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1 **Reducing whale-ship collisions by better estimating damages to** 2 **ships**

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15 **Abstract**

16 Collisions between ships and whales raise environmental, safety, and economic concerns. The
17 management of whale-ship collisions, however, lacks a holistic approach, unlike the management
18 of other types of wildlife-vehicle collisions, which have been more standardized for several years
19 now. In particular, safety and economic factors are routinely omitted in the assessment of
20 proposed mitigation solutions to ship strikes, possibly leading to under-compliance and a lack of
21 acceptance from the stakeholders. In this study, we estimate the probability of ship damage due
22 to a whale-ship collision. While the probability of damage is low, the costs could be important,
23 suggesting that property damages are significant enough to be taken into consideration when

24 assessing solutions. Lessons learned from other types of wildlife-vehicle collisions suggest that
25 the whale-ship collision should be managed as wildlife-aircraft collisions. For several years, the
26 International Civil Aviation Organization (ICAO) manages collisions between aircrafts and
27 wildlife at the international level. We advocate that its United Nations counterpart, namely the
28 International Maritime Organization (IMO), get more involved in the whale-ship collision
29 management. Further research is needed to more precisely quantify the costs incurred to ships
30 from damages caused by whale-ship collisions.

31 **Keywords:** whale-ship collision, damage, cost, FSA, wildlife-vehicle collision, risk assessment

32 **1 Introduction**

33 Collisions between vehicles and wildlife pose significant threats to wildlife conservation, but also
34 to human safety, and economy (Visintin et al., 2018). While less studied than other types of
35 wildlife-vehicle collisions (e.g., car, aircraft, and train), the literature on collisions between
36 commercial ships and whales, also referred to as ship strikes, has increased in the last years. This
37 increased interest is linked to the identification of those collisions as one of the main human-
38 induced threats for whales (IWC-ACCOBAMS, 2012; Panigada et al., 2006; Thomas et al., 2016).
39 Recent studies have shown that whale-ship collision events occur more frequently than assumed
40 (Frantzis et al., 2019). The ship crew often fails to detect a collision with a whale, as the
41 difference of rigidity between the two objects leads to a low impact force (IMO, 2009; Silber et
42 al., 2010). Hence, most of the time, collisions go unnoticed (Peltier and Ridoux, 2015).
43 Furthermore, as the reporting of these events is rarely mandatory, even noticed collisions might
44 not be reported (Lammers et al., 2013).

45 Many solutions to avoid those collisions have been proposed over the last two decades (IMO,
46 2009; Silber et al., 2008). Nevertheless, most of the time, the implementation of these solutions
47 faces low compliance from the shipping industry (Chion et al., 2017; Silber et al., 2012). Silber
48 and Bettridge (2012) identified “*lack of public recognition of the rule, disregard for it, or inadequate early*

49 *enforcement*' as potential limiting factors to compliance. More recently, literature started to
50 highlight the lack of risk and economic assessments of these solutions as a drag to decision-
51 makers recommendations, government enforcement or industries willingness to act upon the
52 problem (Ayyub et al., 2007; Kirchler et al., 2008; Silber et al., 2015, 2012; Whitney et al., 2016).
53 As it has been highlighted at the last International Conference on Marine Mammal Protected
54 Areas (ICMMPA 2019), the lack of a holistic vision prevents the implementation of synergies
55 between the environmental and shipping stakeholders; see also Mansouri et al. (2015) and Venus
56 Lun et al. (2015).

57 Unlike the whale-ship collision case, holistic approaches are implemented for a long time for
58 other types of wildlife-vehicle collisions (Huijser et al., 2009). The evaluation of wildlife, safety,
59 and economic risks has been used for several decades now to target the most efficient solutions
60 to reduce collisions between wildlife and cars (Seiler et al., 2016), trains (Seiler and Olsson, 2017)
61 or aircrafts (Crain et al., 2015; ICAO, 2012).

62 In order to promote a similar holistic approach for whale-ship collision management, Sèbe et al.
63 (2019) adopted a framework used by the International Maritime Organization (IMO), namely the
64 Formal Safety Assessment (FSA), to propose a more holistic assessment of costs, benefits, and
65 risks associated with measures to avoid ship strikes. While the probability of collision between
66 whales and ships is addressed in the literature (e.g., Martin et al., 2015), the literature on the
67 economic consequences of a collision is rather scant (e.g., Nathan Associates Inc, 2012). In
68 particular, no extensive research has been undertaken, to our knowledge, to assess the ship
69 damages after a collision with a whale. While this probability has been deemed low (Van
70 Waerebeek and Leaper, 2008), good estimates of both the probability and, actually also, of the
71 monetary consequences from the shipper's perspective are needed to inform a robust assessment
72 of the costs and benefits of proposed mitigation measures, as in the case of other wildlife-vehicle
73 collisions (e.g., Allan, 2000; Conover et al., 1995).

74 The objective of our study is to evaluate the added value of integrating the ship damages to
75 whale-ship collision management. To this end, we assess (1) the probability of ship damage due
76 to a collision with a whale, using, among others, the International Whaling Commission (IWC)
77 ship-strike database, and (2) provide a brief overview of the potential costs for shipping
78 companies.

79 **2 Methodology and data**

80 2.1 Data preparation

81 Since 2007, the IWC collects worldwide ship-strike events information in a public database. The
82 database includes records from 1970 to 2010; data after 2010 is not publicly available. A cross-
83 reference of the IWC database with other databases and scientific publications (e.g., Laist *et al.*,
84 2001; Jensen and Silber, 2004; Panigada *et al.*, 2006) was performed to check for duplicate entries
85 and gather supplementary information on the recorded events. Note that, events including non-
86 commercial ships were excluded (e.g., sailing ships and small boats). Of the 501 entries in the
87 IWC database and additional information gathered, 250 were selected for this study (1970-2019).
88 Hereafter, the selected events will be referred as the Updated Database (UD).

89

90 2.2 Damage and cost information

91 For our analysis, we gathered information on the ship speed, length, and associated damages for
92 the collision events in the UD. In the case where the ship's speed or length were not available in
93 the original dataset, we used online databases such as MarineTraffic and VesselFinder to extract
94 the ship's particulars. As ship speed during a strike is sometimes not known provided in the UD,
95 and as ship speed for a given type of ship does not change dramatically over time (1970-2010),
96 when needed, we used average operational speeds based on AIS data for similar ships, as
97 presented in IMO (2014). We believe, though that more information on the exact speed during

98 collisions is needed to get better insights. When the damage status was not available, other
99 sources of information were checked to recover damage information related to the UD, such as
100 IWC archives, IMO Global Integrated Shipping Information System archives, scientific
101 publications, and journal articles. Besides, the type and the cost of damages were included in the
102 UD.

103

104 2.3 Probability and damage costs

105 Vanderlaan and Taggart (2007) proposed a methodology to define the ‘probability of lethal whale
106 injury based on ship speed’ when struck. The methodology used the IWC ship strike database to
107 derive the probability of lethal injury and has, since then, been widely used as a basis for risk
108 assessment studies (Martin et al., 2015; Nichol et al., 2017). We, therefore, follow the same
109 reasoning to derive the probability of ship damage as a result of a whale-ship collision, depending
110 on ship length and speed. Only events for which information on ship speed, length, and damages
111 were reported are included in the analysis.

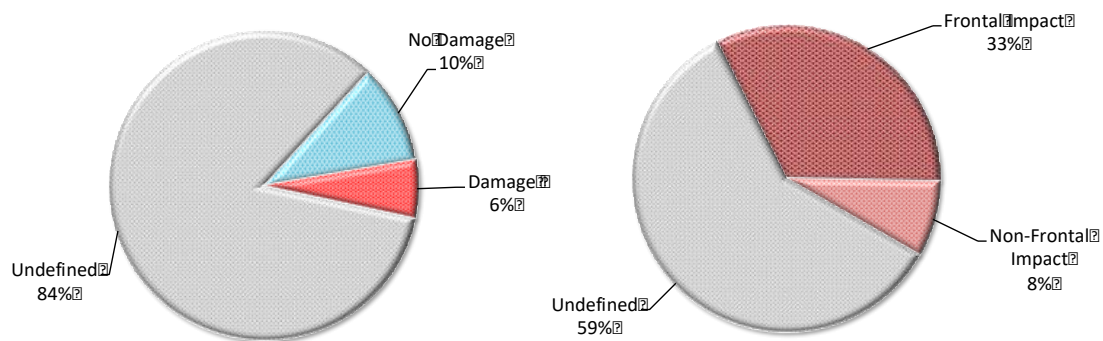
112 The probability of ship damages subsequent to a collision with a whale as a function of the ship
113 speed or length, and their ratio, was calculated by performing a logistic regression analysis, with
114 bootstrapping, using “R” (R Development Core Team, 2008). A lack of observations limited the
115 needed degrees of freedom and prevented a logistic regression of both the speed and length
116 variable (Peduzzi et al., 1996). As a result, we used the use of the ratio of the variables as a proxy.
117 Note that the logistic regression is the appropriate regression analysis when the dependent
118 variable, in our case, the damage to the ship, is dichotomous (binary). Bootstrapping is a type of
119 resampling where large numbers of smaller samples of the same size are repeatedly drawn, with
120 replacement, from a single original sample – in our analysis, 1,000 iterations were performed
121 (Haman and Avery, 2019; Venables and Ripley, 2002). To illustrate our results, we then compute
122 the probability of damages on four typical ships, which are often involved in collisions (oil tanker,
123 bulk carrier, container and cargo-ferry ships).

124

125 3 Results

126 3.1 Descriptive results

127 Most of the events in the UD (N=250) do not include any information on ship damages. Only
128 16.4% of the events describe the damage status (Fig. 1a). Of this 16.4%, 36.6% exhibit proof of
129 damage, whereas the remaining 63.4% attest to the absence of damage to the ship. Most of the
130 events in the UD do not include information on the area where the ship was struck (58.4%; Fig.
131 1b). Collisions in the front part of the ship seem to be the most frequent type of collision. 82.8%
132 of these events were most likely noticed because the whales were stuck on the bow. Hence, the
133 proportion of frontal impacts may be an overestimation in comparison to non-frontal impacts.
134 Non-frontal impacts include events that occurred on the ship draft, except the bow section (fore
135 draft).



136

137 **Figure 1: Damage status (left) and area of collisions on ships (right) in the UD in percentages.**

138 The primary damages identified were done to the following appendixes:

- 139 • Bow (hull);
- 140 • Hull;
- 141 • Propeller blade;
- 142 • Propeller shaft;
- 143 • Rudder;
- 144 • Steering arm;
- 145 • Stabilizer;
- 146 • T-foil.

147

148 There is very limited information regarding the damage costs in the database, as only 3 records
149 include the costs of damages (1.2% of the UD). First, the replacement of a propeller blade was
150 estimated at \$125,000 (US\$₁₉₉₁). Second, multiple damages to the steering arm and to the hull,
151 which lead to a waterway, of a ship were evaluated at \$1,000,000 (US\$₁₉₉₁). Finally, several
152 damages on a shipping company fleet between 2004 and 2006 led to an overall cost of \$3,500,000
153 (US\$₂₀₀₆). Some events described speed reduction due to whales stuck on the bow, which may
154 have resulted in additional expenses as a result of increased fuel costs due to the increased time at
155 sea, and to the delayed arrival at ports. Note also that, in total, 2 human losses and 194 human
156 injuries (three events are responsible for this total) are reported in the UD.

157

158 3.2 Regression results

159 Based on extensive analysis and cross-references with other sources, we were able to obtain the
160 required information for the regression (i.e., joint information on the ships' speed, length, and the
161 damage status subsequent to a whale-ship collision) for 12.8% of the events in the UD. These
162 events were used in the regression analysis.

163 We performed three separate regressions: one taking only ship speed into account, another with
164 ship length only, and one with the ratio of speed to length; see Table 1 for the results. As the
165 models are estimated through a maximum likelihood method, the Akaike Information Criterion
166 (AIC) can be used to select the best model; in our case the specification with the ratio of
167 speed/length has the best overall performance (i.e., having the lowest AIC; Figure 2; DeLeeuw,
168 1992). A large dataset, of course, would allow for the testing of more specifications. Based on
169 the model using speed/length, the probability of ship damage can be calculated as: $P_{damage} =$

170 $\frac{1}{1+e^{-(\alpha+\beta \times \chi)}}$, where α , β , and χ (Table 1 and Figure 2).

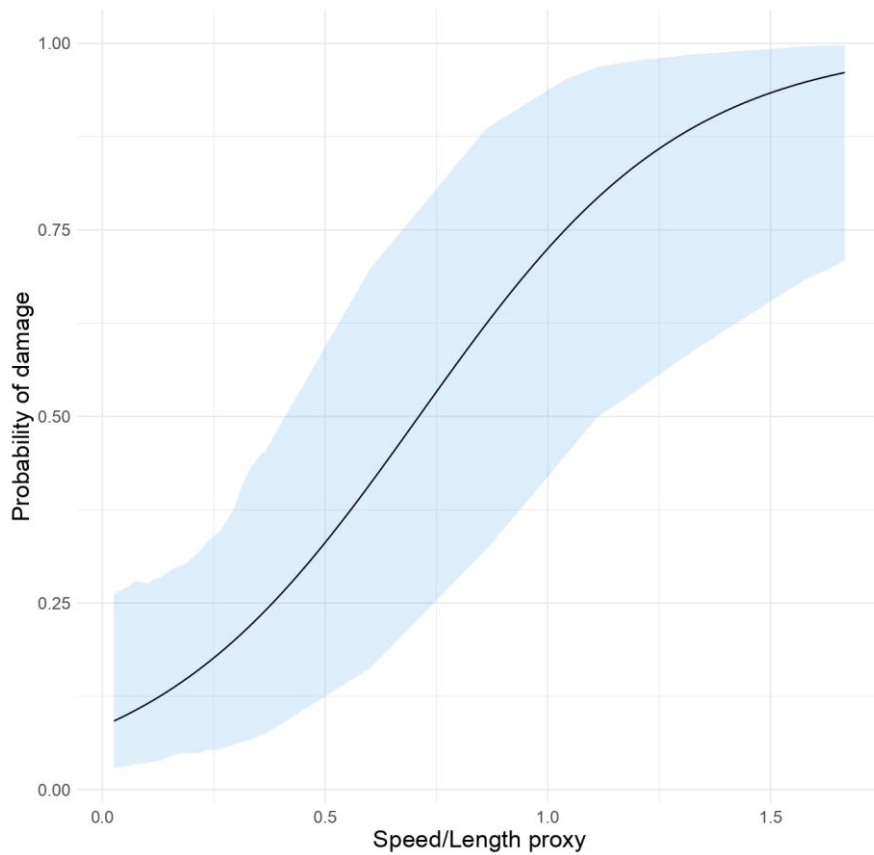
171

172 **Table 1: Logistic regression results**

Logistic regression	α [CI]	β [CI]	χ	P-value	Adjusted R ²	AIC
With speed only	-4.194 [-7.829; -1.753]	0.176 [0.064; 0.347]	Speed	0.0006	0.409	35.55
With length only	0.728 [-0.461; 2.034]	-0.017[-0.034; -0.004]	Length	0.005	0.286	39.52
With a speed/length proxy	-2.377 [-4.053; -1.097]	3.346 [1.485; 5.935]	Speed/Length	9x10 ⁻⁵	0.505	32.08

173

174



175

176 **Figure 2: Probability of ship damage depending on a speed/length proxy. The blue area represents the confidence**
 177 **interval.**

178

179 We illustrate our findings using four “hypothetical” ship types to show the impacts of ship length
 180 and speed on the probability of damage. We use the best model (with the speed/length proxy) to
 181 calculate the probability of damage for these typical ships (Table 2). Our study focuses on large
 182 commercial ships, as these are the ones that inflict most damages to whales (Ritter and Panigada,

183 2019). These are also the focus of potential risk and economic assessments of mitigation
 184 measures within the International Maritime Organisation (Sèbe et al., 2019).

185 **Table 2: Results of the logistic regression model on the hypothetical ships selected for the study**

Ship category	Oil Tanker	Bulk Carrier	Container ship	Cargo-Ferry
IHS StatCode5v	A13	A21	A33	A34
Ship type	Suezmax oil tanker	Panamax bulk carrier	Container ship	Ro-Ro-pax
Capacity	166,300 DWT	63,580 DWT	5,150 DWT	9,710 DWT
Length overall (L_{oa})	281.1 m	199.9 m	147.7 m	165.25 m
Selected speed (MarineTraffic)	13.3 kn	13.7 kn	12 kn	18.5 kn
Speed/Length proxy	0.0473	0.0685	0.0815	0.1120
Probability of damage after a whale-ship collision (P_{damage})	0.0981	0.1046	0.1086	0.1190

186
 187 The logistic regression model results show that the probability of damage for the typical
 188 commercial ships is around 0.10 (Table 2). In other words, after a whale-ship collision, there is 1
 189 out of 10 chance that a commercial ship would exhibit some damages. The Cargo-Ferry (A3)
 190 category seems to be the most at risk as some of these ships can achieve very high speeds. For
 191 example, high-speed passenger ships exhibit the most damages in the UD, as their Speed/Length
 192 proxy is high (e.g., Ryu *et al.*, 2010).

193

194 **4 Discussion**

195 4.1 Descriptive results

196 The UD includes a limited amount of data in comparison with other wildlife-vehicle collisions
 197 datasets. In contrast, the Federal Aviation Administration (FAA) gathered 99,530 collisions
 198 events between 1990 and 2014 (vs. 250 for the UD in 40 years; Dolbeer *et al.*, 2015).

199 Nevertheless, some interesting comparisons can be made. Indeed, the percentage of damage
 200 status mentioned in the wildlife-aircraft collision reports is between 16% and 45%, and damage
 201 costs are mentioned in 5% of the events (Anderson et al., 2015; Dolbeer, 2011). These

202 percentages are higher – or roughly equal for the lower bound – to the ones presented in the UD
203 (16.4% and 1.2%, respectively). By taking into account that reporting is more standardized for
204 aviation (ICAO, 2017a), we can assume that reporting standardization of whale-ship collisions
205 would lead to an increased percentage of damage information in the UD. Furthermore, while the
206 number of collisions between aircrafts and wildlife is higher than the ones between whales and
207 ships, it is interesting to notice that, in the USA, in 2014, there were 32.52 strikes per 100,000
208 aircraft movements (Dolbeer et al., 2015). In comparison, from Panigada *et al.*, (2006) and
209 Rendell and Frantzis (2016), we can account for around more than 50 whale collisions per
210 140,000 ship movements in the Mediterranean Sea, which is equivalent to 35.71 ship strikes per
211 100,000 ship movements (gross estimation of ship movements based on AIS data from the
212 ENVIGIS software). Of course, further research needs to be performed, but the order of
213 magnitude expressed in this paper advocates for a similar risk, in terms of probability of
214 occurrence.

215

216 4.2 Probability of ship damage

217 Our study estimates the probability of ship damage as a result of a whale-ship collision by using a
218 logistic regression model in line with Vanderlaan and Taggart (2007). Similarly to their study, the
219 limitation of data, and the non-integration of relevant variables to shipping (e.g., thickness of the
220 hull, material resistance; Zhang, 1999), or whales (e.g., size, direction) results in large confidence
221 intervals. Nevertheless, our results represent the first step towards the integration of ship
222 damages in whale-ship collision risk assessments.

223 Results show that Cargo-Ferries (A3) ships face the most significant risk for damage, especially
224 passenger ferries and high-speed passenger ships. The literature revealed several events of severe
225 impacts involving these ship categories. These events lead to a sudden loss of speed, damages
226 requiring towage, or human injuries and fatalities (Laist et al., 2001; Ryu et al., 2010). Other ship
227 categories exhibit lower probabilities of damages. Nevertheless, the overall probability of ship

228 damage for large commercial ships seems to be around $P_{\text{damage}} \approx 0.10$, although again, we want to
229 stress out that the dataset is very limited. This observation may indicate that some damages may
230 go unnoticed, or are not linked to a ship-strike, even when the ship requires repairs.

231 By using a logistic regression model, our study allows a straightforward assessment of the risk
232 reduction induced by a particular collision mitigation solution: speed reduction. When
233 implementing speed reduction, one can observe a reduction in the probability of whale lethal
234 injury (Parrott et al., 2016; Vanderlaan and Taggart, 2007). Based on our study, the probability of
235 damage can also be estimated to expose the risk reduction in ship damages for this mitigation
236 solution. If a Cargo-Ferry of 165 meters length and navigating at a speed of 18.5kn ($P_{\text{damage}} =$
237 0.119) is asked to reduce its speed to 12kn, it reduces the risk of damage by 11% ($P_{\text{damage}} = 0.106$).
238 To be noted that at the same time, the probability of lethal injury to whales is reduced by 45%
239 (from 0.937 to 0.507 based on the model derived by Vanderlaan and Taggart, 2007).

240 Note that this study assesses the probability of damage but does not deal with the severity of the
241 damages, as there are not sufficient data in the IWC database. The severity depends on several
242 factors, such as the thickness of the hull, the material resistance, or the shape of the bow (Liu et
243 al., 2018). Some hydrodynamic models were used to study the behavior of these parameters
244 under different scenarios, i.e., ship-ship, ship-container, and ship-floating log collisions, or
245 groundings (Zhang, 1999). Some researchers studied the hydrodynamics of a whale-ship collision,
246 but in order to assess damages to whales (Knowlton et al., 1998; Silber et al., 2010). To our
247 knowledge, there are no similar studies on ship damages. The undertaking of such studies
248 focusing on the damages to ships after whale-ship collisions would improve our understanding of
249 these events and help improve the management of the risk that ships face as a result of ship
250 strikes. Note that there is a parallel body of literature on dynamic models for wildlife-vehicle
251 collisions (e.g., car and train), which could be applied to whale-ship collisions (Anderson et al.,
252 2015; Visintin et al., 2018).

253

254 4.3 Costs of damage

255 Damage costs to ships can be divided into two categories. One is related to the ship repair cost,
256 which depends on several factors, such as the extent of the damage, the cost of replacement
257 parts, the place of repair (difference in labor costs and raw materials depending on localization of
258 the repair yard), the docking time required and the workload of the yards (IMO, 2010). The
259 second category is the loss of earnings, as the ship is unable to trade (Stopford, 2009).

260 Estimating these costs is very challenging as there is a significant variation in costs between ship
261 categories (Stopford, 2009). The costs of damages in the UD are expressed only for 3 records;
262 more observations would obviously result in more accurate assessments of these costs.

263 Nevertheless, the literature allows giving an insight on costs associated with whale-ship collisions.
264 According to the UD, the damages to the hull, and the propeller blades can be extensive. Below,
265 we highlight the estimations of some repair costs related to these damages.

266 The cost of repair for a breached or warped hull depends on labor costs, the price of steel, and
267 the price of docking. The steel work associated with this repair would require between 60 and
268 105 man-hours for the hypothetical ships selected in the study (Butler, 2012). The number of
269 docking days associated with these man-hours will depend on the number of workers and the
270 length of shifts. The amount of steel needed would be of between 260 and 470 kg, which would
271 not be expensive as the price of steel is at 711 \$/t (worldsteelprices.com, accessed on
272 09/25/2019). The dry-docking costs for repair differ depending on various factors (Hansen,
273 2013), but can be estimated at a few thousand dollars per day (Guarin, Konovessis and Vassalos,
274 2009; IMO, 2010, Piriou company, comm.pers.)

275 The cost of repair for a damaged propeller blade also depends on labor costs, the price of
276 replacement parts, the price of docking. According to Butler (2012), the work needed to replace
277 the propeller blade can vary between 100 and 240 man-hours for the ships that were studied. The
278 price of parts replacement will depend on various parameters. For instance, the UD described
279 that the replacement of a propeller was estimated at \$125,000 (US\$₁₉₉₁) for a 126m naval ship. Of

280 course, the replacement cost of a propeller will depend on the size and type of the ship, and the
281 value here given is purely indicative of an example of cost. Similarly to hull work, the dry-docking
282 costs can be estimated at a few thousand dollars per day (Guarin, Konovessis and Vassalos, 2009;
283 IMO, 2010, Piriou company, comm.pers.)

284 Revenue losses are determined based on the time during which the ship has been deprived of
285 income (the loss of time) and the loss of income per day (the daily amount). The income of the
286 ships depends on various parameters, including the type of trade and charter (e.g., if the ship is
287 time-chartered or in the spot market), the ship type and commodity carried, amongst others. The
288 income of ships (even for the same ship, carrying the same commodity on the same route) varies
289 substantially, mainly as a result of the supply of the ships and the demand for transport work
290 (Stopford, 2009). For instance, a bulk carrier (e.g. the one presented in Table 2) chartered for 1
291 year had an average per day revenue of around 10,000 US\$ per day in 2017 and 13,029 US\$ per
292 day in 2018. On the other hand, a very large oil tanker carrying oil from the Arab Gulf to Japan
293 had an average net profit of around 20,000 US\$ in 2018. Every day lost in the shipyard for repairs
294 would therefore have a significant economic impact (Clarksons Research, 2019).

295 To sum up, repair costs are, in general, lower than the loss of revenue due to a whale-ship
296 collision. Direct costs of damages linked to the repairs may be worth from a few thousand to
297 several hundreds of thousands of dollars depending on the work needed, the docking time, and
298 the replacement of parts. Due to the lack of data on costs in the UD, we want to highlight that
299 this section provided an overview of the potential costs, but did not provide a full assessment of
300 the costs. Indirect costs involve the revenue loss endured by the company during the repair time.
301 These costs might be higher, as it is linked to the freight rate and the type of merchandise
302 (Stopford, 2009). We should stress out that the costs of repairs are most of the time covered by
303 the ship's insurance, while this is not always the case for revenue losses (Stopford, 2009). In any
304 case, insurance is not taken into consideration in the IMO decision-making framework (Sèbe et
305 al., 2019).

306

307 4.4 Implication for the whale-ship collision management

308 The assessment of damages and costs is crucial to managing more efficiently the whale-ship
309 collisions. Lessons can be learned from the management of other wildlife-vehicle cases. While
310 deemed low by the transportation industry, the damages, and their associated costs are often
311 taken into account in balancing the benefits and costs (ICAO, 2009). This accounting helps
312 decision-makers to define fund allocations for existing mitigation solutions, research and
313 development (R&D), or even for fixing penalties (Allan, 2000; Dolbeer et al., 2015; Lienhoop et
314 al., 2015; VerCauteren et al., 2006). The literature highlights several regional, national, or
315 international policies advocating for the accounting of the damages in the management of
316 wildlife-vehicle collisions.

317 Various collisions management initiatives exist at regional and national levels. For wildlife-car
318 collisions, the costs of damages are often integrated into cost-effectiveness or cost-benefit
319 assessments to define the most efficient mitigation solution depending on the study site
320 characteristics (Gren and Jägerbrand, 2019; Santos et al., 2018; Seiler et al., 2016). More recently,
321 investigations into wildlife-train collisions have been undertaken to define damages, delays,
322 animal suffering, and driver stress caused by those events (Seiler and Olsson, 2017). The wildlife-
323 aircraft collisions issue was identified early, as its management was motivated by some marking
324 accidents, which lead to human losses (Dolbeer et al., 2015). Since 1988, an FAA National
325 Wildlife Strike Database has been implemented in the U.S. to prevent human loss and aircraft
326 damages (Devault et al., 2009). The assessment of the damages allows both to reduce the costs of
327 mitigation solutions, and to reduce the environmental and human risks associated with collisions
328 (Bissonette et al., 2008; Huijser et al., 2009; Visintin et al., 2018).

329 Wildlife-aircraft collisions management is the most standardized one at the international level. In
330 1990, following the national database initiatives, the International Civil Aviation Organization
331 (ICAO), which is the United Nations specialized agency “*whose mission is to achieve safe, secure, and*

332 *sustainable development of civil aviation*”, started getting involved in the collision issue and helped to
333 standardize the management process (Devault et al., 2009; Dolbeer and Wright, 2009). Among
334 other things, the ICAO maintains a bird-aircraft strike database (the ICAO Bird Strike
335 Information System; IBIS), encourages the reporting of strikes and the damages related with
336 them, and advocates for holistic risk assessments, through guidelines and standardized process,
337 such as the Safety Management System (SMS) (Devault et al., 2009; Dolbeer and Wright, 2009;
338 ICAO, 2017a, 2017b, 2012). Nowadays, these initiatives allow pro-active management of bird-
339 aircraft collisions, such as better airport site selection, seasonal adaptation of the traffic,
340 anticipated mitigation solutions, or government compensation (Anderson et al., 2015; Devault et
341 al., 2009).

342 Following the ICAO approach, Sèbe et al. (2019) advocated for the involvement of the IMO into
343 whale-ship collision management. The IMO represents the counterpart of the ICAO for
344 maritime transport, as it is a United Nations specialized agency (Tarelko, 2012). IMO provides
345 guidance for maritime-related risk assessment, through the so-called Formal Safety Assessment
346 (FSA; IMO, 2018). FSA is a similar process to SMS, or other guidelines provided by the ICAO.
347 Usually used for human safety or pollution (Haapasaari et al., 2015; Kontovas and Psaraftis,
348 2008), Sèbe et al. (2019) conceptualized the use of this framework to standardize the
349 management of whale-ship collisions at an international level.

350 However, the lack of knowledge on damages associated with whale-ship collisions is a barrier to
351 the successful implementation of one of the critical steps of the FSA, the Cost-Benefit
352 assessment. This FSA step aims to identify the costs and benefits associated with the
353 implementation of a mitigation solution. One of the benefits is the avoided cost, such as damage
354 costs. Unlike other wildlife-vehicle collisions database, the IWC ship strike database is limited by
355 the number of events recorded and by the lack of intelligence on the details of the events (e.g.,
356 speed, length, damage). Several factors explain those limitations. While some collisions might go
357 unnoticed, many are underreported as shipping companies guidelines do not compel the crew to

358 do it, or to avoid bad publicity (David et al., 2011; IWC-ACCOBAMS, 2012). Besides, the lack of
359 coordination between organizations can be at the expense of the assessment of costs associated
360 with whale-ship collisions. The IMO Casualty database (GISIS) does not provide any links to the
361 IWC database, and hence whale-ship collisions do not appear into the scope of the IMO casualty
362 events (Sèbe et al., 2019). Improvements in the collision reporting are therefore essential for the
363 integration of the damages in the FSA, allowing for a holistic integration of the whale-ship
364 management at the IMO level.

365

366 **5 Conclusions and perspectives**

367 The management of whale-ship collisions lacks of holistic risk assessment approaches. Similarly
368 to what is done by the ICAO for wildlife-aircraft collisions, Sèbe et al. (2019) conceptualized a
369 risk assessment approach to ship strikes using IMO's Formal Safety Assessment methodology.
370 Nevertheless, limited knowledge hampers the application of such risk assessment techniques,
371 especially related to the lack of information on the damages. Our works provide a first study on
372 the subject by estimating the probability of ship damage. There is evidence that further research
373 is required to improve the results. Better and standardized reporting would increase data
374 availability and, thus, the robustness of the regression analysis. We acknowledge the fact that
375 some other parameters such as the type of ship and species may provide more explanatory power
376 for the model. However, the small size of our dataset prohibited the use of more than one
377 variable in our prediction model (e.g., Peduzzi et al., 1996). Besides, as we have mentioned in the
378 Introduction section, data after 2010 are not publicly available. There is, therefore, a clear need
379 for more open and better data.

380 Furthermore, the extensive involvement of shipyards and shipping companies is needed to assess
381 the costs of damages. Further research could also be undertaken for high-speed passenger ships,
382 which have the highest damage probability, in order to prevent human losses. Lastly, the
383 integration of the damages and the costs would provide a more transparent way for assessing the

384 mitigation solutions' effectiveness, similar to what is performed on other wildlife-vehicle
385 collisions.

386

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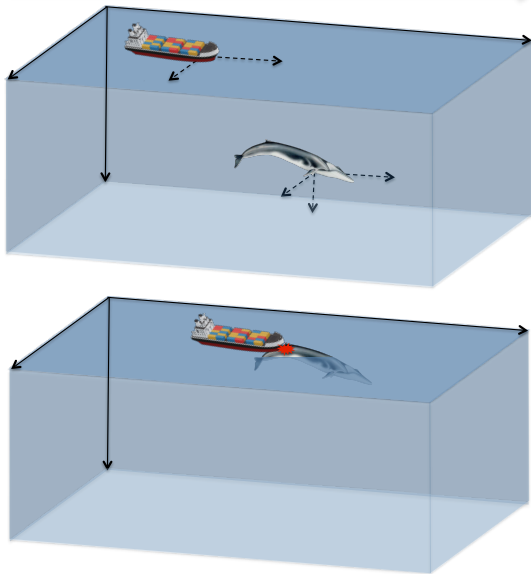
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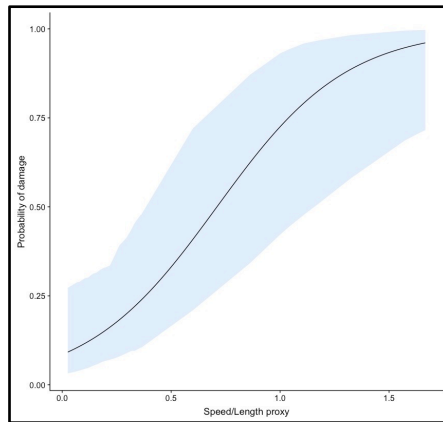
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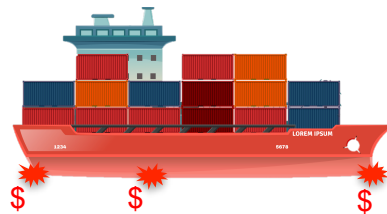
Whale-Ship collision event



Probability of ship damages



Associated cost



Integration in CBA for management?

