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Abstract

Ship strikes represent one of the major causes of mortality for large whales. All types of vessels can be involved and cause direct injuries to cetaceans. Unfortunately, relatively little is known about the impact of collisions on cetaceans. In this context, we have created a consortium, named *Share The Ocean*, which aims to develop a ship strikes risk assessment procedure and propose mitigation measures to reduce collisions between cetaceans and ships, using offshore racing as a demonstrator. Through this paper, we want to inform the scientific committee of the IWC of the existence of this consortium to mutualise the actions that will be undertaken to best respond to the problem of collisions with large cetaceans.

1 Introduction

Ship strikes represent one of the major causes of mortality for large whales (Douglas et al., 2008). All types of vessels can be involved, oil tankers, cargo or cruise ships, ferries, whale-watching and racing boats, and cause direct injuries to cetaceans (Laist et al., 2001 ; Ritter, 2012). Laist et al. (2001) have shown that most fatal or serious injuries are caused by vessels larger than 80 m or moving at more than 14 knots. Eleven species of large whales are known to be sensitive to ship strikes (Laist et al., 2001). Among them, fin whales (*Balaenoptera physalus*) are the most impacted, but also right whales (*Eubalaena glacialis* and *E. australis*), humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*) and gray whales (*Eschrichtius robustus*), notably, because their migratory routes cross many marine routes (Roman et al., 2014). Several areas have been identified as high collision risk areas for some species by the International Whaling Commission (IWC), e.g. the Northwest Atlantic Ocean for northern right whales, around Sri Lanka for blue whales (*Balaenoptera musculus*) and the Mediterranean Sea for fin whales (Cates et al., 2017). With the increase in marine traffic and vessel speed, ship strikes are becoming a priority conservation issue for large whales (Douglas et al., 2008 ; Cates et al., 2017), particularly for endangered, recovering, or overexploited populations (Meyer-Gutbrod and Greene, 2018)

Unfortunately, relatively little is known about the impact of collisions on cetaceans (Van Waerebeek et al., 2007). Most information comes from examining stranded animals (Laist et al., 2001 ; Peltier et al., 2019). Since 2007, the IWC has developed a global database to report ship strikes with cetaceans, focusing on direct observations of whales being struck by vessels (Cates et al., 2017). Now, effective mitigation measures must be implemented. Although technological solutions are being developed, none of them allows for reducing ship strikes to zero and their real efficiency is often still to be demonstrated (Cates et al., 2017). Reducing the spatial overlap between whales and ships remains the best way to reduce ship strikes. The first step is to identify areas with a high risk of ship strikes, by crossing areas with high densities of cetaceans and vessels. Second, taking these areas into account in the routing for both commercial and recreational navigation can be an efficient mitigation strategy. Finally, quantitative indicators of absolute mortality at sea are necessary to model total ship-strike mortality at various levels: navigational area, whale conservation unit, or basin-wide to globally.

Although we know the major shipping routes (Halpern et al., 2015), it is difficult to access the route of the vessels and whether collisions have occurred on that route. In the case of offshore racing with sailboats, which also causes mortality in large cetaceans (Ritter, 2012), this information is known because a such event can severely interfere with the performance and the safety of the vessels and the crews. Therefore, an offshore sailing race represents an ideal case study to estimate ship strikes probability and to implement mitigation measures because it is possible to incorporate whale density in the environmental variables commonly used to route vessels. Thus, studying ship strikes through the prism of offshore racing would allow identifying the physical and ecological parameters that lead to collisions and how they could be avoided while involving actors who can participate in the remediation.

In this context, we have created a consortium, named *Share The Ocean*, which currently involves a naval architecture and maritime engineering bureau (*BAÑULSDESIGN*), a mathematics laboratory (*Centre de Mathématiques Appliquées, Ecole Polytechnique*) and a laboratory in marine mammal ecology and conservation (*Observatoire Pelagis, La Rochelle Université*). The objective of this consortium is to use offshore racing as a demonstrator to develop a collision model that would be applied in the broader context of commercial shipping. We aim to develop a ship strikes risk assessment procedure and propose mitigation measures to reduce collisions between cetaceans and ships. Through this paper, we want to inform the scientific committee of the IWC of the existence of this consortium to look for possible synergies and collaborations in order to best respond to the problem of collisions with cetaceans. We will first describe the input data we use, then the collision model that was adapted from Martin et al. (2016) and finally a concrete example to illustrate how this model is currently used to estimate the probability of ship strikes with cetaceans during "The Ocean Race 2022-2023".

2 A case study, the offshore racing

2.1 Cetacean densities

To assess the probability of collision between boats and cetaceans, it is necessary to first estimate cetacean densities. Habitat models allow predicting species densities based on observation data and environmental variables (e.g. currents, temperature, bathymetry; Elith and Leathwick (2009)). Observation data are mainly collected (ideally with a standardised protocol) during surveys conducted by boat or plane (available for example on the OBIS-Seamap repository[1]), and environmental data are obtained from oceanographic models (e.g. NOAA[2] or Copernicus[3] repositories). Models are fitted to this data to obtain distribution maps (Lambert et al., 2017 ; Virgili et al., 2019). Recent projects allowed modelling the large-scale distribution of cetaceans by aggregating different observation surveys (Figure 1). These maps represent the ideal input data for collision models. Unfortunately, surveys are expensive and often carried out near the shores in summer (the most favourable season). Consequently, cetacean densities are not known on a global scale, and many gaps remain (Kaschner et al., 2012 ; Mannocci et al., 2018). The best-known areas are probably the northeast and northwest Atlantic Ocean, the northeast Pacific, the Mediterranean Sea and the Australian waters.

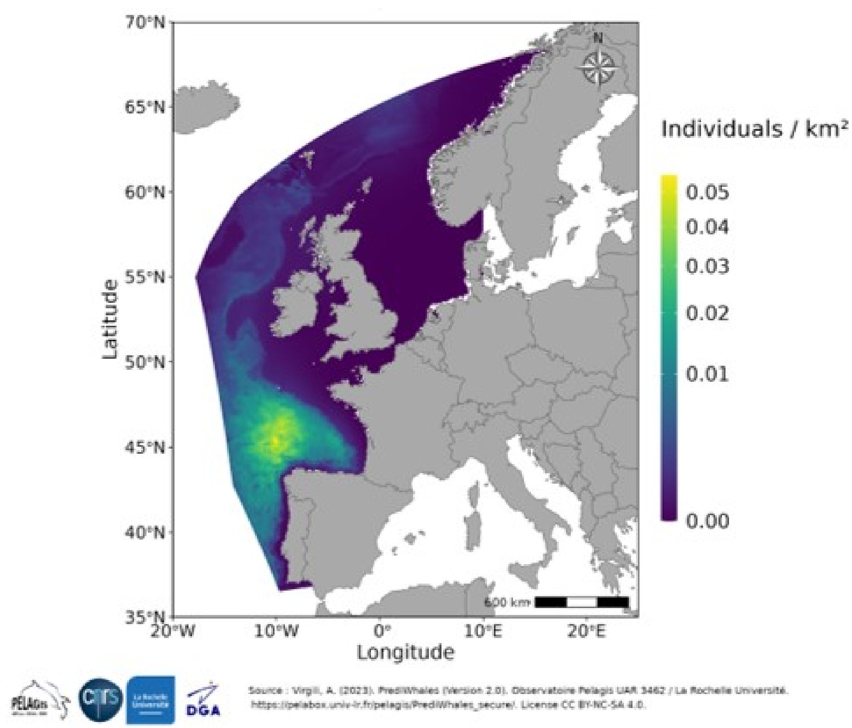

Figure 1. Fin whale distribution in the northeast Atlantic Ocean. Densities are estimated in individuals/km² during the spring/summer season (Virgili, 2023).

[1] https://seamap.env.duke.edu/
[2] https://data.noaa.gov/datasetsearch/
[3] https://data.marine.copernicus.eu/products

Other types of data are available on cetaceans, such as tracking or opportunistic data. The former does not allow obtaining densities of individuals but allows for example identifying the main migratory routes of the species. The opportunistic data are more difficult to use because they are very linked to the knowledge of the observers (experienced or inexperienced) and to the trips (generally very close to the coasts during summer), which leads to biases in the observation process due to uneven and uncontrolled effort.

2.2 The collision model

The collision model used in this work is derived from Martin et al. (2016). The number of collisions is determined as a Poisson distribution of parameter $\lambda_c t$ where t is the amount of time and λ_c is the collision rate determined as $\lambda_c = \lambda_e P_c$.

The mean encounter rate $\lambda_e\left(x\right)$ is defined as :

$$\lambda_e\left(x\right) = 2r\delta\left(x\right)\int_{v_c} I\left(v_c, v_s\right) f_V\left(v_c\right) dv_c, \tag{1}$$

where r is the collision radius, whose original definition in Martin et al. (2016) is obtained as the sum of the ship's collision radius r_s and the cetacean's collision radius r_c. Without prior information on the direction of the ship and the cetacean, these collision radii are calculated as ellipses of length L_s and radius B_s (respectively L_c, B_c for the cetacean) such that:

$$r_s = \sqrt{\frac{L_s B_s}{\pi}}, \quad r_c = \sqrt{\frac{L_c B_c}{\pi}}, \quad r = r_s + r_c.$$

In this present work, the speed of the sailboat is much higher than the speed of the cetacean, so it is more likely that the ship will collide with the cetacean than vice versa, resulting in an asymmetric collision. To account for this phenomenon, the ship radius is assumed to be equal to the beam of the sailboat, i.e.: $r_s = B_s$.

$\delta\left(x\right)$ is the cetacean density (number of individuals per unit surface) at point x.

$I\left(v_c, v_s\right)$ is a monotonically increasing function of the boat and cetacean velocities, if the ship and cetacean speeds increase, the mean encounter rate increases. It is defined as:

$$I\left(v_c, v_s\right) = \sqrt{v_c^2 + v_s^2}\int_0^{2\pi} \sqrt{1 - \frac{2v_c v_s}{v_c^2 + v_s^2}\cos\theta}\,\frac{d\theta}{2\pi}. \tag{2}$$

where v_s is the ship speed, v_c is the cetacean speed. $f_V\left(v_c\right)$ represents the variability of the cetacean speed depending on its activity (foraging, resting, socializing).

It is also necessary to take into account the probability P_c that the cetacean is at a depth where a collision can occur. This probability varies considerably between species that have different dive times (from a few minutes to a few hours), the longer the animal spends at depth, the lower the probability of collision.

The number of collisions for a ship spending a time t at speed v_s in an area of density $\delta(x)$ is thus computed as $C(x, v_s, t) \sim \text{Pois}(\lambda_c(x, v_s)\, t)$. It is possible, using the additivity of Poisson distributions, to estimate the total number of collisions for a boat trajectory defined as a set of points reached by the boat at different times.

Finally, we estimate the probability that at least one collision occur for a given route, i.e $P(C \geq 1)$.

In future developments, we aim to include the probability of avoiding a collision when an encounter occurs, either due to an avoidance action of the cetacean, the ship captain or both.

2.3 The Ocean Race 2022-2023

The Ocean Race is a crewed round-the-world sailing race for monohulls. It takes place every three years. Two classes of monohulls are represented, the one-design VO65 fleet and the foiling IMOCA 60 class. The current edition started in Alicante, Spain, on January 15, 2023, and will finish in Genoa, Italy, in the early summer of 2023. The race visits nine cities over a six-month period (Alicante, Spain - Cabo Verde - Cape Town, South Africa - Itajaí, Brazil - Newport, USA - Aarhus, Denmark - Kiel Fly-By, Germany - The Hague, Netherlands - Genoa, Italy; Figure 2).

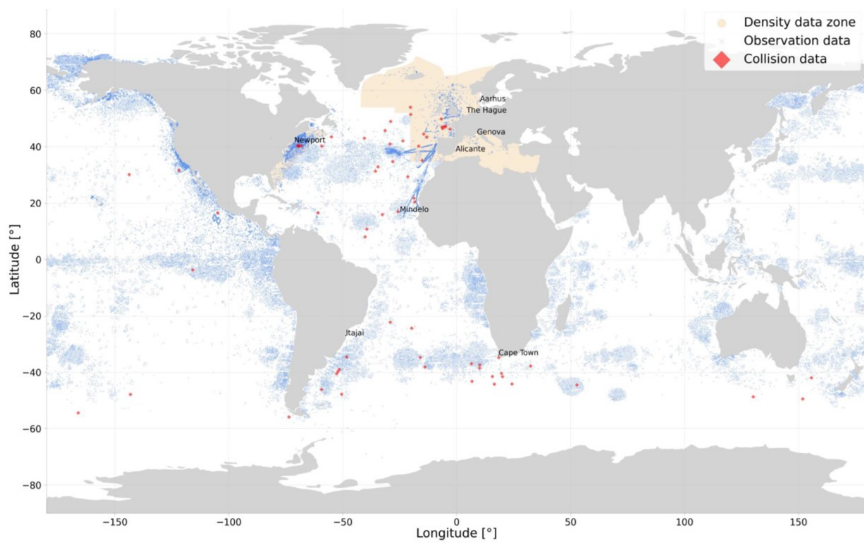

Figure 2. Availability of density data in the Ocean Race area and race stages. Cities in black are the race stages. Areas where density data are available are represented by beige polygons. Blue dots represent cetacean observations available in the OBIS-Seamap repository (most of them come from the IWC whaling database and are extracted from logbooks). Red diamonds represent collisions that took place during previous races.

Share the Ocean was commissioned by the race organizers to estimate the probability of collisions with cetaceans and to identify high-risk areas to avoid along the route for each leg of the race. In some areas (Figure 2), cetacean densities are estimated (the Mediterranean Sea, the eastern and western North Atlantic Ocean), so the collision model can be applied. In other areas, we do not have information on densities, but we know that animals have been observed (OBIS-Seamap repository) or that collisions have already taken place. Our role is to inform the high-risk areas along the route, either quantitatively when we have sufficient information or qualitatively when densities are not available. It should be noted, those areas where densities are available represent a small proportion.

For example, for Leg 1, between Alicante and Cabo Verde, we had densities in the Mediterranean Sea and in the Atlantic Ocean down to 35°N for five species (Cuvier's beaked whale *Ziphius cavirostris*, sperm whale, pilot whale *Globicephala melas*, minke whale *Balaenoptera acutorostrata* and fin whale). In areas where we had densities, we were able to estimate a priori the overall probability of encountering at least one individual, as well as per boat, under different scenarios, without restriction, with exclusion zones in the Alboran Sea and with obligatory checkpoints (Figure 3, Table 1). By adding exclusion zones and obligatory checkpoints, the collision probability decreased from 47.5% to 38.8%. Following this, we have recommended to the race organizers to set up an exclusion zone in the Alboran Sea with a checkpoint at Punta Elena to favour a northern route to Gibraltar that would significantly reduce collision probability.

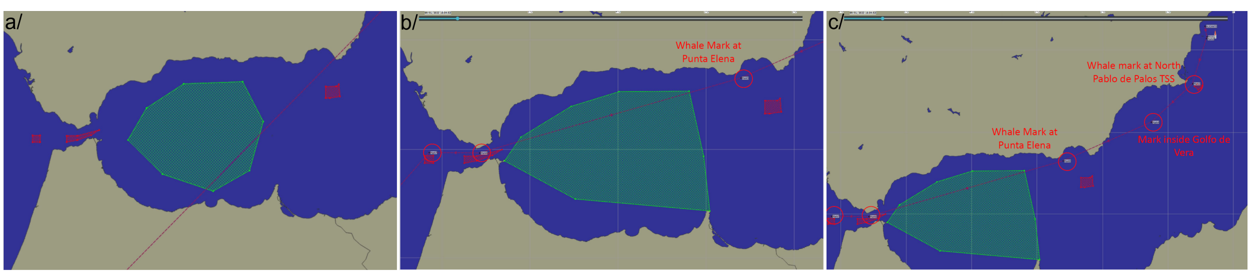

Figure 3. Scenarios tested to estimate the probability of encountering individuals. a/ With a small exclusion zone (green polygon). b/ With a large exclusion zone (green polygon) and 3 checkpoints (red circles). c/ With a large exclusion zone (green polygon) and 5 checkpoints (red circles).

Table 1. Estimated probability of encountering at least one individual under different scenarios.

Scenarios	Probability of encountering at least one individual	Probability of encountering at least one individual per boat
Without restriction	47.5 %	5.6 %
With a small exclusion zone	43 %	5.1 %
With a large exclusion zone and 3 checkpoints	40.9 %	4.9 %
With a large exclusion zone and 5 checkpoints	38.8 %	4.5 %

After the race, we had access to the route of each sailboat. We were then able to estimate the collision probability by species and by boat on the route they followed. The collision probability with a pilot whale was estimated at 32.2% while for beaked whales, this probability was estimated at 87%. Depending on the followed route, some vessels had higher collision probabilities with either species, and the lowest probabilities were estimated for routes that avoided the large exclusion zone we defined in the Alboran Sea (Figure 3). The two boats that crossed the Alboran Sea had the highest collision probabilities. After the Leg 1 was completed, the race organizers informed us that a collision had occurred with a boat. We will be able to identify afterwards where this collision took place, which will help us to calibrate the model.

3 Perspectives

The offshore race was chosen as a demonstrator, it is an experimental situation in which all parameters are controlled. This will allow a better understanding of the phenomenon of collisions with cetaceans. In the short and medium terms, we aim to continue to develop the model. For this, we need to acquire density data on cetaceans, but also to calibrate the model by taking into account the size of the individuals, the avoidance capacities of the boats and the animals, the number of collisions that have actually taken place during the races... In the long term, we plan to apply the model for commercial navigation. In particular, this will require adding an economic cost model that would consider the economic gains or losses induced by a route change while reducing the probability of collision. The idea is to develop models that take into account all collisions (regardless of vessel type) in order to estimate the number of animals exposed and to develop indicators and mitigation measures.

4 Recommendations

The IWC Scientific Committee meeting is an opportunity to present the *Share The Ocean* consortium. Sharing data between *Share The Ocean* and IWC would be beneficial from all points of view. The IWC database could be supplemented with good quality, verified collision data from offshore racing and *Share The Ocean* could benefit from the data in this database to calibrate collision models, especially when applied to commercial shipping.

We would like to take advantage of the expertise of the scientific committee to identify other experimental situations, outside offshore racing, even at a local scale, for which we would have knowledge of cetacean density, maritime traffic and a census of collisions in order to be able to adjust the collision model in these areas and calibrate the model on other types of vessels.

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