Egg size in breeding great cormorants (*Phalacrocorax carbo*):

Variation between colonies, a methodological evaluation and a comparison between great cormorants and European shags (*Gulosus aristotelis*)

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Abstract

Great cormorants (*Phalacrocorax carbo,* hereafter called cormorant) are blamed for depletion of fish populations and have been subject to several control measures, such as culling and oiling of eggs. On the Swedish west coast the European shag (*Gulosus aristotelis*, hereafter called shag) is present as well. In contrast to the cormorant, the shag is a red listed species.

By examining colonies in the south of Sweden, a study examining egg size variation of cormorant eggs between colonies was conducted, as well as a study comparing shag and cormorant egg sizes to see if that could be a way of separating eggs of the two species from each other.

The study showed that cormorant eggs are larger on the west coast compared to the east coast. It also showed the overlap in size range between shag and cormorant eggs to be too large for it to be a safe method for separating eggs of the species with certainty.

In addition, the study showed that image analysis of photos of eggs could be a possibly effective method for gathering large sets of data in the field in a quick way.

In summary, this study contributed with fundamental knowledge of cormorant biology.

Hopefully the gathering of egg size data can continue beyond this project, building a larger and more established summary of egg size variation.

Keywords: Cormorant, *Phalacrocorax carbo*, Shag, Egg size, Image analysis

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1. Background

We live in an age where anthropogenic exploitation of natural resources is the rule rather than the exception, even though the fact that resources aren't endless is consensus. The biodiversity is decreasing in an unprecedented way, with the extinction rate of species being *at least* 100 times faster than baseline, and estimated to reach a rate of 1000 times faster than baseline (Pimm 2010). At the same time, Swedish fish populations are under severe pressure from overfishing (Havet.nu 2025). The challenge of protecting species at the same time as meeting people's needs is therefore larger than ever.

In Sweden, the great cormorant *Phalacrocorax carbo*, hereafter cormorant, has been accused of diminishing fish stocks and impairing biodiversity, thus damaging not only nature but also people's income and food production. Despite general lack of scientific evidence of negative effects of cormorants, the species has been subject to a number of population control measures over the years (Naturvårdsverket 2023; Länsstyrelsen Gävleborg 2026).

Harming birds or their nest site is forbidden according to EUs directive 2009/147/EC - the conservation of wild birds. For a bird to be exempt from these rules, other solutions to minimize the consequences caused by the bird have to be deemed unsatisfactory. They also need to meet the criteria of article 9.1(a) where, amongst other things, damage to fisheries is mentioned. Methods used in Sweden to control the cormorant population are culling, scaring tactics and oiling of eggs (Naturvårdsverket 2025).

In order for stakeholders, in this case government politicians and officials at Sweden's County administrative boards, to make informed decisions when allowing radical measures of actually killing birds, in-depth knowledge of the species in question as well as the role in its ecosystem is crucial. Otherwise, the possibly unforeseen damage can be devastating.

1.1 The impact of cormorants on fish populations

The impact of cormorants on fish populations and natural ecosystems is a topic where the debate in the media and in politics does not always align with the research carried out on the subject (Hamrén 2025). Multiple researchers point out that knowledge about the impact from cormorants on fish populations is limited, and that existing data show no general negative effects of cormorant predation on healthy fish populations, though it can have a negative impact on more vulnerable populations (Ovegård et al 2021). Aquatic ecosystems are also affected by multiple factors, biotic and abiotic, making it challeninging to determine which effects are caused by cormorants alone (Lundström et al 2024). In a global meta-analysis of cormorant predation effects on fish populations, no definite conclusion of whether their effect in general is positive, negative or neutral could be made (Ovegård et al 2021). Therefore, simply saying cormorants are good or bad for fish populations, lacks scientific basis.

1.2 The impact of cormorants on terrestrial ecosystems

Beside the impact on fish populations, there are also people claiming that cormorants damage fishing gear and/or fishery catches as well as destroying or harming terrestrial ecosystems when their feces destroy the trees they nest in (note that the cormorant nest both on the ground and in trees but that the European shag (*Gulosus aristotelis*, hereafter called shag) strictly nest on the ground (SLU Artdatabanken 2026a; SLU Artdatabanken 2026b)).

A study of the effects breeding cormorants have on Stockholm's archipelago in Sweden showed that a more heterogeneous structure in the archipelago benefitted several taxa such as scavenging and fungivorous *Coleopteras* (beetles). A more heterogenous landscape most likely is beneficial for the overall biodiversity of Stockholm's archipelago. (Kolb et al 2010). A study have shown that even though the vegetation dies while the colony is active, it recovers when the cormorants leave the islands (Somers m.fl., 2007). However, an active cormorant colony is not equal to an ecosystem set on hold until they leave. It has been shown that other bird species seek refuge in cormorant colonies as a way of evading dangers (Morandini m.fl., 2020). Cormorant colonies also contribute with nutrition which benefits future vegetation. Due to the interconnection between cormorant and other species, removal of cormorants might cause unforeseen effects elsewhere in the ecosystem.

1.3 Measures used to control the cormorant population in Sweden

Cormorants are a topic of discussion and conflict in Sweden and several measures have been taken in order to control the population. Oiling of eggs is a recent but nowadays common method. By dipping the eggs in oil (usually similar to cooking oil), air cannot enter the egg, which results in the fetus suffocating. (Broome 2022).

1.4 Measuring bird eggs in research

When measuring bird eggs it is common to use length, breadth and volume rather than weight. Traditionally, eggs have been measured using calipers, but as technology has advanced, other methods such as measuring size with the help of an image analysis software, has developed. An example of this is a study from 2007. The authors say photographing and analysing the eggs requires less handling of the eggs than calipers. However, their method used a camera mounted on a stand and a plate where the eggs were put for photographing nests (Bridge et al 2007).

1.5 Ecology and history of the cormorant

The cormorant is an aquatic bird specialising in eating fish. They nest in colonies around lakes or along the coast, either on the ground, in bushes or up in trees. (SLU Artdatabanken 2026b). What the nests are made of and their integrity vary a lot, from simply pushing together scrapes of vegetation to building more sturdy nests of vegetation (Cramp & Simmons 1977). The species is split into several subspecies, of which *Phalacrocorax carbo carbo* and *Phalacrocorax carbo sinensis* can be found in Sweden. (SLU Artdatabanken 2026b). It is assumed that the continental subspecies *Phalacrocorax carbo sinensis* is the cormorant subspecies nesting in Sweden. However, sightings of the Atlantic subspecies *Phalacrocorax carbo carbo, based on morphological characters,* nesting on the west coast, have been made. This suggest that both subspecies nest there and that hybrids between the two can not be excluded (Lundström 2024; Grøndahl & Johnsen 2024). This study will therefore not be limited to *P. c. sinensis* when reading previous studies but include both subspecies. Furthermore, a recent study from Norway concludes that genetic hybrids of the two subspecies exist (Grøndahl & Johnsen 2024).

To have a better understanding of the cormorant, a short history of Swedish cormorant distribution is beneficial. In a study from 2001, Engström summarizes the historical occurrences of the cormorant in Sweden, starting from the last glaciation until present. The cormorant has been recorded in Sweden on and off over the centuries with bones as old as 9 000 years. More modern records of the species can be found in Olof Rudbeck the Youngers' notes in the late 17th century. Cormorant is missing from the famous Carl von Linneaus notations, which might suggest that cormorants were not present in Sweden during that time. Records show that the cormorant actually went extinct as a nesting bird in Sweden at the turn of the last century only to return in the middle of the 1900's.

During the 20th century, the cormorant population fluctuated in Europe and Sweden. In the 1970s, measures to protect the cormorant were applied since there were only a couple of thousand of breeding couples left in Europe. (Engström 2001). Since then, the population has increased, and today, there are many people describing the populations as too large instead.

1.6 Previous studies on the egg size of cormorants

Studies of the egg size of cormorants in Sweden have not been published before this. However, a thorough study was made in Greece in 1999-2000. Researchers monitored four colonies on different islands and found that even though egg length did not show any significant difference between the colonies, breadth did. This resulted in a difference in mean egg volume between the islands. The authors point out that more research of how multiple factors such as size of female and male parent influence egg size is needed for definite conclusions, but a factor behind the difference in mean egg breadth could be that the islands are inhabited by different subspecies of cormorant; *P. c. carbo* and *P. c. sinensis*. (Liordos & Goutner 2003). Findings like these would need to be validatet with genetic testing.

An important disclaimer in Liordos & Goutner's study (2003) is that egg size for the most part is hereditary. Even though the parent's size plays a role in egg size, it won't, most likely, trump genes. This further reinforces the hypothesis made by Liordos and Goutner (2003) of the islands consisting of two different subspecies of cormorants. They believed that the eggs of *P. c. carbo* were larger than those of *P. c. sinensis*. The larger eggs had a mean breadth of 3.98 cm and mean volume of 50.63 cm3 while the smaller eggs' mean breadth were 3.89 cm and mean volume 47.69 cm3. (Liordos & Goutner 2003).

Older birds tend to lay larger eggs. This is a phenomenon that's been recorded in several other bird species (Forslund & Pärt 1995). In 1969, Coulson et al published a study confirming that the same patterns apply to the cormorant (in the study, restricted to the subspecies *P. c. sinensis*). They also state that this pattern occurs in shag populations as well.

In 2008, Liordos and Goutner did another study in Greece on cormorants, this time in three colonies. They found that the mean volume in the eggs laid was between 47-50 cm^3. At the colony with the largest eggs, they believe the individuals to be older, hence laying larger eggs. In the colonies with the largest eggs, the difference in mean volume compared to the other colonies was significant. (Liordos & Goutner 2008).

Cormorant egg laying has been studied in Tibet as well. During 1999 and 2000 researchers observed egg size, among other things. The average size of the eggs was 61.01 mm in length and 34.1 mm in breadth. (Zhang et al. 2007). This phenomenon of breadth being the factor showing significant difference and not length has also been shown in an article where cormorants were observed in the Caspian sea (Rahimi et al. 2012)

At the lake in Tibet, the cormorants started to build nests in April until the middle of June, a time period which corresponds with other observations of the birds breeding behaviour (Zhang et al 2007; Liordos & Goutner 2003; Lundström et al 2024). When measuring egg size, an ANOVA-analysis showed no significant difference size-wise between the breeding season of 1999 and 2000 (Zhang et al. 2007).

In Rahimi's study (2012) in the Caspian sea, they also measured average length and breadth of eggs but also the range of each parameter. Mean breadth of eggs in the colony during 2009 and 2010 was 37.3 mm and 36.8 mm, respectively. Mean length was 62.9 mm and 62.7 mm. The range for breadth is close to 35-40 mm in both years and 60-66 mm for length.

1.7 Ecology of the European shag

The shag was first known to nest in Sweden in 2004, on the west coast. Since then, the shag has still only been found off the west coast of Sweden, with an increasing number of nesting birds. (SLU Artdatabanken 2026b). Compared to the cormorant (classified as Least Concern, LC), the shag is classified as near threatened (NT) by Artdatabanken, the Swedish agency responsible for assessing conservation status for species in Sweden (2026a).

The shag is a strictly marine species, another aspect that sets the cormorant and the shag apart from each other. Despite the birds differing in size and appearance, it can be difficult to tell the species apart in the field, something biologists as well as hunters can testify to (SLU Artdatabanken 2026b; Ekeström 2023).

As shags become more common in Sweden and breed together with cormorants in joint colonies, finding effective ways to make sure it is cormorant eggs, and not shag eggs, getting oiled is crucial in order to avoid illegal actions and not damage the redlisted species.

1.8 Previous studies on the egg size of shags

In 1963 - 1967, researchers examined egg size variation of shags, and other species, on Farne island, England. According to the study, multiple bird species, including *Rissa tridactyla*, exhibit the behaviour of older females laying larger eggs and having a higher nesting success. Additionally, studies from the 1950's claim that the order in which eggs are laid within a clutch contribute to their size variation. This data led the researchers to investigate whether the same was true for the shag, which it was.

Farne island has shag colonies where almost all newborns have been ringed, hence enabling studies connected to age. In short, shags tend to lay larger eggs as they age and older birds also tend to lay their eggs several weeks earlier than younger birds. Egg size also showed a larger variation among younger females. These patterns, of older females laying larger eggs, also showed when females of different ages breeding at the same time were studied. (Coulson et al. 1969). Therefore, with enough knowledge about the relationship between egg size and age of the female, it might be possible to say something about the parent bird's age in general at colonies simply by observing the eggs.

In Coulson et al's study (1969) all measurments are divided by age group. Since this study does not take age into account, I have taken the liberty to calculate the mean length, breadth and volume (Hoyt 1979) of all the eggs measured in their study. Some eggs are annotated as mean values of a clutch. Looking at the population as a whole, the shag eggs have a mean length of 61.2 mm, mean breadth of 38.1 mm and mean volume of 45.3 cm^3.

In 1985, in the northern parts of Norway, researchers studied the importance of egg size and parental quality for shag nestling success. The study examined both egg size and the size of females laying eggs. By exchanging small eggs with large eggs and vice versa in nests, researchers were able to determine whether or not the nestlings' success correlated with size in female and egg size. Conclusions from the study points to large egg size being the main contributor to successful nestlings for the first third of their life in the nest. For the remaining time in the nest, the size of nestlings depends more on the parent providing food and safeguarding the nestlings. (Amundsen & Stokland 2024).

Furthermore, the researchers examined egg size variation within shag clutches and found that larger eggs were less vulnerable to predation (Amundsen & Stokland 2024). Reasons behind this phenomenon are not discussed further in this article, but would be an interesting subject to conduct research on.

1.9 Objectives and research questions

The complex situation the cormorant finds itself in, has inspired me to conduct a study which can contribute and hopefully add, to the knowledge of the ecology of the species. By taking the first step in understanding what egg size variation looks like for cormorants, I hope to not only contribute to basic research, but also spark interest in researchers and practitioners to study egg size in relation to other traits such as age in parent birds, food availability, genetics and much more, further. This study examines egg size in relation to geographical dispersion of the ten visited colonies.

With a potential risk for shag eggs to be subject to controlling measures aimed at cormorants, such as oiling of eggs, I hope research on what the two species share and not (in this case egg size), to be one way of finding a science-based method to make sure shag eggs don't fall victims for culling and/or oiling of eggs. The study of shag egg variations will be conducted at a small scale, as a first attempt to see whether it is possible to distinguish between the species using egg size or not, or if more shag egg data need to be collected to draw any conclusions.

In order to get as complete a picture as possible of egg size variation in Sweden, effective but still accurate methods to collect data is needed. I will therefore also carry out an evaluation of image analysis to measure eggs from photographs as a method, rather than measuring each egg by hand with calipers in the field.

For the measuring of eggs to be effective and to disturb the breeding birds' environment as little as possible, as well as minimizing the risks that comes with climbing trees, the study is limited to ground nesting colonies. This type of data collection will be, as far as I know, the first to be done in Sweden. Therefore the study will be as much about gathering data about egg sizes as well as testing methods for measuring eggs effectively. Data will be collected on multiple colonies both on the east and west coast in the south of Sweden.

The questions examined are;

1. *How does egg size vary between cormorant colonies?*
2. *Is there a difference in egg size of cormorant between regions?*
3. *Can eggs from cormorants and shags be separated based on egg size?*
4. *Can photos of eggs and image analysis software work as an effective method of measuring egg size compared to caliper measurements in the field?*

2. Materials & methods

2.1 Field studies

The data for this study was collected in April and May 2026, in ten different colonies located in the south of Sweden (see figure 1). A complete table of colony name, what marine area and county they belong to as well as the amount of eggs measured from cormorants and shags is presented in table 1. In each colony, the aim was to measure 30–50 nests, unless there were too few in total. In some cases time was limited, hence fewer than 30 nests measured. In some colonies, tree nests were abundant, thus making available nests limited for this study.

All measured nests were numbered, and length and breadth of the eggs were measured using a digital caliper. When time and opportunity permitted, the eggs in the nests were also photographed with a standardized reference object next to them, in this case a matchbox from the Swedish brand Solstickan or a small ruler, for subsequent analysis in the image analysis software Image J. The Solstickan matchbox was used since it's an object commonly found throughout Sweden which made it accessible for me and also external people who helped with data collection to get a hold of. Its length was measured with the same pair of calipers used in the field to avoid measurement errors as much as possible. The length was 58.0 mm. The small ruler's own measurements were used.

In order to collect as much data as possible, I received help so that I did not have to be present at every colony where data was gathered.

2.2 Analysis

For the written text in this study, the website Deepl have occasionally been used to help with translations from Swedish to English. Translations have only been made on text produced and written by me. Deepl is an AI translation website, but this website has not been used to generate new text or, for example, summarize scientific articles. I have done the assessment that I have used Deepl in the same way as more traditional translation services, such as google translate.

2.2.1 Hoyt's volume formula

In Hoyt's study from 1979 he explains how intra- and interspecific variation in egg size often balance each other out which results in the possibility to determine most bird species' egg volume with a constant, $K_v = 0.51$. Therefore most species' egg volume can, with 2 % margin of error, be determined with Hoyt's formula volume, $V = 0.51 \times LB^2$. (Hoyt 1979). This method was used in this study, as well as in scientific articles mentioned in the background (see 1.6 and 1.8).

2.2.2 Image analysis

To the best of one's ability, each egg was placed parallel to the matchbox or ruler with a known length in the nest and photographed from above with the aim of causing as little distortion as possible. These pictures were later analysed in the software Image J. The measurements from the caliper measuring were then compared to the measurements from photographs. Before importing the photos in Image J, they were edited so that the contrast between background and egg + matchbox/ruler was as high as possible. In Image J the matchbox or ruler was set as scale, the photo was adjusted to binary through **image > type > 8-bit**. Then **process > binary > make binary** and finally **analyze > analyze particles**. Then Feret (length) and minFeret (breadth) measurements were annotated.

2.2.3 Statistical analysis

In this study, several statistical analyses were used. Therefore, this part will be sectioned off into two pieces; analysing field data and comparing image analysis with calipers. Tukey-tests were carried out in the cases ANOVA-analyses showed a statistically significant difference between categories. These tests will be refered to as post-hoc-tests throughout the rest of the text, since that explains the function of the tests. The code used in R studio was generated with the help of Chatgpt.

Analysis of egg size

In each nest sampled, length and breadth of all eggs were measured. Since several colonies were compared, ANOVA-analysis seemed the most appropriate test-method and a method that's been used in other similar studies as well (Liordos & Goutner 2008; Amundsen & Stokland 2024). The null hypothesis of these tests was as follows (in the examples length is used as variable but the same goes for breadth and volume):

$H_{0(lenght)=}$ egg length in colony 1 = egg length in colony 2 =...= egg length in colony n

(the same goes for breadth and volume)

The alternative hypothesis was:

$H_{1(length)}$ = egg length of at least one colony differs from the other colonies

The test follows a 95% confidence interval meaning that if $p < 0.05$, the difference is significant and the null hypothesis is disproven meaning that there is a difference between the colonies.

For analysing and comparing counties to each other, mean values of length, breadth and volume of counties were calculated. This means that all eggs found in a region were grouped together. In order to do this, the ANOVA-analyses comparing colonies within a county to each other needed to show a p-value > 0.05. The null hypothesis was that there was no difference between the counties, and the alternative hypothesis was that there was a difference between at least two of the counties. A 95% confidence interval was used here as well.

H_0 = egg length/breadth/volume in $county_1$ = … = egg length/breadth/volume in $county_n$

H_1 = egg length/breadth/volume in a county differs from at least one other county

Analysis of image analysis as a method for measuring egg size

For each photographed egg, the software Image J was used to measure length and breadth. Volume was then calculated using Hoyt's formula (1979). Colony by colony, measurements done by hand in the field and with Image J were compared with the help of ANOVA-analyses. If a test did not show a significant difference between the two methods, the possibility of photographs + image analysis being an effective method was deemed more likely.

3. Results

In total, 10 colonies, located in the south of Sweden were visited. It resulted in 667 measured cormorant eggs (two dwarf eggs were removed in analysis = 665 eggs analysed) and 35 shag eggs. Shag eggs were only found in four colonies (Knarrskär, Vindelskär, Sadeln and Stora Orskär) all of which are located in Kattegat on the west coast of Sweden. Measurements were collected by me and Karl Lundström. I collected samples in Västerskär and Östra Trälhavsgrundet and Karl Lundström in the remaining eight colonies. Results are presented in an order from the northernmost colony on the east coast, down south and up north again on the west coast (see the map in figure 1 for reference).

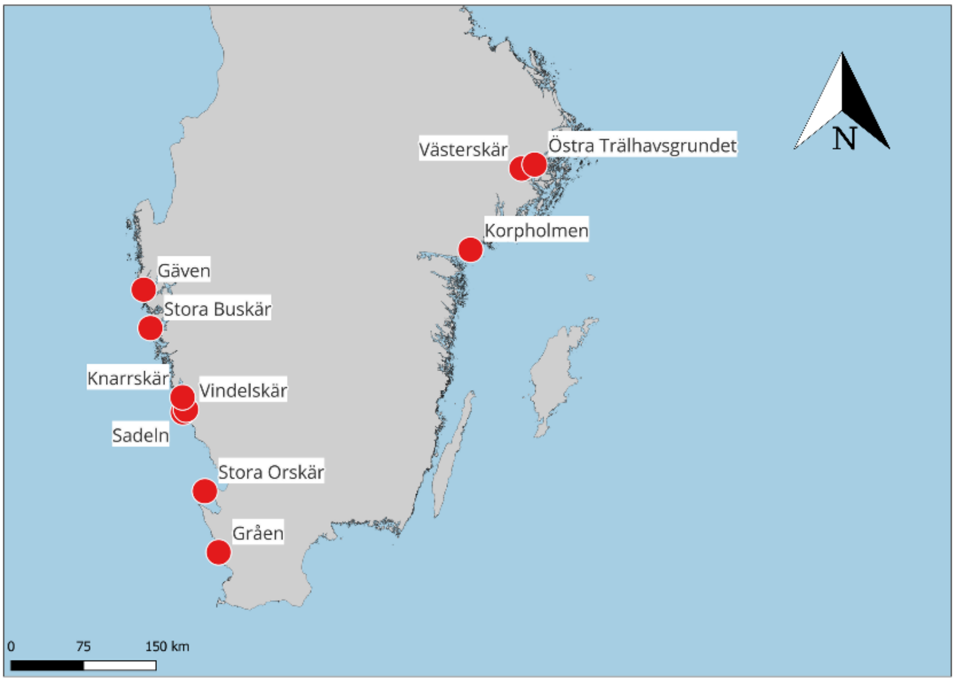

Figure 1. A map of southern Sweden showing the ten colonies visited during the project.

Table 1. Table of colonies visited, their location and how many eggs were measured from each species.

Colony	Marine area	County in Sweden	Amount of cormorant eggs	Amount of shag eggs
Västerskär	Baltic Sea	Stockholm	108	NA
Östra Trälhavsgrundet	Baltic Sea	Stockholm	48	NA
Korpholmen	Baltic Sea	Södermanland	119	NA

Gråen	Öresund	Skåne	118	NA
Stora Orskär	Kattegat	Skåne	25	4
Sadeln	Kattegat	Halland	35	21
Vindelskär	Kattegat	Halland	42	4
Knarrskär	Kattegat	Halland	68	6
Stora Buskär	Skagerrak	Västra Götaland	44	NA
Gäven	Skagerrak	Västra Götaland	60	0
			= 667	= 35

3.1 Egg size in cormorants

Much like previous studies on cormorant eggs, the results of this study highlight the wide range of egg sizes occurring in the population.

Table 2. A table showing the smallest and largest cormorant eggs measured on each colony, as well as the mean length/breadth/volume of all eggs measured on each colony.

	Mean length [mm] ($Length_{min}$ - $Length_{max}$)	Mean breadth [mm] ($Breadth_{min}$ - $Breadth_{max}$)	Mean volume [cm^3] ($Volume_{min}$ - $Volume_{max}$)
Västerskär	61.7 (55.3 - 68.7)	39.0 (34.2 - 43.9)	47.9 (35.0 - 64.1)
Östra Trälhavsgrundet	62.6 (58.7 - 68.9)	39.1 (35.5 - 42.2)	48.9 (38.6 - 61.4)
Korpholmen	62.7 (54.7 - 69.5)	39.8 (35.7 - 43.0)	51.0 (35.9 - 62.1)
Gråen	63.2 (45.4 - 69.0)	40.5 (32.7 - 43.6)	53.1 (24.8 - 64.1)
Stora Orskär	65.2 (59.0 - 69.8)	40.4 (38.3 - 43.6)	54.4 (47.3 - 65.6)
Sadeln	64.1 (58.5 - 68.9)	40.8 (38.7 - 43.4)	54.5 (46.8 - 61.8)
Vindelskär	64.9 (54.3 - 71.2)	40.4 (37.8 - 43.1)	54.0 (42.6 - 63.8)

Knarrskär	65.1 (60.6 - 72.9)	40.6 (35.0 - 43.8)	54.8 (41.7 - 68.7)
Stora Buskär	64.7 (59.4 - 72.9)	41.1 (38.3 - 43.4)	55.9 (46.6 - 69.7)
Gäven	66.1 (61.6 - 70.3)	41.2 (36.5 - 43.7)	57.3 (44.5 - 66.6)
All colonies	63.7 (54.3 - 72.9)	40.1 (34.2 - 43.9)	52.5 (35.0 - 69.7)

3.1.1 Breadth

An ANOVA-analysis of breadth variation between the ten visited colonies resulted in a p-value < 0.05, thus meaning there is at least one colony mean that differs in the group. A post-hoc was carried out to see which colony/ies it applies to. Out of 45 possible combinations of the ten colonies, 15 showed a p adj < 0.05. Out of these 15 combinations, the colony Västerskär was the most frequently occurring colony, suggesting that this is the colony being the most statistically different from the other colonies in terms of breadth of the eggs measured. The only two colonies Västerskär didn't differ from are Östra Trälhavsgrundet and Korpholmen.

A surprising result of colonies showing no statistically significant difference are Stora Orskär (Skåne) and Korpholmen (Södermanland). Skåne is located in the southernmost place in Sweden, while Södermanland is located further north. However, when another colony in Skåne (Gråen) is compared to Korpholmen in Södermanland, the p adj < 0.05, meaning a statistically significant difference have been found.

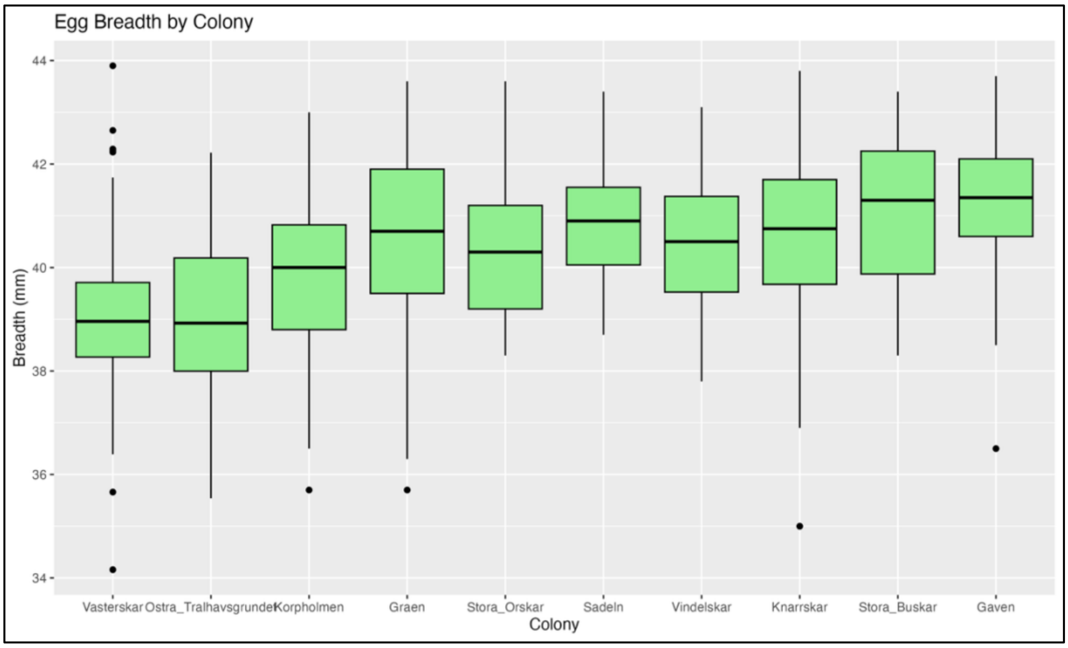

Figure 2. Box plot from the ANOVA-analysis comparing breadth of all colonies with one another.

All colonies within a county had p adj > 0.05 when compared to each other, meaning no statistically significant difference between said colonies could be found. Since no colony within a county showed a p adj < 0.05 compared to the other colonies withing the county, an ANOVA-analysis comparing egg breadth based on counties rather than colonies could be made.

The ten colonies are distributed in five counties; Stockholm, Södermanland, Skåne, Halland and Västra Götaland. The ANOVA-test had a p-value < 0.05 and therefore a post-hoc was conducted to examine where the differences appeared. This test showed that Skåne and Halland were the only counties without statistically significant difference between each other. All other combinations tested had a p adj < 0.05. A pattern of mean breadth increasing as one moves from the northernmost colonies on the east coast, down south and up on the northern side on the west coast can be inferred by looking at the box plot. Mean breadth in Stockholm county was 39.0 mm and 41.1 mm in Västra Götaland

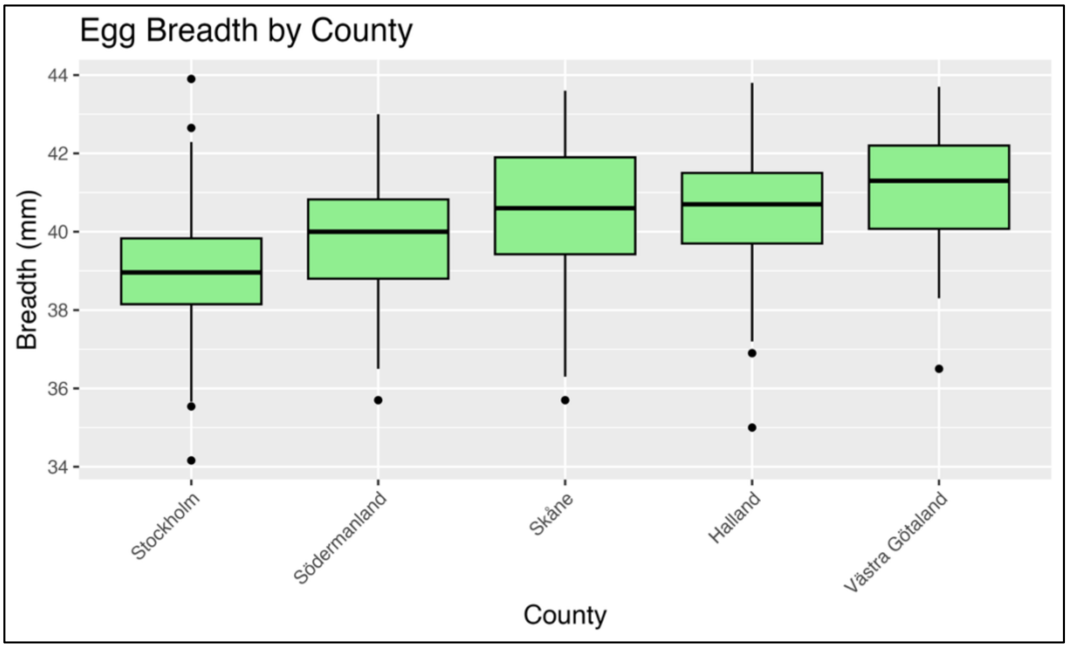

Figure 3. A comparison of egg breadth where colonies have been grouped based on what Swedish county they belong to.

3.1.2 Length

As with breadth, an ANOVA-analysis comparing egg length between the ten visited colonies was carried out with a p-value < 0.5. Västerskär stood out as the colony having a statistically significant difference with the most colonies here as well, with seven out of nine possible combinations. The two colonies Västerskär doesn't differ from are Östra Trälhavsgrundet and Korpholmen, the same result as the post-hoc of breadth. There isn't one colony that isn't different from at least one other.

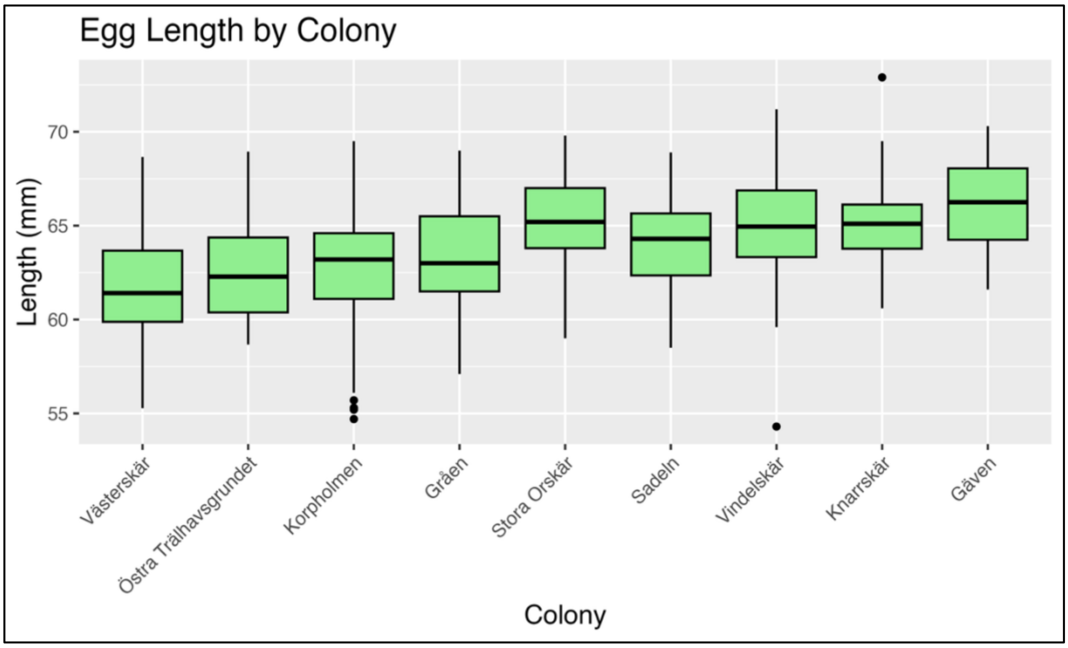

Figure 4. Box plot from the ANOVA-analysis comparing length of all colonies with one another.

As with breadth, all colonies within a county received p adj > 0.05, meaning no statistically significant difference between those colonies could be found. However, Sadeln in Halland and Gäven in Västra Götaland, both counties located on the west coast, have a p adj < 0.05.

Because of the results from the post-hoc-test comparing colonies to each other, it was possible to compare egg length between Swedish counties. The ANOVA-analysis received a p-value < 0.05, leading to a post-hoc test being carried out. Stockholm - Södermanland and Halland - Västra Götaland are the only two combinations showing no statistically significant difference between each other (p adj ≈ 0.17 and p adj ≈ 0.28 respectively). Something that sets breadth and length apart from each other.

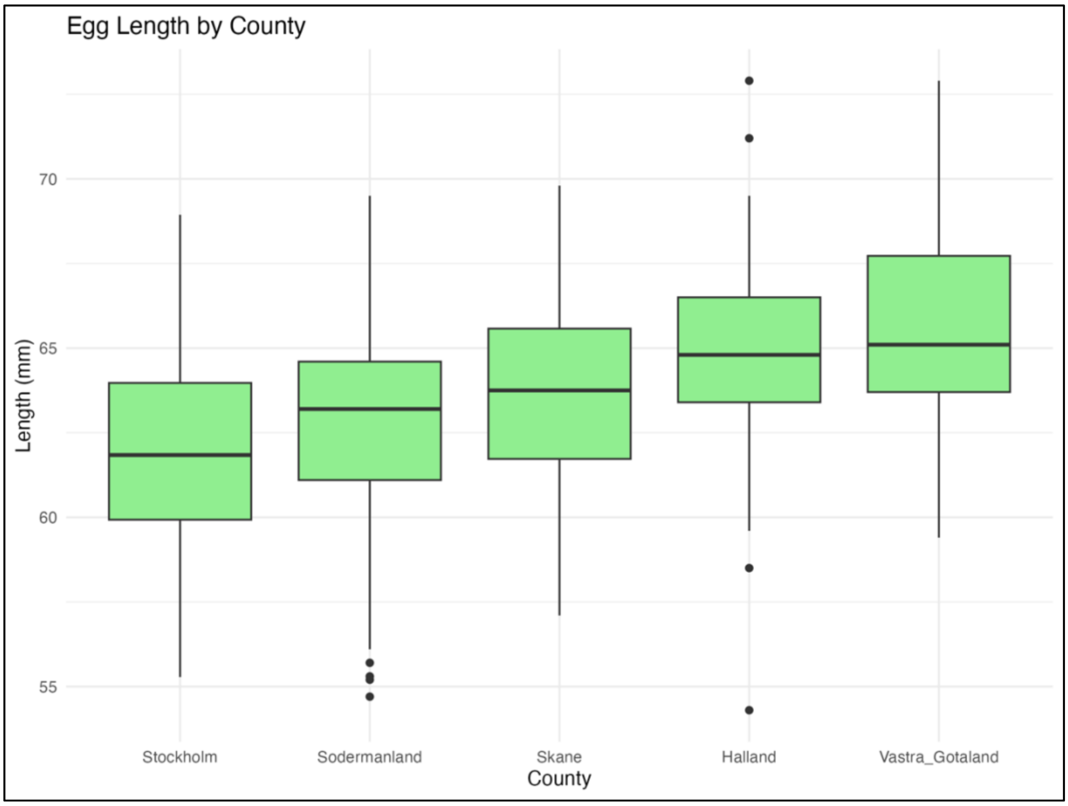

Figure 5. A comparison of egg length where colonies have been grouped based on what Swedish county they belong to.

Looking at the box plot, egg length increases from Stockholm → Södermanland → Skåne → Halland and finally Västra Götaland. The mean length in Stockholm was 62.0 mm and 65.5 mm in Västra Götaland.

3.1.3 Volume

As with breadth and length, an ANOVA-analysis comparing volume in the ten colonies was conducted with a p-value < 0.05. As with breadth and length, the results from the post-hoc test showed the same pattern of colonies within a county receiving a p adj > 0.05, meaning no statistically significant difference between colonies in a region could be found. Proximity, however, is not always linked to differences or similarities. There are colonies on the west coast with a p adj > 0.05 showing no statistically significant difference (for example Stora Buskär in Västra Götaland and Sadeln in Halland), but there is also examples of colonies somewhat close to each other having a statistically significant difference (Västerskär in Stockholm and Korpholmen in Södermanland).

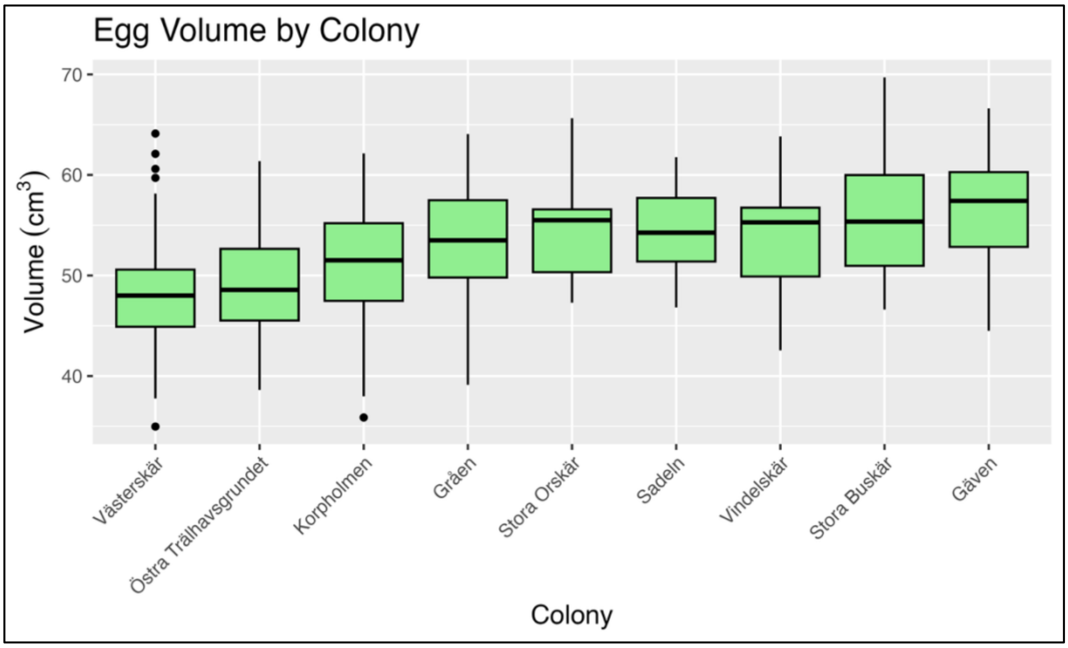

Figure 6. Box plot from the ANOVA-analysis comparing volume of all colonies with one another.

When analysing the results from the post-hoc test that was made on the ANOVA-analysis comparing egg volume from different counties, Skåne - Halland were the only counties showing no statistically significant difference between each other. This corresponds with the results when counties and breadth were analysed.

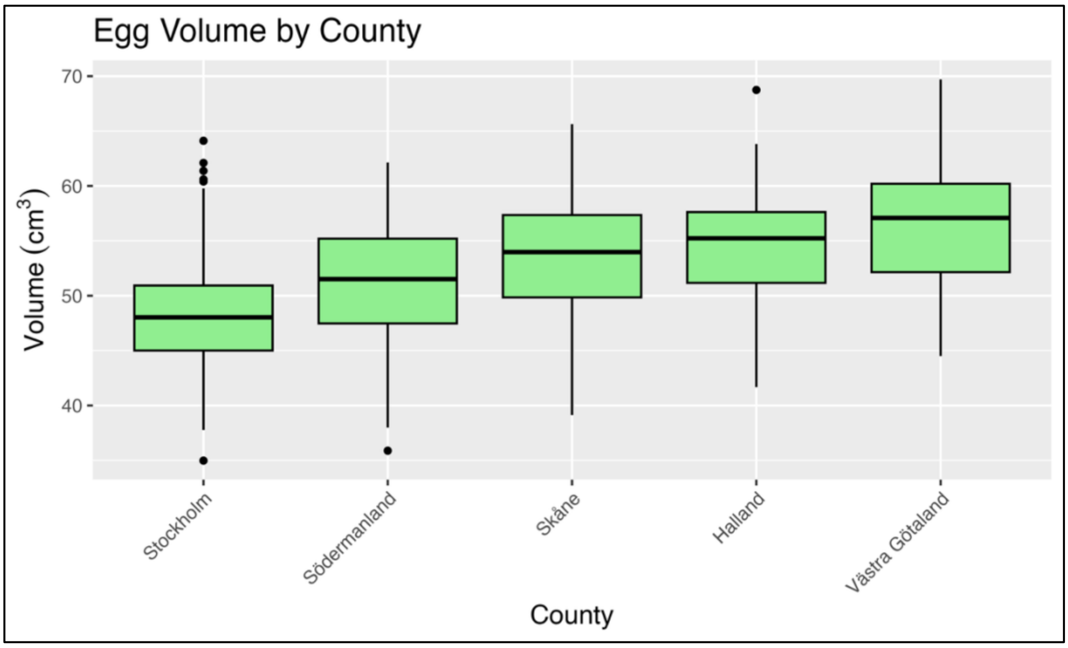

Figure 7. A comparison of egg volume where colonies have been grouped based on what Swedish county they belong to.

Just like breadth and length, results suggest egg volume increasing in a gradient from the northernmost colony on the east coast, down south and up again to the northernmost colony on the west coast. The mean volume in Stockholm was 48.2 cm^3 and in Västra Götaland 56.7 cm^3.

3.2 Egg size in shags

Since only 35 shag eggs were measured, I argue that the sample to be too small to conduct statistical analyses on. The results presented in this chapter will therefore focus on showcasing the range of length, breadth and volume of shag eggs.

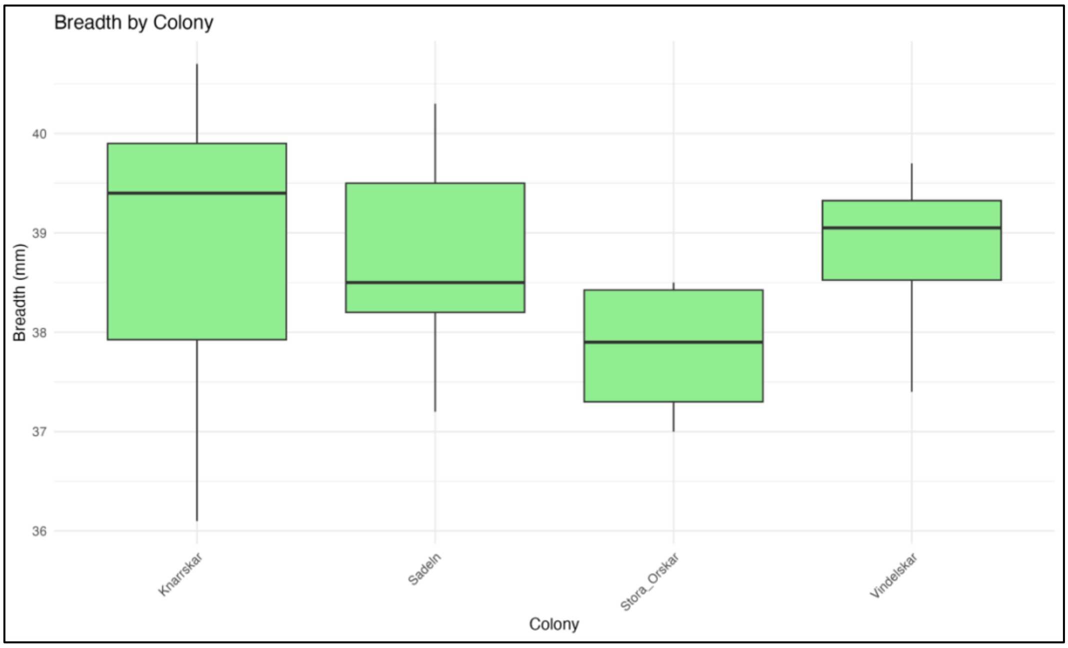

Figure 8. Box plot showcasing breadth of all colonies with shag eggs.

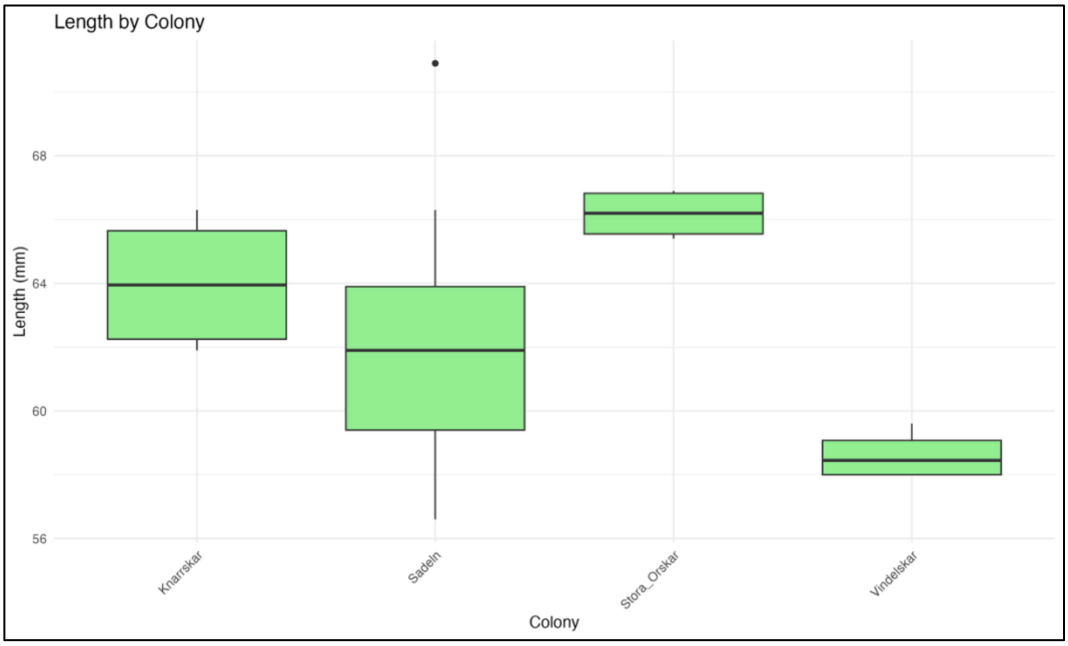

Figure 9. Box plot showcasing length of all colonies with shag eggs.

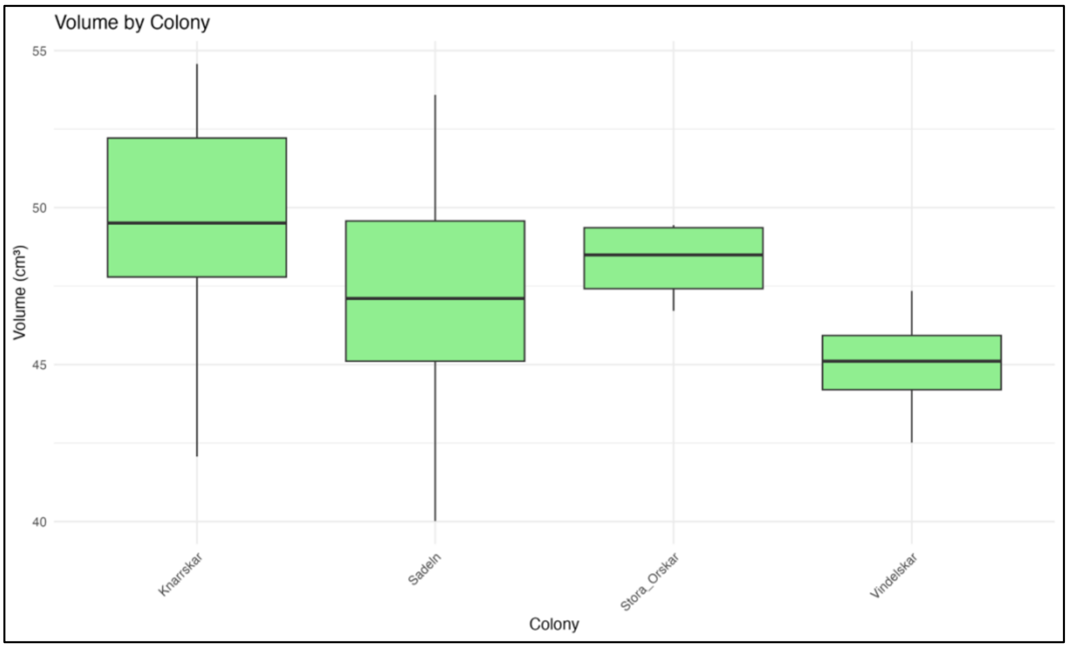

Figure 10. Box plot showcasing volume of all colonies with shag eggs.

Mean length of shag eggs, for all colonies in this study combined, is 62.4 mm, breadth 38.6 mm and volume 47.5 cm^3. Compared to cormorant eggs, no mean volume for shag eggs exceeds 50 cm^3 and no mean breadth exceeds 40 mm.

Table 3. A table showcasing the range of egg sizes found on the four colonies inhabited by shags, as well as the mean value. Ranges goes from the smallest to the largest egg measured on each colony.

	Mean length [mm] (Length$_{min}$ - Length$_{max}$)	Mean breadth [mm] (Breadth$_{min}$ - Breadth$_{max}$)	Mean volume [cm^3] (Volume$_{min}$ - Volume$_{max}$)
Stora Orskär	66.2 (65.4 - 66.9)	37.8 (37.0 - 38.5)	48.3 (46.7 - 49.4)
Sadeln	61.9 (56.6 - 70.9)	38.7 (37.2 - 40.3)	47.3 (40.0 - 53.6)
Vindelskär	58.6 (58.0 - 59.6)	38.8 (37.4 - 39.7)	45.0 (42.5 - 47.3)
Knarrskär	64 (61.9 - 66.3)	38.9 (36.1 - 40.7)	49.3 (42.1 - 54.6)
All colonies	62.4 (56.6 - 70.9)	38.6 (36.1 - 40.7)	47.5 (40.0 - 54.6)

3.3 Comparison of cormorant and shag eggs

In the four colonies where both shags and cormorants were found, the intervals of length, breadth and volume of cormorant eggs overlap with intervals of shag eggs, as is shown in table 4.

Table 4. A comparison of the range (smallest and largest) of length, breadth and volume, between the measured all cormorant and shags eggs in the study.

	Cormorant	**Shag**
Range of length [mm]	54.3 - 72.9	56.6 - 70.9
Range of breadth [mm]	34.2 - 43.9	36.1 - 40.7
Range of volume [cm^3]	35.0 - 69.7	40.0 - 54.6

3.4 Image analysis

46 eggs from the four colonies Västerskär, Östra Trälhavsgrundet, Stora Orskär and Gäven were, besides measured with calipers, also photographed. With the help of the Image analysis software Image J, length and breadth were measured from images and then compared with the measurements measured in the field.

ANOVA-analyses comparing eggs colony by colony where the eggs had been both measured with calipers and photographed and analysed in Image J were conducted for length, breadth and volume. The results are not one-sided.

On Västerskär and Gäven, length, breadth and volume all had p-values > 0.05 meaning no statistically significant difference between measurements made in Image J and by calipers could be found. Östra Trälhavsgrundet had a p-value < 0.05 for length but p-values > 0.05 for breadth and volume, while Stora Orskär had p-values > 0.05 for length and volume, but a p-value < 0.05 for breadth.

This means that a difference between the methods could be found in:

- length in Östra Trälhavsgrundet
- breadth in Stora Orskär

No egg received the exact same measurement in the field and in Image J when measuring with a precision of 0.01 or 0.1 mm. With a precision of a whole millimeter, only one egg shows the same measurements as in the field while measuring with the automated method in Image J. Box plots show us that measurements from Image J give results with a wider range compared to measurements from calipers. This occurred for all parameters and colonies but is showcased with a box plot from Västerskär where egg length was compared.

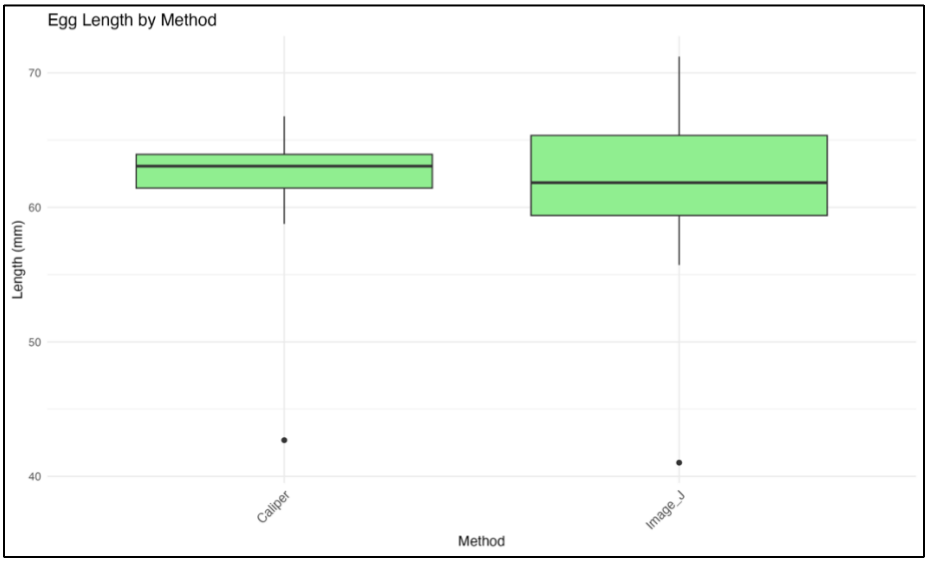

Figure 11. A comparison between measurements done by hand with the help of calipers and measurements from the image analysis made in Image J. This box plot is from the colony Västerskär and acts as an example of how Image J shows a wider range of egg sizes compared to measurements done with calipers.

4. Discussion

4.1 Analysis of egg size: breadth, length and volume

4.1.1 The cormorant

Mean (and range) of breadth of cormorant eggs in the ten colonies combined in this study were: 40,1 mm (34.2 - 43.9 mm). In Greece, Liordos & Goutner (2003) had colonies with mean breadths of 40 mm. In Iran, Rahimi et al (2012) had a mean breadth of 37.3 mm in 2009 and 36.8 mm in 2010. BTO (n.d) states 40 mm as typical breadth of cormorant eggs. Swedish colonies seem to correspond well with earlier studies as listed above. Breadth in Liordos & Goutners studies (2003 & 2008) was the parameter showing significant difference and was the main contributor to the significant difference in volume between colonies in their study. In my study, length, volume as well as breadth received p-values < 0.05, hence statistically significant. Results from their and my study therefore show somewhat contradictory results.

Mean (and range) of cormorant egg length in all the colonies combined is 63.7 mm (54.3 - 72.9 mm). Earlier studies have observed mean lengths of 61 mm (Zhang et al 2007), 62.9 mm and 62.6 (Rahimi et al 2012). The British Trust of Ornithology (BTO) (n.d) states 66 mm as a typical length for cormorant eggs.

Comparing these values, the range of mean length shows trends of following each other even though the studies have been executed in different parts of the world; Sweden, Iran, Greece and Tibet. It therefore seems that there is quite a wide range in egg size, but that this range is relatively consistent. This pattern has previously been recorded for another cormorant species, namely the Imperial cormorant (*P. atriceps*) (Svagelj & Quintana 2011).

Interestingly though, compared to other studies (Liordos & Goutner 2003; Liordos & Goutner 2008), this study actually received a significant p-value from the ANOVA-analysis when comparing length of eggs between the ten colonies.

What sets my study apart from the others mentioned in the introduction is the number of colonies observed. In this study, a total of 10 colonies were visited, resulting in 667 (665) cormorant eggs. In Liordos & Goutner's studies (2003 & 2008) they visited 4 colonies, Zhang et al (2007) observed one colony and Rahimi et al (2012) only looked at one colony as well, but during two consecutive years. Perhaps measuring eggs on ten different colonies, the effect of spatial autocorrelation was smaller than when sampling is done on a handful of nearby colonies as in Liordos & Goutner's case (2003 & 2008), resulting in a larger variation between colonies and a greater distance between colonies. Not only have this study looked at a more diverse composition of colonies in terms of geography, it has also collected data on over 600 eggs. The more eggs sampled, the more representative the result might be.

Since no other tests or observations were made in order to link egg size to age, health etc, I can't know for sure what lies behind the differences of egg size between colonies. However, previous studies can help create hypotheses which could be examined in the future to learn more.

While examining the results of length, breadth and volume in cormorant eggs from this study, a pattern where eggs are larger on the west coast compared to the east coast appears. This might suggest that there is a possibility that the colonies with the largest eggs from this study have either breeding birds of the *P. c. carbo* subspecies or some type of hybridisation between the two subspecies of cormorant. It would therefore be interesting to gather DNA-samples from different colonies on the east and west coast and learn more about this, since the method has been tried before by Grøndahl & Johnsen (2024). Further research could provide an answer to the question of whether subspecies *P. c. carbo* or hybrids between the subspecies actually breed in Sweden or not.

One can also play with the idea of genetics being somewhat similar between the populations, but that the parent bird's health is different between the colonies. Maybe the amount of fish available varies between colonies, or wintering feeding areas, resulting in different capabilities to render large eggs. Causing smaller eggs which eventually can grow up to smaller parents and then the cycle is repeated. Or competition for nesting sites and/or partners, disturbance, food availability or food quality differ between the colonies. This would also be interesting to study further since egg sizes, according to my results comparing counties, showed egg size increasing as colonies move from the east coast, down south and up along the west coast. What causes the eggs to be larger in Skåne than in Stockholm?

With studies examining how egg size is connected to subspeciation as well as food availability and parent health further, the possibility to assess cormorant colonies through egg size might be possible. Establishing a baseline of what the variation looks like can therefore be a key for us to understand this species further.

Lastly, a more in-depth study of age in connection to egg size could reveal more about egg size variation. Since Västerskär in Stockholm county seemed to have the smallest eggs out of the ten colonies, it would be interesting to find a way to determine the age of both the colony and the birds. Coulson et al (1969) describes older birds nesting earlier in the year than younger birds as well as laying larger eggs.

By learning more about genetic variations between colonies as well as age variation, more could be understood as to why egg size varies between colonies and coasts, possibly helping us have a better understanding of cormorant health.

4.1.2 The shag

I claim that species identification of shags and cormorants as not possible through egg sizes, even though no colony with shag nests had a mean breadth over 40 mm or a mean volume over 50 cm^3 as some cormorant colonies had. By examining the ranges of which both cormorant and shag eggs occur in, there is a clear overlap. Therefore it will be impossible to, with certainty, determine wether or not an egg has been laid by a shag or a cormorant using statistic analysis or assessments in a field setting, in colonies where the species both breed.

Since shags grow more and more common along the Swedish west coast, the two species has been shown to build nests close to each other. In practice, this means that if a colony have both shags and cormorants breeding, there is no fool proof method of separating what nests belongs to what species, if the nest doesn't look like a typical shag nest (in a crevice or sheltered), meaning a control measure for cormorants like oiling of eggs, can’t be carried out without the risk of possibly violating the EU directive 2009/147/EC - the conservation of wild birds, since it condemns disturbance of nesting grounds.

Even though data tells us that egg size might not work as an identification characteristic, more knowledge about shag eggs in general is relevant knowledge to obtain in itself. Looking at previous studies of shag’s egg size, only a few have been made, of which one of the most cited is 57 years old (Coulson et al 1969). As a relatively new species in Sweden and in a world heavily affected by climate change (warmer temperatures and more extreme weather), an updated knowledge base can help give a more realistic view of shag eggs today. Older studies are, however, not to be discarded. They can provide valuable knowledge and possibilities to observe possible variations over time. One can play with the thought of the possibility to examine bird health in general through their eggs. As stated earlier, several factors impact egg size (Liordos & Goutner 2008).

4.1.3 The future for cormorants and shags

Fish populations in the Baltic Sea and the North Sea have plummeted in the last 100 years largely because of overfishing (Havet.nu 2025). Adding climate change to that, it seems only reasonable that aquatic birds have been affected by this. Several species such as kittiwakes and Capes gannets have met disastrous nesting results in the last decades as a result of just that; overfishing and climate change (Taylor 2017; Layton-Matthews 2024). Cormorants and shags are opportunists, something that benefits them in a changing world. But if no fish are left or the water becomes too warm or oxygen deprived, eventually opportunistic species will take damage as well. A study from Finland actually looked more into egg size connected to climate change and found that there was a significant effect on egg size and a warmer climate. The study furthermore notices that climate change might benefit stationary birds, while migratory birds might take more damage from a warming climate. (Järvinen 1994). On an evolutionary time scale, discovering differences on egg size as a result from poorer health of parent birds in ≈ 60 years is difficult and only a very small part of the species' entire time on Earth. Therefore continuous observations of seemingly trivial data can, in the future, provide a timeline over not only the species health but the marine ecosystems as a whole.

4.2 Dwarf eggs

One interesting detail while measuring eggs was two eggs found in cormorant nests in the colonies Gråen and Västerskär. Both eggs were around 40 mm in length, around 20 mm smaller than the average cormorant eggs. Eggs that are considerably smaller than the average egg size for the species have been called dwarf eggs. Due to their extreme lengths in comparison to the rest of the eggs, they were excluded in ANOVA-analysis and calculations of mean values since their small size can result in a misleading mean number on the respective colonies.

Figure 12. A dwarf egg found in one of the nests at the colony Västerskär in Stockholm county. The light blue arrow points to the dwarf egg. Photo by Agnes Hjortsberg.

I can not know for sure why these dwarf eggs were laid since no further examination of the eggs were made. It occurs now and then in several wild bird species. In 2002 Sören Svensson published an article discussing the phenomenon of dwarf eggs. He found that dwarf eggs had been observed in a number of species (*Anas clypeata, Sterna hirundo, Larus canus, Certhia familiaris and Stercorarius longicaudus*). His observations are limited but according to observations from multiple people, a rough estimate of the prevalence of dwarf eggs is 1 in 1000. Dwarf eggs occur as a result of something abnormally stimulating the fallopian tube. They usually lack yolk or have a severely reduced yolk, hence not producing viable offspring. (Svensson 2002). If the data collection of egg size in cormorants and shags continue, it might give us an idea of how widespread it is in these species.

4.3 Image analysis

The reason photography was examined as an alternative method to calipers was the hope of it being quicker and simpler. If it requires a lot of time for each photo, the purpose of the method gets lost.

A take-home-message from the field work to future practitioners is to be sure to place the egg(s) without the reference, or another egg, right next to it, since that becomes difficult for Image J to interpret, which leads to extra work in the analysing process. Instead leave at least some millimeters of space between each object.

Image J also had a difficult time separating the egg from the background (nest), which made it difficult to automate the analysis procedure. If the eggs had had a darker more homogenous background, such as a dark paper to place underneath the eggs in the nest, this step would most likely not have been needed.

The results showed that there was no statistically significant difference on any of the parameters on the four colonies except for length in Östra Trälhavsgrundet and breadth in Stora Orskär. However, by looking at the box plots in figure 11, it is evident that Image J render a wider range than measurements done by hand with calipers. I believe the difficulty in converting a 3D object to a 2D image plays a part in this. The eggs have a curvature which I believe can be distorted when photographing the eggs. Depending on the purpose of gathering measurements of eggs in colonies, the difference in range between the two methods can have varying importance.

If measurements can be made through mobile photos and a reference object with a known distance, the possibility to collect egg size data increases. Since cormorants are heavily controlled through both culling and oiling of eggs, people already visit many colonies every year to carry out the control measures. If they were willing to help collect data, a quick, easy and accurate method is needed. It is most likely quicker and easier for people to take one photo of each nest where all the eggs are placed without touching each other and with a reference object in the nest and send to researchers gathering data, than to ask people to measure each egg by hand with calipers.

4.4 Methodological reflections

A digital caliper was used when measuring eggs in the field which helped with interpreting the results quickly which was important for maximizing the amount of eggs measured during limited time at the colonies. Another benefit of digital calipers was that the arbitrariness of interpreting regular calipers was mitigated. Even though this probably helps with errors while measuring, multiple margins of errors remain.

Cormorant eggs vary in shape (Liordos & Goutner 2003), something which can complicate measuring. A way of mitigating the effect of this was to round off measurements to one decimal. Measuring a lot of eggs also helped mitigating this error. In future studies, including shape index could be helpful to get an estimation of shape variation as well.

Cormorant colonies often consist of hundreds of nests as was evident during the field work in this study, given the time on the colonies, only a small sample of nests could be visited. I it was primarily availability from the ground and time at the colony which determined which eggs were measured and not. Given those circumstances, nests were selected at random. A randomized sample is a method used throughout several research disciplines as a way of minimizing subjective sampling (Zaveri 2024). The problem is *if* Swedish cormorant populations follow the pattern where older females lay larger eggs and nest closer to the centre of the colony (Janiszewski et al. 2017). If so, a seemingly random sampling method not taking these factors into account could have a different result compared to a method where equal amounts of eggs were sampled from all parts of the colony.

In comparison to the rest of the colonies, the nests found in the colony Stora Orskär all contained one egg. This might have affected the results from that colony, since previous studies have shown a correlation between egg size and the order they are laid in (Coulson et al 1969).

In order to examine varieties in egg size in cormorants in Sweden, it is favourable to visit colonies located in different places in Sweden. Another benefit of not only studying populations close to each other is that that can help mitigate the risk of spatial autocorrelation being the explanation for patterns and trends on test sites (Groen 2025). Although this study seems to look at more colonies than others have before (Liordos & Goutner 2003; Rahimi et al 2012; Zhang et al 2007), gathering even more data from around the country would give an even better overview of egg size variation in the Swedish cormorant population. This could be from colonies further north but also from populations breeding inland.

5. Conclusions

In summary, this study shows us that egg size variation in cormorants in Sweden corresponds well with previous studies carried out in other countries. Egg sizes vary between colonies, but the range of length, breadth and volume appear relatively consistent with previous studies. Further studies are needed to learn the reasons behind an egg's size, but previous studies suggest genetics being a big contributor as well as the size of the parent birds. With the help of ringing programmes or other observational studies, the connection between parent bird age and egg size would be something interesting to study, as was done in Coulson et al's study (1969).

While comparing cormorant eggs between counties in Sweden, my results suggest that egg size increases from smallest in Stockholm on the east coast, to largest on the northernmost colonies on the west coast. A hypothesis to why this is, is that birds of the Atlantic subspecies *P. c. carbo* breed on the west coast or that there is some kind of hybridisation between the subspecies *P. c. carbo* and *P. c. sinensis.* In order to test this hypothesis, genetic testing is be needed.

By observing both cormorant and shag eggs in four colonies where they nested together, their egg sizes were compared. Even though ANOVA-analyses showed a statistically significant difference between the species, I argue that egg sizes overlap far too much to be able to use egg size for species identification with certainty. Colonies where both species nest will therefore be difficult to perform control measures such as oiling of eggs in without putting shag nests at risk, something that is forbidden due to the EU directive 2009/147/EC - the conservation of wild birds.

Lastly, image analysis as a way of measuring eggs more effectively showed to be a useful method. Results suggest that, with some adjustments, photographing eggs and then analysing size with the help of Image J or similar software could be a quick and easy way of collecting egg size at a larger scale, though more research is needed in order to determine its accuracy further.

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