Kleptoparasitic relationships between common eiders (*Somateria mollissima*) and large gulls in Solheimsviken, Bergen

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Abstract

Kleptoparasitism is defined as the theft of procured resources from another individual and is common in many species, especially so in birds. This kind of interaction is well documented between common eiders and gulls. This study is documenting the kleptoparasitic relationship between eiders and gulls in the urban inlet, Solheimsviken. The aims of the study were 1) to examine the number of gulls present in different sized groups of eiders, and whether the gull presence changed over time. 2) To examine the ratio of attacks and successful attacks from gulls in eider groups of increasing sizes. 3) To document the abundance of eiders visiting Solheimsviken. 4) To record what the eiders brought to the surface, and what the gulls managed to steal. A positive correlation between the eider group size and the number of gulls present was found. The presence of gulls in groups of eiders did change over time, with less gulls present in the groups of eiders as the season progressed. The number of attempted attacks and successful attacks did increase with increasing size of eider groups. However, the success ratio did decrease as the size of the eider groups increased. The eiders were observed bringing starfish, sea urchins, and blue mussels to the surface. There was a large bias towards starfish being the prey stolen with over half of all starfish recorded at the surface being stolen. In contrast, blue mussels recorded at the surface were only stolen approximately 10% of the times. These findings are in concordance with other studies which have shown that gulls do prefer starfish as they require more handling time at the surface by the eiders, and starfish are more energetically favorable than blue mussels. The correlation between the number of eiders and number of gulls have previously been studied with different outcomes. Some studies have shown that gulls defend their groups of eiders against other gulls, while other studies found a positive correlation in accordance with ideal free distribution. This study found a linear increase between the number of eiders and number of gulls, following a type 1 functional response.

ACKNOWLEDGEMENTS

After long and cold hours filming from the roof of a building, in the heart of my hometown, my thesis is finally ready to be turned in. It has been a long and tough process, and I could not have done it myself.

First and foremost, I want to extend my sincerest gratitude to my supervisor Øystein Varpe. I went into this project with minimal knowledge of eiders and research, but through your guidance and patience I have now completed something I am very proud of.

A special thank you to my mother and father. If it was not for you, I would not have been where I am today. Thank you for all your never-ending support and guidance.

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Lastly, I would like to thank R-klubben for helping me a lot with the coding and analyses in R.

And, if anyone from Bergen Kommune should happen to read this thesis, please take my beloved eiders into account when continuing the building along Puddefjorden. They are easily startled and very afraid of humans. They are the coolest birds, and we should treasure having this enormous amount overwintering in the best city in the world!

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1 INTRODUCTION

1.1 KLEPTOPARASITISM

Kleptoparasitism is defined as the theft of procured resources from another individual and is a strategy adopted by many different groups of animals, but is especially widespread in birds (Brockmann & Barnard, 1979; Morand-Ferron, Sol, & Lefebvre, 2007). Interspecific kleptoparasitism is well documented (Källander, 2006; Morand-Ferron et al., 2007; Varpe, 2010), but kleptoparasitism might also occur intraspecific (Shealer, Spendelow, Hatfield, & Nisbet, 2005). Some species specialize in kleptoparasitism and rely on food theft as their main source of energy, while other species resort to kleptoparasitism only when it is more favorable than other strategies (Brockmann & Barnard, 1979; Furness, 1987). Stealing resources acquired by another individual negates the cost of foraging but comes at the cost of chasing and potential injuries (Iyengar, 2008). It is therefore beneficial for the parasite to be larger than the host and have a high cognitive sense (Hamilton, 2002; Morand-Ferron et al., 2007). Being larger than the victim might induce an anti-predator response in the prey species where they drop their food to escape the kleptoparasite to avoid damage to itself (Grant, 1971). Cognitive abilities might improve the probability of success in kleptoparasitic attacks by using previous acquired information (Morand-Ferron et al., 2007).

1.2 WHY KLEPTOPARASITISM EVOLVES

The optimal foraging theory is often used to explain why kleptoparasitism evolves. The theory states that individuals should prefer the foraging strategy which maximizes the income of energy over the energy expenditure, maximizing the net energy intake (MacArthur & Pianka, 1966). In other words, kleptoparasitism must be more energetically favorable than other strategies available for it to be adopted by organisms. The optimal foraging theory is based upon prey density and is therefore prone to change over time as the prey density fluctuates. When the number of prey increases the predators will attack an increasing number of prey, or a fixed number of prey more rapidly (Solomon, 1949). This kind of behavioral change is known as a functional response and is adversely true when the prey density decreases. Kleptoparasitism is expected to arise when pay-offs from other foraging strategies decline (Brockmann & Barnard, 1979; Flower, Child, & Ridley, 2013), possibly through getting access to a food source usually not accessible for the parasite. Kleptoparasitism is therefore common, and largely favorable, when the host has access to a food source otherwise inaccessible for the parasite (Flower et al., 2013; C. M. Waltho, 2013).

1.3 Common eiders and gulls

Kleptoparasitism has been widely documented between common eiders (*Somateria* mollissima) and different species of gulls (*Larus spp.*). Common eiders feed on benthic organisms where smaller prey are consumed under water while larger prey requiring a longer handling time is brought to the surface (Guillemette et al., 1992; MacCharles, 1997). When eiders bring prey to the surface gulls might attempt to steal the prey. The eiders sometimes avoid the attack by diving with their prey, but usually dive without it, leaving it at the surface for the gulls to take (Ingolfsson, 1969; Paulsen, 1987; Varpe, 2010). Leaving the prey is an anti-predator mechanism (Grant, 1971), in which the eiders avoid damage to themselves fighting the gulls, at the cost of losing the prey they caught. Gull presence is tolerated by the eiders, which let gulls swim in between the group (Ingolfsson, 1969). Therefore, the gulls might attack surfacing eiders from a distance, or from within the group of eiders (Källander, 2006). Even though gulls are tolerated it has been shown that eiders will modify their diving behavior when gulls are nearby. Eiders will, like other sea birds, increase their diving synchrony as a response to kleptoparasites being present (MacCharles, 1997; Schenkeveld & Ydenberg, 1985).

1.4 Ideal free distribution, social foraging and spatial distribution

Ideal free distribution is a model which describes how individuals should distribute themselves between feeding sites. The model assumes that individuals are free to choose feeding sites without a cost of changing, and that they will distribute themselves freely between feeding sites to maximize their own net gain (Fretwell & Lucas, 1969). Gulls have previously been found to defend eider groups from other gulls (Ingolfsson, 1969; Prŷs-Jones, 1973), which breaks with the assumptions of ideal free distribution as individuals are not freely choosing feeding sites. As larger groups of hosts are shown to positively affect the robbing success rate (Dunn, 1973), gulls following ideal free distribution should choose large groups of eiders and move to smaller groups if the number of gulls per group becomes too high. This type of free distribution has previously been documented by Varpe (2010), which found that groups of eiders with several gulls present were larger than groups of eiders with one gull present.

For eiders, social foraging has multiple benefits. Diving in groups can increase the habitat profitability by information sharing (Clark & Mangel, 1984; Guillemette et al., 1993). These studies show that eiders feeding in patchy habitats would share where the profitable diving spots are, thereby decreasing search time. When kleptoparasites are present, diving in groups might also prove beneficial. Diving in groups makes it safer for each individual eider to bring prey to the surface. Larger groups might decrease the risk of having prey stolen through confusing the predator, or diluting the risk to another individual in the group (Fox et al., 1994; MacCharles, 1997). This safety in numbers strategy is widely adopted by many species, for example simultaneous hatching in some turtle species (Colbert, Spencer, & Janzen, 2010) and schooling in minnows (Orpwood, Magurran, Armstrong, & Griffiths, 2008).

The spatial distribution of benthic species has been shown to be affected by abiotic factors, such as substrate or depth (Bustnes & Lønne, 1997; Guillemette et al., 1993). Given that benthic species have a patchy distribution, some spots would contain prey requiring handling time at the surface while other spots would contain prey possible to consume under water. Hence, it is to be expected that the presence of gulls in eider groups will vary based upon where the eiders dive. MacCharles (1997) found that gulls in Cape ST. Mary´s, Newfoundland, did not attend eider groups feeding on mussels which could be consumed underwater, but focused on groups feeding on sea urchins which need more handling time at the surface. What the eiders are feeding on would therefore affect the presence of gulls, not solely group size.

1.5 SEASONALITY

Seasonality is caused by the variations in solar radiation, which in turn is caused by the rotation of the earth. These variations cause a variety of changes in ecosystems, for instance temperature swings and day length (Lisovski, Ramenofsky, & Wingfield, 2017). Abiotic changes will cause biotic responses from the inhabiting organisms (Varpe, 2017), as many organisms live in environments which vary through the year (McNamara & Houston, 2008). A common response to abiotic variations is migration to more favorable environments. Some species often overwinter closer to the equator to escape harsh conditions in their breeding grounds (Alerstam, 1993; Weimerskirch et al., 2015), while other species migrate to exploit spatiotemporal variation in resource abundance (Varpe, 2017). Some species inhabiting the temperate zones might migrate thousands of kilometers, while some migrate closer to their breeding grounds (Visser, Perdeck, Van Balen, & Both, 2009). Migration is costly, and the cost of migration has been shown to affect the distance in which species are willing to migrate (Somveille, Rodrigues, & Manica, 2015).

Birds are especially known for migration, with 19% of the extant species being migratory (Kirby et al., 2008). A species being migratory does however not mean that every single population within that species migrates (Herrera, 1978). There might even be different migratory strategies within populations (Magnusdottir et al., 2012). Common eiders are an example of a species with different migration strategies. Common eiders might migrate like the Svalbard populations migrating to Iceland or Norway (Hanssen et al., 2016), or they might stay sedentary, such as the Northern Norwegian populations (Fauchald et al., 2015). Where the eiders overwintering in Solheimsviken originate from is not known. Explaining why they choose Solheimsviken as an overwintering site might be more relevant. Studies have shown that common eiders prefers diving at depths of less than 10 meters (Bustnes & Lønne, 1997; Guillemette et al., 1993), which coincides with Solheimsviken which has a depth of around 7 meters (Hartvedt & Skreien, 2009). Solheimsviken does not have any inhabiting species which are predators to the common eiders. The only stressors encountered are human disturbances, for instance boats driving by (Keller, 1991; MacCharles, 1997), and kleptoparasites in the form of gulls. Lastly, and most importantly, Solheimsviken contains various prey previously shown preferred by common eiders.

1.6 HYPOTHESIS AND AIM FOR THESIS

My hypotheses for this work were: 1) The numbers of gulls present in groups of eiders will increase linearly with group size, and 2) the numbers of gulls present in groups of eiders will change throughout the study period as the number of eiders present in the study area will fluctuate.

The main aim of this thesis was to examine the interactions between common eiders and herring gulls in the urban inlet, Solheimsviken. There are a lot of studies based upon this interaction, but few in urban areas and certainly none from Solheimsviken.

My sub aims were:

- To examine the presence of gulls in different sized eider groups, and potential changes in gull numbers through the study period.
- To examine the ratio of attacks and successful attacks from gulls with increasing eider group sizes.
- To document the seasonal abundance of eiders in the system through the study period.
- To examine what the eiders bring to the surface and what the gulls manage to steal.

2 METHODS

2.1 STUDY AREA

Puddefjorden is a fjord running 3,5km from the ocean, ending in Solheimsviken, where this study was conducted. Puddefjorden has previously contained a lot of heavy metals and organic toxins, but in 2018 a large project to rid these toxins was started. According to the project, 400kg of mercury, 15kg of PCB7 and 27,5 tons of lead have been covered up by 350,000 tons of rock (Miljødirektoratet, 2018). The removal of these toxins will enable organisms to reestablish in the future in a cleaner and healthier environment.

The study area was divided into diving spots based on where the eiders were observed diving (Figure 1). In the early phase of the study the eiders mainly dove in one spot, which was named “pkt1”. Later in the study the eiders started diving in a wide variety of places which in turn were named after nearby structures (Table 1). The diving spots were combined into four groups for later statistical tests. They were grouped together based on their physical traits, for instance all diving spots which were under bridges were grouped together as "bridges" (Table 1).

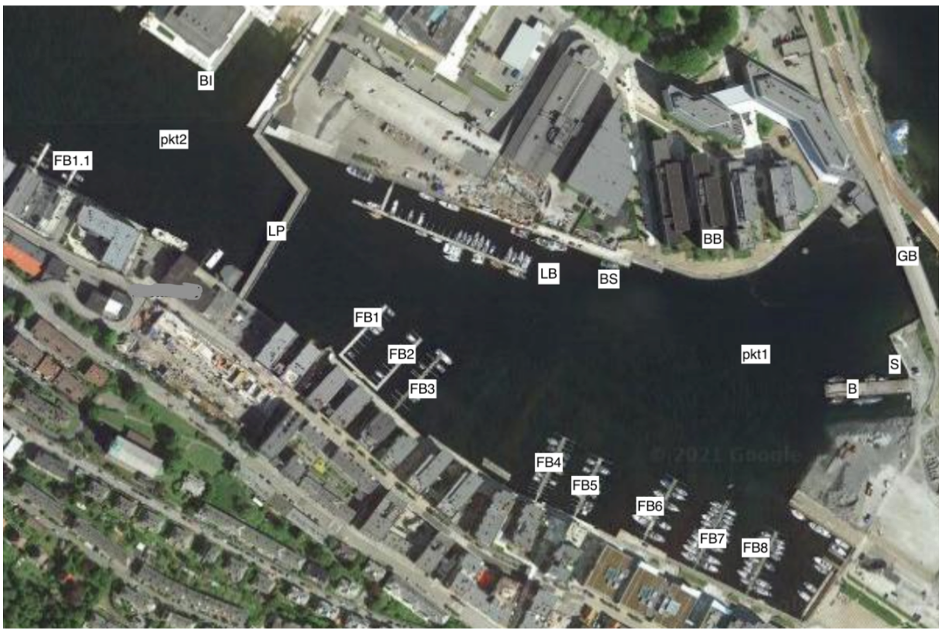

Figure 1: An overview of the study area, Solheimsviken in Bergen. The labels are abbreviations, explained in Table 1, for the main structures nearby to the locations where the eiders were observed diving. Picture collected from (Google, 2021).

Table1: An overview of the different diving spots with the abbreviations shown in Figure 1, split into four groups based on physical attributes of the diving spots.

Open water	**Floating-Piers**	**Bridges**	**Land structures**
Punkt 1-2 (pkt1-2)	Flytebrygge 1-8 (FB1-8)	Lillepuddefjordsbro (LP)	Biologen B-blokk (BB)
Empty spots	Langbrygge (LB)	Gangbro (GB)	Handelshøyskolen BI (BI)
	Badstue (BS)		Brygge (B)
			Strand (S)

2.2 STUDY SPECIES

The common eider is a large diving duck that breeds in the arctic and boreal zones of the northern hemisphere (Norsk Polarinstitutt, n.d.). The diet of eiders mainly consists of mollusks, but also contain crustaceans and echinoderms (Cabot, 2021; Goudie & Ankney, 1986; Guillemette et al., 1992), which they obtain by diving under water. The eiders in this study overwinter in Solheimsviken before leaving for their pre-breeding grounds. While in their feeding ground the eiders usually follow a fixed cycle. The cycle consists of a continuous feeding period followed by a resting period, most likely to digest what has been consumed and to replenish oxygen stores (Guillemette, 1998; Heath et al., 2007). Common eiders are not new inhabitants of Solheimsviken, and according to sightings recorded on Artsobservasjoner.no they have been observed there since 2011.

The other specie which is the focus of this study was the European herring gull (*Larus argentatus*). They naturally breed along the coast of Norway but are also found breeding in the cities (Helberg, 2021). Along the coast they mainly feed on fish, but as they are opportunistic, they feed on most of what they find (Fuirst, Veit, Hahn, Dheilly, & Thorne, 2018; Gjershaug & Lorentsen, 2020) and are therefore well suited to live in urban environments. By own observations, gulls are not present in the Solheimsviken at all times, but rather drawn there by foraging opportunities, for instance upwellings, which is discussed later.

2.3 Data collection and processing

All data presented in this study has been filmed in Solheimsviken, either from the roof of the B-Block of Biologen (BB from Figure 1) or along the fjord at ground level. The data was collected from the 16th of December 2020 until April 23rd, 2021. The study was ended on April 26th, 2021, when no eiders had been observed for three days in a row. The filming was performed with a Sanyo Xacti VPC-WH1 camera with a 30x optical zoom, mounted on a tripod. Using this camera, it was easy to distinguish genders of the eiders when not facing direct sunlight and it was waterproof, which allowed filming in all types of weather. The camera also had a built-in microphone allowing inclusion of comments about the clips. This also negated the need for a notepad as notes could be taken verbally.

All the data in this study originates from the videos filmed through the study period. After being transferred to a computer, the videos were watched using QuickTime Player. Specific data from all videos was noted, as described below, and put into a Microsoft Excel sheet (Version 16.54) prior to analysis. Every clip was marked with an ID number and which date it was filmed. Some rows in the Excel sheet share the same ID number and date because some of the clips had multiple groups of eiders filmed which produced multiple rows. For each group the number of eider males, females, and NA (if indistinguishable) were counted and written down, and later added together to get the total amount of eiders. The number of gulls present in each group was counted, as defined in section 2.4.2. Eider activity were noted with a 1 for actively diving groups and a 0 for resting groups. The number of attacks and successful attacks were counted and put in two separate columns. If prey brought to the surface by eiders was distinguishable, it was counted and put into columns based on the prey type. Lastly, the type and number of prey stolen by gulls were counted, and put into columns based on the prey type.

In total, 115.65 GB (approximately 1606.25 minutes) of film was recorded over 90 days of data collection. These minutes were split between 1546 separate clips with length varying from 2 seconds to 7 minutes and 18 seconds. Every clip filmed did not necessarily end up producing a line of data in the Excel sheet. Some of the clips were filmed with the sole purpose of supplying additional information to another clip, while a few clips filmed were off to low quality to extract data (camera not focusing or rain/snow on the lens). In total, the 1546 clips resulted in 1261 individual rows of data in the Excel sheet.

2.4 Specifications and definitions

2.4.1 Total abundance of eiders

The total amount of eiders observed in the fjord each day is referred to as total abundance. To gain the most accurate count of eiders present each day, an effort was put to film the eiders when they were all gathered in one group. However, this was not always possible as the flock was sometimes spread out in multiple groups. When the flock were spread out multiple clips were needed, and the total amount of eiders were added together. When multiple clips were needed, it was ensured that there were no eiders moving between the clips, making the number artificially high. As all the eiders usually arrived approximately at the same time of the day and left usually in a large group, the abundance clips were filmed when a large proportion of the eiders had arrived, but in good time before they left the fjord.

2.4.2 Defining what a group is

A key factor in this study was defining what a group of eiders is, and when gulls are a part of the group. Lacking a form of measurement tool, a descriptive way was used to determine this. A group was defined as; eiders in close approximation doing the same activity, where activity is either diving or resting. In a group all the individuals will not necessarily do the same activity, some might dive while some might rest. A threshold was therefore set at approximately 25%, meaning that the group would only be marked active if more than approximately 25% of the eiders were diving. The gulls included were both the ones in between the eiders, but also the gulls that observed the group from a distance. Defining a distance in which to include the gulls was challenging, as they are quick fliers and can attack from large distances when they notice emerging eiders with prey. Therefore, gulls waiting in proximity and gulls sitting far away which attacked during the diving periods were both included. As the gulls do not attack a resting flock, only the ones in proximity were included when the flock was resting.

2.4.3 Defining which groups to focus on

As there were hundreds of eiders visiting the fjord for most of the study, and they were not all diving at the same spot at the same time, an important aspect of this study was which groups of eiders to focus on. Since one of the main hypotheses regarded the number of gulls in each group of eiders, and there was an idea that the locations where the eiders dove affected the gull's presence, a focus was put on filming as many group sizes as possible in varying locations. Thus, the same groups were not filmed multiple times a day if all the variables (group size, gull presence and location) were identical. To test whether diving activity affected the presence of gulls in groups of eiders, resting groups of eiders was filmed in addition to the groups actively diving. As resting groups were not the main focus, most of these clips were filmed when there were no other groups to focus on, for instance if all groups were diving multiple times with the same variables. The rest of the clips of resting eiders were gathered before a diving period when trying to count the number of eiders diving, or when filming the abundance that day.

The diving cycle of each group was not necessarily filmed in its entirety. While active, the eiders could stay under water for around a minute. Thus, if the threshold set for defining a group as active was met, there was nothing to observe until the eiders resurfaced. If a new different group was seen swimming towards another diving spot, while the original group was under water, the new group would be filmed, before returning the focus to the original group. A few times the camera was left filming the new group while the activity of the original group was stated verbally to the camera. This only happened on a few occasions and was only done when no gulls were present, to not miss any potential attacks. By focusing on multiple groups simultaneously it was possible to increase the number of groups filmed, without losing out on any important data. Attacks were defined as a gull flying towards an eider which resulted in the eider evading the gull, whether the gull procured the prey or not. Attacks were only marked successful when prey could be seen stolen, or if the gull had a behavior indicating consumption of prey after an attack. If multiple gulls attacked the same eider, it was noted as multiple attacks.

2.5 STATISTICAL ANALYSIS

The data was analyzed using R, version 4.0.2 (R Core Team, 2020) with RStudio version 1.3.1073 (RStudio Team, 2020). All plots were made using the *ggplot2* package in Rstudio (Wickham, 2016). For all data which were log transformed, the natural logarithm was used. The full reproducible code can be found in Appendix 6.2

When testing if the collected data was normally distributed, ggdensity and ggqqplot from the *ggpubr* package (Kassambara, 2020) were used as visual tests.

When testing the significance of grouped diving spots, activity, eider gull correlation, and success ratio, a linear mixed-effects model (lme) were chosen. This model was chosen as the data in focus was continuous, and it allowed for testing the random effects. The models were made by using the lmer function from the *lme4* package (Bates, Maechler, Bolker, & Walker, 2015), using diving spots as the random effect. When testing the significance for attacks and successful attacks a generalized linear mixed-effects model (glmm) was chosen. This model was chosen as the data in focus was count data, and it allowed for testing the random effects. The model was made by using the glmer function from the *lme4* package (Bates et al., 2015) with a Poisson distribution, and diving spots as the random effect.

For all significance tests, a statistical significance level (alpha) of 0.05 was used, with the null hypothesis that there is no significant difference. When testing significance between the four grouped locations, a Tukey test was used to compare the four means to each other. This test was conducted with the emmeans function from the *emmeans* package (Lenth, 2021). For the significance test with only two groups compared a Wald chi square test was used, using the Anova function from the *car* package (J. Fox & Weisberg, 2019).

3 RESULTS:

3.1 GULL PRESENCE

The main species of gulls present in the study are herring gulls. Juvenile gulls are not as easy to distinguish as adult gulls, so there might have been juvenile individuals from other species present in the study. As herring gulls were the only adult species observed in the study area, it was assumed that most of the juvenile gulls present were herring gulls.

The test used to examine the influence of activity on gull presence in eider groups returned a value ($p < 0.0001224$) lower than 0.05, which indicates that the activity of the group does affect the number of gulls present. Figure 2 shows the correlation between the group size of active eiders and the number of gulls present in each group. The test for correlation between active eiders and gulls resulted in a value ($p < 2.2*e^{-16}$) which indicates that there is a correlation between the number of active eiders and number of gulls. To better show the trend, the values were log transformed (Figure 2B).

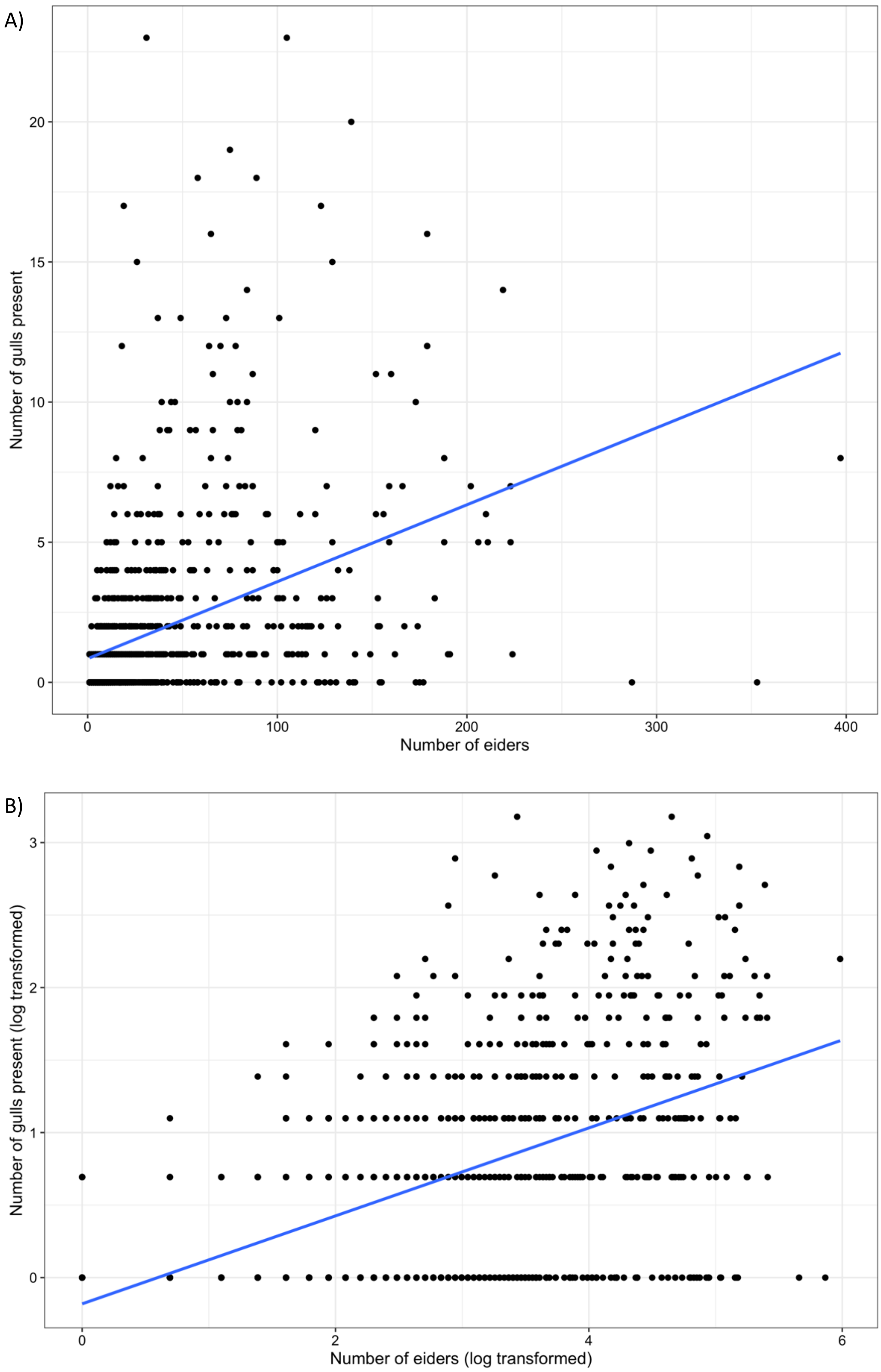

Figure 2: A) The presence of herring gulls plotted against the group size of common eiders, in Solheimsviken. B) The same data as in A, but log transformed to better show the trend.

Figure 3 shows the degree of gull presence in the different sized eider groups through the study period. By looking at the number of large blue circles, compared to large orange circles, the figure shows that actively foraging eiders have a higher number of gulls present than resting eiders. The size of the circles, indicating gull presence, decreased markedly between January and February before dropping even further in late February. This indicates that the number of gulls present in groups of eiders did decrease as the season progressed.

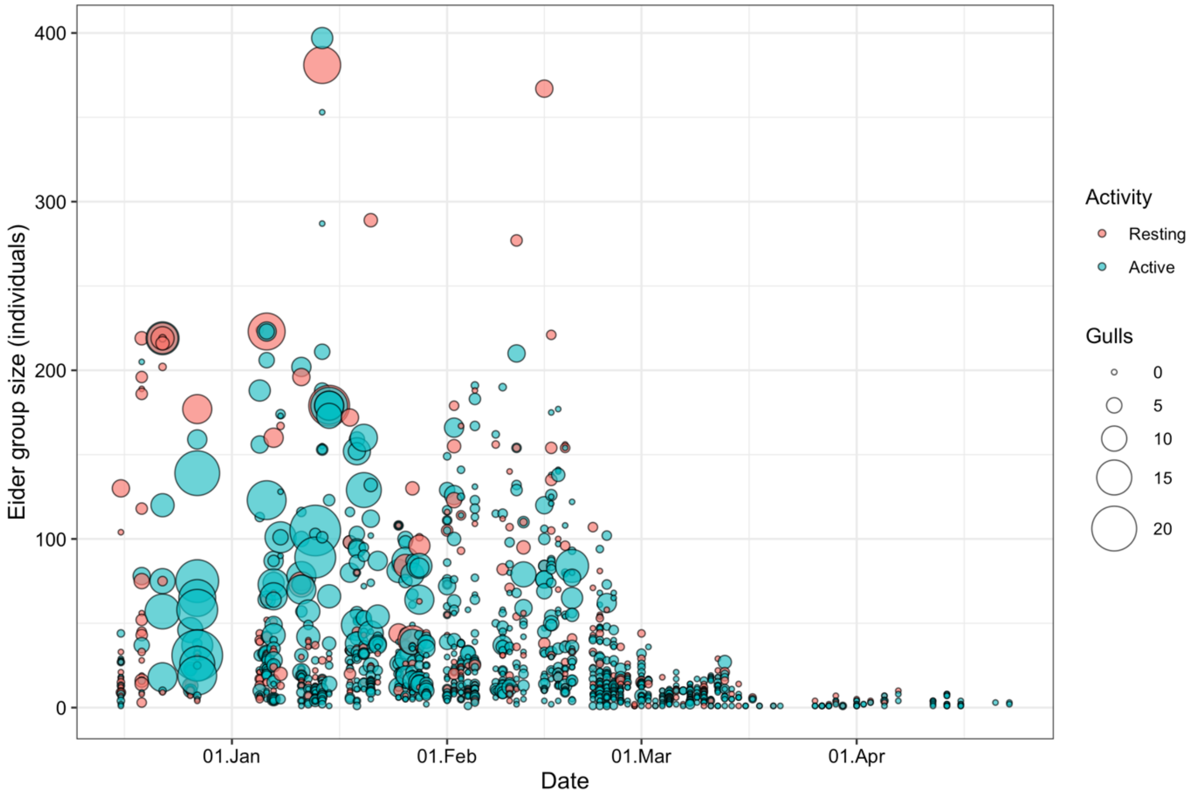

Figure 3: Number of common eiders per group (y-axis) with the number of gulls present, during the whole observation period (x-axis). Activity is either orange for resting groups of eiders or blue for actively diving groups of eiders. The size of the circle indicates numbers of gulls present in each eider group.

3.2 Success ratio in gull attacks

Figure 4 shows three scatter plots presenting the response from gulls with increasing eider group sizes. Because of the skewedness of the data and outliers, the number of eiders is log transformed to better show the trends. The first plot is a combination of the last two plots, showing a decrease in the success rate of gull attacks (in percentage) when the eider group sizes increase ($p<0.0001101$). The second plot show an increase in the number of attacks from gulls when the eider group sizes increase ($p<2.2*e^{-16}$). The third plot shows that the number of successful attacks from gulls increase as the eider group size increase ($p<0.00103$).

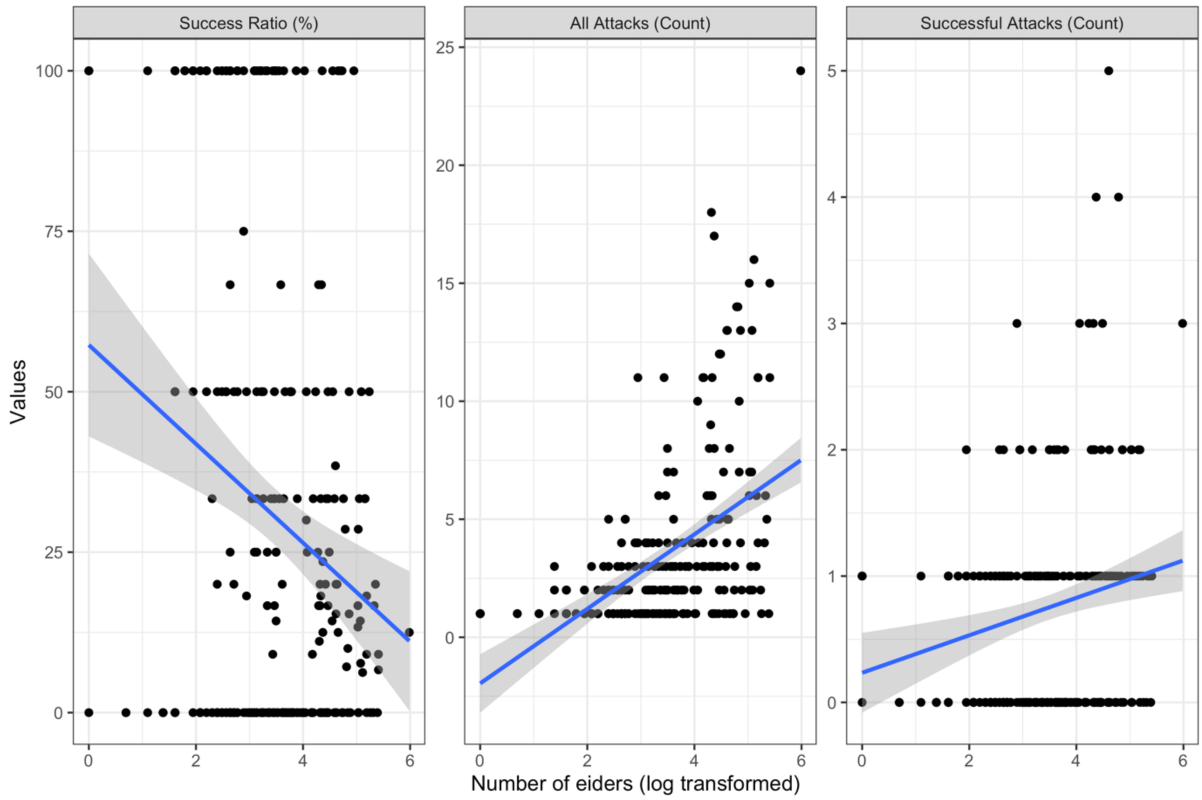

Figure 4: The response of gulls to increasing eider group size. The x-axis is the log transformed number of eiders in each group. The values for the y-axes are shown in the parenthesis in the header of each plot.

3.3 ABUNDANCE OF EIDERS THROUGH THE STUDY PERIOD

As seen in Figure 5, the total number of eiders visiting Solheimsviken varied around the 250 mark each day from study start until mid-February and peaked at around 400 eiders in early to mid-January. In the middle of February, the total abundance dropped below 100 in about two weeks. From March until the end of the study period the total number of eiders never recovered and never peaked above 50.

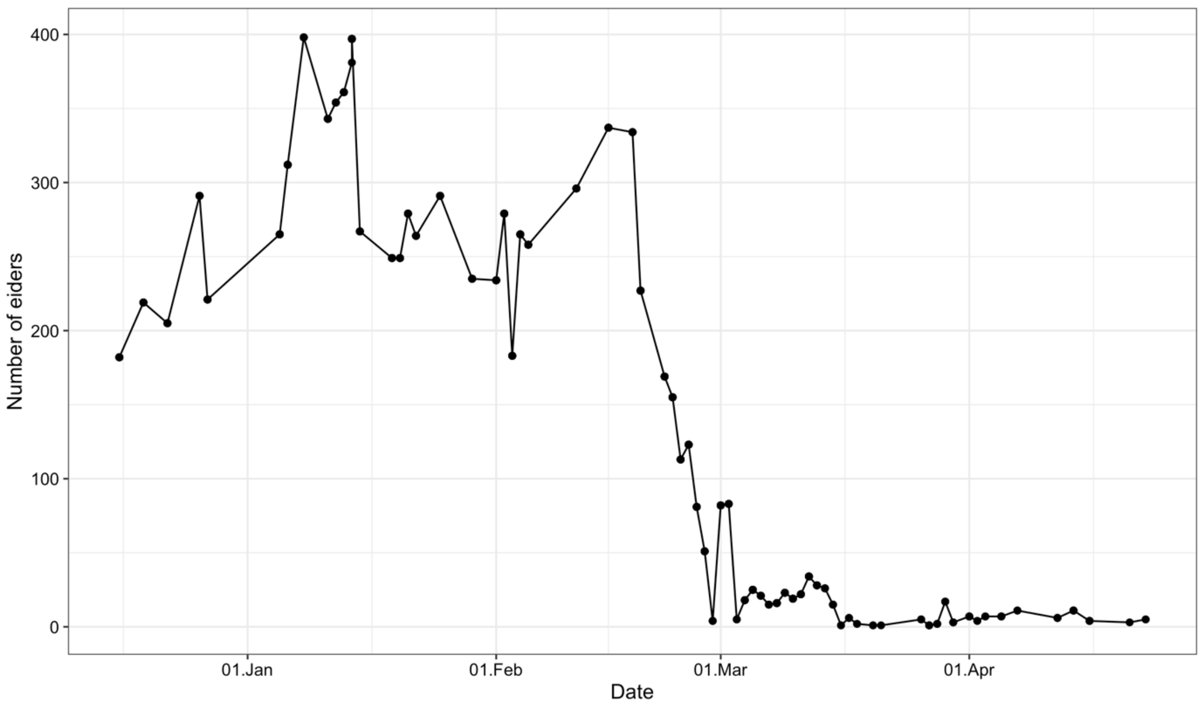

Figure 5: The total abundance of common eiders in Solheimsviken through the study period. The figure is made from the clips which were taken with total abundance in focus.

3.4 EIDER PREY OBSERVED AT THE SURFACE

The only prey the eiders with certainty were observed to consume were blue mussels, starfish, and sea urchins. The eiders were observed handling prey at the surface on more occasions than shown in Figure 6, but prey that could not be distinguished beyond reasonable doubt were not included in the data. The figure shows a vast difference in what prey was stolen by gulls. Only a few of the Echinodermata are sea urchins, with the majority being starfishes. Over half of all starfish and sea urchins were stolen, while only a small part of the blue mussels was stolen.

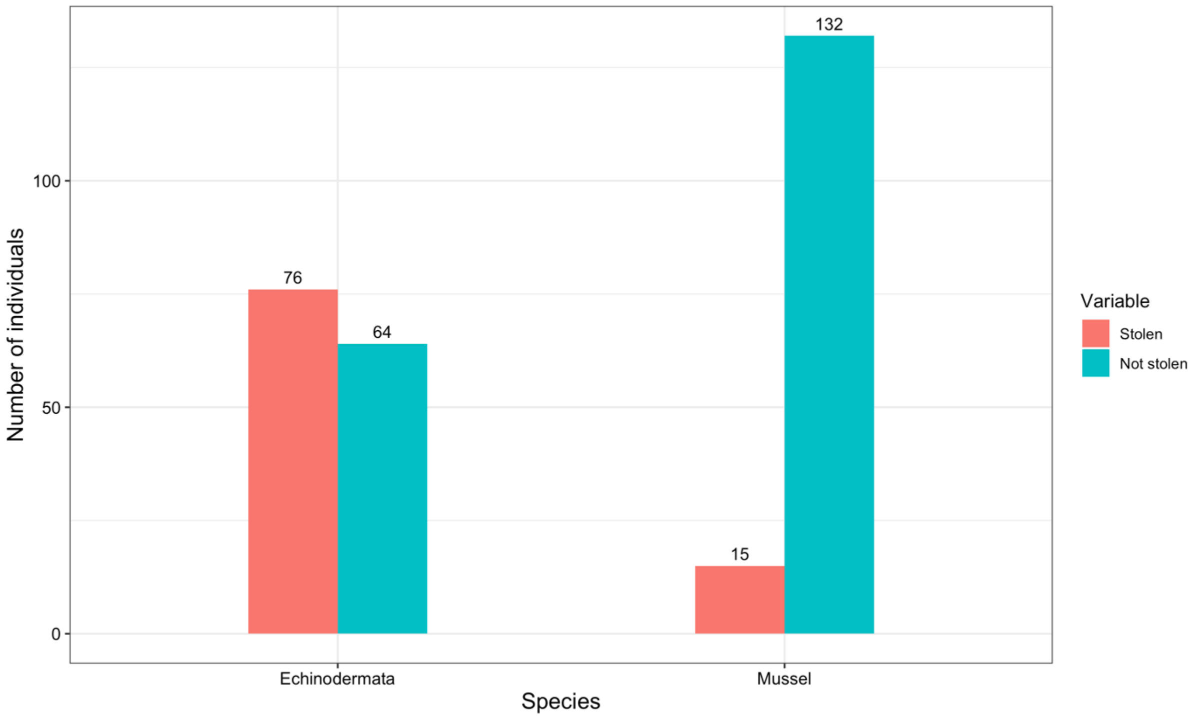

Figure 6: The total amount of visible prey brought to the surface by eiders observed through the study period. The x-axis contains the prey stolen (red) or not stolen (blue), and y-axis the number of individuals observed.

Figure 7 shows four screenshots from the videos of three common eiders and one gull. There were multiple occasions where eider prey was visible at the surface, but many of these clips did not have high enough quality for a photo to be extracted.

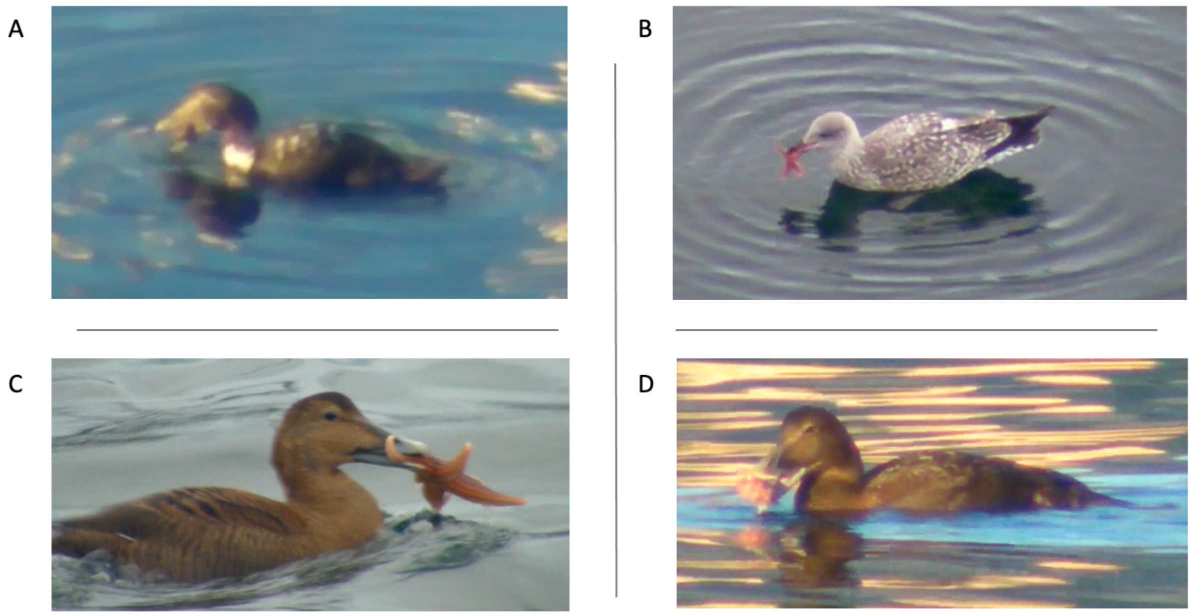

Figure 7: Prey brought to the surface by eiders. A) A young male eider consuming a blue mussel. B) A young herring gull consuming a starfish stolen from an eider. C) An eider female trying to consume a large starfish which is eventually dropped due to it being too large. D) A female eider consuming a sea urchin. As the mussels were small and swallowed rapidly by gulls no photos were managed to be found of gull consuming mussels.

3.5 DATA USED TO TEST SPATIAL DISTRIBUTION

Table 2 contains the total amount of data gathered through the study. The table shows that piers had the highest number for all variables of active groups. Bridges had the lowest number of active groups recorded but had the second highest number of attacks and successful attacks recorded. Open water showed the second highest number of data points but had the lowest number of attacks and successful attacks.

Table 2: Total amount of data collected through the study. "Number of rows" is the total amount of rows from the Excel-sheet containing the data. The values are for groups which were recorded as active, with inactive groups in parenthesis. Third and fourth row show the total amount of eiders and gulls extracted from the number of groupings in the second row. Attacks is the total amount of attacks recorded, both successful and unsuccessful, while the last row show the total amount of successful attacks.

	Open water	**Piers**	**Bridges**	**Land structures**
Number of rows	282 (132)	417 (92)	103 (6)	140 (28)
Eiders	6633 (6140)	17785 (4384)	3408 (77)	5732 (969)
Gulls	328 (135)	940 (142)	198 (5)	258 (52)
Attacks	84	465	201	125
Successful Attacks	17	87	44	35

Table 3 shows the result of the Tukey test for the four grouped locations. As seen, there was not recorded significance between any of the four groups.

Table 3: The p-values of gull/eider ratio for the four grouped locations compared to each other. Values above the **X** line are gull/eider ratio for active and resting groups of eiders. Values below the **X** line are gull/eider ratio for solely active groups of eiders.

	Bridge	**Landstructure**	**FB**	**Openwater**
Bridge	**X**	0.7997	0.4843	0.2269
Landstructure	0.9318	**X**	0.9023	0.4608
FB	0.5370	0.7108	**X**	0.7073
Openwater	0.6573	0.8688	0.9814	**X**

4 DISCUSSION:

4.1 CONSIDERATIONS IN URBAN ENVIRONMENTS

This study provides, for the first time, documentation on the interactions between common eiders and herring gulls in Solheimsviken, Bergen. Since this study was conducted in an urban environment, there has been some additional challenges which would not be experienced in a natural environment.

In some locations there are upwellings caused by excess water from land being pumped into the fjord, both during and after heavy rain. These upwellings are said to not contain any sewage, but they do contain land-living organisms such as worms. Mallards (*Anas platyrhynchos*) and gulls are therefore often observed foraging in these upwellings. At most, over 130 gulls were observed feeding in one of these upwellings. Since the upwellings contain such a high number of gulls, regardless of eider presence, it was decided not to include eiders diving there, as the number of gulls present would be artificially *high*. No kleptoparasitism was observed between mallards and gulls, likely because they both have access to the same prey. Attacking mallards would probably not be energetically efficient, as simply waiting for the prey to surface would yield the same energetic income.

In urban areas where humans are abundant, they can directly affect bird behavior by providing food sources such as breadcrumbs. Often through the study people was observed feeding the swans and mallards in the fjord. Eiders did not show any interest in the feeding, but as gulls are highly opportunistic, they preferred the throwing of food rather than stealing food from eiders. This resulted in an artificially *low* presence of gulls in eider groups, so when people were feeding birds in the study area, no groups of eiders were recorded. When humans walked too close to eiders, the eiders got scared and fled by “running” on the water flapping their wings. However, this rarely happened, and only affected a few of the recordings.

4.2 GULL PRESENCE & SEASONALITY

4.2.1 GULL PRESENCE

Many previous studies have focused on the number of kleptoparasites with the abundance of hosts (Barnard, Thompson, & Stephens, 1982; Brockmann & Barnard, 1979; Caldow & Furness, 2001; Dunn, 1973; Thompson, 1986). To my knowledge, there are few studies with extensive counting of gull presence in different sized groups of eiders (C. M. Waltho, 2013). The main hypothesis in this study was that the number of gulls in eider groups would increase linearly with the size of the group. This type of functional response is type 1, where the number of prey consumed per predator is directly correlated to the prey density, as described by Holling (1959). In this study, a positive correlation between the number of eiders and the number of gulls was found (Figure 2), and the activity of the eider groups were found to affect the number of gulls present. The positive correlation found in this study indicates that gulls follow an ideal free distribution. Both the findings are in accordance with the results of the study by Varpe (2010). Varpe (2010) found that eider groups diving regularly had a higher chance of gulls being present than groups diving more seldom, and that groups of eiders with multiple gulls present were larger than groups of eiders with one gull present. Ideal free distribution was also found by Waltho (2013) who found a positive correlation between eider group sizes and gull presence in lakes in Scotland. The ideal free distribution in this study is, however, in contrast to the findings of Ingolfsson (1969) and Prŷs-Jones (1973), who found that gulls defended their rafts against other gulls.

4.2.2 SEASONALITY

The number of gulls present in eider groups had a decreasing trend through the study. This finding is in accordance with the findings of Varpe (2010), which also show this trend. Varpe (2010) found that the probability of gull presence declined with season and hypothesized that the decreasing number of eiders present might be the reason. This might explain the large drop in gull presence when the abundance of eiders fell from 400 to 50 in late February, but the gull presence decreased even before this massive drop. The number of gulls present did indeed drop from December to mid-February (Figure 5), when a large number of eiders still visited the study area.

The large decrease in gull presence after the large drop in eiders abundance might be explained through the optimal foraging theory. When there are less eiders in the system, the profitability of kleptoparasitism should decrease, resulting in the profitability of other foraging strategies surpassing kleptoparasitism. When this happens, gulls should adopt other foraging strategies, which will likely cause them to leave Solheimsviken.

4.3 Attack success ratio & Prey brought to the surface

4.3.1 Attacks and success ratio

Previous studies have found that when kleptoparasites are present, foraging birds increase synchrony in order to reduce the kleptoparasitism (Le Corre & Jouventin, 1997; Schenkeveld & Ydenberg, 1985). In this study, synchrony was not measured. However, the study does show that eiders in Solheimsviken benefit from diving in groups with regards to having their prey stolen. When eider group sizes increased, both the number of attacks and the number of successful attacks increased (Figure 4). However, even though both these number increased, the success rate of gull attacks did decrease with the increase in eider group sizes (Figure 4). This happens because the number of successful attacks is increasing slower with group size than the total number of attacks. In other words, large groups of eiders experience an increased number of attacks compared to small groups, but not an equal increase in the number of successful attacks. Thus, when looking at kleptoparasitism alone, these results suggest that it is safer for each individual eider to dive in large groups.

During the observations it was noticed that when being attacked by gulls, eiders usually left the prey for the gull to steal. The eiders did however sometimes dive multiple times with the prey when being attacked. Diving with the prey gives the eider more time to handle it, increasing the chance to successfully consume it. However, diving with the prey does not guarantee the prey being consumed. On several occasions, the eiders lost their prey after trying to evade attacks. The gulls did not always attack by flying towards the eiders. During the study, gulls were observed swimming after eiders with prey, where the eider tried to escape by swimming in another direction. This interaction might be explained by the gull trying to conserve the energy used by flying, trying to harass the eider to drop the prey instead. However, the gulls were never observed to be successful in obtaining prey when swimming after the eiders.

4.3.2 Prey brought to the surface

For kleptoparasitism to be deployed by gulls, it should be the most profitable strategy available (MacArthur & Pianka, 1966). Blue mussels are the main prey for common eiders, but previous studies have shown that when more favorable prey are available, gulls will prefer these over blue mussels (MacCharles, 1997; Paulsen, 1987; C. M. Waltho, 2013). These studies showed that sea urchins and starfish were the preferred prey, and gulls seldom stole blue mussels when other prey were available. Waltho (2013) showed that starfish have a higher energetical content than both sea urchins and blue mussels. When only accounting for energetical content, starfish should be the preferred prey. This was found by Verbeek (1977), showing how herring gulls choose starfish over blue mussels when feeding in areas where both were available. This has further been supported by Sibly & McCleery (1983), stating that gulls can fulfill their daily energy requirement faster when feeding on starfish. MacCharles (1997) found that sea urchins would be preferred by gulls over blue mussels. As sea urchins are not energetically favorable (reviewed by Waltho, 2013), energy content is not the reason for gulls choosing them over blue mussels. The handling time are a more likely explanation to the preference of sea urchins. Sea urchins do in general require a longer handling time at the surface, which increase the chances of gulls managing to steal them, decreasing the chances of spending energy on unsuccessful attacks.

In this study, mussels were undoubtedly the prey least stolen from eiders. Approximately the same number of Echinodermata and mussels was observed brought to the surface, however, over half of all Echinodermata brought to the surface was stolen (Figure 6). The majority of Echinodermata stolen were starfish, which both require more handling time and are energetically more favorable compared to blue mussels. The few sea urchins brought to the surface by eiders were not stolen, probably because of their small size and hence low handling time. Mussels brought to the surface required shorter handling time than a starfish, increasing the chance for eiders to swallow it before the gull could attack.

4.4 SPATIAL DISTRIBUTION

Early in the study it was speculated that gull presence in eider groups was influenced by what the eiders were feeding on. Large groups were noticed feeding in some locations with no gulls present, while small groups were feeding in other locations with multiple gulls present. Not having any information about the benthic distribution, the theory was that there in fact were differences throughout the study system. This theory was further supported by the work of MacCharles (1997) which found that gulls do in fact follow groups foraging on favorable prey, as defined earlier. To test whether the locations in which the eiders dove had any effect, all the diving spots were grouped together in four groups. These four groups were run through a Tukey test to see whether there was a significant difference in gull presence between the four groups. None of the four groups were significantly different from each other (Table 3), and the system was therefore treated as one system.

4.5 FURTHER STUDIES

To further understand the spatial distributions in Solheimsviken a mapping of the benthic communities would likely give an increased understanding of the interactions between eiders and gulls. Knowing the benthic distribution would enable the possibility of studying the relationship between eider diving frequency and the different types of prey. A study of the benthic distribution before and after the overwintering period would open the possibility to investigate how the constant feeding from the eiders affect the benthic organisms. And it would open the possibility to examine the prey selection of eiders, through examining the size of the benthic species not consumed by the eiders.

Continuing the monitoring of eider abundance during overwintering in Solheimsviken would also be an important future study. Since most of the toxins have been removed from the fjord, the benthic communities should be able to recover. Over time it would be interesting to see if the same number of eiders continue using Solheimsviken as an overwintering ground, or if the numbers decline. As eiders are easily startled by human activities it is important to take them into account when continuing building along the fjord.

4.6 CONCLUDING REMARKS

The main aim of this study was to examine the interactions between common eiders and gulls in the urban inlet, Solheimsviken. The study shows a clear positive correlation between the number of eiders and the number of gull present and found that the activity of the eiders affected the number of gulls present. The number of attacks and successful attacks did go up with increasing eider group sizes, but the success ratio did decrease as the number of eiders increased. The study identified the number of eiders visiting the system in most days throughout the study period. Lastly, the study documented what the eiders brought to the surface, and what the gulls were able to steal, showing that large energy dense prey is preferred by gulls when stealing from eiders.

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6 APPENDICES

6.1 NORMAL DISTRIBUTION TESTS

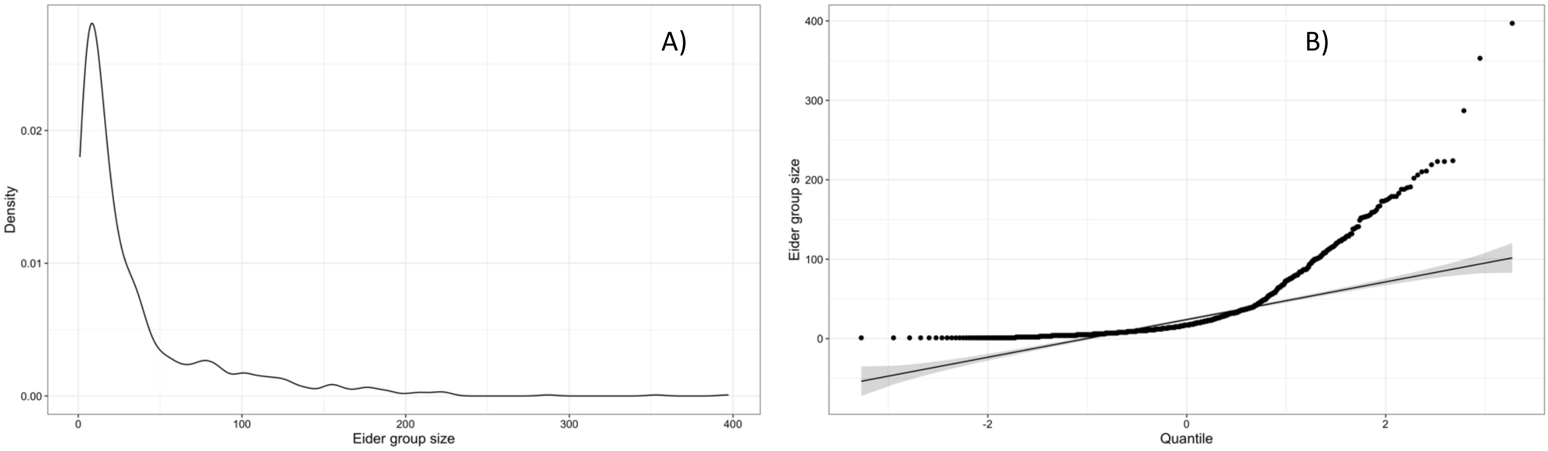

Figure 5: Two visual analysis checking the different eider group sizes for normal distribution. In A) the peak would be more central in the plot if the data were normally distributed. For B to be normally distributed the dots should be inside the greyed-out area, around the solid black line.

6.2 FULL REPRODUCIBLE CODE

```
library(patchwork)
library(ggplot2)
library(ggExtra)
library("readxl")
library("dplyr")
library(tidyverse)
library(hrbrthemes)
library(viridis)
library(lubridate)
library(ggpubr)
library(betareg)
library(emmeans)
library(gapminder)
library(viridis)
library(reshape2)
library(lme4)
library(car)

setwd("~/Desktop/Master/R/StianStatistikk")

#raw data fra excel fila
data <- read_excel("Observasjoner_Myeslettet.xlsx")
data4 <- read_excel("Observasjoner_Myeslettet.xlsx", 7)
dataTes <- read_excel("Observasjoner_Myeslettet.xlsx", 8)
dataTesA <- read_excel("Observasjoner_Myeslettet.xlsx", 9)
DataSuccess <- data4 <- read_excel("Observasjoner_Myeslettet.xlsx", 7)

data <- transform(data, Date = as.Date(Date))
class(data$Date)

data4$Attacks <- as.numeric(data4$Attacks)
class(data4$Attacks)

data4$Successful <- as.numeric(data4$Successful)
class(data4$Successful)


#lage ny column med log distribuert gull
data4$logEiderTot=log(data4$EiderTot)
data4$logGulls=log(data4$Gulls)

ggplot(data4,aes(log(Gulls+1), log(EiderTot))) +
  geom_point() +
  geom_smooth(method=lm, se=FALSE)


#Lage Øystein Graf ####

dataGraph <- data %>% mutate(Month = month(ymd(Date), label = TRUE,
abbr = FALSE),
                             activity=factor(Activity))%>%
  filter(!is.na(activity))

# Bytte navn fra December til Januar i datasetter under Month
```

```
levels(dataGraph$Month) [match("December", levels(dataGraph$Month))] <-
"January"

ggplot(dataGraph, aes(x=Date, y=EiderTot, size = Gulls, fill =
activity)) +
  geom_point(alpha=0.7,shape=21) +
  #facet_wrap(~Month,scale="free")+
  theme_bw()+
  theme(legend.position="right") +
  labs(x="Date", y="Eider group size (individuals)")+
  font("xlab", size=12)+
  font("ylab", size = 12)+
  theme(axis.text.x = element_text(size = 10, color = "black")) +
  theme(axis.text.y = element_text(size = 10, color = "black"))+
  scale_x_date(date_labels = "%d.%b")+
  scale_fill_discrete(name = "Activity", labels = c("Resting",
"Active"))+
  scale_radius(range = c(1,12)) +
  guides(fill = guide_legend(order = 1),
         size = guide_legend(order = 2)) #+
  #ggsave("OysteinGraf.tiff")

#Trying to make a grouped bar chart ####
PreyBar <- data.frame(Species = c("Mussel","Echinodermata"), Stolen =
c(15,76), Non_stolen = c(132,64))
PreyBarM <- melt(PreyBar, id.vars='Species')
PreyBarM

ggplot(PreyBarM, aes(x = Species, y = value, fill = variable)) +
  geom_col(position = "dodge",width = 0.4) +
  geom_text(
    aes(label = value),
    colour = "black", size = 3.5,
    vjust = -0.5, position = position_dodge(.4)
  )+
  theme_bw()+  labs(x="Species", y="Number of individuals",
legend="Variable")+
  font("xlab", size=13)+
  font("ylab", size = 13)+
  theme(axis.text.x = element_text(size = 10, color = "black")) +
  theme(axis.text.y = element_text(size = 10, color = "black"))+
  scale_fill_discrete(name = "Variable", labels = c("Stolen", "Not
stolen")) #+
#ggsave("GroupedbarChar.tiff")

#Testing if data is normal distributed, it is not:
# Normal distribution ####
sign_test<- data4
set.seed(1234)
dplyr::sample_n(sign_test, 10)

ggdensity(sign_test$EiderTot) +
  theme_bw()+
  labs(x="Eider group size", y="Density") +
  font("xlab", size=13)+
  font("ylab", size =13) +
  theme(axis.text.x = element_text(size = 10, color = "black")) +
  theme(axis.text.y = element_text(size = 10, color = "black"))#+
```

```
  #ggsave("ggdensity.tiff")

ggqqplot(sign_test$EiderTot) +
  theme_bw()+
  labs(x="Quantile", y="Eider group size") +
  font("xlab", size=13)+
  font("ylab", size =13) +
  theme(axis.text.x = element_text(size = 10, color = "black")) +
  theme(axis.text.y = element_text(size = 10, color = "black"))#+
  #ggsave("ggqqplot.tiff")
shapiro.test(sign_test$EiderTot)

mean(data4$EiderTot)
sd(data4$EiderTot)
var


# Eider/Gull correlation plot with log ####

  ggplot(data4, aes(x=log(EiderTot), y=log(Gulls+1))) +
    geom_point(fill="blue", aes(group = Gulls)) +
    theme_bw()+
    geom_smooth(method=lm, se=FALSE)+
    labs(x="Number of eiders (log transformed)", y = "Number of gulls
present (log transformed)")+
    font("xlab", size=12)+
    font("ylab", size = 12) +
    theme(axis.text.x = element_text(size = 10, color = "black")) +
    theme(axis.text.y = element_text(size = 10, color = "black")) #+
    #ggsave("EiderGullCorrelationLog.tiff")

#Eider/Gull correlation plot without log ####
ggplot(data4, aes(x=EiderTot, y=Gulls)) +
  geom_point(fill="blue", aes(group = Gulls)) +
  theme_bw()+
  geom_smooth(method=lm, se=FALSE)+
  labs(x="Number of eiders", y = "Number of gulls present")+
  font("xlab", size=12)+
  font("ylab", size = 12) +
  theme(axis.text.x = element_text(size = 10, color = "black")) +
  theme(axis.text.y = element_text(size = 10, color = "black")) #+
#ggsave("EiderGullCorrelation.tiff")



#Teste egen sig.test (Over X linjen med grouped locations) ####
Vector_main2 <- dataTes %>% select(c("Group_Location",
"Ratio_GullEider", "Location"))%>%filter(!Group_Location=="undef")

Vector_main2 <- Vector_main2 %>%
 mutate(rge4=(Ratio_GullEider*((1259)-1)+0.5)/(1259))

modelTest <-
lmer(log(rge4)~Group_Location+(1|Location),data=Vector_main2)

res2 <- emmeans(modelTest , ~ Group_Location)
pairs(res2)
```

```
#Egen sign. test for kun aktivitet (under X linjen med grouped) ####

Vector_main3 <- dataTes %>% select(c("Group_Location",
"Ratio_GullEider", "Location", "Activity"))%>%filter(!Activity=="0")
Vector_main3 <- Vector_main3 %>%
  mutate(rge3=(Ratio_GullEider*((942)-1)+0.5)/(942))

modelTestA <-
lmer(log(rge3)~Group_Location+(1|Location),data=Vector_main3)

res3 <- emmeans(modelTestA , ~ Group_Location)
pairs(res3)

#Testing active groups vs inactive ####

Vector_main4 <- dataTes %>% select(c("Activity", "Ratio_GullEider",
"Location"))
Vector_main4 <- Vector_main4 %>%
  mutate(rge5=(Ratio_GullEider*((1260)-1)+0.5)/(1260))

modelTestB <- lmer(log(rge5)~Activity+(1|Location),data=Vector_main4)

Anova(modelTestB, type="III")


#Sign test 2 ####

ModelEider <- lmer(log(EiderTot) ~ log(Gulls+1)+(1|Location),
data=dataTes)

Anova(ModelEider, type="III")


#fjerner dager hvor det ikke er m?lt Total.Abundance, lagrer det som
data3
data3 <- data[!(data$Total.Abundance==0),]

# Abundance plot ####
ggplot(data3, aes(x=Date, y=Total.Abundance)) +
  geom_line()+
  geom_point(shape=19, color="black", size=1.5) +
  theme_bw() +
  labs(x="Date", y="Number of eiders")+
  font("xlab", size=12)+
  font("ylab", size = 12)+
  theme(axis.text.x = element_text(size = 10, color = "black")) +
  theme(axis.text.y = element_text(size = 10, color = "black"))+
  scale_radius(range = c(1,12)) +
  scale_x_date(date_labels = "%d.%b")#+
  #ggsave("Total Abundance.tiff")

#Success and attacks ####
DataSuccess$Attacks <- as.numeric(DataSuccess$Attacks)
class(DataSuccess$Attacks)
DataSuccess$Successful <- as.numeric(DataSuccess$Successful)
class(DataSuccess$Successful)

DataSuccess$GullEider=(DataSuccess$Gulls/DataSuccess$EiderTot)
```

```
DataSuccess$AttackRatio=((DataSuccess$Successful/(DataSuccess$Attacks))
*100)

DataSuccess <- DataSuccess[!is.na(DataSuccess$AttackRatio),]
DataSuccess2<- DataSuccess%>%pivot_longer(cols =
c("Attacks","Successful", "AttackRatio"),names_to="Attack_Type",
values_to="Values")


# Point plot for success ratio (previously violin) ####

new_labels <- c("AttackRatio" = "Success Ratio (%)", "Attacks" = "All
Attacks (Count)", "Successful" = "Successful Attacks (Count)")

# Three scatplots with attack and successful attacks
pViolin <- ggplot(DataSuccess2, aes(x=log(EiderTot), y=Values)) +
  geom_point() +
  facet_wrap(~Attack_Type, scales="free", labeller =
labeller(Attack_Type = new_labels))+
  geom_smooth(method="lm")+
  labs(x="Number of eiders (log transformed)")+
  font("xlab", size=12)+
  theme(axis.text.x = element_text(size = 10, color = "black")) +
  theme(axis.text.y = element_text(size = 10, color = "black"))+
  theme_bw() #+
  #ggsave("AttackRatio.tiff")

pViolin

#Significance tests for the three plots ####
SigTestAttack <- glmer(Attacks~log(EiderTot)+(1|Location), data =
DataSuccess, family = "poisson")
Anova(SigTestAttack, type="II")
SigTestSucc <- glmer(Successful~log(EiderTot)+(1|Location), data =
DataSuccess, family="poisson")
Anova(SigTestSucc, type="II")
SigTestTot <- lmer(AttackRatio~log(EiderTot)+(1|Location), data =
DataSuccess)
Anova(SigTestTot, type="II")
```