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Towards Safer Navigation of Hydrofoils: Avoiding Sudden Collisions with Cetaceans

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ABSTRACT: Recently, sudden collisions between large cetaceans and high-speed hydrofoils have become problematic to Japanese sea transport in some localities. We therefore initiated a project to investigate approaches for minimizing risk to both ships and cetaceans. Under the present project, the following three subprojects are underway: clarifying which whale species are found near sea routes and determining their seasonal variations; identifying whale species that have a high collision risk; and determining the unique acoustic characteristics of high-collision-risk cetaceans for the improvement of underwater speakers (UWS). By conducting acoustic surveys using novel methods, including an anatomical approach based on characteristics of the inner ear, the aim of this project is to accurately estimate the audible range of species with a high collision risk and improve the sounds generated by the UWS. Thus far, we have identified the cetacean species at high-risk in two major sea routes. In the next phase of the study we plan to develop an imaging system that recognizes a cetacean's unique blow using an infrared camera, in an attempt to warn of the approach of high-collision-risk whale species at an early stage by sounding an alarm.

1 INTRODUCTION

Although the situation has improved somewhat recently, a series of collisions have occurred in some Japanese sea routes between hydrofoil-type super high-speed vessels (hereafter "HF vessels"; Fig. 1) and large marine life and continue to concern transport officials and other relevant peoples to this issue. These collisions are often the target of marine accident inquiries that examine the responsible factors, and it would be accurate to state that in most instances, the collisions involve cetaceans (Fig. 2). Thus, such collisions not only negatively impact safe navigation, but also represent a risk to the survival of cetaceans.

Figure 1. Hydrofoil type of high-speed vessel, which are used for important high-speed sea routes linking remote islands with the Japanese mainland. (Photograph by H. Kato)

Figure 2. Sperm whale, a whale species with a high collision risk with hydrofoil-type super high-speed vessels. Their population in the waters around Japan has increased in recent years. (Photograph by H. Kato)

Beginning around the year 2000 in Europe, the Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS), which is based on the Bonn Convention on the Conservation of Migratory Species of Wild Animals (UNEP/CMS), was formed in response to increased concerns about collisions between large cetaceans and ships. In tandem, discussions were also initiated at the International Whaling Commission (IWC), which is the main organization for the management of cetacean stocks and whaling issues. In 2008, at the 60th IWC Annual Meeting held in Santiago, Chile, cooperation with the International Maritime Organization (IMO) was strengthened, as proposed by the Netherlands, and this cooperation was also promoted at the 61st IWC Annual Meeting held in June 2009 in Madeira, Portugal. Under this cooperative effort, both international organizations organized the Joint IWC-ACCOBAMS Workshop on Reducing Risk of Collisions between Vessels and Cetaceans (Anon, 2010).

Against this background, this paper outlines our research project aimed at reducing risks to both ships and cetaceans against sudden collisions, particularly for large cetaceans, and discusses future directions in this field. The main sections of this paper have been taken from selected sections presented in a previous paper by Kato (2009).

2 WHY IS OUR RESEARCH PROJECT NECESSARY?

The IWC, ACCOBAMS, and IMO regard collisions between large cetaceans and super high-speed vessels as one of significant threats to the survival of cetaceans. Their main strategies for deterring such collisions are clear and simple, and involve requiring HF vessels to settle on the surface and reduce speed whenever whales appear, and establishing protection areas for whales. However, as these approaches will not always prevent collisions, additional research projects to identify more effective strategies are necessary.

Japan, which is completely surrounded by sea, has a population of approximately 130 million people. The Japanese population is predominantly concentrated in urban areas, whereas in rural and mountainous areas, extreme depopulation is occurring. The numerous islands surrounding Japan are no exception; the depopulation of the once well-developed islands will devastate them, leading to environmental damage and disturbances to the coastline, which will eventually penetrate the offshore areas. HF vessel services help limit the depopulation of the islands, as they drastically shorten the travel time between them and the mainland, making frequent travel more feasible. However, increases in the number and frequency of HF vessels on sea routes poses increased risk for collisions between vessels and cetaceans. . The main goal of our research project is to identify effective approaches for limiting the risks associated with collisions between large cetaceans and HF vessels.

3 OUTLINE AND PROGRESS OF THE RESEARCH PROJECT

In April 2006, the Maritime Bureau of the Ministry of Land, Infrastructure, Transport and Tourism established a committee for considering safety measures for HF vessels. The Laboratory for Cetacean Biology at Tokyo University of Marine Science and Technology, based on the working group established by the above-mentioned committee, began conducting research on collision avoidance by seeking the cooperation of Kawasaki Shipbuilding Corporation, a maker of Jetfoils (JF) which are the main type of hydrofoil-type HF vessels, KHI JPS Co., Ltd., which is in charge of HF vessel maintenance, and several additional companies, such as Sado Kisen Co., Ltd., and Tokai Kisen Co., Ltd., which operate JF services.

A number of HF vessels are equipped with underwater speakers (UWS) that emit sound waves with the aim of repelling cetaceans. However, whales (86 species in total; 14 species within the suborder Mysticeti and 72 species within the suborder Odontoceti, as recognized by the Scientific Committee of the IWC in 2010) differ markedly in their acoustic characteristics depending on the species, particularly between baleen whales, which are highly adapted to the ocean, and toothed whales, which have retained numerous traits from their terrestrial mammal ancestors (Fig. 3).

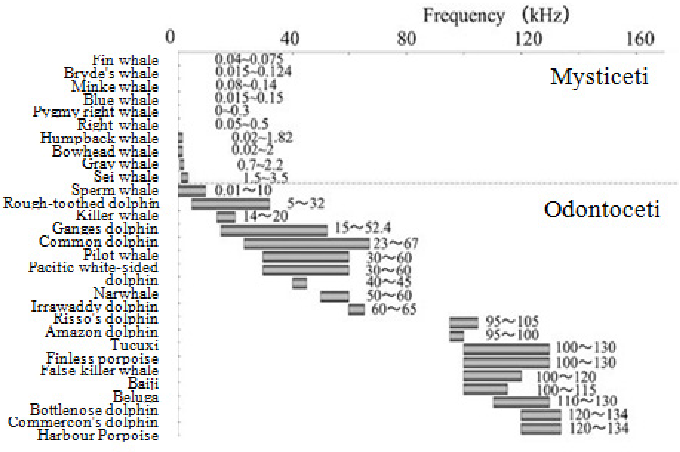

Figure. 3 Differences in the sonar frequency bands of cetacean species grouped at the sub-order level of taxon. Cited literature for sonar frequencies: Mysticeti (baleen whales), Au, 2000; Odontoceti (toothed whales), Backus and Schevill, 1966.

Due to the large variations in sonar frequency bands among cetaceans, questions remain concerning the efficacy of the currently used UWS. It is also not clear what type of sound each whale species can hear, particularly by large cetacean species, which are difficult to keep in captivity. However, working on the assumption that cetaceans are capable of hearing calls of their fellow whales, we propose identifying the hearing range of high-collision-risk cetacean species using a novel method.

To this end, the following two sub-projects have been established:

1 Clarify which whale species are found near shipping routes and determine their seasonal variations to identify whale species that have a high collision risk, and then reflect their unique acoustic characteristics in UWS. To achieve this goal, we have initiated the following sub-projects.
   - Analysis of visual data typically collected by ship crews in service
   - Visual surveys to determine whale species by whale specialists
   - Improvement in the accuracy of typical visual data collection by visual training of ship crews to identify whale species
   - Improvement in the identification accuracy of cetacean species and detection ability through the introduction of high-definition video cameras. Identify whale species with a high collision risk based on surveys of whale body size and the above research results, and then modify the sounds generated by UWS for each route and season

2 Conduct acoustic surveys using novel approaches, with the aim of estimating the audible range of whale species with a high collision risk.
   - Estimations using an anatomical approach of the inner ear
   - Estimations from correlations with vocal characteristics
   - Further improvement of the sounds generated by UWS based on the above findings

With regards to sub-project (1), significant progress has been made, and the results have been compiled in two Master's theses submitted to Graduate School, Tokyo University of Marine Science and Technology (Odagawa, 2007; Shakata, 2008).

In addition to the analyses presented in these two theses, we collected further survey data until 2010. Through analyses of visual data typically collected and data from specialized cetacean sightings on the major HF vessel sea routes from Tokyo to Okada on Izu-Ohsima Island and from Niigata to Ryotsu on Sado Island (Fig. 4), we were able to identify the high-risk species and their peak season for predicting the most probable months for collisions (Table 1).

Table 1. High-risk cetacean species involved in collisions with HF vessels and their peak season associated with selected sea routes.

Sea route	Critical species	Season
Tokyo – Okada (Izu-Ohshima Island)	Sperm whale (*Physeter Macrocephalus*)	Year round with peak in Oct.-Dec
	Baird's beaked whale (*Berardius bairdii)*	May-Aug.
Niigata – Ryotsu (Sado Island)	Minke whale *(Balaenoptera acutorostrata*)	Year round with peak in Apr.-May

Table 2. Estimated vocal frequencies for sperm and Bryde's whales based on vocalizations collected from field surveys using a hydrophone (from Yamada et al., 2011).

Survey location	Species	Vocal frequency (kHz)
Tosa Bay	Bryde's whale (*Balaenoptera edeni*), Mysticeti (baleen whales)	0.15-0.40
Bonin Island	Sperm whale (*Physeter macrocephalus*) Odontoceti (toothed whales)	1.90-4.80

With respect to sub-project (2), we have been conducting field surveys for the collection of natural vocalizations of several large cetaceans. The results of this work are described in the report by Yamada *et al.* (2011), submitted to the same volume as the separate dedicated paper.

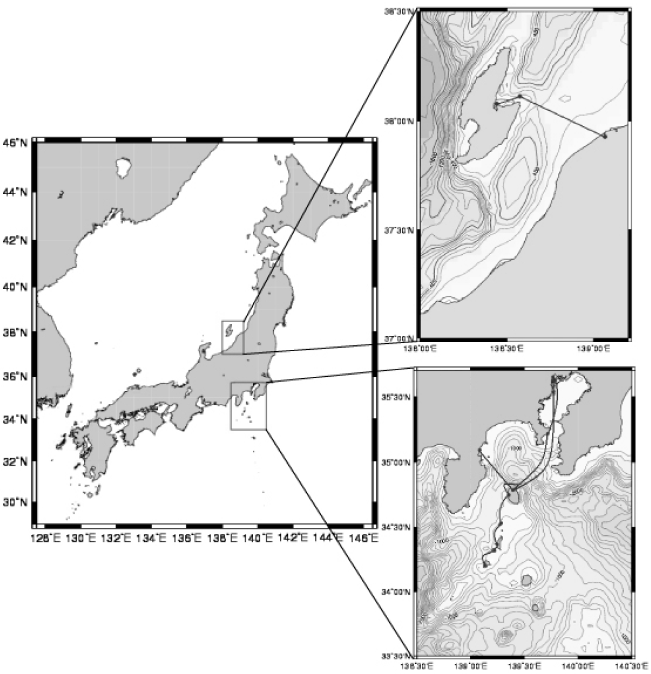

Figure 4. Map showing the two major HF vessel sea routes for Tokyo - Izu Ohshima Island (bottom right) and Niigata - Sado Island (top right).

Due to logistical limitations to access large cetaceans, we prioritized two field sites to collect vocalizations from Bryde's whales (*Balaenoptera edeni*) and sperm whales, which were located in the neritic waters off Kochi (Tosa Bay; approx. 33N–133E) and in the waters off the southern coast of Chichijima Island (Bonin Islands; 27N-142.2E), respectively, which are promising locations to access these cetacean species. As reported in Yamada *et al*. (2011), the observed ranges of vocal frequencies were 1.90-4.80 kHz and 0.15-0.40 kHz for sperm and Bryde's whales, respectively (Table 2). As both upper values for the vocal frequencies of the two species are higher than the reported values presented in Fig. 1, this finding may allow the signals emitted by UWS to be modified for increased efficacy.

Although vocal frequencies provide indirect evidence of the audible (frequency) range, more direct measurements clearly represent a more suitable approach in the context of UWS. Yamada *et al*. (2011) also reported the predicted audible range for several large cetaceans determined using an anatomical approach of the inner ear: 0.12-15.00 kHz and 0.11-31.10 kHz for the common minke and Baird's beaked whale, respectively (Table 3). Due to differences in the species examined, the values estimated using this approach cannot be directly compared to those of the vocal frequency estimated in the field surveys. However, as similarities in vocal characteristics are generally expected among related taxon groups (Fig. 1), comparisons among Balaenoptera species (common minke whale - Bryde's whales) would appear to be valid.

Table 3. Predicted audible ranges for the common minke and Baird's beaked whales based on anatomical approaches using the inner ear (from Yamada et al., 2011).

Sampling location	Species	Predicted frequency (kHz)
Off Ishinomaki, Miyagi, Japan (Pacific coast)	Common minke whale *(Balaenoptera acutorostrata)* Mysticeti (baleen whales)	0.12 - 15.93
Off Wadaura Chiba, Japan (Pacific coast)	Baird's beaked whale *(Berardius bairdii)*, Odontoceti (toothed whales)	0.27 - 33.09

From the reported literature, it was confirmed that the audible range is wider than that of the vocal frequency range, indicating that cetaceans can hear sounds of higher frequency than of their own vocalizations, at least among Balaenoptera cetaceans and also likely among Mysticeti cetaceans. Although the obtained evidence is not strong enough to reach a firm conclusion, this nature of cetaceans (i.e, audible range > vocal frequency range) is likely also true among Odontoceti species, as determined from the comparison between the vocal frequency of sperm whales and the audible range of Baird's beaked whale. As a further step for reducing risk of collisions between HF and cetaceans, this rationale can be implied for the improvement of UWS.

4 SHORT-TERM PROPOSAL FOR IMPROVEMENT OF UWS

To minimize risks for both HF vessels and cetaceans, we are presently preparing interim proposals for improving specifications of UWS by taking into account the results of the present project; these improvements are ongoing and are halfway complete.

First, it is necessary to adjust the sounds generated by UWS using appropriate acoustic specifications of the high-risk cetacean species for which sudden collisions are to be avoided. We have already identified the critical cetacean species to be sperm whales and Bride's whales in the Tokyo-Izu-Ohshima sea route, and common minke whales in the Niigata-Ryotsu sea route. For the seas routes in other localities, identification of the critical species through cetacean sighting surveys is an essential first step.

For the improvement of UWS, it is of critical importance to identify the most effective sound frequency to repel the critical cetaceans. In this regard, Yamada *et al*. (2011) suggested that existing UWS (operating at 6-20 kHz) should be modified to produce frequencies less than 15 kHz for common minke whales, less than 0.4 kHz for Bryde's whales, and less than 4.8 kHz for middle to large-toothed whales, such as sperm whales. However, it is unknown whether such modification is technically feasible, or if installation of the necessary hardware is realistic. Therefore, more investigations are needed to better estimate the audible range for critical cetacean species, and to determine the required technical and mechanical improvements of UWS. Particularly, an increased number of anatomical inner ear samples is expected to help clarify the audible range and effective frequency for deterring high-collision-risk cetacean species.

5 FUTURE CHALLENGES AND POTENTIAL APPLICATIONS

In the course of our investigations and research for the improvement of UWS, specific challenges for future research have been identified. We previously attempted to introduce high-definition cameras to improve the accuracy of identifying whale species, but a new technique for obtaining high-quality images has emerged that might contribute to the early detection of whales, as well as allow the more accurate identification of cetacean species.

In a potential application utilizing this imaging technique, we are considering constructing a system that recognizes a whale's unique blow in an image to warn of the approach of high-collision-risk cetacean species at an early stage by sounding an alarm by UWS. We have already initiated the implementation of such a system, as outlined in a pilot study by Yonehara *et al*. (2011). Although some collisions are inevitable, considering the user friendliness of current HF vessels and the high ability of crew members to steer and maneuver ships, we believe that if an approaching cetacean is detected in advance, the frequency of collisions with large cetaceans can be drastically reduced.

The positions of the HF vessel manufacturers and operating companies regarding this issue have been very positive, and further efforts are being made in the pursuit of greater safety for both passengers and cetaceans.

ACKNOWLEDGEMENTS

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