



Homing Ability of Goldsinny Wrasse (*Ctenolabrus rupestris*)

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SUPERVISORS

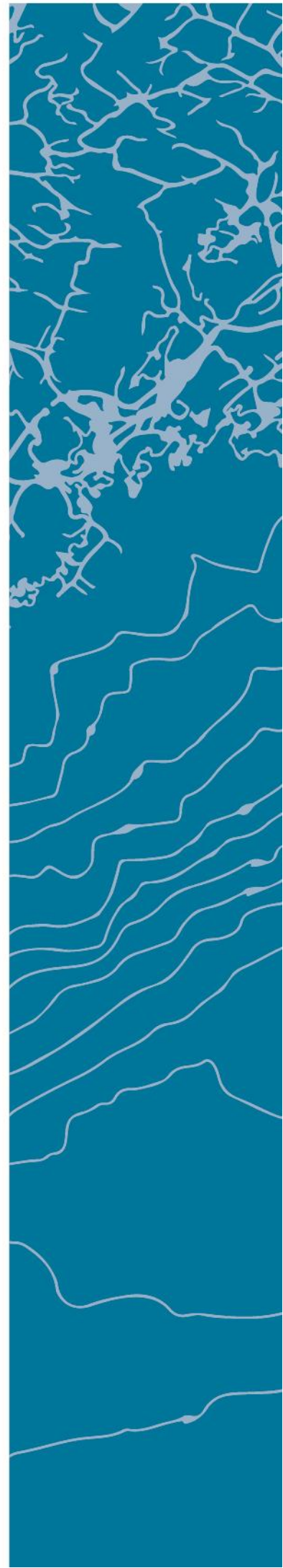
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Abstract

After the discovery of delousing abilities of temperate wrasses, several wrasse species are increasingly harvested in Norway and supplied to salmonid aquafarms to combat sea lice infestations. An increased harvesting intensity has raised concerns regarding the sustainability of this comparatively new fishery. Therefore, more research is needed about the targeted wrasses species. Goldsinny wrasses (*Ctenolabrus rupestris*) are known for having small home ranges and being highly territorial. Minimum size restrictions oblige fishermen to release goldsinnies smaller than 11 cm back to the sea, but this is often done far from the capture site. It is very important to know the fate of discarded fishes because fishing mortality might be higher than anticipated if those individuals cannot manage to survive. Animals derive benefits from being familiar with their environment. Therefore, homing is regarded to contribute to overall fitness of individuals. In this mark-recapture study, I examined the homing ability and site fidelity of goldsinny wrasses by experimentally translocating 104 PIT-tagged goldsinnies at 100m and 300m, while 53 individuals were released to the capture site as a control group. The impact of length, sex, and behavioral traits (catchability and mobility) on homing success of goldsinny wrasses were also tested. Logistic regression analysis revealed 92% of translocated goldsinny wrasses having homed from up to 300m. The translocation distances tested in this study did not affect the homing success of goldsinny wrasses. 54% of homed individuals were still found to be present at the capture area 30-62 days post-release. The control group's site fidelity (52%) was also similar to that of translocated ones (54%), suggesting that translocation did not affect the site fidelity of goldsinny wrasses. No evidence was found for the effect of length and sex on homing success. As for behavioral traits, mobility was found to have no significant effect on homing. Homing probability was found to be increasing with increased catchability values; however, this effect was only marginally significant. This study provides basic knowledge about the homing ability of short-distance translocated goldsinny wrasses in southern Norway and their site fidelity after having successfully homed. Further research is recommended to find the furthest distance from where goldsinny wrasses can successfully home. In this thesis, the fishes were translocated to a habitat with similar bottom topography and similar depth; translocating goldsinny wrasses to structurally different habitats than their capture sites would be an important topic for future investigations. Homing ability might be species specific, therefore similar research is needed to examine the homing ability of other harvested wrasses species in Norway (i.e., corkwing and ballan wrasses).

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*To my lovely mom, Yedigar Gül,
for your endless support and love... This thesis is dedicated to you!*

Preface

First and foremost, I would like to express my deepest gratitude to my supervisor at University of Agder, Lars Korslund, for his guidance, advice, encouragement, and support throughout the whole process. I appreciate your valuable feedback and I feel so privileged to learn from you.

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1. Introduction

Goldsinny wrasse (*Ctenolabrus rupestris*) is one of six wrasse (family: Labridae) species found in Norway (Espeland et al., 2010). The others are cuckoo wrasse (*Labrus mixtus*), corkwing wrasse (*Symphodus melops*), ballan wrasse (*Labrus bergylta*), rock cook (*Centrolabrus exoletus*) and scale-rayed wrasse (*Acantholabrus palloni*), the latter one being a quite rare species in Norwegian waters (Costello, 1991). All mentioned wrasses except cuckoo wrasse have been observed to have some ability to clean other fishes' ectoparasites and can therefore be used as cleaner fishes in salmon and trout farms (Kvenseth, 1996; Skiftesvik et al., 2014). Before the discovery of their natural cleaning ability, wrasses were mostly out of commercial interest, since they are not considered a delicacy and not used for fish meal production either (Darwall, Costello, Donnelly, & Lysaght, 1992). Today, however, wrasse fishery have become a very valuable fishery in Norway (Henriksen, 2014; Skiftesvik, Durif, Bjelland, & Browman, 2015). Since it is a comparatively newly established fishery, more research about the targeted wrasse species is needed to ensure its sustainability.

Wrasses are known for having small home ranges, being highly territorial (Hilldén, 1981) and forming social groups (Hilldén, 1983; Quignard, 1966). Stationary animals can thrive within a small area, because they, in that area, can access all their needs such as food, shelter, mating opportunities etc. (Caldwell & Vincent, 2012). Fishermen usually sort and discard the undersized individuals far away from the original capture sites (Hanssen, 2014). Little, however, is known about the reaction of wrasses to this disturbance. It is very important to study the fate of discarded, undersized wrasses, because fishing mortality might be higher than anticipated if those discarded wrasses are unable to survive (Blanco Gonzalez & de Boer, 2017). Regardless of the degree of similarity between releasing site and capture site, mortality in unfamiliar sites often increases due to the fact that fish lack crucial information about the new site such as location of shelters, mates, competitors, and predators (Piper, 2011). Therefore, homing ability is regarded as a crucial factor to be investigated as it contributes to overall fitness of individuals (Noda, Gushima, & Kakuda, 1994; Shapiro, 1986). However, maintaining site fidelity after homing is not always guaranteed and needs to be examined as well in order to develop a better understanding of the space use of fishes (Streit & Bellwood, 2017).

This thesis is focusing on the homing ability and site fidelity of experimentally translocated goldsinny wrasses. I also examine the effect of translocation distance and test intraspecific differences in homing behavior. Besides life history traits such as length and sex, the effects of some behavioral features on homing such as probability of being captured, hereafter referred to

as catchability, and the mobility level of fish in terms of movement between stations are tested as well because harvesting can be selective not only against life history traits but also against behavioral ones (Alós, Palmer, Rosselló, & Arlinghaus, 2016). Maintaining the behavioral diversity within a population supports sustaining a population's resilience to environmental and/or anthropogenic disturbances as different behavioral strategies will be favored in different conditions (Dingemanse & Réale, 2013). Any differences in homing ability caused by these traits -biological or behavioral- would exacerbate the impacts of selectivity in wrasse fishery.

1.1 The Norwegian Wrasse Fishery

Temperate wrasse's cleaning ability was first observed by Potts (1973) in a public aquarium in Plymouth. Later, Hilledén (1983) observed goldsinny removing the ectoparasites of other fishes in the field in Sweden. Bjordal (1988, 1991) tested this natural delousing ability of wrasses by deploying them into tanks of farmed salmon (*Salmo salar*) at the Institute of Marine Research in Bergen. The results of these trials were rising optimism that wrasse could be used in salmon aquaculture industry to control sea lice (*Lepeophtheirus salmonis* and *Caligus elongatus*) infestations (Bjordal, 1988; Darwall et al., 1992). Goldsinny was the first wrasse species used as a cleaner fish in salmon open net-pens (Gjøsaeter, 2002). Afterwards, corkwing wrasse, rock cook and juvenile ballan wrasse were also commercially harvested to be used in salmon aquafarms (Skiftesvik, Bjelland, Durif, Johansen, & Browman, 2013). Even though the wrasse fishery has been started in Norway back in 1988 (Darwall et al., 1992), concerns regarding its sustainability have been particularly raised in 2009, when sea lice became resistant to antibiotics used in salmon farms and the salmon industry was increasingly more focused on other methods to reduce the sea lice challenges (Besnier et al., 2014).

The wrasse fishery in Norway has not been regulated before 2011, when the Directorate of Fisheries set a minimum size requirement as of 11cm for all kinds of wrasses and established a fishing closure in spring aiming to protect wrasses during parts of their spawning period. However, those measurements might not have been adequate to protect the wrasse populations, mainly because they failed taking into consideration the different life history strategies of different wrasse species (Halvorsen, 2016). Obviously, the fishing closure was also supposed to be extended because it was still overlapping with the spawning period of wrasses (Skiftesvik et al., 2015). In 2015, the Directorate of Fisheries refined the measurements. The fishing closure was extended from late May to mid-July and minimum size limits were increased to 12 cm and 14 cm for corkwing and ballan wrasse, respectively, while remaining the same (11cm) for rock cook and goldsinny (Halvorsen et al., 2017). In 2017, the landings reached around 27 million

individual wrasses (**Appendix A, Figure A.1**), leading to the establishment of a fishing quota of 18 million wrasses (Norwegian Directorate of Fisheries, 2020). These 18 million landing caps were distributed between southern (4 million), western (10 million), and mid-Norway (4 million).

1.2 Homing Ability

Homing is defined as “the return of an animal to a place formerly occupied rather than to equally probable places” (Gerking, 1959). In fishes, this behavior is mostly associated with the diadromous species which migrates between their feeding habitats and the spawning grounds such as salmon and eel (Dittman & Quinn, 1996; Tsukamoto, 2006), yet homing has been also observed in relatively site attached species in a variety of habitats; in freshwater (Halvorsen & Stabell, 1990; Hert, 1992; Svenning & Grotnes, 1991), on coral reefs (Booth, 2016; Kaunda-Arara & Rose, 2004; Marnane, 2000; Streit & Bellwood, 2017) and on temperate rocky reefs (Green, 1971, 1973; Hartney, 1996; Hildén, 1984; Lowry & Suthers, 1998; Thompson, 1983; Thyssen, Triay-Portella, Santana del Pino, & Castro, 2014; White & Brown, 2013; Yoshiyama et al., 1992).

Site fidelity refers to “an animal’s ability to remain at its home site without being displaced” (Ivanova et., 2019). However, translocated individuals may not continue showing site fidelity after successful homing (Streit & Bellwood, 2018) for several reasons, including reoccupation of left sites by conspecifics since those sites often offer valuable resources (Hert, 1992; Ivanova et al., 2019) or the occupation of better alternative places that translocated individuals find along the way back to their homes (Streit & Bellwood, 2018). High site fidelity is not the only driver in successful homing; a species’ degree of sociality or being a generalist or specialist in terms of habitat preference can also play important roles (Gardiner, N.M., and Jones, 2016).

Most of the studies on homing behavior of reef fishes have focused on the capacity of fish to return to their home sites from various distances. In general, homing success appears to be decreasing with increased translocation distances (Marnane, 2000; Streit & Bellwood, 2017; Thompson, 1983; Thyssen et al., 2014). Size and sex of the fish are also among the examined traits in several homing studies. The results show variability from species to species, even within the same family. For instance, Booth (2016), demonstrated that larger individuals of lemon damselfishes, *Pomacentrus moluccensis* (Family: Pomacentridae), were better at homing than smaller ones. However, the same study revealed no size effect for the humbug damselfish, *Dascyllus aruanus* (Family: Pomacentridae). Shima et al. (2012) studied variation in homing ability of three distinct ontogenetic stages of the common triplefin, *Forsterygion lapillum*

(Family: Tripterygiidae), and found adults to be able to home within 200m (success rate: 64%), while juveniles could do so only from 50m (success rate: 20%). Settlers of the species did not show any homing behavior at all.

Many fish species are able to use different types of cues to home (for example visual, olfactory, polarized sun or lunar stage) (Papi, 1992). For instance, coral patches play an important role as landmarks in butterfly fish's homing (Reese, 1989). On the other hand, when displaced at an unfamiliar area, rockfish (*Sebastes cheni*) exhibited search movements to find their homeward direction, suggesting that *S. cheni* use the olfactory cues to home from an unfamiliar area (Mitamura et al., 2012). However, *S. cheni* exhibited a linear and faster movement in the final stage of their homing, indicating that they can use visual landmarks as well once they arrive in a familiar area (Mitamura et al., 2012).

Little is known about the homing behavior of wrasses in the Northeast Atlantic. Hildén (1984) translocated 10 goldsinny wrasses individually up to 200m in Sweden. He reported 50% of goldsinnies were able to home at least from 70m, one homing from 150m distance from its capture site. Since only one goldsinny was released at each translocation distance, it is difficult to evaluate if homing failure from the furthest point (200m) was a general pattern or attributed to only that individual. The small sample size in Hildén's study underlines the need to repeat similar experiments with higher sample sizes and to ensure evenness in the groups in order to draw more reliable conclusions about the homing behavior of goldsinny wrasses.

1.3 Study Objectives

The primary objective of this thesis is to examine if goldsinny wrasses would home successfully when being translocated at various distances from the capture site. A secondary objective is to identify any effect of length, sex, catchability, and mobility on homing success of goldsinny wrasses. A third objective is to examine the site fidelity of goldsinny wrasses after successful homing. The goldsinny wrasse was chosen as a sample species because it is, together with the corkwing, the most harvested of wrasse species in Norway (Faust, Halvorsen, Andersen, Knutsen, & André, 2018). In addition, goldsinny abundance was much higher than corkwing abundance in our sampling area, which enabled us to do experimental translocations with sufficiently high numbers of individuals.

2. Materials and Methods

2.1 Study Species

Goldsinny (*Ctenolabrus rupestris* Linnaeus, 1758) are common in shallow coastal waters of the Northeast Atlantic from Morocco to Norway. Their distribution stretches also into the Mediterranean, the English Channel, North Sea and Baltic Sea (Sayer, 1999). Recent surveys also recorded goldsinny presence as far north as 69,5°N (Rueness et al., 2019; **Figure 1**).



Figure 1. Distribution of Goldsinny (*C. rupestris*) Source: Rueness et al., 2019.

Goldsinny wrasse is the smallest wrasse species found in Norway, usually attaining 10-12cm in total length (Quignard & Pras, 1986; Sayer & Treasurer, 1996). However, it can reach up to 18cm (Darwall et al., 1992; Skiftesvik et al., 2015). The longevity can be as long as 20 years for females, while males can live up to 14 years (Sayer & Treasurer, 1996). Maturation occurs at the age of about 1-2 years (Costello, 1991; Darwall et al., 1992). Sex is often visually distinguishable in goldsinnies. Female goldsinnies have rib shaped patterns, while males may have orange horizontal stripes on the lower part of their abdomen (Hilldén, 1981; **Figure 2**), although this orange coloration of males has not been recorded in the Mediterranean (Quignard, 1966).



Figure 2. (a) A female goldsinny with white rib shaped pattern on the abdomen (b) a male goldsinny with orange coloration. Photo: Özge Işın Starbatty.

Some goldsinny males adopt a different reproduction strategy trying to sneak into the dominant males' territory and join the fertilization there (Costello, 1991). Those are called “sneaker males” and they are visually indistinguishable from female goldsinnies (pers. communication Torkel Larssen, pers. observation). However, during the spawning season, sneaker males can be distinguished from females if they release milt. Spawning takes place from mid-May to late July (Matland, 2015). By July, the number of spawners decrease, but for a few individuals it can continue until late summer (Skiftesvik, 2015). Goldsinnies are batch spawners and unlike other temperate wrasses, they do not build nests for their eggs (Hilldén, 1981) due to having pelagic eggs (Costello, 1991; Darwall et al., 1992). Rocky shores with macroalgal cover are typical habitats for goldsinnies (Gjøsaeter, 2002). Habitats with many hiding spots provide them secure shelters and goldsinnies are limited by the availability of areas of refuge (Costello, 1991; Sayer, Gibson, & Atkinson, 1993). They have a very small home range and show high site fidelity (Hilldén, 1981). Males can defend territories up to a size of 2m² (Hilldén, 1981).

Goldsinny prey mainly on molluscs and crustaceans (Deady & Fives, 1995; Sayer & Treasurer, 1996) and hold an intermediate position in the food web. Being an important prey for coastal cod and marine birds, depletion of goldsinny populations may cause a trophic cascade (Olsen, Halvorsen, Larsen, & Kuparinen, 2018).

2.2 Study Location and Sampling Gears

The study was carried out on in Flødevigen, on the Hisøya island, southern Norway (58°25.56'N, 8°45.30'E) (**Figure 3**). The place of study is located within a marine protected area (MPA) which has been established in 2006 to protect the European lobster (*Homarus gammarus*) (Olsen et al., 2018). Inside the MPA (1.1km²), all passive gears such as fyke nets and pots are banned to be used, only hook and line fishing is allowed (Sørdalen, Halvorsen, Vøllestad, Moland, & Olsen, 2020). Since wrasses are harvested by fyke nets and pots, the gear restrictions set for European lobsters protect wrasses as well within the MPA boundaries.

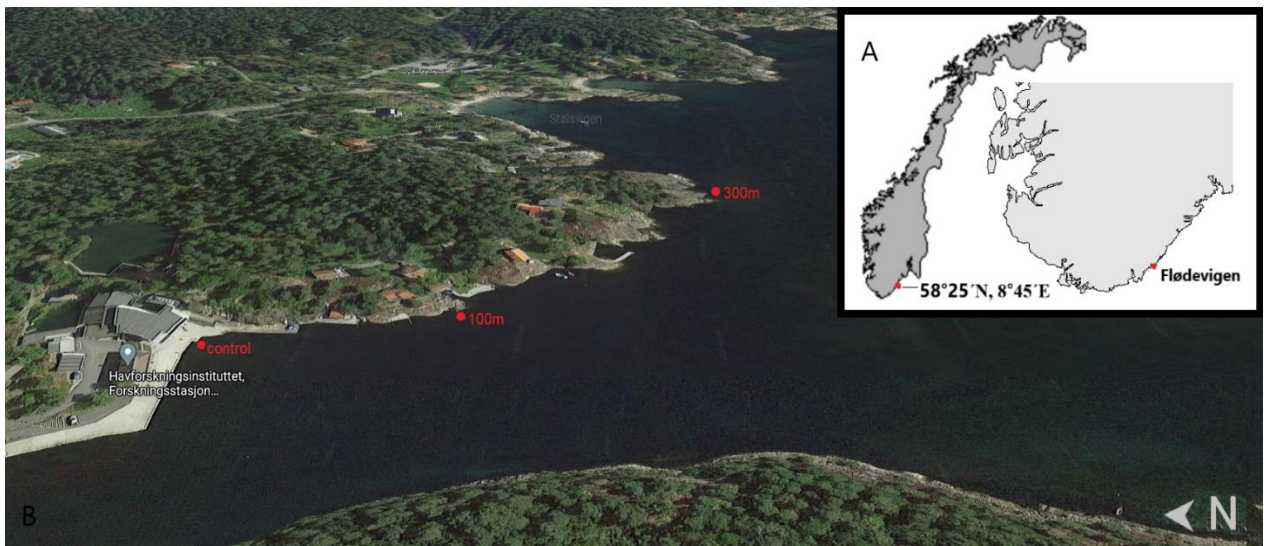


Figure 3. A.) Maps showing the study location in southern Norway, created in R using the *mapdata* package (Becker & Wilks, 2018). B.) Detailed satellite view of the study area, retrieved from Google Earth Pro on 11.12.2020.

Wrasses were sampled using pots baited with 3-4 frozen shrimps (*Pandalus borealis*). Pots were rectangular prism (80×40×28 cm) having 2 circular 75mm diameter entrances and 11mm mesh size (**Figure 4**). 6 pots were placed on each sampling day in sampling sessions 1,2,3, and 5 along the dock of the Institute of Marine Research in Flødevigen. In sampling session 4, 28 pots in total were set and hauled every day. Detailed explanation about the sampling sessions is provided in the next section.

The wrasses were sampled always at the same 6 stations along the dock. The distance between these 6 stations varied between 4 to 5m. The pots were set in the afternoon, shallower than 7m of depth on rocky substratum covered with macroalgae and hauled next morning, resulting in soak times between 14 and 20 hours.



Figure 4. A hauled baited pot used in the study. Photo: Özge Işın Starbatty.

2.3 Data Collection

2.3.1 Sampling Sessions

Goldsinny wrasses were sampled in five sampling sessions in 2019 (**Table 1**). The first session of the study started in late April and lasted 11 days. In this session, the fish were identified on species level and their length was measured to the nearest mm (**Figure 5.b**). Sex of wrasses was determined by visual inspection and gently stroking the abdomen of the fish to check if milt or eggs were extruded from the urogenital opening. Since that period coincided with the spawning of wrasses, we were also able to note the reproductive status of the fish.

Table 1: Overview of sampling periods. *Some antennas were active from the first day of translocation (23rd August). The details about their location and duration of their active time are presented in the following paragraphs.

Period	Date	Duration	Activity	Gear
1	April 30 th - May 11 th	7 days	Tagging Recapturing	Pots
2	May 15 th -July 9 th	9 days	Recapturing	Pots
3	August 19 th -23 rd	5 days	Recapturing to translocate	Pots
4	August 27 th - 30 th	4 days	Recapturing to detect successfully homed fishes	Pots & Antennas*
5	September 24 th - October 22 nd	4 days	Recapturing to detect late returners	Pots

Wrasses were checked by a PIT (Passive Integrated Transponder) reader to see whether they have been PIT-tagged before. A PIT-tag is a small, glass encapsulated electronic microchip which does not require a battery (**Figure 5.c**). It is energized by an electromagnetic field generated by a reader.

The PIT-tag is inserted into the body cavity or a muscle tissue of an animal and used widely as a well-proven method for monitoring individual fish movements and habitat use (Bolland, Cowx, & Lucas, 2009; Gibbons & Andrews, 2004). If the fish has been tagged with a PIT-tag before, a unique number appears on the screen of the PIT-reader. This number can be thought of as an ID number (Gibbons & Andrews, 2004) and helped us to identify individuals.



Figure 5. A PIT-tag injector (a), a goldsinny measured with an edged measuring device (b), half duplex PIT-tags and a PIT-tag reader (c). Photo: Özge Işın Starbatty.

Wrasses who were bigger than 100mm and were not tagged before were anaesthetized by immersion in an 8-10l sea water solution of 50-100mg l⁻¹ tricaine methanesulfonate (MS-222) for 2-3 minutes until the loss of equilibrium in order to prevent pain during PIT-tagging. A PIT-tag (half duplex, 12.0mm× 2.12mm, SMARTRAC RFID) was injected into the cavity of the fish using a PIT-tag injector (**Figure 5.a**). Post tagging, we monitored the goldsinnies in a bucket full of sea water until it reestablished equilibrium to ensure there were no signs of distress. After recovery, all the fish were released at the capture site.

In the second session (May 15th -July 9th), we monitored the recaptures, with pots active once a week. No tagging was done during this period. Previously tagged fishes were detected by a PIT-tag reader and the species, sex, reproductive status, as well as the length of the fish were noted.

In the third session (19th-23rd of August), we recaptured the fish and collected the tagged ones to translocate. Individuals without tag were released back to the capture site. Over the course of five days, 157 goldsinny and three corkwing wrasses were recaptured. Because of the few numbers of corkwing, the translocation experiment was done only with goldsinny wrasses. Goldsinnies were divided into three groups: a control group (N=53), a group to be released 100m away (N=52) and a group to be released 300m away from the capture site (N=52). The fish were assigned to either of these three groups randomly. Translocation took place on August 23rd at 15:30. The fishes in the control group were monitored for presence and absence instead of being tested for their homing ability.

In the fourth session (27th -30th of August), the homing success of fish was monitored by PIT-tag antennas (**Figure 6**) located in the water along the pier and captures in baited pots. Four antennas were deployed at the pier between 23rd and 30th of August. To cover all the six stations, we had to change the place of two antennas from station 1 and 2 to station 6 and 5, respectively (August 26th) (**Table 2**). The other two antennas remained at the same place and detected the fishes that visited station 3 and station 4. However, we recognized that the antenna at station 4 did not function properly. The problem was fixed, and it recorded the PIT-tags from 26th of August until 30th of August.

Table 2. Duration of antennas detection at 6 stations

Station	Start Time	Stop Time
1	August 23 rd 18:00	August 28 th 10:40
2	August 23 rd 18:00	August 28 th 10:44
3	August 23 rd 18:00	August 30 th 16:00
4	August 26 th 10:30	August 30 th 16:00
5	August 28 th 10:49	August 30 th 16:00
6	August 28 th 10:55	August 30 th 16:00



***Figure 6.** The circular antennas used in the study were deployed under water, lowered to the bottom, and tied to the pier with a rope. Each antenna covered specific stations at a particular time and detected the tagged fish passing over it. Photo: Özge Işın Starbatty.*

The antennas were used as a supplement to ordinary recapturing, aiming to determine the homing success as recapture probability seems to be highly variable between individuals (Kim Halvorsen pers. comm.). This way, we were able to detect successfully homed fishes even if some of them were not attracted to the bait in the pots or avoided entering the pots for other reasons.

In the fourth session, we defined 7 different regions for recapture in the study area and deployed baited pots at these areas (**Figure 7**). Those seven regions were named as follows: A, pier, B, C, D, E and F. At the pier, 6 pots were set at the same stations as usual. Region A was also located at the pier, but in an area where we had not set pots before. Two pots were set in Region A in order to see if those fish capable of homing, arrived in their capture stations or somewhere around. Region B was located on the other side of station 6. In this region, we set 2 pots. Fishes which were recaptured at region A and B were also considered among the successfully homed ones.



Figure 7. The map of the study location showing the stations where pots were set in Session 4. Red circles represent the release points (control, 100m, 300m) and 6 pots were set at each of these release points. Blue dots show the pots set in region A, B, D and F. The map was retrieved from (<https://kart.fiskeridir.no/fiskeri>), stations where pots were set and hauled were marked using the map engine Yggdrasil.

Region C is 100m far away from the pier and 6 pots were set here. Region D was between the two release points (100m-300m) and monitored by 4 pots. Region E is another release point and 300m far from the pier. This region was examined with 6 pots. Region F was located further out than the furthest release point. We set 2 pots here in order to see if any fish swam toward other directions than their home direction. In the 4th session, a daily total of 28 pots was set.

In sampling session 3 and 4, due to time constraints (e.g., dealing with more pots or having more captures in the pots), the wrasses were categorized either as big ($\geq 100\text{mm}$) or small ($<100\text{mm}$), instead of being measured exactly unless the fish had PIT-tag.

In session 5 (September 24th – October 22nd), a last recapture was carried out at the same six stations at the pier to monitor the site fidelity of both homed translocated individuals and the control group. Furthermore, this last session provided the opportunity to potentially detect any

late returners that were not captured during session 4. Only baited pots were used during this phase of the study.

2.3.2 Biological Data

Length and sex were the two biological covariates used in the analysis. Length was measured on each sampling day. Although goldsinny grows slowly (Skiftesvik, 2020), measured lengths showed some small variations from one sampling day to another in some individuals. We assumed those variations might happen due to the different precision level of people who measured the fish. In case of two or more measurements for the length of a single individual among all sessions, the median length was calculated. This way, outliers were eliminated as well. The median of length was used in the analysis.

Sneaker males were not tagged in the study due to their small size. Therefore, the sex covariate used in the analysis included only two categories: dominant male and female.

2.3.3 Behavioral Data

From the beginning of the study until the translocation week, we carried out many capturing efforts (total 16 days). This period allowed us to collect valuable data on movement and catchability of the fish. In the following, I account for each of the behavioral variables collected in the study.

2.3.3.1 Catchability

Several studies have shown that bolder individuals are caught more often than their more cautious conspecifics, and hence show higher catchability (Biro & Post, 2008; Biro & Sampson, 2015; Carter, Heinsohn, Goldizen, & Biro, 2012; Uusi-Heikkilä, Wolter, Klefoth, & Arlinghaus, 2008). In this thesis, individual catchability is considered to be a proxy of being bold.

Individual catchability of a fish was calculated by dividing the number of times that the given fish was caught prior to the translocation week by the total number of capturing efforts (n=16).

2.3.3.2 Pot Diversity

Pot diversity shows the presence of an individual fish in the different pots located at six different stations at the pier. Inspired by how to calculate species diversity, this is calculated using the formula for Simpson's Index (Simpson, 1949). Instead of different species found in a population, different pots that an individual fish visited were used in the formula:

$$D = \frac{\sum n(n-1)}{N(N-1)}$$

Where n is the number of captures of a particular individual at a given station and N is the total number of captures of that individual including all stations. In this index, a bigger D value represents a lower diversity, which does not seem logical. To overcome this problem, D is subtracted from 1. " $1 - D$ " is called Simpson's Index of Diversity, and now the greater the value, the greater the sample diversity. In this study, this index ($1 - D$) represents the probability for two randomly selected pots visited by one individual fish to be located at different stations. The value " $1 - D$ " ranges between 0 and 1, and while 0 implies that a fish was caught always at the same station, 1 implies that a fish was caught at different stations each time.

To be able to calculate pot diversity, a fish must be caught at least twice, otherwise the denominator would be "0" and this gives us NA values. The diversity index describes to what extent an individual is captured at different stations but does not take into account the distance between the stations in which the individual has been captured. An example showing how pot diversity was calculated is given in Appendix B.

2.3.3.3 Mobility Index (MI)

Mobility index (MI) shows the average movement of the fishes between stations during all sessions prior to translocation. Each distance between adjacent stations (i.e., 4-5 meters) represents 1 unit of movement. MI is calculated by:

$$MI = \frac{(j_{1,2} + j_{2,3} + \dots + j_{n-1,n})}{n - 1}$$

Where n represents the number of captures of a given individual and $j_{n-1,n}$ represents the distance in units of movement between the two capture occasions $n-1$ and n . For a detailed visual example see the **Figure C.1** in Appendix C.

MI has a range between 0-5 in this study. For any fish that was caught only once, we could not calculate a MI value, as we did not get any information regarding its movement. In this case it was coded as NA and resulted in a reduction of our sampling size where we used MI as a covariate in the analysis.

2.4 Data Analysis

Homing behavior of individual goldsinny wrasses was tested using a logistic regression model applying a glm function with a binomial distribution and logit link. Having homed (1) or not (0) was considered the response variable. To detect a fish's presence at the pier, data from antennas and baited pots were combined. While testing the potential effect of individual behavioral characteristics (Catchability, diversity, mobility), the data was based only on detections from the antennas as attraction of fish to the baits inside the pots might be associated with those behavioral traits. On the other hand, detections through antennas and fish presence in the pots were pooled and then used together as a response variable to test the effect of biological covariates (length, sex) on homing ability of goldsinny wrasses. There was one NA value in the sex variable due to disagreement between observers, thus the sample size was reduced to 156 individuals while testing the models which include sex as a covariate. The three behavioral covariates in the data were catchability, mobility index and pot diversity. Due to the high correlation between mobility index and pot diversity (**Appendix D, Figure D.1**), only one of them was used in the analyses, in this case mobility index. Using mobility index in the analysis reduced the sample size from 157 to 139 due to the NA values. However, pots diversity had the same amount of NA values, so using either mobility index or pots diversity would not have changed the test results.

Model selection was performed using Akaike Information Criterion (AIC) (Akaike, 1973). The model with the lowest AIC score was considered the best unless the difference in AIC scores (ΔAIC) between two models was less than two; in this case the most parsimonious model, i.e. the one requiring fewest parameters, was preferred to be used in statistical inferences (Burnham & Anderson, 2004).

Statistical analyses were performed using the R software version 3.6.3 (R Core Team, 2020) and Rstudio (version 1.2.5033). The ggplot2-package (Wickham, 2016) was used to create all the graphics. To show the correlation between covariates, the corrplot package (Wei & Simko, 2017) was used.

3. Results

3.1 Overview

Throughout the project, all caught animals were identified, measured, and counted, regardless of their species. The landings included 20 different species (**Appendix E, Table E.1**). 95.6 % of the landing caps were wrasses (**Figure 8.a**). Among the wrasses, the most caught ones were goldsinnies with 86.3%, followed by corkwing wrasse with 12.7%, while ballan, rock cook and cuckoo wrasse accumulated for the remaining 1% (**Figure 8.b**).

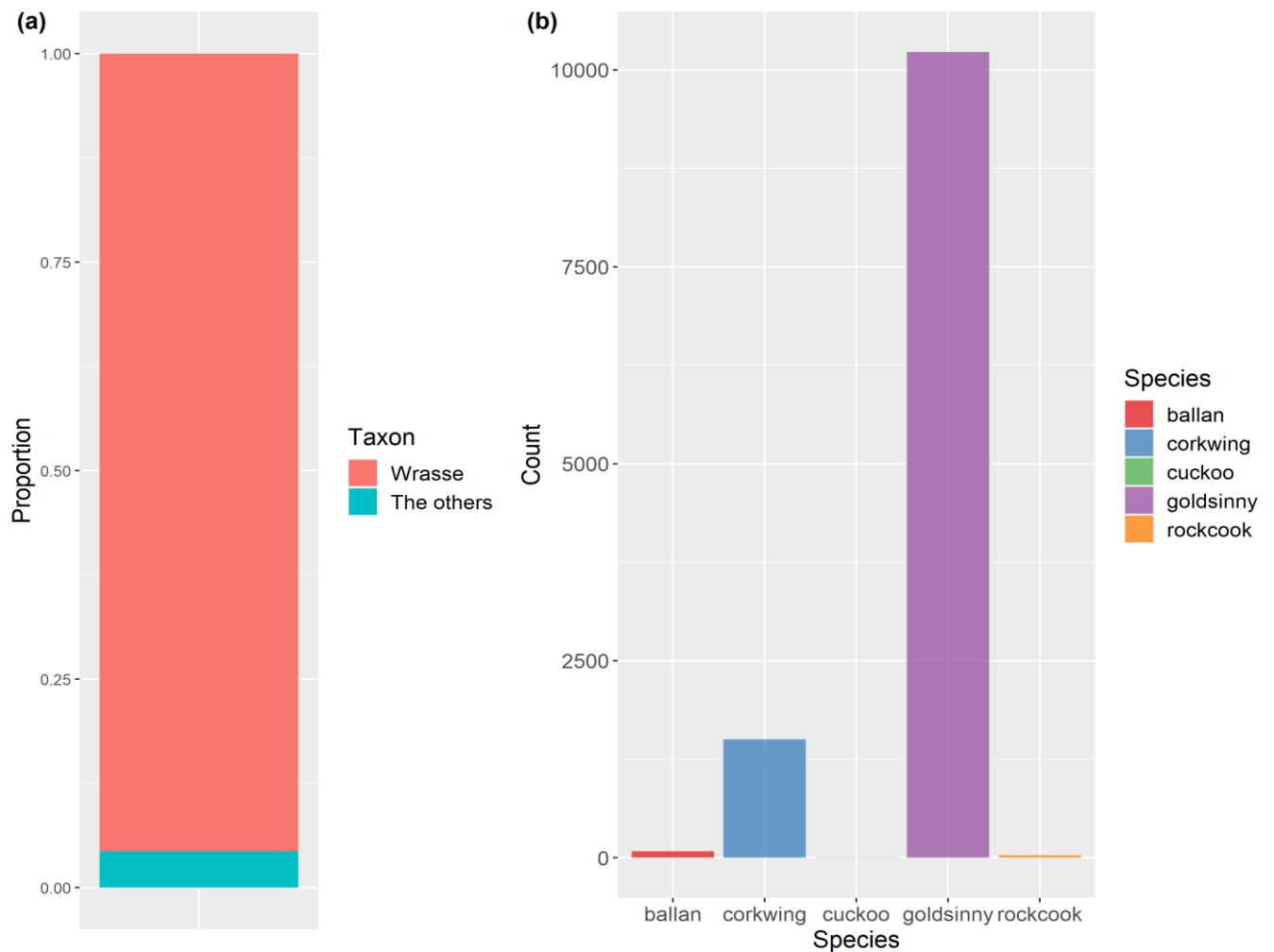


Figure 8. a) The proportion of wrasses to all species caught throughout the study. Composition of the other species caught in the study is provided in **Appendix E. b.)** Abundance of wrasse species in the study.

The total number of goldsinny wrasses caught during the study was 10225. Exact length measurements of wrasses are coming from session 1,2 and 5 or 3 and 4 if they had PIT-tags and include 4099 individuals. The length distribution of sexed and measured goldsinnies showed that males had a slightly higher average size than females. Sneakers were few and among the smallest individuals captured (**Figure 9**). 98.4% of the sneaker goldsinnies were under the official minimum size limit of 110mm, compared to 89% and 78.5% for male and female goldsinnies, respectively. (**Table 3**).

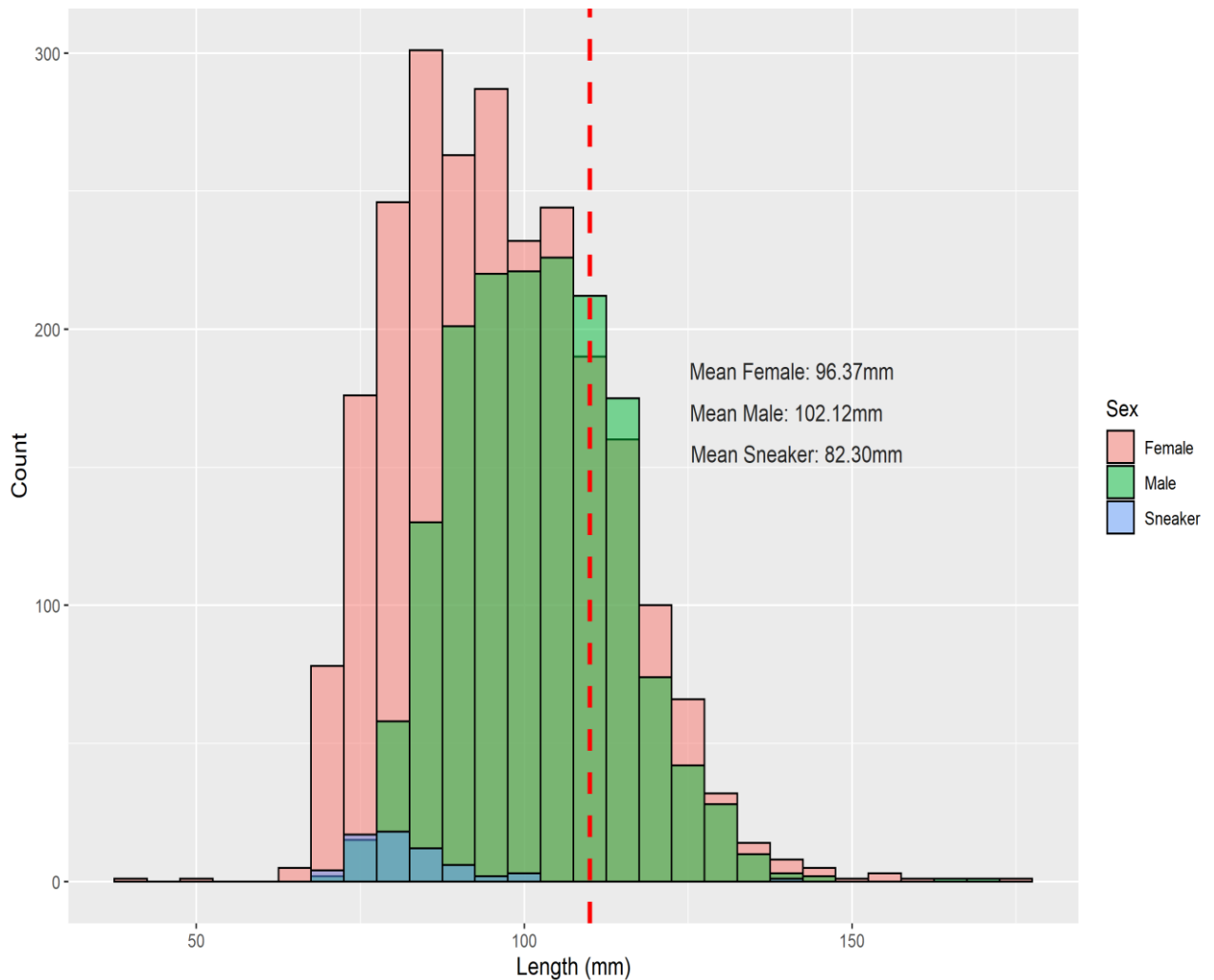


Figure 9. Length distribution of 4099 captures of sneaker male, male and female goldsinny wrasses, with their mean values. Note that some individuals could be captured more than once. The vertical red line shows the official minimum length for goldsinny (110mm).

Table 3. Number of sexed and measured goldsinnies

Size Class (mm)	Female	Male	Sneaker
<110	1896	1444	62
≥110	519	477	1
Total	2415	1621	63

In 2019, 241 new goldsinny wrasses were tagged. Together with recaptures of some of the goldsinnies that had already been tagged in the previous years, a total of 310 tagged goldsinnies was recorded present at least once from the beginning of the first sample period until the translocation day. In the 3rd sampling session, 157 tagged goldsinnies were recaptured to be translocated. 53 of them were released at the pier as a control group, 52 of them were released 100m away from the original capture site and 52 of them were released 300m away from their capture site. The mean length of each sex in each of the groups was similar, however both sexes in the 300m group were slightly bigger (**Table 4**).

Table 4. Number of individuals of each sex in the translocation groups. Mean length and standard deviation (SD) were provided separately for each sex for every group and given in mm. In the control group, sex of one individual was coded as NA, due to disagreement between observers.

Groups	Mean length ± SD (males)	Mean length ± SD (females)	Count (males)	Count (females)	Sex (NA)
Control	111.6 ± 9.2	111.9 ± 8.36	27	25	1
100m	111.2 ± 6.80	111.7 ± 5.32	26	26	0
300m	114.1 ± 9.06	112.3 ± 9.71	25	27	0

Among the 157 focal goldsinny wrasses, 139 individuals were recaptured at least twice prior to the translocation day, enabling the calculation of a mobility index (MI) value. 39% of these individuals had a MI value of “0”, implying that they were always recaptured at the same stations, and only 8% had a MI value of greater than 2.

Data obtained from the first two sampling sessions (recapturing effort =16 days) revealed that catchability of individual goldsinny wrasses varies between 0 and 0.63 (mean ± SD = 0.18 ± 0.15). One individual having been tagged in the previous year was not recaptured in 2019 prior

to the third sampling session, and 38 individuals were recaptured only once during the course of sampling session 1 and 2. 10 individuals (5.4% of the sample size) exhibited a catchability value of 0.50 or more.

Throughout a week after the release, 47 individuals in the control group were recaptured at the pier or at the region A and B at least once (1 fish was detected in the last sampling session, therefore in total 48 individuals were recaptured from the control group). 32-60 days post-release (after 4 recapture days), 25 of the resighted goldsinny wrasses were still found at the pier (site fidelity: 52%).

Out of the experimentally translocated goldsinny wrasses (n=104), 96 individuals (5 of them being detected as late returners) were recaptured either at the pier or at the region A and B at least once and therefore considered successfully homed (homing success: 92.3%) (**Figure 10**). 52 of the successfully homed fishes were resighted at the pier even 32-60 days post-release (site fidelity: 54%).

Recording by antennas helped us to detect the presence of 32 goldsinny wrasses at the pier that we were not able to recapture by pots. Antennas also recorded the arrival time of fish and the fastest fish homed within 4 hours from 100m distance. 27 individuals (15 from 100m, 12 from 300m) returned to their home within a day (26%). The rate of fishes which homed successfully within a day is most probably higher than found here because during the first three days, only three antennas were active (at stations 1, 2 and 3). Goldsinny wrasses which eventually returned to stations 4,5 or 6 could therefore not be detected earlier. After translocation, no fish from the region C (100m) and E (300m) was detected to swim towards the direction opposite to their initial capture site. However, one individual which was translocated at 300m was detected to return to its translocation site 2 days after having successfully homed. As for the control group, one fish swam from the pier towards region C (100m), but then swam back to the pier, another one swam to region D (approximately 150m) and returned to the pier afterwards as well.

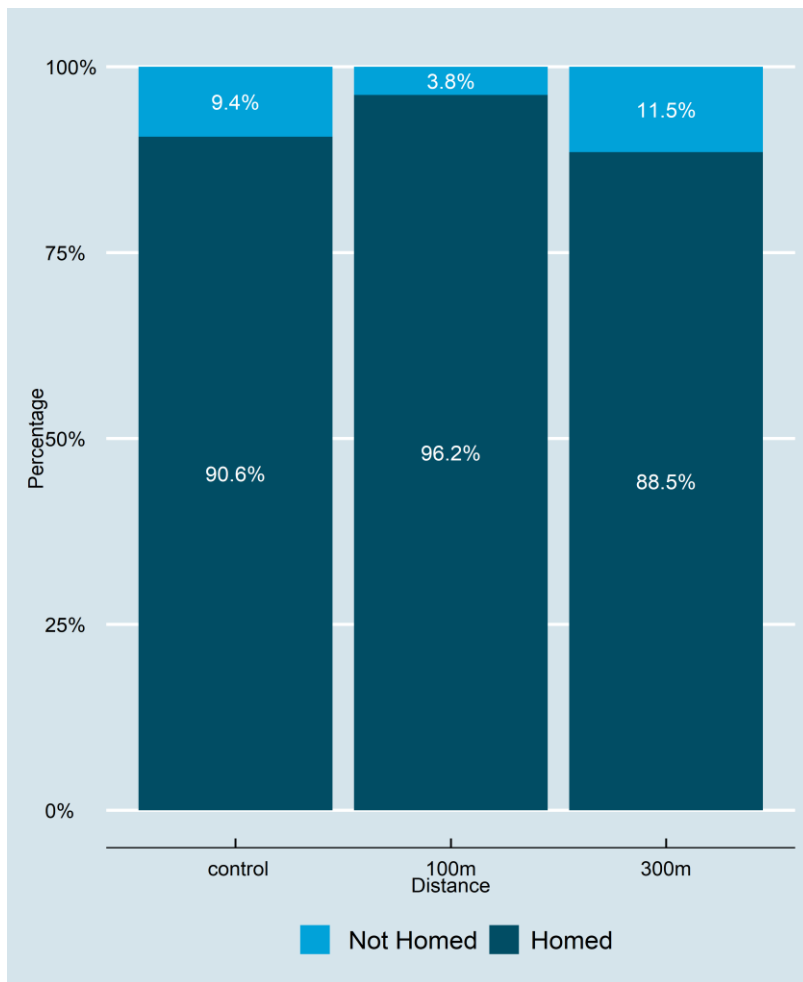


Figure 10. Percentage of recaptured goldsinnies at the pier (region A and B included) either after being translocated or released at the pier as a control group. In the control group, 48 out of 53 individuals were resighted at the pier (region A and B included). 50 out of 52 individuals from 100m group homed successfully and 46 individuals out of 52 homed from the furthest translocation distance, 300 m.

3.2 Model Selection Including Biological Covariates

The starting model consisted of an additive effect of sex, length, and translocation distance (TD) and interaction effect between sex and length. This model was then compared with 15 reduced candidate models comprised of all possible covariates' combinations, including the null model (**Table 5**). The model with the lowest AIC score had sex and length as additive effects (model 5). However, there were three more models (including the null model) within 2 AIC units that had fewer estimated parameters (models 7, 8 and 16). Model 7, having only length as the explanatory variable ($\Delta\text{AIC} = 0.12$), and model 8, having only sex as the explanatory variable ($\Delta\text{AIC} = 0.09$) were chosen for statistical inferences. Estimates from model 7 showed that bigger individuals have slightly higher homing probability ($p=.176$) and

estimates from model 8 revealed that homing probability of males seems to be higher than in females ($p=.158$). However, those findings were not significant, suggesting that there was neither a clear difference between the homing probability of males and females nor a clear effect of length. Predictions of models 7 and 8 are shown in **Appendix F**, Figure F.1 and Figure F.2, respectively.

Table 5. Model selection of logistic regression for the effects of biological traits and translocation distance on homing ability of goldsinny wrasses. The table shows the model structure, number of estimated parameters, AIC values, weight and ΔAIC , which is the difference between the lowest AIC value and the AIC of a given model. The models (no:7&8) chosen for statistical inference are indicated in bold and enclosed with red mark. TD stands for translocation distance.

Model no	Model Structure Homed (0,1) ~	Parameters	AIC	ΔAIC	Weight
1	Sex*Length + TD	6	94.79	3.54	0.01
2	Sex + Length +TD	5	92.79	1.54	0.04
3	Sex + TD	4	92.92	1.67	0.04
4	Length + TD	4	92.82	1.57	0.05
5	Sex + Length	3	91.25	0.00	0.11
6	TD	3	93.07	1.82	0.04
7	Length	2	91.37	0.12	0.10
8	Sex	2	91.34	0.1	0.11
9	Sex*Length	3	91.27	0.02	0.11
10	Sex*Length + Sex	4	93.25	2.00	0.04
11	Sex*Length + Length	3	91.27	0.02	0.11
12	Sex*Length + TD	5	92.80	1.55	0.04
13	Sex*Length + Sex + TD	6	94.80	3.55	0.01
14	Sex*Length + Length + TD	5	92.80	1.55	0.04
15	Sex*Length + Sex + Length	4	91.27	0.02	0.04
16	Null	1	91.49	0.24	0.10

Table 6. Summary of the chosen logistic regression model on homing ability of goldsinny wrasses with length as an additive effect. Response variable is 'homed' (0,1). The table shows model coefficients, estimates, odds ratio, standard error of the estimate, z-value, and associated p-value.

Coefficients	Estimate	Odds Ratio	Std.error	z value	Pr(> z)
Intercept	-4.1388	0.016	4.780	-0.866	0.387
Length	0.0591	1.061	0.044	1.354	0.176

Table 7. Summary of the chosen logistic regression model on homing ability of goldsinny wrasses with sex as an additive effect. Response variable is 'homed' (0,1). The table shows model coefficients, estimates, odds ratio, standard error of the estimate, z-value, and associated p-value. Reference level is the female sex.

Coefficients	Estimate	Odds Ratio	Std.error	z value	Pr(> z)
Intercept	2.0369	7.666	0.354	5.747	< 0.0001
Sex male	0.8809	2.413	0.624	1.412	0.158

3.3 Model Selection Including Behavioral Covariates

The starting model consisted of an additive effect of mobility, catchability and translocation distance and interaction effect between mobility and catchability. This model was then compared with 15 reduced candidate models comprised of all possible covariates` combination, including the null model. (**Table 8**). The model with the lowest AIC score had catchability as additive effect (model 14) and only null model had fewer estimated parameters being within 2 AIC units. The model with only catchability as explanatory variable (model 14), therefore, was chosen for the statistical inferences. However, it was rerun with the full dataset after concluding that only catchability was retained in the model. Estimates from model 14 showed that for an increase in catchability by one unit, the odds of “successful homing” increase by a factor of 9.55 (**Table 9**). However, the effect of catchability on predicting homing probability of goldsinny wrasses was not significant ($p=.065$), suggesting that there was no significant difference between homing ability of individuals which have higher catchability rates and those which have lower catchability rates (**Figure 11**).

Table 8. Model selection of logistic regression for the effects of behavioral traits and translocation distance on homing ability of goldsinny wrasses. The table shows the model structure, number of estimated parameters, AIC values, weight and ΔAIC , which is the difference between the lowest AIC value and the AIC of a given model. The model (no:14) chosen for statistical inference is indicated in bold and enclosed with red mark. MI and TD stand for mobility index and translocation distance, respectively.

Model no	Model Structure Homed (0,1) ~	Parameters	AIC	ΔAIC	Weight
1	Catchability*MI + TD	6	185.95	5.74	0.01
2	Catchability +MI+ TD	5	184.73	4.52	0.02
3	Catchability*MI+ MI +TD	5	184.69	4.48	0.02
4	Catchability*MI + Catchability +TD	5	184.2	3.99	0.02
5	Catchability*MI + Catchability + MI	4	183.41	3.20	0.04
6	Catchability*MI + MI	3	182.08	1.87	0.08
7	Catchability*MI + TD	4	184.05	3.84	0.03
8	Catchability*MI + Catchability	3	181.56	1.35	0.10
9	Catchability + TD	4	182.85	2.64	0.05
10	MI + TD	4	186.31	6.1	0.01
11	Catchability + MI	3	182.03	1.82	0.08
12	Catchability*MI	2	181.09	0.88	0.13
13	MI	2	183.1	2.89	0.05
14	Catchability	2	180.21	0.00	0.21
15	TD	3	184.35	4.14	0.03
16	Null	1	181.17	0.96	0.13

Table 9. Summary of the chosen logistic regression model on homing ability of goldsinny wrasses with catchability as additive effect. Response variable is 'homed' (0,1). The table shows model coefficients, estimates, odds ratio, standard error of the estimate, z-value, and associated p-value. *Catchability is significant at a level 0.1.

Coefficients	Estimate	Odds Ratio	Std.error	z value	Pr(> z)
Intercept	0.198	1.219	0.264	0.750	0.453
Catchability	2.256	9.547	1.224	1.843	0.065*

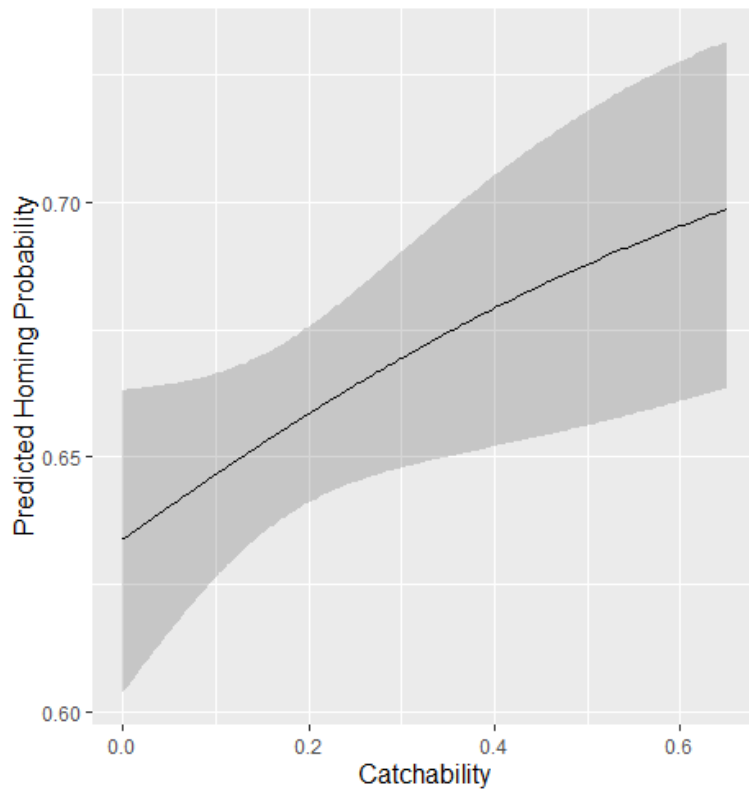


Figure 11. Predictions on homing ability of goldsinny wrasses from the chosen model which had an additive effect of catchability. The predicted homing ability (line) with the confidence interval at 95% level (shaded area) are plotted against catchability. Note that the effect of catchability on homing probability of goldsinnies was not significant at $\alpha .05$ ($p=0.065$).

4. Discussion

This mark-recapture study was designed to investigate homing success of goldsinny wrasses from various distances and to test the effect of length, sex, mobility, and catchability on homing. Homing success of goldsinny wrasses was found to be very high overall, and more than half of them were still detected in their capture sites 32-60 days post-release, indicating that goldsinny wrasses are having both homing ability and site fidelity. The translocation distances tested in this study did not affect the ability to home. Mobility and biological covariates (length and sex) do not seem to be correlated with homing success. On the other hand, the effect of catchability on homing showed a pattern with high catchability, leading to a high homing success. However, this finding is not significant at the 95% confidence interval. In the following paragraphs, I discuss each finding in the context of previous studies and make some suggestions for future research.

Goldsinny wrasses homed successfully (92%) after being translocated up to 300m away from their home sites. The homing ability is not something unique to goldsinny wrasses; other species of Labridae (*Scarus sp.*: Streit & Bellwood, 2017; *Tautogolabrus adspersus*: Green, 1975; *Crenilabrus ocellatus*: Fiedler, 1964) and species from other families including Apogonidae (Gardiner, N.M., and Jones, 2016; Marnane, 2000; Rueger et al., 2014), Blenniidae (Thyssen et al., 2014), Pomacentridae (Booth, 2016; Haines & Côté, 2019; Turgeon et al., 2010), Serranidae (Kaunda-Arara & Rose, 2004; Kiel, 2004), Cottidae (Green, 1971, 1973; Yoshiyama et al., 1992), are also able to home. However, the translocation distance required to swim to return to home varied a lot among the studies, from a few meters (Green, 1973; Haines & Côté, 2019; Turgeon et al., 2010; White & Brown, 2013), to several kilometers (Gardiner, N.M., and Jones, 2016; Green, 1975; Kaunda-Arara & Rose, 2004; Kiel, 2004; Marnane, 2000).

26% of translocated goldsinny wrasses homed within a day, the fastest individuals using only 4 hours to move 100 m. Since only 3 stations were monitored with PIT-tag antennas at the pier the first three days, due to technical problems, the percentage of individuals returning within a day was possibly higher than 26%, and the fastest fish might have arrived back at its home site within less time than 4 hours. At least 15 and 12 individuals returned to their home sites within a day from 100 and 300 m distances, respectively, indicating that translocation distance did not affect the time needed to home successfully. Similarly, Arara and Rose (2004) found no correlation between translocation distance and the time taken to home from those distances for greasy groupers (*Epinephelus tauvina*). In contrast, Thyssen et al. (2014) reported that time taken to home for rock pool blenny (*P. parvicornis*) increased with further distances. In both

mentioned studies, the ratios between the investigated fishes' size and the translocation distances were not differing greatly from the ones in my study. Thus, the question whether time taken to home and translocation distances are correlated or not seems to depend on species-specific factors or other parameters yet to be investigated.

Wrasses are known to have limited home ranges (Espeland et al., 2010). A male goldsinny can defend its territory up to 2m² (Hilldén, 1981) but its home range could be wider than its territory. However, no study calculated the detailed home range size of goldsinny wrasses using traditional home range techniques such as Kernel density estimates. Nevertheless, a few studies shed light on their movement behavior (Aasen, 2019; Hilldén, 1981, 1984). Aasen (2019) measured their horizontal movement and found that the furthest distance travelled by a goldsinny was 385m. However, individuals moving over 100m represented only a small percentage of the population and the average horizontal movement for a goldsinny was only 42.5m (Aasen, 2019). Based on these results, I expect that most, if not all, translocated individuals in my study were introduced to an unfamiliar site, and I can therefore assume that the translocation distances were large enough to test homing behavior of goldsinny wrasses. However, I cannot exclude the possibility that some individuals might already have been in their release sites before and thus were familiar with the path back to their home. Nevertheless, it seems likely that this would be true for only a small percentage of the translocated individuals. Therefore, it can be concluded that goldsinny wrasses in this study returned to their home sites successfully when being translocated outside of their home ranges.

The translocation distances used in this study did not appear to have an effect on homing success of goldsinny wrasses. In general, homing success seems to be decreasing with increased translocation distances if the fish are released to sites located outside of their home range (Kiel, 2004; Marnane, 2000; Streit & Bellwood, 2017; Thompson, 1983; Thyssen et al., 2014; Yoshiyama et al., 1992). Translocation distances of 100m and 300m seem to be outside of the home range size of goldsinny wrasses, therefore there should be another explanation for not finding any effect of distance on homing. Like other animals, fishes can use many cues to find their homes (e.g., visual, chemosensory). It is likely that at least some of those cues were still reachable at the release sites for goldsinny wrasses. However, to understand the mechanisms behind the homing ability of goldsinny wrasses is beyond the scope of this thesis. For future studies, these mechanisms should be tested, and fish should be translocated at further distances than used in this study to find the threshold distance where the homing starts to decrease or cease.

In his master study, Aasen (2019) reported no wrasse movement between three islands located in Western Norway which are separated from each other by 80m of depth / 473m of horizontal distance and 50m of depth / 273m horizontal distance, respectively. He underlined that this behavior of wrasses would especially make island populations of wrasse more vulnerable to overexploitation as the spillover effect from nearby populations would be rare if it ever occurs. This depth avoidance of wrasses may also lead to a failure in their homing success, exacerbating the consequences of harvesting pressure on island populations of wrasse. A study on cunners (*Tautoglabrus adspersus*), a wrasse species dwelling in the Northwestern Atlantic, found that individuals were able to home from 4km distances with a 57% success, however none of the cunners released to an island where they were required to swim across deep water to return to their capture sites managed to home (Green, 1975). In contrast, deep open water passages did not act like a barrier in the homing movement of cardinal fishes (Gardiner, N.M., and Jones, 2016). In the case of goldsinny wrasse, the major decisive factor for its distribution is the presence of refuges (Costello, 1991; Darwall et al., 1992; Hilledén, 1984; Sayer et al., 1993). In this study, I demonstrated that the homing probability of goldsinny wrasses was very high at least when they moved along the continuous rocky shore. However, I have not tested their homing success on habitats with low structural complexity. Turgeon et al. (2010) reported that homing success of longfin damselfishes (*Stegastes diencaeus*), a species usually inhabiting coral reef substrates, decreased below 50% when the width of sand gaps increased beyond 3.9m. For larger sand gaps, longfin damselfishes preferred to take detours over solid reef to home instead of taking the shortest route over sandy substratum (Turgeon et al., 2010). Similarly, Haines and Côté (2019) found that bicolor damselfish (*Stegastes partitus*) was unlikely to cross sand gaps wider than 3.3m. However, larger individuals of bicolor damselfish crossed wider sand gaps than their smaller conspecifics. If goldsinny wrasses had to swim across deep areas with sandy or muddy bottom substrates, which do not offer complex shelter availability as rocky areas with crevices or algae do, it would be likely to observe a decrease in homing success of goldsinny wrasses compared to the one found in this study. This probable decrease in homing success of fish could be either due to the fact that goldsinny wrasse would not dare to swim across large sandy areas or would take risk to do so but fail to home due to the higher risk of predation (Haines & Côté, 2019; Shulman, 1985; Turgeon et al., 2010).

Size of fish had no impact on homing of many species, for example cunners (Green, 1975), mosshead sculpins (Green, 1973), rock pool blennies (Thyssen et al., 2014) and gag groupers (Kiel, 2004). In contrast to these results, Streit and Bellwood (2017) found that larger juvenile individuals of seven species, including families of Labridae, Pomacentridae and Siganidae, are

better at homing than their smaller conspecifics. Effects of body size on homing appear to be much clearer for the juvenile stages, as smaller juvenile fish might still be in the process of developing the sensory skills that are involved in homing (Lecchini et al., 2007). In my study, all translocated goldsinny wrasses were adults (size range: 100-140mm) (Costello, 1991; Hilldén, 1984), so it seems reasonable to assume that all had fully developed sensory skills required to home and all had enough time to learn the detailed map of their home ranges. Therefore, adult individuals of goldsinny wrasses are thought to have shown similar homing success independent of their body size. Effect of body size on homing could also be species-specific. Booth (2016) demonstrated no effect of size on homing of humbug damselfish, however homing success of larger individuals of lemon damselfish was higher than that of smaller ones. Likewise, White and Brown (2013) also found that only fortescue (*Centropogon australis*) among other four focal species (Families: Tetraogoniidae, Gobiidae, Tripterygiidae, Kyphosidae) showed a higher tendency to home with increasing size. However, the homing success of fortescue started to decrease after it reaches a medium size. The authors related this behavior of fish to its ontogenetic shift to offshore water rather than to a homing failure.

I found no evidence for the effect of sex on homing abilities of goldsinny wrasses. This result corresponds with the results of previous studies conducted on other fish species (Green, 1971, 1973; Ivanova et al., 2019; Rueger et al., 2014; Thyssen et al., 2014; Yoshiyama et al., 1992). Unlike these results, Thompson (1983) demonstrated that males of mottled blenny (*Forsterygion varium*) were better at homing from distances of 700m than the female ones. However, it is unclear if this difference was due to the sex or size effect since the male mottled blennies are generally larger than females (Thompson, 1983). Knope et al. (2017) repeated a study on homing ability of sculpin species carried out 2 decades ago by Yoshiyama et al (1992). When they used the similar statistical approach that Yoshiyama et al (1992) applied, they could not find any difference between the homing ability of sexes in *Oligocottus maculosus* either, however they found significant difference between the homing success of female and male *O. maculosus* when they considered the encounter probability of the fish (Knope et al., 2017).

The failure to find a significant effect of sex on homing ability of goldsinny wrasses contrasts the results of Hilldén (1984), who translocated 10 goldsinny wrasses individually up to 200m in Sweden. Homing success was 50% with 80% of successful homers being females. However, it is difficult to infer that the sex of goldsinny wrasses had an impact on their homing, as all the females in Hilldén's study were larger than males and the females were released at shorter distances than males. The difference in homing between the sexes of goldsinny wrasses found

in Hildén's study, therefore, could also be due to the size and/or distance. Even if that was the case, it still contradicts with the result of this study, as in this study it was found no effect of neither size nor distance on homing. Especially when taking into account the small sample size ($n=10$), it is possible that the differences in homing success of male and female goldsinny wrasses in Hildén's study might simply stem from individual differences or by coincidence instead of sex, size or distance. He claimed that one of the explanations for the unsuccessful return of males might be due to the attack of stranger males on them. My study does not provide any support for this view since in my study both sexes managed to home successfully. However, I did not observe the fish directly underwater, therefore it is impossible to know what kind of reaction the translocated fish faced from their conspecifics and from other species throughout their journey. I can only conclude that even though males might have more troubles than females on their journey back home due to the potential aggressiveness from other males around, it did not significantly affect the homing success of males in my study. Another difference between the results of the two studies is the overall homing success rate of goldsinny wrasses. Hildén (1984) attributed return of only half the number of fishes to the increased risk of predation due to the colorful visible tags. In the present study, PIT-tags which were inserted into the body cavity were used, and thus, any increased predation risk due to higher visibility can be excluded.

In addition to the impacts of biological traits, the impacts of individual fish behavior (i.e., activeness and catchability) on homing success of goldsinny wrasses were also examined. Many researchers studying the movement of animals have recognized that animal personality, i.e. consistent individual differences in behavior (Sih et al., 2004), may affect the movement of animals. Many of those studies focused mainly on the impact of animal personality on dispersal (Clobert et al., 2009; Cote et al., 2010; Niels J. Dingemanse et al., 2003; Fraser et al., 2001; Rasmussen & Belk, 2012; among others). Few researchers studied the role of animal personality in spatial traits other than dispersal such as home range, immigration, vertical activity etc. (see the review of J.-Å. Nilsson et al., 2014). So far, to my knowledge, no study has been carried out to investigate the correlation between animal personality and homing behavior. To be counted as personality, a behavior must be repeatable (Bell et al., 2009). In this study, neither the repeatability of activeness nor of catchability were calculated. Therefore, it is not known whether the activeness and catchability of fish are personality traits or not. However, regardless of being a personality trait or not, activeness (mobility index) of goldsinny wrasses was not found to have a significant effect on homing success.

Catchability of goldsinny wrasses was used as a proxy of boldness level, based on the fact that shy individuals are more likely to avoid passive fishing gears than bolder ones (Biro & Sampson, 2015; Réale et al., 2007). Sih and Del Giudice (2012) stated that being more exploratory, bold individuals gather more rewards in terms of food and mate, but at the same time may reduce their survival chance by taking risk on the way. In this study, catchability was found to vary between individual goldsinny wrasses, and homing probability appeared to be increasing with higher catchability. This result, however, was not significant at the 95% confidence interval. Independent of their catchability, the homing probability of each goldsinny wrasse was over 60%. Previous studies documented that the advantage of being bold or shy depended on the environmental conditions (Bremner-Harrison et al., 2004; Sih & Del Giudice, 2012). In the present study, risk taking individuals might be rewarded (high homing success), however their boldness might cause a reduction in their homing success if the study was conducted in a habitat with low structural complexity (e.g., sandy areas).

Repeated recapture of goldsinnies at the pier in the last session offers a glimpse on the species site fidelity. The site fidelity at 32-60 days post-release was found to be 52% and 54% for control and translocated groups, respectively. This result supports the previous findings of other researchers. Green (1973) reported that 59% of mosshead sculpins (*Clinoscottus globiceps*) in the control group were still found in the home pool 3 months later. Thyssen et al. (2014) showed that 57% of homed individuals of rock pool blenny (*Parablennius parvicornis*) remained in their capture sites at least for 4 months. In both studies, like in this study, species showed both homing success and site fidelity. Site fidelity is common among species which are able to home. White and Brown (2013) showed that individuals of three species inhabiting the rock pools all year around exhibited both high homing success and high site fidelity, on the other hand two species which inhabit the rock pools only during their early ontogeny showed relatively low homing success and low site fidelity to their home rock pools. However, site fidelity and homing are not always correlated to each other. Streit and Bellwood (2018) demonstrated that *Coris batuensis* and *Pomacentrus amboinensis* re-established their site fidelity after homing, whereas *Pomacentrus moluccensis* and *Scarus sp.* were not faithful to their sites after homing. In the study of Rueger et al. (2016), 94% of pajama cardinalfishes (*Sphaeramia nematoptera*) showed site fidelity to their coral patches but only 2 individuals out of 37 were observed returning to their home sites. In another study, 74% of marine threespine stickleback (*Gasterosteus aculeatus*) homed from 100-300m within a day, however many of them did not stay at home more than four days (Ivanova et al., 2019). In some cases when the fishes were displaced, the home sites could be re-occupied by conspecifics and homing fishes might not

always have a high chance to regain their home sites (Hert, 1992; Ivanova et al., 2019). In the present study, replacement of homed goldsinny wrasses by re-occupants seems unlikely as both homed individuals and individuals in the control group had similar site fidelity. Observed decline in resighting of control and homed individuals in the pier after 32-60 days may result from natural mortality and/or difficulty to detect the presence of individuals without using antennas. In the last sampling session, the site fidelity of the fish was monitored only by baited pots. Since antennas were not used in this session, the presence of many fishes might not be detected. Therefore, the site fidelity of goldsinny wrasses was likely to be underestimated.

Goldsinny wrasses showed high site fidelity to their capture sites by homing within a week (for most individuals, even shorter) and by remaining in their capture sites at least for 2 months. This observed site fidelity of goldsinny should be considered when managing the stocks as high site fidelity together with the small home range makes fish populations especially vulnerable to local depletions (Bryars & Rogers, 2016).

5. Conclusion

Overall homing success of goldsinny wrasses was very high and they were also found to have site fidelity to their capture sites, remaining there at least for 2 months after homing. Goldsinny wrasses managed to home even from the furthest distance tested in the study, and, most probably, are able to home from more than 300m. These findings may reduce the concerns regarding the survival of discarded undersized goldsinny wrasses, provided they are released to an area which has structural connectivity with the capture site. However, further studies are needed to find the threshold distance where homing starts to decrease. I also recommend repeating a similar research on other harvested wrasses (i.e: corkwing and ballan) due to the species-specific nature of homing.

To my knowledge, this is the first study examining the homing ability of discarded goldsinny wrasses in Norway. Hopefully, by providing basic knowledge about the response of short-distance translocated goldsinnies, this thesis contributes to literature and helps policymakers to take necessary steps to ensure a sustainable wrasse fishery.

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Appendix A

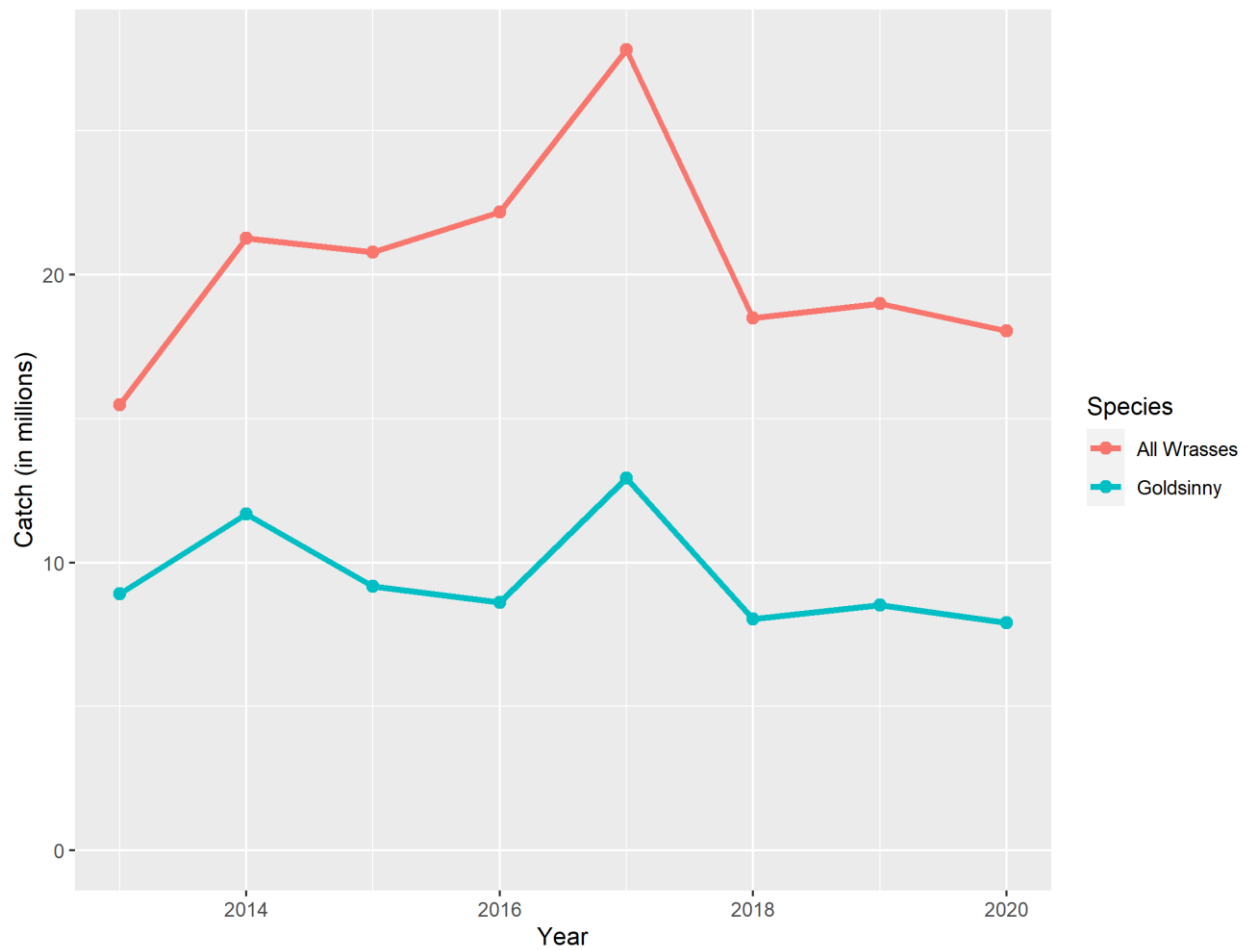


Figure A.1. The landing caps of wrasses in Norway between 2014-2020. Landing caps reached a peak in 2017, leading to the establishment of a fishing quota of 18 million wrasses. The graph was drawn using data from: <https://www.fiskeridir.no/Yrkesfiske/Tall-og-analyse/Fangst-og-kvoter/Fangst/Fangst-av-leppefisk>

Appendix B

Pot diversity shows the presence of an individual fish in the different pots located at six different stations at the pier. Similar to species diversity it is calculated using the formula for Simpson's Index. Instead of different species found in a population, different pots that an individual fish visited were used in the formula.

$$D = \frac{\sum n(n - 1)}{N(N - 1)}$$

In this index, a bigger D value leads to a lower diversity, which does not seem logical. To overcome this problem, D is subtracted from 1. "1 - D" is called Simpson's Index of Diversity, and now the greater the value, the greater the sample diversity.

In this study, this index (1 - D) represents the probability for two randomly selected pots visited by one individual fish to be located at different stations.

Here:

n: total visits of an individual fish to a particular station

N: Number of times that an individual fish was caught

1-D: Pots diversity for a given individual.

To understand it better see the following example.

- Fish with ID number "201415" was caught 10 times. So, the N is 10 for this fish. It was caught 7 times at station 1, twice at station 2, once at station 3. Station 1, 2 and 3 can be thought as different species (n) in the original formula of Simpson's Index of Diversity.

$$D = \frac{\sum 7(7 - 1) + 2(2 - 1) + 1(1 - 0)}{10(10 - 1)}$$

$$1 - D = 0.51$$

Pot diversity for this fish was found to be **0.51**.

Appendix C

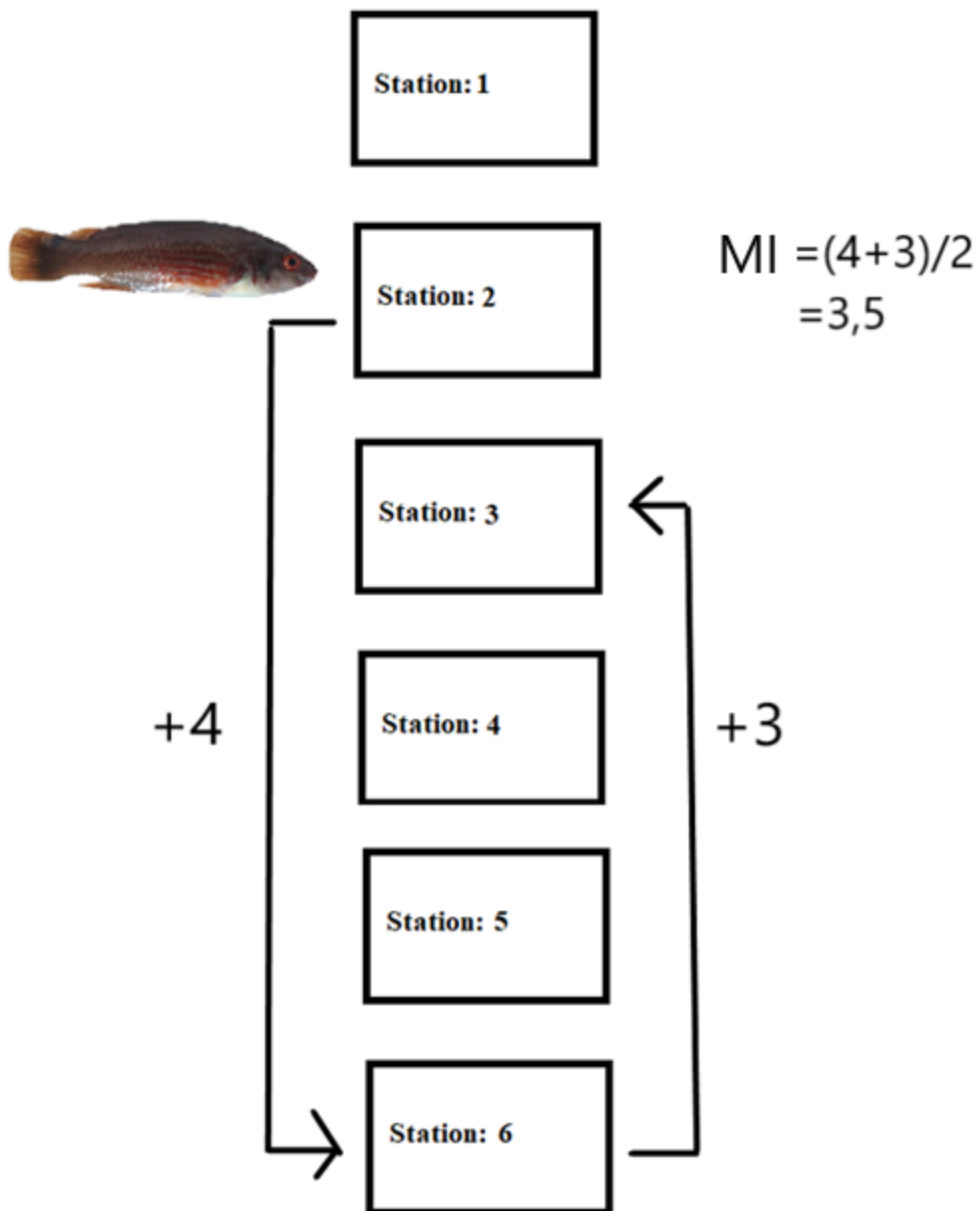


Figure C.1. Calculation of Mobility Index (MI). Fish “434502” was caught for the first time at station 2. Therefore, station 2 was considered as starting point for this fish. Next time, it was recaptured at station 6, meaning that it moved 4 units. When it was encountered again, it changed its place from station 6 to station 3, adding 3 more units to its total distance. Since it was recaptured twice, its mobility index (MI) is $(4+3)/2=3.5$.

Appendix D



Figure D.1. Correlation matrix between numerical variables. Blue represents a positive correlation, while red represents a negative correlation. In this matrix, there is a strong positive correlation between mobility index and pot diversity.

Appendix E

Table E.1 Overview of species caught in the pots throughout the study. The table shows the total number of individuals caught (N) for each species, from highest occurrence to lowest.

Species (Common Name)	Scientific Name	Abundance (N)
Goldsinny wrasse	<i>Ctenolabrus rupestris</i> , Linnaeus 1758	10225
Corkwing wrasse	<i>Symphodus melops</i> , Linnaeus 1758	1501
Shore crab	<i>Carcinus maenas</i> , Linnaeus 1758	147
Atlantic cod	<i>Gadus morhua</i> , Linnaeus 1758	97
Brown crab	<i>Cancer pagurus</i> , Linnaeus 1758	91
Ballan wrasse	<i>Labrus bergylta</i> , Ascanius 1767	80
European eel	<i>Anguilla anguilla</i> , Linnaeus 1758	46
Long-spined bullhead	<i>Taurulus bubalis</i> , Euphrasen 1786	39
Rock cook wrasse	<i>Centrolabrus exoletus</i> , Linnaeus 1758	33
Shorthorn sculpin	<i>Myoxocephalus scorpius</i> , Linnaeus 1758	31
Black goby	<i>Gobius niger</i> , Linnaeus 1758	24
Rock gunnel	<i>Pholis gunnellus</i> , Linnaeus 1758	19
Poor cod	<i>Trisopterus minutus</i> , Linnaeus 1758	17
Fivebeard rockling	<i>Ciliata mustella</i> , Linnaeus 1758	12
Atlantic Pollock	<i>Pollachius pollachius</i> , Linnaeus 1758	8
Cuckoo wrasse	<i>Labrus mixtus</i> , Linnaeus 1758	6
Black squat lobster	<i>Galathea squamifera</i> , Leach 1814	5
Snake pipefish	<i>Entelurus aequoreus</i> , Linnaeus 1758	3
Saithe	<i>Pollachius virens</i> , Linnaeus 1758	1
European lobster	<i>Homarus Gammarus</i> , Linnaeus 1758	1

Appendix F

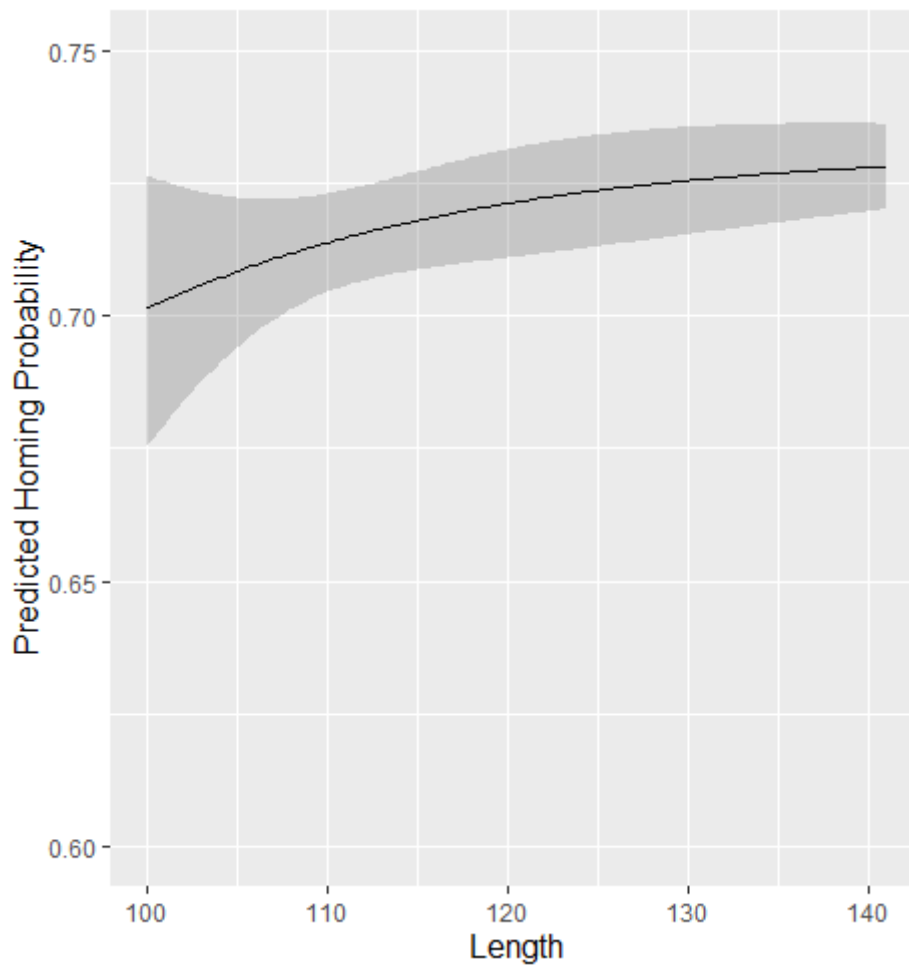


Figure F.1 Predictions on homing ability of goldsinny wrasses from the chosen model which had an additive effect of length. The predicted homing ability (line) with the confidence interval at 95% level (shaded area) are plotted against length. Even the smallest fish had a probability of homing of around 70% and homing probability appears to be slightly increasing with increasing size. However, this is not significant ($p=0.176$).

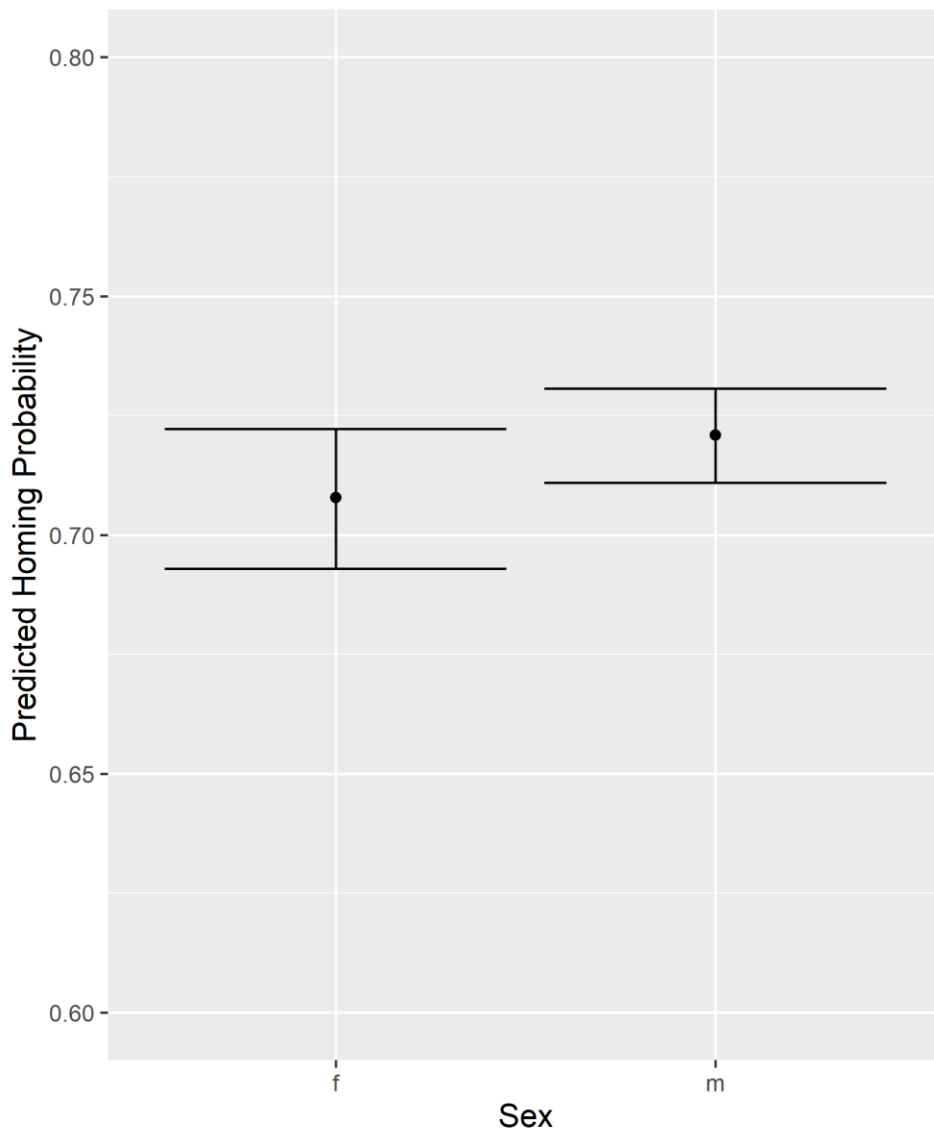


Figure F.2 Predictions on homing ability of goldsinny wrasses from the chosen model where sex was the only explanatory variable. The predicted homing probability of each sex are presented with the error bars using 95% confidence intervals. The figure shows that both female and male goldsinnies have a homing probability over 50%. Even though males' homing probability seems higher than females', the results showed that this was not significant ($p=.158$).

