7
Estimation of Cetacean Hearing Criteria Levels

7.1. Introduction

Essential for answering the question whether the Cuvier's beaked whales were stranded by the SWAC research activities is knowledge on the sound levels causing acute hearing damage to these whales. For, hearing damage might have been a reason for the stranding. However, information on intense sound levels, causing adverse effects on marine mammal hearing are very scarce, especially for the Ziphiidae family.Therefore these levels were assumed based on a practical approach. A summary is given by Ing. Wim C. Verboom, TNO Institute of Applied Physics, The Netherlands.

7.2. Hearing system Groups

Only very limited detailed information is available on the hearing capabilities of the various cetacean species. Actual information on Cuvier's beaked whales is lacking, both with respect to their sound production as well as to their hearing system (Section 3). It is expected that there will be a relation between the sound signals produced by a whale and the properties of whale's hearing system. For instance, whales producing signals in the range below 1 kHz are expected to have a higher hearing sensitivity in the low-frequency (LF) range than the sensitivity of whales producing sounds in the range above 100 kHz. Furthermore it is likely that the dynamic hearing range of odontocetes producing high source levels (SL) will be larger than the range of smaller odontocetes, porpoises for instance. Therefore, to judge the influence of intense LF sounds on whales, it is proposed to make a division into various groups, dependent on the expected hearing system properties. The influence of sound for each group may be different. Ketten (1992) (1998) has stated that, based on the structural formats of cetacean ears and on the frequency of the maximum energy in a typical echolocation click, 2 odontocete groups can be distinguished: *type I*, with peak frequencies above 100 kHz and *type II*, with frequencies below 80 kHz. A third group, *type M*, is the Mysticeti (signals up to 1 kHz). Type II may be subdivided to separate the largest species, because of their typical signal range 1 - 5 kHz, assuming an increased sensitivity in the lower frequency ranges. In that case the following groups may be distinguished:

- ***Group 1 (type M)****:* Mysticeti (baleen whales), SL up to 190 dB re 1 µPa, dominant signals in the range below 1 kHz,
- ***Group 2****:* largest Odontoceti (toothed whales: Sperm whale, Killer whale, Pilot whale), high SL, signals in the range below 3 kHz,

- ***Group 3 (type II):*** most Odontoceti, SL above 190 dB re 1 µPa, signals in the range above 40 - 80 kHz,
- ***Group 4 (type I):*** smallest Odontoceti (porpoises, etc.), SL up to 175 dB re 1 µPa, signals in the range above 80 kHz.

Based on the information in Section 3, it is expected that Cuvier's beaked whales would belong to Group 3.

7.3. Criteria Levels with respect to Hearing Injury

One reason for the Cuvier's beaked whale strandings may be acute damage of the inner ear due to intense sound levels. We define the *Zone of Hearing Damage or Injury* as a spherical area around a sound source in which the sound level causes hearing loss or tissue damage to auditory or other systems. The radius of this zone depends on the physical and physiological behaviour of the animal and is species, as well as signal dependent. However, the relationship between intense sound levels and effects on marine mammals has not been extensively investigated, so the radius within which hearing injury will occur has to be estimated, for instance, as is done below, by extrapolation of human hearing system data. Table 7.1 gives the relevant data for humans expressed in 'weighted levels' (dB(A)); for instance 80 dB(A) means that, when the sound spectrum is corrected for (filtered by) the shape of the human audiogram, the total (broadband) level of the sound is 80 dB above hearing threshold. A temporary decrease in hearing sensitivity due to high sound levels, the so-called Temporary Threshold Shift (TTS), is (here) defined as a temporary decrease in sensitivity of 6 dB which recovers within a number of minutes.

Table 7.1. *Criteria levels for humans and calculated levels for Group 4 and Group 3 odontocetes, expressed in 'weighted levels' in dB re 20 µPa in air or dB re 1 µPa in water*

	Humans dB(A) re 20 µPa in air	*Harbour porpoise dB re 1 µPa in water Group 4*	*Bottlenose dolphin dB re 1 µPa in water Group 3*
hearing threshold	0	50	40
severe disturbance	80	130	150
TTS (1 sec. pulses)	115	165	200
hearing injury	130	180	220
max. SL	-	165 dB re 1 µPa/1m	200 dB re 1 µPa/1m
dynamic range	140 dB	140 dB	195 dB

For cetaceans the criteria levels (in water) are unknown, but a rough method to estimate the various criteria for odontocetes is by extrapolating the properties and effects of the human hearing system, a method that has to be verified by future studies, of course. This

can be done by applying a similar 'weighting methodology' as the human dB(A) methodology. The dynamic range of the human hearing system is approximately 140 dB; for some odontocetes this range may be larger (because they produce loud signals), but for smallest odontocetes (Group 4, for instance harbour porpoises) one might suppose that their range is also 140 dB. Maximum hearing sensitivity/minimum threshold for harbour porpoises is 50 dB re 1 μPa (in water). By applying the human criteria ratios, criteria for harbour porpoises can be derived. The larger -Group 3- odontocetes, among which bottlenose dolphins (and presumably also Cuvier's beaked whales) produce higher SLs than harbour porpoises do: bottlenose dolphins emit a SL of 200 dB re 1 μPa (RMS) at 1 m distance. Their maximum hearing sensitivity is at 40 dB re 1 μPa. Due to their high SLs the dynamic hearing range of bottlenose dolphins is expected to be considerably larger than that of porpoises. Extrapolating the porpoise criteria ratios gives a bottlenose (continuous wave) criterion level for hearing injury of 220 dB.

Temporary Threshold Shift (TTS) is an accepted method of determining the sound level that causes a temporary reduction in the ear's hearing ability. This phenomenon occurs before actual hearing injury occurs. Carder *et al.* (1998) determined TTS for bottlenose dolphins for signals of 1 s duration and for frequencies of 3, 10, 20 and 75 kHz. The signals were emitted during a background noise level of 75 dB re 1 μPa_/Hz. TTS was somewhat background noise dependent. They also observed changes in animal's behaviour. The results are shown in Table 7.2.

Table 7.2. *Bottlenose dolphin; averaged TTS levels (in dB re 1 μPa) for 1 s and 10 s pulse duration (Carder* et al. *1998); 600Hz- and 10s-values were derived by Verboom*

Frequency	*TTS level 1sec- pulses*	*TTS level 10sec-pulses*	*Behaviour change 1sec-pulses*
600 Hz	201	201	-
3 kHz	198	196	186
10 kHz	194	191	180
20 kHz	195	192	181
75 kHz	193	190	178

The results for frequencies lower than 3 kHz can be derived from the slope of the TTS-curve, resulting in a TTS-level at 600 Hz of 201 dB re 1 μPa. TTS-level correction for pulse duration of 10 s can be derived by using observations of Johnson (1968). The levels shown in Table 7.2 are somewhat lower than the TTS-level of 200 dB indicated in Table 7.1. Therefore we use the data of Table 7.2.

7.4. Zone of Hearing Damage or Injury

From Table 7.2 the hearing injury criterion for bottlenose dolphins/Cuvier's beaked whales can be derived (which is supposed to be approximately 20 dB above TTS -see Table 7.1): for 600 Hz and 3 kHz pulsed signals the criterion level would be respectively 221 and 217 dB re 1 µPa. As the difference in criterion level is a maximum of 3 dB, no distinction is made between 1 and 10 s pulse duration. Applying a propagation loss of [20 log (distance/1m)] the hearing injury radii for various sound levels is shown in Table 7.3.

Table 7.3 *Radius of Zone of Hearing Damage or Injury; criteria 221 dB (600 Hz) and 217 dB (3 kHz)*

sound SL	*radius in m 600 Hz*	*radius in m 3000 Hz*
215 dB	-	0
220 dB	-	1.5
225 dB	1.5	2.5
230 dB	3	4.5
235 dB	5	8

7.5. Summary

It can be concluded that acute hearing loss might be possible only at very close distance to a pulsed sound source, emitting pressure levels higher than 220 dB re 1 µPa at 1 m distance. Would the criteria levels, mentioned above, be too 'optimistic' and for instance be 20 dB lower, then acute hearing loss is to be expected within 80 m from a 235dB low-frequency sound source.