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SAKAMATA:
THE IDEAS AND ALGORITHMS BEHIND IT

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World-wide a concern exists about the influence of man-made noise, and particularly of high power sonar, on marine life and divers in the sea. Most concern lies with marine mammals that use acoustics for hunting, communication and/or navigation. This concern is fed by recent strandings of whales that could be related to military sonar transmissions and seismic explorations. Especially sonars that use audible frequencies seem to be harmful for these mammals. However, little is known about the exact influence of active sonar on marine mammals and therefore many countries apply the precautionary principle. In practice this means that mitigation measures are defined for the use of active sonars:

- *careful planning of sonar operations,*
- *monitoring of marine mammals in best possible way before using the sonar,*
- *ramp-up schemes to scare marine life away, before using high power.*

The implementation of mitigation measures is no sinecure. Background knowledge (presence of mammal species and their hearing sensitivity and behaviour, acoustic conditions) is often lacking. Therefore historical and in situ information must be used to implement the measures in an effective way. A software tool can support these mitigation measures. TNO-FEL developed the tool SAKAMATA that supports all described mitigation measures. This article focuses on the ideas and algorithms applied in this tool.

1. INTRODUCTION

World wide a concern is emerging about the effects of anthropogenic (man-made) noise in the marine environment. In particularly high power sonars and airguns can have impact on marine life. At present most concern lies with marine mammals, i.e. cetaceans (whales and dolphins) and pinnipeds (seals, etc.), but also an increasing interest in effects on fish arises. The concerns are fed by recent strandings of whales that could be related to military sonar transmissions and signals generated during seismic surveys.

2. THE PROBLEM

Marine mammals spend most of their live submerged and they fully depend on sound in their natural behaviour (foraging, navigation and communication). Therefore most marine mammals have good hearing sensitivity, and may be vulnerable to high levels of anthropogenic noise. The effects of sounds on the marine mammals may vary between 'audible', via 'change in behaviour' and 'severe disturbance' up till 'hearing injury/death'. However, precise knowledge on acoustic disturbance and/or injury of marine mammals is still very limited, and the same holds for the detailed information on the marine mammal hearing sensitivity (especially for the large whales). This is due to the fact that only a few species can be studied in captivity while the remainder can only be studied at sea.

Fig.1: A stranded juvenile fin whale, found in Normandy by W.C. Verboom (photo by M. Verboom).

3. MITIGATION MEASURES (THE SOLUTION?)

Since little is known about the exact influence of anthropogenic sound on marine mammals many governments and organisation apply the *precautionary principle*. In practice this means that the following three mitigation measures are commonly applied:

- careful mission planning of sonar operations;
- monitoring of marine mammals in the best possible way before the use of active sonars;
- ramp-up schemes to scare marine life away, before using high sound intensities.

None of these mitigation measures are easy to implement. They require knowledge that is far beyond the scope of an average sonar operator. Therefore at TNO-FEL software is developed to assist the operator in implementation of the above mitigation measures. The following subsections describe the support that the tool can give. The tool is called SAKAMATA (Japanese for Orca) which is an abbreviation of Sea Animal Kind Adaptive Mitigated Active Transmission Aid. SAKAMATA is a commercially available tool that can be adapted to your specific wishes and nation's legislation.

3.1. Careful mission planning of sonar operations

Before planning a mission in which an active sonar is operated, it needs to be verified whether the area is inhabited by marine mammals in that season. This verification procedure is supported by an inspection of a database that stores the habitats of all marine mammals. In addition one can inspect mammal observation loggings of that area and also mammal strandings. Within SAKAMATA several maps can be included of operation areas. One click on a specific area will show a complete list of possibly present marine mammals. By means of selecting the season mammal migration is taken into account.

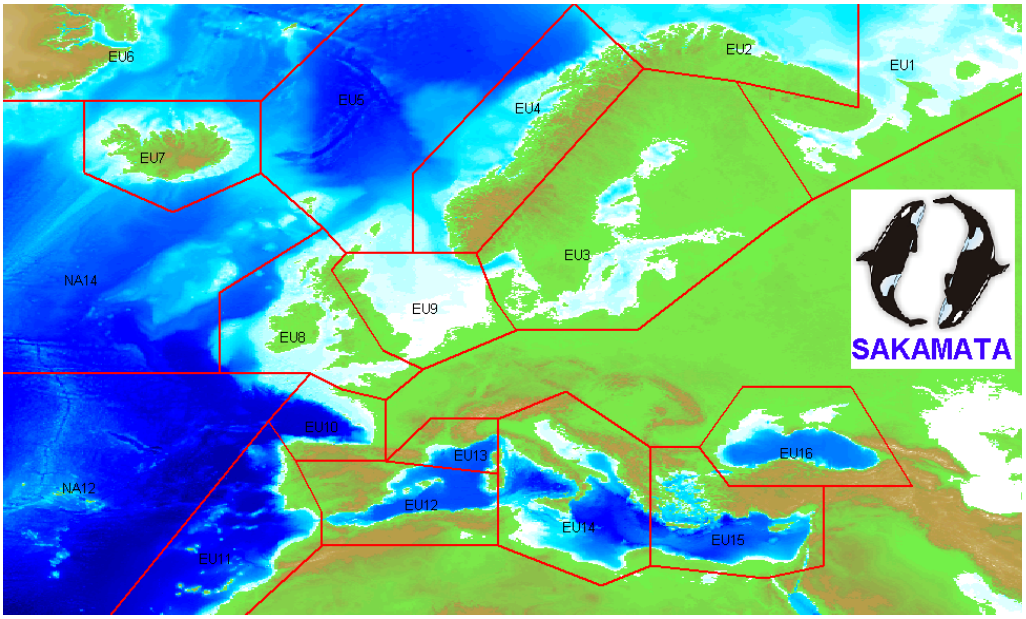

Fig.2: Example of a map including predefined areas.

3.2. Monitoring of marine mammals before active sonar use

Not using the active sonar when marine mammals are present is a very efficient mitigation measure. Therefore in situ monitoring should support the careful mission planning. SAKAMATA supports the user with the audio-visual monitoring process by means of a mammal database. Visual monitoring is supported by pictures of (half-submerged) mammals, and a description including useful hints on how to detect and classify mammals (e.g. diving pattern, blows). Since visual monitoring is only possible during daytime and only mammals near the surface can be detected, additional acoustic monitoring is also necessary. Furthermore, typical mammal sounds and an advanced audio player that produces audiograms (see Fig.3) is available to support the audio monitoring. Within the description of a mammal also the frequency bands the mammals uses are described. Audio monitoring can for example be done by using a passive sonar or the underwater telephone, but not all mammals can be detected since they not all produce sounds themselves. New studies are looking at multi-sensor mammal detection using radar and infra-red in addition to acoustic monitoring.

3.3. Ramp-up scheme design

When no mammal is detected in the close vicinity, the sonar can be started safely using a ramp-up scheme. These ramp-up schemes are specially designed sound transmission procedures to warn possibly unobserved mammals in the area. When the sonar produces an annoying sound, it is assumed that the warned mammals will swim away from the sonar and try to escape before the required higher sound intensities are transmitted. In the ramp-up scheme the sound level is slowly raised, such that the received sound level is kept to an acceptable value and protects the mammals for ear damage. A well designed ramp-up scheme takes into account:

- transmitter sound specification (source level, pulse duration and duty cycle);
- in situ acoustic environmental conditions;
- hearing sensitivity and reaction behaviour of mammals possibly present.

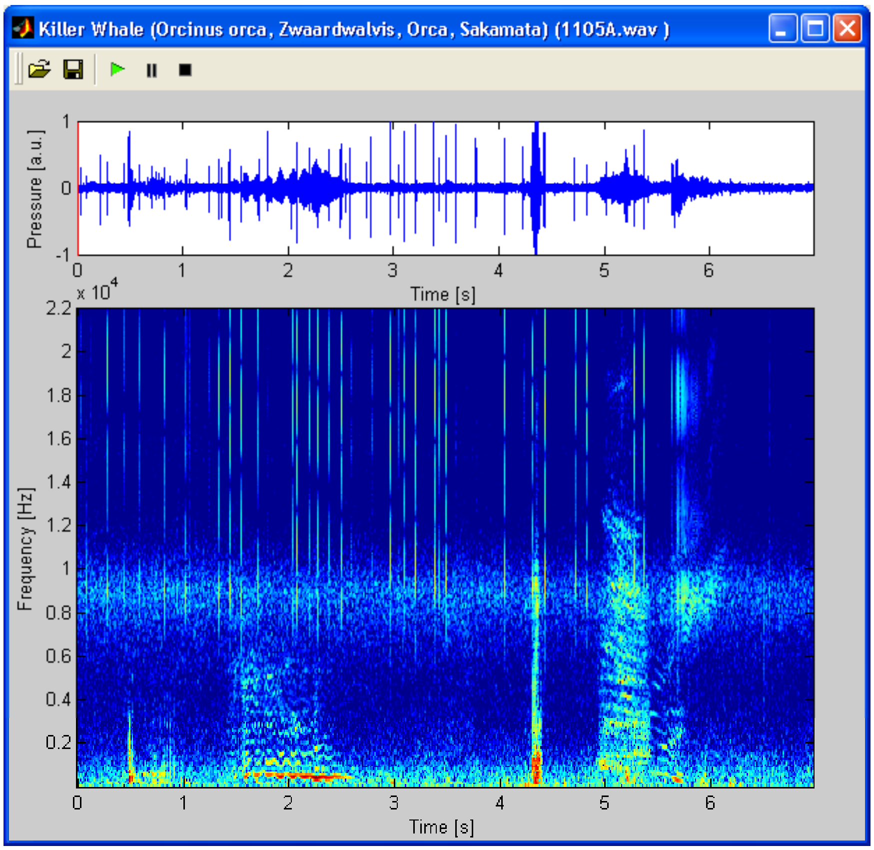

Fig.3 Audiogram of sounds produced by an Orca.

The most important information for calculating the ramp-up scheme is the hearing sensitivity and behaviour (escape speed) of the marine mammals. Each marine mammal has its own hearing sensitivity, but several groups of mammals can be identified that have similar hearing sensitivity [1]. For each group of marine mammals a pessimistic estimation of the Temporary Threshold Shift (TTS) curve is determined, on which Maximum Allowable Exposure Levels (MAEL) have been based. These curves are plotted in Fig.4.

The curves are extrapolations of the human ear (a well studied mammal) sensitivity and related to the estimated dynamic hearing range [1]. The curves are validated for the harbour porpoises and seals by means of measurements on captive animals [2][3]. Beside the hearing sensitivity, also the behaviour of the mammal is very important. At first the mammal needs to be able to estimate the direction of the transmitted sound and needs to know how to escape from the transmitter. At the moment little is known about the behaviour of the mammals that try to escape from a transmitter. Such studies are highly needed, as they are essential for judging the success of using ramp-up schemes.

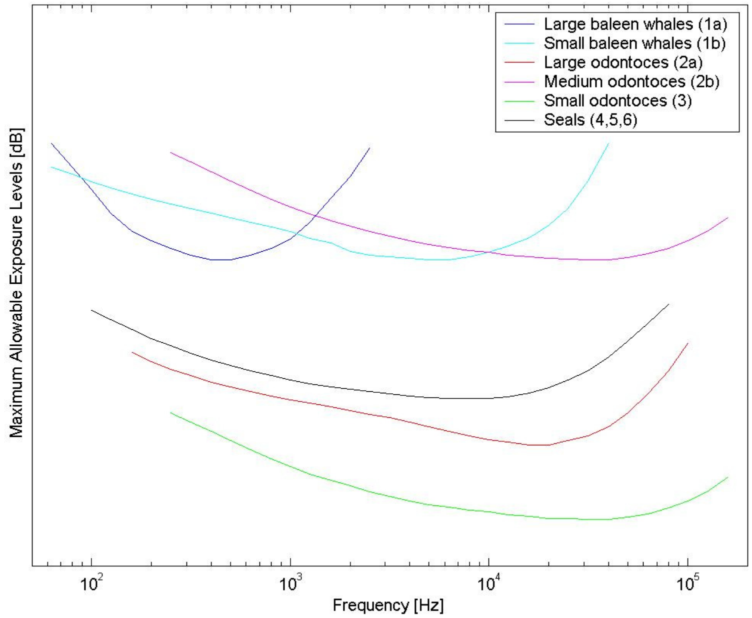

Fig.4 Maximum Allowable Exposure Levels, based on hearing sensitivity curves, according to Verboom [1].

Also the environment plays a major role in how the transmitted sound is observed by the mammal. The propagation loss depends on the sound speed profile, water depth, and bottom type. Within SAKAMATA, the ALMOST (Acoustic Loss Model for Operational Studies and Tasks) model (developed by TNO-FEL and in operational use throughout the Royal Netherlands Navy) is used for the calculation of the propagation loss as a function of range and depth.

The following calculation method is used to find the optimal ramp-up scheme:

- In the selected area all mammals are determined that can be present.
- For each group of mammals *g* that is present, the escape swim speed *V(g)* of the slowest mammal species is determined and the Maximum Allowable Exposure Level *MAEL(g)* for the used transmitter frequency is derived from the hearing sensitivity curves. Alternatively a fixed level can be used (e.g. 180 dB as is required in the US legislation).
- The propagation loss *PL(r,d)* is calculated as a function of the range *r* and depth *d* where mammals can be present for the given transmitter settings.
- For safety reasons, the minimum (over all possible mammal depth) propagation loss is derived as a function of the range *PL(r)*.
- A specific ramp-up scheme is determined for each group *g* of mammals based on the *PL(r)*, *V(g)* and *MAEL(g)*.
- Finally, the most pessimistic ramp-up scheme is determined out of the ramp-up for each group.

Note that within this calculation the escape speed is determined as ¾ of the maximum swim speed. The maximum allowed exposure level *MAEL* is defined as the *TTS – 15 or 20* dB (dependent on hearing group). The *MAEL* is corrected for the Pulse Duration (*PD*) and Pulse Repetition Time (*PRT*) with the following formula:

$$MAEL = TSS - 15 - 5 * {}^{10}\log(PD) - {}^{10}\log(10*PD/PRT)$$

As an example the calculated ramp-up scheme for a Low Frequency Active Sonar (1-2 kHz) is shown in Fig.5

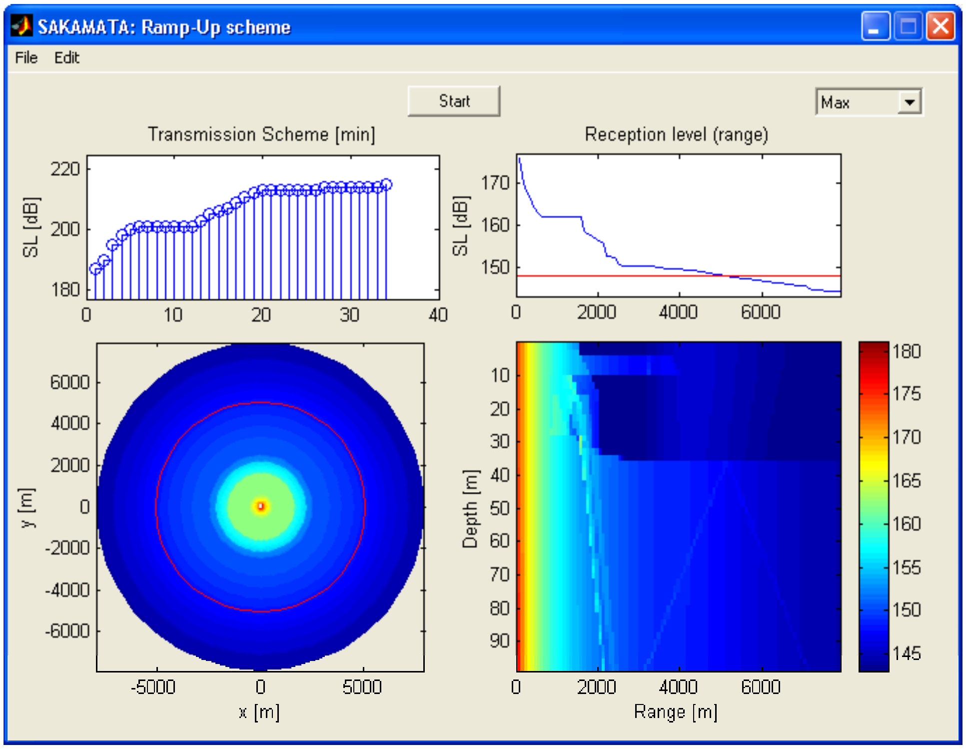

Fig.5 An example of the ramp-up scheme calculation output of the SAKAMATA tool

4. CONCLUSIONS

It can be concluded that careful use of active sonar is required and will prevent severe disturbance of the marine mammals. The mitigation measures are complex and the use of a dedicated tool, that combines all available knowledge about the marine mammals and their behaviour is recommended. SAKAMATA is such a tool that can facilitate the sonar operator to use their sonar carefully. For future improvement of the tool, studies need to be carried out to gather more knowledge about marine mammals and their behaviour and reactions on sonar sounds.

REFERENCES

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