# A Study of the Congregation of Ghost Nets

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**Github repository**: https://github.com/olavforland/GhostNetModeling

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# 1

# Introduction

Plastic waste in the world's oceans has become a significant point of interest for companies and the general population in recent years. Recent videoes and images of animals suffering from being caught in plastic waste have brought awareness of this issue to the general population. In addition, National Geographic estimated some 150 million metric tons of plastic waste in the oceans (Parker, 2020). A significant part of the waste comes from industrial production, also making corporate companies accountable. In particular, the World Wide Fund for Nature (WWF) estimates that the fishing industry adds as much as 1 million tons of waste every year. These lost nets, ropes, and traps are called ghost nets and are estimated to make up almost half of all ocean garbage (Alexander Nicolas). The waste comes in varying sizes, from big trawl nets used by big industrial ships to lobster traps used by fishing enthusiasts. The lost equipment floats with the ocean currents, catching fish, dolphins, and other marine animals in the process, and eventually gets tangled into coral reefs or other obstacles. The marine life affected is likely to get hurt or die, and removing these ghost nets is an important measure for keeping marine environments healthy.

However, removing such waste takes time and effort. The removal generally requires divers, as the waste is often submerged underwater and located in hard-to-reach areas. Because they easily get entangled in marine structures, they often need to be meticulously cut by hand to be removed. Furthermore, there is no unified framework for mapping out their location. The manual aspect of the current solution makes it inefficient and cumbersome. We are part of the Experts in Team (EiT) village *Robotic Ocean Waste Removal* that aims to automate the process of localizing and removing ghost nets. Our contribution is to streamline the process of localizing ghost nets by mapping out areas likely to contain a cluster of ghost nets.

## 1.1 Problem description

The localization of ghost nets is the first of the obstacles that come with the task of removing them from our oceans. Due to pollution, ghost nets are present in all the world's oceans. However, there are locations where ghost nets are more likely to congregate. These local hot spots are affected by many variables, such as ocean currents, fishing activity, and coastal topography. Different types of ghost nets will also behave differently in the ocean. This project studies the phenomena of ghost nets and the factors affecting them. Based on these factors, models can be made for estimating the location of such hot spots. These models can be used as a starting point for the removal process. A good model can save resources and time by focusing the search on areas more likely to contain ghost nets.

## 1.2 Delimitations and assumptions

The project focuses on the coastal and ocean areas outside of Norway. In particular, we study the areas south of Namsos, Trøndlag. This is due to one of our data sets being too sparse to develop a meaningful model north of this point. We therefore focus on the areas where we have

As mentioned initially, there are many different types of ghost nets. We have chosen to focus on two particular types, i.e. ghost nets we assume remain stationary after they are lost, and ghost nets we assume float with the current after they are lost.

The probability of an area containing stationary ghost nets can be modeled directly from reported lost and found equipment. However, for the mobile nets, it is more challenging to pinpoint where they end up. There are many unknown factors below sea level, and the weight of the nets varies with how much prey they have caught. We have therefore chosen to restrict our model to only floating nets, effectively side-stepping the problems unknown factors would induce.

Where these floating nets are dropped is also not known. As we did not find any data on it, we assume that where there is much fishing activity, the likelihood of losing nets is higher. Therefore, the higher the fishing activity, the more nets are assumed to be lost. In the project, the hours of fishing activity at each location determine how many lost nets we drop at that point in the simulation.

Furthermore, the lost nets are approximated as point particles, as the size of the nets is much smaller than the scale of our simulation. As explained above, we disregard both the buoyance and topology of the nets. Finally, we assume that nets always float and can thus be simulated by our model.

## 1.3 Structure of the report

The report is divided into six sections: Introduction, Background, Socioeconomy, Methodology, Results  Discussion, Conclusion, and Teamwork Evaluation. The background part will present elements necessary for understanding the ghost net phenomena, elements affecting the models, and the theoretical foundation of the models. Next, the socioeconomic part sheds light on the scope of the problem, emphasizing our motivation for tackling the issue. Then, the methodology section describes the techniques used to implement the models. Subsequently, the results are presented and discussed, both alone and in light of the other team's projects in the village. Finally, we conclude our work, discuss how the work can be continued, and end with an evaluation of the teamwork.

# 2

# Background

Many elements contribute to the movement of ghost nets in the ocean. Here, some of the elements we have considered to be the most impactful, while also being possible to implement in our models, are introduced. In addition, we introduce the data sets and present the theoretical foundation of the models we used.

## 2.1 Physical oceanography of the North sea

The North Atlantic Current is one of the more critical factors in our climate system. Bringing nutrients and temperate water further north than any other current in the Northern Hemisphere, this current ensures that there is food for marine life and stops the Baltic Sea from freezing. Hence, the current is critical for providing a business for fishermen and fisheries and maintaining the ecosystem. The current flows mainly southward, but due to the topography, the saline Atlantic water mixes with fresh water in the estuarine processes of the British Isles and continues eastward into Skagerrak and the Baltics. From there, the brackish water circulates back west to hit the Norwegian Trench on the southeastern coast of Norway and continues further north along the coast Winther and Johannessen (2006). The study by Winther and Johannessen (2006) also shows that the inflow to Norwegian waters from the North Atlantic Current is significantly impacted by the differences in the North Atlantic Oscillation index, where the greater inflow occurs at the greatest pressure index, and vice versa.

Humans have also, for a long time, believed that only a smaller amount of plastic and garbage could be found in the arctic waters north of the North Sea. However, in several studies cited by Ashley Yeager (2015), the researchers have found more plastic and microplastic in the Arctic than hypothesized. The common denominator here is that they all derive from Europe and North America, meaning much of the plastic may have come through the North Sea Yeager (2019). In 2012, researcher van Sebille and his team performed a computer modeling of the ocean's garbage drifts to better understand how garbage travels across our planet using the oceans as highways. Models of this concept have been developed previously, but none of the models considered the release from coasts and that the concentration of garbage is affected by seasons. The results from van Sebille's new model show that the five garbage patches we already know about change more than we thought, as the garbage will drift from one garbage patch to a neighboring patch in another ocean. The most surprising result, however, is that there seems to be an unknown garbage patch in the Barents Sea close to the Arctic. The study, therefore, indicates that there has been garbage concentrated there for longer than they initially thought van Sebille et al. (2012).

## 2.2 Categories of ghostnets

Ghost net is a broad term referring to fishing equipment lost on the sea. Although the fishing equipment is lost, it keeps catching prey, consequently damaging wildlife and contaminating and destroying the natural habitat of marine life.

When modeling ghost net behavior, it is important to distinguish between the different types of fishing-equipment. Løset (2019) distinguish between 5 types of ghost nets: *fyke nets*, *gill nets*, *parlour pots*, *folding traps*, and other traps. We henceforth refer to parlour pots and folding traps when writing pots and traps. This equipment is made to stay at the bottom of the sea and is unlikely to float far from where it was lost or abandoned. Fyke nets are normally placed in very shallow waters or rivers, and will not be a big concern for this project. Gill nets refer to general purpose fishing nets that are placed at varying depths

### 2.2.1 Gill nets

Tschernij and Larsson (2003) performed an experiment from autumn 1998 to late spring 1999, where the goal was to characterize the behavior of lost gill nets in the Baltic Sea. The general hypothesis was that gill nets continue to catch fish for an extended period after being lost from their vessel. The gill nets were placed in sets of 3 and retrieved at different times during the experiment to observe the number of fish caught. From this, the authors could assess the deterioration of the nets' fish catching ability. They identified three phases.

In the first phase, the degradation rate is the largest before stabilizing at around 20% of the initial catch rate after about three months. While strong water movements are believed to be the most prominent factor of degradation by fishermen, Tschernij and Larsson's (2003) experiment also indicates that fish caught in the net contribute just as much to the degradation. Hence the degradation and reduction in the fishing ability of the lost gill nets are connected to the currents and water movements and the abundance of fish in the area.

In the second degradation phase, the nets have stabilized, and the gill net has become enmeshed. Tschernij and Larsson (2003) observed that the caught fish are trapped in tangles and loose hanging parts of the net, clearly visible and avoidable by the fish. This contradicts the hypothesis of the fishermen who participated in the experiment, as they thought that dirty and visible nets would lose their catching ability as the fish would be spooked. However, the observations done in the experiment show that in the second phase, benthic species have made a shelter out of the gill nets along with algae. Smaller fish and cod might be hunting smaller prey taking shelter in the enmeshed net, and therefore getting trapped themselves. The last experimental nets were removed 27 months after "loss", after which the catching efficiency was at 6-7%. This shows that ghost nets are able to catch fish even three years after they are lost.

### 2.2.2 Fyke nets

Based on the master thesis of Løset (2019), fyke nets will contribute to ghost fishing to a similar extent as gill nets. The primary difference between the ghost fishing phenomenon of fyke nets and gill nets is that the fyke net's catch rate seems to increase with increased depth. In contrast, gill nets will decrease their catch rate when there is an increase in depth. This is shown in 2.1. In addition, Løset (2019) had an initial hypothesis stating that the gear's catch rate would be independent of substrate, slope, and depth. The different characteristics of this are again shown in Figure 2.1 and in Figure 2.2.

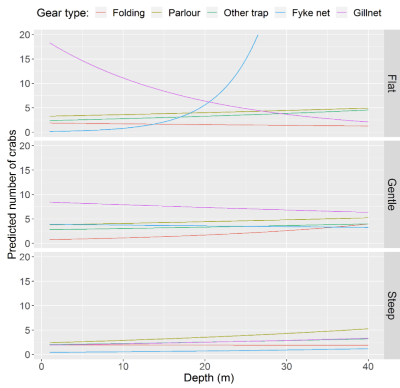


**Figure 2.1:** Shows the predicted number of crabs caught with derelict gear when there is different slopes (Løset, 2019).

Based on the figures and Løset's (2019) own conclusion, the different substrates, slopes, and depths are crucial factors when determining the effect of ghost fishing from derelict fishing gear. Løset (2019) also agrees with the findings of Tschernij and Larsson (2003), stating that gear left at a lower depth will be more affected by the weather. Hence, fyke nets at lower depths will rapidly decrease their catch rate because the tear will increase.

### 2.2.3 Pots and traps

Pots and traps consist of parlour pots and folding traps, constituting 60% percent of the fishing gear retrieved from the Norwegian coast from 2015 to 2018 Løset (2019). Løset (2019) found pots to be the most likely to catch prey. Here, 1 out of 2 nets was ghost fishing, with a catch rate of 3.09 animals per pot. For folding traps, only 15 percent were ghost fishing. Moreover, pots and traps catch more crabs for increasing depths, considering depths from 0 to 40 meters. On average, the number of crabs caught increased roughly linear in depth. However, different depth dependencies were found for different bottom

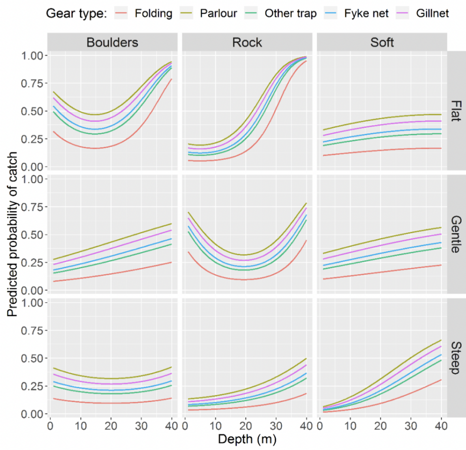


**Figure 2.2:** Shows the predicted probability of catch with derelict fishing gear in different substrates (Løset, 2019).

types with different inclines, as is visualized in 2.2. Furthermore, pots and traps also catch fish. For example, lost pots catch approximately 0.88 fish per pot.

## 2.3 Data sets

We use two different data sets for modeling ghost nets. For modeling gill nets, we use professional fishing activity to determine the likely distribution of lost nets at sea. We use lost and found data reported by amateur fishers for modeling pots and traps. This is due to professional fishers setting pots and traps in far deeper waters than amateurs fishers, thus making them much harder to retrieve. We will subsequently follow the naming convention used in the dataset and refer to pots and traps as lobster traps.

### 2.3.1 Fishing activity

To gather information about fishing activity in the sea surrounding Norway, we used data retrieved from Global Fishing Watch (2023a). Global Fishing Watch is an organization focused on creating and publicly sharing knowledge about human activity at sea. Their website has maps, visualizations, data, and analysis tools for fishing activity around the globe. Their mission is to enable transparency and scientific research about how we manage our oceans. Global Fishing Watch combines tracking data from automatic identification systems (AIS), which are publicly available, with vessel monitoring systems (VSM) operated by collaborating governments of the Global Fishing Watch. Combining the data from AIS and VSM with satellite imagery and imaging-based systems for detecting vessels without tracking devices, Global Fishing Watch (2023b) creates a complete picture of global fishing activity.

We used data from the Norwegian coast over the time period 01.01.2021 - 01.01.2023.

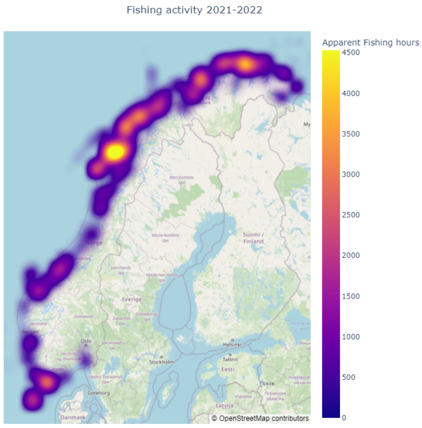


**Figure 2.3:** Heat map showing apparent fishing hours off of the Norwegian coast.

The data contains the latitude and longitude coordinates of the fishing position, which fishing gear used, and total fishing hours in the area. We further filtered the data to contain only entries of gill nets. Figure 2.3 shows the distribution of fishing hours along the coast of Norway. Although most professional fishing activity happens in northern Norway, we only focus on activity south of Namsos. This is partly due to limited computational resources and partly because of limitations in the data set for lobster traps.

### 2.3.2 Lost  Found Lobster Traps

The data for modeling the distribution of lobster traps are gathered from Fiskeridirektoratet (2023). Two distinct data sets contain lost and found fishing gear, respectively. The data covers the time period 01.01.2020 - 01.03.2023. Each data set consists of lost and found gear self-reported by amateur fishers and diving clubs through *Fritidsfiske-appen* (hobby fishing application). Both data sets contain the type of equipment, its latitude and longitude, and the number of items found. Figure 2.4 show how each data set is distributed accross Norway.

## 2.4 Modeling

We use both statistical inference and artificial intelligence techniques to model the congregation of ghost nets. The following section contains the theoretical foundation for the most important methods used in our modeling.

### 2.4.1 DBSCAN

Density-based spatial clustering of applications with noise (DBSCAN) is a clustering algorithm proposed by Ester et al. that groups together points with many close neighbours,

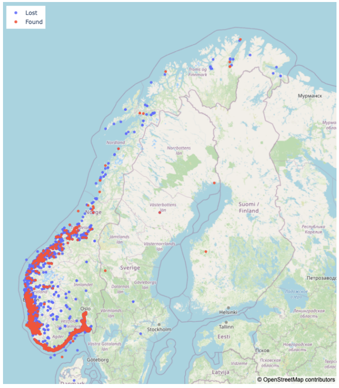


**Figure 2.4:** Lost and found fishing gear as reported through Fiskeridirektoratet (2023).

while clearly marking outliers. It defines a radius $\epsilon$ and a minimum number of points, *min_samples*, per cluster. Every point is then classified according to:

- *Core point*: A point *p* that has at least *min_samples* neighbours within distance $\epsilon$ away.
- *Directly reachable poins*: A point *q* is directly reachable from *p* if *p* is a core point and *q* is within distance $\epsilon$ of *p*
- *Reachable point*: A point *q* is reachable from *p* if there exists a path from *p* to *q* of core points.
- *Outliers*: All points that are not reachable are considered outliers

For any *core point p*, every point *q* that is *reachable* from *p* is in the same cluster as *p*.

### 2.4.2 K-Means Clustering

K-Means clustering (Lloyd, 1982) is a method of partitioning *n* data points into *k* clusters by minimizing the sum of squared euclidean distances within each cluster. From observations $(x_1, x_2, ..., x_n)$, the objective is to partition the observations into $k \leq n$ sets $\mathbf{S} = \{S_1, S_2, ..., S_k\}$ by minimizing the within-cluster sum of squares:

$$\underset{S}{\operatorname{argmin}} \sum_{i=1}^{k} \sum_{x \in S_i} ||x - \mu_i||^2$$

where $\mu_i$ is the centroid of $S_i$ given by

$$\mu_i = \frac{1}{|S_i|} \sum_{x \in S_i} x$$

### 2.4.3 Silhouette score

The silhouette score is a common evaluation metric for clustering algorithms. It is calculated using the average distance within each cluster (a) and the average distance to the nearest cluster (b):

$$s = \frac{b - a}{max(b, a)}$$

The best value is 1 and the worst is -1, with values close to zero indicating overlapping clusters (Pedregosa et al., 2011).

### 2.4.4 Gaussian Mixture Models

Gaussian Mixture Models (GMM) is a parametric probability density function consisting of a weighted sum of *k* Gaussian distributions (Reynolds, 2009),

$$p(x|\lambda) = \sum_{i=1}^{k} w_i g(x|\mu_i, \Sigma_i)$$

where *x* is a D-dimensional continuous-valued data vector, $w_i$ are the learned mixture weights satisfying $\Sigma_i w_i = 1$, and $g(x|\mu_i, \Sigma_i)$ the Gaussian probability densities with mean vector $\mu_i$ and covariance matrix $\Sigma_i$ for each component

$$g(x|\mu_i, \Sigma_i) = \frac{1}{(2\pi)^{D/2} * |\Sigma_i|^{1/2}} \exp\{-\frac{1}{2}(x - \mu_i)^T \Sigma_i^{-1}(x - \mu_i)\}$$

### 2.4.5 Poisson distribution

The Poisson distribution models the number of events that occur in a given time frame. For a distribution with parameter $\lambda t$, its probability mass function is given by:

$$f(x) = \frac{(\lambda t)^x}{x!} * e^{-\lambda t}$$

for x = 0, 1, 2, ...

The fundamental assumption of the Poisson distribution is that occurrence of events can be described as a *Poisson process*:
Let N(t) denote a process. It is called a Poisson process with rate $\lambda$ if it satisfies the following properties:

1. $N(0) = 0$
2. $N(t_2) - N(t_1)$ and $N(t_4) - N(t_3)$ are independent for all $0 \leq t_1 < t_2 \leq t_3 < t_4$
3. For all $t \geq 0, \Delta t > 0$ we have

$$P(N(t + \Delta t) - N(t) = 1) = \lambda * \Delta t + o(\Delta t)$$

$$P(N(t + \Delta t) - N(t) \geq 2) = o(\Delta t)$$

where $o(\Delta t)$ is the ”little-o” function satisfying

$$\lim_{\Delta t \to 0} \frac{o(\Delta t)}{\Delta t} = 0$$

For our project, this translate to the following assumptions:

1. No fishing nets are dropped in areas with no fishing activity
2. The number of fishing nets lost in two non-overlapping time windows are always independent
3. The number of fishing nets lost in a time interval is proportional to the size of the time window (plus a small error term), and there is a diminishing probability of losing more than one fishing net the smaller the time window becomes.

### 2.4.6 Kernel Density Estimation

Kernel Density Estimation (KDE) is a non-parametric technique for estimating the probability density function of a random variable. In our application, the random variable is whether a point along the coast of Norway contains a ghost net.
For a set $x_1, x_2, ..., x_n$ of i.i.d samples drawn from a univariate distribution with density *f* at a point *x*, the *kernel density estimator* is given by:

$$\hat{f}_h(x) = \frac{1}{nh} \sum_{i=1}^{n} K(\frac{x - x_i}{h}),$$

where *K* is a non-negative function called the kernel and $h > 0$ is the *bandwith* that controls the smoothness of the estimate.

We use the implementation of Pedregosa et al. (2011) in the Python library *Scikit-Learn*.

### 2.4.7 The Opendrift simulation framework

The simulations are performed using the OpenDrift (2020b) library in Python. This software is used for modeling the trajectory of substances drifting in the ocean and can thus estimate where they will end up. Opendrift uses the Lagrangian method to simulate particles, which requires many particles to get a meaningful result. The simulation takes in a set of longitude and latitude coordinates, as well as the step size and number of steps to perform. It then simulates each point’s trajectory over the given time steps.

Several different models are available in OpenDrift (2020a). The *PlastDrift* model is used in this project. It was developed at the Norwegian Meteorological Institute and simulates the propagation of plastic particles based on ocean currents while taking *Stokes drift* and wind drag into account. If a particle reaches the shore, it is registered as stranded and stays put until the simulation ends.

# 3

# Socioeconomy

This section aims to shed light on the issue's total consequences, revealing the problem's total scope. This is done by exploring the different socioeconomic effects ghost nets have. By elaborating on the scope of the problem, this section effectively highlights the team's motivation for tackling the issue.

Socioeconomics is a technical term in the social sciences that describes something related to social and economic conditions. It can also be linked to the interaction between the social and the economic (Tjenernshaugen and Tjora, 2023). The socioeconomic aspect regarding the phenomenon of ghost nets is essential to account for their negative impact. This is because it highlights the long- and short-term effects it has both on individuals, local communities, and the global community.

## 3.1 Affects

The root issue with ghost nets, or ALDFGs (abandoned, lost, or otherwise discharged fishing gear), represents a major pollutant in the world's oceans. The issue with this phenomenon is that it interferes with marine life. Ghost nets can move through the ocean by riding on ocean currents or become attached to structures on the ocean floor. The nets floating on the ocean surface do so until they have entangled enough marine fauna to sink. These nets can become kilometers long, weighing up to several tons (Government, 2023). Lost crab stones and trawling nets are also examples of ghost nets that do not float around but stick to the bottom rather quickly. That being said, all nets eventually end up on the ocean floor or on shore. Since the invention of synthetic fabrics such as nylon, these nets have taken significantly longer to decompose, thus being a continuous obstacle for marine life (Enrichetti et al., 2021).

Ghost nets affect everyone from a socioeconomic perspective. However, the direct effects are on marine life. The ghost nets that float will often do so until enough marine life is caught in the net. The net becomes too heavy when this happens and sinks to the bottom. Once at the bottom, the nets keep interfering with marine life as it covers structures such as coral reefs or similar habitats for smaller fish and marine life. This leads to interference in the natural ecosystems. Pichel et al. (2007)

However, the socioeconomic effects rarely come directly from losing fishing nets. More often than not, most socioeconomic effects come as part of a chain reaction, starting with losing fishing gear. Further in this chapter, the most apparent of these are explained, as well as existing and potential future countermeasures for the problem are highlighted. Additionally, as a supplement to our research, we have gathered views on the issue from representatives of some of the most prominent actors in the aquaculture industry.

## 3.2 Effects

### 3.2.1 Social

#### Micro plastics

Synthetic materials lost in the ocean, such as ghost nets or other ALDFGs, decompose slower than older, natural fishing gear. This is because synthetic material fragments rather than decay. The fragments come in the form of microparticles, creating microplastics. These microplastics are then consumed or absorbed by microorganisms such as plankton or other algae. Other marine flora, such as seaweed, can also consume the particles. These particles then circulate through the food chain before eventually ending up in our food and nutrition, such as seafood, salt, and drinking water. Enrichetti et al. (2021)

The impact of microplastics in foods and nutrition is an issue we still need to understand fully. However, several chemicals found in plastic can be linked to different health problems, including cancer, heart disease, and poor fetal development. Other unwanted side effects include allergic responses and inflammation (Gerretsen). Microplastics' effects on health and the human body were analyzed at the University of Hull. The analysis compared data from 17 other studies and confirmed that ingesting microplastics hurt human cells. This is mainly through microplastics breaking cell barriers and causing oxidative stress. However, the exact magnitude of the damages is still unknown (Danopoulos et al., 2022).

#### CO2 footprint

The production of new fishing gear and nets to replace the ALDFGs creates negative socioeconomic consequences in the form of a CO2 footprint. This comes from the production and transportation of products and materials Butler et al. (2013).

When plastics initially became used, the human population deemed them harmless. Since then, it has become part of the world's most significant problem with pollution Alabi et al. (2019). In addition to microplastics, CO2 emission is a real threat to our environment, and plastic production is a crucial factor in this problem Alabi et al. (2019). ADLFGs are composed of different oil-based polymers and pollutants, as other plastics Alabi et al. (2019). Because the world's population is continually growing, so will the need for plastics.

**Bio-diversity**

Having established the dangers of ghost fishing, it is clear that ghost fishing could be fatal for vulnerable marine life. This is especially true in areas with large-scale fishing and endangered species, such as the Mediterranean Brown and Macfadyen (2007). Loss of such species is both damaging for coastal tourism and could also result in a disruption of food chains. Unfortunately, the effects of such disruptions can not be determined beforehand.

### 3.2.2 Economic

**Macroeconomic**

The exact extent of ghost catch is difficult to determine. However, for the Baltic Sea, it is estimated that ghost catch of cod corresponds with between 0,01% and 3,2% of landed cod catch. This correlates with between 1,3 and 388 tonnes of cod per year. Given that the price of cod is kr 25 per kg, this is a total cost of between kr 32.500, and kr 9.700.000 Råfisklag. These numbers are for cod in the Baltic Sea alone. Similar figures are estimated for the Southwestern waters of the northeast Atlantic in the Cantabara region. Here, between 1,46% and 4,46% of landed Hake catch is approximated to be ghost catch. In the Mediterranean, ghost catch is estimated at 0,54% of total commercial crawfish landings. Brown and Macfadyen (2007)

Based on this information, it is clear that ghost catch constitutes a significant portion of total catches. It is also clear that most estimates are highly imprecise and could be even higher. One study on catches of Greenland halibut concludes with ghost catch being even higher Humborstad et al. (2003). This shows that the problem's exact scope is somewhat uncertain. In general, the total ghost catch is believed to be below 1% of land catches. Brown and Macfadyen (2007)

Using this simplification that ghost catch corresponds with about 1% of total landed catches; we can also estimate a rough cost of ghost fishing on a global scale. According to Statista, the global Seafood market in 2022 reached a value of 257 billion dollars worldwide, predicted to reach 350 billion within 2027 Statista (a). Using the seafood market in 2022, we can calculate that the macroeconomic loss from ghost fishing is approximately 2,57 billion dollars annually. To put this into context, this is equivalent to 0,46% of Norway's GDP in 2022 Statista (b). Once again, it is important to note that this is a vague approximation. However, it does show that ghost fishing has huge macroeconomic effects.

Another consequence of lost fishing nets and ALDFGs is the general pollution of coastal areas. This pollution, in addition to the consequences mentioned earlier, can make coastal areas less "beautiful" than before, thus leading to a decline in coastal tourism.

**Microeconomic**

While the most significant economic loss from ghost fishing is the cost of its ghost catch, it is also worth mentioning that ghost nets, or ALDFGs, also affect each individual fishing vessel. It is estimated that the cost of lost fishing nets and other gear is about kr 100.000 per vessel per year. Out of these, approximately half are from ghost catch that could otherwise have been caught. The remaining kr 50.000 are associated with acquiring new nets and gear to replace the lost (Brown and Macfadyen, 2007).

## 3.3 Countermeasures

### 3.3.1 Existing

#### Legal

Most of the world has different legal initiatives to limit ocean littering. For example, Australia has the Ghost Net initiative, while in Norway, we have, for instance, "Havressurslova." Since we have chosen to focus on the Norwegian coast, this section will be limited to the Norwegian Laws and regulations regarding the subject. "Havressurslova" of 2008 is perhaps the most important law in Norway regarding preserving marine life and resources. The law aims to secure sustainable and economically profitable management of the wild marine resources and the associated genetic material and contribute to securing employment and housing in the coastal communities cf. Havressurslova §1.

The law, among other things, states that those who have lost fishing gear must also search for it cf. §17(1). "Fiskeri og næringsdepartementet" can also, through the same paragraph, make it mandatory to report lost fishing gear to the authorities. It is also illegal to deliberately dump fishing gear, trash, and other objects at sea cf. §28.

#### Disposal methods

All types of plastics, polyamides, and plastics take a long time to decompose, just like most synthetic fabrics do. The most relevant fabric is nylon when considering fishing gear. When these synthetic fabrics decompose in nature, they usually do so by turning into microplastics Danopoulos et al. (2022). However, there are other ways that polyamides can decompose. It is also possible to use chemical solutions to decompose Polyamides. One of many examples of this is described in the patent EP059611A1. The patent describes decomposition using liquids with concentrated nitrogen and carbon. Unfortunately, these chemical methods are rarely used, especially in developing countries, resulting in the majority of discarded polyamides ending up underground or in landfills Brown and Macfadyen (2007).

#### Raising awareness

While it is clear that ghost fishing is a significant issue, it is one that most people either neglect or are unaware of. Therefore, an important measure is to raise awareness of the case. Awareness can be raised in several ways. In Indonesia, for example, retrieved fishing gear and ghost nets are reused and braided into bracelets. These are then sold to raise awareness Brown and Macfadyen (2007). In addition, campaigns from different activist groups such as Greenpeace, WWF, and Oceana have also raised awareness.

### 3.3.2 Proposed Alternatives

#### Decomposing gear

The fishing industry has been active for thousands of years. Still, the issue of ghost fishing and ghost nets only came to be in the mid-1900s. At this time, the industry started using synthetic materials such as polyester and other plastics rather than decomposable nets and gear. Plastics are the root cause of most of the negative socioeconomic effects of ghost nets, ranging from microplastics to the destruction of marine habitats. Therefore, a possible countermeasure could be to phase out the use of plastics and substitute it with decomposing material. Unfortunately, decomposable alternatives are generally more expensive and often less robust than plastic ones. Therefore, individual fishers lack the incentive to buy decomposable fishing gear.

**Political measures**

As previously mentioned, the use of plastics in fishing gear is due to greater use at lower costs than the alternatives, making economic incentives not to choose decomposing alternatives. The same goes for the retrieval of ghost nets and ALDFGs. There rarely is an economic advantage to doing the job. Therefore, political decisions could be used to create incentives for using decomposing alternatives. Simultaneously, state-funded operations for removing the existing ghost nets could make it economically profitable.

In Norway, a new tax reform called *NOU 2022: 20* aims to, among other things, tax the fishing industry heavily. An example of how political decisions could create an incentive for using decomposing fishing gear is to give taxation discounts to those who use less harmful materials. Simultaneously, some of the increased tax revenue from those still using plastics in their gear could be used to fund the removal of existing ghost nets.

Political decisions can affect more than economic incentives as well. For example, Fiskeridirektoratet can easily regulate the duty to report lost fishing nets and gear. Political decisions such as mandatory trackers in nets and ALDFGs would make it easier to locate these nets. If the mentioned measures do not resolve the issue, the ultimate consequence could be an absolute ban on plastics in fishing gear.

## 3.4 Input from the industry

At Havbruksdagen, an event by NTNU on the 20. of April 2023, the team did some quick interviews on the socioeconomic aspect of ghost nets. “Havbruksdagen” is an event where different organizations involved in aquaculture meet to mingle and introduce themselves to students at the university. We found interviewees representing a more comprehensive range of the industry. We interviewed representatives from SINTEF and Aker Solutions for the views of someone working with the technical aspect of the industry. We also interviewed representatives from the company MOWI and Blueacre, as well as the trainee association Seafood trainee, representing most of the prominent aquaculture associations along the Norwegian coast. The interviewees also had various scientific backgrounds, such as electronic systems design and marine techniques. Our interviews were mainly open dialogue. Due to privacy reasons, personal names will not be mentioned.

### 3.4.1 Solutions

Regarding possible solutions, several mentions cooperating with companies working on solutions. Among others the company PingMe, which we were in contact with in the early stages of our work. Another mentioned a company working on a solution where blowers are attached to nets so they do not sink. This way, the nets do not sink and are easier to retrieve, especially in combination with GPS trackers. Robots are also used to collect seafood, such as shells and sea sausages which could be modified to retrieve ghost nets. Using AUVs to assist divers in retrieving ghost nets is also a highly plausible solution.

### 3.4.2 Roadblocks

The interviewees agree that this issue has a low priority due to minimal economic incentives. Naturally, they also suggest that the government must make solving this problem profitable for it to be prioritized. As a counter-argument, it is also mentioned that several fishing companies can benefit by doing such work to improve their reputation.

*There are no one who directly profits from retrieving ghost nets, even though it is a major problem. Therefore, very few try to solve it* - Anonymous representative

*If more people are to try to solve the problem, the state authorities must make it so that it can be profitable by financing clean-up actions themselves* - Anonymous representative

Another reason blamed for the lack of work done on the issue is the lack of information on the issue. One goes as far as saying that there are individuals, such as Kjell Inge Røkke, who probably would want to help solve such an issue if informed of its scope. It is also mentioned that the new EU taxonomy could potentially become a pretext for solving the problem.

# 4

# Methodology

Two different models were used to estimate the position of ghost nets in the fjords and off the coast of Norway. The first is a simulation-based model for tracking the trajectory of floating ghost nets. The second is a model for the probability of finding a lost pot or trap. Following the naming convention in the data set described in 2.3, we call the latter the lobster trap model. Both models are written using Python.

## 4.1 Ghost net simulation model

As mentioned in 2.3, it does not exist complete data sets for lost fishing nets by professional fishers in Norway. Therefore, we use fishing activity to indicate the number of fishing nets lost. We process the data by keeping only entries of *gill nets* and filter out points north of Namsos, Trøndelag. This is done so that the data covers the same area as the data over lobster traps.

We assume a fixed loss rate, $\lambda = 1/300$ nets per minute, constant for every area. Note that this rate is picked arbitrarily, and we consider it future work to estimate a correct value. For each area in the data set, we multiply it by the recorded fishing time and draw random ghost net samples according to a *Poisson distribution*. These are dropped randomly within a radius of 1000m at the location, and their trajectory is simulated using the OpenDrift (2020a) library in Python. This was done to prevent the particles from being placed on top of each other, better representing real-life situations. Since we do not know anything about the distribution of lost ghost nets in the time frame of our data, we start the simulation on a random date and repeat the process ten times to reduce the variance the sampled dates introduce. Each date has different parameters for the factors affecting their trajectory, e.g. weather and time of year. In the simulation, we use a step size of 1 hour. Due to limited computing power, we simulate the points for six simulation days, when $60\%$ of the initial points have hit land. We finally fit a distribution to the points that hit land using the non-parametric technique *Kernel Density Estimation* (KDE). We use the KDE implementation of Pedregosa et al. (2011) in the Python library *Scikit-Learn* with $h = 0.3$ and the exponential kernel.

## 4.2 Lobster trap model

As mentioned in 2.3, we have access to both data over lost and found fishing gear as reported by amateur fishers and diving clubs. Both data sets contain some outliers that we don't want to include in our final model, such as erroneous points placed on land, points reported in lakes, and otherwise points that are placed to sparsely to be useful for the model. We used the DBSCAN implementation in *Scikit-Learn* to detect these points (Pedregosa et al., 2011). For the lost data we used the parameters *eps=0.25, min_samples=40*, while for the found data we used the parameters *eps=0.5, min_samples=8*. The detected outliers for the lost data is shown in Figure 4.1.


**Figure 4.1:** Outliers detected in lost data using DBSCAN

We proceed to fit two models independently, one on the found data and one on the lost data. The approaches are identical, as well as the approach to finding the optimal parameters.

We start by identifying different fishing areas in Norway. This is done by clustering the points into *k* clusters using the *K-means* algorithm implemented in *Scikit-Learn* (Pedregosa et al., 2011). Then, for each cluster $i = 1, 2, ...k$ we fit a Gaussian Mixture Model with $m_i$ components. We choose the *k* that maximizes the average silhouette score over all GMMs. For the GMM in each cluster *i*, we choose the number of components $m_i$ that maximizes the silhouette score.

Now we define the event of finding a trap as *F* and the event of losing a trap as *L*. After performing the steps above we have one model estimating the probability of losing a lobster trap, *P(L)*, and one model estimating the probability of finding a lobster trap, *P(F)*. We combine the models to estimate the probability of lost lobster traps *that are not yet found*, i.e. *P(L - F)*:

$$\begin{aligned} P(L - F) &= P(L) - P(L \cap F) = P(L) - P(L) * P(F|L) \\ &\approx P(L) - P(L) * P(F) = P(L) * (1 - P(F)) \end{aligned} \tag{4.1}$$

This assumes that *P(F—L) can be well estimated by P(F)*. In practice, this means that most nets that are reported found have previously been reported lost. Although this is not necessarily true, the resulting value has the desired properties of the model - likelihood increasing in P(L) and decreasing in P(F).

Still, both of the models are fitted on geospatial coordinates only, hence ignoring whether a point is in the ocean. Since we only want to model the probability of points in the ocean, we perform a Bayesian update of the model. Let *O* be the event of being in the ocean. We then update our probability estimates as follows:

$$P(L - F|O) = \frac{P(O|L - F) * P(L - F)}{P(O)} = \frac{P(L - F)}{P(O)} \tag{4.2}$$

where we used that $P(O|L - F) = 1$, as all lost points are in the ocean.

# 5

# Results & Discussion

In this section, we present the results of our analysis. The results are meant indicators of where ghost nets are likely to congregate and not as absolute ground truths. The goal is that the models can be utilized to gain meaningful insight into the way ghost nets behave after being dropped and get their approximate terminal positions. Despite the simplifications used in the models, the results show a promising base for figuring out where ghost nets are located.

## 5.1 Floating ghost net simulation

We placed in total 109,540 particles. Approximately 60% of these hit land and were considered in our final model. Figure 5.1a) shows the initial placement of these particles. The denser spots of the particle distribution correspond to higher values of fishing activity, as we saw in Figure 2.3. Figure 5.1b) shows the particle placements at the end of the simulation after six simulation days. The green particles are still active in the simulation, meaning they have not hit land. The red particles are the stranded particles. These are the ones we consider in the final model.

The result of applying KDE to the stranded points is seen in Figure 5.2. The resulting probability density function colors each point to highlight areas where ghost nets will likely congregate. These are the areas that are interesting concerning the retrieval of ghost nets.

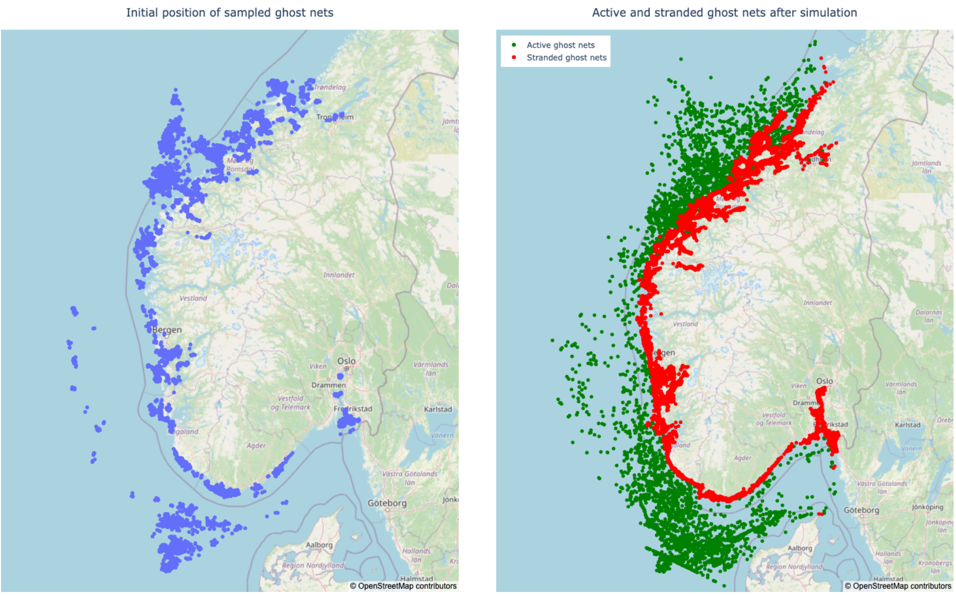


**Figure 5.1:** The left figure (a) shows the initial placement of the particles. The right figure (b) shows the particles at the end of the simulation. There is the same amount of particles in both pictures.

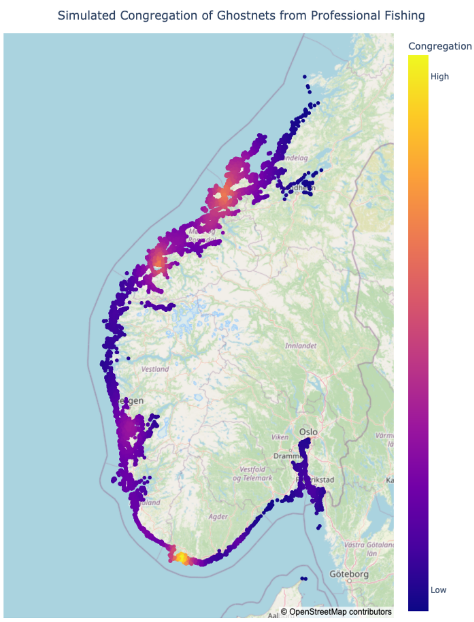


**Figure 5.2:** Probability density distribution of the congregation of ghost nets.

## 5.2 Lobster trap model

Figure 5.3a) shows the partitioning into fishing areas in Norway and the 95% confidence ellipsis around each Gaussian component. This also highlights the violation of the constraint that the probability should be zero for points on land. After combining the lost and found models and performing the Bayesian update, the result is visible in Figure 5.3b). This is a meaningful heatmap highlighting areas that have a high probability of containing lobster traps that are lost but not found.

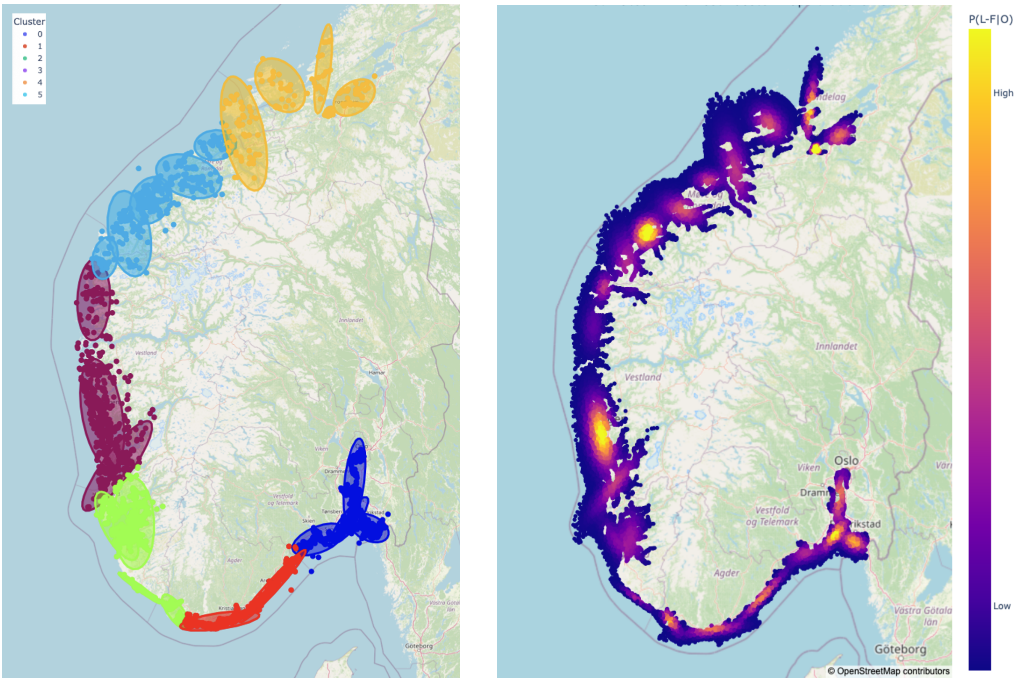


**Figure 5.3:** The left figure (a) shows the Resulting clusters and 95% confidence for each fitted Gaussian component for the lost data. The right figure (b) shows the result of combining the lost and found model, and resampling the distribution.

## 5.3 Comparing the models

A big drawback of the models is that they are not compatible. They are based on vastly different data sets, and they are built with different techniques and assumptions. For example, the Lobster trap model is based on historical data, while the simulation data is based on the hypothesis that fishing nets float with ocean currents. In addition, we do not have an accurate measure of the rate at which fishing boats lose ghost nets. Therefore, it is difficult to say how one should weigh the models towards each other when deciding where to start searching for ghost nets.

As can be seen in Figure 5.3b), the lobster trap model primarily highlights areas with many inhabitants, such as Oslo, Bergen, or Ålesund. This is not unexpected if we assume that the distribution of people that report lost gear is constant regardless of the number of inhabitants in the area. However, the lost gear may be under-reported in areas with fewer people. Communities with fewer people are statistically less likely to hear about *Fritidsfiske-appen* (the application for reporting lost gear), negatively affecting the reporting. Simultaneously, there exists a bias in the data on fishing gear found. Since most gear is found by divers-clubs, areas with many diver clubs searching for ghost nets will be more likely to report a found ghost net.

The simulation model provides a perspective that ignores these biases. By only considering fishing activity and disregarding reported lost and found nets, the model provides a view of where fishing nets are likely to end up, given the ocean currents. This results in a notably different picture, displayed in Figure 5.2. However, this model introduces significantly more uncertainty and noise than the lobster trap model. The uncertainty is tied to, among others, the fishing net loss rate, the ocean currents, and the date of loss.

Therefore, we need more basis for quantitatively combining the models, with the main obstacle being the incompatibility of the data sets. However, if we can estimate the rate at which fishing boats lose gear, we can achieve a basis for comparing the models.

## 5.4 The Broader Picture

Being part of the EiT village Robot Ocean Waste Removal, we want to take a step back and consider this project in relation to the other projects in the village. The village aims to automate the process of removing ghost nets in the ocean, which consists of three main steps: localization, detection, and removal. The first step is to *localize* the area to search for nets. Next, we need to search in this area until we have *detected* the net. Finally, when the net is detected, it can be removed. This process is performed today mainly by independent diving clubs searching for ghost nets in their vicinity and removing them manually. Our part in the broader picture is to aid the teams trying to detect ghost nets by emphasizing areas that are likely to contain ghost nets. The hope is that by making the search process more efficient, more time can be dedicated to the removal of ghost nets. In addition, the end product can also be a stand-alone guide for further localization of ghost nets. Finally, by making the product available for anybody, we could also support the decentralized search that is most common today.

# 6 Conclusion & Future Work

The report started with a qualitative investigation into the behavior and effects of ghost nets. Then we saw two approaches to model ghost nets along the coast of Norway. First, we focus on gill nets that we assume float with ocean currents. Then, we simulate that we drop them off at random points along the coast of Norway according to the fishing activity in the area and estimate their trajectory towards the shore. We then use the stranded points to estimate the probability density function of the congregation of the nets. In the second approach, we use historical data of lost and found lobster traps to model the likelihood of an area containing a lost trap that is yet to be found. Currently, these two models are incompatible, as we cannot quantitatively combine the two models into a single one. Therefore, a qualitative assessment must combine the models to support the search for ghost nets. The investigation into the effects of ghost nets in 2 can provide the basis for such an assessment.

At this moment, there are two main problems with the models. Firstly they cannot be combined into one unified framework. Secondly, we need to assess the quality of the models. Therefore, the next step of the project aims at improving these aspects. Firstly, we can unify the two models by estimating the loss rate of fishing vessels. Secondly, we can get feedback on the models by incorporating newly reported data and performing observations in the areas.

By incrementally improving the product, we aim to accurately describe the ghost net situation in the coastal regions of Norway. This is a first step to streamline the process of removing ghost nets.

# 7 Teamwork Evaluation

Despite the village theme being *Robot Ocean Waste Removal*, none of the team members have a robotics background. The team comprises five members: Henrik, Kaja, Olav, Magnus, and Robert. Our competence spans several different fields. Henrik has a Bachelor's degree in Economics and Administration, specializing in finance and tax law. He is currently pursuing his Master's degree in Real Estate Development and Facility Management. Both Kaja and Robert are Physics and Mathematics students specializing in technical physics, while Magnus is pursuing his Master's degree in Civil Engineering, specializing in project management. Finally, Olav specializes in optimization and machine learning through his Master's in Industrial Economics and Technology Management.

Our diverse backgrounds have been advantageous in approaching the problem from different angles, and each member has provided unique perspectives on the solution. In particular, the decision to focus on the localization aspect of ghost net retrieval was a natural fit for the team's combined expertise. Both physics students, Kaja and Robert, had substantial experience simulating physical processes, while Olav knew statistical modeling. Because of Henrik's strong background in economics, and Magnus' keen interest in the field, a natural focus of the project was also mapping out the damaging effects ghost nets have.

However, such diverse backgrounds can also lead to communication and coordination difficulties, as each member sees the problem through different lenses. We faced this challenge early on, leading to team members working individually on diverging tasks. To enforce effective communication and coordination, we established clear roles and responsibilities and defined each member's contributions to the project. We experienced that by doing this, we could leverage each member's academic competence better.

In conclusion, the team's diverse backgrounds have been valuable in approaching the problem from different angles and providing unique perspectives. However, effective communication and coordination were essential to ensure the team could work together efficiently, despite different perspectives and approaches. As we have worked collaboratively and leveraged each member's strengths and expertise, we are proud of the project's outcome.

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