study documents how variation in these habitats affect corkwing growth.

However, previous studies found sheltered inshore populations of bluehead wrasse had higher growth rates than high exposure populations close to the open sea, and it was claimed that this difference in growth rate resulted from different habitat qualities, where high exposure in the offshore leads to reduced availability of food or other resources (Schultz & Warner, 1991).

This seems likely to be true if productivity is hindered by high disturbance levels. My results showed no difference in growth between exposure and sheltered areas, but this could be the result of too low exposure variation between the examined areas. There was great exposure

variation between populations investigated by Schultz and Warner (1991), where inshore and offshore populations were several kilometers apart, whereas my populations were relatively close. Further studies are needed to examine habitat effects on corkwing, and perhaps it is necessary to examine populations located further away from each other to find greater habitat differences than those found in my study.

The three scale and otolith analyses had a combined error reading of 13.18 %. Error levels less than 20 percent is considered to be within good limits, which means all three scale age readings separate and combined were acceptable. All three readers were also well coordinated, where correct age was often determined for the same scales. There was a tendency for higher error rates with increasing otolith age, but deviation from correct age was usually with only one year. My regression analyses (table 3.1.1) for the three readers showed high r-values (0.795, 0.920, and 0.898) which further indicate that scales are well suited for age determination.

5. Conclusion

According to my results, size had more effect than age on corkwing growth, where longer individuals had lower growth rates than shorter individuals, males grew faster than females, corkwing growth was affected by seasonal variation, where there were higher growth rates in spring and summer, and less in fall and winter, there was reduced growth in high goldsinny densities, particularly in spring and summer, where males were more affected than females, and none of the habitat types had any significant effect on growth rate. The three scale and otolith analyses had a combined error reading of 13.18 %, and error levels less than 20 percent is considered to be within good limits, which means all three scale age readings separate and combined were acceptable.

Further research on this topic is needed to understand how corkwing growth is affected, as this information may be used to develop a sustainable fishing industry on corkwing wrasse.

References

- Bagenal, T. B., & Tesch, F. T. (1978). Age and Growth. In T. B. Bagenal (Eds.), *Methods for Assessment of Fish Production in Fresh Waters* (3rd ed., pp. 101–136). Oxford: Blackwell Scientific Publications.
- Barreto, R. E., Gontijo, A. M. M. C., Alves-de-Lima, R. O., Raymundi, V. C., Pinhal, D., Reyes, V. A. V., ... Salvadori, D. M. F. (2007). MS222 does not induce primary DNA damage in fish. *Aquaculture International*, *15*(2), 163–168.
- Berkeley, S. A., Chapman, C., & Sogard, S. M. (2004). Maternal age as a determinant of larval growth and survival in a marine fish, *Sebastes melanops*. *Ecology*, *85*(5), 1258–1264.
- Besnier, F., Kent, M., Skern-Mauritzen, R., Lien, S., Malde, K., Edvardsen, R. B., ... Glover, K. A. (2014). Human-induced evolution caught in action: SNP-array reveals rapid amphi-atlantic spread of pesticide resistance in the salmon ectoparasite *Lepeophtheirus salmonis*. *BMC Genomics*, *15*(1), 937.
- Bolland, J. D., Cowx, I. G., & Lucas, M. C. (2009). Evaluation of VIE and PIT tagging methods for juvenile cyprinid fishes. *Journal of Applied Ichthyology*, *25*(4), 381–386.
- Boughamou, N., Derbal, F., & Kara, M. H. (2014). Otolithometry and scalimetry—two valid methods to describe the growth of peacock wrasse, *Symphodus tinca* (Actinopterygii: Perciformes: Labridae) from eastern Algeria. *Acta Ichthyologica et Piscatoria*, *44*(4), 285–293.
- Buesa, R. J. (1987). Growth rate of tropical demersal fishes. *Marine Ecology Progress Series*, *36*, 191–199.
- Busacker, G. P., Adelman, I. R. & Goolish, E. M. (1990). Growth. In C. B. Schreck & P. B. Moyle (Eds.), *Methods for fish biology* (pp. 363–387). Bethesda: American Fisheries Society.
- Casselman, J. M. (1983). Age and growth assessments of fish from their calcified structures - techniques and tools. In E.D. Prince & L.M. Pulos (Eds.), *Proceedings of the international workshop on age determination of oceanic pelagic fishes: tunas, billfishes and sharks* (pp. 1–17). Miami: NOAA Technical Report NMFS 8.
- Costello, M. J. (1991). Review of the biology of wrasse (Labridae: Pisces) in Northern Europe. *Progress in Underwater Science*, *16*, 29-51.
- Cowan, J. H., Rose, K. A., & DeVries, D. R. (2000). Is density-dependent growth in young-of-the-year fishes a question of critical weight? *Reviews in Fish Biology and Fisheries*, *10*(1), 61–89.
- Deady, S., & Fives, J. M. (1995). The diet of corkwing wrasse, *Crenilabrus melops*, in galway bay, Ireland, and in Dinard, France. *Journal of the Marine Biological Association of the United Kingdom*, *75*(3), 635–649.
- Deady, S., Varian, S. J. A., & Fives, J. M. (1995). The use of cleaner-fish to control sea lice on two Irish salmon (*Salmo salar*) farms with particular reference to wrasse behaviour in salmon cages. *Aquaculture*, *131*(1–2), 73–90.

- Dipper, F. A. (1976). *Reproductive biology of manx Labridae (Pisces)* (Doctoral dissertation). University of Liverpool.
- Dipper, F. A., Bridges, C. R., & Menz, A. (1977). Age, growth and feeding in the ballan wrasse *Labrus bergylta* Ascanius 1767. *Journal of Fish Biology*, 11(2), 105–120.
- Dipper, F. A., & Pullin, R. S. V. (1979). Gonochorism and sex-inversion in British Labridae (Pisces). *Journal of Zoology*, 187(1), 97–112.
- Doherty, P. J. (1983). Tropical territorial damselfishes: is density limited by aggression or recruitment? *Ecology*, 64(1), 176–190.
- Donnelly, R. (1992). *The biology and use of wrasse (Labridae) as a biological control of external parasites in salmonid cultures* (Masters' thesis). The University of Dublin.
- Espedal, P. G., Glover, K. A., Horsberg, T. E., & Nilsen, F. (2013). Emamectin benzoate resistance and fitness in laboratory reared salmon lice (*Lepeophtheirus salmonis*). *Aquaculture*, 416–417, 111–118.
- Espeland, S. H., Nedreaas, K., Mortensen, S., Skiftesvik, A. B., Agnalt, A. L., Durif, C., ... Gjørseter, J. (2010). *Kunnskapsstatus leppefisk—Utfordringer i et økende fiskeri* [Knowledge status—Challenges related to increased harvest] (Report No. 7). Bergen: Fisken og Havet.
- Forrester, G. E. (1990). Factors influencing the juvenile demography of a coral reef fish. *Ecology*, 71(5), 1666–1681.
- Fullerton, A. H., Garvey, J. E., Wright, R. A., Stein, R. A. (2000). Overwinter Growth and Survival of Largemouth Bass: Interactions among Size, Food, Origin, and Winter Severity. *Transactions of the American Fisheries Society*, 129(1), 1-12.
- Gries, G., & Letcher, B. H. (2002). Tag Retention and Survival of Age-0 Atlantic Salmon following Surgical Implantation with Passive Integrated Transponder Tags. *North American Journal of Fisheries Management*, 22(1), 219–222.
- Halvorsen, K. (2016). *Selective harvesting and life history variability of corkwing and goldsinny wrasse in Norway: Implications for management and conservation* (Doctoral dissertation). University of Oslo.
- Halvorsen, K. T., Sjørdalen, T. K., Durif, C., Knutsen, H., Olsen, E. M., Skiftesvik, A. B., ... Vøllestad, L. A. (2016). Male-biased sexual size dimorphism in the nest building corkwing wrasse (*Symphodus melops*): implications for a size regulated fishery. *ICES Journal of Marine Science*, 73(10), 2586–2594.
- Halvorsen, K. T., Sjørdalen, T. K., Vøllestad, L. A., Skiftesvik, A. B., Espeland, S. H., & Olsen, E. M. (2017). Sex- and size-selective harvesting of corkwing wrasse (*Symphodus melops*)-a cleaner fish used in salmonid aquaculture. *ICES Journal of Marine Science*, 74(3), 660–669.
- Hill, J. V., Davison, W., & Forster, M. E. (2002). The effects of fish anaesthetics (MS222, metomidate and AQUI-S) on heart ventricle, the cardiac vagus and branchial vessels from Chinook salmon (*Oncorhynchus tshawytscha*). *Fish Physiology and Biochemistry*, 27(1–2), 19–28.

- Hilldén, N. O. (1984). *Behavioural Ecology of the Labrid Fishes (Teleostei: Labridae) at Tjärnö on the Swedish West Coast* (Doctoral dissertation). University of Stockholm.
- Imslund, A. K., Folkvord, A., Grung, G. L., Stefansson, S. O., & Taranger, G. L. (1997). Sexual dimorphism in growth and maturation of turbot, *Scophthalmus maximus* (Rafinesque, 1810). *Aquaculture Research*, 28(2), 101–114.
- Johnston, I. A., & Dunn, J. (1987). Temperature acclimation and metabolism in ectotherms with particular reference to teleost fish. *Symposia of the Society for Experimental Biology*, 41, 67–93.
- Jones, G. P. (1987). Competitive interactions among adults and juveniles in a coral reef fish. *Ecology*, 68(5), 1534–1547.
- Jones, M. W., Sommerville, C., & Wootten, R. (1992). Reduced sensitivity of the salmon louse, *Lepeophtheirus salmonis*, to the organophosphate dichlorvos. *Journal of Fish Diseases*, 15(2), 197–202.
- Jones, P. G., Hammell, K. L., Gettinby, G., & Revie, C. W. (2013). Detection of emamectin benzoate tolerance emergence in different life stages of sea lice, *Lepeophtheirus salmonis*, on farmed Atlantic salmon, *Salmo salar* L. *Journal of Fish Diseases*, 36(3), 209–220.
- Kjesbu, O. S. (1994). Time of start of spawning in Atlantic cod (*Gadus morhua*) females in relation to vitellogenic oocyte diameter, temperature, fish length and condition. *Journal of Fish Biology*, 45(5), 719–735.
- Lake, M. (2013). *Freshwater fish: passive nets - fyke nets* (Version 1.1). New Zealand: Department of Conservation.
- Nilsson, P. A., & Brönmark, C. (2000). Prey vulnerability to a gape-size limited predator: Behavioural and morphological impacts on northern pike piscivory. *Oikos*, 88(3), 539–546.
- McKenzie, J. R., Smith, M., Watson, T., Francis, M., Ó Maolagáin, C., Poortenaar, C., & Holdsworth, J. (2014). *Age, growth, maturity and natural mortality of New Zealand kingfish (Seriola lalandi lalandi)*. New Zealand: Ministry for Primary Industries.
- Papageorgiou, N. K. (1979). The length weight relationship, age, growth and reproduction of the roach *Rutilus rutilus* (L.) in Lake Volvi. *Journal of Fish Biology*, 14(6), 529–538.
- Persson, L., Andersson, J., Wahlström, E., & Eklöv, P. (1996). Size-specific interactions in lake systems: Predator gape limitation and prey growth rate and mortality. *Ecology*, 77(3), 900–911.
- Post, J. R. & Parkinson, E. A. (2001). Energy allocation strategy in young fish: Allometry and survival. *Ecology*, 82(4), 1040–1051.
- Potts, G. W. (1974). The colouration and its behavioural significance in the corkwing wrasse, *crenilabrus melops*. *Journal of the Marine Biological Association of the United Kingdom*, 54(4), 925–938.
- Quignard, J.-P. (1966). Recherches sur les Labridae (Poissons Téléostéens Perciformes) des

- côtes européennes: Systématique et Biologie [Research on Labridae (Pisces, Teleosts, Perciformes) from the European coasts: Systematic and Biology]. *Naturalia Monspeliensis*, 5, 1-248
- Robertson, D. R., & Hoffman, S. G. (1977). The Roles of Female Mate Choice and Predation in the Mating Systems of Some Tropical Labroid Fishes. *Zeitschrift Für Tierpsychologie*, 45(3), 298–320.
- Roff, D. (1983). An Allocation Model of Growth and Reproduction in Fish. *Canadian Journal of Fisheries and Aquatic Sciences*, 40(9), 1395-1404.
- Ross, R. M. (1984). Growth and sexual strategies in the fish *Thalassoma duperrey* (Labridae), a protogynous hermaphrodite. *Environmental Biology of Fishes*, 10(4), 253–259.
- RStudio Team (2016). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL <http://www.rstudio.com/>.
- Sayer, M. D. J., Cameron, K. S., & Wilkinson, G. (1994). Fish species found in the rocky sublittoral during winter months as revealed by the underwater application of the anaesthetic quinaldine. *Journal of Fish Biology*, 44(2), 351–353.
- Sayer, M. D. J., Gibson, R. N., & Atkinson, R. J. A. (1995). Growth, diet and condition of goldsinny on the west coast of Scotland. *Journal of Fish Biology*, 46(2), 317–340.
- Sayer, M. D. J., Gibson, R. N., & Atkinson, R. J. A. (1996). Growth, diet and condition of corkwing wrasse and rock cook on the west coast of Scotland. *Journal of Fish Biology*, 49(1), 76–94.
- Schludermann, E., Keckeis, H., & Nemeschkal, H. L. (2009). Effect of initial size on daily growth and survival in freshwater *Chondrostoma nasus* larvae: A field survey. *Journal of Fish Biology*, 74(4), 939–955.
- Schultz, E. T., & Warner, R. R. (1991). Phenotypic plasticity in life-history traits of female *Thalassoma bifasciatum* (Pisces: Labridae): 2. Correlation of fecundity and growth rate in comparative studies. *Environmental Biology of Fishes*, 30(3), 333–344.
- Skiftesvik, A. B., Durif, C. M. F., Bjelland, R. M., & Browman, H. I. (2015). Distribution and habitat preferences of five species of wrasse (family Labridae) in a Norwegian fjord. *ICES Journal of Marine Science*, 72(3), 890–899.
- Thangstad, T. (1999). *Spatial and temporal distribution of three wrasse species (Pisces : Labridae) in Masfjord, western Norway : habitat association and effects of environmental variables* (Masters' thesis). University of Bergen.
- Tonn, W. M., & Paszkowski, C. A. (1992). Piscivory and recruitment: mechanisms structuring prey populations in small lakes. *Ecology*, 73(3), 951–958.
- Treasurer, J. W. (1994). The distribution, age and growth of wrasse (Labridae) in inshore waters of west Scotland. *Journal of Fish Biology*, 44(5), 905–918.
- Trivers, R. L. (1972). Parental investment and sexual selection. In B. Campbell (Eds.), *Sexual Selection and the Descent of Man* (pp. 136–179). Chicago: Aldine Publishing Company.

- Uglem, I., & Rosenqvist, G. (2002). Nest building and mating in relation to male size in corkwing wrasse, *Symphodus melops*. *Environmental Biology of Fishes*, 63(1), 17–25.
- Uglem, I., Rosenqvist, G., & Wasslavik, H. S. (2000). Phenotypic variation between dimorphic males in corkwing wrasse. *Journal of Fish Biology*, 57(1), 1–14.
- Victor, B. C. (1986). Larval Settlement and Juvenile Mortality in a Recruitment-Limited Coral Reef Fish Population. *Ecological Monographs*, 56(2), 145–160.
- Warner, R. R. (1982). Mating Systems, Sex Change and Sexual Demography in the Rainbow Wrasse, *Thalassoma lucasanum*. *Copeia*, 1982(3), 653–661.
- Warner, R. R., & Schultz, E. T. (1992). Sexual Selection and Male Characteristics in the Bluehead Wrasse, *Thalassoma bifasciatum*: Mating Site Acquisition, Mating Site Defense, and Female Choice. *Evolution*, 46(5), 1421–1442.
- Wohlschlag, D. E. (1962). Antarctic Fish Growth and Metabolic Differences Related to Sex. *Ecology*, 43(4), 589–597.
- Wright, P. J., & Trippel, E. A. (2009). Fishery-induced demographic changes in the timing of spawning: Consequences for reproductive success. *Fish and Fisheries*, 10(3), 283–304.

Appendix A

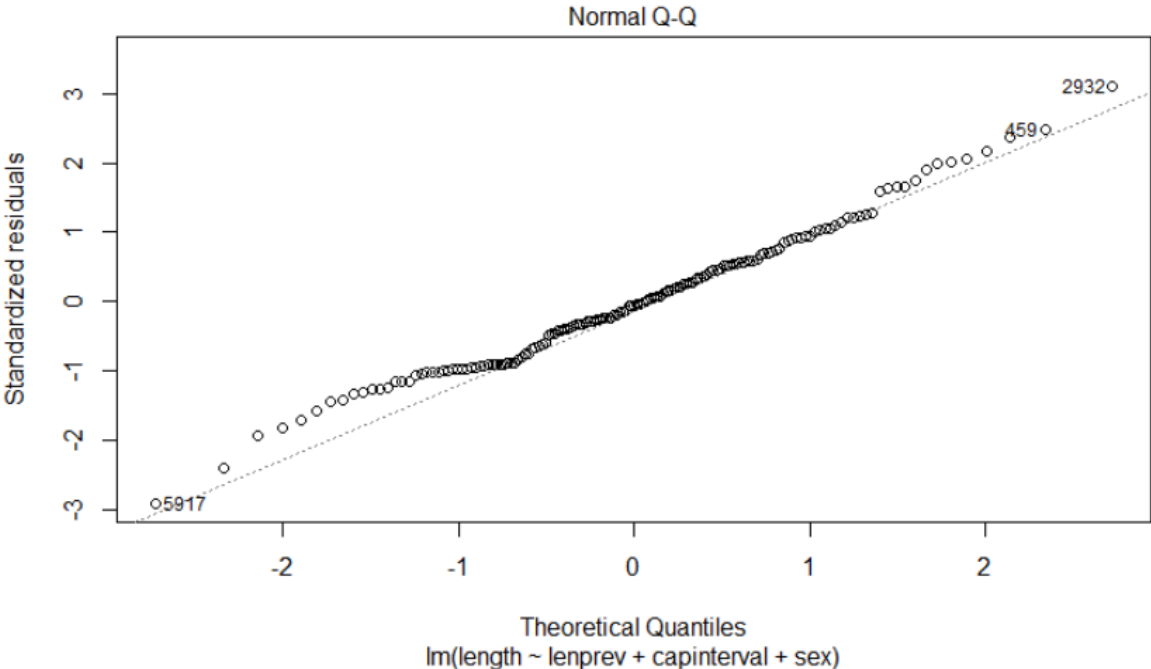


Figure A.1: Normal QQ-plot from the best primary model including sex as factor variable.

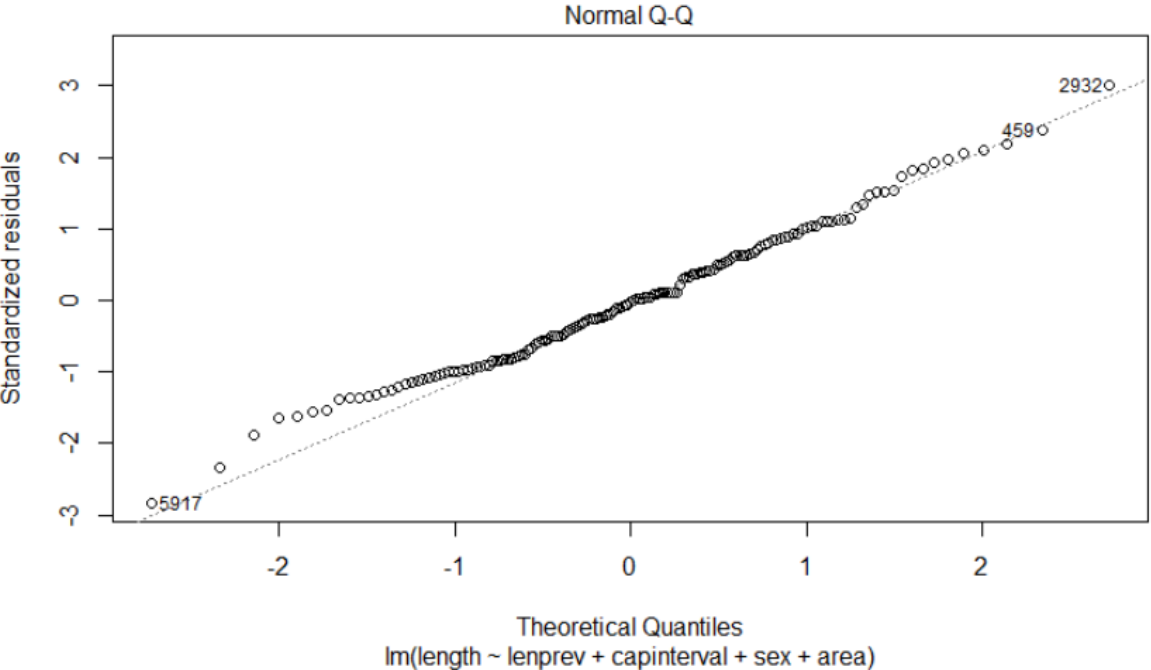


Figure A.2: Normal QQ-plot from the best secondary model including area as factor variable.

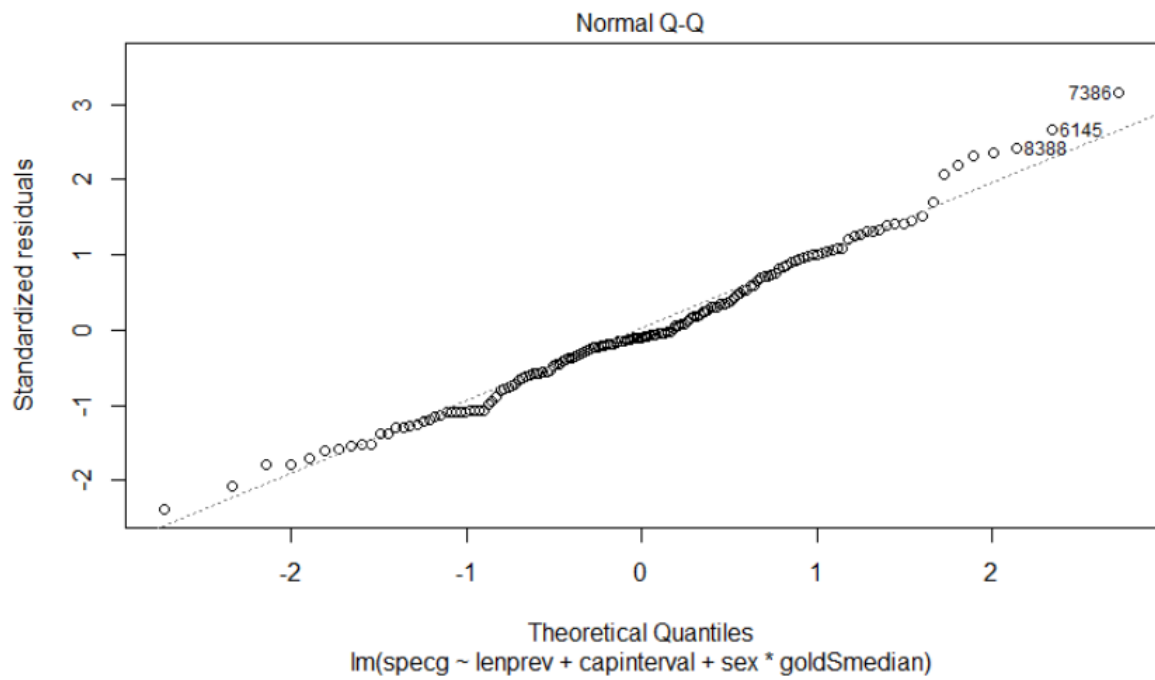


Figure A.3: Normal QQ-plot from the best final model including sex and goldsinny density as interacting variables.

Appendix B

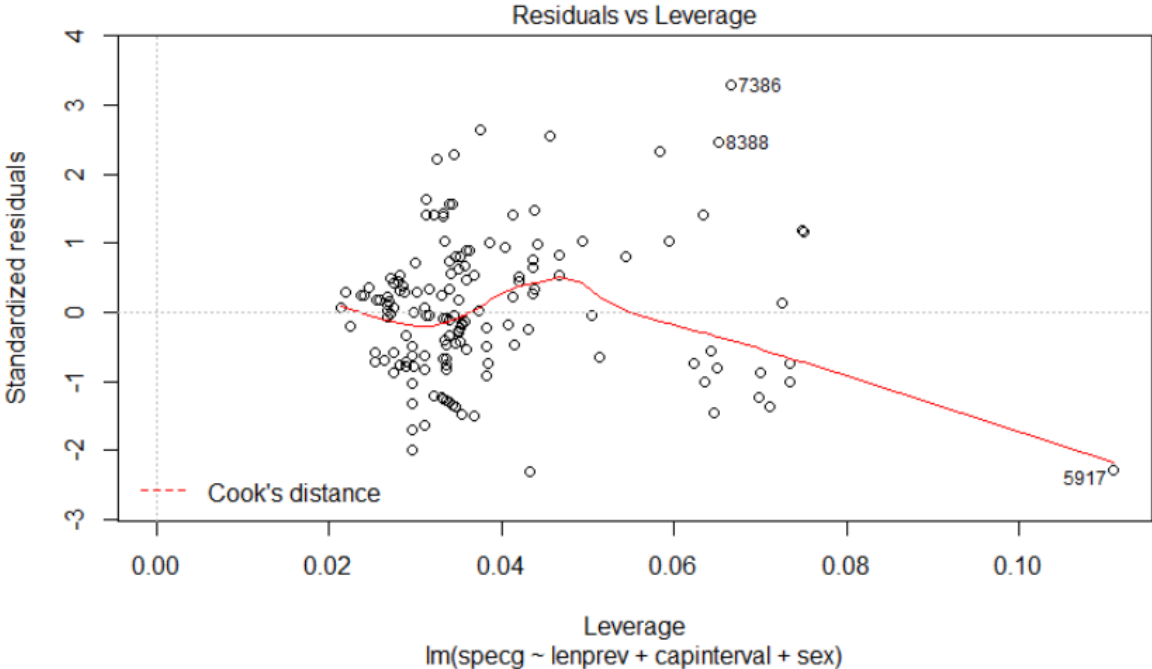


Figure B.1: Residuals VS Leverage-plot from the best primary model including sex as factor variable.

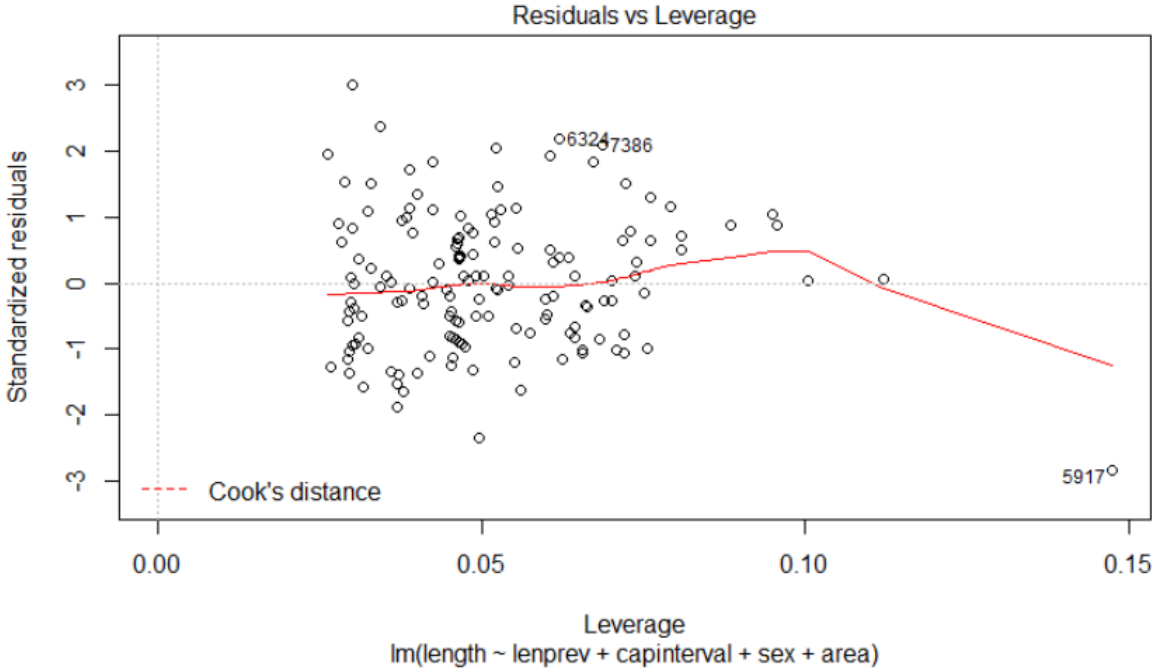


Figure B.2: Residuals VS Leverage-plot from the best secondary model including area as factor variable.

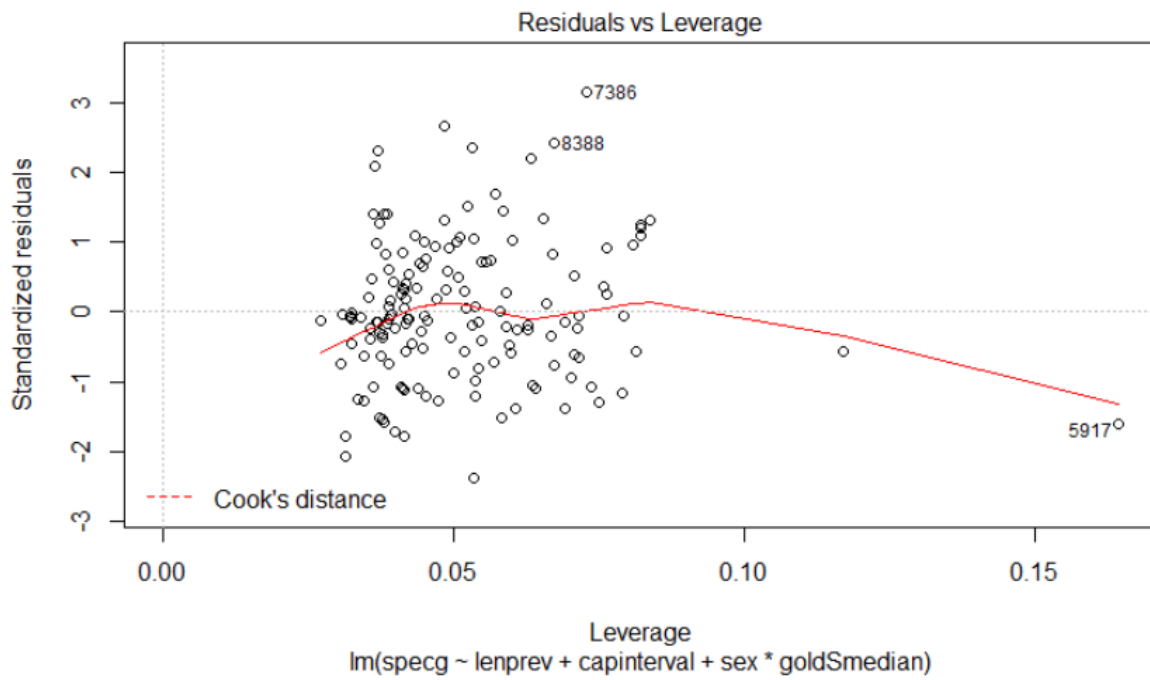


Figure B.3: Residuals VS Leverage-plot from the best final model including sex and goldsinny density as interacting variables.

Appendix C

Table C.1: Linear regression analysis showing the relationship between corkwing- and goldsinny density ($r=0.334$)

Coefficients:	Estimate	Std. Error	t-value	P-value
(Intercept)	7.825	0.627	12.481	<0.001
Corkwing density	0.220	0.055	3.971	<0.001

Appendix D

Table D.1: Best secondary model including factor variable “Area”. AIC-value= -1851.955.

Coefficients:	Estimate	Std. Error	t value	p value
(Intercept)	1.588e-03	2.584e-04	6.145	<0.001
Length1	-1.163e-05	1.748e-06	-6.655	<0.001
Season2_3	6.362e-04	1.249e-04	5.094	<0.001
Season3_4	1.381e-03	1.068e-04	12.926	<0.001
Season4_5	-5.650e-05	1.019e-04	-0.554	0.580
sexMale	3.396e-04	7.833e-05	4.336	<0.001
Lambøya	2.417e-05	1.211e-04	0.200	0.842
Saltskjærholmane	1.669e-04	1.126e-04	1.482	0.141