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Using choice experiment designs to evaluate mitigation solutions to reduce whale-ship collisions

Sèbe Maxime [1, *], Nassiri Abdelhak [1], Pendleton Linwood [2, 3, 4, 5, 6]

[1] Univ Brest, Ifremer, CNRS, UMR 6308, AMURE, IUEM, 29280, Plouzané, France
[2] World Wildlife Fund, Global Science, Washington DC, USA
[3] Duke University, Durham, NC, USA
[4] Global Change Institute, University of Queensland, Brisbane, QLD, Australia
[5] Ifremer, CNRS, UMR 6308, AMURE, IUEM, 29280 Plouzané, France
[6] Ocean Data Foundation, Lysaker, Norway

* Corresponding author : Maxime Sèbe, email address : maxime.sebe@univ-brest.fr

abdelhak.nassiri@univ-brest.fr ; linwood.pendleton@oceandata.earth

Abstract :

Whale-ship collisions represent a threat to some whale population survival. The shipping industry rarely adopts solutions to reduce the risk of collisions. This lack of compliance is partly due to the fact that previous work has failed to assess the economic and logistic constraints these solutions put on the shipping industry. Our work explored for the first time the logistical considerations affecting the adoption of whale-ship collision avoidance approaches by shipping companies. We used a choice experiment approach to assess the shipping industry's preferences for mitigation solutions, by questioning ship crews. Amongst other things, our results demonstrated a preference for avoiding a high-density whale area instead of reducing speed in it, and a requirement for upstream information to plan the journey depending on these areas. Our findings could be used as guidelines for the implementation of mitigation solutions depending on situational characteristics (e.g., travel distance, area's size) and provide insights for policy-making to reduce the risk of whale-ship collisions.

Highlights

► Shipping industry's preferences for solutions to whale collisions were assessed. ► Shipping industry rather avoid than reduce speed in high-density whale areas. ► Upstream information is pivotal to increase the shipping industry compliance. ► Results can be used as guidelines for solutions selection and implementation. ► Knowledge of preferences provides insights for transportation policy-making.

Keywords : Avoidance, Choice experiment, Preference, Shipping industry, Speed reduction, Whale-ship collision

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1. Introduction

Maritime traffic threatens marine mammals in many ways, directly or indirectly [1]. While chemical and noise pollution are often described as the main indirect threats of shipping to marine mammals [2], ships are also responsible for direct removals – deaths – of marine mammals, more specifically of whales, through ship strikes [3,4]. For whales, collisions with ships are one of the main threats to the survival of some populations (IWC-ACCOBAMS, 2012; Reimer et al., 2016 [5,6]. Shipping routes crossing whales' core habitats create high collision risk areas – often associated with high mortality rates [7,8]. Furthermore, the current growth in maritime traffic, whether in terms of units, speed or engine capacity, tends to increase the level of risk of this threat in the coming years [4,7,9].

In recent years, various solutions have been proposed to tackle the problem of ship collisions with whales [10]. On one hand, technical solutions have appeared, mainly including whale detection tools, such as the Real-Time Plotting of Cetaceans System (REPCET) or the Boston passive acoustic network [11,12]. On the other hand, operational solutions have also been implemented such as speed reduction measures, traffic separation schemes (TSS), or areas to be avoided (ATBA) [13].

However, shipping companies have not always adopted these solutions, and especially the operational ones [14]. Various factors can explain the lack of responsiveness on the part of shipping companies. Silber and Bettridge [15] highlighted, as contributing factors, the lack of public recognition of the solution, or the lack of regulatory enforcement by the government. Recently, the absence of holistic approaches when proposing solutions to the shipping industry's policy-makers was highlighted [9,16]. More precisely, the integration of the logistic and economic dimensions is currently missing from mitigation proposals [14,17,18], which fail to give an overall view of the issue to the decision-makers. Indeed, the studies on whale-ship collision mitigation solutions focus, most of the time, on the theoretical effectiveness of the solutions, but very rarely take into account the economic and logistic dimensions of maritime traffic [14]. Consequently, the applied effectiveness is often significantly different from the theoretical effectiveness, because of the shipping industry's low compliance with the proposed solutions [19,20].

Only a few attempts have been made to study the logistic and economic factors that may influence whether shipping companies adopt collision avoidance approaches or not. Mainly, these studies investigated the additional fuel cost incurred by the avoidance of an area or the reduction of speed in it. For example, Kite-Powell and Hoagland [21] defined the costs associated with the reduction of speed around the Boston harbors (USA). In this study, the reduction in speed led to the loss of some ports of call. Indeed, the short distance between the regional ports did not make it possible to make up for lost time by increasing ship speed. The economic losses for harbors were estimated to be between \$300,000 (US$\$_{2005}$) and \$4,800,000 (US$\$_{2005}$) per year, depending on the size of the harbor. A similar study, conducted by Nathan Associates Inc. [22], estimated the cost of collision reduction solutions at between \$2,790,000 (US$\$_{2009}$) and \$142,476,000 (US$\$_{2009}$) for the U.S. East Coast, based on different scenarios (e.g., speed reduction, dynamic management area). Recently, Gonyo et al. [23] estimated the inventory carrying costs and the transportation costs of avoidance and speed reduction in the Channel Islands region (U.S. West Coast). This study reported a decrease in costs for the re-routing solution (1.6%-3.4%) and an increase in costs for the speed reduction solution (1.3%-2.0%). In parallel with these studies of the total costs of mitigation solutions, other studies focused on the cost of setting up and maintaining technical solutions [24]. These costs are often relatively low compared to company revenues (e.g., REPCET; [25]), but they did not take into account operational costs associated with implementation (e.g., gas emission tax, fuel consumption, port of call loss; [26]).

Thus, these studies often only partially reflect the economic dimension, which in turn would show an incomplete knowledge of the logistic dimension. Indeed, to the authors' knowledge, few studies have tackled the preferences of the shipping industries regarding whale-ship collision mitigation solutions depending on the logistical features required to implement the said solutions (e.g., [6]). Before looking at the costs of any solution, the study of the logistic dimensions could be decisive to propose viable solutions for shipping companies, depending on the organization of the shipping industry. Some solutions may be impossible to implement because of delays in arrival in ports of call [21], the inability of engines to adapt to a solution (*slow steaming*; [27]) or because of specific navigational rules (e.g., COLREG; [28]).

Our study aims to give first insights into how logistical considerations affect the adoption of whale-ship collision avoidance approaches by the shipping industry. Because of a lack of economic and logistic data regarding the interactions between ships and whale-related collisions, we attempt to estimate the shipping industry's preferences for risk reduction solutions by using the Choice Experiment (CE) method. CE design is used to invite maritime professionals to reveal their preferences among different alternatives. We propose mitigation solutions to the shipping industry – through their crew – accounting for situational characteristics (e.g., travel distance, area's size) in order to determine those factors that are most consequential in determining the adoption of avoidance methods and thus reflect the most significant features to take into consideration when proposing these solutions. We used collected data to estimate Lancasterian utility function with mixed logit specifications, which takes into account the impact of unobservable heterogeneity of each attribute preference [29], and its importance, or conversely, its non-attendance [30,31]. This model relaxes the Independence of the Irrelevant Alternative hypothesis because the preferences of the five attributes are not supposed independent [32]. This allows highlighting the complementarity/substitutability relation between attributes.

2 Methods

2.1 Choice Experiment Design

The CE methods are often used to assess the preferences of various stakeholders regarding environmental policies [33]. CE surveys present a series of alternatives – also known as choice sets – which encompass attributes describing a situation and a policy. The respondents must select the best alternative, in their opinion, allowing an implicit trade-off between the attributes [34,35]. The preference between attributes is then usually revealed through a willingness-to-pay value, which can be used as a monetary value, or as an indicator of the change in the utility [33,36]. Identifying relevant attributes that compose the alternatives proposed to respondents is crucial to designing a CE survey [34]. In our study, the attributes – and the values (referred to as levels in the CE terminology) that these take – were defined by consulting several experts on maritime traffic, whale conservation, and habitat modeling (Table 1).

Table 1. List of attributes and levels

Type of attribute	Attributes[a]	Number of levels	Levels[b]
Situational characteristics	Travel distance (TD)	4	100 nm; 300 nm; 500 nm; 700 nm
	Time of reception of the information (TRI)	4	24h before port departure; 12h before port departure; 1h before port departure; 1h before arrival on AOI;
	Size of the area of interest (AOI)	4	2.5 nm; 8 nm; 14 nm; 26 nm
Mitigation solutions	Avoidance solution (AS)	2	Yes; No
	Speed reduction solution (SRS)	4	No speed reduction (0%); 18kn to 14kn (20%); 23kn to 16kn (30%); 20kn to 12kn (40%)

[a] The variables names as used in the model are in parentheses

[b] The percentages of reduction in speed are in parentheses. These percentages were not visible in the questionnaire

Using the CE method, we propose two mitigation solutions to the shipping industry by using a questionnaire distributed to maritime professionals. The first one is the avoidance solution (AS) of a high-density whale area – or a high probability of collision area. The AS is a binary attribute composed of two levels, namely to avoid or not to avoid the area. The second solution is a speed reduction solution (SRS) for the area. The SRS attribute is composed of four levels representing speed reductions of 0%, 20%, 30%, and 40%. These levels convey what can be seen in the literature with speed reduction proposals to 12kn, 14kn and 16kn [37,38]. It should be noted that both AS and SRS can be combined in the same alternative, similar to that which is found in the literature (e.g., [39]).

To understand the contextual factors influencing the shipping industry preferences for mitigation solutions, situational characteristics are also included into the alternatives (i.e., each alternative is composed of three situational characteristics and two mitigation solutions; Fig. 1). First, we offer different sizes – diameter – of the whale high-density area, hereafter referred to as the area of interest (AOI). The levels describing area sizes have been selected to reflect the range of possibilities between the current habitat suitability models and future predictive abilities (5-10 years; [40–42]).

For each choice alternative, one of the attributes represents the time of reception of the information (TRI) about the AOIs' characteristics (size and location). The TRI is crucial for the crew to take a decision on avoidance action possibilities. To define the levels of TRI, some logistical features were highlighted by informal interviews with captains, watch officers, and company environmental managers. These interviews underlined that, without a fleet center, the watch officers prepare the trip of the ship on the day of the journey or a day earlier. Then, the captain validates the journey one hour before departure. These times vary between companies, but the levels chosen for the study integrate this range of variability. Besides, one of the TRI levels was chosen to represent the possibility of receiving information at the last moment (1h before the arrival on the area), which can be the case with some observation networks' technologies (e.g., REPCET). To be noted that Reimer et al., [6] defined that the TRI is a key factor in the decision process, and our study will quantify this factor.

Finally, the last attribute is the travel distance (TD), which is an essential parameter of the shipping industry, as it defines the type of navigation a ship operates [26]. The travel distance levels selected represent a range of different types of navigation, from coastal navigation to long-distance travel.

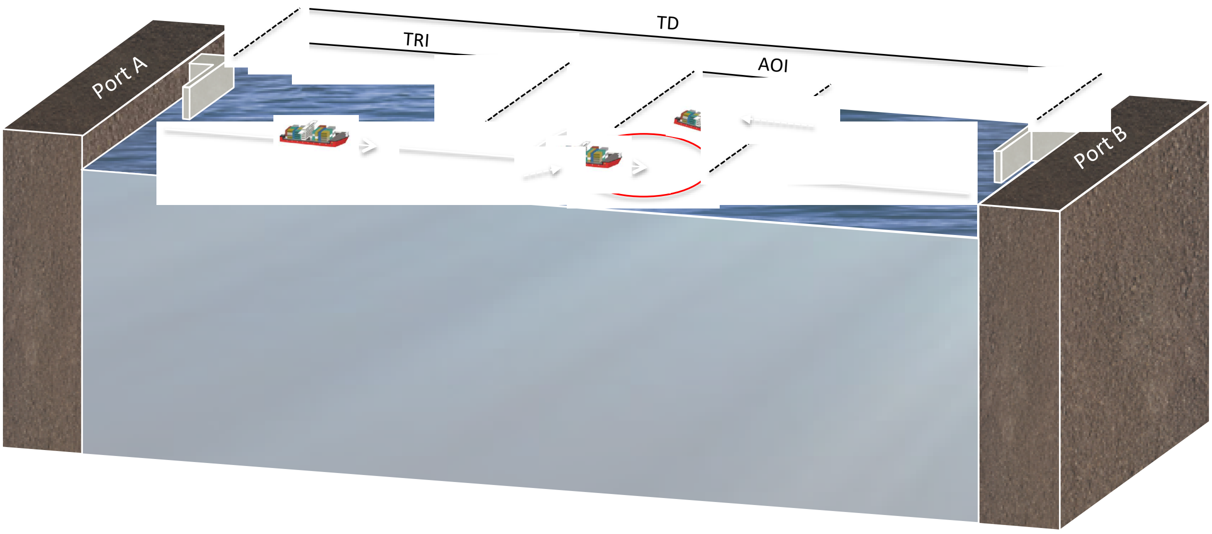

Figure 1. Conceptual illustration of the questionnaire. Note that the AS can be combined with the SRS in the questionnaire. TD = Travel distance; TRI = Time of information reception; AOI = Size of the area of interest; AS = Avoidance solution; SRS = Speed reduction solution. The situational characteristic attributes are in black; mitigation solutions are in white. Conception: Authors.

The survey protocol was presented to a panel of maritime professionals who helped select and validate the attributes and their levels. The resulting experimental design – matrix of all the attributes' levels (Table. 1) – in our study is composed of $4 \times 4 \times 4 \times 2 \times 4 = 512$ alternatives. We then followed the different steps that are recommended and applied in the majority of the literature that uses the multi-attribute choice method to build an optimal design (e.g., [34]). A D-optimal fractional factorial design of 16 alternatives was generated[1] by the SAS® software using the OPTEX procedure (Edition 9.3). This optimal design is composed of 8 sets of 2 alternatives.

[1] This first design assumes all the parameters null.

2.2 Questionnaire

The questionnaire is composed of four parts. First, an introductory text explains the problem of whale-ship collisions. In this introduction, the logistical and economic issues that collision mitigation solutions could generate are also presented. At the end of this part, an explanation on how to fill in the CE questionnaire is provided.

The second part of the questionnaire seeks demographic information to weigh CE results. For example, questions about the respondent's job (captain or watch officer), the size of the vessel on which the respondent is deployed, and the ship category (tanker, bulk carrier, cargo ship - without passengers, cargo - with passengers) were asked.

The third part of the questionnaire introduces the CE survey. For each choice set (8 choice sets in total), respondents were asked to assume that they had performed the two alternatives proposed. Based on this principle, respondents were asked to answer the following question: *"In your opinion, which alternative represents the best compromise between the issues of maritime traffic and the protection of whales?"*.

For the various options proposed to be comparable in the multi-attribute choice surveys, it is usually necessary to introduce a reference option. Some authors use the current state (*"status quo"*; e.g., [43]) as a reference option. This state corresponds to a predefined and observable combination of the attributes, which is unique and common to all respondents [44], and the other alternatives correspond to changes in these attributes. This approach is usually used when studies focus on a given geographical area or a market [45–47]. In our study, the current state corresponds to the actual practices of each maritime professional. These practices are not identical between ship categories nor between professionals. In addition, these practices are not observable; therefore, they cannot be a common frame for all alternatives [48,49]. To solve this issue, we opt for CE design, which consists of proposing several alternatives (two in our case) with the possibility of rejecting them. The latter option is referred to as *"no action"* or *"opt-out option"* [48,50]. In each choice set, two alternatives were, therefore, presented to answer the question: *"Alternative 1"* and *"Alternative 2"*. In addition, the following opt-out alternative was proposed in each choice set: *"None of the alternatives are realistic"* (Fig. 2).

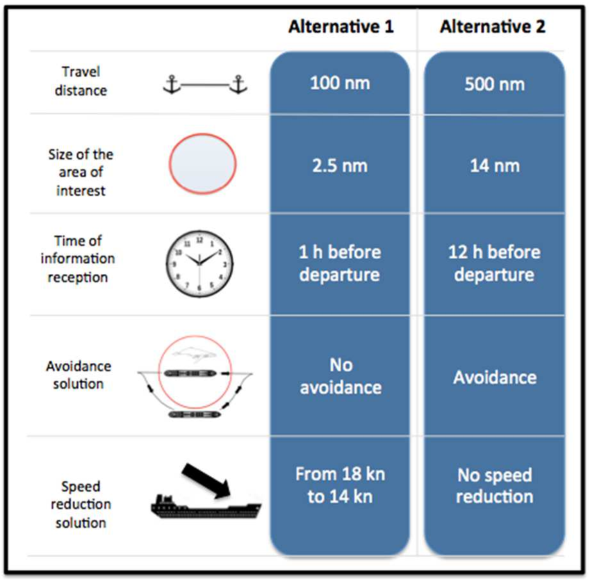

Figure 2. Example of a choice set. Respondents were presented with 8 unique choice sets, each composed of different alternatives. Conception: Authors.

Finally, in the fourth and last part of the questionnaire, a Likert scale is proposed to respondents in order to measure how important was each attribute in their choices [29,51]. The authors' contacts were also provided to the respondents so that they could share any comments on the questionnaire, or their activity.

Before administering the questionnaire to maritime professionals, we submitted a first draft to several commanders, watch officers, and environmental managers to identify clarity and terminology issues, or issues due to the authors' misunderstanding of the maritime traffic processes. Afterward, the questionnaire was also submitted for testing to researchers from the AMURE Economics Laboratory to identify flaws in the survey protocol. Answers and comments from both phases were integrated to build the final optimal design, and, therefore, the final questionnaire.

Maritime companies – mainly from the south of France – were contacted, and the questionnaire was administered via the Internet by using the LimeSurvey platform [52]. The environmental officers of the shipping companies transferred the LimeSurvey questionnaire to commanders and watch officers. Therefore, this administration protocol allowed us to define precisely the sample size.

2.3 Econometric Analysis of Choice Data

We used a questionnaire based on the discrete choice method to collect empirical data on maritime professionals decisions to reduce the risk of whale-ship collision. This CE protocol aims to identify the preferences of these maritime professionals between the proposed solutions. We proposed eight choices sets, *t*={1,..,8}, to each respondent, *i*={1,...,n}, which were asked to choose among three alternatives, *l*={1,2,3} in each set. To study these choices, we assume as in McFadden's pioneering paper [53] that the underlying preferences are characterized by a separable additive utility function $U_{ijt} = V_{ijt} + \varepsilon_{ijt}$ with ε_{ijt} corresponding to its random component. The probability of choosing the j^{th} alternative is then characterized by the logit specification $\Pr(y_{it} = j|\beta) = e^{V_{ijt}} / \sum_{l=1}^{3} e^{V_{ilt}}$ if the random component have cumulative density function of Gompertz $F(\varepsilon_{ijt}) = exp\left(exp(\varepsilon_{ijt})\right)$. The non-stochastic component of utility $V_{ijt} = \sum_{k=1}^{5} V_{ijt}(x_k)$ depends on the 5 attributes with x_k being the value of each attribute *k* in each alternative *j* chosen by the respondent *i* facing a set *t* of choices.

The developments in the random utility models' applications over the past two decades included four points [30,31]. The first one is (1) the unobservable heterogeneity of preferences for each attribute [31]. We select the specification of mixed logit of the form $\beta_k = b_k + \epsilon_k$, with

$\epsilon' = (\epsilon_1, \dots, \epsilon_k, \dots, \epsilon_5)$ a Gaussian vector of zero mean and a var-cov matrix, Ω. This specification has a triple advantage of: testing the unobservable heterogeneity of preferences for each attribute *j* using the diagonal elements of Ω; identifying the interdependence of preferences between the different attributes *j* using the signs of the correlation coefficients deduced from this matrix Ω; and releasing the Independence of the Irrelevant Alternative (IIA) hypothesis [54].

The second point deals with (2) the functional form of preferences. We opt for non-linear forms. We tested several forms by coding all quantitative attributes as qualitative explanatory variables (with modalities), and by applying linear, quadratic and logarithmic transformation. Given the estimates, we selected the quadratic specification, which is the most adequate according to the BIC criterion (Tables available upon request). For each quantitative attribute noted x_k, its utility is then specified in the form $\mathrm{V_{ijt}}(x_k) = \beta_k x_k + \beta_{k2} x_k^2$, which can be concave/convex depending on the sign (-/+) of β_{k2} where the first derivative $\mathrm{V}_{x_k} = \beta_k + 2\beta_{k2} x_k$ informs on the variations in preferences according to the level of this attribute and to $-\beta_k / 2\beta_{k2}$ its inflection point[2].

The third point (3) is to know if the level of importance or attention that respondents give to attributes when making their choice biases the protocol (Attribute Non-Attendance; ANA; [55,56]). Two solutions are usually proposed. The first solution is to use adequate econometric specifications to take into account the importance of each attribute endogenously. This method, called inferred ANA, is applied when the authors fail to measure the importance given to each attribute by each individual when administering the survey. Scarpa et al. [49], Hensher and Greene [51], Hess et al. [57], Hole [58], Campbell et al. [59], and Hensher et al. [60] used discrete distributions (models with classes), and Hensher et al. [61] proposed a more flexible specification

[2] The level of the attribute at which preferences change directions of variation, increasing first, and then decreasing.

allowing releasing the constraints of the parameters' equality between the classes [62]. The second solution is to directly question respondents concerning the importance of each attribute (stated ANA; [63]). Some authors added these questions after each set of alternatives [64], but this option has been criticized because it disrupts the individual's choice process and, consequently, complicates the questionnaire and the cognitive effort to complete it [55,65–68]. Also, this solution may lead to answers that are not consistent with the decision taken. For these reasons, in our study, we adopt the second solution by proposing respondents a 5-level Likert scale[3] for each attribute at the end of our questionnaire.

The fourth and final point deals with (4) the impact on the evaluation of the respondents' heterogeneity. During prior discussions with the maritime professionals, the only notable heterogeneity observed were the differences between captains and watch officers, and between the types of ship (e.g., cargo, tanker). Consequently, we re-estimated our different models by stratifying our sample according to these two variables, but only by retaining the majority group[4]. Few variations of the results are observed.

Based on these four points, in our study, each estimated model is based on a mixed logit model specification with a non-linear random utility function of the form $U_{ijt} = V_{ijt} + \varepsilon_{ijt}$ with $V_{ijt} = \beta_1 TD_{jt} + \beta_{12} TD_{jt}^2 + \beta_2 TRI_{jt} + \beta_{22} TRI_{jt}^2 + +\beta_3 AOI_{jt} + \beta_{32} AOI_{jt}^2 + +\beta_4 AS_{jt} + \beta_5 SRS_{jt} + \beta_{52} SRS_{jt}^2$. The vector $\beta = (\beta_1, \dots, \beta_k, \dots, \beta_5)'$ follows a multivariate Gaussian law $N(b, \Omega)$ of density $f(\beta / b, \Omega)$. The parameters of the model (b, Ω) are estimated by maximizing the expectation of

[3] Furthermore, disregarding the importance of each attribute in fact skews the results of the estimates and distorts the willingness to pay that can be deduced from them, in particular when the monetary attribute is ignored [49]. Note that there is no monetary attribute in our assessment and there is no question of willingness to pay.

[4] The number of respondents is not large enough. However, this is not a sample. We cannot, therefore, venture to estimate our models for all the sub-groups, which therefore have very few respondents.

the likelihood of the observations according to the density $f(.)$ of the unobservable heterogeneity, $L(b,\Omega) = E_{[f]}[L(\beta)]$. This expectation is calculated by the simulation method[5] proposed by Train [69] using 500 random draws of the vector of the parameters β^r according to the density $f(.)$. The simulated likelihood $L^*(b,\Omega) = \prod_{i=1}^{n} \frac{1}{500} \sum_{r=1}^{500} [\prod_{t=1}^{8} \prod_{j=1}^{3} Pr(y_{it} = j|\beta^r)^{y_{it}}]$ with $Pr(y_{it} = j|\beta^r) = e^{V_{ijt}} / \sum_{l=1}^{3} e^{V_{ilt}}$ the probability that the individual i chooses the alternative j among the set of options t conditional on the fact that the preferences of this individual are subject to an unobservable heterogeneity characterized by density distribution $f(.)$.

3 Results

3.1 Respondents Characteristics

The survey was conducted in June 2019. In total, 67 respondents completed the questionnaire, which represents 19.7% of the sample size. The sample frame was composed of captains and watch officers of leading French shipping companies (N=6). The proportion of captains and watch officers that responded to the questionnaire was similar (Table 2). No crew navigating on ships below 100m in length answered the questionnaire, which is not surprising as few of these ships are represented in the shipping companies surveyed. Most of the respondents belonged to cargo ships of sizes ranging from 100m to 250m (Fig. 3).

Table 2. Respondents characteristics expressed in percentages

Respondents' characteristics	Share
Response rate	19.7%
Captains	44.8%
Watch officers	55.2%

[5] The estimation of this model is carried out using the Stata estimation procedure developed by Hole.

Ship size - <50m	0%
Ship size - 50 to 100m	0%
Ship size - 100 to 150m	20.9%
Ship size - 150 to 200m	35.8%
Ship size - 200 to 250m	17.9%
Ship size - 250 to 300m	9.0%
Ship size - > 300m	14.9%
Tanker	9.0%
Bulk carrier	1.5%
Cargo ship without passengers	68.7%
Cargo ship with passengers	20.9%

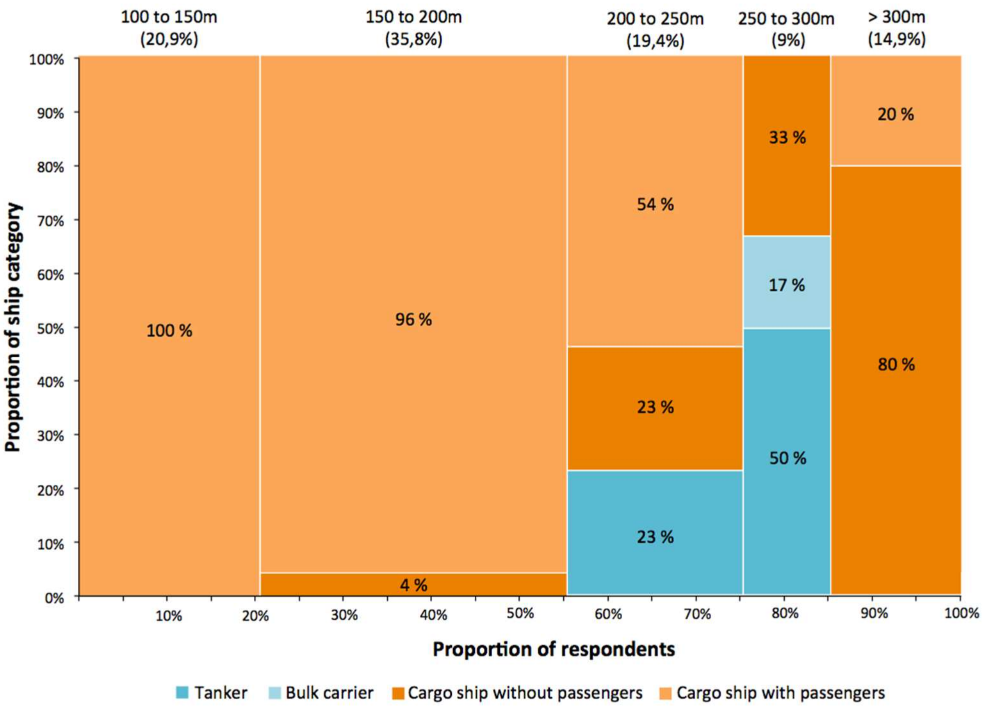

Figure 3. A Marimekko chart in which the percentage of ships in each size class are divided among the different types of vessels. Conception: Authors.

The distribution of responses to the 5-point Likert scale is given in Table 3. One can notice that the table is asymmetric and skewed to the right. This means that captains and watch officers give a high value, and, therefore more importance to all attributes. None of them give a value lower than 3 to all the attributes; 62.69% give at least the value 3 to the four discriminating attributes (TRI, AOI, AS, SRS). By only considering AS and SRS, 97% of the respondents give these mitigation solutions a value greater than or equal to 3, and 95.52% the value of 5 (Supplementary Material). These results indicate that prior discussions with maritime professionals helped build a robust questionnaire. Consequently, the attributes selected for this survey are relevant to the shipping industry and did not bias our study.

Table 3. Respondents' perception of the importance of the attributes

	Not important	Slightly important	Moderately important	Important	Very important
Travel Distance (TD)	16.42%	16.42%	17.91%	37.31%	11.94%
Time of reception of the information (TRI)	4.48%	19.40%	13.43%	34.33%	28.36%
Area of interest size (AOI)	0.00%	1.49%	14.93%	43.28%	40.30%
Avoidance (AS)	2.99%	5.97%	11.94%	40.30%	38.81%
Speed reduction (SRS)	4.48%	2.99%	14.93%	26.87%	50.75%

3.2 Model Results

Table 2 summarizes the best-fitted models. The model[6] *M1.a* is the most relevant one, because its BIC value is the lowest (1042). On one hand, the model *M1.a* shows that the preferences of the interviewees are subject to non-observable heterogeneity (i.e., the values of the standard deviations are significant for all the attributes). On the other hand, the model demonstrates that preferences are variable according to the attribute level (Fig. 4).

[6] As mentioned in the previous section, other models have been estimated (Conditional Logit, Mixed Logit with different transformations of quantitative attributes). The results tables are large and provide little additional information. The BIC values are significantly higher (available to the readers upon request).

Table 4. Mixed logit results (online discrete choice experiment with 67 respondents, 1608 observations). In bold, the model selected for the study. Abbreviations: TD = Travel distance; TRI = Time of reception of the information; AOI = Area of interest; AS = Avoidance solution; SRS = Speed reduction solution. Subscript numbers correspond to the subscript in the utility function.

	ML, U linear		ML, U quadratic				ML with only significant parameters			
Attributes	Independant		(M0.a) Independant		(M0.b) Dependant $\hat{\Omega}$		**(M1.a) Independant**		(M1.b) Dep. .$\hat{\Omega}$	
	$\hat{b}$	$\hat{\sigma}$	$\hat{b}$	$\hat{\sigma}$	$\hat{b}$	$\hat{\sigma}$	$\hat{b}$	$\hat{\sigma}$	$\hat{b}$	$\hat{\sigma}$
	(pvalue)	*(pvalue)*	*(pvalue)*	*(pvalue)*	*(pvalue)*	*(pvalue)*	***(pvalue)***	***(pvalue)***	*(pvalue)*	*(pvalue)*
TD	0.00172	-0.0022	0.00277	0.00249	0.00262	0.00301	**0.00169**	**0.00261**	0.00210	0.00299
	(0.000)	(0.000)	*(0.044)*	*(0.000)*	*(0.068)*	*(0.000)*	***(0.001)***	***(0.000)***	*(0.000)*	*(0.000)*
TD^{2*}			-1.3e-06		-7.9e-07					
			(0.486)		*(0.689)*					
TRI	0.0284	0.0507	0.133	0.0592	0.145	0.0496	**0.141**	**0.0594**	0.144	0.0516
	(0.011)	(0.001)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.005)*	***(0.000)***	***(0.000)***	*(0.000)*	*(0.004)*
TRI^{2*}			-0.0042		-0.0048		**-0.00464**		-0.00470	
			(0.0059)		(0.003)		**(0.000)**		(0.000)	
AOI	-0.0345	0.0478	-0.0764	0.0576	-0.0712	0.0543	**-0.0700**	**0.0584**	-0.0810	0.0466
	(0.010)	(0.051)	*(0.032)*	*(0.009)*	*(0.059)*	*(0.005)*	***(0.000)***	***(0.009)***	*(0.000)*	*(0.028)*
AOI^2			0.00041		-0.00037					
			(0.751)		*(0.785)*					
AS (coding effect)	0.113	0.586	0.385	0.674	0.413	0.668	**0.391**	**0.653**	0.439	0.549
	(0.303)	(0.000)	*(0.005)*	*(0.000)*	*(0.006)*	*(0.000)*	***(0.002)***	***(0.000)***	*(0.002)*	*(0.035)*
SRS	-0.0248	0.0627	0.0738	0.0847	0.0742	0.0354	**0.0740**	**0.0863**	0.0783	0.0420
	(0.013)	(0.000)	*(0.005)*	*(0.000)*	*(0.008)*	*(0.039)*	***(0.001)***	***(0.000)***	*(0.002)*	*(0.029)*
SRS^2			-0.0029		-0.0033		**-0.00310**		-0.00326	
			(0.000)		*(0.000)*		***(0.000)***		*(0.000)*	
BIC	1065		1056		1103		**1042**		1091	

* Estimated parameters $\hat{b}$ of these variables are not significant in both model M0. a/b and M1. a/b. Therefore, there are removed in the last model.

Regarding situational characteristics attributes, results show that the crew preference positively increases with distance travelled (TD) attribute (Fig. 4). In other words, the greater the distance, the less reluctant the crews of surveyed companies are to implement a whale-ship collision mitigation solution. Similarly, the preferences for the time of reception of the information (TRI) are positive up to an inflection point at 15.19h. This result means that the crew prefers to have upstream information about an area of interest (AOI) up to a point (15.19h) where there is no added value of having more time to prepare the journey. Not surprisingly, the crew prefers AOI limited in size. Each additional nautical mile to the AOI results in a loss of utility of 0.00345.

For the whale-ship mitigation solutions, we find that the shipping industry is well aware of the underlying issues and is not reluctant to either solution (the estimated parameters are positive and more than 99% reliable). However, their preferences for speed reduction sharply decreases when the reductions imposed are too high– exceeding the inflection point of 11.94% of speed reduction) – and become negative when they exceed 30.39%. We can use our estimates to compare the trade-offs between the preferences of the two mitigation solutions. In Figure 4, the curve of the utility function of the attribute SRS is higher than its value for the attribute AS for speed reductions between 7.9% and 16% (the two roots of polynomial $(SRS) = U(AS) \Leftrightarrow 0.074 \times SRS - 0.0031 \times SRS^2 = 0.391$). This means that avoidance is preferable in these cases (when the speed reductions are too high above 16 and too weak below 7.9). Undoubtedly, avoidance is an opportunity for ships to take other alternative shipping routes that are just as beneficial to their commercial activity.

a)

Attribute	Correlated with	Preferences sign (inflection point)
TD	TRI (positively) AOI (negatively)	+
TRI	SRS (positively)	+/- (15.19)
AOI	AS (negatively)	-
AS	AOI (negatively) SRS (negatively)	+
SRS	TRI (positively) AS (negatively)	+/- (11.94)

b)

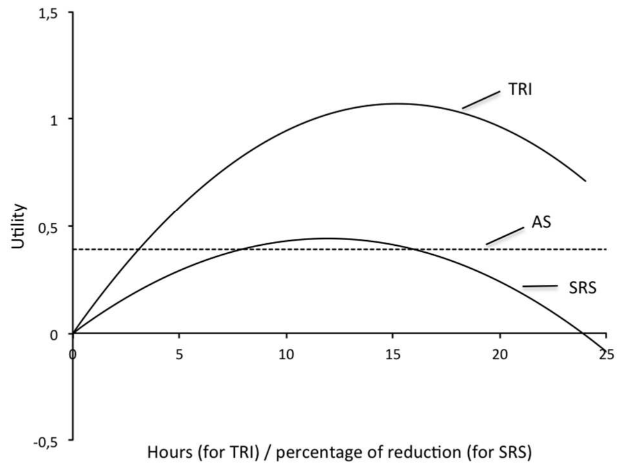

Figure 4. Correlation and variation in the utility of the attributes. The AS attribute in the illustration is constant (a). Its variation is dependent on other attributes (see (b)). Conception: Authors.

Further, our mixed logit specification *M1.b* with a dependent multivariate Gaussian distribution allows estimating the correlation between attributes due to the unobservable heterogeneity of preferences It should be noted that, we refer to the results of this model without forgetting that its BIC value is higher than the one from the *M1.a* specification ($BIC_{(M1.a)} = 1042 < BIC_{(M1.b)} = 1091$). For mitigation solutions, these first results highlight a significant negative correlation (more than 99% reliable depending on the bilateral Student's t-test), which demonstrates a form of substitutability between the two solutions. In other words, maritime transport professionals prefer when they are given a choice between the two solutions. Depending on the situational characteristics, they can decide on their own to avoid or reduce their speed.

4 Discussions and Conclusions

4.1 Shipping Industry's Preferences

In this research, we performed an empirical evaluation of the shipping industry's preferences for mitigation solutions using a Choice Experiment. We surveyed ships' crews, composed of captains and watch officers. The crew takes navigational decisions based on their training, international regulation, but also based on instructions of its companies regarding schedules and economic aspects [14,70]. Consequently, their choices reflect the overall policies and constraints of the shipping industry. Therefore, the crew preferences are reflective of shipping industry behavior regarding mitigation solutions.

The avoidance solution appears to be the ship crews' most appreciated solution – with some exceptions. This observation corroborates other findings of compliance in the literature regarding these kinds of solutions. The avoidance of an area of interest can be undertaken either by TSS or ATBA. Regarding TSS, Lagueux et al. [20] found a 96.2% rate of compliance with recommended routes in the right whales' southeast US calving ground (in Georgia and Florida). Similarly, McKenna et al. [71] showed compliance rates of between 79% and 89% with the TSS for blue whales protection off the coast of southern California. The compliance with ATBA also seems to align with our results; Vanderlaan and Taggart [72] found a 71% rate of compliance with the voluntary ATBA in Roseway Basin right whale habitat. Speed reductions are not favoured by our respondents nor do they enjoy high levels of compliance in the literature. Several studies found compliance below 33%, and in one case authors show a 1% rate of compliance [9,20,71,73,74]. One exception that should be highlighted is in St. Lawrence Estuary where investigators found a 72% compliance rate with speed reductions. This case was remarkable for a high level of collaboration by stakeholders [75]. Note the compliance often increase when a solution is mandatory (e.g., compliance from 9.8-23.2% to 75%; SRS; [20]) or with the application of incentives to comply with it (e.g., compliance from 13% to 77%; SRS; [71]). Also, Weinrich et al. [76]noted that the avoidance solution was preferred in cases of last-minute decisions.

Economically, the preference for avoidance appears to make sense. Gonyo et al. [23] studied the variation in costs between the avoidance and speed reduction solutions. While the implementation of the speed reduction solution decreases transportation cost – linked to fuel consumption –, the inventory-carrying costs do increase. In opposition, there is a slight decrease in the inventory carrying and the transportation costs for the avoidance solution. Additional transit time appears to be a driving factor in the lack of preference for speed reduction. Speed reduction will have positive economic impacts because fuel consumption per kilometres decreases with lower speeds [77]. On the other hand, speed reduction results in longer transit times and may require increasing the speed outside the area of interest to offset lost time. Because *slow steaming* speeds are different than normal operational speeds, adapting to speed reductions could require a reconfiguration of the engine to achieve an efficient lower power output [27]. Furthermore, the distance between harbors might be too short to offset lost time, and supplementary constraints might appear (e.g., delays of arrival in port, disrupted land transportation; loss of docking; [22,78,79]). These parameters lead to an increase in inventory carrying costs (i.e., costs unrelated to fuel consumption). On the other hand, the avoidance solution could increase the transit time by increasing the distance traveled. However, a slight increase in operational speed can offset lost time, which explains the low additional costs.

Logistically, our results highlight the importance of receiving early information (TRI) about the characteristics of high-density whale areas, especially for watch officers. The sooner the information is received, the more it will impact the utility function positively. When we know the role of each crew member (e.g., captain, watch officer; Supplementary Material), we underline that the TRI is significant for the watch officers, but not for the captains. These results confirm the hypothesis collected during informal interviews regarding voyage planning; the watch officers formulate a voyage plan at least 12 hours before departure, and the captain validates it around one hour before departure. Our results confirm this feature, as the delay of reception of the information is more important to watch officers than for captains. Besides, regulations impose that the voyage plan *"should be approved by the ships' [captain] prior to the commencement of the voyage"* [80], and the captain should also validate significant modifications during the voyage (Varin, pers. comm. 2019). It is then pivotal that watch officers know the information in advance in order to organize the journey and propose solutions to the captain, before departure, when the validated voyage plan does not constraint decisions. Our results are in line with those of Reimer et al. [6], which show a preference for receiving information before leaving port, or within a few hours of arriving at the AOI (respectively 53% and 35% of the respondents). However, Reimer et al. [6] did not find a clear consensus on the best time to receive the information. In light of our results, this lack of consensus may be explained by the fact that Reimer et al. [6] did not make a distinction between captains and watch officers. Moreover, our study quantified the maximum reception time of information. As mentioned before, at one point – inflection point – there is no added value of having more time to prepare the journey (15.19h).

Also, not surprisingly, whatever the solution selected; the utility function increases with the distance covered meaning that collision mitigation measures are more likely to be complied with for longer voyages. This feature can be decisive for whale protection. For example, Mediterranean fin whales exhibit a coastal distribution in summer between France, Italy and Corsica, where whales are at risk of collisions with short-travel distance passenger ships [25]. For short-travel cruises, through preferences, our study shows that avoidance would meet more compliance from companies than the speed reduction solution (i.e., utility increases with shorter traveled distances). However, in winter, this population is partly suspected to inhabit more offshore waters, such as the ones of Western Sardinia [81]. In this area, ships travel longer distances, between, for example, France and Africa. Our results suggest that, if habitat modeling confirms fin whales' offshore winter distribution, the implementation of mitigation solutions – even speed reduction, to a lesser extend – should be effective thanks to potential high compliance. To be noted that the compliance depends on various factors such as enforcement

[82], and that our observations on the compliance are interpretations from the preferences highlighted in this study.

4.2 Implications For Conservation

Conservation scientists often propose the whale-ship collision mitigation solution that achieves the greatest benefit to whales when adopted. Speed reduction is one of the best-identified solutions [7,75] to reduce whale mortality due to collisions. This solution acts directly on the probability of mortality, whereas the avoidance solution acts on the probability of encounter – occurrence [39]. Hence, the implementation of speed reduction guarantees having a positive impact on the risk of lethal collision, even in a data-poor environment. On the contrary, to be effective, avoidance solutions require an extensive understanding of whale habitat and distribution, which is not always the case. Therefore, conservation scientists are more prone to advocate for speed reductions, despite some recent reconsiderations on the subject [23,83].

While theoretically effective, the applied effectiveness of the speed reduction solution is often limited by a lack of compliance. In the literature, the risk reduction induced by solutions is often expressed by assuming full compliance from the shipping industry (e.g., [23,24,38,39]). However, this level of compliance is rarely met [71]. According to the preferences highlighted in this paper, compared to speed reduction, the avoidance solution is more likely to be applied by the shipping industry, and therefore, might have a higher applied effectiveness.

The shipping industry's preferences, elicited by our choice experiment, advocate for the use of the avoidance solution instead of speed reduction, at least for professionals sharing our respondent characteristics. For our respondents, which navigate mainly Mediterranean and Atlantic waters, the primary preferences of the shipping industry and of the conservation scientists are therefore at odds. As a consequence, conservation scientists should integrate the shipping industry's preferences before presenting a mitigation solution to achieve more effective protection of whales. For short journeys, such as the ones in the summer habitat of Mediterranean fin whales, avoidance solutions should prevail, especially for ships providing cabotage services. This solution is logistically more efficient to offset time lost [84]. According to our results, for offshore navigation, the type of mitigation solution matters less to the shipping industry, as longer distances allow for better offsetting of lost time.

However, to be able to offset the cost of any mitigation solutions, ships need to be advised in advance of the characteristics of the areas where whale collisions are likely. Whale habitat suitability models that are dynamically updated are needed provide this information with sufficient advanced notice. Whale habitat suitability models are becoming increasingly sophisticated with the integration of biotic (e.g., whale acoustic and observation) and abiotic (e.g., bathymetry; chlorophyll) parameters [85–87]. The emergence of Big data, using satellite information, opens-up the possibility of more frequent habitat updates or even near real-time updates [40,42,88]. Of course, the technology leading to a predictive tool is not yet operational, and, meanwhile, other promising options of alerting can be implemented such as acoustic networks (e.g., Boston harbor; [13]) or observation networks (e.g., REPCET; [89]). Reimer et al. [6] showed that crew's have a preference for receiving such updated information via their Automatic Identification System (AIS). The AIS presents the advantage of not being disruptive of the crews' activities. Nevertheless, several limitations to the incorporation of whales' areas of interest to the AIS have yet to be overcome [90].

While our study highlights the required features for mitigation solutions, the resulting compliance with them might still be low if their implementation is not standardized. This aspect has recently been highlighted for greenhouse gas emission reduction solutions. Shipping companies appear to approve speed reductions for decreasing these emissions, but request a clear regulation to act [91,92]. A regulation would dictate the implementation of the solution to the entire fleet of a region, and avoid the loss of competitiveness that countries' unilateral implementation would bring [93]. This reasoning applies to whale-ship collision solutions, as expressed by a former captain at the International Conference on Marine Mammal Protected Areas [94]. During a public conference, this former captain criticized the implementation of a mitigation solution (REPCET) to only French ships: *"We can't have a rule that applies to a French vessel and not to an Italian vessel, this is discrimination. We need solutions at the International Maritime Organization level"* (Varin, pers. comm. 2019).

The International Maritime Organization (IMO) represents then a promising way of implementing standardized approaches and evaluating the most efficient solutions. The IMO is a United Nations agency, which regulates all aspects of maritime safety and protection of the marine environment [9] and is recognized as the authority in international shipping [16]. The IMO *"produces conventions which become law when they are enacted by each maritime state"* (p. 656; [26]). While the implementation of voluntary mitigation solutions often meets low compliance, the IMO's involvement through mandatory or recommended measures – mostly TSS and ATBA – has been proven to be effective in increasing the compliance [16]. Furthermore, as the Roseway Basin seasonal ATBA exhibits, the IMO recommendations can be flexible [95]. This flexibility can be used to provide the best-suited solutions based on the preferences of the shipping industry and whale habitat dynamics.

Our study may also contribute to other IMO mechanisms that can be adapted to collision management, such as Particularly Sensitive Sea Areas (PSSA). A PSSA is *"an area that needs special protection through action by IMO because of its significance for recognized ecological, socio-economic, or scientific attributes where such attributes may be vulnerable to damage by international shipping activities"* [96]. Crew' preference can be used, for example, in the ongoing reflection for a PSSA in the Mediterranean [97]. This PSSA should cover a large part of the Western Mediterranean, and could – according to guidelines – combine several solutions inside the PSSA. Depending on the different types of navigation within the potential PSSA, various solutions can be considered based on the preferences of the shipping industry to optimize their compliance.

4.3 Further Research

Further research is required to improve our understanding of the shipping industry's preferences. For example, our results highlight that the utility for small speed reductions, below 7.9%, is inferior to moderate speed reductions – 7.9% to 16% – for which the utility is even superior to the avoidance solution. These preferences might be linked to how the ships and the industry operate [21,27,28]. For example, small changes in speed might be logistically challenging, as modifications might be required in the engine room. These modifications might be worth doing only for larger changes in speed [27]. These results might also indicate that the shipping industry prefers to be given a choice, rather than to have a solution imposed.

In addition, more ship and crew characteristics should be investigated to improve our results. Most of the survey respondents in our study operate small to medium-size cargo ships, which are typical of short-haul trips (Fig. 2; [25]). Consequently, respondents' answers for longer journeys might be biased. Also, on one hand, more than 20% of the respondents operate passenger ships that are more likely to undergo damages following whale-ship collision [18] and, therefore, the crew presumably might be more careful in avoiding obstacles, such as whales. On the other hand, passenger ships' contribution to deadly whale collisions are known to be higher than that of other ship categories [25], leading to a higher focus of conservationists on passenger ships. Hence, the crew of other categories of ships might be less aware of the whale-ship collision issue, because conservationists raised less awareness of the crew in the categories. These heterogeneity factors – amongst others – might influence our results and require further investigation. Future studies using applied route choice data might help refine our understanding of the shipping preferences, as it is done for fishery management [98,99].

Our survey also was carried out on a limited number of respondents – mainly due to the limited sample frame that represents captains and watch officers. To be noted, we used a D-efficient design, which requires a smaller sample size to estimate all parameters at the level of statistical significance [100], as it has been shown in previous studies [101,102]. Contacting other shipping companies might be decisive to overcome the lack of heterogeneity in respondents. Further research expanding the sample to areas outside the Mediterranean and Northeastern Atlantic is required to have an overview of the shipping industry's preferences at the international level. Also, while we tested several specifications in our study, other specifications might be adapted to this kind of survey (e.g., endogenous NAA; [62]).

4.4 CONCLUDING REMARKS

To sum up, our study highlighted some features to define best-suited whale-ship collisions mitigation solutions. In the end, our results could be used as guidelines to solution proposals based on the situational characteristics of a studied site; and help conservationists propose solutions that are the most likely to meet the shipping industry's compliance. In most situations, avoidance is the preferred operational solution, and might reach the highest applied effectiveness due to a potential high compliance. However, in order to improve the solutions' effectiveness, receiving information in advance about the area of interest location and size is required. Also, the spatial information regarding the area of interest location and size should be more precise (model resolution) to improve compliance. These features emphasize the need for improved habitat suitability modeling, or other tools to define the areas of interest; that currently often do not meet the required precision to help the shipping professionals to decide on the best option to avoid whales. The emergence of Big Data and predictive modeling is likely to improve these models, and improve collision management.

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