Geophysica (2004), 40(1-2), 23-38

Measurements and Descriptions of Underwater Noise in Finland

Jukka Seppänen[1] *and Mika Nieminen*[2]

[1]Department of Biological and Environmental Science, University of Jyväskylä, Finland
[2]Department of Environmental Engineering, Tampere Polytechnic, Finland

(Received: September 2004; Accepted: November 2004)

Abstract

Underwater noise was measured with two hydrophones and an investigator just inshore Lake Jyväsjärvi, the northernmost part of Lake Päijänne in Finland. Lake Jyväsjärvi is an urban lake with heavy boat and cruising vessel traffic in summer times.

By nature this research is multidisciplinary: In addition to the perspective of physical acoustics, the perspectives of acoustic ecology and psychoacoustics were also taken into account. Therefore Finnish divers were asked to describe the nature of underwater sounds and soundscapes.

According to the divers, the most common sound in Finnish waters was the noise of motor vessels, i.e. ships and motorboats. Inshore Lake Jyväsjärvi, 50 - 100 meters from the waterway, biggest underwater noise levels during vessel traffic were 120 - 140 dB (linear SPL, re 1 μPa). In the measurements most of the sound energy produced by motorboats was centered to frequencies 1-5 kHz, and the noise of motorboats was described as buzzing or whirring. The sound energy produced by steamers was mainly centered at low frequencies. According to the divers, the noise of motor ships was like rumbling and roaring.

Most divers considered the technogenic noise as noxious and often frightful. Some very weak natural sounds made by physical phenomena like waves and raindrops were heard in Finnish waters, too, and the silence was considered as the most pleasing underwater soundscape.

Key words: underwater noise, diving, soundscape, Lake Päijänne

1. Silent and not so silent underwater soundscapes

After publishing the first colored underwater photographs in National Geographic Magazine in 1952, Captain Jacques Cousteau wrote his famous book ‘The Silent World’ one year after. As the title of Cousteau’s book, so is the common belief about the underwater world as a silent and tranquil place. However, the underwater world is silent only from the human point of view: The frequency-dependent hearing threshold of human ears in underwater conditions is relatively high, 84-100 dB, when referenced to 1 μPa (*Brandt and Hollien*, 1967).

The underwater noise is not a significant part of the human world, and therefore studies dealing with the acoustic environments of the underwater world have not been started until recently. Many species living in the water are quite sensitive against noise and many of them are able to hear sounds that are impossible to hear with human ears. The visibility is usually very

Published by the Geophysical Society of Finland, Helsinki

limited in the aquatic environments and therefore production of sounds and hearing of them are important for underwater species to sense the surroundings (*Nowak*, 2003; *Scholik and Yan*, 2001).

The objective of this article is to introduce some of the basics of underwater acoustics. After that, an introductory case study of noise levels in Finnish lakes is introduced.

2. Introduction to underwater acoustics

Sound travels through the water better than any other form of radiation known to man (*Gordon and Tyack*, 2001; *Urick*, 1975). Differences between air and water can be explained e.g. with the help of the specific acoustic impedance, which in the water is about 3500 times greater than in the air. The specific acoustic impedance, or resistance, is defined with the equation

$$Z = \rho c \tag{1}$$

where ρ [*kg/m*^{3}] is the density of the medium and c [*m/s*] the speed of sound in the medium.

The Snell's Law is applicable also for the sound rays, i.e. the sound ray that reflects from the surface has the same angle of reflection with respect to the surface's perpendicular as the angle of incidence. If the angle of incidence is bigger than the boundary angle of the total reflection, no sound goes through the surface, and when the angle is smaller, a part of the sound signal propagates the interface and refracts, depending on the change in velocity (*Backman*, 2001). Another part is reflected and the reflection coefficient at an interface of two media, R_{12} (e.g. from water to air) can be calculated with the equation

$$R_{12} = \frac{Z_2 \cos\theta_1 - Z_1 \cos\theta_2}{Z_2 \cos\theta_1 + Z_1 \cos\theta_2} \tag{2}$$

where θ_1 means the angle of incidence with respect to perpendicular of the surface (Snell's law), θ_2 means the angle of departure with respect to perpendicular of the surface (Snell's law) and Z means the specific acoustic impedance (eq. 1). Because of the big acoustic impedance of water ($Z_{water} >> Z_{air}$), we cannot hear the underwater sounds above the surface (*Medwin and Clay*, 1998).

The speed of sound in water is affected by temperature, depth and salinity. The speed of sound in water can be calculated with an empirical equation (*Urick*, 1975; *Pickard and Emery*, 1990)

$$c = 1449 + 4.6t - 0.055t^2 + 1.4(S - 35) + 0.017D \tag{3}$$

where c [*m/s*] means the speed of sound, t [*°C*] temperature, S [*PSU*] salinity and D [*m*] depth. The speed of sound in water is about 4.5 times greater than in the air. In addition, wavelength of sound in water is also about 4.5 times greater as the wavelength of an equifrequent sound in the air. The relation between frequency and wavelength can be seen in the basic equation below.

$$\lambda = \frac{c}{f} \tag{4}$$

When measuring the underwater sound levels, the commonly used reference sound level is 1 μPa, whereas the reference sound level in the air is 20 μPa. Therefore decibel values are always bigger under water, which is often forgotten, when the sound pressure levels in the water and in the air are compared. In addition, people often compare too straightforwardly the perception of loudness from their own point of view, without taking into account the obvious differences in the sense of hearing between aquatic species and humans. (*Gordon and Tyack*, 2001). Technically the conversion from the air reference level to the underwater reference level can simply be calculated:

$$20\log(\frac{p_{air}}{p_{water}}) = 20\log(\frac{20\mu Pa}{1\mu Pa}) = 26dB \tag{5}$$

The speed of sound becomes faster as temperature and pressure increase. The consequence of this is the formation of the deep sound channels in the oceans, also called the sound fixing and ranging channel (SOFAR). The speed of sound decreases as it travels from the sun heated surface deeper into the ocean. The temperature of the deep water stays fairly constant, but the increasing pressure increases also the speed of sound. Changes in pressure and temperature force the sound rays to bounce back and forth, between depths of 0.5 and 1.5 km. Thus, the sound can travel long distances in the deep sound channels, without losing much of its energy (*Urick*, 1975).

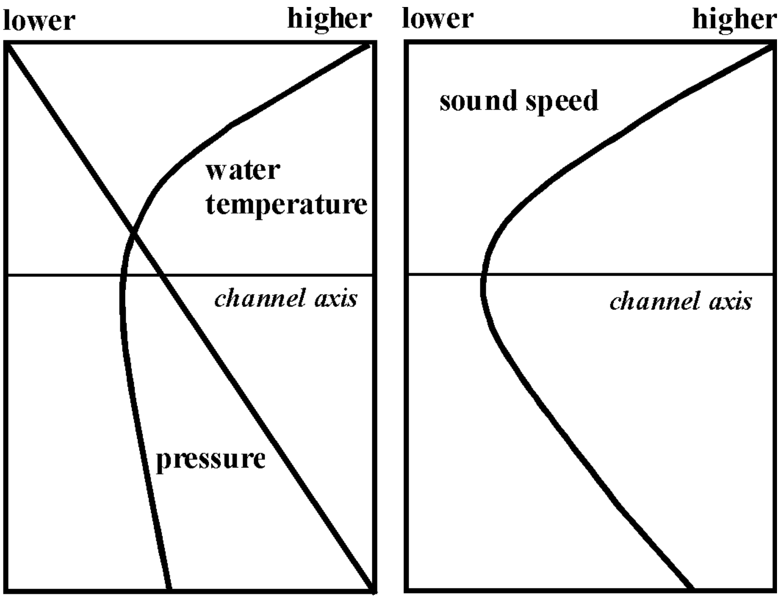

Fig. 1. The effect of water temperature and pressure to the speed of sound. The sound waves are bent towards the depth of minimum velocity (channel axis at the depth of about 1 km). This happens when the sound wave propagates from acoustically denser substance to less dense (Snell's law). A loud voice can travel thousands of kilometres in the deep sound channel.

Finland is bordering the Baltic Sea, which is a relatively shallow inland sea with the mean depth of only 55 meters and the maximum depth of 459 meters. Therefore, the real deep sound channeling does not occur in Finnish waters.

Passive sonar equations can be used when describing underwater hearing and when assessing whether a receiver can get the message or not. If the source level (*SL,* i.e. dB-level at the distance of 1 meter) is known or can be measured, the received level (*RL*) is

$$RL = SL - TL' \tag{6}$$

where *TL'* stands for attenuation. In addition to geometric attenuation, *TL'* also describes signal losses caused by surface and bottom sediments. The signal has to be more powerful for the receiver than the background noise level (*NL*). The difference between the ambient noise level and signal can be described with signal to noise ratio (*SNR*).

$$SNR = RL - NL \tag{7}$$

In order to detect the signal, it has to exceed the detection threshold (*DT*), i.e. hearing threshold (*Urick*, 1975; *Gordon and Tyack*, 2001). Also active sonar equations can be used in addition to passive sonar equations, if the question is about reflecting the echo back to the source, i.e. *TL'* has to be doubled and, for instance, information about the target's reflective characteristics is required (*Urick*, 1975).

3. Underwater sounds and their impacts

3.1 Natural underwater sounds

Underwater sounds can be divided into natural and anthropogenic sounds. Different physical phenomena and living organisms are the sources of various kinds of background noise in the aquatic ecosystems. The most important physical source of underwater noise is wind (20-80 dB depending on the swelling of the sea). The frequency range of the so called Knudsen wind noise is 0.5-20 kHz and it is caused by breaking whitecaps, which produce tiny air bubbles into water. These kind of air bubbles collapse fast and at the same time they make a short pulse of sound (*Urick*, 1975). Near the surface, middle sized raindrops can cause the sound level of 60-70 dB. During a heavy rain, big drops or hailstones battering the surface, can cause the sound level of 85 dB. The frequency range of the sounds of rain is 20 Hz-100 kHz, which is relatively wide. The aquatic environment is also full of occasional sounds (*Medwin et al.*, 1992; *Tyack* 1998). The natural background noise in the seas has been estimated to be about 50-70 dB at 100 Hz. (*Evans and Würsig*, 2001).

In aquatic fauna many species produce sounds for different purposes. All marine mammals use sounds when communicating with each others and many species can listen or even produce sounds used in hunting and echolocating. Usually the communication sounds are lower and more powerful than sounds related to echolocation. (*Evans and Würsig*, 2001; *Gordon and Tyack*, 2001). Some fish species produce mating call sounds and some are noisy when eating.

The major part of the background sounds in the warm seas is produced by clicking and snapping shrimps, lobsters and mussels (frequency range 2-15 kHz) (*Tyack*, 1998; Urick, 1983).

3.2 Auditory senses of marine mammals and fishes

Fishes and many marine mammals do not have external or middle ears, because in the underwater conditions it is not necessary to collect the sound waves and external ears would cause extra hydrodynamic friction. The density of the bodies of the underwater species is very close to the density of water. Therefore, the pressure differences are transmitted almost without any losses through the tissues and bones (*Gordon and Tyack*, 2001).

Marine mammals and especially small toothed whales are the best hearers in the aquatic ecosystems. Mammal species living in Finnish waters are grey and ringed seals (ringed seal also in Lake Saimaa, the largest lake of Finland) and sometimes visiting harbour porpoises. Seals have a well-developed sense of hearing in the water, with the greatest sensitivity between 3-50 kHz (hearing threshold about 60-70 dB), and on contrary to humans, their hearing ability is greatly reduced in the air. Many toothed whales have the most sensitive hearing at high frequencies, e.g. harbour porpoises at 100 kHz, with hearing threshold about 30 dB. (*Evans and Würsig*, 2001; *Madsen and Payne*, 2003; *Henriksen et al.* 2004; *Kastak and Schusterman*, 1999).

On the grounds of the hearing ability, fishes can be classified into *hearing specialists* (e.g. roach) or *hearing generalists* (e.g. pike). Hearing generalists cannot hear sounds over 1-2 kHz and their hearing threshold is 80-120 dB. Hearing specialists can hear 2-4 kHz or even higher sounds and their hearing threshold is 60-80 dB. In addition, fishes sense with their lateral line, which they can use in sensing low frequency sounds. (*Hawkins and Myrberg*, 1983).

3.3 Water traffic and other anthropogenic noise

Water traffic is the most significant source of underwater noise. All vessels from sailing ships to rowboats cause at least hydrodynamic friction noise, which is caused by the friction between the hull and water. However, it is not significant when comparing it to the noise of the power-driven vessels (*Urick*, 1975; *Eloheimo*, 1992). A significant amount of noise is caused by cavitation. Cavitation generates small air bubbles due to the momentary low pressure in the propeller blades and it is the main source of noise in large vessels. Instantaneous low pressure makes the water to boil, and the bubbles produce short and loud broadband high frequency sounds (*Urick*, 1975). In power-driven vessels noise is also caused, e.g., by the engine, vibration of the hull, rotation of the axels and propellers, steering gear, and in small boat also by exhaust gas bubbles.

In addition to these, the echo sounding causes noise, which cannot be heard by human ears (*Urick*, 1975; *Eloheimo*, 1992). Some doubts of the harmful impacts of the echo sounding have also been presented in Finland, e.g. the spawn of some fishes are rumoured to become difficult in Lake Rautavesi (more precise, see: *Mustonen and Nieminen*, 2004). Studies about the impacts of echo sounding on spawn have not been made in Finland, although echo sounders for recreational fishermen are in wide commercial use.

The noise caused by the water traffic is affecting more the underwater life than the human life. It is inevitable that animals are affected by the man-made sounds. Disturbing sounds can cause e.g. behavioural changes, temporary loss of hearing and, in addition, more powerful individual sounds and underwater explosions can cause physiological harm and even death. The use of the low-frequency active sonar system (LFAS), used by the US Navy and NATO, can generate 215 dB noise. After using the LFAS, there has been numerous strandings and deaths of whales. In further investigations of the carcasses, the whales have found to be bleeding internally around their brains and ears (*Protecting Whales from Dangerous Sonar*, 2004; *Marine Mammals and Low Frequency Active Sonar* (LFAS), 2004).

The underwater ambient sound levels in California have increased about 10 dB within the frequency range of 20-80 Hz, during the last 30-35 years (*Andrew et al.*, 2001). *Evans and Würsig* (2001) suggested that the ambient noise level in the seas has increased 10 dB between 1950 and 1975, and is about to increase 5 dB more by the end of the twentieth century. The Baltic Sea has one of the busiest shipping routes in the world and during the last decade, shipping has been increasing around it. According to HELCOM, approximately 2000 sizeable ships are at the Baltic Sea at any time (*HELCOM*, 2004). International trade shipping can also reach Lake Saimaa via the Saimaa channel, and the traffic of pleasure boats is increasing in all Finnish waters.

4. Measurements of underwater noise

4.1 Research site and methods

This case study is an introductory survey of noise levels in Finnish lakes, being centered in Lake Jyväsjärvi, the northernmost part of a large Finnish lake, Lake Päijänne. Lake Jyväsjärvi is an urban lake located in Central Finland in the heart of Jyväskylä, a town of 80 000 inhabitants. The surface area of the lake is 3.1 km^2, its mean depth is 6 m and maximum depth 24 m. Lake Jyväsjärvi is connected directly to the other parts of Lake Päijänne through the Äijälänsalmi strait (see Fig. 2).

Measurements were made in summer 2002 with hydrophones and an investigator (see table 1). Hydrophones were calibrated to the airborne reference level 20 µPa and the difference between airborne and underwater reference levels was corrected while the data was processed with software. Therefore all underwater decibel values reported here are referenced to 1 µPa.

Fig. 2. Lake Jyväsjärvi is situated in the heart of Jyväskylä. The source of the map is the website of University of Jyväskylä, *www.jyu.fi/jyvasjarvi/english*, where more information on the lake is available.

Table 1. Equipments and softwares used in the project.

Function	**Type**
investigator	Brüel&Kjaer 2260
hydrophones	Brüel&Kjaer 8101 & 8103
preamplifier	Brüel&Kjaer WH1057 (only with 8101)
calibrator	Brüel&Kjaer 4229
softwares	Brüel&Kjaer Noise Explorer 7815
	Microsoft Excel
	Corel Quattro Pro

All noise levels measured were linear values (not weighted) and equivalent for one second. Spectra were analyzed within the investigator using third bands from 16 Hz to 12.5 kHz, altogether 30 bands. Correlation analyses were made by statistical software and correlation coefficients were calculated with the following formula:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\left\{\left[n\sum x^2 - (\sum x)^2\right]\left[n\sum y^2 - (\sum y)^2\right]\right\}^{1/2}} \qquad (8)$$

4.2 Inshore underwater noise levels

Underwater noise levels were measured during calm and rainless conditions in two places inshore Lake Jyväsjärvi (from the piers near each others in Rauhalahti bay, 62°14,3’N, 25°48’E) in a total of eight vessels. All decibel values and spectra reported here were measured when the vessel was nearest and the noise was most intense. Distances to vessels, moving along the route, varied between 50 and 100 meters. Thus, results shown in this report and in the table 2 are characteristic only of the underwater noise expanded to the inshore. Due to the lack of accurate distances to vessels, source levels at one meter cannot be calculated.

Table 2. The biggest noise levels (L_{Leq}) just inshore of Lake Jyväsjärvi when the vessels were passing by the piers. NOTE! Distances to vessels varied from 50 to 100 meters.

Vessel	**SPL dB (re 1 µPa)**
outboard Yamaha 15	128.8
outboard Johnson 20	124.7
outboard Johnson 55	127.8
outboard Yamaha 100 4-stroke	139.9
fast jetboat, diesel	124.7
slow steelboat, diesel	133.2
s/s Kaima	126.1
s/s Suomi	122.7

4.3 Outboard noise

Four boats with outboard motors were measured, all of them on plane travelling at or near the maximum speed and one of them powered by a four-stroke engine (Fig. 3.). Although four-stroke engines have smoother sounds in the air, in this underwater measurement the four-stroke Yamaha 100 hp produced the loudest sounds with the total noise level (SPL) of 139.9 dB. When exhaust gas is led to water (as in all outboards measured here) the underwater noise will be louder when more exhaust gas is discharging. Therefore, the noise levels produced by much smaller two-stroke outboards were 10 and more dB’s less.

The sound energy produced by outboard motors was centred to the high frequencies (above 1 kHz) because all outboard motors have engines with high rounds per minute, underwater gearing units and fast rotating propellers.

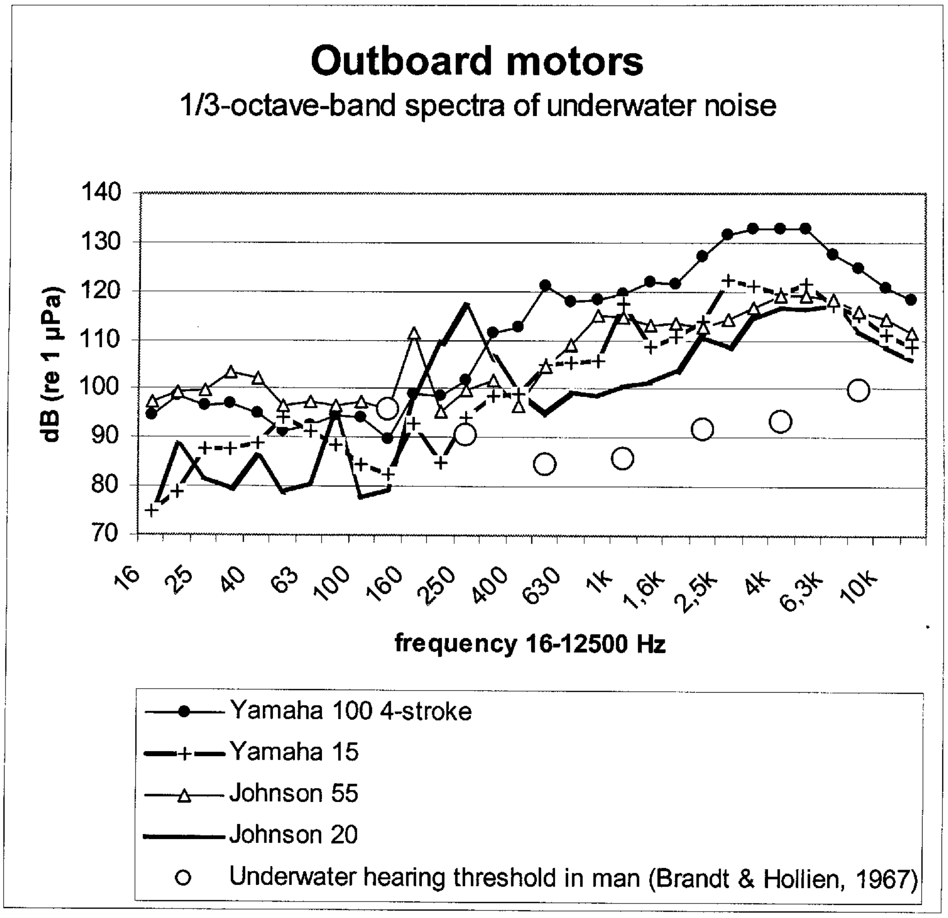

Fig. 3. The underwater sound energy produced by outboards was centered to frequencies 2.5-5 kHz, where the loudest 1/3-octave-band values were over 130 dB.

4.4 Noise of diesel boats

Two diesel-powered boats were measured, a Dutch type 10-meter long slow steel boat with propeller-propulsion and a fast 5.5-meter long aluminium boat with jet-propulsion (Fig. 4.). Although the slow steel boat was a little bit ship-like, most of the noise energy was centred to higher frequencies (1-4 kHz). The total noise level of 133.2 dB was the second highest from all the measured vessels. In higher frequencies jet-propulsion proved to be a little bit quieter, because the sound energy cannot be emitted to water as easily: There is no propeller or any gearing unit (like in outboards) below the bottom line.

Unlike the outboard motors, either of the diesel boats do not discharge exhaust gas under water. Compared to outboards, the absence of masses of vibrating exhaust gas bubbles may be the reason for weaker sounds in the lower frequencies.

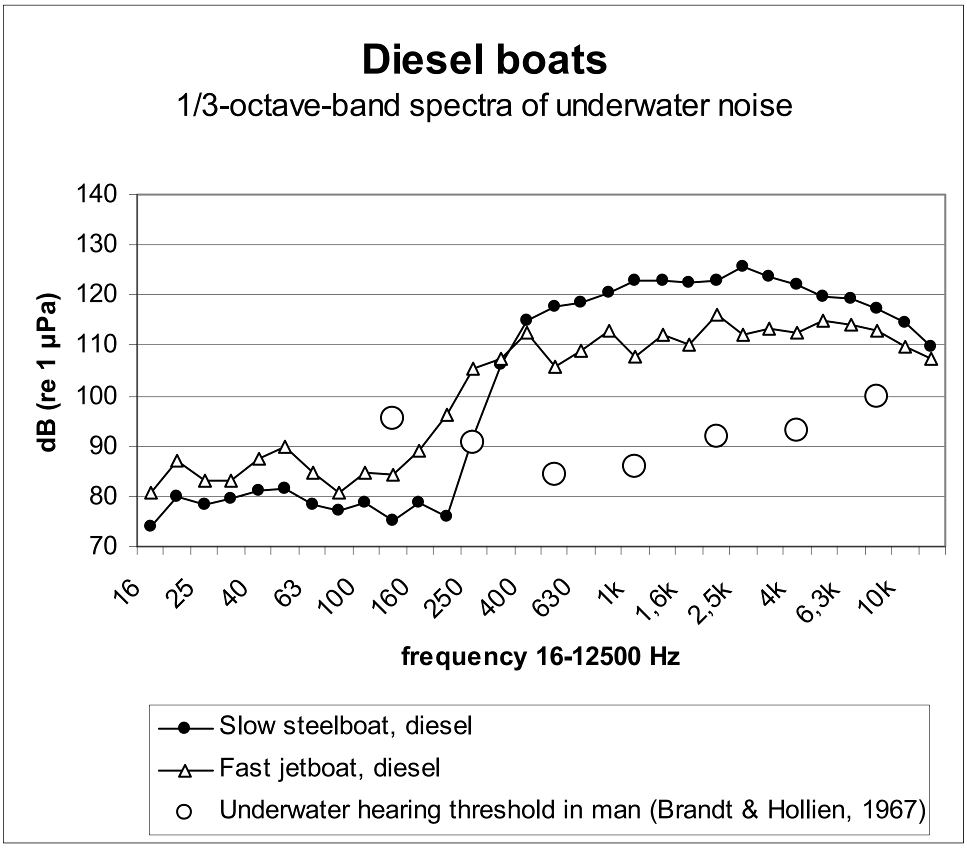

Fig. 4. Both diesel-motors had a very similar spectrum, with most of the sound energy above 300 Hz.

4.5 Steam ship sounds

Two old steamers were measured, s/s Kaima (=”Namesake”; length 21.12 m, beam 4.65 m, draught 1.8 m; 87 indicated horsepowers), built in 1898, and s/s Suomi (=”Finland”; 30.0 m x 6.4 m x 2.5 m; 200 ihp), built in 1906 (Fig. 5). Unlike all the other measured vessels, both steamers had 5-7 dB differences between the minimum and maximum dB-values (fast time weighted) inside the equivalent time of one second, maybe due to the back and forth movements of the piston in the steam engine. Compared to all motorboats, most of the sound energy was found on much lower frequencies. s/s Suomi was the quietest vessel measured with the SPL of 122.7 dB.

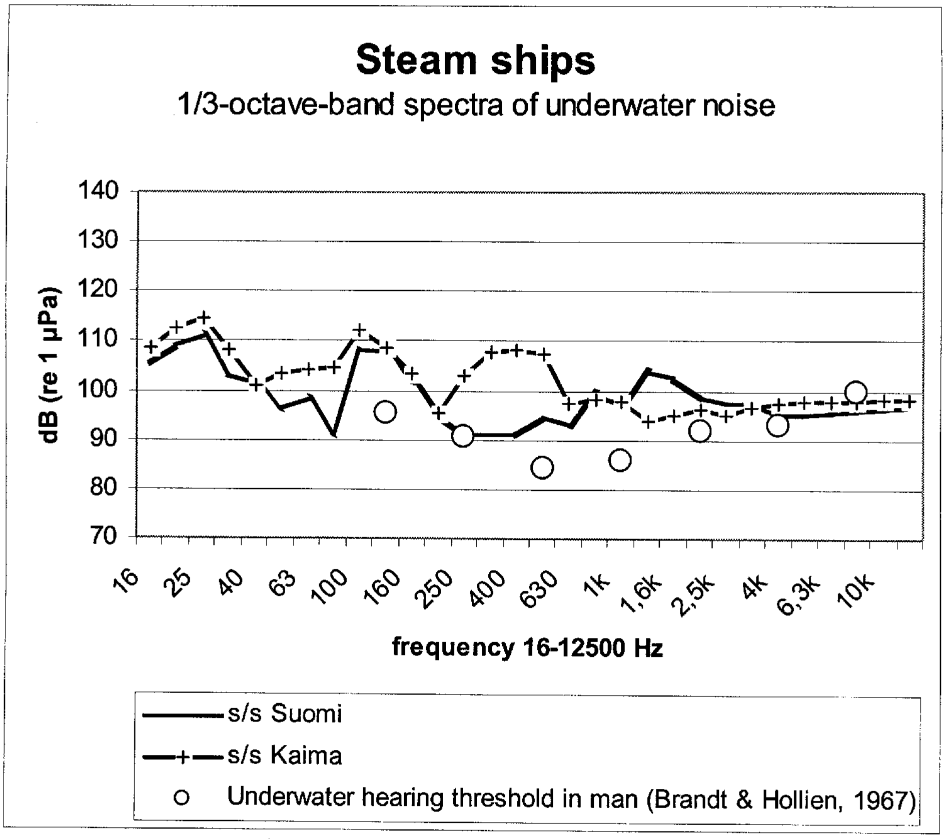

Fig. 5. There is a clear resemblance between the spectra of both steamers, especially in frequencies below 250 Hz. The highest values are in the 1/3-octave-band of 25 Hz.

4.6 Correlations

Correlations between separate series of 1/3-octave-band noise levels (from which spectra were drawn) were calculated using formula (8). Inside the group of outboards correlations varied from +0.69 to +0.98, and the highest value was between two Yamahas. Correlation between spectra of the two diesel boats was +0.95 and correlation between two steamers +0.43.

Correlations inside each group were all positive and quite high, and all correlations between outboards and diesel boats were very high, too. On the contrary, correlations between steamers and all smaller boats were negative. Therefore underwater sound of steamers is completely different than any sounds of motorboats (Fig. 6).

In the group of outboards correlation between the total noise level (SPL) and engine power was calculated, too, and it was +0.88. Therefore underwater noise levels of outboard motors seemed to depend primarily on the size of the engine.

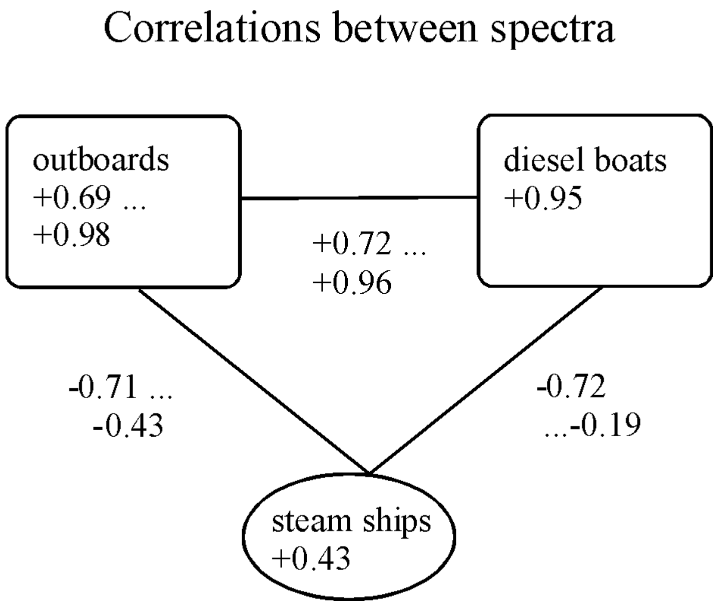

Fig. 6. Correlations between different spectra were calculated from the third band value series. On the ground of the correlations, the steamers formed themselves into their own group.

5. *Descriptions of underwater sounds*

5.1 *Meaningful soundscapes and studying methods*

Much information can be reached studying the structure of sound as a physical variable, and different underwater sounds can even be divided in groups of motorboats and bigger vessel. If more precise information about the nature of sounds is needed, sounds must be heard and analyzed by living ears. In the navies human ears are needed to listen water traffic and find out which vessels are not wanted and which submarines belongs to enemies. In the underwater creation marine mammals and fishes use all environmental sounds as information sources. In addition many marine mammal species use active sounds to find food, partners etc.

A quite new scientific sub-field called acoustic-ecology focuses research on the sonic relationships between all living organisms in the natural world. Acoustic ecology is partly suggestive of psychoacoustics, which deals with relations between perception of sound and physical properties of sound waves. Psychoacoustic research is oriented towards defining relations between measured features of sound and their subjective counterparts described by people (*Fundamentals of psychoacoustics*, 2004).

As a counterpart for the term landscape, composer and musicologists R. Murray Schafer coined the term soundscape in the late 1960s. In describing the soundscape's capacity to convey information, sound can be describes as a mediator between listener and the environment (*Wrightson*, 2000). This relationship is illustrated in Figure 7.

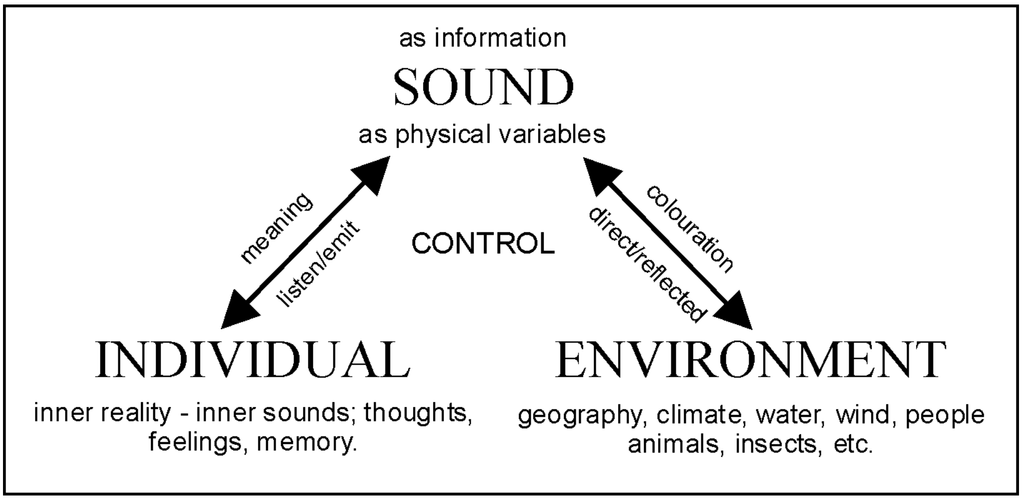

Fig. 7. The mediating relationship of an individual (man or animal) to the environment through sound. (*Wrightson*, 2000)

In the underwater world sound is much more effective mediator as above the surface due to the big difference between visual range and acoustic horizon: In extremely clear waters it's possible to see one hundred meters or even a little bit more, whereas loud sounds can travel hundreds or in the oceans even thousands of kilometres (see Fig. 1). Although human ears are not very keen underwater, sounds and signals, or the lack of them, play a big role in diving. Different characters of sounds inform divers of the underwater environment and invoke inner feelings.

One of the first reports about nature of the underwater soundscapes was published last year in *Musiikin suunta* –magazine (*Seppänen*, 2003b) and it was based on divers' descriptions, collected via email correspondence. For continuation of the above-mentioned study a new web-based inquiry form was created at the home pages of University of Jyväskylä, and the inquiry was advertised in the magazine of Finnish divers. During the one year in total 16 relevant answers were received. The age of the respondents varied from 25 to 42 years (mean 32) and they had taken an interest in diving from one to 18 years (mean 5). The answers represented the whole country geographically and were based on divers' memories – any real time listening test was not arranged. Except one, all respondents were male.

5.2 Nature of sounds in underwater environment

The underwater noise made by vessels was the most familiar sound, and all respondents had experience with that. The sound of outboard motors and other small motorboats was usually described as buzzing or whirring, and also by terms bumbling and growling. Some respondents defined noise as a sharp, aculeate and irritating; food mixer was mentioned once.

The sound of a motor ship was, according to respondents, like rumbling and roaring, or like (bass) pumping. Some described the sound by terms like tremble, boom, pound and not-nice; one wrote that it is like keeping one's head in the barrel which is sledgehammered at the same time.

Natural underwater sounds were rarer for divers. Every third had heard sounds of the waves, when they are breaking against the shore or the side of the vessel, and every fourth had heard sounds of the raindrops and noise made by rolling sand and stones. These weak natural sounds were mainly described with the same terms used above the surface, too. Sounds of waves were like rush and murmur and the sound made by raindrops was said to be like rattling and pattering, or like electric bristling. Sand moved by waves, currents or fishes made scratchy noise and stones were clacking. None of the respondents had heard biological sounds in Finnish waters.

5.3 Important silence and frightening noise

Finnish underwater soundscapes were described as very quiet, if no motor vessels are present and if the sound of scuba bubbles is not taken into account. The underwater silence was merely considered as positive and nice: three of the five respondents used terms peaceful or restful, others wrote that silence is natural, relaxing, pleasing etc. Three of four mentioned that breathing sounds, like even gurgle of bubbles and sound of the regulator bring the feeling of safety. The silence was also considered as the most pleasing underwater soundscape.

Divers will be frightened when hearing technogenic sounds or motor noise just above or nearby (mentioned by every fourth respondent), when hearing very sudden sounds (every fifth) or sounds which not belong to the context (every fifth). Divers will also be frightened when hearing distress signals emitted by co-divers, sounds caused by technical problems in scuba equipment or sounds of explosions.

6. Conclusions

1. Human divers can hear the underwater silence due to the quite high underwater auditory threshold and because of this most divers consider underwater environment as a peaceful and restful place. Even that, underwater noise is increasing all the time and it can damage the sonic relationships between living organisms in the underwater world (Seppänen, 2003a).
2. Underwater sounds are very significant signals for divers. Like underwater creatures, divers use sounds as an information source. Many kinds of underwater sounds and also the silence cause strong inner feelings.
3. When set against to the earlier study of underwater soundscapes (Seppänen, 2003b), all divers' descriptions were much alike.
4. At least two relations between measured features of underwater vessel sounds and their subjective counterparts were found:

   higher frequencies in the spectrum <==> *buzzing and whirring*
   lower frequencies in the spectrum <==> *rumbling and roaring*
5. All respondents had heard noise of motor vessels and all vessels measured here could also have been able to hear by a human diver. The biggest overlaps over the human auditory threshold (per one 1/3-octave-band) varied from 12 dB (s/s Suomi) to 37 dB (outboard Yamaha 100).

6. Underwater vessel sounds were possible to separate technically into two main categories, motorboats and steamers, also without a narrow band FFT analyze. Successful separation was made by taking account of the shape of the 1/3-octave-band spectra and correlations between different third band value series. Differences between minimum and maximum values inside the equivalent time may also give some further information of the ships engine (m/s versus s/s).

7. References

Andrew, R.K., B.M. Howe, J.A. Mercer and M.A. Dzieciuch, 2002. Ocean ambient sound: Comparing the 1960s with the 1990s for o receiver off the California coast. *Acoustics Research Letters Online* **3**, 65. Acoustical Society of America.

Backman, J., 2001. Akustiikan perusteet. Material for Akustiikan perusteet II –course in autumn term 2001 (Helsinki University of Technology: Laboratory of Acoustics and Audio Signal Processing). Five-part printed handout. Edita. Espoo.

Brand, J.F. and H. Hollien, 1967. Underwater hearing thresholds in man. *Journal of the Acoustical Society of America*, **42**(5), 966-971.

Eloheimo, K. 1992. Veneily ja sen ympäristövaikutukset. Vesi- ja ympäristöhallitus. Helsinki.

Evans, P.G.H. and B. Würsig, 2001. Cetaceans and Humans: Influences of Noise.In: Evans, P.G.H. and J.A. Raga, (eds). *Marine Mammals: biology and conservation*. Kluwer Academic, New York.

Fundamentals of psychoacoustics. At 29.7.2004 in the web site of the team of the Multimedia. Systems Department of the Technical University of Gdańsk, Poland. (http://sound.eti.pg.gda.pl/SRS/psychoacoust.html)

Gordon, J. and P.L. Tycak, 2001. Sound and Cetaceans. In: Evans, Evans, P.G.H. and J.A. Raga (eds). Marine Mammals: biology and conservation, 139-196.

Hawkins, A.D. and A.A. Jr. Myrberg, 1983. Hearing and sound communication under water. In: Lewis, B. (Ed.) Bioacoustics, A Comparative Approach. Academic Press. London. pp. 347-405.

HELCOM. Shipping. At 2.8.2004 in the web site of Helsinki Commission. (http://www.helcom.fi//manandsea/shipping.html)

Henriksen, O.D., J. Teilman and R. Dietz, 2004. Does underwater noise from offshore wind farms potentially affect seals and harbour porpoises. At 5.8.2004 in the web site of Middelgrunden Wind Turbine Cooperative, (http://www.middelgrunden.dk/MG_UK/article/sealsnoise.htm)

Kastak, D. and R.J. Schusterman, 1999. In-air and underwater hearing sensitivity of a northern elephant seal (Mirounga angustirostris) *Can. J. Zool./Rev. Can. Zool.* **77**(11), 1751-1758.

Madsen, P.T. and R. Payne, 2003. How Ships' Traffic Noise Affects Whales in a Shipping Channel. At 7.11.2004 in the web site of Voyage of the Odyssey. (http://www.pbs.org/odyssey/odyssey/20030506_log_transcript.html)

Marine Mammals and Low Frequency Active Sonar (LFAS). At 2.8.2004 in the web site of Ocean Mammal Institute. (http://www.oceanmammalinst.org/marinemammals-lfas-fact-sheet.htm)

Medwin, H. and C.S., Clay, 1998. *Fundamentals of Acoustical Oceanography*. Academic Press. San Diego.

Medwin, H., J.A. Nystuen, P.W. Jaconus, D.E. Snyder and L.H. Ostwald, 1992. The anatomy of underwater rain noise. *Journal of the Acoustic Society of America*, **92,** 1613-1623.

Mustonen, T. and M. Nieminen, (Eds), 2004. Ahdin nuotta-apajilla. *Pirkanmaan kalastajat*. Publication of Tampere Polytechnic.

Nowak, R.M., 2003. *Walker's Marine Mammals of the World*. Johns Hopkins University Press.

Pickard, G.L. and W.J. Emery, 1990. *Descriptive Physical Oceanography*. 5th Edition. Pergamon Press. New York.

Protecting Whales from Dangerous Sonar. At 31.7.2004 in the web site of Nature Resource Defense Council. (http://www.nrdc.org/wildlife/marine/nlfa.asp)

Scholik, A.R. and H.Y. Yan. The Effects of Underwater Noise on Auditory Sensitivity of Fish. In: *Proc. of Institute of Acoustics*, **23**(2), 27-36. At 16.2.2004 in (http://biology.uky.edu/Yan/Amy-Scholik-v2.pdf)

Seppänen, J., 2003a. Vedenalainen melu ja sen vaikutukset luonnossa. *Ympäristö ja terveys,* **3-4**, 56-59.

Seppänen, J., 2003b. Sukeltajien kokemuksia vedenalaisista äänimaisemista. *Musiikin Suunta,* **2**, 60-74.

Tyack, P.L., 1998. Acoustic Communication Under the Sea. In: Hopp, S.L. et al. (Eds) *Animal Acoustic Communication.* Springer Verlag, Heidelberg. pp. 163-220.

Urick, R.J., 1983. *Ambient Noise in the Sea*. Peninsula Publishing, California.

Urick, R.J., 1975. *Principles of Underwater Sound*. 2nd Ed. The Kingsport Press. New York.

Wrightson, K., 2000. An Introduction to Acoustic Ecology. *Soundscape,* Vol. **1**, 10-13.