Orca attacks on sailors off the Iberian Peninsula

A. Feedback: Whale-PAL effectively protects from orca attacks

Boris Culik (12. Dez. 2023) F³: Forschung . Fakten . Fantasie, Am Reff 1. 24226 Heikendorf, bculik@fh3.de, 18 pp.

The central question is: does the Whale-PAL really protect your vessel? At the end of November 2023, the 205 users of the Whale-PAL were contacted and asked for feedback on their experiences with the acoustic warning device. 150 sailors reported back, the device was deployed and towed 109 times in the "Orca Alley". All results were compared with literature data on sailing without Whale-PAL (control).

Abb. 1: Killer whale (Orcinus orca)

Conclusion: 107 of 109 passages with the Whale-PAL went without problem, a chance of 98% as opposed to 89% without. The Whale-PAL increases the chance of not seeing orcas in the first place: in 96 passages with the acoustic device there were no killer whale sightings at all, a proportion of 88%, whereas 75% were expected from control. 13 sailors with Whale-PAL reported an orca interaction: there were 11 sightings and 2 damaged vessels. With the Whale-PAL you get away safely in 85% of interactions, but without it it's only 50%. All differences are statistically significant (binomial test).

The evaluation of the feedback shows that the Whale-PAL, with its specific towing rigg and its unique acoustic signal, measurably reduces the risk of an orca attack. This is the first report on the effectiveness of a protective measure for sailors.

What feedback is there from Whale-PAL users?

The questionnaire asked whether the Whale-PAL (Pat.; Culik, 2013) had been deployed, in which marine area, and whether there had been orca (killer whale) sightings, interactions or damage. 150 of 205 users shared their feedback (Tab. 1). Of these, sailors had deployed and towed the Whale-PAL in 109 passages through the "Orca Alley, some sailed several times. 25 sailors did not sail in the affected sea area at all or even gave up sailing completely ("Cancelled") and 23 only kept the whale PAL ready on deck ("Stby").

Of the total of 109 passages through Orca Alley, 96 went without sighting any orcas at all, 5 skippers reported a sighting in the distance, and 6 a sighting close to the boat (within 100 meters). 2 yachts were attacked despite towing their Whale-PAL. The term "interaction" summarizes sightings and attacks, so a total of 13 interactions were reported. Users reported 26 attacks on yachts close by, but they themselves were spared. The most important feedback from the sailors surveyed is posted at https://www.f3mt.net/whale---pal.html.

Table 1: Analysis of feedback from Whale-PAL users. 107 of 109 passages went without problems when the Whale-PAL was deployed, a proportion of 98.2%. "Interaction" adds up sightings near and far as well as damage. For further explanations please see text.

Category	Observations	Proportion (%)
Sailors	150	
Cancelled	25	
PAL Stby.	23	
Deployments	109	100,0%
No damage	107	98,2%
No sighting	96	88,1%
Interaction:	13	11,9%
-Sighting dist.	5	4,6%
-Sighting near	6	5,5%
-Damaged vessel	2	1,8%
Damage nearby	26	23,9%
PAL:		
-Fin kaputt	5	21,7%
-Bite marks	13	56,5%
-Leakage	2	8,7%
-Total loss	10	43,5%

In most cases, towing a Whale-PAL worked without any problems. The rig has been continually optimized based on ongoing feedback, the stainless steel line is now equipped with stainless steel press sleeves, the swivels and shackles on the paravane are made of stainless steel or are nickel-plated, the PAL is towed on a Dyneema line and is now equipped with a tail unit keeping it in track. Many sailors reported that the system worked very well for them.

However, some sailors were unlucky: one captain forgot to retrieve his Whale-PAL before anchoring, another was able to recover his with difficulty after a collision with a fishing net and yet another had a collision with a tree trunk and lost the device. Attacks by fish were most common: in total there were bite marks on 13 PALs. A sailor reports that a large fish turned his yacht 90 degrees before the PAL broke off. 10 PAL were lost at sea. The fin of another 5 devices broke (we have improved its design since) and 2 PALs leaked (probably also due to a fish attack). The attacking fish include potentially large sharks and tuna, but so far only one shark has been directly observed.

Is the Whale-PAL effective and how is this measured?

To sum it up: yes. In order to prove the effectiveness of a method, you need a control. In other words: what would have happened if the Whale-PAL had not been used? Would the sailor in question have been attacked during an orca sighting? With what probability?

In their study, Lopez and Esteban (2021) provide the only available information on the expected damage frequency after an "interaction". They compiled this data through inspection of 19 ships,

feedback from 145 skippers, reports in the press and social media. In 214 of the sightings and attacks collected in 2020 and 2021, damage occurred in 119 ships, or 56% of the cases (Table 2 “Control 1”).

Table 2: The damage caused by orca interactions to marine vessels without Whale-PAL (Control 1 and 2; from Lopez and Esteban, 2021) reached a mean of 50% in 2020 and 2021.

	Control 1		Control 2		Whale-PAL	
Category	**Obs.**	**Proport.**	**Obs.**	**Proport.**	**Obs.**	**Proport.**
No damage	95	44%	22	55%	11	85%
Damages	119	56%	18	45%	2	15%
Sum	214	100%	40	100%	14	100%

In their report, Lopez and Esteban (2021) also mention another, comparable study based on information in social networks (Table 2, “Control 2”). Of the 161 anonymous sailors recorded who sailed Orca Alley in 2021, 121 had no sightings or problems, while 12 reported orca sightings, 10 reported problems with orcas, and 18 reported damage. Out of a total of these 40 interactions, damage occurred in 18 cases, a damage frequency of 45%. Averaging both studies, an interaction without Whale-PAL deployment results in a damage probability of around 50%.

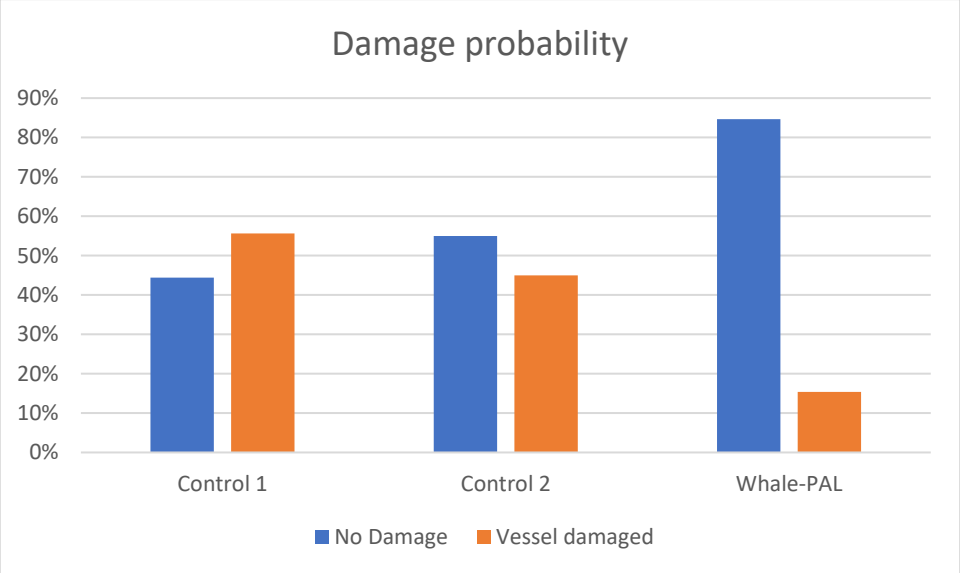

Fig. 2: The probability that a damage occurs during an orca-interaction is reduced from 45-56% (control 1 and 2) to only 15% when the Whale-PAL is deployed. The difference is significant.

Sailors using the Whale-PAL report 13 interactions during 109 passages through the Orca Alley (see Table 1; 6 near and 7 distant sightings, 2 damages). However, the number of damages was only 2, and not the 50% expected from the two controls in Table 2 - that would have been 7. This means that the probability of damage during deployment of the Whale-PAL was reduced from around 45-56% (Lopez and Esteban, 2021) to just 2/13 = 15% (Fig. 2). A sailor who tows his Whale-PAL has a very good chance of being able to continue his trip undamaged after sighting an orca. But now is this just a coincidence or the effect of the Whale-PAL?

To check this, you can use a simple statistical test, the binomial test. (It also allows you to check if your dice have been tricked). In this case we test 12 successful results in 14 attempts with an expected damage probability of 50%. The probability that the Whale-PAL is successful and that the result obtained is not due to coincidence is 99.83% (Significance level 95%). We can reduce the data set even further and test whether the Whale-PAL also helps to ward off an attack when killer whales have been spotted nearby. There were 6 passages without damage in 8 close interactions (expected damage ratio 50%). With 96.5% probability, this again significant.

What other comparisons can be made?

Sailors traveling with Whale-PAL sailed through the Orca Alley without any problems in 107 of 109 passages, that is 98.2% of the time. In contrast, in control 2 in the study cited by Lopez and Esteban (2021) only 143 out of 161 sailors (18 suffered a damage) sere lucky, i.e. 88.8%. So, deploying the Whale-PAL reduces the risk of damage from 11% to just 1.8%, a reduction of 85%. We ask the binomial test whether it can be coincidence that no damage occurred 107 times in 109 passages, even though the expected ratio is 89%. Result: 99.9999% not a coincidence.

Sailors towing the Whale-Pal reported that they had no orca sightings in 96 of 109 passages (88.1%). In the study cited by Lopez and Esteban (2021), there were 121 out of 161 sailors, i.e. only 75%, who had no sighting. Could it be that the Whale-PAL also reduces the number of interactions overall? The binomial-test shows that with a probability of 99. 98%, this is not due to chance. The Whale-PAL not only reduces the likelihood of damage after a sighting, but also that orcas come close enough to the boat to be spotted. However, one must be careful when interpreting sightings, as many users also reported that they have used updated interaction maps provided by websites such as orcas.pt or GTOA/Orcaiberica to actively avoid orca areas.

On the other hand, there was also a large difference between the 26 attacks reported by Whale-PAL users in close time and space proximity of their route (Table 1) compared to only 2 attacks on Whale-PAL users themselves (total number of data: 28). Here we are comparing within the user feedback data only. When you sail through Orca Alley towing a Whale-PAL and receive reports of damages in the immediate area, you have a 92.5% chance of getting through this hotspot unscathed. You already guessed it: the occurrence of 26 successes in 28 attempts (assumed damage probability 50%) is not random. With 99.9999% probability.

So to make a long story short: one can twist and turn it, the Whale-PAL doubtlessly works and reduces the risk of orca-Interactions and damages. Significantly.

Culik, B., Conrad, M., L3-Communications Elac Nautik (2013) Patent “Vorrichtung zum Schutz von Zahnwalen vor lebensbedrohlichen, gesundheitsschädlichen und/oder beeinträchtigenden Gegenständen”. DPM Nr.: 102011109955

López A, Esteban R (2021) Elaboración de un estudio científico sobre la interacción de la población de orca (*Orcinus orca*) del estrecho de gibraltar con embarcaciones, para el diseño y propuesta de medidas de prevención, actuación y gestión. Intemares, 88 pp. (Copy here).

B. Background on orca-attacks off the Iberian Peninsula

Boris Culik (9. Dez. 2023) F³: Forschung . Fakten . Fantasie, Am Reff 1. 24226 Heikendorf, bculik@fh3.de, 18 pp.

Summary

On March 9, 2023, the TO blue water micro-seminar "Orca attacks on yachts" took place with 820 participants. TO is "Trans-Ocean" e.V., a network by and for offshore sailors. (https://www.trans-ocean.org/wir-ueber-uns). Background and countermeasures were presented and discussed in the seminar. Since then, there have been many more testimonials from sailors, some summarized at https://www.f3mt.net/whale---pal.html. Here I present the topic and the knowledge gained to date.

Killer whales are the largest dolphins and orientate themselves visually and acoustically under water: the animals have very sensitive hearing, especially in the ultrasonic range, and also use it in their far-reaching biosonar.

Killer whales are distributed worldwide and live in different, specialized populations. The population of the Iberian Peninsula is focussed on bluefin tuna, and follows its migration routes every year from the entrance of the Mediterranean Sea beyond the Shetland Islands in the North Atlantic. Attacks by orcas on boats of all kinds have been recorded along this route since 2020, primarily on sailing boats.

Feedback from sailors indicates that 5-11% of them suffered damage to the boat while sailing along the Iberian Peninsula. The boats most affected are monohulls, presumably also because they are the most common boats in the region. The number of registered attacks reached around 500 from 2020 to summer 2023, three boats sank due to the damage suffered. Iberian killer whales mainly attack the keel and rudder, which often leads to the rudder breaking off.

Various countermeasures are discussed or recommended on forums and websites such as orcaiberica.org and orcas.pt. Playing dead man, stopping the boat, and hoping for help doesn't seem to have any effect on the outcome of the attack. However, active countermeasures that are not specified in more detail can reduce the occurrence of severe damage by around 40%.

A countermeasure discussed in more detail here is towing a Whale-PAL. Feedback from customers of F3: Maritime Technology shows that the Whale-PAL (Pat. Culik et al. 2013) is effective. Please see "Part A: Feedback" above.

In conclusion, it is recommended: a) to avoid areas of current attacks, b) to distract or drive away the animals towing a Whale-PAL and to make it difficult for orcas to approach the rudder, c) to head for the coast in the event of an attack, d) to carry out erratic rudder movements, complicating orca homing in on the rudder and e) to plan further countermeasures. Orca defence should be well planned, and the processes should be tested and optimized beforehand.

Introduction

Orcas (*Orcinus orca*), also known as killer whales, are toothed whales from the Delphinidae family. They grow up to 9.8 m long and reach a maximum weight of up to 9,000 kg. The animals can dive for up to 15 minutes and can reach speeds of up to 55 km/h (30 kn). Their cruising speed is about 5 kn. Orcas are mammals and hunt in groups. Males live up to 30 years, females up to 50 years. After puberty, which begins at the age of 10-15, adult males carry a dorsal fin up to 2 m high (Culik, 2011).

In addition to smell, taste, sight and touch, orcas use their biosonar. Similar to bats, toothed whales acoustically illuminate their environment with the help of loud ultrasonic clicks and use the echoes they receive to orient themselves. Their large brain is used to visualize this sound image of the environment, objects, obstacles, prey and conspecifics. This is similar to an ultrasound examination at the doctor's. The range of their biosonar is up to several hundred meters (Jensen et al. 2018). Orcas also communicate with each other acoustically, using clicks, whistles, and other sounds.

Figure 1: Killer whale (Orcinus orca) distribution is world wide in all oceans (mod. from Reeves et al. 2017, IUCN).

Killer whales are distributed worldwide (Fig. 1) and are most commonly found along temperate and polar coasts. Depending on the population, they feed on salmon, marine mammals or various prey such as herring, halibut, seals and large whales. Off the Iberian Peninsula, orcas specialize in preying on tuna, while off Norway they prey on Atlantic herring (Culik, 2011).

The killer whales of the Strait of Gibraltar differ from other populations in the NE Atlantic on the basis of various characteristics, including genetics (Esteban et al. 2016a). The small Iberian subpopulation relies heavily on an endangered prey species, bluefin tuna (*Thunnus thynnus*; García-Tíscar 2009). The Iberian killer whale numbers between 35 (Orcaiberica.org) and 63 (De Stephanis, Circe) and has been classified as Vulnerable by the Spanish Ministry of the Environment (RD

139/2011). It is listed on the IUCN Red List since 2019 (Esteban and Foote, 2019). From whale-watching boats in the Strait of Gibraltar, for example from Tarifa, the animals can be observed chasing tuna (Guinet et al. 2007) or stealing tuna from fishermen's longlines (Esteban et al al. 2016b).

In 2020, a new disruptive behaviour was observed when some juvenile killer whales began interacting with and attacking sailboats and other watercraft. Killer whales push and ram the boats, turning them and hitting the rudder blades, which can cause severe damage. Around 500 sailing boats have been attacked since 2020, and a total of three sailing boats have been sunk (Hunt, 2023).

1. How dangerous is a passage along the Iberian Peninsula?

According to Bert Frisch from Transocean e.V., around 4,000 sailors passed the Iberian Peninsula in 2022. Around 200 of them were attacked, which corresponds to 5%. In a scientific study by Lopez and Esteban (2021), a survey from the Orca Attack Reporting website is quoted (Fig. 2). Of the 161 sailors who took part in the survey, damage to the boats occurred in 11% of the cases (Table 1).

Table 1: Conversion of Observations in Fig. 1 to % (161 observations)

	%	Number
No sighting	75%	121
Sighting	6%	10
Interaction	7%	12
Damage	11%	18

The discrepancy between 5% and 11% may be because sailors who were involved in interactions or suffered damage participated more frequently in the Lopez and Esteban (2021) survey. More exact figures are not known.

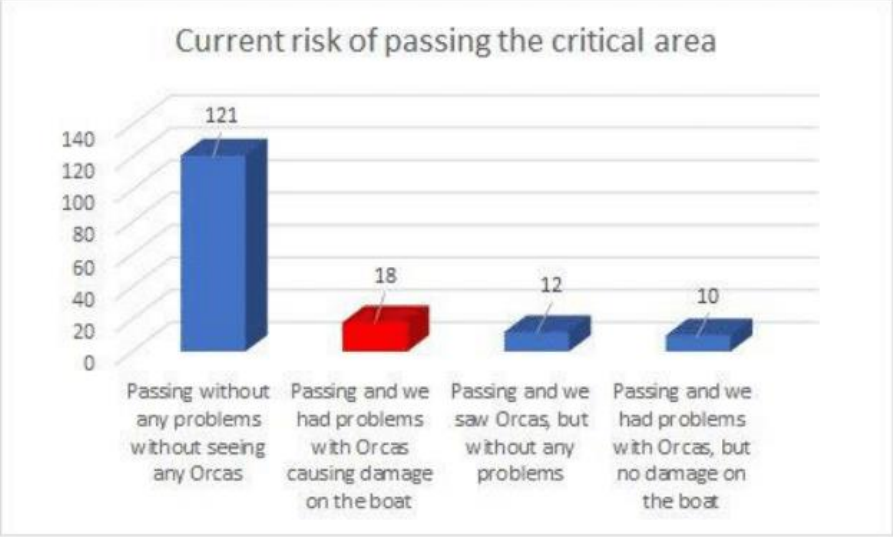

Figure 2: Results of Interviews with 161 sailors in „Orca Attack Reporting" (from Lopez und Esteban, 2021)

2. Where do orcas interact and attack?

Until recently, orca attacks on sailing boats took place off the entire Iberian Peninsula, from Gibraltar to A Coruña, in the Bay of Biscay and up to Brittany (orcaiberica.org, “mini-orcas” in Fig.3). An attack off the Shetland Islands was reported for the first time in June 2023 (Hoare and Hoekendijk, 2023).

The geographical distribution of the attacks coincides very well with the well-known migration route of their main prey, the bluefin tuna: tuna migrate from July every year from the Mediterranean Sea, past the Shetlands up to the southwest Norwegian coast (Cort & Nottestad, 2007).

The number of attacks on vessels west of the Iberian Peninsula has increased since 2020: from 52 attacks in 2020, to 197 in 2021 and 207 attacks in 2022 (Hunt, 2023). The number of unreported cases is likely to be much higher. While in previous years the winter months were considered safe, this no longer seems to be the case: in February 2023 Orcaiberica registered 12 attacks.

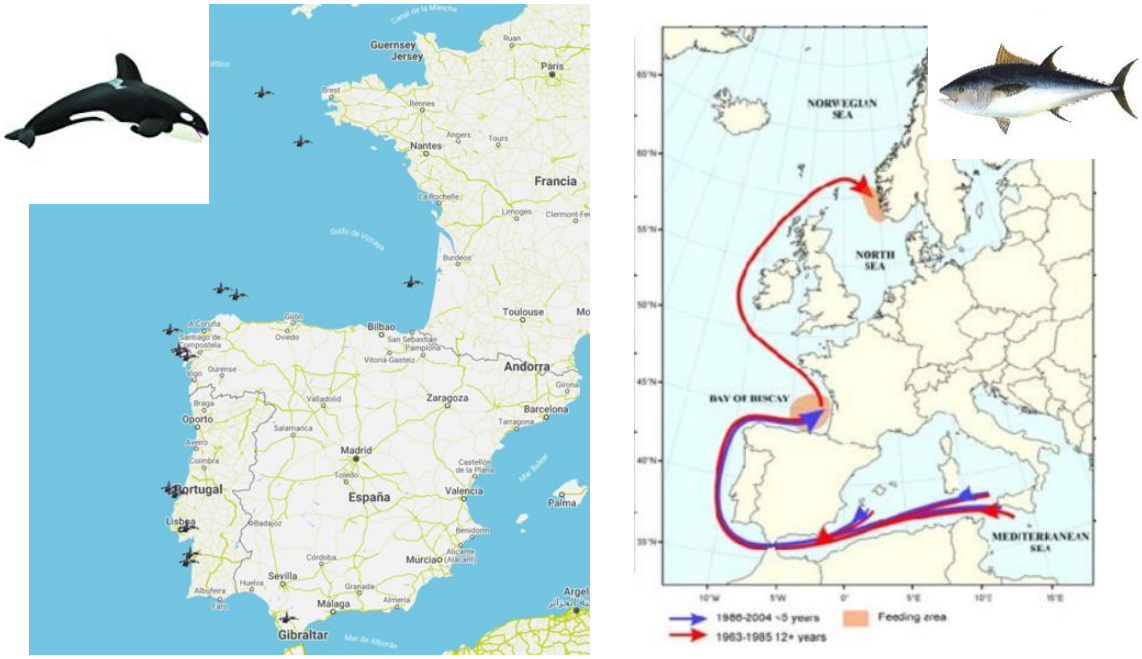

Fig. 3: Left: Killer whale attacks off the Iberian Peninsula in July 2022 (marked with a mini-orca, from orcaiberica.org). Right: the migratory route of bluefin tuna from the Mediterranean Sea along the Iberian Peninsula and on through the Biscay to Norway (from Cort and Nottestad, 2007).

3. Which boat types are affected?

A total of 143 vessels involved in interactions with orcas were classified regarding vessel type, length, and sailing speed (Lopez and Esteban, 2021). An interaction can be an approach and sighting, or an attack. Attacks cause damage in most cases, but not always. The comparison shows that by far the largest proportion of interactions applies to monohull sailing boats (Tab. 2). Although the proportion

of these boats in relation to the total number of pleasure craft is not known, it is likely to predominate.

Table 2: Boat class frequency, boat length and speed of orcas visiting or attacking watercraft (n=143; from Lopez and Esteban, 2021)

Boat type	Interaction	Length	Speed (kn)
Sailb. Monohull	72%	7-35	0-10
Catamaran	14%	7-35	0-10
Motor boat	6%	6-12	0-25
RHIB	5%	10	2-6
Fishery vess.	3%	5-11	3-4

4. How do interactions with orcas turn out?

A total of 239 interactions were recorded (Lopez and Esteban, 2021). Table 3 shows that in 2020 around 45% and in 2021 around 51% of the interactions yielded no damage to the boat (including "no data"). However, in both years, after "interactions", 30% of the boats suffered minor damage. The proportion of severe damage was 19-25%.

Table 3: Damage due to orca-interactions (n=239 sightings and attacks) on watercraft (from Lopez and Esteban, 2021)

Damage	2020	2021
No Data	8%	11%
None	37%	40%
Light	30%	30%
Severe	25%	19%

5. How and why do orcas attack?

Various sources address these issues and agree that the attack focuses on the rudder (Käsbohrer 2022, Lopez and Esteban 2021). In her article, Gill (2021) describes the attack (Fig. 4). She quotes Ruth Esteban (Whale Museum Madeira): "*They always seem to go for the rudder and I think that's because it's a moving part of the ship. In some cases they can move the whole boat with it. In some videos we see the sailboat turning almost 180 degrees. When they see that they have the power to move something really big, that might be impressive for them*." A very telling video was made by Team Jajo at the Ocean Race 2023 (https://youtu.be/E1rqcI2jULY?si=yate7fUsSytSC39d). Additional videos can be found on Youtube and Instagram.

Many other hypotheses about "why" are circulating in the media, the most likely being the instinct to hunt and play (Käsbohrer, 2023). A reward for this, in the form of a broken rudder blade or objects thrown in the water and which may be perceived as toys, or edible fish waste from fishing boats, seems to me to be the goal and to explain the endurance of the animals. A "reward" of this type appears to end the behaviour.

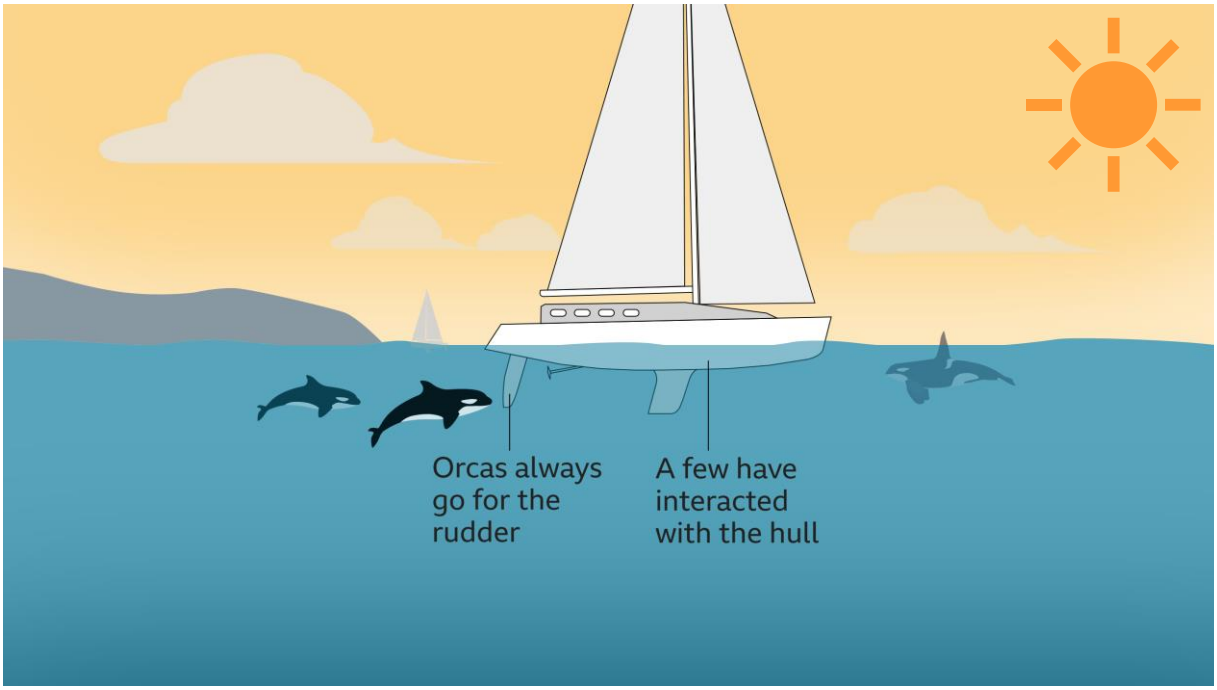

Fig. 4: Killer whale attacks are mostly aimed at the rudder, which the animals bump with their heads, shoulder and back (mod. from Gill, 2021).

6. What damage does an orca attack cause?

When killer whales attack a ship, they tend to focus on the rudder. The survey by Lopez and Esteban (2021) recorded which types of rudders occur and how often these were affected by interactions (n=143 boats). Boats with a spade rudder are much more frequently (67%) the target of interaction than boats with a skeg rudder (1%; Table 4). However, if a damage occurs, it is severe in one of two cases in skeg rudders (50%), compared to only 19% of spade rudders.

Table 4: Frequency of rudder types (n=143) in boats that were the target of an orca interaction (from Lopez and Esteban, 2021). The highest frequency of severe damage after orca-interaction occurred on skeg rudders (50%) followed by spade- (19%) and semi-balanced skeg rudders (17%)

		Damage		
Rudder type	**Occurrence**	**None**	**Light**	**Severe**
Spade	67%	26%	55%	19%
SB skeg	22%	33%	50%	17%
Skeg	1%	25%	25%	50%
Outboard	10%	48%	48%	4%

7. Recommendations: Does playing Dead Man help?

The research organization "orcaiberica" recommends (Fig. 5) that in order to stop an attack quickly and to keep the damage to a minimum, sailors should slow down or halt completely, recover sails, and switch off: engine, autopilot, sonar and other sources of sound, and silently disappear below

deck to meet the animals passively so that they lose interest in the attack. However, after re-analysis of the data presented by Lopez and Esteban (2021), doubts arise as to whether these recommendations are helpful (Table 5).

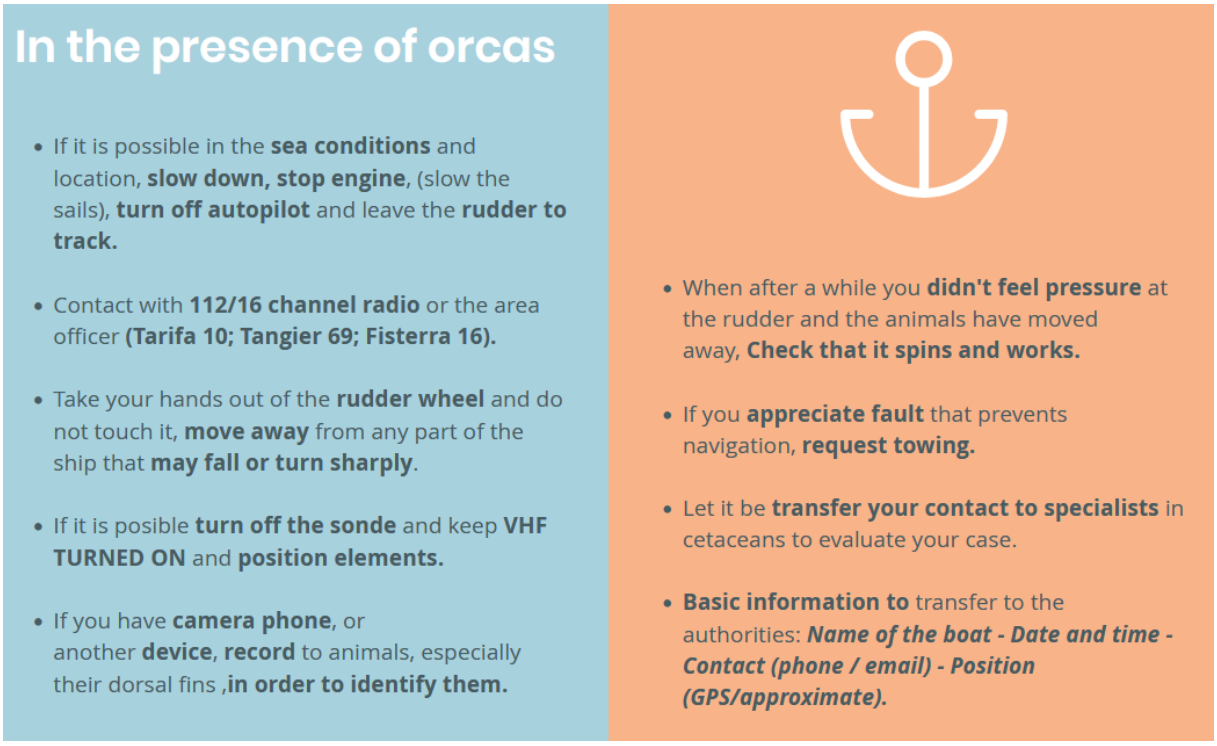

Fig. 5: Recommendations for sailors (from orcaiberica.org). These essentially involve playing dead man and passively waiting for the killer whales to lose interest in attacking.

Analysis of 148 reports from participating sailors (Lopez and Esteban, 2021) shows (Table 5) that around half of them followed the recommendations and stopped (49%). However, the differences in the no-damage ratio between stopped (49%) and continued (45%) are small. If a damage occurred, it was severe in only 24% of the boats that stopped, as opposed to 31% in the boats that sailed on. However, these relatively small differences would need to be confirmed by additional data.

Table 5: The compliance of the sailors in relation to the recommendations of orcaiberica (percentage stopped to onward journey) is around 50%. The frequency of damage hardly differs between the two groups (recalc. from Lopez and Esteban, 2021).

	Stopped	Sailing on
Occurence	49%	51%
No damage	49%	45%
Damage	51%	55%
Slight D.	76%	69%
Severe D.	24%	31%

As opposed to this, the website Orcas.pt recommends: a) to follow the 20m depth line, b) when orcas approach the boat, not to stop but to leave the area at full throttle, if possible towards shallow water, c) not to sail into hotspot areas at night and d) to always use the engine in hotspot areas. Orcas.pt supports sailors to avoid hot spots by publishing current interaction maps.

Pierre Lang, a civil engineer from Brussels, Belgium, sailing on board his yacht "Thoe" recommends that during an attack: "*The very first thing to do is disengage the autopilot to avoid destruction of the rudder transmission which is blocked by the autopilot drive part... The rudder must come back to the neutral position after each attack. I suggest to use an elastic line to amortize the rudder.... Most sonars use 200 kHz which is above 120 kHz (hearing range of orcas, see below). Only sonar below 120 kHz must be turned off. It is important because now it is recommended to sail in shallow waters. If you stopped the engine, wait 30 minutes before re-starting it, otherwise the orcas can come back. Run away to shallow water. If not possible run away in the opposite direction of the whales (as they are supposed to migrate in the direction of their prey)* ".

8. What is the benefit of taking "countermeasures"?

Many of the sailors engaged in "interactions" by orcas took the initiative and deployed a variety of defensive countermeasures. Since the number of reports on any particular measure was probably too low, Lopez and Esteban (2021) grouped them all under "countermeasures": a) items used such as fishing lines, bait, torches, diesel oil, stones, b) manoeuvres such as reversing, c) discharge of black water and d) screaming, music, noise and others.

In the analysis of 190 reports the authors came up with interesting differences (Table 6). Of the 190 accounts only 18% report using countermeasures (CMS; 34 sailors), which explains the grouping of all countermeasures into one category. The proportion of damage-free boats was about the same in the group without measures (37%) and those with (CMS, 32%). The proportion of damaged boats also hardly differs between these two categories (63% and 68% respectively). Are countermeasures therefore useless?

Table 6: Evaluation of 190 reports from participating sailors (recalc. from Lopez and Esteban, 2021). Only 18% engaged in countermeasures (CMS). If a damage occurred, it was only severe in 26% of cases with CMS, as opposed to 42% without.

	None	CMS
Occurence	82%	18%
No Damage	37%	32%
Damaged	63%	68%
Slight D.	58%	74%
Severe D:	42%	26%

No: there is an interesting difference when comparing severe damage. If a damage occurred, it was less often severe (26%) when countermeasures had been taken, than without (42%). The difference is minus 40%: This is a first indication that certain measures, which unfortunately are not defined in

more detail by Lopez and Esteban (2021) may limit the damage. Negative stimuli can also lead to negative conditioning and reduce orca readiness for interaction (Käsbohrer, 2023).

9. Can killer whales be successfully distracted acoustically?

The countermeasures presented in Chapter 8 include noise, but not explicitly acoustic deterrents, such as those used in fisheries to avoid bycatch. Can such devices help mitigate orca attacks?

F3: Maritime Technology, Heikendorf (F3MT) offers the so-called Whale-PAL (Pat. Culik et al. 2013), an acoustic deterrent that is also intended to deter killer whales from attacking sail boats. The acoustic warning device is spindle-shaped and equipped with a tail fin and is towed behind the boat on a 10 m long steel line (Fig. 6). A paravane is used to bring the device to depth - a water depth of 2-3 m is required for acoustic effectiveness. This suspension has been successfully tested on various types of boats (motorboat, monohull, catamaran) up to 8 knots each. During an interaction, speed must be reduced to 6 kn to keep the PAL low in the water. The aim of the Whale-PAL is to distract or deter orcas from attacks astern and to deny direct access to the rudder and keel by means of the towed, bioacoustically well "visible" steel line.

The acoustic signal of the Whale-PAL is of particular importance (Fig. 7). The killer whale's hearing range extends from frequencies that humans can hear (100 Hz) to the ultrasonic range (100,000 Hz). The range of the highest orca hearing sensitivity (10 - 100 kHz) is covered by the Whale-PAL with its broadband signal.

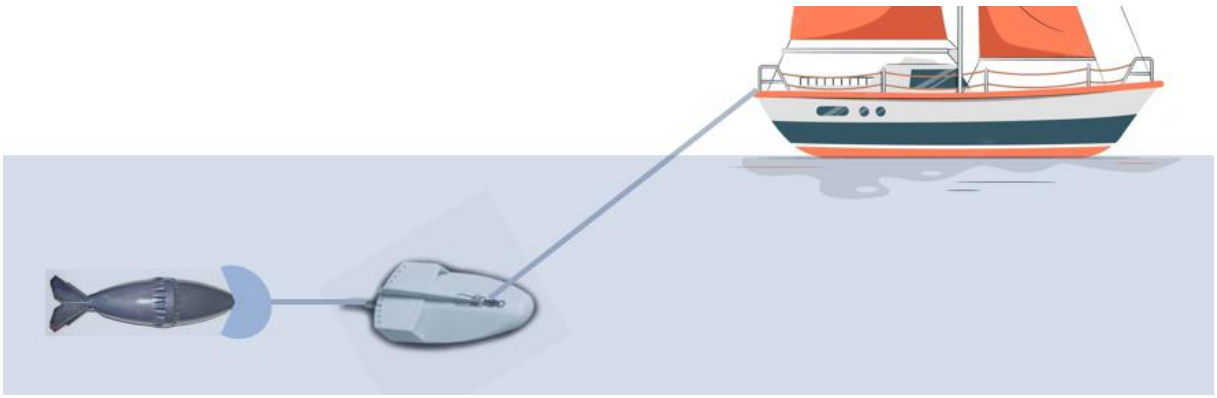

Fig. 6: The Whale-PAL is towed behind the boat on a 10m long stainless-steel line using a paravane at a water depth of 2-3m. In this way it blocks orca access to the rudder

The signal used in the Whale-PAL is based on the formerly popular fishing pinger "Dukane Netmark 1000", which is no longer produced, and which has been extensively researched (e.g. Dawson et al. 2013). It sounds every 4 seconds in the range of 10 - 130 kHz and is supplemented by a variable secondary signal that is emitted randomly to prevent the animals from habituating.

The Whale-PAL signal has been successfully tested in Icelandic and Black Sea fisheries where it reduced porpoise bycatch by 80-100%. The Whale-PAL complies with the EU guidelines for acoustic warning devices (EU Regulation 2020/967) and achieves a source level of 145 dB. The deterrent

signal generated by the Whale-PAL is always up to date. Since each PAL is programmable, its software can be updated during servicing. Battery and seal are also replaced then. Battery life using the lithium battery is 1 year in continuous operation and 4 years in standby.

Customers who purchased a whale PAL until December 2023 were repeatedly asked by F3MT to report their observations, attacks and damage in order to be able to optimize the system continuously. Their reports were analysed in "Part A: Feedback" above: Users of a Whale-PAL have a 92.9% chance of getting unscathed through an area where there have been immediate reports of orca attacks. They have a significantly lower probability of even seeing orcas and, if they do see them or have an "interaction", they have an 85% chance of getting out of the affair unharmed.

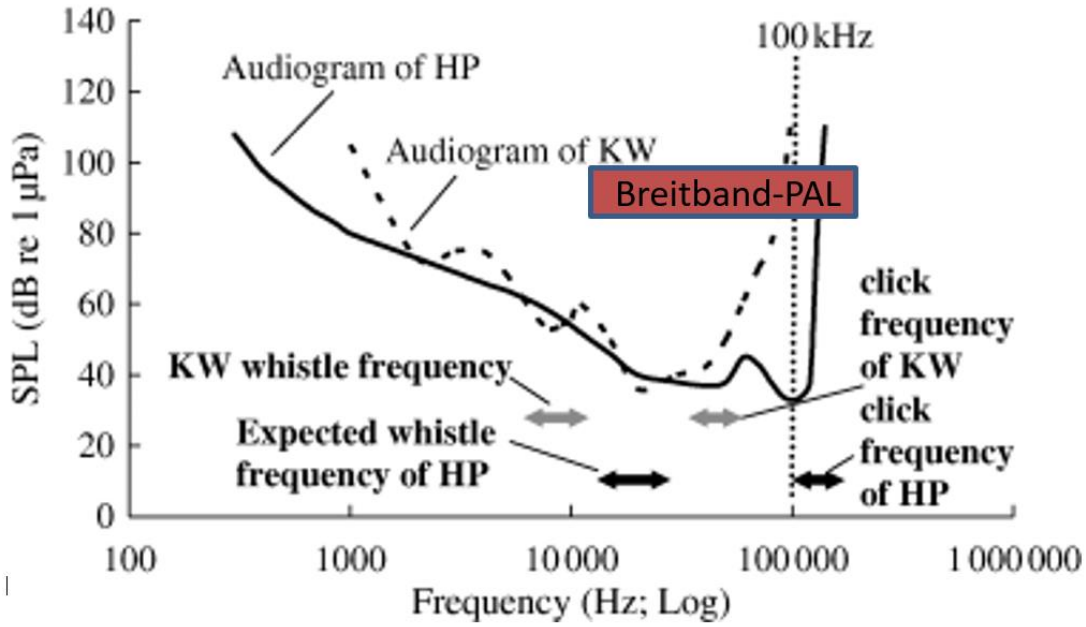

Fig. 7: The hearing curves of killer whales (KW, dashed line) and harbour porpoises (HP, black line) reach their greatest sensitivity at 10 – 100 kHz. This range is completely covered by the broadband signal of the Whale-PAL (own measurements; Szymanski et al., 1999; Kastelein et al., 2002).

Data on the Whale-PAL confirms the effectiveness of certain defensive measures also found by Lopez and Esteban (2021). If the difference between 11% severe damage (general) and just 1.8% (whale PAL, Table 1, Part A) is further supported in the future, the Whale-PAL would reduce the chance of damage by 85%. Even if one takes as a basis the above figure from Bert Frisch (TO) of only 5% serious damage in sail boats along the Iberian Peninsula, the Whale-PAL would still reduce this by 2/3. These values are in good agreement with the Whale-PAL bycatch reduction achieved in the Icelandic and Black Sea fisheries (Sigurdsson, Hafogvatn, Reykjavik; Popov, Green Balkans, Plovdiv; pers. comms.).

10. What other defensive measures are conceivable or have been used so far?

The countermeasures discussed by sailors and already used by some are divided into spatial, navigational and effector-based measures.

For **spatial avoidance**, many sailors use the current interaction maps published by either orcaiberica.org, also known as GTOA, or by orcas.pt. Some sail along the 10m depth line. Advantage: killer whales cannot dive so deep in shallow waters and therefore cannot go unnoticed for long. Disadvantage: Challenging to navigate and still leaves enough space for the orcas (body diameter around 1.5 m) to attack the boat.

Other sailors prefer to sail far out, avoiding the areas shown in Figure 3 near the shores through which bluefin tuna pass and where most attacks have taken place. This probably reduces the likelihood of an interaction, but also has the disadvantage that the beautiful coastline is no longer in sight.

In terms of **navigation**, it is conceivable that the course of the ship could be changed erratically when orcas are sighted and interacted with: orcas have specialized in ramming the keel and rudder blade (Fig. 5). To do this, they "sneak" up from the stern, which is only possible if the rudder and keel, as well as the Whale-PAL, remain in predictable places. Erratic course changes can thwart this. It is also conceivable to "*navigate circles of short diameter as fast as possible. So the rudder is changing its position and orientation all the time*"(Pers. Comm. Pierre Lang). Disadvantage: the rudder blade can deflect wildly during orca attacks, which can lead to injuries in the helmsman. This is important to remember (do not touch the rudder directly). The position and approach of the orcas must be kept in sight and reported by the lookout.

Non-invasive countermeasures include towing the Whale-PAL (see Chapter 8). However, there are reports on various effectors such as diesel, sand, rocks, baitfish, etc., which are discussed in various chats. What good can that do?

Diesel oil may be effective due to its unpleasant odour. However, video recordings show that orcas surface often to the side of the attacked vessel to catch their breath. The discharged, buoyant spot of diesel behind the ship should hardly have any effect on this.

Spreading large amounts of sand, several 20 kg sacks are reported, can be effective as the sand scratches the orcas' eyes, making approach from astern uncomfortable. The second effect may be that light-colored sand makes the boat disappear under water in a "cloud of fog". As a "hard" acoustic reflector, sand also leads to an acoustic smoke screen, behind which the structures of the ship are no longer clearly discernible, even for the biosonar of the attackers. So the effect of the sand would be similar to the ink of fleeing squid. Squid escape strategies should be deployed accordingly.

A "fog cloud" could also be achieved by fine air bubbles. These reflect light, which, at least during the day, makes the ship disappear visually for orcas in the "fog". Acoustically, air bubbles, like sand, are also "hard" reflectors and blur the contours of the ship. The question is how to introduce air bubbles around a yacht: Pond pumps or compressed air bottles, air hoses and aerating stones at a sufficient depth would be conceivable. However, these require energy to overcome water pressure and fittings… Apparently, this is one method that might be tested by GTOA.

Throwing over board (not on the animals, that is illegal) fish, scraps of food or stones, tennis balls, boards, fenders or other objects that either float or sink slowly may be useful to confuse and distract the animals. They may turn to these objects and remain engaged long enough to navigate the ship out of harm's way. This would however "reward" the animals behaviour.

Invasive effectors such as stones (see Chap. 8) may have been thrown at the whales or shot at them with a slingshot. As a hard reflector, stones would distract the animals, but only for a short time and in a very limited space, since they sink quickly. Hits of the animals with the slingshot could distract

the orcas from their behaviour or instead lead to increased aggression. The author's experiences with arrowheads for placing tracking devices in the whale blubber show that whales perceive the impact, even with fine biopsy arrows, may slap the water with their fluke and quickly dive away.

Pyrotechnic effectors that have been reported on various websites are flares, flare guns, and firecrackers. With these, it must not be overlooked that orcas are protected, which can quickly call the police and prosecutors into action. Pyrotechnic measures are highly visible and attract a lot of attention. They also pose danger to the crew and the ship. As for the effect: A sailor reported: "*We only had one firecracker on board, the use of which caused the attack to be interrupted for about 10-15 minutes. After that the orcas started again*."

11. Conclusions

Many discussions in the TO-Whatsapp groups and with individual sailors have shown that no single measure prevents an orca attack by 100%. Examples for this are playing "dead man", sailing in the immediate vicinity of the coast, as can be seen in various videos, or poorly positioned and therefore acoustically ineffective pingers.

My suggestion is therefore to plan several staggered measures of defence. Of course, the skipper is always responsible. For example:

1. Iberian killer whales follow the tuna and are probably on their way along the west coast of Europe to southern Norway, see Fig. 3. Here it is important to avoid current attack areas or hot spots. You can get timely updates on orcaiberica.org and orcas.pt. But beware: orcas travel at up to 5 knots (but they can also stay in place for quite a while). In any case, the radius of uncertainty to be avoided is increasing by the hour after the report.

2. Take countermeasures. The study by Lopez and Esteban (2021) showed that playing dead man does not help. Countermeasures that are not defined in more detail, on the other hand, can reduce the occurrence of severe damage by 40%.

The Whale-PAL seems to work very well here: feedback from sailors shows that only 1.8% serious damage occurs when using it, as opposed to 5-11% for sailors in general. The Whale-PAL warns and distracts, making access to the rudder difficult. When attacking, reduce speed to 6 kn so that the towed PAL stays well under water.

3. Sailing evasive manoeuvres, “hooking”: then the rudder is more difficult for the heavy whale to home in and the line of the Whale-PAL is also constantly moving. Videos of attacks show that the orcas usually wait until the ship is still before launching the next attack on the rudder blade. But be careful: Bumps on the rudder blade lead to very strong deflections of the rudder. Safety first.

4. Head towards the coast and shallower water at full speed: this gives the animals less space and is also one of the recommendations of orcas.pt. It may also help because the orcas would then also have to leave their hunting area to follow the boat: costs of their "play" behaviour increase.

5. Plan further distractions: have heavier floating objects such as old fenders, boards, etc. ready to throw over board. While this rewards the orcas for their behaviour, it can also end the interaction. Many sailors report that the animals lose interest after breaking the rudder. With sand, the ship can be visually and acoustically "fogged" under water. This is time-consuming and not feasible in all weather conditions, but it has previously helped.

Finally, I would recommend, in addition to planning a staggered defense against attacks, to also simulate countermeasures and to practice and optimize the processes and possible reactions. Just like you practice "man overboard". Sailors' reports show that attacks can otherwise quickly lead to overwhelm and panic, because sailors are often attacked without sighting or warning.

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