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Grant Proposal

SEADETECT: developing an automated detection system to reduce whale-vessel collision risk

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Abstract

With the continuous intensification of marine traffic worldwide, whale-vessel collisions at sea (or "ship strikes") have become one of the primary causes of mortality for cetaceans and a widely recognised cause of concern for human safety and economic losses. The Mediterranean Sea is a global hotspot for whale-vessel collisions, with one of the highest rates involving large cetaceans, especially the endangered fin whales (*Balaenoptera physalus*) and sperm whales (*Physeter macrocephalus*). Evidence indicates that both species are experiencing higher chances of a fatal collision than what predictions have estimated so far, with ship strikes being the main human-induced threat in the area. Regional and international organisations have stressed the need to address the issue by investigating the projected impacts of ship strikes on whale populations and by identifying possible mitigation measures to reduce chances of collision. Amongst the most popular and feasible options, there is the improvement of animal detection during navigation. Here, we present SEADETECT, a LIFE project that aims at developing an automated detection system to reduce vessel collision risk with marine mammals and unidentified floating objects (UFOs), combining state-of-the-art and novel technologies with existing approaches in the study of large whale ecology. This detection system consists of three elements; an automated onboard detection system composed of several sensors, a real-time passive acoustic monitoring (PAM) network at sea and a real-time detection-sharing and alert system (REPCET®). In this paper, we propose the development of a mitigation measure framework tailored for the issue of collision with fin and sperm whales in the north-western Mediterranean Sea, but that has the transferability features necessary for its application in other high-risk areas for ship strikes worldwide.

Keywords

marine traffic, whale-vessel collision, cetaceans, endangered species, conservation, mitigation measures

Collision overview and background

Worldwide marine traffic is projected to significantly intensify (Tournadre 2014; Sardain et al. 2019; Robbins et al. 2022) and with it the pressure on marine environments with likely implications for the welfare and persistence of threatened and at-risk species (Pirotta et al. 2018; Rae et al. 2023). At sea, collisions with vessels (also referred to as "ship strikes") are one of the primary causes of mortality for large cetaceans and are widely recognised as a cause of concern for human safety and economic losses (Schoeman et al. 2020). While the more direct consequences of vessel collisions with large whales are easily understood, with strikes often being fatal or resulting in severe injuries leading to a delayed death for the animal involved, the more subtle welfare implications, the long-term population consequences and the potential to hamper any conservation effort are yet to be fully understood and described (Schoeman et al. 2020; Blondin et al. 2020). Alongside environmental and conservation concerns, the severity of vessel damages, increased risks for mariners and passengers and, in general, the socio-economic impacts of collisions should not be underestimated (Sèbe et al. 2020; Industrial Economics Incorporated 2020).

Ship strikes are recognised as a global threat (Laist et al. 2001; Cates et al. 2017; Schoeman et al. 2020; Winkler et al. 2020) and several hotspot areas have been identified worldwide (Minton et al. 2021). In fact, the rate, the risk and the likelihood of ship strikes are spatially and temporally variable, depending on the biological and ecological characteristics of the species involved and the type of vessel considered, leading to local areas with high risk and especially impacted species. Amongst others, the North Atlantic Right whales (*Eubalaena glacialis*) are recognised to be particularly at risk from vessel strikes, with collisions having caused one-third of the known or suspected deaths in the US and Canada north-western North Atlantic in the last seven years (NOAA Fisheries 2023). In the Canary Islands, during the period 2000-2017, at least 81% of the sperm whales stranded with signs of ship strike were alive at the moment of the collision and died subsequently (Arregui et al. 2019), with such a high rate of mortality deemed to be unsustainable for the persistence of this population (Fais et al. 2016a, Fais et al. 2016b). Mortality for blue, humpback and fin whales in the U.S. West Coast waters off California is estimated to be 7.8, 2.0 and 2.7 times higher, respectively, than the U.S. recommended limit for these species, suggesting that death from vessel collisions may be a significant impediment to population growth and recovery (Rockwood et al. 2017; Rockwood et al. 2018; Kelley et al. 2020).

The Mediterranean Sea is another global hotspot, with one of the highest rates of collisions involving large cetaceans, estimated to be 3.5 times higher than other areas (Minton et al. 2021). Within the Basin, five high-risk areas for these species have been identified in the Strait of Gibraltar, the Eastern Alborán Sea, the Balearic Islands, the Hellenic Trench and the north-western Mediterranean (Minton et al. 2021), where the highest number of fatal and harmful collisions (Panigada et al. 2006; Di-Meglio et al. 2018; Panigada et al. 2020; Ham et al. 2021; Grossi et al. 2021; David et al. 2022; Fortuna et al. 2022; Sèbe et al. 2022), as well as high numbers of near-miss events (NME; surprise encounters occurring at less than 80 m distance from the animal) (Tort Castro et al. 2022), have been reported. The Mediterranean subpopulations of fin (*Balaenoptera physalus*) and sperm whales (*Physeter macrocephalus*), both listed as 'Endangered' under the International Union for the Conservation of Nature (IUCN) Red List Criteria, are the species mostly affected by vessel collisions, which, at the current rates, likely result in a decline of their abundance (Panigada et al. 2021; Pirotta et al. 2021).

Fin whales occur across the entire Mediterranean Region with animals' abundance being higher in the western sector (Notarbartolo di Sciara et al. 2016) and roam across the Basin for feeding and mating purposes (Panigada et al. 2017). During the summer months, fin whales congregate in the waters of the Corso-Ligurian-Provençal Basin for feeding purposes (e.g. Panigada et al. (2005); Panigada et al. (2011); Druon et al. (2012)) where they occur primarily in offshore deep waters (Panigada et al. 2008). For fin whales, their large body size and surface behaviour, characterised by long surface time, make them particularly susceptible to collide with ships (Grossi et al. 2021; Sèbe et al. 2022). Recent reviews of historical and modern information (Manfrini et al. 2022) show that mortality associated with whale–vessel collisions is, in general, high in the Italian seas and involves younger animals in particular.

Sperm whales' summer occurrence and distribution in the north-western Mediterranean Basin reflects the general sexual segregation scheme found in the open oceans, with animals, primarily adult males, generally observed in loose aggregations and mostly engaging in feeding activity (Rendell and Frantzis 2016). The species is mostly encountered over the steep continental slope and canyon systems (Azzellino et al. 2008; Praca and Gannier 2008; Pirotta et al. 2011). Evidence suggests an elevated risk of collision between sperm whales and vessels in the north-western Mediterranean, in particular within the waters of the Pelagos Sanctuary for Mediterranean Marine Mammals, with potential detrimental effects on the entire population (Di-Meglio et al. 2018; Panigada et al. 2020; Minton et al. 2021; Grossi et al. 2021).

In Fig. 1, an example of how the spatial overlap of shipping routes of passenger and cargo vessels, the two vessel types mostly contributing to collision and whale distributions result in collision risk hotspots, is shown. Evidence indicates, for both sperm and fin whales, that current predictions of fatalities due to ship strikes likely underestimate the extent of the issue (e.g. Panigada et al. (2020)) and that collision with large ships is the main human-induced threat in the area (e.g. Winkler et al. (2020)). Recently, Sèbe et al. (2023) concluded that, for fin whales, mortality from collisions alone is in excess of the species Potential Biological Removal, the Alert Reference Point and the Critical Reference Point, likely resulting in a population decline. Detrimental effects from ship strikes contribute, together with a variety of other threats like entanglement, anthropogenic noise and pollution, to the cumulative effects on the two species, which are overall further inhibiting recruitment and multiplying mortality (Thomas et al. 2015).

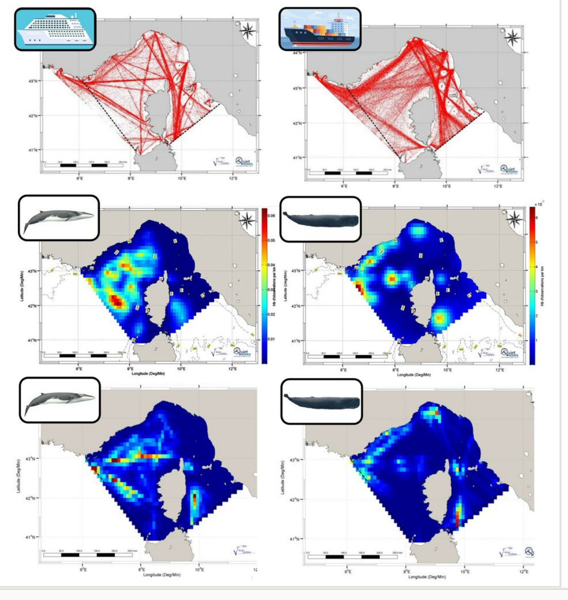

Figure 1. doi

Exemplificatory comparison between shipping routes of the two vessel types mainly contributing to collision (passenger and cargo vessels) shown as Automatic Identification System data points (top panels) and modelled summer maps of fin whale and sperm whale contact rates shown as number of sightings/km (middle panels). The interplay of the vessel routes and whale distribution and movements lead to a spatially variable map of whale-vessel collision risk (bottom panels), shown as number of Near Miss Events/km (NME i.e. surprise encounter at < 80 m distance). The figure is adapted from Jacob and Ody (2016).

Collision risk depends on the behaviour of the whale and the whale's reaction to an approaching vessel, with the time spent at or near the surface as an important factor determining the susceptibility to a strike (McKenna et al. 2015; Izadi et al. 2018; Keen et al.

2019; Caruso et al. 2020). In the Ligurian Sea, fin whales diving/surfacing behaviour tends to differ considerably amongst individuals. Data suggest that Mediterranean fin whales are unlikely to dive deeper than 600 m and that the depth and the numbers of dives are affected by the distribution of their prey through the water column (Panigada et al. 1999, Panigada et al. 2003). In general, fin whales show two distinct surfacing and diving patterns related to feeding and travelling. During feeding, animals show a convoluted route pattern characterised by sharp turning angles, long dive and surfacing times, while during travelling, animals usually perform shallow and short dives, spending limited time at the surface (Jahoda et al. 2003). In the same area, where animals primarily engage in feeding activities, sperm whales perform long deep dives of approximately 45 minutes, with an inter-dive-interval (i.e. the time spent at the surface between dives) of about 9 min, during which they are "lethargic" and move slowly with an average horizontal displacement of about 1.3 nautical miles between dives (e.g. Drouot et al. (2004)).

In this context, the International Whaling Commission (IWC) has stressed the need to address the effects of ship strikes on large whale populations. In conjunction with the International Maritime Organisation (IMO), other relevant international, governmental- and non-governmental organisations, industry and the scientific community, the IWC is focussing on identifying high risk species and areas, as well as mitigation measures to reduce collision risk in a way that causes minimum disruption to shipping (Sèbe et al. 2019). The French, Italian, Monegasque and Spanish governments have recently proposed a Particularly Sensitive Sea Area (PSSA) to be implemented in a large portion of the north-western Mediterranean Sea, including the entire Corso-Provençal-Ligurian Basin and the Balearic Sea. The proposed PSSA includes the two Specially Protected Areas of Mediterranean Importance (SPAMI) dedicated to cetaceans (i.e. the Pelagos Sanctuary and the Spanish whale migration corridor) and partially overlaps with the North-West Mediterranean Sea, Slope and Canyon IMMA (Tetley et al. 2022; Sèbe et al. 2023). While waiting for this process, given the gravity of the issue, immediate action is required.

While the dynamics of whale–vessel collisions are not fully understood, several underlying factors have been identified (e.g. Dolman et al. (2006)). The probability and severity of a collision are affected by several factors related to both vessels and whales with large ships travelling at high speed more likely to result in lethal injuries (Vanderlaan and Taggart 2006 Schoeman et al. 2020). A variety of operational and technical measures have been identified to reduce the risk of collision with cetaceans (see Sèbe et al. (2019) for a synthesis), including speed reduction, traffic limitation schemes and areas to be avoided. However, it has been noted that several of the proposed approaches come with limitations when used alone (Schoeman et al. 2020) and in the absence of a holistic approach that accounts for the cost-effectiveness, the regulatory regime, the compliance to existing collision avoidance tools (Sèbe et al. 2019) and the collaborative involvement of the shipping industry (e.g. Reimer et al. (2016)).

Here, we present the outline and objectives of the ongoing LIFE SEADETECT project (https://life-seadetect.eu/), developed to integrate state-of-the-art and novel technologies with existing approaches in the study of large whale ecology to mitigate and reduce sperm and fin whales' collisions with vessels in the region, in collaboration with major

Mediterranean shipping companies. The project aims at developing a mitigation measure that is tailored for the issue in the north-western Mediterranean Sea, but with the transferability for application in other high-risk areas for ship strikes worldwide.

Project objectives

SEADETECT is a 4-year project of the LIFE programme, financed by the European Climate, Infrastructure and Environment Executive Agency (CINEA), which aims at developing an automated detection system to reduce vessel collision risk with marine mammals and unidentified floating objects (UFOs), combining state-of-the-art technologies. The project brings together eleven partners from Belgium, France and Italy with the objectives to: i) create an innovative, low-cost and effective solution, that, ii) can positively impact the environment by reducing collisions by 80% with vulnerable species, while, iii) improving safe navigation conditions required by current and future regulations. The system intends to detect and identify cetaceans up to 1 km from the vessel and alert the crew in time for responding accordingly. To design such system, the project articulates in the development of the following elements, visualized in Fig. 2:

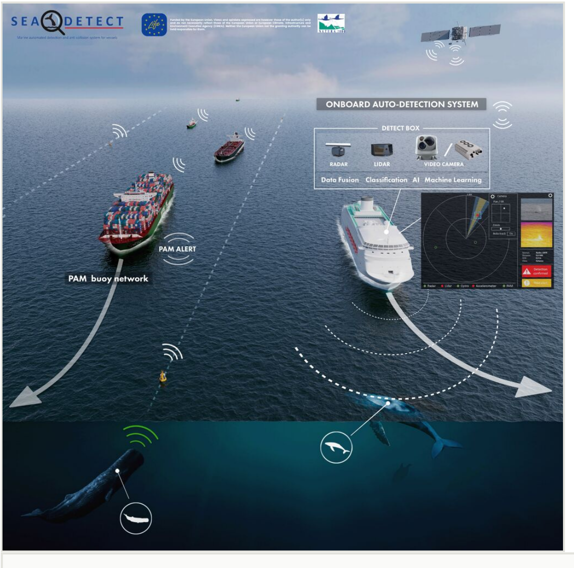

Figure 2. doi

Visual representation of the key aspects of the project SEADETECT.

1. an automated Onboard Cetacean Detection System (OCDS) composed of several sensor technologies able to detect and identify marine mammals and UFOs electro-magnetically, thermally and visually in most weather conditions, both during day and night;
2. a Passive Acoustic Monitoring (PAM) hydrophones network at sea able to detect and geolocate whales by triangulation and alert in real time navigating vessels;

3. the optimisation of an already existing onboard sharing detection and alert system (REPCET®) implemented by both systems combined alerts and distributed to the equipped network of vessels;
4. the analysis of whale behaviour in response to vessels and the prediction of population consequences using passive tracking data (including tagging data), footage and modelling tools to assess the potential impact that the implementation of the three combined elements (hereafter called "full system") would have on targeted whale species.

Scientific challenge and methods

Element 1: Onboard Cetacean Detection System (OCDS)

The automated OCDS is composed of multiple highly sensitive complementary sensors that are processed and then fused thanks to artificial intelligence algorithms in order to allow equipped vessels to self-detect cetaceans (Fig. 3). The following sensors technologies are used within this system:

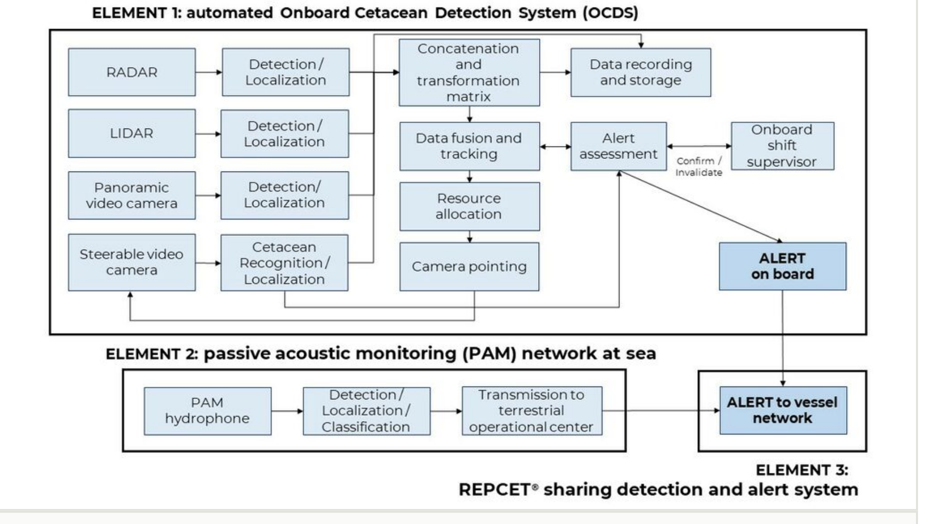

Figure 3. doi

Schematic representation of the three technologies (three of the four elements of the project objectives) that compose the full system functioning and data flow that will be developed by the LIFE SEADETECT project to reduce whale-vessel collision risk, starting from sensor detection until alert distribution to the network of navigating vessels.

1. RADAR
2. 3D-LiDAR
3. Optronic sensors system (mechanics, optics and electronics)

The RADAR system is composed of a coherent 12 KW scanner using a gyro-stabilised antenna. Thanks to this capability, it enables an immediate and stable 360° scan of the environment regardless of sea condition. The Doppler Based Signal Processing implemented in the Radar Processing unit will allow an efficient filtering of the traditional environmental clutter (sea, rain) and will optimise the detection of objects of interest (e.g. cetaceans, other UFOs). A multi-dimensional filtering segmentation is implemented to further isolate cetaceans. The plot and video output will then be sent to the fusion box for correlating data coming from the radar with data from other sensors. The radar will be controlled by the ASTERIX protocols.

The 3D-LiDAR is an active sensing technique using a laser in the infrared range-band (eye-safe system) and delivering an immediate and accurate 3D representation (high resolved telemetry) of the surveyed environment in its field of view. The resulting information is a 3D point cloud that is subsequently processed to differentiate between water and objects of interest in the scanned scene. This sensing technique provides a locally higher resolution than the RADAR and is largely independent of environmental factors like, for example, natural lighting. The COTS-based 3D-LiDAR 3D prototype to be installed has a wide field of view of 120° and a range of up to 500 m. In addition, a high-performance prototype with a longer range, but more restricted field of view, will be tested for a short period of time during the project.

The optronic sensors system is in turn composed of: i) an on-sea object detection and classification video camera with 180° panoramic view and a panoramic dual band (thermal infrared LWIR 1920x480 + visible band 12Kx4K) customised from https://nexvision.fr/products/panoramic-camera/panomix-panoramic-vision/; ii) a cetacean recognition and tracking zoom camera equipped with a long range view, a gyro-stabilised gimbal with zoom optics (continuous magnification x10, 4° - 40°) and triple band (thermal longwave infrared LWIR 1280x1024 vision + visible-near infrared VNIR 4Kx4K quarter moon night vision + visible colour band 4Kx4K), customised from https://nexvision.fr/products/gsg9-gsg11-gyrostabilized-gimbal/; iii) a vision calculator to analyse images and detect cetaceans by an artificial intelligence algorithm, customised from https://nexvision.fr/evpu-embedded-vision-processing-unit/; and iv) a command and control Human-Machine Interface with 24 in 4 K tactile display.

Dedicated detection algorithms on each of these sensors will identify and locate objects of interest, which are then sent to a data fusion module for comparison and analysis. Based on this analysis, candidate detections are then prioritised and sent to the steerable optronics system, which has a much higher zoom factor, but limited field of view, to confirm and recognise the candidate targets. The analysis of the multi-sensor data depends strongly on the conditions: the ability of the sensors to distinguish marine mammals in the water varies with light conditions, weather conditions and sea state. One of the research tasks is, therefore, to quantify the performance of the subsystems in a variety of conditions in order to calibrate the data fusion. In case of cetacean recognition confirmed by the on-board shift supervisor, alerts are communicated in real time to the vessel network.

The detection box will undergo several testing and validation phases on board four different vessels. The first testing phase will be done on board the whale-watching vessel of the organisation Découverte du Vivant (https://www.decouverteduvivant.org/). For six months, the optronic component of the system will be trained and tested in capturing images and videos and identifying targeted cetaceans. Learning from the results from this testing phase, the optronic component will undergo enhancement and optimisation towards a second prototype. The second and third testing phase will take place on board two high-speed passenger ferries from the company La Méridionale, the Piana and Kalliste, having an average length, beam and draft of 173 m, 30 m and 6.3 m, respectively and an average speed of 17.5 knots. The two testing phases will work in parallel for one year, testing the complete set of sensors composing the automated detection box along the shipping routes within the Pelagos Sanctuary. The results of the second phase will be used to optimise the detection box tested during the third phase. A fourth testing and validation phase will take place on board the *RV* Belgica, the national research vessel of Belgium having a length, beam and draft of 71.4 m, 16.8 m and 4.8 m, respectively. The detection box will be tested navigating in the North Sea or the Arctic Sea under different environmental and meteorological conditions, targeting different marine mammals species. The objective of this phase will be to test and validate the complete set of sensors on different species, on board a different type of vessel and in a different environment, to demonstrate the transferability and replicability of the project.

Element 2. PAM network

The PAM hydrophones system is composed of a network of hydrophones connected to autonomous energy buoys that are able to record the presence of cetaceans, based on the sounds they emit (i.e. echolocating ‘clicks’ of sperm whales and vocal calls of fin whales) (Fig. 3). Networks of hydrophones will be deployed in key areas important for the species ecology or witnessing high density of marine mammals, such as corridors for cetacean passage which overlap or not with highly-trafficked shipping lanes. Hydrophones will be able to detect sounds and identify the species, geolocate the animal by triangulation and alert in real time navigating vessels by sharing the detection on the network. A testing and validation phase will take place for a period of one year in which explicatory networks will be deployed in important areas in the north-western Mediterranean Basin.

Element 3: Detection sharing network

Both detection elements developed within the project will provide accurate alerts that will be transmitted to navigating vessels through a sharing detection network (Fig. 3). This share detection network will rely on the REPCET® system (https://www.repcet.com) which allows to report, share and receive in real time cetaceans’ positions within a network of subscribers. Today, 39 vessels are equipped with the system and five institutions are also equipped with the shore interface. Each cetacean detected by both detection elements is transmitted in real time by satellite to a server located on land. The server centralises the data and issues an alert to ships equipped with REPCET® and likely to encounter the cetacean on their route. The alerts are then mapped on board on a dedicated screen and listed 24 hours on the screen.

Element 4: Cetaceans behaviour and ecological impacts

A deeper understanding of marine mammal behaviour in the presence of a vessel is one of the fundamental elements in the effort to reduce whale-vessel collision. In this project, data on cetacean behaviour near high-speed vessels will be collected from four sources: 1) from the analysis of data collected from a variety of sensors, including acoustic tags equipped with accelerometer and pressure sensors that will be placed on individual animals using non-invasive suction cups and satellite transmitters (Panigada et al. 2017); 2) from surface observations collected by experienced marine mammal observers on board pilot passenger and research vessels; 3) from the 3D positions collected through the PAM buoys network and 4) from the data collected from the testing phases on board passenger and research vessels. Furthermore, existing knowledge on the potential effects and efficiency of acoustic warning devices on cetacean behaviour will be reviewed in a bibliographic study. On one hand, acoustic warning devices may have the benefit of reducing chances of collision, on the other hand, they introduce additional underwater noise which may elicit behavioural responses. High-speed vessel acoustic signatures, equipped with or without acoustic warning devices, will be measured and compared and a modelling exercise to characterise the acoustic propagation of several kinds of devices in several environmental scenarios will be developed.

The data collected from tags, field observations, PAM and testing phases onboard vessels will provide information on species distribution, species behaviour - including time spent at the surface and reaction to vessels - and detection system efficiency, including number and type of detections acquired. Such data will be used to investigate the full system capability and effectiveness and to project the potential impact that the wide-scale implementation of the full system would have on targeted whale populations. To assess such impact, the potential consequences on the Mediterranean subpopulations of sperm and fin whales will be quantified using multiple statistical and modelling tools. Stochastic predictive modelling methods that include the use of estimates of population size, age-or stage-specific birth and death rates to simulate population responses will be used. The PCoD (Population Consequences of Disturbance) is a theoretical framework that evaluates how changes in behaviour due to a specific or cumulative disturbance may influence population dynamics (National Research Council 2005). PCoD models have already been applied to marine mammals' population (e.g. Kraus et al. (2015); New et al. (2015); Christiansen and Lusseau (2015); Tollit et al. 2017; Farmer et al. 2018; Rumes and Degraer 2020) and specifically to quantify impacts of ship strikes (Murray et al. 2019). PCoD models link behavioural or physiological changes due to disturbances with species specific biology and life traits to estimate impacts on population dynamics. In LIFE SEADETECT, the detection data collected from the field campaigns will be linked with the knowledge available on the target species biology and behaviour (e.g. Jahoda et al. 2003; Panigada et al. 2005; Pirotta et al. 2011; Panigada et al. 2017; Zanardelli et al. 2022) to test different scenarios of implementation: no full system implementation, minimal implementation (i.e. as if only used on trial vessels), regional implementation (e.g. by the existing REPCET® vessel network) and large-scale implementation (Mediterranean Sea level). Furthermore, the effectiveness of detections in avoiding collisions will depend on the use of the REPCET® sharing network, which will be assessed by means of interviews and performance data, to assess if the reduction in collision risk may be different if detections are shared by other vessels compared to coming from your own vessel. The impact of the full system on targeted species will depend on several regulatory frameworks at national and international level which will influence its implementation and which will be considered in the scenario analysis. Finally, the full range of benefits and support for ecosystem services that would derive from the protection of cetaceans at population level will be discussed and estimated.

Innovation and expected impacts

The LIFE SEADETECT project builds on previous research to upscale marine mammal detection and alerting systems to avoid whale-vessel collisions. The integration of several state-of-the-art sensor technologies in one OCDS optimised for cetacean detection is a novel approach that will be applied in this project. By integrating the sensors with a data fusion and processing system, the OCDS is expected to detect and identify UFOs, with a focus on cetaceans species, at large distances with high accuracy (at least 80%) and, hence, be able to send alerts in time for their avoidance. The detection of UFOs with a minimum of 1 m^2, of individual large cetaceans or of groups of them will be possible in most weather conditions, both at day and night, between 100 m and 1 km distance from the front of the ship and at the surface, covering 140° in Azimuth. Concurrently, the PAM hydrophones network will be optimised for the detection, identification and triangulation of fin and sperm whales in real time. Their combined use offers unique opportunities for significantly reducing NME with marine mammals, as both systems will provide detections and identifications of cetaceans at distances sufficient for the vessel to be alerted, reduce its speed or detour, at a combined false alarm rate lower than 2%. The use of the alert sharing system through the existing REPCET® network is expected to allow vessels to communicate promptly and efficiently. This will enhance the existing limitations of REPCET®, which has yet to prove its effectiveness due to its strong dependency on observations (therefore, active engagement from users) and weather conditions. The validation of the boosted REPCET® tool amongst the currently-engaged 39 users has the aim to make the system appealing for other end users and promote its diffusion to a larger vessel network.

The OCDS will be robust and expected to withstand and work with severe weather conditions, overcoming some limitations that other systems have experienced, such as the LIFE WHALESAFE project (LIFE13 NAT/IT/001061). The project is less prone to receive opposition from the industry as it works in cooperation with it. The full system proposed by the project provides a low-effort, cost-effective and environmentally-friendly alternative to common mitigation measures, including re-routing and speed reduction. Despite speed limitations being recognised as efficient in reducing collision-risk, they are also not applicable nor welcomed from mariners and business owners, as they are not suited for certain vessel types, such as passenger ferries. Speed restriction measures, as may be adopted within a PSSA, are difficult to implement as they require the agreement of all IMO Member States. Instead, the implementation of the full system will require speed reduction only in case of a close detection. Once validated and distributed to the vessel network, the system is automated and, therefore, requires lower human effort in comparison to other projects that rely on crew and volunteer observations and reporting or aerial surveys (e.g. Whale Safe in US; https://whalesafe.com/). Data acquisition is passive and silent; therefore, the system does not introduce additional underwater noise, nor disturbance to the environment. The OCDS is a small investment that becomes economically profitable as it certainly reduces chances for vessel and transported goods damage and immobilisation times, which may also lower insurance premiums. Finally, for those vessels that will not be equipped with an OCDS, the installation of a PAM hydrophones network in areas of intense traffic or critical corridor areas for the cetaceans (e.g. migratory routes, feeding grounds, aggregation hotspots) will be complementary in reducing collision risk and, therefore, offering additional economical convenience and profitability. The combined implementation of a network of vessels equipped with the OCDS with the installation of PAM hydrophones networks has potential for large spatial coverage, making the project suited for large-scale applications.

Given the knowledge on collision-influencing factors including vessel and trajectory features and whale behaviour (Di-Meglio et al. 2018), the onboard system is estimated to record around 300 detections and about 40 NME during the testing and validation campaigns. The scientific data collected with regards to the cetacean's biology and ecology will feed into the growing knowledge on species distribution and behaviour currently acquired by parallel research in the Mediterranean Sea (including the project LIFE CONCEPTU MARIS; LIFE20 NAT/IT/001371 https://www.lifeconceptu.eu/) needed to develop comprehensive conservation strategies. Animal welfare will be improved by strongly reducing the number of stressful near miss events, the number of actual collisions and, amongst those, the number of lethal ones. Such improvement in animal welfare will impact positively on marine mammal species populations. A lower impact on species population will, in turn, determine a lower environmental impact of marine traffic on the concerned areas. At the societal level, the project will raise awareness on the whale-vessel collision issue and the importance of protecting cetaceans within the scientific community, amongst the general public and the maritime actors, especially amongst shipowners. By the end of the project, both the effectiveness of the full system and its transferability to other seas and species will be assessed. Large-scale implementation of the LIFE SEADETECT system could provide a valuable tool for the effort aimed at reducing whale-vessel collisions in other high-risk areas for ship strikes. Cetaceans are part of a complex marine ecosystem and, as such, are key players in several ecosystem services. Due to their body size and long lifespan, baleen and sperm whales are large carbon sinks that contribute to climate regulation (Pershing et al. 2010). The recovery of whale populations would enhance carbon storage (Pearson et al. 2023). As key players in local food webs, population recovery would also stimulate primary productivity via nutrient provisioning (Pearson et al. 2023). Furthermore, whales provide socio-cultural ecosystem services (Cook et al. 2020; Malinauskaite et al. 2021). Their socio-cultural value may come under the form of indirect use value (e.g. recreational value for tourism) or non-use value, in turn under the form of both existence and bequest values (Plottu and Plottu 2007).

Concluding remarks

Whale-vessel collisions are one of the principal causes of mortality for several whale populations and species worldwide. The LIFE SEADETECT project was conceived to directly target the complexity of the collision issue and the demand of regional and international actors for better solutions. By creating an integrated automated detection and anti-collision system, this project provides an alternative solution to existing mitigation measures and will significantly reduce collision risks and protect highly-vulnerable species, while minimising shipping disruption. This is in alignment with international strategic plans (e.g. International Whaling Commission (2022)) and international environmental guidelines (e.g. International Maritime Organization (2014)). By developing and testing the system in a high-risk area with recognised ecological value for marine mammal species (i.e. Pelagos Sanctuary) and especially targeting two endangered cetacean species, the project aligns with current national and regional requirements (e.g. Fortuna (2021)). In alignment with the standards of the European Marine Strategy Framework Directive and the objectives of the EU Biodiversity Strategy for 2030, LIFE SEADETECT will contribute to the European advancement against biodiversity loss, nature protection and environmental restoration.

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Conflicts of interest

The authors have declared that no competing interests exist.

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