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Fish and Marine Mammal Audiograms: A summary of available information

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by

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Contents

1. Introduction 1

2. Fish and marine mammal hearing mechanisms 3

2.1. Fish hearing mechanisms 3

2.1.1. Structure of the inner ear 3

2.1.2. Hearing mechanisms 4

2.1.2.1. The otolith 4

2.1.2.2. Gas-filled cavities 4

2.1.2.3. Lateral Line System 4

2.1.3. Hearing specialisations 4

2.1.3.1. Introduction 4

2.1.3.2. High Sensitivity 5

2.1.3.3. Medium Sensitivity 5

2.1.3.4. Low Sensitivity 5

2.2. Mammal hearing mechanisms 6

2.2.1. Introduction 6

2.2.2. Hearing mechanisms 6

3. Audiograms 8

3.1. Introduction; the audiogram 8

3.2. Quality of the experimental environment 8

3.2.1. Calibration of the field 8

3.2.2. Independent measurement and control of pressure and particle velocity 9

3.2.3. Uniformity of field 10

3.2.4. Background noise 10

3.2.5. Number of individuals tested 10

3.2.6. Frequency and dynamic range of measurements 11

4. Methods of obtaining audiograms 13

4.1. Introduction 13

4.2. Behavioural methods 13

4.3. Evoked auditory potential methods 14

5. General comments on the audiograms 15

5.1. Fish audiograms 15

5.2. Mammal audiograms. 15

5.3. Summary. 15

6. References. 34

Appendix 1. The ABR method 36

Appendix 2. Fish audiograms. 39

Appendix 3. Marine mammal audiograms. 181

Appendix 4. Miscellaneous data 267

Appendix 5. Record of changes. 278

1. Introduction

This report draws together the public domain information regarding the audiograms of marine species, that is, the measurement of their hearing, and presents this information in a standard format. The format includes a summary of the conditions of the measurement and its conclusions.

Studies have been conducted for many years on the hearing abilities of both fish and marine mammals. In many cases, these studies have been driven by curiosity or by the need for largely qualitative information concerning the way in which sound is used by marine mammals and fish for communication, navigation and exploration and exploitation of the environment.

With the increasing level of man-made noise in rivers and the oceans it is becoming more and more important to be able to form objective estimates of the effect of noise on a wide range of species. To achieve this objective, good quality and reliable data is needed on the hearing sensitivity of these animals.

Concerns over the environmental effects of offshore seismic shooting using airguns prompted the authors to develop and propose the dB_{ht}(*Species*) scale as a formal method of evaluating the effects of noise (Nedwell and Turnpenny (1998)).

Man made noise underwater can cover a wide range of frequencies and level of sound, and the way in which a given species reacts to the sound will depend on the frequency range it can hear, the level of sound and its spectrum. Both the sensitivity of hearing, and the frequency range over which sound can be heard, varies greatly from species to species. For man, sound is ultrasonic (i.e. above human hearing range) above about 20 kHz. However, for many fish sounds above 1 kHz are ultrasonic. For a marine mammal, much of the energy of an airgun may be infrasonic, as many cannot perceive sounds below 1 kHz. These considerations indicate the importance of considering hearing ability when evaluating the effect of underwater noise on marine animals.

The dB_{ht}(*Species*) accounts for these differences by passing the sound through a filter that mimics the hearing ability of the species, and measuring the level of sound after the filter; the level expressed in this scale is different for each species (which is the reason that the specific name is appended), and corresponds to the perception of the sound by that species. A set of coefficients is used to define the behaviour of the filter so that it corresponds to the way that the acuity of hearing of the candidate species varies with frequency: the sound level after the filter corresponds to the degree of perception of the sound by the species.

The scale may be thought of as a dB scale where the species' hearing threshold is used as the reference unit; it is identical in concept to the dB(A) scale used for rating the behavioural effects of sound on man. In effect, the dB(A) may be thought of as the dB_{ht}(*Homo sapiens*). One major benefit of the scale is simplicity; a single number (the dB_{ht}(*Species*)) may be used to describe the effects of the sound on that species.

The research program in conjunction with which this report has been produced aims to validate the dB_{ht}(*Species*) as a means of objectively evaluating the effects of noise on a wide range of species.

The purpose of this review of audiograms is to assess their quality and hence suitability in the dB_{ht}(*Species*) process and hence in assessing the likely effects of man-made noise on marine mammals and fish. This report therefore presents a review of the available information on fish and marine mammal hearing, and in particular summarises the audiograms that are available for marine species. Fay, in his 1988 book 'Hearing in Vertebrates: a Psychophysics Databook', assembled most of the data available at that time, presenting it in graphical and tabular form with brief comments on it. This report draws together information which has been obtained since then, and also considers many of the studies dealt with in Fay's book, but gives more details of the experimental conditions and methods. Whenever possible original sources of data have been used for assembling this report. While it is believed that it covers much of the material on audiograms that is available in the open literature, there are instances where papers have been cited by authors but the original source papers have not been located.

Section 2 briefly outlines the hearing mechanisms of marine mammals and fish, while Section 3 considers the validity and shortcomings of this earlier work. Section 4 considers the methods that are used to estimate audiograms. Section 5 provides a brief summary of the available literature.

The audiograms that have been located, after extensive searching through the literature, are given in Appendices 2 (for fish) and 3 (for marine mammals), while Appendix 4 contains other data that has been found which, while not presenting audiograms, has information on hearing which is of relevance.

The audiograms have been summarised in a standard form which, it is hoped, will allow their convenient comparison and use.

2. Fish and marine mammal hearing mechanisms

The purpose of this section is to provide a brief review of the mechanisms by which fish and marine mammals hear underwater.

2.1. Fish hearing mechanisms

2.1.1. Structure of the inner ear

The main structures within the inner ear of fish are three semicircular canals and the otolithic organs: the utriculus, the sacculus and the lagena. The relationship between these structures defines the division of the ear into the *pars superior* and the *pars inferior*, which are responsible for the vestibular senses (related to equilibrium) and the auditory senses (involved with sound detection), respectively (Popper & Coombs (1980)).

The semi-circular canals have an ampulla at the base, which contains sensory receptive hair cells located on the crista. The lumen of the canals contains a fluid known as endolymph, which has a particular ionic composition and special viscous properties (Hawkins (1986)). Associated with the canals are the three otolithic structures the utriculus, the sacculus and the lagena. The utriculus has a direct association with the canals and forms the *pars superior*, while the sacculus has a connection with both the utriculus and the lagena, though it is with the lagena that the *pars inferior* is formed.

Otoliths are found within the utriculus, the sacculus and the lagena. These are essentially stones of calcium carbonate and are situated on a sensory epithelium, the macula. In elasmobranchs and more primitive fish the otolith is replaced with numerous spherules of calcium carbonate, the otoconia.

In many fish the inner ear is the main structure in fish hearing, though in other species there are defined structural linkages with gas-filled cavities. Cypriniformes have a connection between the inner ear and the swimbladder through the Weberian ossicles, while in Clupeiformes the swimbladder directly enters the cranium (Hawkins (1986)). The specialisations of different fish families will be discussed later.

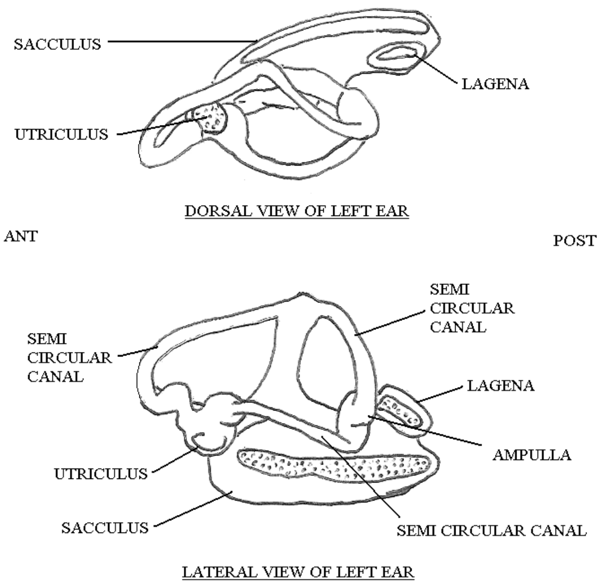

Fig. 2.1. Figure showing main structures of the inner ear. Adapted from Hawkins (1986).

2.1.2. Hearing mechanisms

2.1.2.1. The otolith

A study carried out on the plaice (*Plueronectes platessa*) showed that when fish were placed in a standing wave tank where particle motion and sound pressure could be varied independently, a response was only shown to changes in particle motion. This was also backed up with field experiments on the dab (*Limanda limanda*) and the salmon (*Salmo salar*), where sound pressure thresholds within the nearfield of the source were lower, thus confirming that fish respond to the greater amplitudes of particle motion that occur close to the source (Hawkins (1986)).

2.1.2.2. Gas-filled cavities

Fish having a close association between the swimbladder and the inner ear are sensitive to sound pressure (Hawkins (1986)). It appears that the gas-filled cavity acts as an acoustic pressure-to-motion transformer; sound pressure causes the chamber to pulsate, generating a higher amplitude of particle motion (Hawkins (1986)). Groups of fish showing these specialisations are the Otophysi, mostly freshwater species, including the order Cypriniformes (e.g. goldfish, carp, minnows) (Popper & Fay (1993)).

2.1.2.3. Lateral Line System

The other main mechanoreceptory system in fish is the lateral line system (Helfmann, Collette and Facey (1997)). In teleost (bony) fish the lateral line is usually visible as a row of small pores along the trunk and the head. These pores lead to the underlying lateral line canal (Bleckmann (1986)). The basic unit of the ordinary lateral line system is the neuromast, consisting of a cluster of pear-shaped sensory cells called hair cells, surrounded by supporting cells. Neuromasts are covered by a gelatinous cupula which encompasses the sensory hairs from the underlying mechanosensitive hair cells (Bleckmann (1986)).

The sensory hair cells of the lateral line system are sensitive to minute water movements (Hawkins (1986)). This is essential for fish to be able to detect currents, maintain position in a school, capture prey and avoid obstacles and predators (Popper and Platt (1993)).

Detection begins when sound waves around the fish or in the canals displace the gelatinous cupula, causing bending of the stereocilia, thus altering the firing rate of the sensory neurons system (Helfmann, Collette and Facey (1997)).

Sand (1981) confirmed that the trunk lateral line is an acutely sensitive vibration (particle motion) detector. Using vibrational stimuli he found that roach (*Rutilus rutilus*) displayed optimal sensitivity to frequencies around 50 Hz. The lowest threshold value measured at this frequency was 3.3×10^{-6} cm rms.

The lateral line system responds to near-field water displacements produced by a sound source and to tiny water currents set up by the fish's own motion which are reflected from static objects. The ordinary lateral line organs found throughout teleosts are used as "distance touch" receptors. They are of special importance for the detection and localisation of prey, for predator evasion, for schooling, and for intraspecific communication (Bleckmann (1986)).

2.1.3. Hearing specialisations

2.1.3.1. Introduction

The anatomical, behavioral and physiological variation among fishes is immense. This includes the ear and associated structures and suggests that various species may detect and process sound in different ways (Popper and Fay (1993)).

Table 2.1 shows a summary of the fish species, showing different levels of specialisation. Those fish with specialist structures have been classified as 'high' sensitivity, non-specialists with a swimbladder are 'medium' sensitivity and non-specialists with no swimbladders are termed 'low' sensitivity.

Table 2.1. Summary to show specialisation levels of a variety of fish species.

Species	Common name	Family	Swimbladder connection	Sensitivity
Anguilla anguilla	European eel	Anguillidae	None(1)	Medium
Clupea harengus	Herring	Clupeoidea	Prootic auditory bullae(2)	High
Cottus scorpius	Sculpin	Cottidae	No swimbladder(1)	Low
Gadus morhua	Cod	Gadidae	None(1)	Medium
Limanda limanda	Dab	Pleuronectidae	No swimbladder(1)	Low
Melanogrammus aeglefinus	Haddock	Gadidae	None(1)	Medium
Merluccius merluccius	European hake	Merluccidae	None(1)	Medium
Pleuronectes platessa	Plaice	Pleuronectidae	No swimbladder(3)	Low
Raja clavata	Thornback skate	Rajidae	No swimbladder(1)	Low
Scomber scomber	Atlantic mackerel	Scombridae	None(1)	Medium
Sprattus sprattus	Sprat	Clupeoidea	Prootic auditory bullae(2)	High

(1) Popper & Fay (1993), (2) Blaxter *et al*. (1981), (3) Turnpenny & Nedwell (1994).

2.1.3.2. High Sensitivity

The Clupeoidea, including herring (*Clupea herringus*) and sprat (*Sprattus sprattus*), show elaborate specialisations of the auditory apparatus. This group is characterised by the presence of a prootic bulla, a gas-containing sphere evolved from the bones of the ear capsule (Blaxter (1980)). A membrane divides the bulla into an upper part containing fluid and a lower part containing gas. Movements of the bulla stimulate both the utricular macula and the lateral line, thus generating a coupling effect. Ducts connecting the bulla with the swimbladder represent a unique adaptation system that prevents the bulla membrane from bursting during a dive and maintains it in a flat resting state where it is most sensitive. The bulla membrane is elastic, enabling much of the pressure to be taken up in the event of the fish diving. The swimbladder is, however, compliant on pressure and a pressure difference is set up between the bulla and swimbladder, causing gas to flow into the bulla, restoring the membrane to its flat state. The hearing ability of clupeoids is enhanced by the presence of the bulla (Blaxter (1980)).

2.1.3.3. Medium Sensitivity

Cod (*Gadus morhua*) have a rather restricted frequency range. Sensitivity to sound pressure indicates that the gas-filled swimbladder may be involved in the hearing of cod, although there is no direct coupling with the labyrinth. At lower frequencies high amplitudes can be obtained close to source, suggesting sensitivity to particle displacements. Hearing thresholds are determined by the sensitivity of the otolith organs to particle displacements re-radiated from the swimbladder (Chapman & Hawkins (1973)).

2.1.3.4. Low Sensitivity

Flat fish such as the plaice (*Pleruronectes platessa*) and dab (*Limanda limanda*) have no swimbladder and are therefore relatively insensitive to sound; they are insensitive to sound pressure and rely on the detection of particle displacement (Turnpenny & Nedwell (1994)).

The sculpin (*Cottus scorpius*) also has no swimbladder and is deaf to propagated sound waves, therefore it can only perceive the near field effect (Enger (1967)).

2.2. Mammal hearing mechanisms

2.2.1. Introduction

In the frequently murky waters of the seas an acute sense of hearing is of central importance in a marine mammal's life, and may be used to retain cohesion in social groups, for echolocation to locate and capture food, for detection of the sound of an approaching predator and for avoidance of harmful situations, such as being struck by boats.

Marine mammals divide into three orders, the Cetacea, Sirenia and Carnivora. The cetaceans comprise two groups, the odontocete, or toothed whales, and the mysticete, or baleen whales.

There are 68 species of odontocetes. Odontocetes are known to communicate at frequencies from 1 kHz to in excess of 20 kHz. Many species also have echolocation systems operating at frequencies of 20-150 kHz.

There are 11 species of mysticetes; these differ from the odontocetes in that they lack a high-frequency echolocation system.

The sirenians are herbivores that inhabit shallow tropical and subtropical waters; they comprise three species of manatees and one species of dugong. Manatees have a hearing range of 400-46,000 Hz.

The carnivora are comprised of the pinnipeds, sea otters and polar bears, and are characterised by being mammals which spend time both in terrestrial and marine environments. The pinnipeds are comprised of the 18 species of Phocidae or true seals, 14 species of Otariidae or eared seals (including the sea lions), and the Odobenidae, represented by a single species, the walrus. Of the carnivora the pinnipeds both call and hear under water and in air. As a result of their visibility and widespread distribution they are probably the group which has received most attention in terms of the effects of noise.

Many marine mammals both produce and receive sound. Seals, seal lions, and male walruses produce vocalizations underwater, probably by cycling air through air pouches in the animal's head. Underwater vocalizations can include clicks, trills, warbles, whistles, and bell-like sounds. Odontocetes produce a wide variety of sounds, which include clicks, whistles, and pulsed sounds within the air sacs of the nasal system. The details of sound production in mysticetes, manatees and dugongs are not well known. Both groups of animals produce vocalizations and possess a larynx and vocal folds. Manatees make high pitched squeaks, while baleen whales produce lower frequency thumps, moans, groans, tones, and pulses.

2.2.2. Hearing mechanisms

This section is a brief overview of hearing in marine mammals, and is not intended to provide an exhaustive summary of the topic. The reader is directed towards useful summaries of hearing in marine mammals provided by Ketten (1994), Richardson *et al* (1995).

The hearing mechanisms of marine mammals, in common with that of terrestrial mammals, may be divided into three components. These comprise an outer ear, a fluid-filled inner ear which contains a frequency-dependent membrane interacting with the sensory cells, and an air-filled middle ear which serves to provide an efficient connection between these. In terrestrial mammals the function of these structures is well established and the auditory pathway, which may be termed the tympanic hearing process, is well understood. However, in marine mammals the detailed structure of the hearing pathway varies significantly between species, and there is evidence that additional auditory pathways exist for some marine species.

The most dramatic differences in hearing between terrestrial mammals and marine mammals can be found in the cetaceans (whales, dolphins and porpoises), where there are no external pinnae; in addition the ear canals are vestigal or absent and may not be functional. In odontocetes sound is channeled from their environment to the middle ear through the lower jaw, through fats in conjunction with a thin bony area called the pan bone. These conduct sound to the tympanic membrane of the middle ear. The middle/inner ear complex is encased in bones and suspended by ligaments in a cavity outside the skull of cetaceans. The details of how the middle ear functions in cetaceans are still being investigated. In mysticetes the narrow ear canal, while present, is terminated by a waxy cap. In the odontocetes the ear canal is narrow and plugged with debris and dense wax. Norris (1980) first speculated that fat filling the lower jaw might act as a preferential path for ultrasonic signals to the middle ear; Brill *et al* (1988) later confirmed this role. Scheifele (1991) indicates that dolphins receive sound through their lower jaw (mandible); the core of the lower jaw is filled with fats that conduct the sound. A thin bony area at the rear of the lower jaw known as the pan bone acts as an acoustic window.

The inner ear of cetaceans functions in the same way as terrestrial mammals (Ketten (1994)). The differences lie in the inner ear characteristics; these include the number of nerve cells, the size of the basilar membrane, and the support of the basilar membrane. Toothed whales have more nerve cells associated with hearing than terrestrial mammals. Baleen whales have fewer nerve cells associated with hearing compared to toothed whales, but more than terrestrial mammals. The thickness and width of cetacean basilar membranes are closely linked to the unique hearing capacities of toothed and baleen whales. The thicker and stiffer the basilar membrane the more tuned an ear will be for higher frequency hearing. Toothed whales have evolved adaptations that increase the stiffness of the basilar membrane. Bony supports are present in toothed whale cochleae to increase stiffness. The thickness of the membrane is also larger compared to terrestrial mammals of the same body size. These adaptations contribute to the exceptionally high hearing range in toothed whales. Baleen whales, on the other hand, have exceptionally broad, thin, and elastic basilar membranes. It is thought on the basis of these characteristics that baleen whales have good sensitivity to low frequencies of sound.

The pinnipeds (seals, sea lions, walruses, sea otters and polar bears) spend time on land as well as in water, and consequently their auditory structures and hearing are similar to those of terrestrial mammals, other than the pinnae (external ear flaps), which are greatly reduced or absent. This presumably arises as a consequence of the longer wavelengths of sound in water than in air, the relative transparency of body tissues and the need for a hydrodynamically efficient outline. Pinnipeds have also not developed high frequency ultrasonic or low frequency infrasonic hearing. The middle and inner ears of pinnipeds, polar bears, and otters are similar to those of humans and other terrestrial mammals. Otarids (eared seals) have small ear flaps and broad ear canals. Phocids (true seals) have no pinnea and narrow ear canals; the ears themselves are still attached to the skull, and muscles around the ear canal hole function to close the ear canal to water.

It is interesting to note that wheareas the physics of mammalian hearing in air is reasonably well understood, and models exist to predict hearing ability from anatomical information (Fay (1988)), there is no generally accepted equivalent ability to specify marine mammals' hearing from morphological detail. It must therefore be concluded that, for the time being at least, the only method of obtaining detailed and accurate information on marine mammal hearing ability is to directly measure it.

3. Audiograms

3.1. Introduction; the audiogram

It is intuitively obvious that the quality of the scale used to quantify the effects of noise on a marine animal will be determined, at least in part, by the quality of the information that is available concerning its hearing.

In general, the principle of measuring an audiogram is that sound at a single frequency and at a specified level is played to the subject, typically as a pulsed tone. A uniform and calibrated sound field is created by means of loudspeakers or headphones in air, or projectors (underwater loudspeakers) in water. A means is required to find whether the subject can hear the tone. In the case of human audiograms, this is provided by the subject pressing a button when the tone can be heard. The level of the sound is reduced, and the test repeated. Eventually, a level of sound is found where the subject can no longer detect the sound. This is the threshold of hearing at that frequency. The measurement is typically repeated at a range of frequencies. The results are presented as the threshold of hearing of the subject as a function of frequency; this is known as the subject's audiogram. Typically, audiograms have the appearance of an inverted bell-shaped curve, with a lowest threshold level (maximum hearing sensitivity) at the base of the curve and increasing threshold levels (decreasing sensitivity) on either side.

In principle, measuring audiograms of marine species in water is identical to performing the measurement in air, other than the need to use suitable underwater sound projectors. It might be noted, however, that it is difficult to create uniform fields underwater; this is further complicated by the fact that marine species can respond not only to the pressure of the sound, but also its particle velocity (level of vibration). It is therefore necessary to ensure that both of these quantities are well controlled during the measurement of the audiogram. In addition, it is very difficult to provide an experimental facility having adequately low acoustic and electrical noise.

3.2. Quality of the experimental environment

There are five factors in respect of the quality of the experimental environment that may influence the quality of an audiogram.

3.2.1. Calibration of the field

In order to provide an accurate estimate of the audiogram of a species, it is necessary to know exactly the acoustic field to which the species is exposed. This is complicated by the fact that there are two parameters of the sound to which the species can respond, the pressure and the particle velocity.

The pressure P of a sound field is the parameter with which most are familiar, since it is the parameter that determines the "loudness" of a sound to humans. Another quantity used to specify a sound field is its particle velocity V. Particle velocity is a measure of the vibration of the fluid transmitting the sound. In open water, the two quantities are related by

$$P = \rho c V$$

where ρ is the density of water and c is the sound speed in it.

However, this simple relationship breaks down in many circumstances, including:

- near to a water surface, where the acoustic pressure drops to zero but the particle velocity increases to a maximum.;
- near a seabed carrying seismic waves, where the evanescent component of the wave can induce high particle velocities in the overlying water without corresponding acoustic pressure;

- near to a source, where the reactive nearfield can induce high levels of particle velocity;
- near to compressible materials, such as bubble swarms, and air-containing materials, such as diver's suits, and
- in small volumes of water, such as experimental tanks.

It is therefore important to understand the pressure and particle velocity fields not only when measuring the audiogram of a species, but also when using the information to determine a species' likely response to a noise.

At low frequency, acoustic fields in experimental tanks generated by a submerged sound projector may have low levels of pressure and high particle velocities, as a result of the walls and surface of the tank displacing outwards under the influence of the pressure. At high frequencies, however, reflections of sound at the tank walls may cause the field to become diffuse, with sound travelling in all directions, such that the pressure is high and the particle velocity low. At intermediate frequencies complex modal patterns of sound may form. The behaviour of the field may be different when a loudspeaker in air above the tank is used to generate sound in the water, as has sometimes been done. For instance, at low frequencies, the pressure induced by the airborne sound will tend to be high, but the particle velocity will be low.

In general, there will be no simple relationship between pressure and particle velocity in an experimental tank, and there is also no reliable method of calculating the relative levels of the two quantities. Hence they must be measured.

3.2.2. Independent measurement and control of pressure and particle velocity

Since animals may be able to detect both pressure and particle velocity, these must be independently controlled in order for the importance of each to be identified and the results of the audiogram to be generally applicable. For instance, consider a simple test in which two identical transducers are placed in a large tank of water facing each other, with an experimental subject on the centreline between them. If the two transducers are in phase, due to symmetry the particle velocity from one transducer will be equal and opposite to the particle velocity from the other, and the subject will be positioned at a particle velocity null. The pressures from the two transducers will, however, sum and be high. If one of the transducers is opposite in phase to the other, due to symmetry the pressure from one transducer will be equal and opposite to the pressure from the other, and the subject will be positioned at a pressure null. The particle velocities from the two transducers will now sum and be high.

Consider two separate audiograms measured under these two conditions. If the animal is more sensitive to the first case than the second, it is responding to pressure, and *vice-versa* if the animal is more sensitive to the second case than the first, it is responding to particle velocity.

The importance of separating these two quantities has not generally been recognised, although several authors have realised that both fish and marine mammals (e.g. Blaxter (1980); Turl (1993)) may be sensitive to particle velocity. It is therefore important that the two fields are calibrated when audiograms are measured. The exact pressure at which the auditory threshold occurs must be known for frequencies at which the animal responds to pressure, and similarly the exact particle velocity for frequencies at which the animal responds to particle velocity. It may be added that the current best practice would be to ensure that such measurements of sound are also traceable to International Standards.

The process of calibrating the sound field is somewhat more involved than would be the case for the equivalent measurement taken in air, since animals in water may interact with the sound field. When a marine animal is placed in a sound field, the field is distorted and may increase or decrease in level. This mainly occurs when there is a compliant structure in the animal, and may occur at lung resonant frequency with marine mammals or at swimbladder resonant frequency with fish.

The simplest method of calibrating the sound level at which the auditory threshold occurs is to measure and note the level of sound while the animal under test is in position, say by a hydrophone placed adjacent to its head. This is usually referred to as a *direct* calibration.

However, in practice, the level of sound adjacent to an animal of a given species will not be known. Typically, the sound in the open water, well away from any animals, will be estimated or measured. The increase or decrease in level that occurs when an animal is present in the sound field is immaterial; what is of interest is the sensitivity of the animal to sound of a given free-field level. In order to relate this to the perception of the sound by the animal, the equivalent free-field threshold of hearing is required. To perform this measurement, the free-field level of sound, in the absence of the animal, is recorded in the experimental tank for a wide range of level settings of the equipment generating the sound. The animal is then inserted into the field and the threshold of hearing of the animal is found. The threshold is then related to the equivalent free-field level of sound, rather than the actual level of sound adjacent to it. This method of measurement is termed an *insertion* measurement, since the level is measured prior to the subject being inserted into the field.

In the only known case of both insertion and direct audiograms being recorded (for human divers wearing neoprene wetsuits), the two measurements varied by 5-10 dB (Parvin, Nedwell *et al* (1994)).

3.2.3. Uniformity of field

A further complication arises when the audiogram measurement involves a free-moving subject, as is usually the case with marine mammals, as even when the animal is called back to a start position it cannot always be guaranteed that the animal will be at a precise location when the sound is played. In this case, the uniformity of the sound field around the test position will be an important parameter.

It is suggested that, as a minimum, the sound field should be recorded and documented over the area in which the experimental animal is confined in order that the level of threshold can be assessed to an adequate and specified accuracy.

3.2.4. Background noise

Background noise has the potential to mask the tones presented to an animal during an audiogram measurement, causing artificially elevated thresholds. Some methods of estimation of audiograms, such as the ABR method, use an averaging procedure and hence are insensitive to noise. Others, such as the behavioural methods, rely on the animal being able to detect the tone above the background noise. It is therefore essential that the background noise is measured in any facility, and compared with the threshold measured.

3.2.5. Number of individuals tested

Inevitably, marine animals will have varying acuity of hearing between individuals. Part of this variation will result from natural variability in ability, and it is possible that certain individuals may have suffered hearing damage as a result of disease processes, age, or as a result of traumatic exposure to sound. Consequently, the number of individuals tested in any given audiogram measurement has to be sufficient to establish reasonable confidence in the quality of the measurement.

A greater degree of confidence arises where audiograms have been reported for the same species by different authors, under different experimental conditions, and using individuals drawn from different stocks. If the results are repeatable it implies that they represent the true threshold of hearing and are not an artefact of the measurement process.

Due to the difficulty of procuring and working with marine mammals, many of the published results are for a single individual. In at least one case known to the authors, the individual was a single elderly animal confined in a zoo, and hence possibly not representative of the natural stock. Published audiograms for single individuals must be considered provisional information only, and in need of confirmation where the results are used to estimate the environmental effects of noise.

Fish are generally easier experimental subjects and generally greater numbers of individuals have been tested in measurements of audiograms. In some cases, such as the goldfish (*Cassius auratus*), sufficient numbers of individuals have been tested to achieve reasonable statistical confidence in the results, and different authors report similar audiograms.

3.2.6. Frequency and dynamic range of measurements

The hearing range of a marine animal may span several decades of frequency. Above and below this hearing frequency band are regions in which the animal is insensitive to sound. Above the hearing band the sound is described as being ultrasonic for the animal, and below the hearing band the sound is described as being infrasonic for the animal. The frequency ranges in which the sound is infrasonic and ultrasonic therefore pertain to a particular animal. A sonar system operating at 1 kHz may be ultrasonic for many fish, as they are mainly low-frequency hearers, but infrasonic for some marine mammals, which hear at frequencies of 10 kHz to 100 kHz.

Within the hearing frequency band for a given species, the sensitivity to sound will vary; usually the audiogram when plotted on a logarithmic frequency axis is roughly an inverted bell-shaped curve, with maximum hearing sensitivity near the centre. It is convenient to split the hearing range into three bands, *viz*:

- the **“peak hearing band”**, extending from the maximum sensitivity to, say, a frequency at which the hearing threshold is 12 dB higher than the peak value;
- a **“high frequency skirt”,** which extends upwards from the peak hearing band to the frequency at which the sound becomes ultrasonic for the species, say at 70 dB above the maximum sensitivity, and
- a **“low frequency skirt”,** which extends downwards from the peak hearing band to the frequency at which the sound becomes infrasonic for the species.

The hearing bandwidth, which may be defined as the width in Hz of the entire hearing range (all three hearing bands), varies from species to species. Generally, animals which use sound to navigate, explore and communicate (hearing specialists) have a wider hearing range and greater sensitivity to sound than other species.

One drawback of many reported audiograms is that the frequency range over which they are recorded is insufficient to define the entire hearing range of the species, from infrasonic to ultrasonic frequencies. This may partly arise because the insensitivity of species to sound at the extremes of hearing means that the high levels of sound that are required to cause an evoked response are difficult to generate. In addition, at high frequencies it is difficult to generate uniform sound fields. It is also probable that some audiograms are measured as a result of the identification of general features of a species’ use of sound, and knowledge of the peak hearing band is sufficient to satisfy this requirement.

In the case of the behavioural response of species to sound, the entire hearing range must be known, as a species may be equally affected by, say, a low level noise generating frequencies in the peak hearing band, or by a high level source generating frequencies at the extremes of the upper or lower skirts. In man, the human hearing range is defined for practical purposes over a dynamic range (from the threshold at the most sensitive frequencies, to the extremes at which hearing becomes ultrasonic or infrasonic) of at least 70 dB.

It will be noted that many of the audiograms herein are reported over much smaller dynamic ranges. In most cases the peak hearing band is reasonably well reported. In many cases, the high frequency skirt is also reasonably well documented. However, in many cases the lower frequency skirt is poorly defined; this probably results from the fact that high levels of undistorted low frequency sound are, in general, difficult to generate.

4. Methods of obtaining audiograms

4.1. Introduction

When conducting experiments to obtain an animal's audiogram it is necessary to gauge response to the sound by a means that does not require the cognitive compliance of the subject. Consequently, there are two principal methods by which audiograms have been obtained for fish and mammals, *viz.* by behavioural means and by evoked potential measurements (by monitoring of the electrical activity of the animal's hearing mechanism).

4.2. Behavioural methods

In behavioural methods the subject is trained to respond unambiguously to the measurement signal. The response may involve, for instance, the subject moving to another location in its test environment, or altering its heart rate. Of the former, there are two approaches, *viz.* a go/no-go method, or a method in which it has to choose between two stations to move towards.

For marine mammals, in the go/no-go method, the subject is stationed at a listening position at the start of a trial. The animal is trained to stay in position if it does not detect the signal, or to move to another position if it does. Typically, it may have to press a switch of some sort at the second location, and if it has responded correctly the subject is rewarded with food. The start of a trial is signaled, perhaps by the switching on of a light, and the subject moves immediately it hears the signal if one has been presented. If no signal has been presented the end of the trial is signaled, by the switching off of the light or the trainer giving a signal.

In the method in which a choice has to be made, a signal is presented to the subject. The subject has to go to either of two locations depending on whether or not it detected the signal; the experiment may be arranged such that the subject initiates the presentation of the signal. Again, a correct response is typically rewarded with food.

Regarding establishing the lowest sound level that the subject can hear, the most common approach is the so-called 'staircase method'. In this the signal is played initially at a level which is known to be above the animal's threshold; consequently it is almost bound to respond in the manner which indicates it has heard it. The level of subsequent signals is lowered steadily (usually in 2 dB steps), until the subject fails to detect it, whereupon the level is increased (again, usually in 2 dB steps) until the subject again detects it. Thereupon the signal is lowered in steps until again the subject fails to detect it. This procedure is repeated until a set number of reversals has been obtained (typically 10). The average of the levels at which reversals took place is then taken as the threshold level. This procedure is repeated for as many frequencies as necessary to establish the complete audiogram.

Another approach is the 'constant stimulus' method. In this, at a particular frequency, a series of sessions of trials is carried out. In each session the signal is presented at the same level a number of times. Typically a total of 20 to 30 trials (including 'catch' trials) are done in a session. For each trial the subject responds as trained if it has heard the signal. At the end of the session the proportion of correct responses is calculated. The series of sessions starts with the signal set at a level known to be above the subject's threshold. Each subsequent session has its signal level reduced, typically by 2 to 4 dB, until a level is reached at which the subject responds correctly in only 50% of the trials. A few further sessions may take place, with the signal level increased, to verify the results. The 50% correct responses level is taken as the subject's threshold level for that frequency.

In both methods 'catch' trials, i.e. trials in which no signal is presented, are interspersed with trials in which signals *are* presented.

A major disadvantage with behavioural measurements of audiograms is that they require the compliance of the subject, and hence only work well with animals that can easily be trained. They are also very time consuming, both as a result of the training and as a result of the large number of individual trials that are required.

4.3. Evoked auditory potential methods

An alternative approach to finding the level of sound at which a response occurs is to directly measure the evoked auditory potential, or electrical impulse in the auditory nerves, that results from the sound. These methods, which were originally developed for use on non-compliant human subjects (babies and in the case of feigned deafness) have largely been used with fish, but some marine mammals have also been tested in this way.

In this approach, subcutaneous electrodes may be inserted in the subject's head to contact an auditory end organ and directly measure the evoked voltage. Less invasively, the electrodes may also be placed cutaneously (on the skin of the subject's head) to monitor in a far-field manner the activity in the eighth nerve and brainstem auditory nuclei. This latter approach is termed the 'auditory brainstem response' (ABR) method.

In a typical ABR measurement two electrodes are used, one of which is referred to as the 'recording' electrode and the other as the 'reference' electrode. The voltage between the two electrodes, of the order of µvolts, is input to the measuring apparatus. When the subject hears a signal there is a typical response waveform, the amplitude of which is dependent on the level of the sound it heard. The signal level is steadily reduced until the typical response pattern can no longer be discerned in the waveform, and the sound level at which this occurs is taken as the subject's threshold. A more complete description of this method is given in Appendix 1.

5. General comments on the audiograms

5.1. Fish audiograms

The fish audiograms that have been found and evaluated are summarised in Table 5.1.

The full details of the audiograms for each species are given in Appendix 2, including methods used to measure the audiogram.

5.2. Mammal audiograms.

The marine mammal audiograms that have been found and evaluated are listed in Table 5 2.

The full details of the audiograms for each species are given in Appendix 3.

5.3. Summary.

A detailed summary of the audiograms is impossible, as the assessment of the quality of any given audiogram will depend to some degree on the detail of the use that is to be made of it.

In the context of the estimation of the environmental effect of noise using the dB_{ht}(*Species*) scale, it may be summarised that:

1. the range of species for which audiograms are available represents a small subset of the marine animals that are of economic or conservational significance worldwide;
2. those audiograms that are available are generally of a lower quality than would be desirable as the basis of a robust dB_{ht}(*Species*) algorithm;
3. there are relatively few audiograms which have sufficient measurements, on sufficient individual animals, by enough different authors, to yield a high degree of confidence in their use or to be accepted as a “definitive” audiogram, and
4. the extremes of hearing (the upper and lower hearing band skirts) are in general more poorly documented than the peak hearing band.

Nonetheless, it is believed that estimates of environmental effect based on the dB_{ht}(*Species*) scale, albeit based on the existing imperfect audiograms presented in this report, will be a significant improvement over the estimates based on unweighted scales currently in use, which embody the assumption that all species have an equal hearing ability and an infinite hearing bandwidth.

It is thought likely that current concerns over the effects of underwater noise, and the prospective adoption of the dB_{ht}(*Species*) scale as a metric for estimation of the noise’ effect, will provide commercial pressures for the provision of good quality audiograms, as a requirement for the assessment of the effects of noise for Environmental Impact Assessments and other offshore activity. It is suggested that in due course there will be the need to provide a public domain repository of this information, and the means to encourage organisations conducting such studies to contribute their information to this repository. A publicly available standard for the dB_{ht}(*Species*), regularly updated to embody the best available information, could be an output of this exercise.

Table 5.1. Fish audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
African mouthbreeder	Fay, R.R. & Popper, A.N.	1975	Cylindrical PVC tank in soundproof chamber; in-air l'speaker	Microphonic potentials	10	Y	N/N	F/AfrcnMthbrdr/01
Bass	Lovell, J.	2003	Tank in underground room; in-air l'speaker	ABR			N/N	F/Bass/01
Bluegill sunfish	Scholik, A.R. & Yan, H.Y.	2002	Tank in sound-proof room; in-air l'speaker	ABR	6	Y (see note 1)	?/N	F/Bluegill/01
Bonefish	Tavolga, W.N.	1974	n/a	n/a	1			F/Bonefish/01
Carp	Popper, A.N.	1972	Tank in acoustic chamber; in-air l'speaker	Behavioural	6	N	Y/N	F/Carp/01
Catfish	Fay, R.R. & Popper, A.N.	1975	Cylindrical PVC tank in acoustic chamber; in-air l'speaker	Microphonic potentials	10	Y	N/N	F/Catfish/01
Clown knifefish	Coombs, S. & Popper, A.N.	1982	Tanks in acoustic chamber; in-air l'speaker	Behavioural	3	N	Y/N	F/Clown/01
Cod	Offutt, G.C.	1974	Tubular tank in rev. room; l'speaker built into wall of rev. room.	ECG - reduction of heart rate.	Varied with frequency - up to 20.	?	Y/N	F/Cod/01

Table 5.1 (contd.). Fish audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Cod	Chapman, C.J. & Hawkins, A.D.	1973	Cages in loch; u'water projectors	ECG - reductionof heart rate.	43	N	N/N	F/Cod/02
Cod	Buerkle, U.	1967	n/a	n/a	10			F/Cod/03
Cubbyu	Tavolga, W.N. & Wodinsky, J.	1963	Tank; u'water projector	Behavioural - shock avoidance	3	N	Y/Y	F/Cubbyu/01
Dab	Chapman, C.J. & Sand, P.	1974	Cages in loch; u'water projector	Cardiac potentials	3	N	N/N	F/Dab/01
Dab	Chapman, C.J. & Sand, P.	1973	n/a	n/a				F/Dab/02
Damselfish	Myrberg, A.A. & Spires, J.Y.	1980	Horizontal glass tube; u'water projector	Behavioural	4	N	Y/Y	F/Damsel/01
Damselfish, Beau-gregory	Myrberg, A.A. & Spires, J.Y.	1980	Horizontal glass tube; u'water projector	Behavioural	4	N	Y/Y	F/DamselBeauGregory/01
Damselfish, Beau-gregory	Tavolga, W.N. & Wodinsky, J.	1963	Tank; u'water projector	Behavioural	4	N	Y/Y	F/DamselBeauGregory/02

Table 5.1 (contd.). Fish audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Damselfish, bicolour	Ha, S.J.	1973	n/a	n/a	2	N	N/N	F/DamselBicolour/01
Damselfish, cocoa	Myrberg, A.A. & Spires, J.Y.	1980	Horizontal glass tube; u'water projector	Behavioural	3	N	Y/Y	F/DamselCocoa/01
Damselfish, honey gregory	Myrberg, A.A. & Spires, J.Y.	1980	Horizontal glass tube; u'water projector	Behavioural	2	N	Y/Y	F/DamselHoneyGregory/01
Damselfish, longfin	Myrberg, A.A. & Spires, J.Y.	1980	Horizontal glass tube; u'water projector	Behavioural	2	N	Y/Y	F/DamselLongfin/01
Damselfish, three spot	Myrberg, A.A. & Spires, J.Y.	1980	Horizontal glass tube; u'water projector	Behavioural	4	N	Y/Y	F/Damsel3Spot/01
Elephant nose fish	McCormick, C.A. & Popper, A.N.	1984	Tank in acoustic chamber; in-air l'speaker	Behavioural	Varied with frequency - up to 4	N	Y/N	F/ElephantNose/01
Fathead minnow	Scholik, A.R. & Yan, H.Y.	2001	Tank in sound-proof room; in-air l'speaker	ABR	6	Y (see note 1)	Overall level of 87dB re 1µPa when fish being held for recovery tests	F/Fathead/01
Goby	Lugli, M., Yan, H.Y. & Fine, M.I.	2003	Tank in sound-proof room; in-air l'speaker	ABR	5		N/N	F/Goby/01

Table 5.1 (contd.). Fish audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Goby	Lugli, M., Yan, H.Y. & Fine, M.I.	2003	Tank in sound-proof room; in-air l'speaker	ABR	4		N/N	F/Goby/02
Goby	Dijkgraaf, S.	1952	n/a	n/a	n/a			F/Goby/03
Goldfish	Yan, H.Y.	2001	Tank in sound-proof room; in-air l'speaker	ABR	6	Y (see note 1)	N/N	F/Goldfish/01
Goldfish	Kenyon, T.N, Ladich, F. & Yan, H.Y.	1998	Tank in sound-proof room; in-air l'speaker	ABR	8 sedated; 3 not sedated	Y (see note 1)	Y/Y	F/Goldfish/02
Goldfish	Yan, H.Y. & Popper, A.N.	1991	n/a	Behavioural	n/a			F/Goldfish/03
Goldfish	Popper, A.N.	1972	In tank; in-air l'speaker	Behavioural	12	N	N/N	F/Goldfish/04
Goldfish	Popper, A.N.	1971	n/a	n/a	3			F/Goldfish/05
Goldfish	Fay, R.R.	1969	n/a	n/a				F/Goldfish/06

Table 5.1 (contd.). Fish audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Goldfish	Offutt, G.C.	1968	Tank in acoustic chamber; u'water projector	ECG - reduction in heart rate	31			F/Goldfish/07
Goldfish	Jacobs, D.W. & Tavolga, W.N.	1967	Tank in acoustic chamber; in-air l'speaker	Behavioural	4	N	Y/Y	F/Goldfish/08
Goldfish	Enger, P.S.	1966	Trough-like tank; u'water projector & in-air l'speaker	Behavioural	6	N	N/N	F/Goldfish/09
Gourami, blue	Yan, H.Y.	2001	Tank in sound-proof room; in-air l'speaker	ABR	5	Y (see note 1)	N/N	F/GouramiBlue/01
Gourami, blue	Ladich, F & Yan, H.Y.	1998	Tank in sound-proof room; in-air l'speaker	ABR	11	Y (see note 1)	N/N	F/GouramiBlue/02
Gourami, blue	Saidel, W.M. & Popper, A.N.	1987	Vertical cast iron cylinder; u'water projector	Saccular micro-phonics	Between 4 and 9, depend-ing on freq tested.	Y	N/N	F/GouramiBlue/03
Gourami, croaking	Ladich, F & Yan, H.Y.	1998	Tank in sound-proof room; in-air l'speaker	ABR	11	Y (see note 1)	N/N	F/GouramiCroaking/01
Gourami, dwarf	Yan, H.Y.	2001	Tank in sound-proof room; in-air l'speaker	ABR	5	Y (see note 1)	N/N	F/GouramiDwarf/01

Table 5.1 (contd.). Fish audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Gourami, dwarf	Ladich, F & Yan, H.Y.	1998	Tank in sound-proof room; in-air l'speaker	ABR	9	Y (see note 1)	N/N	F/GouramiDwarf/02
Gourami, kissing	Yan, H.Y.	2001	Tank in sound-proof room; in-air l'speaker	ABR	5	Y (see note 1)	N/N	F/GouramiKissing/01
Gourami, kissing	Saidel, & Popper, A.N.	1987	Vertical cast iron cylinder; u'water projector	Saccular micro-phonics	Varied with frequency - up to 8	Y	N/N	F/GouramiKissing/02
Gourami, pygmy	Ladich, F & Yan, H.Y.	1998	Tank in sound-proof room; in-air l'speaker	ABR	9	Y (see note 1)	N/N	F/GouramiPygmy/01
Grunt, blue-striped	Tavolga, W.N. & Wodinsky, J.	1965	Tank; u'water projector	Behavioural	18	N	Y/N	F/GruntBlueStriped/01
Grunt, blue-striped	Tavolga, W.N. & Wodinsky, J.	1963	Tank; u'water projector	Behavioural	4	N	Y/Y	F/GruntBlueStriped/02
Haddock	Chapman, C.J.	1973	n/a	n/a	9			F/Haddock/01
Herring	Enger, P	1967	Trough-like tank; u'water projector	Microphonics	36		Y/N	F/Herring/01

Table 5.1 (contd.). Fish audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Ling	Chapman, C.J.	1973	n/a	n/a	1			F/Ling/01
Mexican blind cave fish	Popper, A.N.	1970	Tank in acoustic chamber; in-air l'speaker	Behavioural	6	N	Y/Y	F/MxcnCave/01
Mexican river fish	Popper, A.N.	1970	Tank in acoustic chamber; in-air l'speaker	Behavioural	11	N	Y/Y	F/MxcnRiver/01
Mormyrid	Yan, H.Y.	2001	Tank in sound-proof room;in-air l'speaker	ABR	4	Y (see note 1)	N/N	F/Mormyrid/01
Oscar	Kenyon, T.N, Ladich, F. & Yan, H.Y.	1998	Tank in sound-proof room; in-air l'speaker	ABR	8, of which 3 were sedated	Y (see note 1)	Y/Y	F/Oscar/01
Oscar	Yan, H.Y. & Popper, A.N.	1992	Tank in acoustic chamber; u'water projector	Behavioural	3	N	Y/N	F/Oscar/02
Oyster toadfish	Yan, H.Y.	2001	Tank in sound-proof room; in-air l'speaker	ABR	5	Y (see note 1)	N/N	F/OysterToadfish/01
Oyster toadfish	Fine, L.F.	1981	Tank; in-air l'speaker	Responses of fibres of saccular nerves	22, 106 units isolated from them	Y (see note (2)	Y/N	F/OysterToadfish/02

Table 5.1 (contd.). Fish audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Oyster toadfish	Fish, J.F. & Offutt, G.C.	1972	In lab., in concrete tank, in-air l'speaker. Also field tests.	n/a	3			F/OysterToadfish/03
Paradise fish	Ladich, F & Yan, H.Y.	1998	Tank in sound-proof room; in-air l'speaker	ABR	11	Y (see note 1)	N/N	F/Paradise/01
Perch	Wolff, D.L.	1967	n/a	n/a				F/Perch/01
Pike perch	Wolff, D.L.	1968	n/a	n/a				F/PikePerch/01
Pinfish	Tavolga, W.N.	1974	n/a	n/a				F/Pinfish/01
Pollack	Chapman, C.J.	1973	n/a	n/a	2			F/Pollack/01
Pollack	Chapman, C.J. & Hawkins, A.D.	1969	Tank in acoustic chamber; in-air l'speaker	Behavioural		N	N/N	F/Pollack/02
Red hind	Tavolga, W.N. & Wodinsky, J.	1963	Tank; u'water projector	Behavioural	1	N	Y/Y	F/RedHind/01

Table 5.1 (contd.). Fish audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Ruff	Wolff, D.L.	1968	n/a	n/a				F/Ruff/01
Salmon	Hawkins, A.D. & Johnstone, A.D.F.	1978	n/a	n/a				F/Salmon/01
Salmon	Hawkins, A.D. & Johnstone, A.D.F.	1976	n/a	n/a				F/Salmon/02
Sardine	Akamatsu, T., Nanami, T. & Yan, H.Y.	2003	Tank in acoustic chamber; inpair l'speaker	ABR	5		N/N	F/Sardine/01
Schoolmaster	Tavolga, W.N. & Wodinsky, J.	1963	Tank; u'water projector	Behavioural	3	N	Y/Y	F/Schoolmaster/01
Shad, American	Mann, D.A., Lu, Z. & Popper, A.N.	1997	n/a	Behavioural (heart rate reduc-tion)	5	N	N/N	F/Shad/01
Skate, little	Casper, B.M., Lobel, P.S. & Yan, H.Y.	2003	Tank; u'water projector. Tank in acoustic chamber; u'water projector	Behavioural & ABR	3 & 4	N	N/N	F/Skate/01
Slender sea robin	Tavolga, W.N. & Wodinsky, J.	1963	Tank; u'water projector	Behavioural	3	N	Y/Y	F/SeaRobin/01

Table 5.1 (concluded.). Fish audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Squirrelfish	Coombs, S. & Popper, A.N.	1979	Tank in acoustic chamber; in-air l'speakers	Behaavioural	3	N	Y/N	F/Squirrel/01
Squirrelfish	Coombs, S. & Popper, A.N.	1979	Tank in acoustic chamber; in-air l'speakers	Behaavioural	2	N	Y/N	F/Squirrel/02
Squirrelfish	Tavolga, W.N. & Wodinsky, J.	1963	Tank; u'water projector	Behavioural	5	N	Y/Y	F/Squirrel/03
Squirrelfish, dusky	Tavolga, W.N. & Wodinsky, J.	1963	Tank; u'water projector	Behavioural	3	N	Y/Y	F/SquirrelDusky/01
Tautog	Offutt, G.C.	1971	Tank in rev. chamber	Monitoring heart rate	14 in total, but reported results are for single fishes	N	N/N	F/Tautog/01 F/Tautog/02 F/Tautog/03
Wrasse, blue-head	Tavolga, W.N. & Wodinsky, J.	1963	Tank; u'water projector	Behavioural	4	N	Y/Y	F/WrasseBlueHd/01
Tuna, yellowfin	Iversen, R.	1967	n/a	n/a				F/TunaYellowfin/01

Notes: (1) Immobilised with Flaxedil
(2) Anaesthetised (ketamine), immobilised (Flaxedil).

Table 5.2. Marine mammal audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Dolphin, Amazon River	Popov, V. & Supin, A.	1990	In rectangular or circular tank	ABR	4	N	N/N	M/DolphinAmazon/01
Dolphin, Amazon River	Jacobs, D.W. & Hall, J.D.	1972	In circular tank	Behavioural - go/no-go. Started with subject resting its rostrum on cradle, and swimming to push paddle if it heard a signal.	1	N	Y/Y; possible masking at low freq.	M/DolphinAmazon/02
Dolphin, beluga	Popov, V. & Supin, A.	1990	In rectangular or circular tank	ABR	2	N	N/N	M/DolphinBeluga/01
Dolphin, bottlenose	Brill, R.L., Moore, P.W.B. & Dankiewicz, L.A.	2001	In pens in San Diego Bay	Used 'jawphones'. Go/no-go method - if heard a signal swam to paddle; if not stayed at station.	2	N	Y/Y	M/DolphinBottlenose/01
Dolphin, bottlenose	Turl, C.W.	1993	In pen at San Clemente Island, California.	Behavioural - go/no-go method.	1	N	Y/Y	X/DolphinBottlenose/01
Dolphin, bottlenose	Popov, V. & Supin, A.	1990	In rectangular or circular tank.	ABR.	4	N	N/N	M/DolphinBottlenose/02
Dolphin, Eastern Pacific bottlenose	Ljungblad, D.K., Scoggins, P.D. & Gilmartin, W.G.	1982	In circular tank with projecting trough.	Behavioural - go/no-go method.	1	N	Y/Y	M/DolphinBottlenose/03
Dolphin, bottlenose	Johnson, C.S.	1967	In circular wooden tank	Behavioural. Subject stationed in a 'stall' at side of tank. If it detected signal it swam to push a paddle	1	N	N/N	M/DolphinBottlenose/04

Table 5.2. (contd.). Marine mammal audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Dolphin, bottlenose	Johnson, C.S.	1966	n/a	n/a				M/DolphinBottlenose/05
Dolphin, Chinese river	Ding Wang, Kexiong Wang, Youfu Xiao & Gang Sheng.	1992	In circular concrete tank	Behavioural - go/no-go method.	1	N	Y/Y	M/DolphinChineseRiver/01
Dolphin, Risso's	Nachtigall, P.E., Au, W.W.L., Pawloski, J.L. & Moore, P.W.B.	1995	In floating enclosure in sea bay.	Behavioural - go/no-go method. Subject stationed in hoop. If it heard signal swam to touch a ball.	1	N	Y/Y. Level high, and comparable to threshold values	M/DolphinRisso/01
Dolphin, striped	Kastelein, R.A., Hagedoorn, M., Au, W.W.L. & de Haan, D.	2003	In indoor oval concrete pool.	Behavioural - go/no-go method. Subject moved to listening station. If it heard signal swam to response buoy, if not it stayed at station.	1	N	Y/Y. Level was low.	M/DolphinStriped/01
Dolphin, Tucuxi	Sauerland, M. & Dehnhardt, G.	1998	In rectangular concrete tank.	Behavioural - go/no-go method. If subject heard signal it swam to trainer, if not it stayed at station.	1	N	Y/Y	M/DolphinTucuxi/01
Dolphin, Tucuxi	Popov, V. & Supin, A.	1990	In rectangular or circular tank.	ABR	2	N	N/N	M/DolphinTucuxi/02
Manatee, West Indian	Gerstein, E.R., Gerstein, L., Forsythe, S.E. & Blue, J.E.	1999	In irregular shaped pools at park	Behavioural - subject had to go to 1 of 2 paddles depending on whether it had heard a signal or not.	2	N	Y/Y	M/Manatee/01

Table 5.2. (contd.). Marine mammal audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Manatee	Popov, V. & Supin, A.	1990	In rectangular or circular tank.	ABR	1	N	N/N	M/Manatee/02
Porpoise, harbour	Kastelein, R.A., Bunskoek, P., Hagedoorn, M., Au, W.L.W. & de Haan, D.	2002	In indoor oval concrete pool.	Behavioural - go/no-go.	1	N	Y/Y	M/PorpoiseHarbour/01
Porpoise, harbour	Bibikov, N.G.	1992	In rectangular tank, lined with sound-absorbing rubber.	ABR	1		N/N	M/PorpoiseHarbour/02
Porpoise, harbour	Popov, V.V., T.F. Ladygina & A.Ya. Supin.	1986	In rectangular tank.	Evoked potentials	4	N	N/N	M/PorpoiseHarbour/03
Porpoise, harbour	Andersen, S.	1970	n/a	n/a	1			M/PorpoiseHarbour/04
Sea lion, California	Kastak, D. and Schusterman, R.J.	2002	In open water, at depths of 50m and 100m.	Pushed paddle if heard signal.	1	N	N/N	M/SeaLionCalifornia/01
Sea lion, California	Kastak, D. & Schusterman, R.J.	1998	In air used earphones; in water used circular(?) tank	Behavioural - go/no-go. Subject rested at listening station; if it heard signal it pressed paddle in box with sliding side which was uncovered for each trial.	2 in water; 1 in air	N	Y/Y	M/SeaLionCalifornia/02

Table 5.2. (contd.). Marine mammal audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Sea lion, California	Kastak, D. & Schusterman, R.J.	1995	In air used ear-phones; in water used circular concrete tank	Behavioural. Both staircase and constant stimulus methods used. NOTE: Tests were for 100Hz signal only.	2	N	N/N	M/SeaLionCalifornia/03
Sea lion, California	Moore, P.W.B. & Schusterman, R.J.	1987	In-air tests, done inside rectangular wooden room	Behavioural - go/no-go. If subject heard signal it moved to push paddle, if not it stayed at station.	1	N	Y/Y	M/SeaLionCalifornia/04
Sea lion, California	Schusterman, R.J.	1974	In outdoor oval redwood tank. Subject's body was immersed, but its ears were out of the water.	Behavioural - subject had to emit burst of clicks if it had heard signal, remain silent if not.	1	N	N/N	M/SeaLionCalifornia/05
Sea lion, California	Schusterman, R.J., Balliet, R.F. & Nixon, J.	1972	n/a	n/a				M/SeaLionCalifornia/06
Seal, grey	Ridgway, S.H. & Joyce, P.L.	1975	In tank, which was drained for in-air tests.	Cortical evoked response	4	N	N/N	M/SealGrey/01
Seal, harbour	Wolski, L.F., Anderson, R.C., Bowles, A.E & Yochem, P.K.	2003	For behavioural tests, in foam-lined box. For ABR tests, strapped to a board.	For behavioural tests, go/no-go method.	1	For beha-vioural - N; for ABR - Y	N/N	M/SealHarbour/01

Table 5.2. (contd.). Marine mammal audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Seal, harbour	Kastak, D. & Schusterman, R.J.	1998	In water used circular(?) pool; in air used earphones on subject - subject was on haul-out area adjacent to pool.	Behavioural - go/no-go. Subject rested at listening station; if it heard signal it pressed paddle in box with sliding side which was uncovered for each trial.	1, in both air and water	N	Y/Y	M/SealHarbour/02
Seal, harbour	Kastak, D. & Schusterman, R.J.	1995	In water, in circular concrete pool. In air, on haul-out area adjacent to pool.	Behavioural. If subject detected signal, it had to press paddle. NOTE: Tests were for 100Hz signal only.	1	N	Y/Y	M/SealHarbour/03
Seal, harbour	Terhune, J & Turnbull, S.	1995		Behavioural.	1	N	N/N	X/SealHarbour/02 NOTE: This paper is a re-analysis of earlier experiments.
Seal, harbour	Terhune, J.M.	1989	Indoors, in circular tank	Behavioural - subject initiated playing of signal, and then had to press 1 of 2 levers depending on whether it had heard signal or not.	1	N	N/N	X/SealHarbour/01
Seal, harbour	Terhune, J.M.	1988	Indoors, in circular tank	Behavioural - subject initiated playing of signal, and then had to press 1 of 2 levers depending on whether it had heard signal or not.	1	N	Y/Y	M/SealHarbour/04

Table 5.2. (contd.). Marine mammal audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Seal, common	Mohl, B.	1968	In water, in pen in disused harbour; in air, on raft in harbour.	Behavioural - subject initiated playing of signal, and then had to press 1 of 2 levers depending on whether it had heard signal or not.	1	N	Y/Y	M/SealHarbour/05
Seal, common	Mohl, B.	1968	n/a	n/a				M/SealHarbour/06
Seal, harp	Terhune, J.M. & Ronald, K.	1972	Indoors, in circular tank	Behavioural - subject initiated playing of signal, and then had to press 1 of 2 levers depending on whether it had heard signal or not.	1	N	Y/Y	M/SealHarp/01
Seal, monk	Thomas, J., Moore, P., Withrow, R and Stoermer, M.	1990	In circular tank.	Behavioural - go/no-go. Subject rested at listening station; if it heard signal it moved to press response paddle.	1	N	N/N	M/SealHawaiinMonk/01
Seal, northern elephant	Kastak, D. & Schusterman, R.J.	1999	In air used ear-phones; in water used circular tank	Behavioural - go/no-go. Subject rested at listening station; if it heard signal it pressed paddle in box with sliding side which was uncovered for each trial.	1	N	In air: Y/N;in water: N/N	M/SealNthnElephant/01

Table 5.2. (contd.). Marine mammal audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Seal, northern elephant	Kastak, D. & Schusterman, R.J.	1998	In air used ear-phones; in water used circular(?) tank	Behavioural - go/no-go. Subject rested at listening station; if it heard signal it pressed paddle in box with sliding side which was uncovered for each trial.	1, in both air and water	N	Y/Y	M/SealNthnElephant/02
Seal, northern fur	Babushina, Ye.S., Zaslavskii, G.L. & Yurkevich, L.I.	1991	n/a	n/a	1			M/SealNthnFur/01
Seal, northern fur	Moore, P.W.B. & Schusterman, R.J.	1987	In-air tests, done inside rectangular wooden room. In-water tests done in rectangular above-ground concrete tank.	Behavioural - go/no-go. If subject heard signal it moved to push paddle, if not it stayed at station.	2	N	Y/Y	M/SealNthnFur/02
Seal, ringed	Terhune, J.M. & Ronald, K.	1975	In indoor wooden rectangular tank	Behavioural - subject initiated playing of signal, and then had to press 1 of 2 levers depending on whether it had heard signal or not.	2	N	N/N	M/SealRinged/01
Walrus, Pacific	Kastelein, R.A., Mosterd, P., van Santen, B., Hagedoorn, M. & de Haan, D.	2002	In outdoor concrete kidney-shaped pool	Behavioural - go/no-go.	1	N	Y/Y	M/WalrusPacific/01

Table 5.2. (concluded). Marine mammal audiograms.

Common name	Author(s)	Year	Location of experiments	Method	Number of subjects in experiment	Sedated?	Background noise measured/ reported	Page in database
Whale, Beluga	Johnson, C.S., McManus, M.W. & Skaar, D.	1989	Pen in San Diego Bay.	Behavioural - go/no-go.	1	N	N/N	M/WhaleBeluga/01
Whale, Beluga	Awbrey, F.T., Thomas, J.A. & Kastelein, R.A.	1988	In rectangular pool. Subject was under-water, but sound source was in air above its head.	Behavioural - go/no-go.	3	N	Y/Y	M/WhaleBeluga/02
Whale, Beluga	White, M.J. (jnr), Norris, J, Ljungblad, K & di Sciara, G.	1978	n/a	n/a	2			M/WhaleBeluga/03
Whale, false killer	Thomas, J., Chun, N, Au, W & Pugh, K.	1988	In irregular shaped pool.	Behavioural - go/no-go.	1	N	Y/N	M/WhaleFalseKiller/01
Whale, killer	Szymanski, M.D., Bain, D.E., Kiehl, K, Pennington, S., Wong, S. & Henry, K.R.	1999	In circular pool.	ABR and behavioural. In latter go/no-go method.	2	N	Y/Y	M/WhaleKiller/01
Whale, killer	Hall, J.D. & Johnson, C.S.	1972	In circular pool.	Behavioural - go/no-go.	1	N	Y/Y	M/WhaleKiller/02

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This section contains the references in the main text, but does not generally repeat those given in the database pages.

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Appendices

Appendix 1. The ABR method

This description of the auditory brainstem response method is based on that given in the paper "A comparative study of hearing ability in fishes: the auditory brainstem response approach" by T.N. Kenyon, F. Ladich and H.Y. Yan (1998).

A sketch of the experimental arrangement is given in Fig. A1.1. The subject is held in a nylon mesh 'sock' in a water tank, such that only the nape of its head, where the electrodes are fitted, is exposed. In fact, this area also is covered with some tissue to keep the top of the subject's head damp. A temperature-controlled gravity-feed aerated water system is used for respiration of the fish.

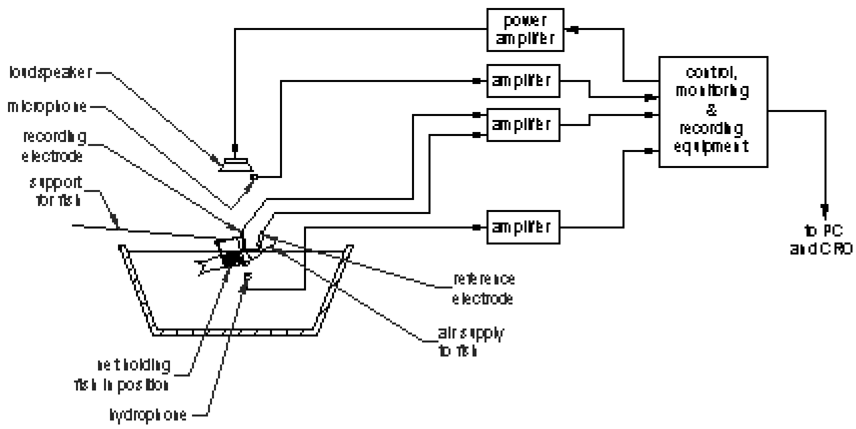


Fig. A1.1. Sketch of set-up for experiments.

The recording electrode is placed on the midline of the fish's skull over the medulla region. The reference electrode is placed 5 mm anterior to the recording electrode. The electrodes, which consist of 0.25 mm dia. Teflon-insulated silver wire with 1 mm of insulation removed at the tip, are pressed firmly against the subject's skin. The electrodes are connected to the differential inputs of an amplifier, care being taken to eliminate extraneous noise pick-up (twisted screened leads are used. The authors note that they used 40 dB of gain, and a passband of 30 Hz to 3 kHz for the tests carried out on goldfish). The amplifier's grounds are connected to the water in the test tank.

The loudspeaker used to generate the sound to which the fish is exposed is located in air above the subject; the particular loudspeaker used depends on the frequency range of the tests. A microphone located near the loudspeaker monitors its output. A hydrophone located near the exterior of the presumed inner ear of the fish monitors the sound level in the water.

In the authors' experiments the water tank was placed on a vibration-isolation table located in a soundproof chamber. The electrode and hydrophone amplifiers were also inside this chamber; the rest of the electronic apparatus was located outside the chamber.

The signals used can be clicks or tone bursts. The authors used clicks 0.1 ms in duration, presented at a rate of 38.2/sec. (this rate was used to prevent phase locking with any 60 Hz mains noise). The number of cycles in a tone burst is adjusted at each test frequency to get the best compromise between rapidity of build-up to steady level and duration of signal at the steady level (greater rapidity of build-up gives greater efficacy of ABR generation, while longer duration gives a sharper spectral peak). The authors used a Blackman window on the tone bursts to reduce spectral sidelobes and to provide ramped onsets and decays.

Typical stimulus and response waveforms for a tone burst are shown in Fig. A1.2, for (i) a goldfish (top curve) and (ii) an oscar (*Astronotus ocellatus*) (second curve). Here two bursts of opposite polarity have been presented and the responses overlaid. The authors used 1000 bursts of each polarity in their experiments, so that they had 2000 responses to establish an average response curve, and thereby eliminated stimulus artifacts. They also carried out this procedure twice at each test frequency to ensure that traces were repeatable.

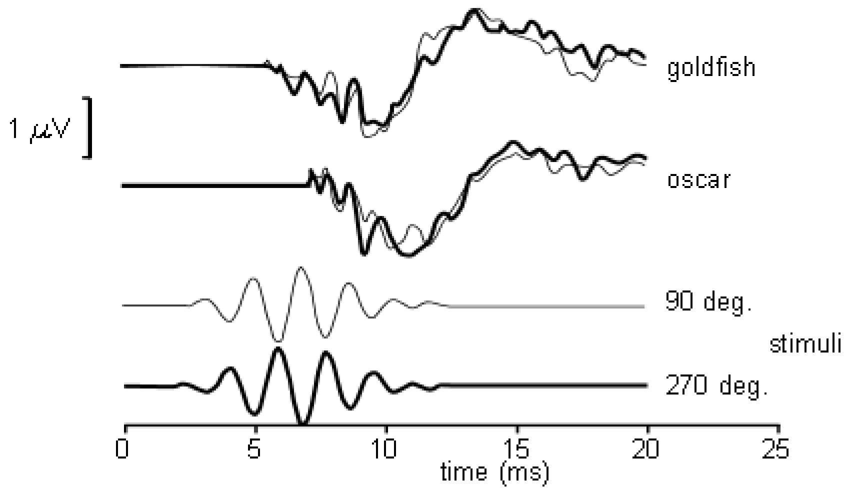


Fig.A1.2. Responses of a goldfish (top curve) and an oscar (second curve) to tone bursts of opposite polarities. Adapted from Kenyon, T.N. *et al* (1998).

The experiments start with the projected sound level above the expected threshold level at the test frequency, and the stimulus level is gradually reduced until a recognizable and repeatable ABR trace can no longer be discerned. Fig. A1.3 shows the responses obtained from tests on a goldfish by Lovell (Nedwell, J.R. (2003)). The level was reduced in 4 dB steps initially, and in 2 dB steps at the lower stimulus levels, until a recognizable and repeatable ABR trace could no longer be discerned. The lowest sound pressure level at which a repeatable trace could be obtained was taken as the threshold level at that frequency.

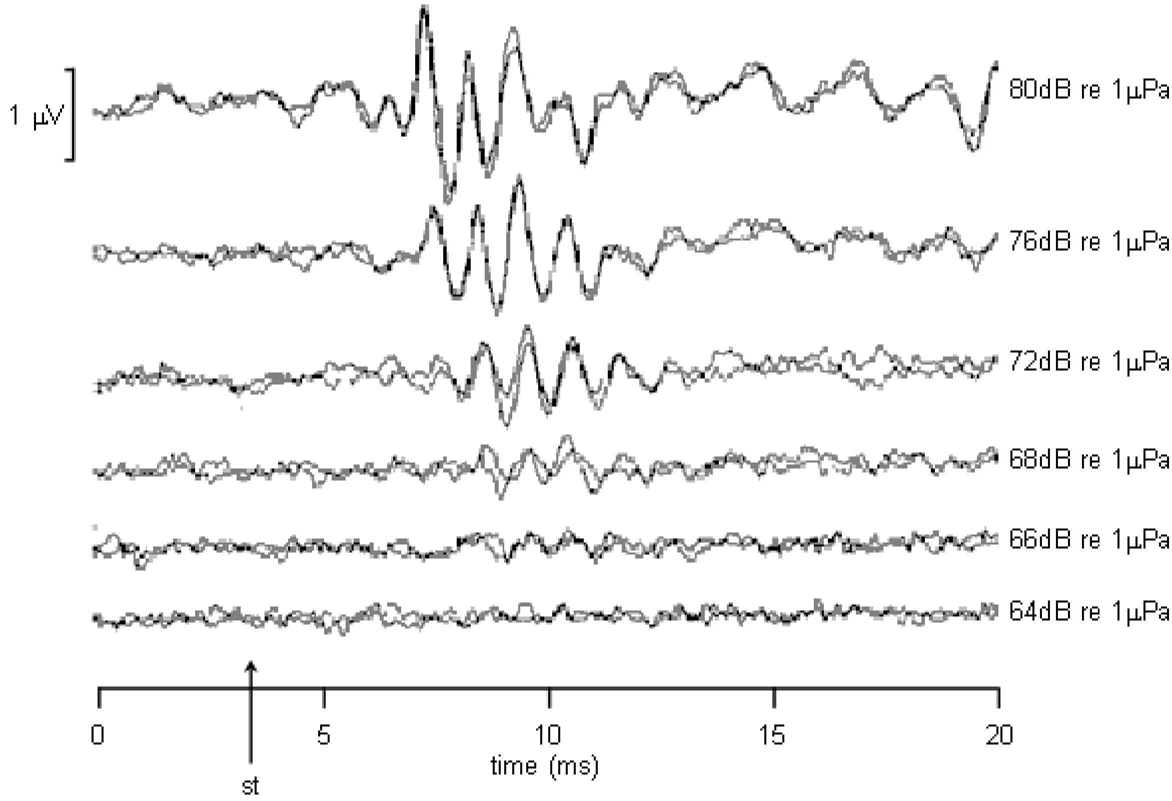


Fig. A1.3. ABR waveforms for a goldfish in response to a 500 Hz stimulus signal of reducing level. The averaged traces of two runs, each of 1000 sweeps, at each stimulus level, are overlaid. The arrow with the abbreviation 'st' indicates the arrival of the centre sinusoid of the stimulus sound. From Nedwell, J.R. ***et al*** **(2003).**

Appendix 2. Fish audiograms.

Common name	Database page ref.	Page number
African mouthbreeder	F/AfrcnMthbrdr/01	41
Bass	F/Bass/01	45
Bluegill sunfish	F/Bluegill/01	47
Bonefish	F/Bonefish/01	49
Carp	F/Carp/01	51
Catfish	F/Catfish/01	53
Clown knifefish	F/Clown/01	55
Cod	F/Cod/01	57
Cod	F/Cod/02	58
Cod	F/Cod/03	59
Cubbyu	F/Cubbyu/01	61
Dab	F/Dab/01	63
Dab	F/Dab/02	66
Damselfish	F/Damsel/01	68
Damselfish, Beau-gregory	F/DamselBeauGregory/01	70
Damselfish, Beau-gregory	F/DamselBeauGregory/02	72
Damselfish, bicolour	F/DamselBicolour/01	74
Damselfish, cocoa	F/DamselCocoa/01	75
Damselfish, honey gregory	F/DamselHoneyGregory/01	77
Damselfish, longfin	F/DamselLongfin/01	79
Damselfish, Three spot	F/Damsel3Spot/01	81
Elephant nose fish	F/ElephantNose/01	83
Fathead minnow	F/Fathead/01	85
Goby	F/Goby/01	87
Goby	F/Goby/02	88
Goby	F/Goby/03	89
Goldfish	F/Goldfish/01	91
Goldfish	F/Goldfish/02	92
Goldfish	F/Goldfish/03	93
Goldfish	F/Goldfish/04	94
Goldfish	F/Goldfish/05	96
Goldfish	F/Goldfish/06	97
Goldfish	F/Goldfish/07	98
Goldfish	F/Goldfish/08	100
Goldfish	F/Goldfish/09	101
Gourami, blue	F/GouramiBlue/01	104
Gourami, blue	F/GouramiBlue/02	105
Gourami, blue	F/GouramiBlue/03	106
Gourami, croaking	F/GouramiCroaking/01	108
Gourami, dwarf	F/GouramiDwarf/01	110
Gourami, dwarf	F/GouramiDwarf/02	111
Gourami, kissing	F/GouramiKissing/01	113
Gourami, kissing	F/GouramiKissing/02	114
Gourami, pygmy	F/GouramiPygmy/01	116
Grunt, blue-striped	F/GruntBlueStriped/01	118
Grunt, blue-striped	F/GruntBlueStriped/02	119
Haddock	F/Haddock/01	121
Herring	F/Herring/01	123
Ling	F/Ling/01	125

Mexican blind cave fish.................F/MxcnCave/01 127
Mexican river fish..........................F/MxcnRiver/01 129
Mormyrid.......................................F/Mormyrid/01 131
Oscar...F/Oscar/01 133
Oscar...F/Oscar/02 134
Oyster toadfish...............................F/OysterToadfish/01.. 136
Oyster toadfish...............................F/OysterToadfish/02.. 137
Oyster toadfish...............................F/OysterToadfish/03.. 138
Paradise fish...................................F/Paradise/01 140
Perch ....F/Perch/01.. 142
Pike perch F/PikePerch/01 144
Pinfish..F/Pinfish/01 146
Pollack ....F/Pollack/01.. 148
Pollack ....F/Pollack/02.. 149
Red hind...F/RedHind/01 151
Ruff..F/Ruff/01 153
Salmon...F/Salmon/01 155
Salmon...F/Salmon/02 157
Sardine...F/Sardine/01 159
Schoolmaster ....F/Schoolmaster/01.. 161
Shad, American ....F/Shad/01.. 43
Skate, little.....................................F/Skate/01.. 163
Slender sea robin F/SeaRobin/01 165
Squirrelfish ....F/Squirrel/01... 169
Squirrelfish ....F/Squirrel/02... 170
Squirrelfish ....F/Squirrel/03... 171
Squirrelfish, dusky.........................F/SquirrelDusky/01 167
Tautog..F/Tautog/01 173
Tautog..F/Tautog/02 174
Tautog..F/Tautog/03 175
Wrasse, blue-head..........................F/WrasseBlueHd/01 177
Yellowfin tuna F/TunaYellowfin/01 179

Database page ref: F/AfrcnMthbrdr/01.

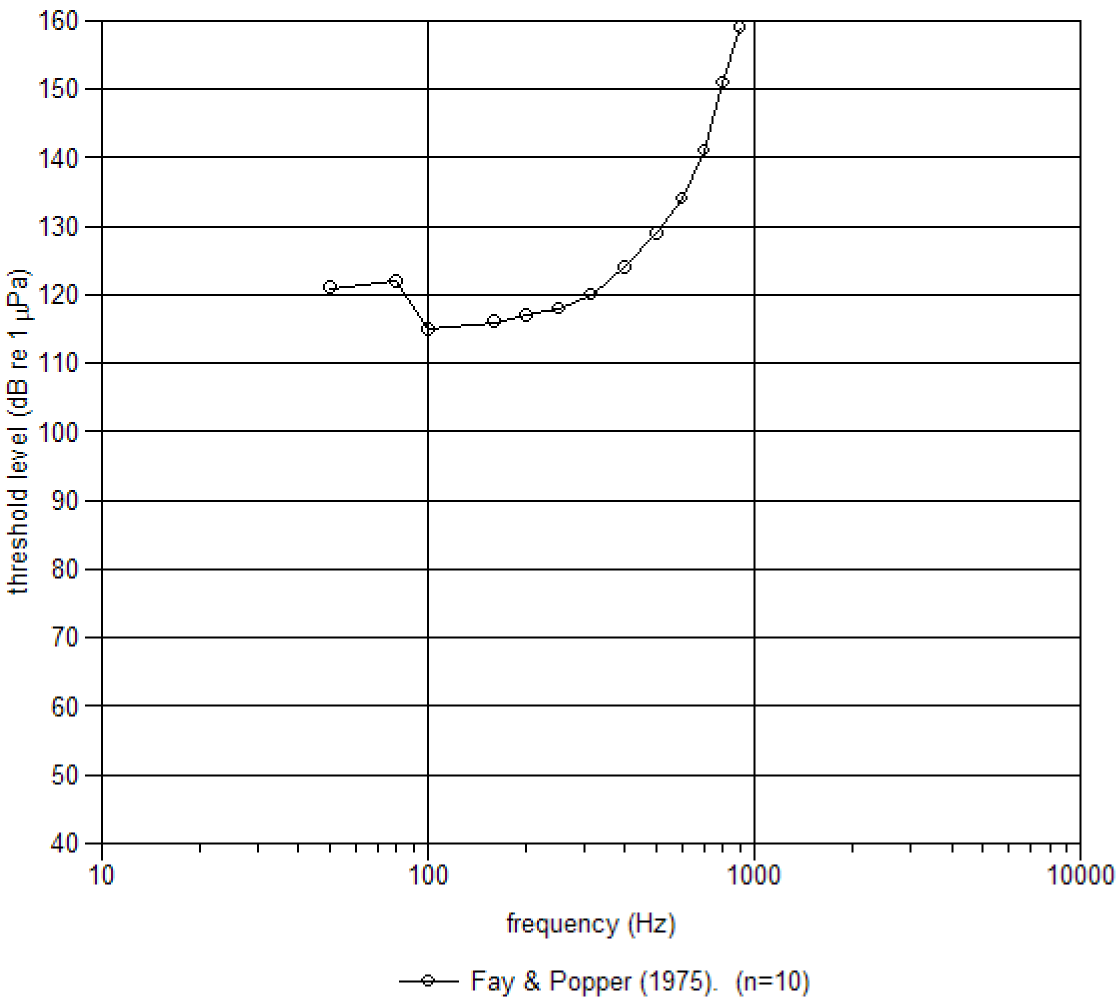
Common name	African mouthbreeder.
Family	
Species	*Tilapia macrocephala.*
Paper from which audiogram obtained	Fay, R.R. & Popper, A.N. (1975). Modes of stimulation of the teleost ear. J. Exp. Biol., 62, 370-387.
Paper having original audiogram data	Fay, R.R. & Popper, A.N. (1975). Modes of stimulation of the teleost ear. J. Exp. Biol., 62, 370-387.
Comments on methodology of getting audiogram	Microphonic potentials were recorded from the fishes' inner ears. Test vessel was a 250mm dia. PVC cylinder 200mm high filled to a height of 160mm. The bottom of the cylinder was made of 5mm thick Rho C rubber supported by a plastic grating. A 200mm dia. loudspeaker was suspended 250mm below the tank of water, facing upwards into an extension of the cylinder and forming an airtight cavity. Animals were anaesthetised and immobilised before surgery to implant a glass-insulated tungsten electrode to measure the saccular potential. They were submerged in the tank, and tonal sounds were produced by the loudspeaker. The electrode signals were filtered between 10Hz and 10kHz before being analysed in a wave analyser with a 10Hz bandwidth filter; the filter was set to twice the stimulus frequency (its 2nd harmonic). The sound pressure level which caused a 1µV RMS response from the inner ear was determined. SPLs were measured with a Clevite Model CH-17T hydrophone placed where the fish's ear would have been.
Any other comments	10 animals, of about 160mm standard length, were tested. All experiments were conducted in a double-walled soundproof acoustic chamber. The two ears in this species are not connected, so the saccular potential recordings were the responses from one ear. Tests were also done in which the potentials were recorded when the fish's head was vibrated, and also with the swimbladder filled with water; no loss of sensitivity at any frequencies was found. Some retesting of specimens was done.

Audiogram from Fig. 2(a). Threshold levels in dB re1µbar. Values are the levels which resulted in a 1µV RMS potential. 10 specimens.

Frequency (Hz)	50	80	100	160	200	250	315	400	500	600	700	800	900
Mean	21	22	15	16	17	18	20	24	29	34	41	51	59
SD	5	8	5	3	4	5	5	3	4	4	12	7	10

Threshold levels in dB re 1µPa.

Frequency (Hz)	50	80	100	160	200	250	315	400	500	600	700	800	900
Mean	121	122	115	116	117	118	120	124	129	134	141	151	159



[Fig. ref: AfrcnMthBrdr_G_01]

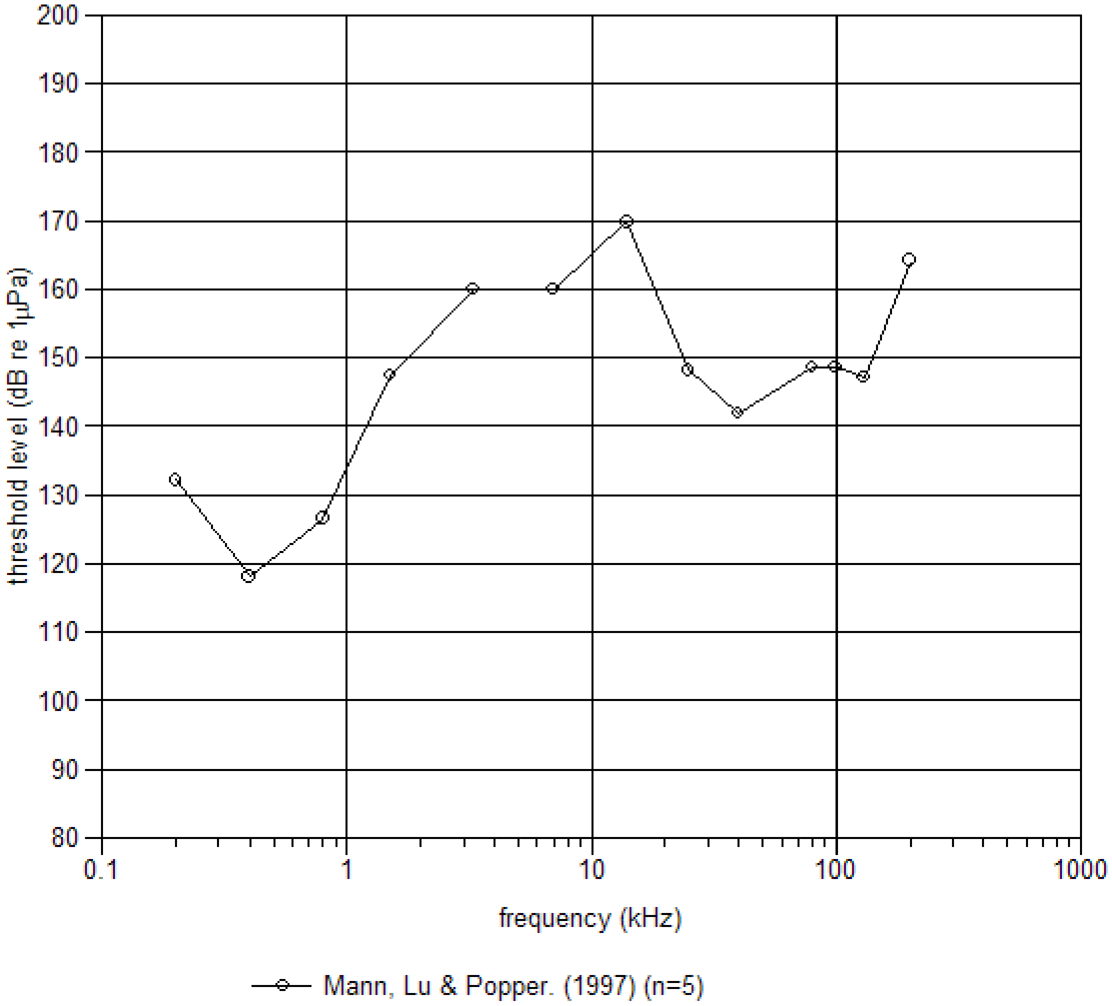
Audiogram for African mouthbreeder.

Database page ref: F/Shad/01.

Common name	American shad.
Family	
Species	*Alosa sapidissima.*
Paper from which audiogram obtained	Mann, D.A., Lu, Z. & Popper, A.N. (1997). A clupeid fish can detect ultrasound. Nature, 48:341. [25 Sept. 1997].
Paper having original audiogram data	
Comments on methodology of getting audiogram	Trained 5 fish to reduce their heart rates when they detected sound.
Any other comments	Notes that low frequency thresholds might have been masked by background noise (pumps)

Audiogram from Fig. 2. Threshold levels in dB re 1µPa.

Frequency (kHz)	0.2	0.4	0.8	1.5	3.3	7	14	25	40	80	100	130	200
Mean	132.1	118.2	126.5	147.5	160.0	160.0	169.8	148.2	141.9	148.6	148.6	147.2	164.2



[Fig. ref: AmericanShad01]

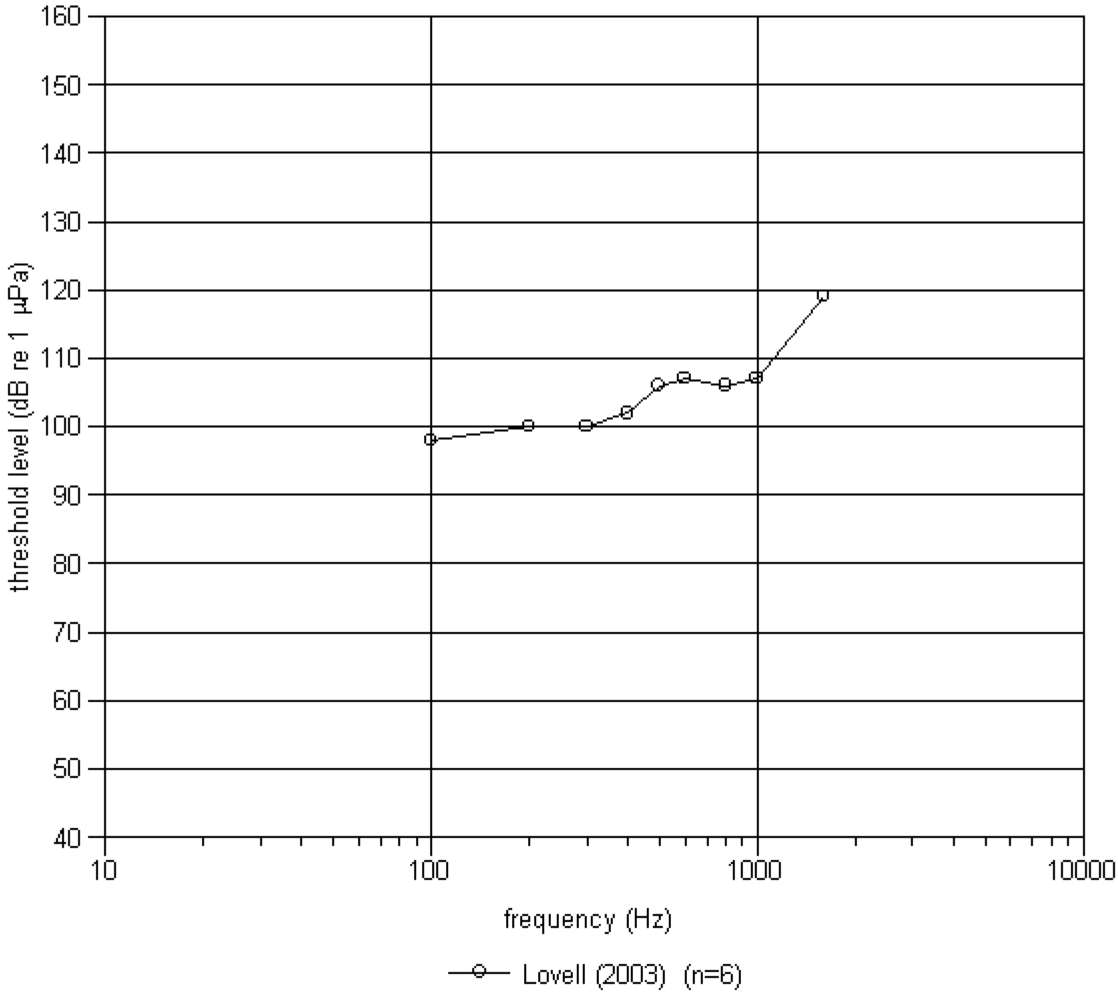
Audiogram for American shad.

Database page ref: F/Bass/01.

Common name	Bass
Family	
Species	*Dicentrarchus labrax*
Paper from which audiogram obtained	
Paper having original audiogram data	Audiogram supplied by J. Lovell.
Comments on methodology of getting audiogram	ABR method used, basically as described in Appendix 1. Subject was held in a block of soft foam saturated with seawater and held with the nape of its head just above the water surface. The electrodes were held in place by micromanipulators. Tests were done in a 0.45 x 0.3 x 0.2m plastic tank placed on a vibration-isolating table, inside a 3 x 2 x 2m underground room. The control equipment was located in an adjacent room. The 200mm dia. loudspeaker was located 1m above the fish, in a Faraday cage grounded in the control room. The stimuli were tone bursts, generated by a PC and amplified. The signals from the electrodes were amplified before being input to a Medelec MS6 system which was connected to the PC. The sound level at the fish's position was measured with a B&K Type 8106 hydrophone in the absence of the fish.
Any other comments	6 specimens.

Audiogram from figure supplied by J. Lovell . Threshold levels in dB re 1µPa. 6 specimens.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1600
Mean	98	100	100	102	106	107	106	107	119



[Fig. ref: Bass01]

Audiogram for bass

Database page ref: F/Bluegill/01.

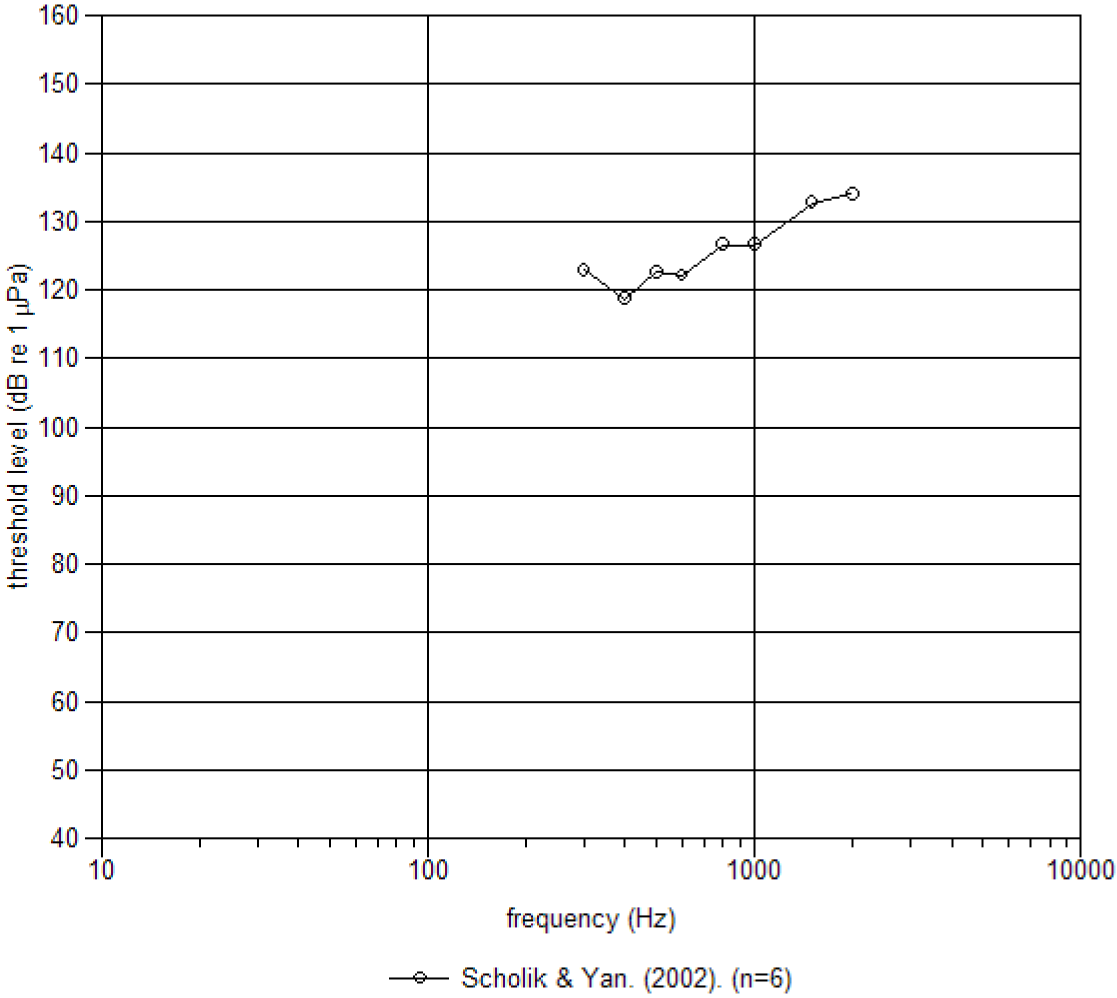
Common name	Bluegill sunfish
Family	
Species	*Lepomis macrochirus.*
Paper from which audiogram obtained	Scholik, A.R. & Yan, H.Y. (2002). The effects of noise on the auditory sensitivity of the bluegill sunfish, *Lepomis macrochirus*. Comp Biochem Physiol A, 133:43-52.
Paper having original audiogram data	Scholik, A.R. & Yan, H.Y. (2002). The effects of noise on the auditory sensitivity of the bluegill sunfish, *Lepomis macrochirus*. Comp Biochem Physiol A, 133:43-52.
Comments on methodology of getting audiogram	Specimens exposed to white noise for selected durations in a plastic tub (38 x 24.5 x 14.5cm), with 5.5cm water depth. Fish were free to swim about the tub during the exposure, but a mesh screen prevented them from jumping out of it. The noise was band limited to 300Hz to 2kHz, and at 142dB re 1μPa. The ABR technique was used to obtain the threshold values (see Appendix 1 for a description of the ABR method, and database page ref. F/Goldfish/02 for a description of the experimental set-up and method). Fish were sedated with Flaxedil. 2 aspects to experiment: (1) establishing thresholds immediately after exposures of 2, 4, 8 or 24 hrs; (2) establishing recovery after 24 hrs of exposure. For this latter, ABR tests were carried out after 1, 2, 4 or 6 days. Subjects were used in groups of 6 for each duration of exposure.
Any other comments	

Audiogram from Table 1. Threshold levels in dB re 1μPa.

Frequency (Hz)			300	400	500	600	800	1000	1500	2000
	Baseline	Mean	122.9	118.7	122.6	122.1	126.5	126.5	132.7	133.9
		SE	±1.3	±2.0	±1.9	±2.0	±1.3	±1.6	±1.5	±1.4
Duration of exposure	2 hrs	Mean	120.9	121.1	123.7	120.0	123.3	124.9	131.1	134.3
		SE	±1.6	±1.7	±1.1	±1.2	±0.9	±2.1	±2.5	±1.4
	4 hrs	Mean	124.4	124.0	125.0	123.9	125.7	125.1	134.2	134.7
		SE	±1.2	±2.3	±1.9	±2.5	±2.1	±1.4	±1.7	±0.9
	8 hrs	Mean	125.3	122.7	124.9	125.8	127.4	128.2	129.1	133.1
		SE	±1.1	±1.8	±0.9	±1.0	±1.4	±1.1	±3.3	±2.4
	24 hrs	Mean	125.0	122.2	123.2	126.1	128.2	128.3	136.1	138.7
		SE	±1.5	±1.2	±1.5	±1.1	±1.3	±2.0	±1.2	±1.4

Audiogram from Table 1. Levels after stated recovery period after 24 hrs exposure to noise. Threshold levels in dB re 1μPa.

Frequency (Hz)			300	400	500	600	800	1000	1500	2000
Elapsed time since cessation of exposure to noise for 24 hrs.	1 day	Mean	124.1	123.7	126.5	125.9	125.7	127.7	129.0	137.1
		SD	±1.1	±0.2	±1.6	±2.4	±2.1	±1.8	±4.6	±2.7
	2 days	Mean	121.3	118.9	119.0	120.3	125.1	124.6	127.8	137.7
		SD	±1.5	±1.9	±1.7	±1.0	±1.9	±2.3	±1.7	±1.6
	4 days	Mean	118.8	120.6	124.6	124.4	125.2	126.8	131.9	138.6
		SD	±1.7	±1.6	±1.9	±1.8	±2.1	±1.2	±1.2	±1.0
	6 days	Mean	122.2	121.8	121.9	121.8	123.2	126.5	135.3	137.8
		SD	±3.0	±1.3	±2.8	±3.3	±2.5	±2.1	±0.9	±1.9



[Fig. ref: BluegillSunfish01]

Audiogram for bluegill sunfish (baseline results).

Database page ref: F/Bonefish/01.

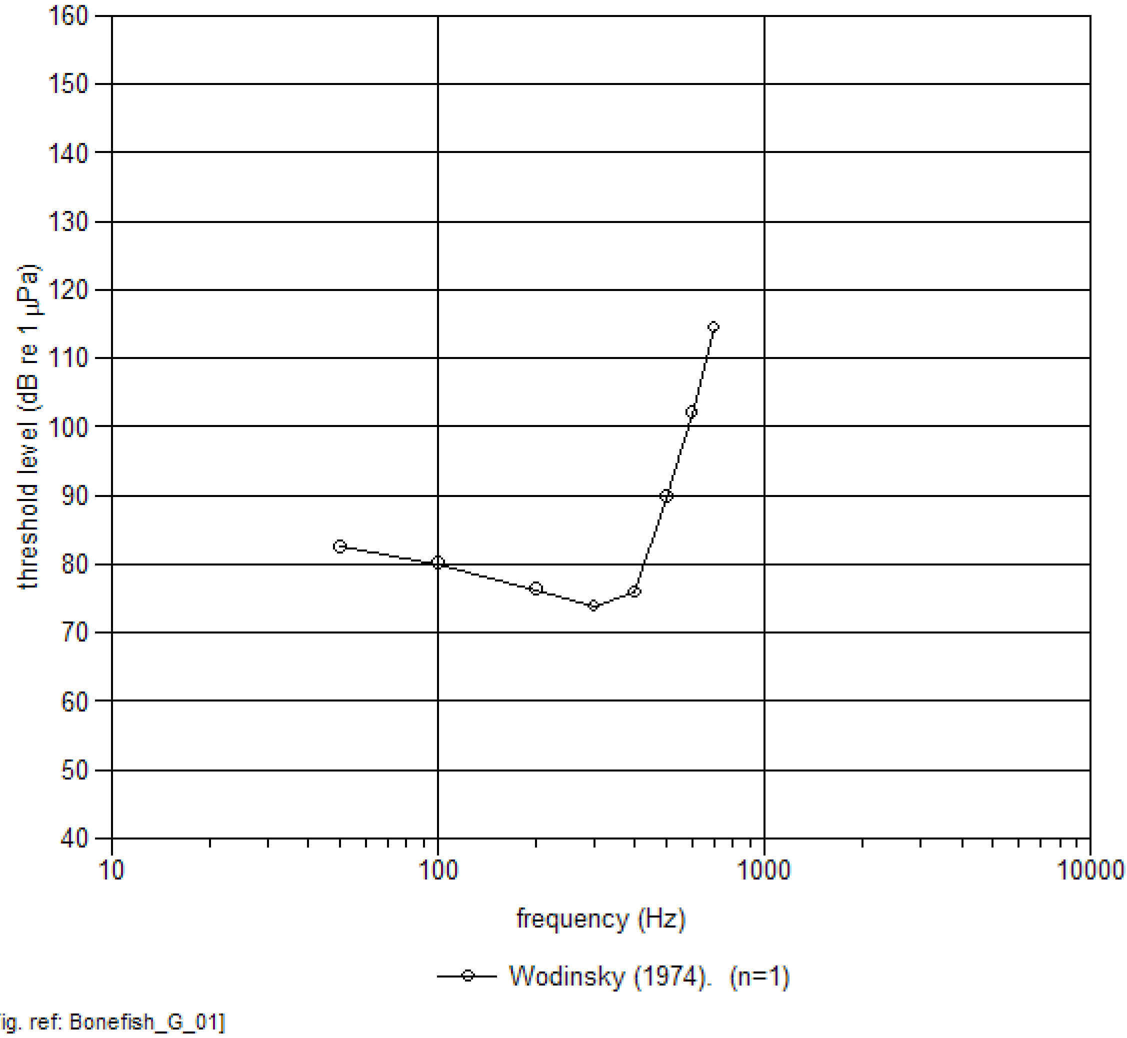
Common name	Bonefish.
Family	
Species	*Albula vulpes.*
Paper from which audiogram obtained	Fay, R.R. (1988). Hearing in Vertebrates: A Psychophysics Databook. Hill-Fay Associates, Winnetka, Ill.
Paper having original audiogram data	Tavolga, W.N. (1974). Sensory parameters in communication among coral reef fishes. Mt. Sinai J. Med., 41, 324-340.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	1 specimen tested. Thresholds below 400Hz likely to have been masked by ambient noise.

Audiogram from Table F8-0. Threshold levels in dB re 1 dyne/cm^2. 1 specimen.

Frequency (Hz)	50	100	200	300	400	500	600	700
Mean	-17.5	-19.9	-23.7	-26.1	-24.1	-10.3	2	14.5

Threshold levels in dB re 1µPa.

Frequency (Hz)	50	100	200	300	400	500	600	700
Mean	82.5	80.1	76.3	73.9	75.9	89.7	102	114.5



Audiogram for bonefish

Database page ref: F/Carp/01.

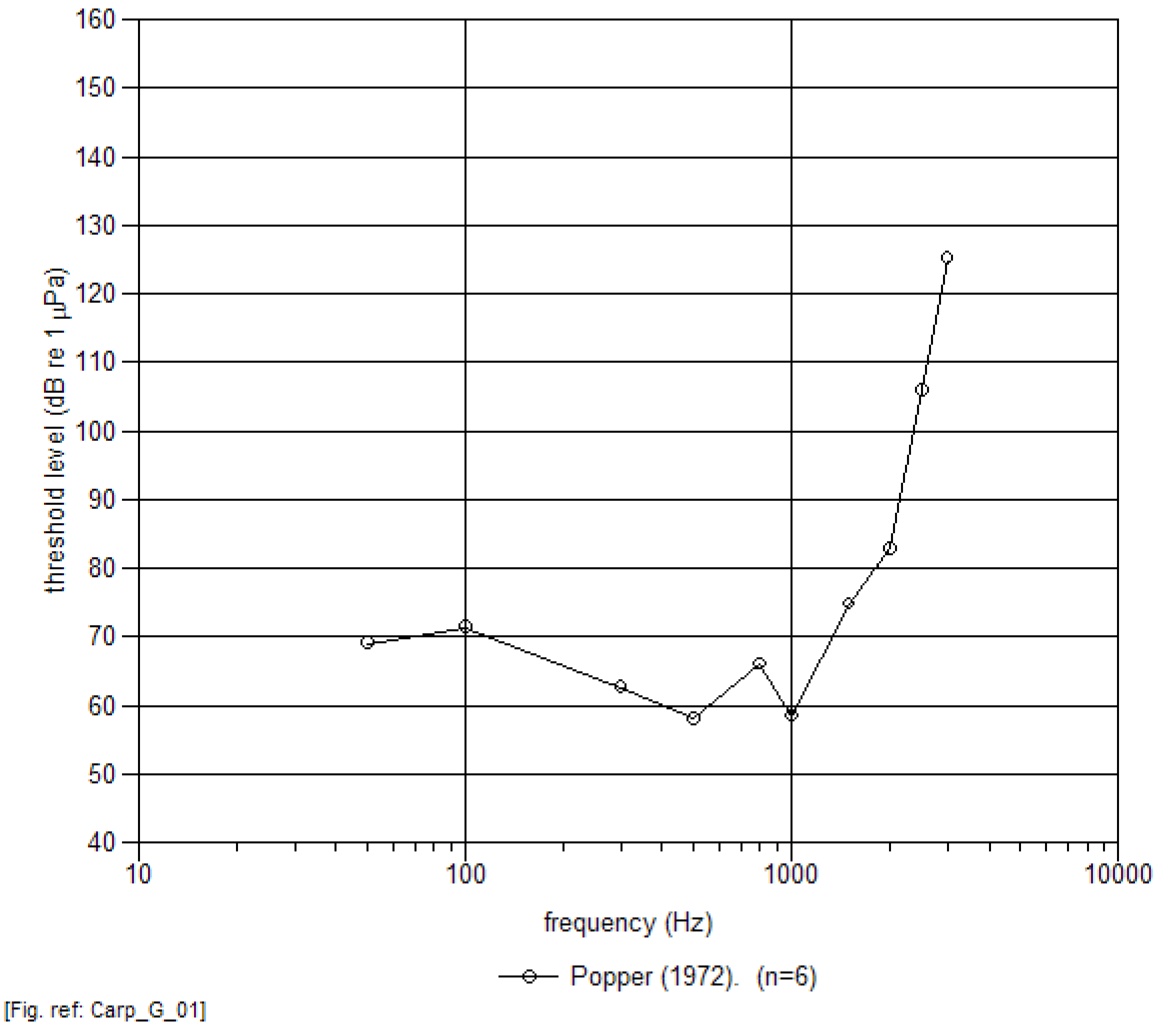
Common name	Carp. (Japanese or Koi).
Family	
Species	*Cyprinus carpio.*
Paper from which audiogram obtained	Popper, A.N. (1972). Pure-tone auditory thresholds for the carp, *Cyprinus carpio*. JASA, 52(6) Part 2, 1714-1717.
Paper having original audiogram data	Popper, A.N. (1972). Pure-tone auditory thresholds for the carp, *Cyprinus carpio*. JASA, 52(6) Part 2, 1714-1717.
Comments on methodology of getting audiogram	Avoidance conditioning procedure used for tests. Fish were trained to cross barrier in middle of tank whenever a pure tone was presented through a loudspeaker in air about 100mm from the test tank. If fish failed to cross barrier when sound was presented it had not detected it. Thresholds were calculated at the 50% threshold level using the up-down staircase method, with at least 20 changes between sound detection and no detection averaged for each day's threshold determination for each animal. Test tank was placed in an acoustic chamber to reduce ambient noise. Apparatus and methods fully described in Popper (1972), JASA 51(1):596-603.
Any other comments	6 animals, 50 to 60mm in standard length, were tested. Sound spectrum levels (ambient noise) were found to be considerably below the threshold levels for the animals at each frequency (no more details given). Carp are in the superorder Ostariophysi, which are considered to have considerably better auditory capabilities in terms of range of sensitivity and in absolute sensitivity at each frequency. Enhanced abilities are related to the presence of a series of bones, the Weberian ossicles, connecting the sound detector, the swim bladder, to the inner ear. They enhance acoustic sensitivity by closely coupling the swim bladder to the inner ear.

Audiogram from Table I. Threshold levels in dB re 1µbar. 6 specimens.

Frequency (Hz)	50	100	300	500	800	1000	1500	2000	2500	3000
Mean	-31.0	-28.6	-37.4	-42.0	-34.0	-41.6	-25.2	-17.2	+5.9	+25.1
Range – upper	-21.8	-22.1	-28.7	-33.4	-27.8	-32.8	-18.4	-12.3	+15.2	+31.4
Range – lower	-40.0	-38.0	-46.9	-47.0	-41.8	-51.9	-35.6	-27.0	-3.3	+20.9
SD	7.09	5.41	4.84	5.81	5.78	6.30	4.59	5.36	5.64	3.45
No. of determinations	9	10	12	16	15	16	15	14	14	12

Threshold levels in dB re 1µPa.

Frequency (Hz)	50	100	300	500	800	1000	1500	2000	2500	3000
Mean	69	71.4	62.6	58	66	58.4	74.8	82.8	105.9	125.1



Audiogram for carp.

Database page ref: F/Catfish/01.

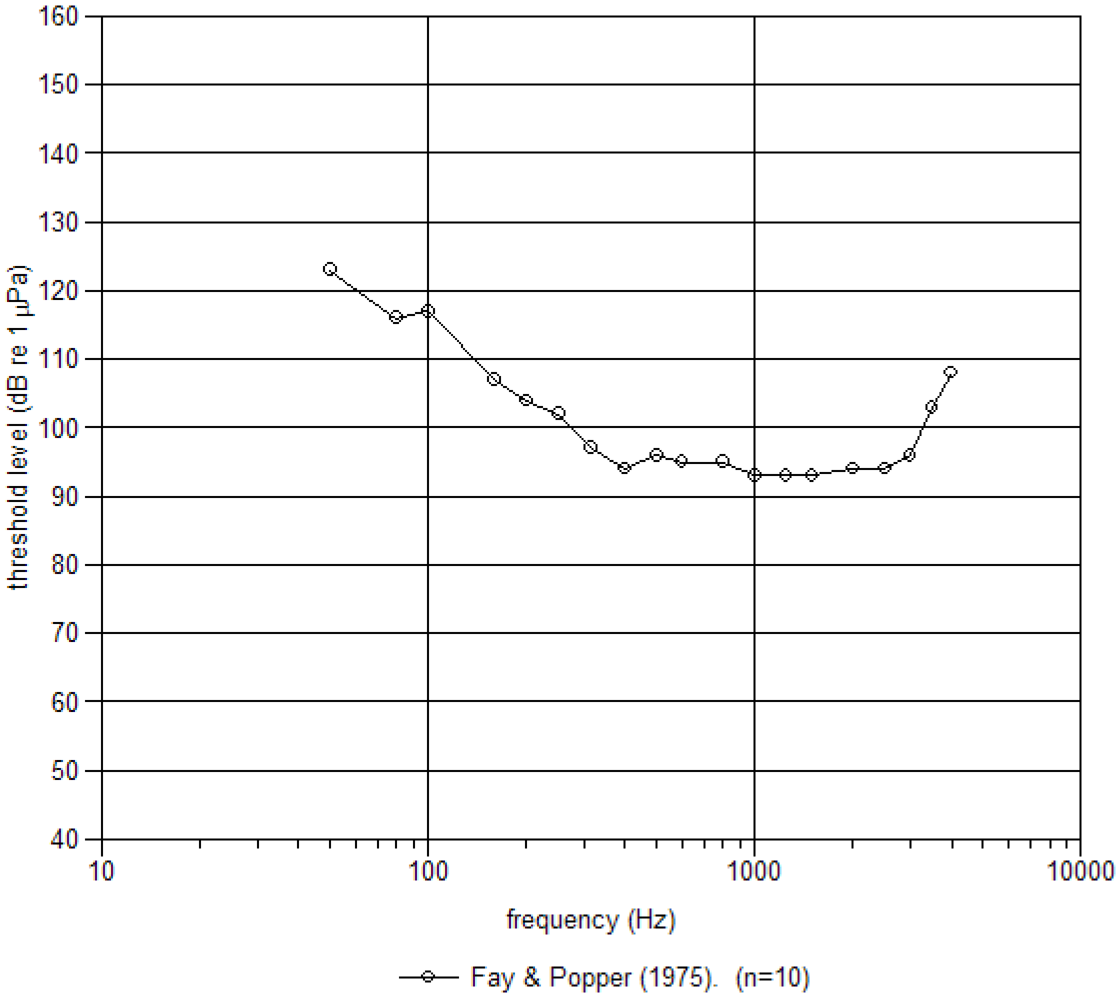
Common name	Catfish.
Family	
Species	*Ictalurus punctatus.*
Paper from which audiogram obtained	Fay, R.R. & Popper, A.N. (1975). Modes of stimulation of the teleost ear. J. Exp. Biol., 62, 370-387.
Paper having original audiogram data	Fay, R.R. & Popper, A.N. (1975). Modes of stimulation of the teleost ear. J. Exp. Biol., 62, 370-387.
Comments on methodology of getting audiogram	Microphonic potentials were recorded from the fishes' inner ears. Test vessel was a 250mm dia. PVC cylinder 200mm high filled to a height of 160mm. The bottom of the cylinder was made of 5mm thick Rho C rubber supported by a plastic grating. A 200mm dia. loudspeaker was suspended 250mm below the tank of water, facing upwards into an extension of the cylinder and forming an airtight cavity. Animals were anaesthetised and immobilised before surgery to implant a glass-insulated tungsten electrode to measure the saccular potential. They were submerged in the tank, and tonal sounds were produced by the loudspeaker. The electrode signals were filtered between 10Hz and 10kHz before being analysed in a wave analyser with a 10Hz bandwidth filter. The sound pressure level which caused a 1μV RMS response from the inner ear was determined. SPLs were measured with a Clevite Model CH-17T hydrophone placed where the fish's ear would have been.
Any other comments	10 animals, of about 200mm standard length, were tested. All experiments were conducted in a double-walled soundproof acoustic chamber. The two ears in this species are connected, so the saccular potential recordings were the summed response from the two ears. Tests were also done in which the potentials were recorded when the fish's head was vibrated, and also with the swimbladder filled with water. This last test resulted in a loss of sensitivity at all frequencies above 100Hz, with losses of 30dB or greater above 200Hz. Some retesting of specimens was done.

Audiogram from Fig. 1(a). Threshold levels in dB re 1μbar. Values are the levels which resulted in a 1μV RMS potential. 10 specimens.

Frequency (Hz)	50	80	100	160	200	250	315	400	500	600
Mean	23	16	17	7	4	2	-3	-6	-4	-5
SD	7	11	7	13	5	5	5	4	4	6
Frequency (Hz)	800	1000	1250	1500	2000	2500	3000	3500	4000	
Mean	-5	-7	-7	-7	-6	-6	-4	3	8	
SD	5	5	7	7	6	6	5	5	7	

Threshold levels in dB re 1μPa.

Frequency (Hz)	50	80	100	160	200	250	315	400	500	600
Mean	123	116	117	107	104	102	97	94	96	95
Frequency (Hz)	800	1000	1250	1500	2000	2500	3000	3500	4000	
Mean	95	93	93	93	94	94	96	103	108	



[Fig. ref: Catfish_G_01]

Audiogram for catfish.

Database page ref: F/Clown/01.

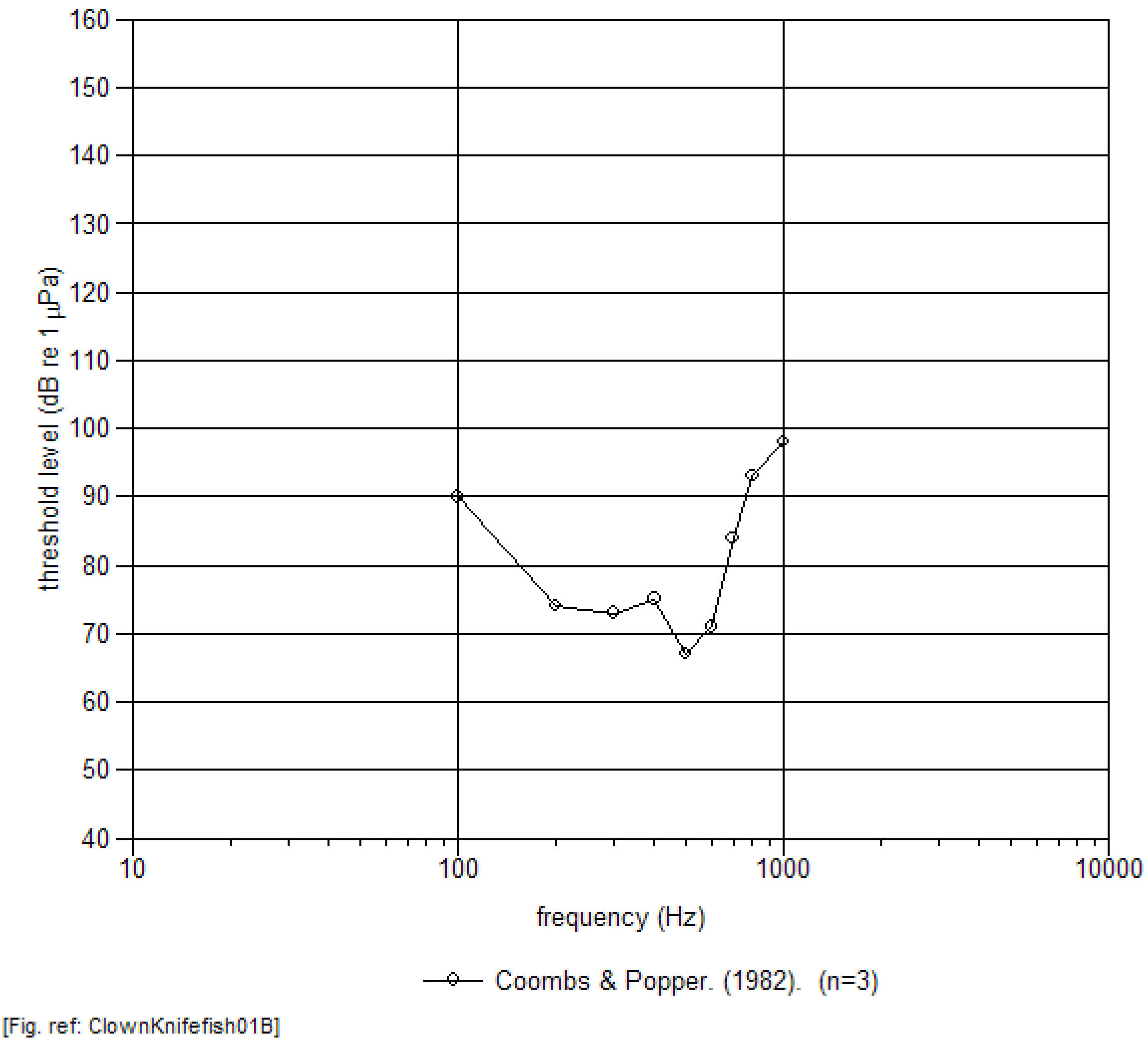
Common name	Clown knifefish.
Family	Notopteridae.
Species	*Notopterus chitala.*
Paper from which audiogram obtained	Coombs, S. & Popper, A.N. (1982). Structure and function of the auditory system in the clown knifefish, *Notopterus chitala*. J. Exp. Biol., 97:225-239.
Paper having original audiogram data	Coombs, S. & Popper, A.N. (1982). Structure and function of the auditory system in the clown knifefish, *Notopterus chitala*. J. Exp. Biol., 97:225-239.
Comments on methodology of getting audiogram	Both ultrastructural and behavioural studies were conducted. Ultrastructural procedures involved dissection and decapitation in order to assess the association between the ear and anterior projections of the swim bladder. Behavioural auditory sensitivity was determined using operant conditioning techniques. Fish were trained to cross a hurdle in the center of a tank when sound was presented to avoid being given an electric shock. Hearing sensitivity was measured using the 'up-down staircase' method. The sound pressure level was decreased by 5dB following each avoidance response and increased by 5dB following each non-detection. Test tanks (2 were used) were placed in sound-attenuated rooms which had 200mm thick walls filled with sand; ambient noise was attenuated by at least 20dB at 50Hz, and more at higher frequencies. The sound source was a single 203mm diameter speaker above the test tank.
	3 specimens were tested. SPLs were measured at 10 locations in the two tanks used at frequencies from 100Hz to 1kHz. The levels had ranges of up to 21dB, and standard deviations about the mean of up to 6.3dB. The median values were used as the final calibration value for each test frequency. Vertical particle velocity was also measured with a velocity hydrophone at four positions. Authors tabulate all the threshold values determined for each specimen, as well as the pooled means. They note that the range of threshold values at 400Hz was 55dB, and the smallest range was about 20dB (Fig. 2(B)). Also, in some cases, there was variability in thresholds in a single test session. In Fig. 1 they present the sound levels as they were presented in one session – the threshold appeared to stabilize at a high value for several trials but then abruptly dropped to a much lower value, where it again stabilized, and then finally returned to the higher level. *Notopterus* belongs to the superorder Osteoglossomorpha, a group in which there is wide variation in structural features of the auditory system. *Notopterus* in particular has a close physical relationship between the inner ear and the swimbladder. As far as is known, no other vertebrate saccular macula is divided into distinct regions along the otolith as it is in *Notopterus*.

Audiogram from Fig. 8-1. Threshold levels in dB re 1dyne/sq.cm. 3 specimens.

Frequency (Hz)	100	200	300	400	500	600	700	800	1000
Mean	-10	-26	-27	-25	-33	-29	-16	-7	-2
SD	8.4	7.7	12.0	10.3	10.3	10.1	10.2	5.7	5.9
Number of determinations	10	10	22	221	25	13	15	10	13

Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	300	400	500	600	700	800	1000
Mean	90	74	73	75	67	71	84	93	98



Audiogram for clown knifefish.

Database page ref: F/Cod/01.

Common name	Atlantic Cod
Family	Gadidae
Species	*Gadus morhua* L.
Paper from which audiogram obtained	Offutt, G.C. (1974). Structures for the detection of acoustic stimuli in the Atlantic codfish, *Gadus morhua*. JASA, 56(2), 665-671.
Paper having original audiogram data	Offutt, G.C. (1974). Structures for the detection of acoustic stimuli in the Atlantic codfish, *Gadus morhua*. JASA, 56(2), 665-671.
Comments on methodology of getting audiogram	Fish was held in a nylon mesh net in a tubular tank 530mm long, 305mm dia, laid on its side in a wooden framework, which in turn was inside a 1.13m^3 rev. chamber. The water level in the test tank was maintained constant. Rev. chamber and all test equipment were housed in an underground, reinforced concrete room. A 410mm speaker was built into the wall of the rev. chamber. Test signals were pure tones. ECGs were obtained using an electrode inserted in the pericardial cavity. Classical conditioning of heart rate was used to determine a threshold; reduction of heart rate indicated fish had heard signal. Thresholds were determined by a staircase procedure, with 2dB steps in stimulus level and a minimum of 10 reversals.
Any other comments	Sound field in tank was found to be uniform within 3dB, except, for pressure, at 18.7Hz (6dB re 1µbar), 37.5Hz (4dB), 500Hz (8dB), and, for particle velocity, at 75Hz (9dB re 1µvar), 300Hz (10dB). Ambient noise was below the instrumentation noise level (pressure spectrum level -42dB re 1µbar). Tests also done with the fishes' labyrinth, lateral line and swimbladder surgically modified.

Audiogram from Fig. 6. Threshold levels in dB re 1µbar. Data for fishes with unmodified labyrinths and lateral lines.

Frequency (Hz)	10	20	37.5	75	150	300	600
Mean	-17.2	-36.6	-24.6	-31.1	-35.2	-24.6	39
Range, high	3.6	5.8	2.9	5.4	3.4	4.0	4.3
Range, low	-4.3	-4.5	-3.9	-3.0	-3.2	-5.6	-4.1
SD			2.2	3.0	2.2	3.4	2.8
No. of fish	4	3	6	5	20	6	6

Threshold levels in dB re 1µPa.

Frequency (Hz)	10	20	37.5	75	150	300	600
Mean	82.8	63.4	75.4	68.9	64.8	75.4	139.0

Database page ref: F/Cod/02.

Common name	Cod
Family	Gadidae
Species	*Gadus morhua.*
Paper from which audiogram obtained	Hawkins, A.D. & Myrberg, A.A. (jnr). (1983). Hearing and sound communication under water. In: Bioacoustics: a comparative approach. B. Lewis (ed.), pp. 347-405. Academic Press, New York.
Paper having original audiogram data	Chapman, C.J. and Hawkins, A.D. (1973). A field study of hearing in the Cod, *Gadus morhua* L. Journal of comparative physiology, 85: 147-167.
Comments on methodology of getting audiogram	Experiments were performed upon a framework immersed in the sea 100m offshore. The top of the framework was 15m below the sea surface and 6m above the seabed. Netlon test cages were mounted at the top of the framework with built-in stainless steel electrodes. 2 sound projectors were placed on a line from the shore at right angles to the axis of the cage. Signals from the hydrophone were amplified by a low-noise amplifier to within the frequency 10Hz – 1kHz. For some experiments a high level of random noise was continuously transmitted from the sound projector and the pure tone stimulus superimposed. 43 immature cod in the length range 21-47cm were used for testing. Fish were anaesthetized in a 1 part in 15000 solution of MS-222. Small silver or stainless steel electrodes were inserted subcutaneously in the ventral aspect, to detect electric potentials from the heart.
Any other comments	Cod have a rather restricted frequency range. Sensitivity to sound pressure indicates that the gas-filled swim bladder may be involved in the hearing of cod, although there is no direct coupling with the labyrinth. At lower frequencies high amplitudes were obtained close to source suggesting sensitivity to particle displacement. Hearing thresholds are determined by the sensitivity of the otilith organs to particle displacements re-radiated from the swimbladder.

Audiogram from Fig. 14. Threshold levels in dB re 1μbar.

Frequency (Hz)	30	40	50	60	100	160	200	300	400	450
Mean	-9.0	-9.6	-16.9	-20.2	-22.7	-24.7	-18.4	-18.8	-15.3	10.2

Threshold levels in dB re 1μPa.

Frequency (Hz)	30	40	50	60	100	160	200	300	400	450
Mean	91	90.4	83.1	79.8	77.3	75.3	81.6	81.2	84.7	110.2

Database page ref: F/Cod/03.

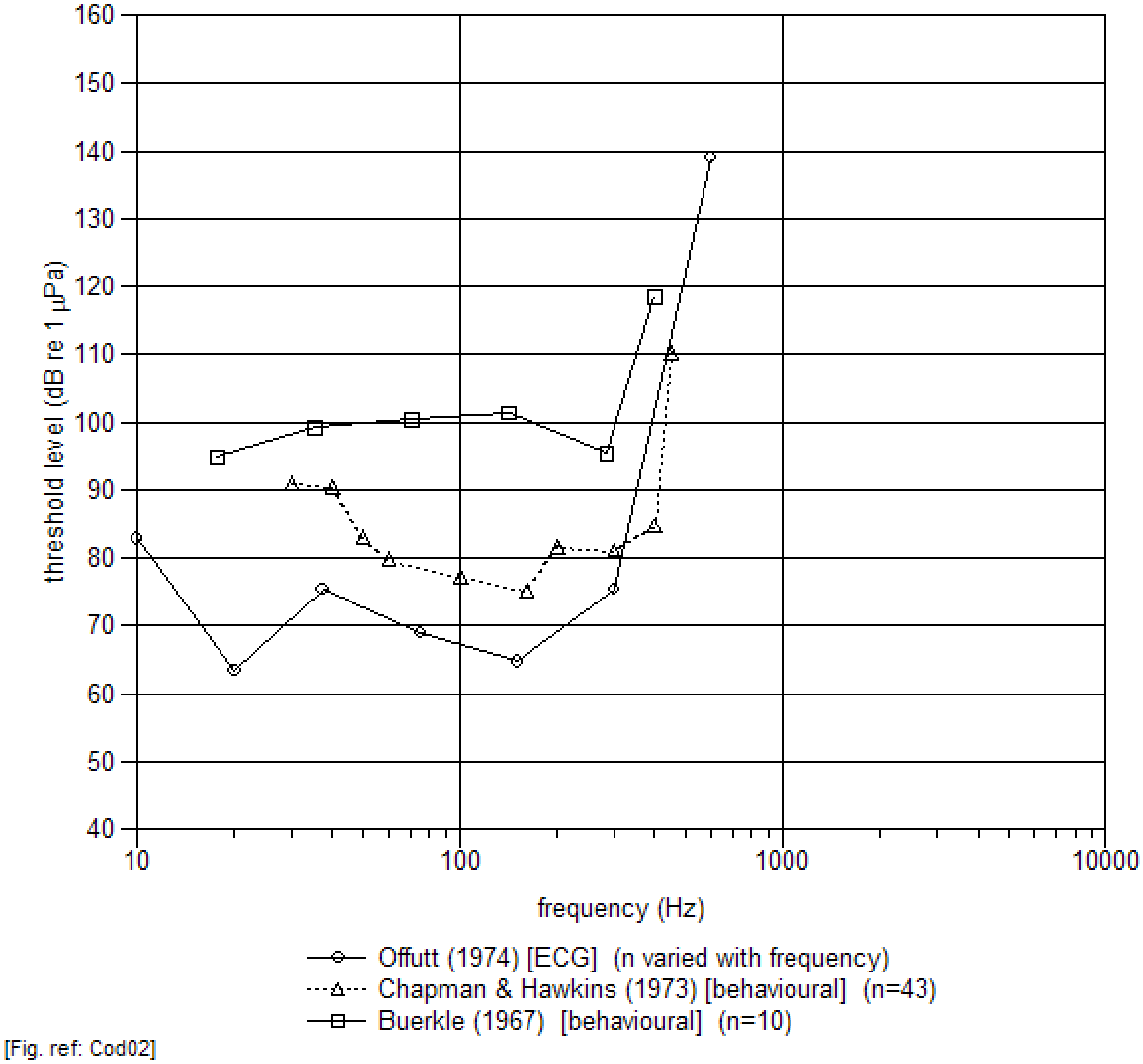
Common name	Cod.
Family	
Species	*Gadus morhua.*
Paper from which audiogram obtained	Fay, R.R. (1988). Hearing in Vertebrates: A Psychophysics Databook. Hill-Fay Associates, Winnetka, Ill.
Paper having original audiogram data	Buerkle, U. (1967). An audiogram of the Atlantic cod, *Gadu morhua* L. J. Fish. Res. Bd. Cananda, 24, 2309-2319.
Comments on methodology of getting audiogram	Original source not seen. J9 loudspeaker in large concrete tank. Classical cardiac conditioning using descending method of limits.
Any other comments	Thresholds below 283Hz likely masked by ambient noise. 10 specimens.

Audiogram from Table F6-0. Threshold levels in dB re 1dyne/cm^2. 10 specimens.

Frequency (Hz)	17.6	35.3	70.7	141	283	400
Mean	-5.2	-0.8	0.4	1.3	-4.6	18.5

Threshold levels in dB re 1μPa.

Frequency (Hz)	17.6	35.3	70.7	141	283	400
Mean	94.8	99.2	100.4	101.3	95.4	118.5



Audiogram for cod.

Database page ref: F/Cubbyu/01.

Common name	Cubbyu.
Family	Sciaenidae.
Species	*Equetus acuminatus.*
Paper from which audiogram obtained	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Paper having original audiogram data	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Comments on methodology of getting audiogram	Glass tank was lined on floor and walls with 2inch layers of rubberised horsehair. Internal dimensions of tank with lining in place were 16"x7" in plan. A curved barrier, also made from horsehair and 4" high, was placed centrally in the tank, spanning its width. Water depth above top of barrier, and therefore in tank, was adjusted to cause the fish to have to exert some effort to swim over the barrier; depth ranged from25 to 30mm. Tank was mounted on 2" thick pieces of foam rubber at its corners. Sound source was a University Model SA-HF public address unit fitted with a rubber bulb over its horn end; the entire unit was waterproofed with tar, tape and rubber. It was placed under the central barrier. A hydrophone (Chesapeake Instrument Co. Model SB-154C) was placed near the wall farthest from the sound source, but it wasn't always used when a fish was in the tank. Electrodes for causing shock were rings of silver solder, with a pair being mounted on the tank sidewalls at each end of the tank. Avoidance conditioning test method was used. Shock was a 0.1s duration pulse repeated at about 40 pulses per minute. If fish heard sound it had to swim to other side of barrier within 10sec to avoid getting a shock. After an inter-trial interval another trial took place, with the fish having to cross the barrier in the opposite direction. Threshold determined by staircase method, starting at high level and reducing level in 2dB steps until a reversal occurred, when level was increased in 2dB steps.
Any other comments	3 specimens used. There was little variability between among the animals tested. Driver unit gave distortion-free output between 200Hz and 5kHz up to 50dB re 1μbar. At lower frequencies harmonic distortion and clipping occurred above 30 to 35dB re 1 μbar. A secondary low-frequency threshold was found for repeat trials after the higher frequencies had been tested.

Audiogram from Fig. 8 (authors' mean line). Threshold levels in dB re.1 μbar. 3 specimens.

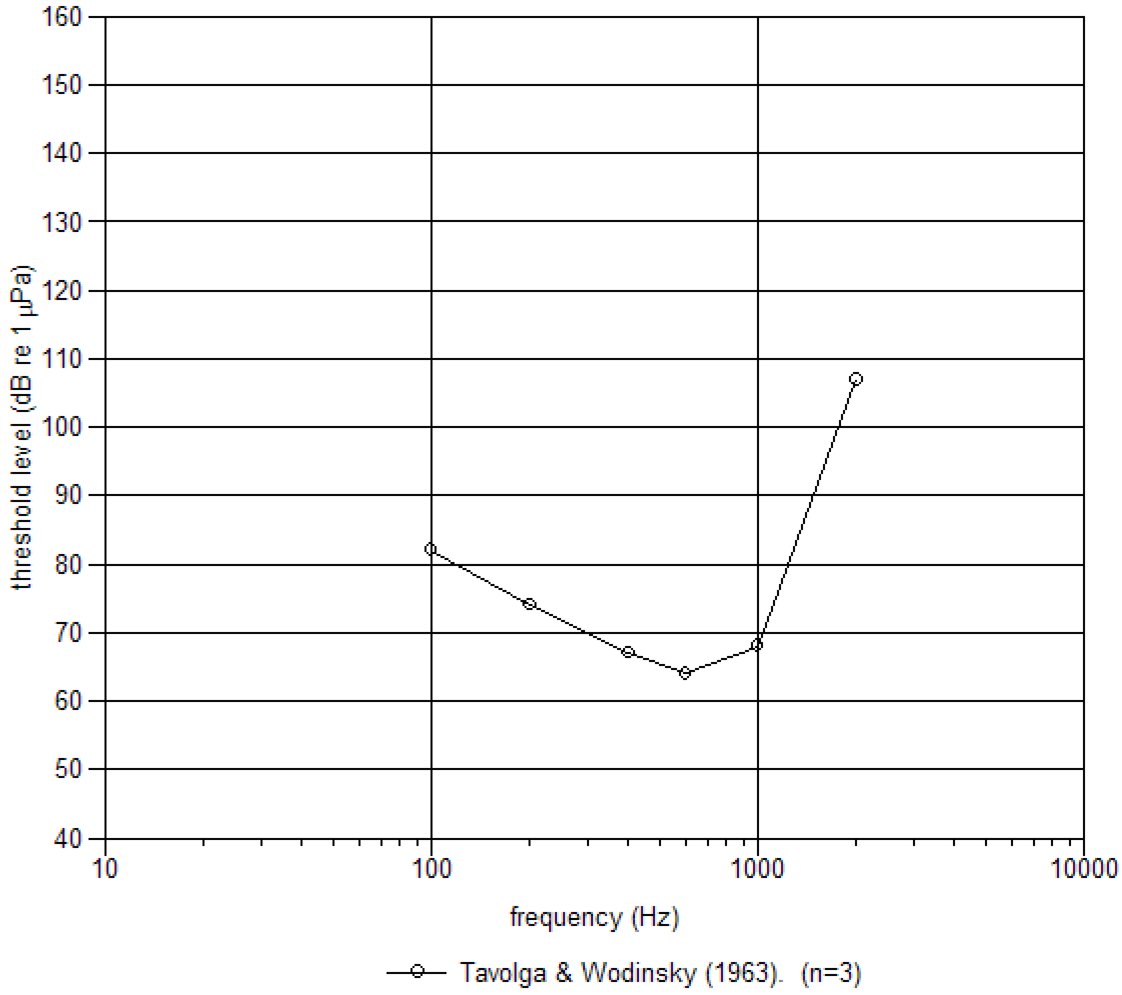
Frequency (Hz)	100	200	400	600	1000	2000
Mean	-18	-26	-33	-36	-32	7

Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	400	600	1000	2000
Mean	82	74	67	64	68	107

Ambient noise levels in tank.

Bandwidth (Hz)	37.5 - 75	75 - 150	150 - 300	300 - 600	600 - 1200	1200 - 2400	2400 - 4800	4800 - 9600
Level (dB re 1μbar)	-43	< -50	< -5	-43	-39	-34	-29	-20
Level (dB re 1μPa)	57	< 50	< 50	57	61	66	71	80



[Fig. ref: Cubbyu_G_01]

Audiogram for cubbyu.

Database page ref: F/Dab/01.

Common name	Dab
Family	Soleidae
Species	*Limanda limanda* L.
Paper from which audiogram obtained	Chapman, C.J. & Sand, O. (1974). Field studies of hearing in two species of flatfish *Pleuronectes Platessa* (L.) and *Limanda limanda* (L.) (family Pleuronectidae). Comp. Biochem. Physiol., 47A, 371-385.
Paper having original audiogram data	Chapman, C.J. & Sand, O. (1974). Field studies of hearing in two species of flatfish *Pleuronectes Platessa* (L.) and *Limanda limanda* (L.) (family Pleuronectidae). Comp. Biochem. Physiol., 47A, 371-385.
Comments on methodology of getting audiogram	Experiments were conducted in Upper Loch Torridon, Scotland. A frame, made from PVC tube; was located offshore. Its top was 15m below the water surface and 6m above the seabed. A flat cage, made from plastic netting, was fixed to the top of the frame; the subject was placed inside this cage. A pair of electrodes (mesh woven from stainless steel wire) was built into the cage to permit application of an electric shock to the subject's tail. A hydrophone was mounted on the framework 10mm below the head of the fish, aligned along the axis of the cage. 2 projectors (Dyna-Empire J9) were placed along a line along the axis of the cage. They were mounted on platforms which were anchored to the seabed and buoyed up by sub-surface floats. 1 projector was placed about 0.7m from the cage, while the other was 3m away. An electrocardiograph electrode was implanted in the subject. This, and the shock-administering, electrode were connected to apparatus on the loch shore. The cardiac potentials from the fish were amplified in a low-noise amplifier and monitored on a storage oscilloscope and a pen recorder. The hydrophone signal was amplified and filtered by a low-noise amplifier, and measured with a B&K Type 2107 narrow band analyser and a B&K Type 2305 level recorder. Sound stimuli were pure tones having a duration of about 10s, with a rise time of 300ms. At the end of the tone transmission period a 6-12V dc pulse of 200ms duration was fed to the shock electrodes. Used 3 specimens. Fish was anaesthetised using MS-222, and a stainless steel electrode inserted subcutaneously in the region of the heart. Fish was placed in cage, which was taken to rig by diver, and left for 24hrs before conditioning commenced. Tone followed by shock was presented to fish until it showed alteration in heart rate after onset of sound but before the shock. Full conditioning was considered to have occurred when 5 consecutive trials had yielded positive responses. Threshold was determined by staircase method, with step changes of 3dB.
Any other comments	By having 2 projectors at different distances authors were able to distinguish between pressure and particle displacement responses. Used equation from Harris (1964) to calculate displacement from pressure measurements in near and far fields. In some experiments a small 34mm dia. spherical air-filled rubber balloon was placed close to the fish to simulate a swimbladder.

Harris, G.G. (1964). Considerations on the physics of sound production by fishes. In: Marine Bio-acoustics, Tavolga, W.N. (ed), 233-247.

Audiogram for 1st dab, from Fig. 3(b). Threshold levels in dB re 1μbar.

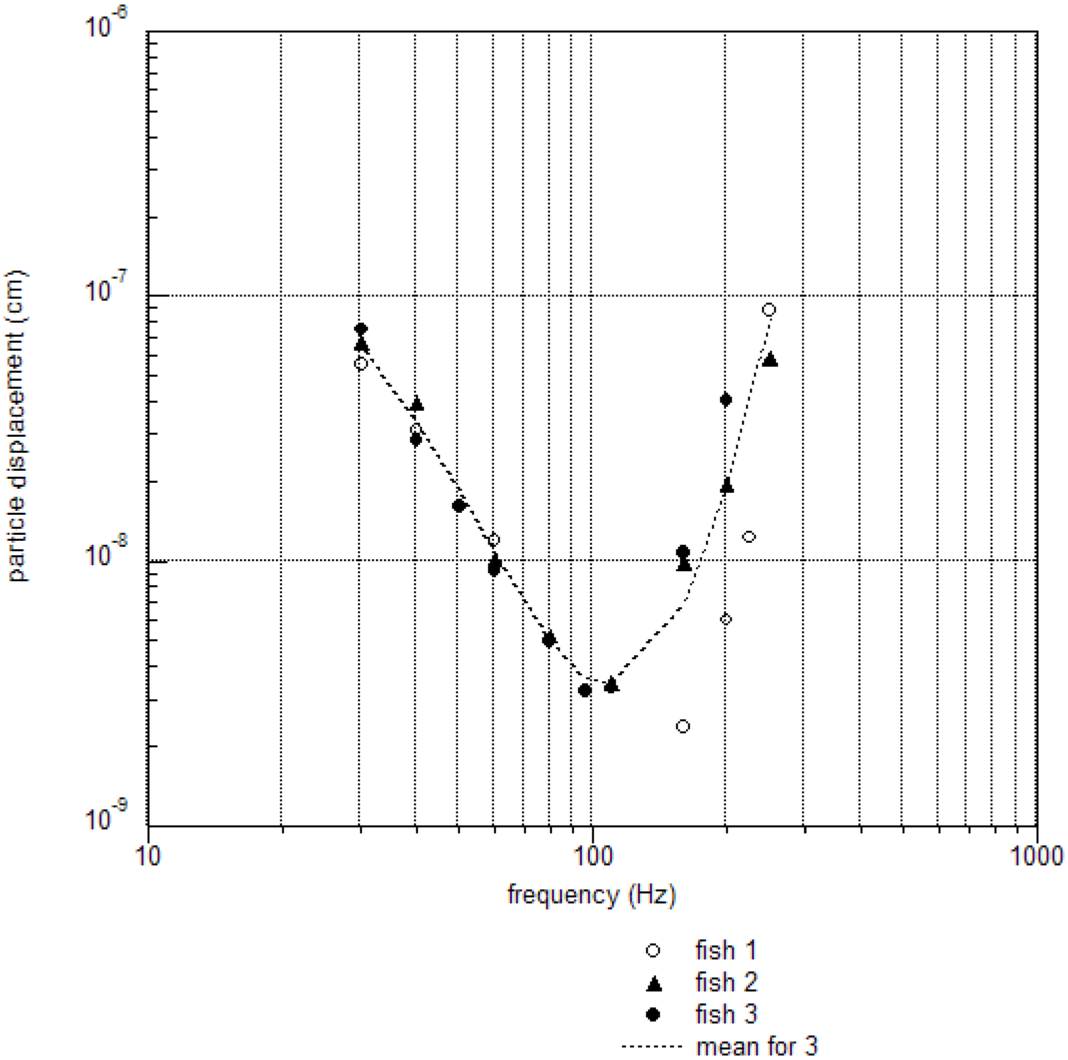
frequency (Hz)		30	40	60	110	165	200	230	260
Source to fish distance 0.7m	level	-16.2	-15.8	-14.4	-16.2	-14.3	-4	3	22
	level		-16.6	-20.6	-18.7	-17.3	-4.5		
	level				-20.2				
	mean level	-16.2	-16.2	-17.6	-18.8	-15	-4	13	22
Source to fish distance 3m	level	-6.3	-7.3	-8.3	-9	-10	1.7		
	level			-9.5	-9.6	-11	-0.7		
	level				-11				
	mean level	-6.3	-7.3	-9	-10.4	-10.5	-1		

Audiogram for 2nd dab, from Fig. 3(c). Threshold levels in dB re 1μbar.

frequency (Hz)		30	40	65	80	110	166	210	270
Source to fish distance 0.7m	level	-14	-12.4	-18.7		-16.1	-3.8	6.3	18
	level			-20.9		-21.2			
	mean level	-12.8	-14.6	-19.5	-20.5	-18	-3.8	8	18
Source to fish distance 3m	level	-5.4	-4.2	-8	-11	-9	4	9.6	
	level		-7.2	-11		-13.4	1.6		
	level					-15.4			
	mean level	-4	-5.5	-9.2	-12	-13	0	8	

Displacement audiograms from Fig. 5(a) for 3 dabs.

frequency (Hz)		40	50	60	80	96	110	160	200	225	250
Mean values (cm)	Fish 1	3.1E-08		1.2E-08				2.4E-09	6.0E-09	1.2E-08	8.8E-08
	Fish 2	4.0E-08		1.0E-08	5.2E-09		3.5E-09	9.9E-09	2.0E-08		5.8E-08
	Fish 3	2.9E-08	1.6E-08	9.1E-09	5.0E-09	3.2E-09	3.3E-09	1.1E-08	4.0E-08		
	Mean for 3	3.4E-08	1.9E-08	1.1E-08	5.1E-09	3.7E-09	3.5E-09	6.9E-09	2.0E-08	4.4E-08	7.9E-08



[Fig. ref: Dab_G_01]

Note: The mean line is that given by the authors in the figure in the paper.

Audiogram for dab (note that it is in terms of particle displacement)

Database page ref: F/Dab/02.

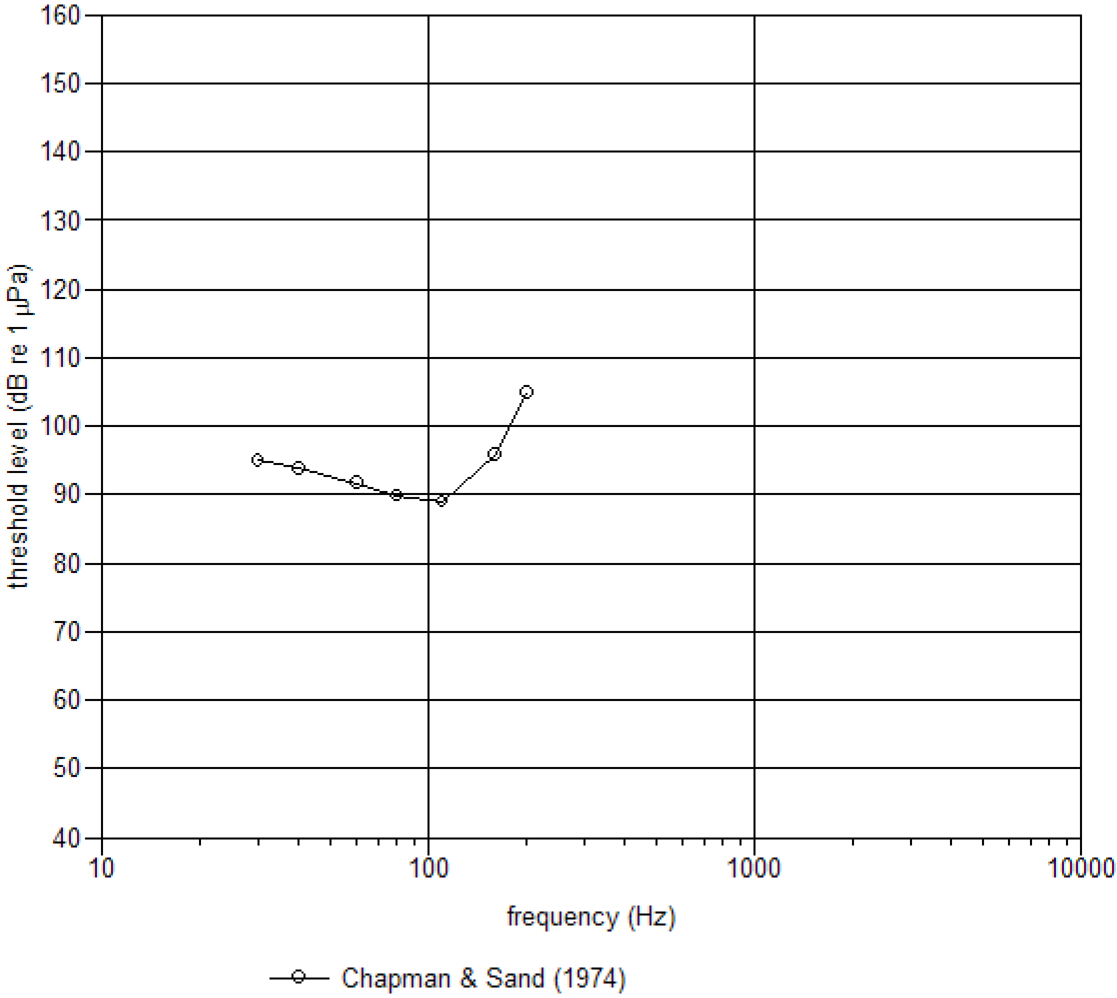
Common name	Dab
Family	Soleidae
Species	*Limanda limanda*
Paper from which audiogram obtained	Hawkins, A.D. & Myrberg, A.A. (jnr). (1983). Hearing and sound communication under water. In: Bioacoustics: a comparative approach. B. Lewis (ed.), pp. 347-405. Academic Press, New York.
Paper having original audiogram data	Chapman & Sand (1973). (The source is probably the same as that for F/Dab/01).
Comments on methodology of getting audiogram	
Any other comments	In text, state that tests in which the ratio of particle velocity to sound pressure was varied showed that some flatfishes (e.g. *Pleuronectes platessa* & *Limanda limanda*), and the Atlantic salmon *Salmo salar* responded to particle motion rather than sound pressure.

Audiogram from Fig. 13 in above paper. Threshold levels in dB re 6.49×10^{-6} cm/sec.

Frequency (Hz)	30	40	50	60	80	110	165	200	260
Mean	5.9	3.1	-2.0	-3.9	-7.9	-8.5	2.0	11.2	25.6

Audiogram from Fig. 2 of Popper, A.N. & Fay, R.R. (1993). Source for this data was Chapman & Sand (1974). Threshold levels in dB re 1µPa.

Frequency (Hz)	30	40	60	80	110	160	200
Mean	95.0	93.8	91.7	89.8	89.0	95.9	104.9



[Fig. ref: Dab01]

Note: This fish is believed to respond to particle velocity rather than pressure. The data from Hawkins & Myrberg is in velocity units; Popper and Fay present the data in pressure units, which are the data that have been plotted.

Audiogram for dab (data from lower table above).

Database page ref: F/Damsel/01.

Common name	Damselfish.
Family	Pomacentridae.
Species	*Eupomacentrus dorsopunicans.*
Paper from which audiogram obtained	Myrberg, A.A. Jr & Spires, J.Y. (1980). Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol., 140, 135-144.
Paper having original audiogram data	Myrberg, A.A. Jr & Spires, J.Y. (1980). Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol., 140, 135-144.
Comments on methodology of getting audiogram	Tests done in 5m long, 150mm i.d., glass tube, divided into two sections. One, in which fish was placed, had a J-9 underwater speaker at its end. This section was mounted on a base which was mounted on vibration-isolating pads. The second section was suspended by elastic bungees from a beam above it. This section was filled with sponges to act as sound absorbers. For some tests, to increase ratio of sound pressure:velocity, a hollow rubber ball (approx. 150mm o.d.) was placed at the end of the first tube opposite the speaker. The tube was filled with seawater. The fish was placed in a restrainer, a small, transparent Plexiglas cylinder constructed such that the fish, while hovering, was equidistant from the surrounding wall of the glass tube. Little sideways movement was possible, but the fish could easily move up and down. Stainless steel rods were located on each side of the restrainer as electrodes for applying a shock to the fish. Sound pressure was measured by an Aquadyne AQ-12 hydrophone placed in the restrainer below the fish's head position. The restrainer was placed at either of 2 positions in the tube:- 400mm from the speaker face, and 1.45m from the speaker face. For the threshold determinations it was placed at the nearer position, and the rubber ball was omitted. The subject was trained to respond to sound by moving downwards if it detected a tone. The staircase method was used to determine the threshold, with the sound level being varied in 2dB steps. Threshold was taken as the average (50%) sound level attained after 50 sound presentations beyond the point where the levels accompanying response and no-response varied by no more than 8dB.
Any other comments	Also did tests to see if fish was particle velocity sensitive. For these tests calibration of the set-up was done by replacing the restrainer and subject with a 120mm dia. Plexiglas disc on which was mounted an accelerometer (Hall-Sears HS-1 refraction geophone). The disc was suspended within a Plexiglas tube by 3 lengths of fine nylon line so that it could move freely along the tube's axis. The hydrophone was placed inside the Plexiglas tube just below and slightly forward of the disc. The output of the accelerometer was measured for the condition when the hydrophone registered the sound pressure that had been established as the threshold of the fish.

Audiogram from Table 2. Threshold levels in dB re 1μbar. 4 subjects.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	16.9	1	-9	-13.3	-18.6	-11.7	9.5	22.2	33.8
SD	2.7	2.4	1.4	0.9	3.4	1.8	2.0	3.4	2.2
No. of determnations	7	6	4	7	8	7	8	6	5

Note: At 100Hz, probably artifactual threshold.

Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	116.9	101	91	86.7	81.4	88.3	109.5	122.2	133.8

Maximum spectrum level noise allowed during testing. From Fig. 3.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	--17	-28	-32	-34	-36	-38	-42	-45	-49

Database page ref: F/DamselBeauGregory/01.

Common name	Beau-gregory (a damselfish)..
Family	Pomacentridae.
Species	*Eupomacentrus leucostictus.*
Paper from which audiogram obtained	Myrberg, A.A. Jr & Spires, J.Y. (1980). Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol., 140, 135-144.
Paper having original audiogram data	Myrberg, A.A. Jr & Spires, J.Y. (1980). Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol., 140, 135-144.
Comments on methodology of getting audiogram	Tests done in 5m long, 150mm i.d., glass tube, divided into two sections. One, in which fish was placed, had a J-9 underwater speaker at its end. This section was mounted on a base which was mounted on vibration-isolating pads. The second section was suspended by elastic bungees from a beam above it. This section was filled with sponges to act as sound absorbers. For some tests, to increase ratio of sound pressure:velocity, a hollow rubber ball (approx. 150mm o.d.) was placed at the end of the first tube opposite the speaker. The tube was filled with seawater. The fish was placed in a restrainer, a small, transparent Plexiglas cylinder constructed such that the fish, while hovering, was equidistant from the surrounding wall of the glass tube. Little sideways movement was possible, but the fish could easily move up and down. Stainless steel rods were located on each side of the restrainer as electrodes for applying a shock to the fish. Sound pressure was measured by an Aquadyne AQ-12 hydrophone placed in the restrainer below the fish's head position. The restrainer was placed at either of 2 positions in the tube:- 400mm from the speaker face, and 1.45m from the speaker face. For the threshold determinations it was placed at the nearer position, and the rubber ball was omitted. The subject was trained to respond to sound by moving downwards if it detected a tone. The staircase method was used to determine the threshold, with the sound level being varied in 2dB steps. Threshold was taken as the average (50%) sound level attained after 50 sound presentations beyond the point where the levels accompanying response and no-response varied by no more than 8dB.
Any other comments	

Audiogram from Table 2. Threshold levels in dB re 1μbar. 4 subjects.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	22.0	6.7	-	-8.7	-14.0	-10.8	6.7	22.3	40.0
SD	2.1	1.8	-	1.5	2.4	3.0	3.2	2.5	1.7
No. of determnations	6	6	-	6	7	7	6	4	3

Note: At 100Hz, probably artifactual threshold.

Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	122.0	106.7	-	91.3	86.0	89.2	106.7	122.3	140.0

Maximum spectrum level noise allowed during testing. From Fig. 3.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	--17	-28	-32	-34	-36	-38	-42	-45	-49

Database page ref: F/DamselBeauGregory/02.

Common name	Beau-gregory (a damselfish).
Family	Pomacentridae.
Species	*Eupomacentrus leucostictus.*
Paper from which audiogram obtained	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Paper having original audiogram data	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Comments on methodology of getting audiogram	Glass tank was lined on floor and walls with 2inch layers of rubberised horsehair. Internal dimensions of tank with lining in place were 16"x7" in plan. A curved barrier, also made from horsehair and 4" high, was placed centrally in the tank, spanning its width. Water depth above top of barrier, and therefore in tank, was adjusted to cause the fish to have to exert some effort to swim over the barrier; depth was about 12mm. Tank was mounted on 2" thick pieces of foam rubber at its corners. Sound source was a University Model SA-HF public address unit fitted with a rubber bulb over its horn end; the entire unit was waterproofed with tar, tape and rubber. It was placed under the central barrier. A hydrophone (Chesapeake Instrument Co. Model SB-154C) was placed near the wall farthest from the sound source, but it wasn't always used when a fish was in the tank. Electrodes for causing shock were rings of silver solder, with a pair being mounted on the tank sidewalls at each end of the tank. Avoidance conditioning test method was used. Shock was a 0.1s duration pulse repeated at about 40 pulses per minute. If fish heard sound it had to swim to other side of barrier within 10sec to avoid getting a shock. After an inter-trial interval another trial took place, with the fish having to cross the barrier in the opposite direction. Threshold determined by staircase method, starting at high level and reducing level in 2dB steps until a reversal occurred, when level was increased in 2dB steps.
Any other comments	4 specimens used. Driver unit gave distortion-free output between 200Hz and 5kHz up to 50dB re 1μbar. At lower frequencies harmonic distortion and clipping occurred above 30 to 35dB re 1 μbar. A secondary low-frequency threshold was found for repeat trials at lower frequencies after the higher frequencies had been tested.

Audiogram from Fig. 20 (authors' mean lines). Threshold levels in dB re.1 µbar. 4 specimens.

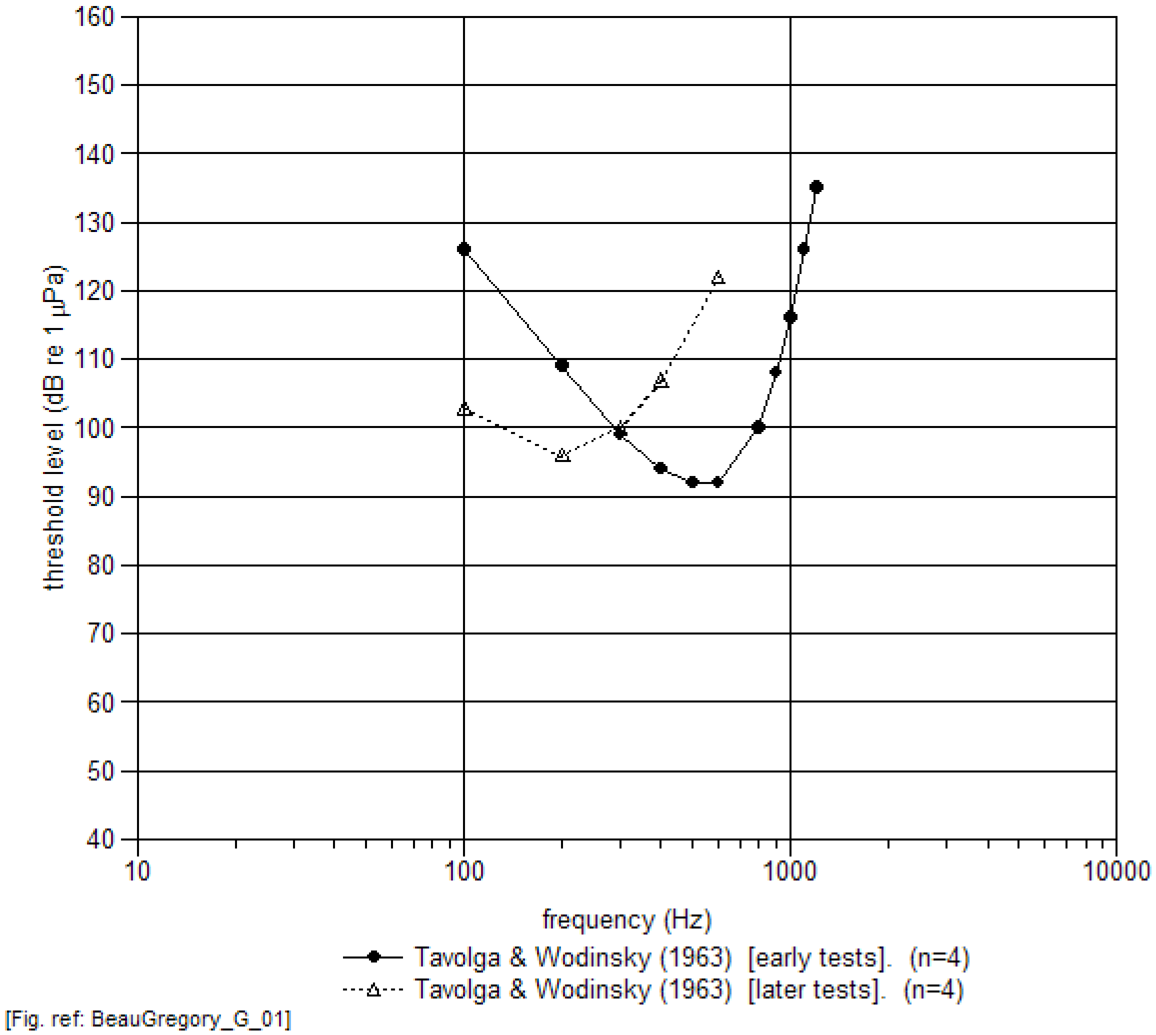
Frequency (Hz)	100	200	300	400	500	600	800	900	1000	1100	1200
Mean (early tests)	26	9	-1	-6	-8	-8	0	8	16	26	35
Mean (later tests)	3	-4	0	7		22					

Threshold levels in dB re 1µPa.

Frequency (Hz)	100	200	300	400	500	600	800	900	1000	1100	1200
Mean (early tests)	126	109	99	94	92	92	100	108	116	126	135
Mean (later tests)	103	96	100	107		122					

Ambient noise levels in tank.

Bandwidth (Hz)	37.5 - 75	75 - 150	150 - 300	300 - 600	600 - 1200	1200 - 2400	2400 - 4800	4800 - 9600
Level (dB re 1µbar)	-43	< -50	< -5	-43	-39	-34	-29	-20
Level (dB re 1µPa)	57	< 50	< 50	57	61	66	71	80



Audiograms for Beau-gregory (data of Tavolga & Wodinsky only).

Database page ref: F/DamselBicolour/01.

Common name	Bicolour damselfish.
Family	Pomacentridae.
Species	*Eupomacentrus partitus.*
Paper from which audiogram obtained	Myrberg, A.A. Jr & Spires, J.Y. (1980). Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol., 140, 135-144.
Paper having original audiogram data	Ha, S.J. (1973). Aspects of sound communication in the damselfish, *Eupomacentrus partitus*. Doctoral dissertation, Univ. of Miami.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	

Audiogram from Table 2. Threshold levels in dB re 1μbar. 2 subjects.

Frequency (Hz)	100	200	300	400	500	600	800	1000
Mean	13.7	-2.0	-11.5	-16.6	-21.0	-12.3	2.7	16.5
No. of determnations	3	2	2	3	2	3	3	2

Note: At 100Hz, probably artifactual threshold.

Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	300	400	500	600	800	1000
Mean	113.7	98.0	88.5	83.4	79.0	87.7	102.7	116.5

Database page ref: F/DamselCocoa/01.

Common name	Cocoa damselfish.
Family	Pomacentridae.
Species	*Eupomacentrus variabilis.*
Paper from which audiogram obtained	Myrberg, A.A. Jr & Spires, J.Y. (1980). Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol., 140, 135-144.
Paper having original audiogram data	Myrberg, A.A. Jr & Spires, J.Y. (1980). Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol., 140, 135-144.
Comments on methodology of getting audiogram	Tests done in 5m long, 150mm i.d., glass tube, divided into two sections. One, in which fish was placed, had a J-9 underwater speaker at its end. This section was mounted on a base which was mounted on vibration-isolating pads. The second section was suspended by elastic bungees from a beam above it. This section was filled with sponges to act as sound absorbers. For some tests, to increase ratio of sound pressure:velocity, a hollow rubber ball (approx. 150mm o.d.) was placed at the end of the first tube opposite the speaker. The tube was filled with seawater. The fish was placed in a restrainer, a small, transparent Plexiglas cylinder constructed such that the fish, while hovering, was equidistant from the surrounding wall of the glass tube. Little sideways movement was possible, but the fish could easily move up and down. Stainless steel rods were located on each side of the restrainer as electrodes for applying a shock to the fish. Sound pressure was measured by an Aquadyne AQ-12 hydrophone placed in the restrainer below the fish's head position. The restrainer was placed at either of 2 positions in the tube:- 400mm from the speaker face, and 1.45m from the speaker face. For the threshold determinations it was placed at the nearer position, and the rubber ball was omitted. The subject was trained to respond to sound by moving downwards if it detected a tone. The staircase method was used to determine the threshold, with the sound level being varied in 2dB steps. Threshold was taken as the average (50%) sound level attained after 50 sound presentations beyond the point where the levels accompanying response and no-response varied by no more than 8dB.
Any other comments	

Audiogram from Table 2. Threshold levels in dB re 1μbar. 3 subjects.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	15.8	-2.0	-3.5	-11.1	-14.7	-12.6	5.4	18.2	38.2
SD	1.3	1.8	3.5	2.0	1.9	1.8	1.9	3.0	2.3
No. of determnations	6	7	8	7	10	7	5	6	4

Note: At 100Hz, probably artifactual threshold.

Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	115.8	98.0	96.5	88.9	85.3	87.4	105.4	118.2	138

2

Maximum spectrum level noise allowed during testing. From Fig. 3.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	--17	-28	-32	-34	-36	-38	-42	-45	-49

Database page ref: F/DamselHoneyGregory/01.

Common name	Honey gregory (a damselfish)..
Family	Pomacentridae.
Species	*Eupomacentrus mellis.*
Paper from which audiogram obtained	Myrberg, A.A. Jr & Spires, J.Y. (1980). Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol., 140, 135-144.
Paper having original audiogram data	Myrberg, A.A. Jr & Spires, J.Y. (1980). Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol., 140, 135-144.
Comments on methodology of getting audiogram	Tests done in 5m long, 150mm i.d., glass tube, divided into two sections. One, in which fish was placed, had a J-9 underwater speaker at its end. This section was mounted on a base which was mounted on vibration-isolating pads. The second section was suspended by elastic bungees from a beam above it. This section was filled with sponges to act as sound absorbers. For some tests, to increase ratio of sound pressure:velocity, a hollow rubber ball (approx. 150mm o.d.) was placed at the end of the first tube opposite the speaker. The tube was filled with seawater. The fish was placed in a restrainer, a small, transparent Plexiglas cylinder constructed such that the fish, while hovering, was equidistant from the surrounding wall of the glass tube. Little sideways movement was possible, but the fish could easily move up and down. Stainless steel rods were located on each side of the restrainer as electrodes for applying a shock to the fish. Sound pressure was measured by an Aquadyne AQ-12 hydrophone placed in the restrainer below the fish's head position. The restrainer was placed at either of 2 positions in the tube:- 400mm from the speaker face, and 1.45m from the speaker face. For the threshold determinations it was placed at the nearer position, and the rubber ball was omitted. The subject was trained to respond to sound by moving downwards if it detected a tone. The staircase method was used to determine the threshold, with the sound level being varied in 2dB steps. Threshold was taken as the average (50%) sound level attained after 50 sound presentations beyond the point where the levels accompanying response and no-response varied by no more than 8dB.
Any other comments	

Audiogram from Table 2. Threshold levels in dB re 1μbar. 2 subjects.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	19.8	2.5	-4.2	-6.8	-13.6	-12.7	8.2	14.4	27.0
SD	3.1	2.1	1.1	0.8	1.5	2.3	1.9	1.8	3.0
No. of determnations	6	6	6	5	5	6	6	5	3

Note: At 100Hz, probably artifactual threshold.

Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	119.8	102.5	95.8	93.2	86.4	87.3	108.2	114.4	127.0

Maximum spectrum level noise allowed during testing. From Fig. 3.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	--17	-28	-32	-34	-36	-38	-42	-45	-49

Database page ref: F/DamselLongfin/01.

Common name	Longfin damselfish.
Family	Pomacentridae.
Species	*Eupomacentrus diencaeus.*
Paper from which audiogram obtained	Myrberg, A.A. Jr & Spires, J.Y. (1980). Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol., 140, 135-144.
Paper having original audiogram data	Myrberg, A.A. Jr & Spires, J.Y. (1980). Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol., 140, 135-144.
Comments on methodology of getting audiogram	Tests done in 5m long, 150mm i.d., glass tube, divided into two sections. One, in which fish was placed, had a J-9 underwater speaker at its end. This section was mounted on a base which was mounted on vibration-isolating pads. The second section was suspended by elastic bungees from a beam above it. This section was filled with sponges to act as sound absorbers. For some tests, to increase ratio of sound pressure:velocity, a hollow rubber ball (approx. 150mm o.d.) was placed at the end of the first tube opposite the speaker. The tube was filled with seawater. The fish was placed in a restrainer, a small, transparent Plexiglas cylinder constructed such that the fish, while hovering, was equidistant from the surrounding wall of the glass tube. Little sideways movement was possible, but the fish could easily move up and down. Stainless steel rods were located on each side of the restrainer as electrodes for applying a shock to the fish. Sound pressure was measured by an Aquadyne AQ-12 hydrophone placed in the restrainer below the fish's head position. The restrainer was placed at either of 2 positions in the tube:- 400mm from the speaker face, and 1.45m from the speaker face. For the threshold determinations it was placed at the nearer position, and the rubber ball was omitted. The subject was trained to respond to sound by moving downwards if it detected a tone. The staircase method was used to determine the threshold, with the sound level being varied in 2dB steps. Threshold was taken as the average (50%) sound level attained after 50 sound presentations beyond the point where the levels accompanying response and no-response varied by no more than 8dB.
Any other comments	

Audiogram from Table 2. Threshold levels in dB re 1μbar. 2 subjects.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	16.0	0.7	-6.7	-7.7	-15.3	-12.5	7.3	18.7	34.0
SD	2.6	3.2	0.6	1.5	2.3	3.5	4.0	2.5	-
No. of determnations	3	3	3	3	3	4	3	3	2

Note: At 100Hz, probably artifactual threshold.

Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	116.0	100.7	93.3	92.3	84.7	87.5	107.3	118.7	134.0

Maximum spectrum level noise allowed during testing. From Fig. 3.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	--17	-28	-32	-34	-36	-38	-42	-45	-49

Database page ref: F/Damsel3Spot/01.

Common name	Threespot damselfish.
Family	Pomacentridae.
Species	*Eupomacentrus planifrons.*
Paper from which audiogram obtained	Myrberg, A.A. Jr & Spires, J.Y. (1980). Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol., 140, 135-144.
Paper having original audiogram data	Myrberg, A.A. Jr & Spires, J.Y. (1980). Hearing in damselfishes: an analysis of signal detection among closely related species. J. Comp. Physiol., 140, 135-144.
Comments on methodology of getting audiogram	Tests done in 5m long, 150mm i.d., glass tube, divided into two sections. One, in which fish was placed, had a J-9 underwater speaker at its end. This section was mounted on a base which was mounted on vibration-isolating pads. The second section was suspended by elastic bungees from a beam above it. This section was filled with sponges to act as sound absorbers. For some tests, to increase ratio of sound pressure:velocity, a hollow rubber ball (approx. 150mm o.d.) was placed at the end of the first tube opposite the speaker. The tube was filled with seawater. The fish was placed in a restrainer, a small, transparent Plexiglas cylinder constructed such that the fish, while hovering, was equidistant from the surrounding wall of the glass tube. Little sideways movement was possible, but the fish could easily move up and down. Stainless steel rods were located on each side of the restrainer as electrodes for applying a shock to the fish. Sound pressure was measured by an Aquadyne AQ-12 hydrophone placed in the restrainer below the fish's head position. The restrainer was placed at either of 2 positions in the tube:- 400mm from the speaker face, and 1.45m from the speaker face. For the threshold determinations it was placed at the nearer position, and the rubber ball was omitted. The subject was trained to respond to sound by moving downwards if it detected a tone. The staircase method was used to determine the threshold, with the sound level being varied in 2dB steps. Threshold was taken as the average (50%) sound level attained after 50 sound presentations beyond the point where the levels accompanying response and no-response varied by no more than 8dB.
Any other comments	

Audiogram from Table 2. Threshold levels in dB re 1µbar. 4 subjects.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	22.3	6.0	-3.1	-7.5	-13.2	-10.8	9.3	24.2	37.8
SD	2.4	2.7	1.8	4.2	3.2	1.0	1.8	3.2	2.5
No. of determnations	6	8	8	8	9	8	6	6	4

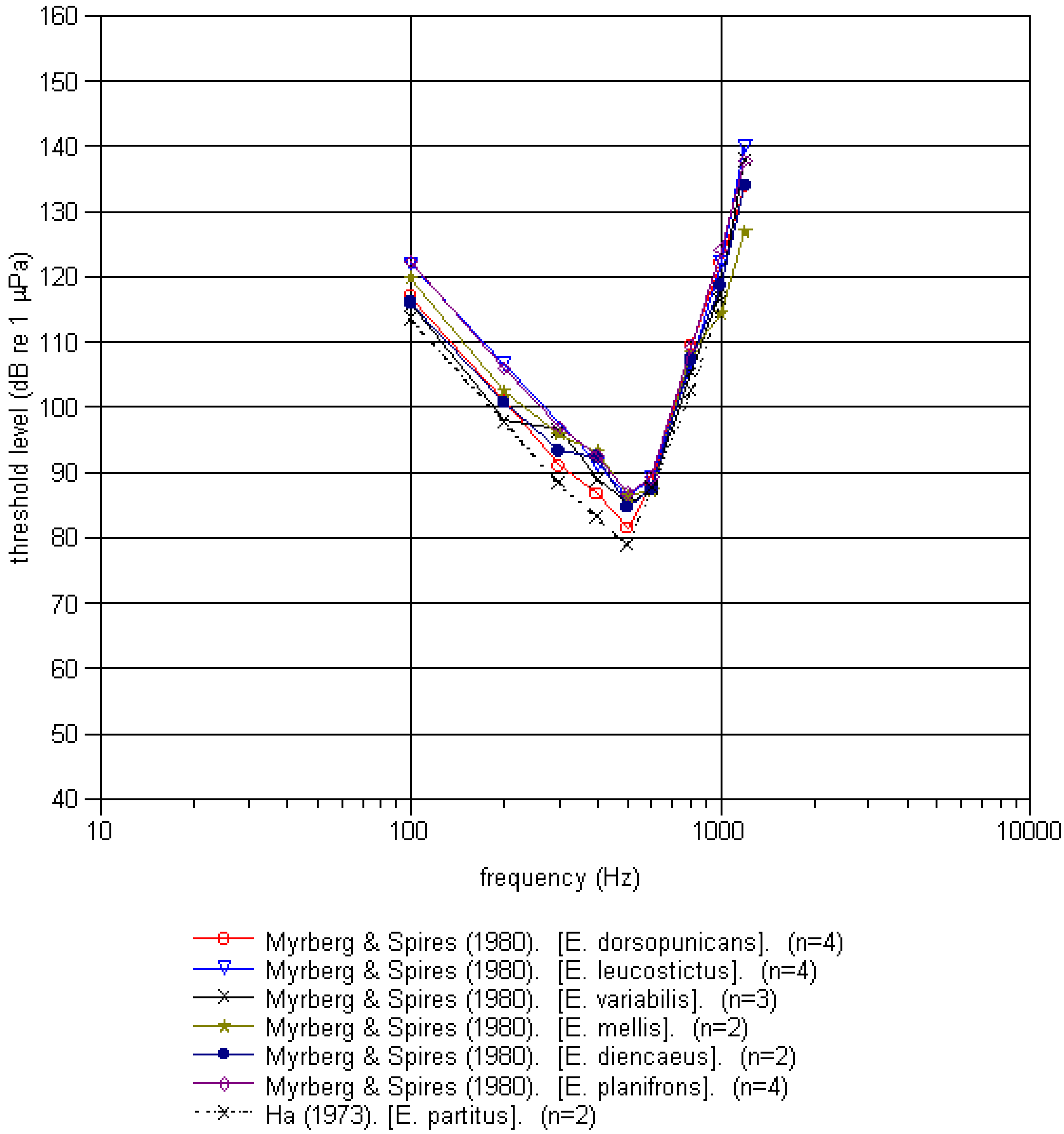
Note: At 100Hz, probably artifactual threshold.

Threshold levels in dB re 1µPa.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	122.3	106.0	96.9	92.5	86.8	89.2	109.3	124.2	137.8

Maximum spectrum level noise allowed during testing. From Fig. 3.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200
Mean	--17	-28	-32	-34	-36	-38	-42	-45	-49



[Fig. ref: Damselfish02B]

Audiograms for various species of damselfish.

Database page ref: F/ElephantNose/01.

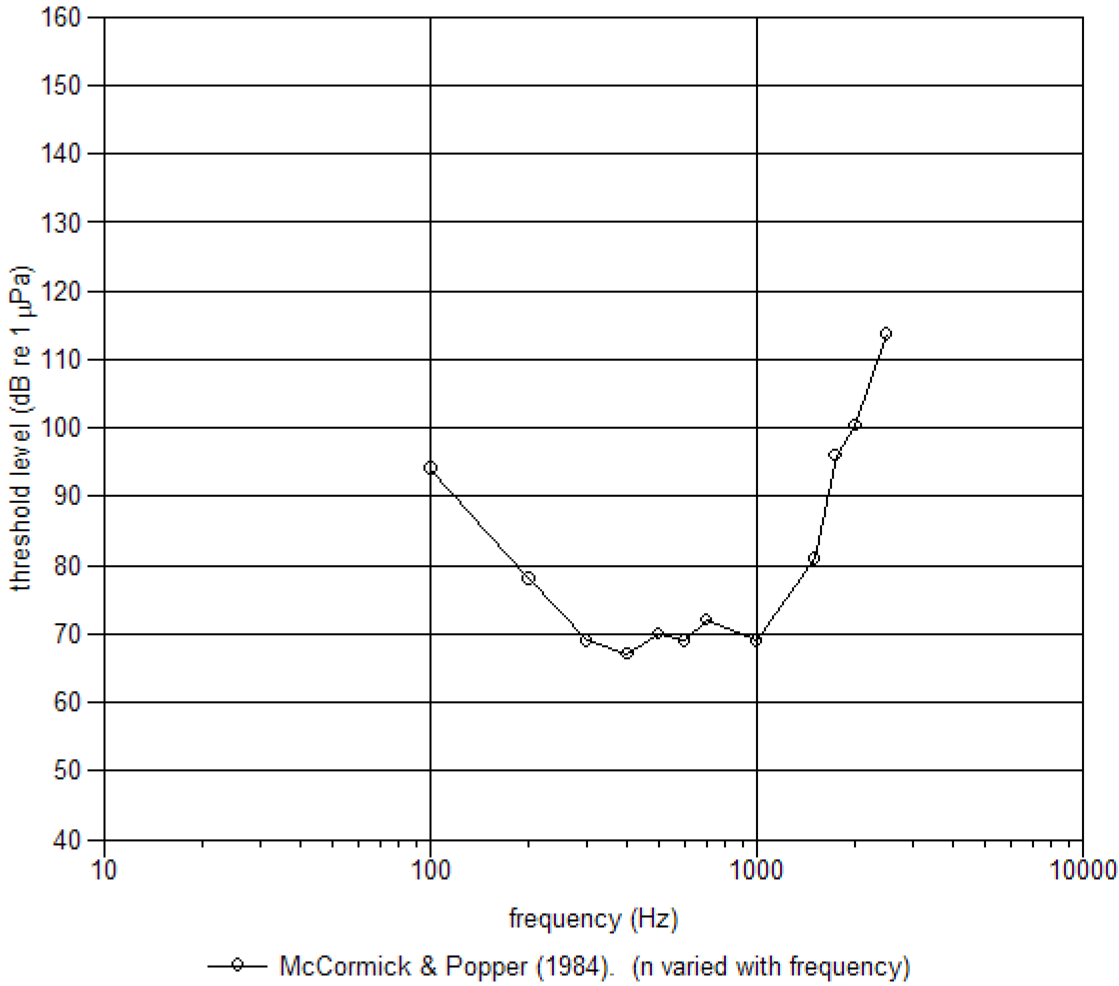
Common name	Elephant nose fish.
Family	
Species	*Gnathonemus petersii.*
Paper from which audiogram obtained	McCormick, C.A. & Popper, A.N. (1984). Auditory sensitivity and psychophysical tuning curves in the elephant nose fish, *Gnathonemus petersii*. J. Comp. Physiol., 155:753-761.
Paper having original audiogram data	McCormick, C.A. & Popper, A.N. (1984). Auditory sensitivity and psychophysical tuning curves in the elephant nose fish, *Gnathonemus petersii*. J. Comp. Physiol., 155:753-761.
Comments on methodology of getting audiogram	Behavioural method used. Tests done in tanks located in chambers having 150mm thick sand-filled walls. Subject had to cross a hurdle placed across the centre of the tank within 10sec of the sound being started to avoid being given an electric shock. Sound source was a 203mm dia. speaker positioned above the test tank. Signals were tones with 5ms rise and decay times. Staircase method was used for threshold determination; sound level varied in 5dB steps. Threshold was calculated from the last 8 reversal levels in a day's testing. Sound level in the tank was measured with a Clevite hydrophone, at 10 locations. The median values of the levels was used as the calibrated value. Particle velocity was also measured at 4 locations using a velocity hydrophone. 'Catch' trials were interspersed in the trials.
Any other comments	Ambient sound pressure was found to be well below threshold levels at all frequencies. Tests were also done to ascertain if the fish might be influenced by electric fields; it was concluded that this was highly unlikely. Also did tests involving masking.

Audiogram from Table 1. Threshold levels in dB re 1dyne/cm^2. (**Note:** It appears that the headings for the pressure threshold and particle velocity threshold columns have been interchanged. The values given in the table here are those from the 2nd. column (labelled in displacement units).

Frequency (Hz)	100	200	300	400	500	600	700	1000	1500	1750	2000	2500
Mean	-6	-22	-31	-33	-30	-31	-28	-31	-19	-4	0.4	13.7
SD	6.9	6.1	4.8	7.9	7.7	5.3	4.5	9.4	5.0	4.1	8.8	6.3
Range	+11	-13	-21	-24	-22	-25	-24	-28	-13	+3	+15	+23
	-15	-33	-36	-49	-47	-42	-38	-43	-28	-13	-15	+10
No. of determinations	16	10	9	9	17	9	16	15	16	11	18	10
No. of animals	4	3	3	3	4	3	4	4	3	3	3	3

Threshold levels in dB re 1µPa.

Frequency (Hz)	100	200	300	400	500	600	700	1000	1500	1750	2000	2500
Mean	94	78	69	67	70	69	72	69	81	96	100.4	113.7



[Fig. ref: ElphntNoseFish_G_01]

Audiogram for elephant nose fish.

Database page ref: F/Fathead/01.

Common name	Fathead minnow.
Family	Cyprinidae.
Species	*Pimephales promelas.*
Paper from which audiogram obtained	Scholik, A.R. & Yan, H.Y. (2001). Effects of underwater noise on auditory sensitivity of a cyprinid fish. Hearing Research, 152:17-24.
Paper having original audiogram data	Scholik, A.R. & Yan, H.Y. (2001). Effects of underwater noise on auditory sensitivity of a cyprinid fish. Hearing Research, 152:17-24.
Comments on methodology of getting audiogram	Specimens exposed to white noise for selected durations in a plastic tub (38 x 24.5 x 14.5cm, with 5.5cm water depth). Fish were free to swim about the tub during the exposure, but a mesh screen prevented them from jumping out of it. The noise was band limited to 300Hz to 4kHz, and at 142dB re 1μPa. The fish were mildly sedated with Flaxedil. The ABR technique was used to obtain the threshold values (see Appendix 1 for a description of the ABR method, and database page ref. F/Goldfish/02 for details of the experimental set-up and method). 3 aspects to experiment: (1) establishing thresholds immediately after exposure of 24 hrs – this was done at 8 frequencies; (2) establishing thresholds after exposures of 1, 2, 4 and 8 hrs – this was done at 4 frequencies (800Hz, 1, 1.5 and 2kHz); (3) establishing recovery after (a) 24 hrs of exposure (done at 4 frequencies, and at 1, 2, 4, 6 and 14 days), and (b) after 2 hrs of exposure (done at frequencies of 1.5 and 2kHz and after 6 and 14 days).
Any other comments	After noise exposure, the fish were kept in aquaria in an isolated area of the laboratory where auditory disturbances were kept minimal (87dB re 1μPa) until auditory testing could be completed.

Audiogram from Fig 1 in paper. Threshold levels in dB re 1μPa. 6 specimens tested.

Frequency (Hz)		300	500	800	1000	1500	2000	2500	4000
Baseline	Mean	81.0	84.2	80.8	76.5	79.4	86.9	104.4	116.8
	SE								
24 hrs exposure	Mean	92.0	91.7	91.5	93.7	99.4	100.1	109.8	122.5
	SE								

Audiogram from Table 1. Threshold levels in dB re 1μPa. 6 specimens for each of the durations.

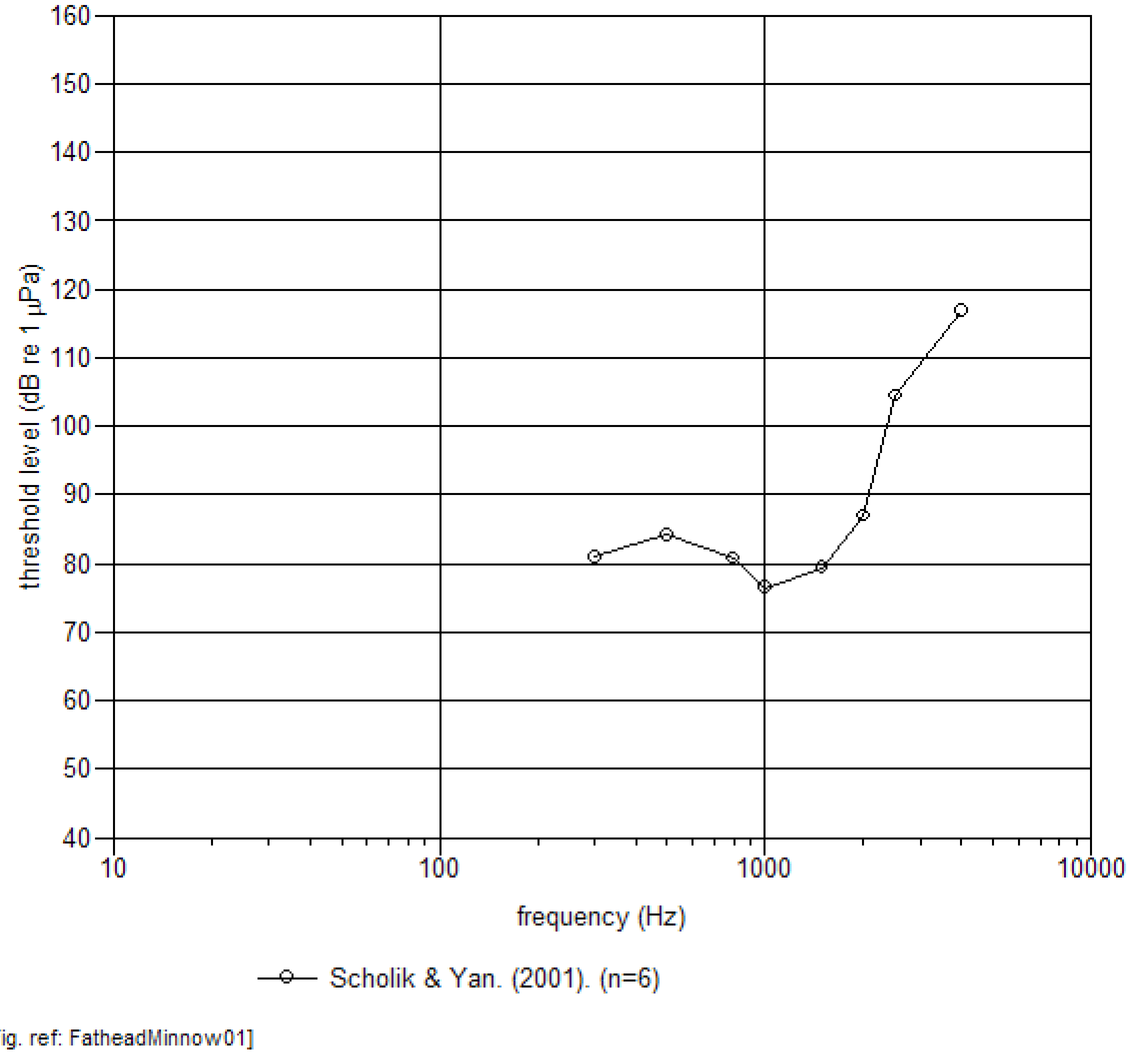
Frequency (Hz)		800	1000	1500	2000
Baseline	Mean	80.4	76.5	79.1	86.5
	SE	2.7	2.0	1.9	1.5
1 hr exposure	Mean	85.9	88.0	92.4	97.7
	SE	2.0	1.5	1.5	1.0
2 hr exposure	Mean	93.2	96.9	99.3	102.4
	SE	0.9	1.8	2.5	2.6
4 hr exposure	Mean	91.8	92.3	98.6	101.6
	SE	1.9	0.7	2.3	1.8
8 hr exposure	Mean	93.5	95.6	96.5	104.0
	SE	2.2	2.3	2.5	1.9
24 hr exposure	Mean	91.4	93.6	99.1	100.0
	SE	1.6	1.4	2.3	1.9

Audiogram from Table 2. Levels after stated recovery period after 24 hrs exposure to noise. Threshold levels in dB re 1μPa.

Frequency (Hz)			800	1000	1500	2000
Elapsed time since cessation of exposure to noise for 24 hrs.	baseline	Mean	80.4	76.5	79.1	86.5
		SE	2.7	2.0	1.9	1.5
	1 day	Mean	81.4	84.3	89.2	94.4
		SE	1.6	2.3	1.9	1.1
	2 days	Mean	81.7	82.8	87.9	91.2
		SE	2.0	1.2	2.0	1.5
	4 days	Mean	79.2	80.8	89.1	94.7
		SE	1.4	1.4	1.0	0.9
	6 days	Mean	81.8	81.7	86.5	92.7
		SE	1.5	1.2	1.0	1.4
	14 days	Mean	81.4	81.9	87.1	94.2
		SE	1.2	1.8	1.5	1.3

Audiogram from Table 2. Levels after stated recovery period after 2 hrs exposure to noise. Threshold levels in dB re 1μPa.

Frequency (Hz)			1500	2000
Elapsed time since cessation of exposure to noise for 2 hrs.	6 days	Mean	82.5	89.9
		SE	1.5	2.5
	14 days	Mean	81.9	89.3
		SE	0.9	1.2



Audiogram for fathead minnow.

Database page ref: F/Goby/01.

Common name	Goby (Italian freshwater).
Family	Gobiidae.
Species	*Podogobius martensii.*
Paper from which audiogram obtained	Lugli, M., Yan, H.Y. & Fine, M.I. (2003). Acoustic communication in two freshwater gobies: the relationship between ambient noise, hearing thresholds and sound spectra. J.Comp.Physiol. A, 189, 309-320.
Paper having original audiogram data	Lugli, M., Yan, H.Y. & Fine, M.I. (2003). Acoustic communication in two freshwater gobies: the relationship between ambient noise, hearing thresholds and sound spectra. J.Comp.Physiol. A, 189, 309-320.
Comments on methodology of getting audiogram	Used ABR technique. Fish was held with the nape of its head just above the water surface in a 380x245x145mm plastic tub. Sound was radiated by a Pioneer 300mm speaker located 1m above the subject. The sound level in the water was monitored with a Celesco LC-10 hydrophone located adjacent to the fish. The sound was 20ms long tone bursts. Sound level was reduced in 5dB steps until the threshold was reached.
Any other comments	5 fish (2 females, 3 males) were tested. Ambient noise could affect a species' absolute hearing sensitivity (Hawkins & Myrburg, (1983), Rogers & Cox (1988)). Part of purpose of experiment was to study the sound produced by the fishes, and how their hearing might be related to the ambient noise in their normal environment (shallow stony streams). Particular aspects were: sound production by male goby when presented with a conspecific female. Sounds emitted were recorded and analysed. Relationship found between sound spectrum and hearing sensitivity examined. effect of sound production before / after the withdrawal of gas from the swimbladder (this was done for 1 specimen). Frequency values were measured on power spectra, also measured was sound duration (ms) and the greatest peak-to-peak amplitude (mV). relationship between auditory sensitivity and stream ambient noise. Noise spectra from quiet locations did not correlate with goby audiograms, although close to noise sources there was a clear tendency of the audiogram to follow mean spectrum level curve. A positive relationship was found between the hearing threshold at a particular frequency and the highest noise spectrum levels of the stream at that frequency. Gobies are relatively insensitive auditory generalists with best hearing within a narrow band ~100Hz.

Audiogram from Fig. 3. Threshold levels in dB re 1μPa.

Frequency (Hz)	70	100	150	200	300	400	500	600	700	800
Mean	106.9	105.8	107.7	115.0	123.7	126.6	130.1	131.2	135.8	137.1

Database page ref: F/Goby/02.

Common name	Goby (Italian freshwater).
Family	Gobiidae.
Species	*Gobius nigricans.*
Paper from which audiogram obtained	Lugli, M., Yan, H.Y. & Fine, M.I. (2003). Acoustic communication in two freshwater gobies: the relationship between ambient noise, hearing thresholds and sound spectra. J.Comp.Physiol. A, 189, 309-320.
Paper having original audiogram data	Lugli, M., Yan, H.Y. & Fine, M.I. (2003). Acoustic communication in two freshwater gobies: the relationship between ambient noise, hearing thresholds and sound spectra. J.Comp.Physiol. A, 189, 309-320.
Comments on methodology of getting audiogram	Used ABR technique. Fish was held with the nape of its head just above the water surface in a 380x245x145mm plastic tub. Sound was radiated by a Pioneer 300mm speaker located 1m above the subject. The sound level in the water was monitored with a Celesco LC-10 hydrophone located adjacent to the fish. The sound was 20ms long tone bursts. Sound level was reduced in 5dB steps until the threshold was reached.
Any other comments	4 fish (1 female, 2 males) were tested. Ambient noise could affect a species' absolute hearing sensitivity (Hawkins & Myrburg, (1983), Rogers & Cox (1988)). Part of purpose of experiment was to study the sound produced by the fishes, and how their hearing might be related to the ambient noise in their normal environment (shallow stony streams). Particular aspects were: sound production by male goby when presented with a conspecific female. Sounds emitted were recorded and analysed. Relationship found between sound spectrum and hearing sensitivity examined. relationship between auditory sensitivity and stream ambient noise. Noise spectra from quiet locations did not correlate with goby audiograms, although close to noise sources there was a clear tendency of the audiogram to follow mean spectrum level curve. A positive relationship was found between the hearing threshold at a particular frequency and the highest noise spectrum levels of the stream at that frequency. Gobies are relatively insensitive auditory generalists with best hearing within a narrow band ~100Hz.

Audiogram from Fig. 3. Threshold levels in dB re 1µPa.

Frequency (Hz)	70	100	150	200	300	400	500	600	700	800
Mean	115.2	104.9	117.5	123.2	127.9	127.6	130.9	132.9	137.4	139.9

Database page ref: F/Goby/03.

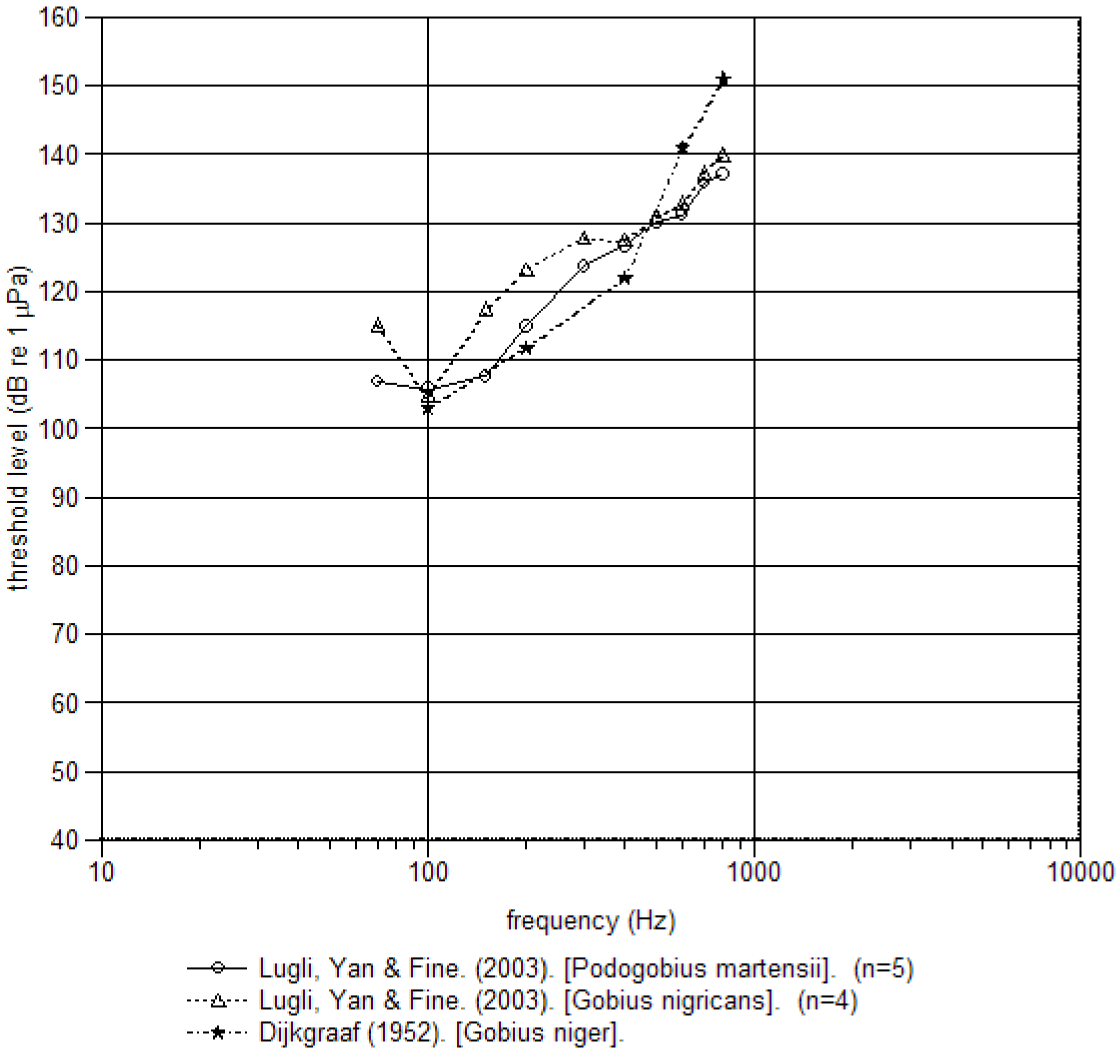
Common name	Goby
Family	Gobiidae.
Species	*Gobius niger*
Paper from which audiogram obtained	Fay, R.R. (1988). Hearing in Vertebrates: A Psychophysics Databook. Hill-Fay Associates, Winnetka, Ill.
Paper having original audiogram data	Dijkgraaf, S. (1952). Űber die Schallwahrnehmung bei Meeresfischen. Z. vergl. Physiol., 34:104-122.
Comments on methodology of getting audiogram	Original source not seen. Conditioned feeding response.
Any other comments	Sound pressures were measured relatively, and the thresholds are presented in dB with respect to human underwater hearing threshold.

Audiogram from Table F9-0. Threshold levels in dB re 1 dyne/cm^2.

Frequency (Hz)	100	200	400	600	800
Mean	3	11.8	22	41	51

Threshold levels in dB re 1µPa.

Frequency (Hz)	100	200	400	600	800
Mean	103	111.8	122	141	151



[Fig. ref: Goby02B]

Audiogram for goby.

Database page ref: F/Goldfish/01.

Common name	Goldfish.
Family	Cyprinidae
Species	*Carassius auratus*
Paper from which audiogram obtained	Yan, H.Y. (2001). A non-invasive electrophysiological study on the enhancement of hearing ability in fishes. Proc. I.O.A., Vol 23 Part 4, 15-26.
Paper having original audiogram data	Yan, H.Y. (2001). A non-invasive electrophysiological study on the enhancement of hearing ability in fishes. Proc. I.O.A., Vol 23 Part 4, 15-26.
Comments on methodology of getting audiogram	The ABR method was used. Experiments took place in soundproof room (2mx3mx2m). Fish clamped in mesh and held in water in tank (380x245x145mm) standing on air table, with just 1mm of top of head above water; tissue placed on head to prevent it from drying out. 2 electrodes attached to head – ref 5mm forward of recording electrode. Insonification by speaker suspended 1m above subject – 30cm speaker for frequencies below 3kHz, 12cm speaker for frequencies above 3kHz. Sound level at fish obtained from hydrophone placed near presumed 'ear' of fish. Tones and clicks played back at various levels to obtain threshold by visual inspection of averaged ABR traces. Clicks were 0.1ms in duration, presented at 38.2clicks/sec. No. of cycles in a tone burst were set to get best compromise between stimulus rapidity and peak frequency bandwidth; bursts were gated using Blackman window. Fish were sedated with Flaxedil (gallamine triethiodode) Once the baseline audiogram had been taken, the gas inside the gasbladder was removed using a needle attached to a syringe, and audiograms taken again. 6 specimens were tested.
Any other comments	In text states that goldfish use Weberian ossicles to mechanically couple gasbladder to inner ear. Radiographs were taken to localise the position of the gas-holding structure.

Audiogram from Fig. 3 – for **intact** gasbladder. Threshold levels in dB re 1 μPa.

Frequency (Hz)	300	500	800	1500	2500	4000
Mean	68.6	64.0	64.0	71.4	100.5	107.4

Audiogram from Fig. 3 – for **deflated** gasbladder. Threshold levels in dB re 1μPa.

Frequency (Hz)	300	500	800	1500	2500	4000
Mean	116.7	117.4	118.8	118.6	133.7	149.1

Database page ref: F/Goldfish/02.

Common name	Goldfish
Family	Cyprinidae
Species	*Carassius auratus*
Paper from which audiogram obtained	Kenyon, T.N., Ladich, F. & Yan, H.Y. (1998). A comparative study of hearing ability in fishes: the auditory brainstem response approach. J. Comp Physiol A 182: 307-318.
Paper having original audiogram data	Kenyon, T.N., Ladich, F. & Yan, H.Y. (1998). A comparative study of hearing ability in fishes: the auditory brainstem response approach. J. Comp Physiol A 182: 307-318.
Comments on methodology of getting audiogram	The ABR method was used. Experiments took place in soundproof room (2mx3mx2m). Fish clamped in mesh and held in water in tank (380x245x145mm) standing on air table, with just 1mm of top of head above water; tissue placed on head to prevent it from drying out. 2 electrodes attached to head – ref 5mm forward of recording electrode. Insonification by speaker suspended 1m above subject – 30cm speaker for frequencies below 3kHz, 12cm speaker for frequencies above 3kHz. Sound level at fish obtained from hydrophone placed near presumed 'ear' of fish. Tones and clicks played back at various levels to obtain threshold by visual inspection of averaged ABR traces. Clicks were 0.1ms in duration, presented at 38.2clicks/sec. No. of cycles in a tone burst were set to get best compromise between stimulus rapidity and peak frequency bandwidth; bursts were gated using Blackman window. 8 fish were given Flaxedil (gallamine triethiodode) to pacify them, and 3 left untreated. However, thresholds were significantly lower for the treated fish.
Any other comments	Electronics used Tucker-Davis Technologies gear – 486 PC with DSP board, which controlled amplifiers, converters, etc. Authors say ambient noise was measured with the hydrophone; signal was digitally filtered and spectrum levels were calculated using appropriate filter corrections and calibration factors.

Audiogram from Table 1. Threshold levels in dB re 1μPa for fishes dosed with Flaxedil. 8 fishes in sample.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1500	2000	3000	4000	5000
Mean	85.8	73.3	68.8	63.9	64	64.1	64	64.6	71.5	80	96.4	107.4	119.5
SD	3.3	4.3	3.3	2.9	4	4.2	2.7	3	3.1	2	4.5	4.3	3.4

Audiogram from Table 1. Threshold levels in dB re 1μPa for fishes **not** dosed with Flaxedil. 3 fishes in sample.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1500	2000	3000	4000	5000
Mean	88	79.3	75.3	74	73.7	71.3	70	66	78.7	84.3	102.3	113.3	122.7
SD	1	2.1	2.1	3.5	4.9	3.8	1	3	3.5	4	4.9	4.9	5.1

Ambient noise spectrum level, from Fig. 6. Levels in dB re 1μPa.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1500	2000	3000	4000	5000
Level	56	54	52	51	50	47	48	42	46	47	48	47	46

Database page ref: F/Goldfish/03.

Common name	Goldfish.
Family	Cyprinidae
Species	*Carassius aurarus.*
Paper from which audiogram obtained	Yan, H.Y & Popper, A.N. (1992). Auditory sensitivity of the cichlid fish *Astronotus ocellatus* (Cuvier). J. Comp. Physiol., A 171, 105-109.
Paper having original audiogram data	Yan, H.Y & Popper, A.N. (1991). An automated positive reward method for measuring acoustic sensitivity in fish. Behav. Res. Meth. Instru. & Compu., 23:351-356.
Comments on methodology of getting audiogram	Original paper not seen. This (1992) paper has the following description for the tests with Oscars. An automatic feeder was attached to the top of a Plexiglas platform which could be placed over the test tank. A vertical tube, which contacted the water surface, delivered food pellets to the fish. 2 paddles (clear plastic tubes housing 10W light bulbs, and designated the 'O-' and 'R-paddles') were suspended from the platform. The paddles sent response signals to a PC to control food delivery. An underwater speaker (University Sound UW-30) was used to present the tone signals. The fish were trained, in 5 phases, to peck the O-paddle and then to peck the R-paddle if they detected the sound signal. A correct response resulted in the fish obtaining food. Once trained, thresholds were determined using the constant stimulus method. 4 to 6 SPLs were used at each frequency. In each test run 5 replicates of a chosen SPL and 5 blank trials were randomly presented. A minimum of 2 test runs was repeated for each fish at each SPL to calculate the response rate. The response rate was calculated by dividing the number of correct responses by the total number of trials. Threshold was the level at which there were 50% correct responses.
Any other comments	

Audiogram from Fig 2. Threshold levels in dB re 1μbar.

Frequency (Hz)	200	500	1000	1500	2000
Mean	-31	-51	-35	-30	5

Threshold levels in dB re 1μPa.

Frequency (Hz)	200	500	1000	1500	2000
Mean	69	49	65	70	105

Database page ref: F/Goldfish/04.

Common name	Goldfish.
Family	Cyprinidae
Species	*Carassius auratus.*
Paper from which audiogram obtained	Popper, A.N. (1972). Auditory threshold in the goldfish (*Carassius auratus*) as a function of signal duration. JASA, 52(2) Part 2, 596-602.
Paper having original audiogram data	Popper, A.N. (1972). Auditory threshold in the goldfish (*Carassius auratus*) as a function of signal duration. JASA, 52(2) Part 2, 596-602.
Comments on methodology of getting audiogram	Tested using an avoidance conditioning procedure. Fish were trained to cross a barrier in the centre of a Plexiglas tank whenever a pulsed sound was presented. If fish did not cross the barrier during a 10s presentation they were shocked once per second (for 50msec with a voltage of 10 to 15V ac) through electrodes at either end of the tank. The shock continued until the fish crossed the barrier. Fish were given 25 to 30 trials per day until they successfully crossed the barrier before shock onset (thus indicating that they had heard the sound) in 90% of a day's trials for 3 consecutive days. Threshold levels were determined using an up-down staircase method, with the fish indicating it had heard the sound by crossing the barrier prior to the shock. The sound pressure was lowered in 2dB steps until fish failed to respond (and therefore got a shock). Threshold was taken to be between the SPL to which the fish had not responded and the last one to which it had responded. Sound level was then raised in 2dB steps until it again responded to the sound. 15 to 20 reversals were averaged each day for each animal. Test signal was pure tone, which had been passed through a bandpass filter set to have its low and high pass frequencies at the frequency of the tone. The signal was presented through a KLH 703 loudspeaker placed, in air, about 90mm from the tank. Speaker and tank were placed on a 2in. layer of foam rubber.
Any other comments	12 fish, 45 to 120mm standard length, were used. Tests were done in acoustic chambers to prevent masking by ambient noise. Sound spectrum levels were found to be at least 20dB below any threshold measured (results given in Popper (1972) 'The effects of size on the auditory capacities of the goldfish', J. Aud. Res. (in press)). The sound level in the tank was regularly checked with a hydrophone. The SPL varied by 1 to 3dB through the tank, but fish tended to remain in places with the maximum SPL. A check was made on pulse shape and duration by comparing, on an oscilloscope, the hydrophone signal from the tank with the signal from a SLM microphone placed at the same position in the chamber as the hydrophone was in the test tank. The signal in water was essentially the same as the signal measured in air. Author concluded that there were no differences in threshold between short pulses and continuous tones and that thresholds were the same whether there was a long or short signal off-time between pulses.

Data from Table I. Threshold levels for different pulse durations in dB re 1μbar. 12 specimens.

Signal parametes		Frequency (Hz)							
On time (msec)	Off time (msec)	300		500		1000		1500	
		threshold	SD	threshold	SD	threshold	SD	threshold	SD
continuous		-40.1	±5.82	-44.9	±4.13	-43.9	±6.31	-26.1	±4.5
10	490			-43.2	±3.02	-43.4	±1.35		
50	500	-39.7	±6.12	-43.3	±5.93	-43.5	±5.57	-29.5	±4.71
100	500	-39.4	±5.40	-43.6	±3.32	-40.7	±6.73	-20.8	±6.55
200	500	-41.4	±6.06	-48.1	±3.41	-40.0	±5.23	-25.2	±5.44
300	700	-37.0	±6.90	-42.6	±2.90	-40.4	±5.13	-23.0	±4.87
500	500	-42.5	±5.66	-46.8	±4.69	-42.8	±5.55	-24.1	±6.14

Threshold levels for continuous signal in dB re 1μPa.

Frequency (Hz)	300	500	1000	1500
Mean	59.9	55.1	56.1	73.9

Table II in the paper presents threshold levels for the same four frequencies for duty cycles ranging from 1% to 90%.

Database page ref: F/Goldfish/05.

Common name	Goldfish
Family	Cyprinidae
Species	*Carassius auratus*
Paper from which audiogram obtained	Kenyon, T.N., Ladich, F. & Yan, H.Y. (1998). A comparative study of hearing ability in fishes: the auditory brainstem response approach. J. Comp Physiol A 182: 307-318.
Paper having original audiogram data	Popper, A.N. (1971). The effects of size on the auditory capacities of the goldfish. J Aud Res 11:239-247.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	

Audiogram from Table 1. Threshold levels in dB re 1μPa. 3 fishes in sample, except for f=100Hz, when 4 fish.

Frequency (Hz)	100	300	500	1000	1500	2000
Mean	73.8	53.8	51.8	60.1	73.6	94.6
SD	5.9	7.2	6.1	7.4	5.8	6.7

Database page ref: F/Goldfish/06.

Common name	Goldfish.
Family	Cyprinidae
Species	*Carassius aurutus.*
Paper from which audiogram obtained	Kenyon, T.N., Ladich, F. & Yan, H.Y. (1998). A comparative study of hearing ability in fishes: the auditory brainstem response approach. J. Comp Physiol A 182: 307-318.
Paper having original audiogram data	Fay, R.R. (1969). Behavioural audiogram for the goldfish. J Aud Res, 9:112-121.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	

Audiogram from Fig. 7 in above paper. Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	350	600	800	1000	1500	1800	2500
Mean	73.7	67.0	64.6	66.3	74.7	77.3	95.6	107.5	115.9

Audiogram from Fig. 2 of Popper, A.N. & Fay, R.R. (1993). Source of data was Fay (1969).

Frequency (Hz)	30	50	100	200	350	600	800	1000	1500	1800	2350
Mean	78.4	76.0	75.2	67.5	63.2	69.1	75.1	66.9	95.9	107.5	116.8

Database page ref: F/Goldfish/07.

Common name	Goldfish.
Family	Cyprinidae
Species	*Carassius auratus.*
Paper from which audiogram obtained	Offutt, G.C. (1968). Auditory response in the goldfish. J. Aud. Res., 8, 391-400.
Paper having original audiogram data	Offutt, G.C. (1968). Auditory response in the goldfish. J. Aud. Res., 8, 391-400.
Comments on methodology of getting audiogram	Used classical conditioning of the heart rate was used to determine thresholds – ECGs were recorded. Test tank, made of 0.25inch Plexiglas and 1.07m x 0.46m x 0.3m deep, was lined with rubberised horsehair (40mm on the bottom and two sides, 100 and 180mm at the ends). Animals were implanted with electrodes made from 600mm pieces of #30 silver-coated copper wire with Teflon insulation; about 8mm of the insulation was removed. The electrodes were implanted so that the exposed wire was located in the visceral cavity. M-222 was used to anaesthetise the fish before implantation, and at least 1 hr was allowed between implantation and the start of conditioning. When tested, the fish were wrapped behind the operculum with several layers of cheesecloth and held by rubber bands in a V-shaped Plexiglas stand so that they were 50mm above the bottom of the tank. The electrodes for administering the shocks were 380 x 127mm, made from mesh galvanised screening and were placed 260mm apart in the tank. Several layers of galvanised screening were grounded and placed between the projector and the fish. Source was a J-9 projector, placed 150mm from the side of the fish. The signal from a hydrophone was displayed on an oscilloscope. Measurement of the sound reaching the fish was made by placing an Atlantic Corp. BC 32 hydrophone in the cradle of the fish stand – this 'phone was approximately the size of the fish's body. The fish were trained to a selected frequency as the conditioned stimulus (CS). The unconditioned stimulus (US) was a shock. The length of the CS was between 2 and 6sec, and the length of the US was between 0.2 and 0.8sec. A slowing of the heart rate during the CS was considered a conditional response (CR). Initially the CS was set about 15dB above the expected threshold and, after the fish showed repeated CRs, the intensity was lowered 5dB and the training continued. This procedure was followed until no CR was observed after 10 training trials. 5 test trials were then recorded. If there was a CR the procedure was repeated with stimulus 5dB lower. After a series of tests showing no CR a final test series was made with the pressure 5dB above the original testing level. The difference in the heart rate before and during the presentation of the test tone was determined. Calculations were then made to determine between which pressure settings the threshold occurred.
Any other comments	31 animals, 124 to 162mm in total length, were used. Instrumentation noise limited the calibration of the sound source output at low levels. All equipment was housed in a Koppers industrial sound control room.

Audiogram from Fig. 1 (line drawn by paper's author). Threshold levels in dB re 1μbar. 31 specimens.

Frequency (Hz)	40	100	400	800	1500	3000	8000	15000
Mean	6	-15	-26	-28	4	43	53	56

Threshold levels in dB re 1μPa.

Frequency (Hz)	40	100	400	800	1500	3000	8000	15000
Mean	106	85	74	72	104	143	153	156

Database page ref: F/Goldfish/08.

Common name	Goldfish.
Family	Cyprinidae
Species	*Carassius auratus.*
Paper from which audiogram obtained	Jacobs, D.W & Tavolga, W.N. (1967). Acoustic intensity limens in the goldfish. Anim. Behav., 15, 324-335.
Paper having original audiogram data	Jacobs, D.W & Tavolga, W.N. (1967). Acoustic intensity limens in the goldfish. Anim. Behav., 15, 324-335.
Comments on methodology of getting audiogram	Tested using an avoidance conditioning procedure. Tests carried using Plexiglas tank with central shallow barrier. 2 pairs of electrodes, a pair at each ends the tank on the sidewalls, administered the electric shock. Test tank was placed within an acoustic chamber in which floor was covered with 2inch thick foam rubber. Chamber was flexibly mounted. Obtained sound reduction of about 60dB. Source was 12inch loudspeaker mounted in ceiling of chamber surrounded by insulation. Cone was about 200mm above the surface of the water. Sound was monitored by a hydrophone in the water and an SLM placed close to the tank – gave almost identical SPLs. Oscilloscope was used to check purity of both signals. Fish was trained to swim across the barrier if it detected the test sound. If it failed to do so within 10s of the onset of the sound it was subjected to an electric shock. Shock consisted of 8msec long pulses of 60Hz current repeated at 1 pulse/sec. Threshold determined by staircase method, with steps of 1, 2 or 5dB.
Any other comments	4 animals, ranging from 40 to 70mm in standard length, were used in threshold determination tests. Each animal was tested at least twice at the same frequency on successive days, except for 3kHz. At this frequency the behaviour of the subjects was erratic and highly variable from day to day. Background noise levels were measured using the hydrophone. Its output was passed through a filter with the same cut-off frequency for its high and low pass sections. Spectrum level was calculated by allowing for the effective bandwidth.

Audiogram from Table I. Threshold levels in dB re 1μbar. 4 specimens.

Frequency (Hz)	50	100	200	500	800	1000	1500	2000	3000
Mean	-24.6	-28.4	-41.7	-45.6	-44.5	-43.1	-27.9	-1.8	+22.3
SD	9.5	6.1	6.0	7.7	5.9	7.6	6.9	6.0	5.7
No. of determinations	14	17	8	12	9	12	8	12	4

Threshold levels in dB re 1μPa.

Frequency (Hz)	50	100	200	500	800	1000	1500	2000	3000
Mean	75.4	71.6	58.3	54.4	55.5	56.9	72.1	98.2	122.3

Background noise levels from Fig. 2.

Frequency (Hz)	50	100	200	500	800	1000	1500	2000	3000
Noise level (dB re 1μbar)	--43	-44	-56	-55	-57	-58	-58	-58	-60
Spectrum level (dB re 1μbar/Hz)	-57	-63	-77	-79	-84	-87	-89		

Database page ref: F/Goldfish/09.

Common name	Goldfish.
Family	Cyprinidae
Species	*Carassius auratus.*
Paper from which audiogram obtained	Enger, P.S. (1966). Acoustic threshold in goldfish and its relation to the sound source distance. Comp. Biochem. Physiol., 18, 859-868.
Paper having original audiogram data	Enger, P.S. (1966). Acoustic threshold in goldfish and its relation to the sound source distance. Comp. Biochem. Physiol., 18, 859-868.
Comments on methodology of getting audiogram	Classical conditioning method used. Tests done in 5m long semi-circular trough made from polyethylene tube 300mm dia. cut across a diameter. Water depth 150mm max. Underwater loudspeaker (Chesapeake Instrument Corp. Model J9) was suspended in the water at one end of, but not touching, the trough. A 2m length of rockwool was placed in the other end of the trough. The trough was lined with a 50mm layer of rockwool. The trough was placed on rockwool, which was also placed around its sides. Fish was kept in a cage made of gauze wrapped around a 100x50x150mm high frame made from thin plastic rods. The fish was constrained to be within the top 50mm layer of water. Tests were also done with a loudspeaker suspended in air approximately 150mm above the trough. Fish were trained to associate feeding with sinusoidal sounds of different frequencies. After a conditioned response was established the sound pressure was reduced in 6dB steps until no response was obtained, and then in 3dB steps. SPLs were measured with an Atlantic Research Corp. Model LC 34 hydrophone placed in the gauze cage at the positions that the fish occupied.
Any other comments	6 fish were used. With the underwater speaker, sound levels varied inside the cage within 1dB (for distances of 1 and 2m) and within 4dB (for distances of 0.1 and 0.2m). With the in-air loudspeaker, sound levels varied within 2dB inside the cage. In discussion considers particle displacement. Uses formula relating displacement and sound pressure to calculate particle displacements associated with the thresholds obtained, and in figure shows that, if use displacement, threshold level is much less dependent on distance from the source for the frequencies tested. Further, makes a rough calculation of particle accelerations, and finds that the curves tend to collapse towards a single curve.

Audiogram from Figs. 2 & 3, from the author's mean lines. Threshold levels in dB re 1µbar. 6 specimens.

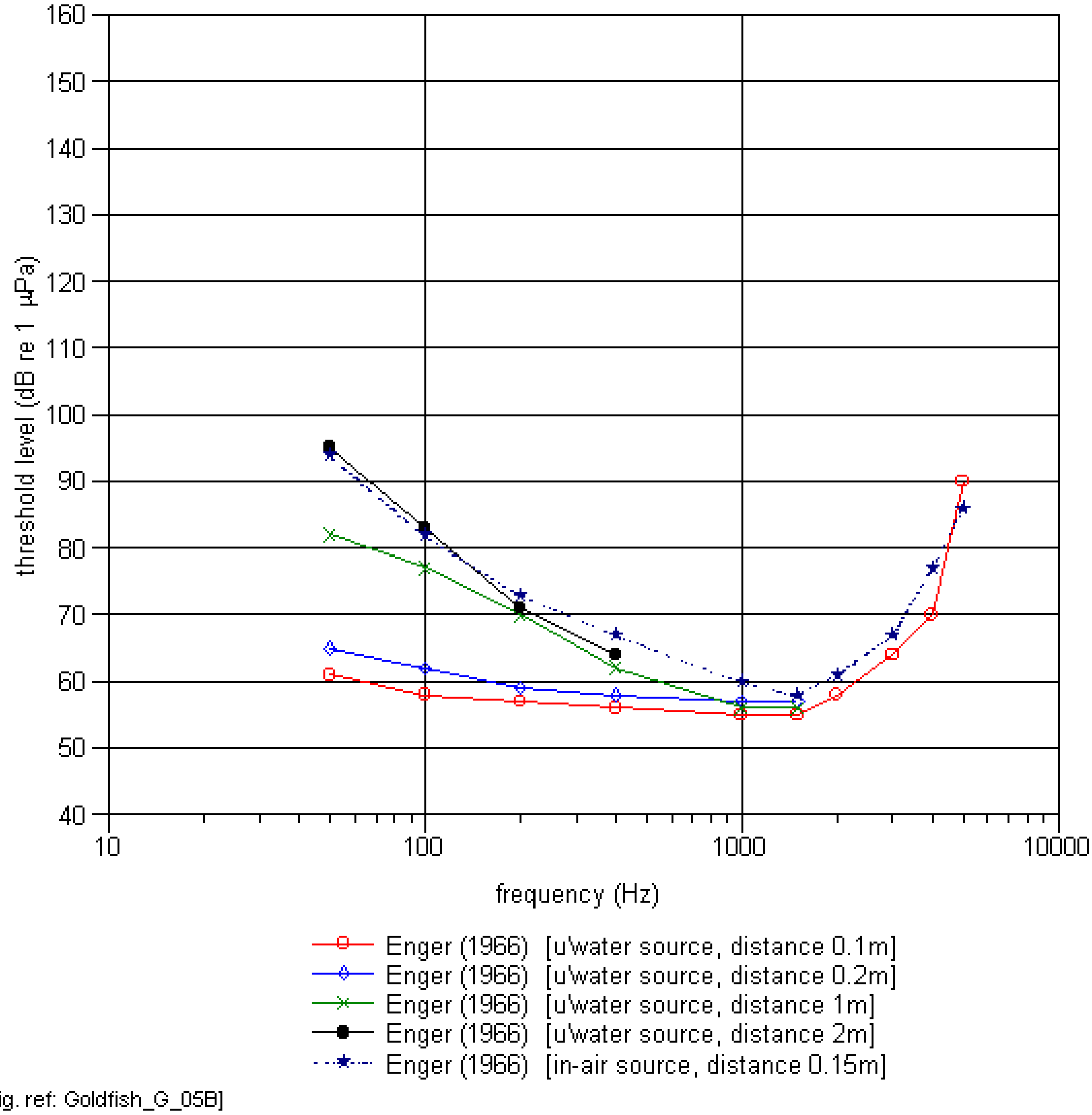
Frequency (Hz)		50	100	200	400	1000	1500	2000	3000	4000	5000
Level, using underwater loudspeaker	Distance 0.1m	-39	-42	-43	-44	-45	-45	-42	-36	-30	-10
	Distance 0.2m	-35	-38	-41	-42	-43	-42				
	Distance 1m	-18	-23	-30	-38	-44	-44				
	Distance 2m	-5	-17	-29	-36						
Level, using in-air loudspeaker	Distance 0.15m	-6	-18	-27	-33	-40	-42	-39	-33	-23	-14

Threshold levels for underwater loudspeaker in dB re 1µPa.

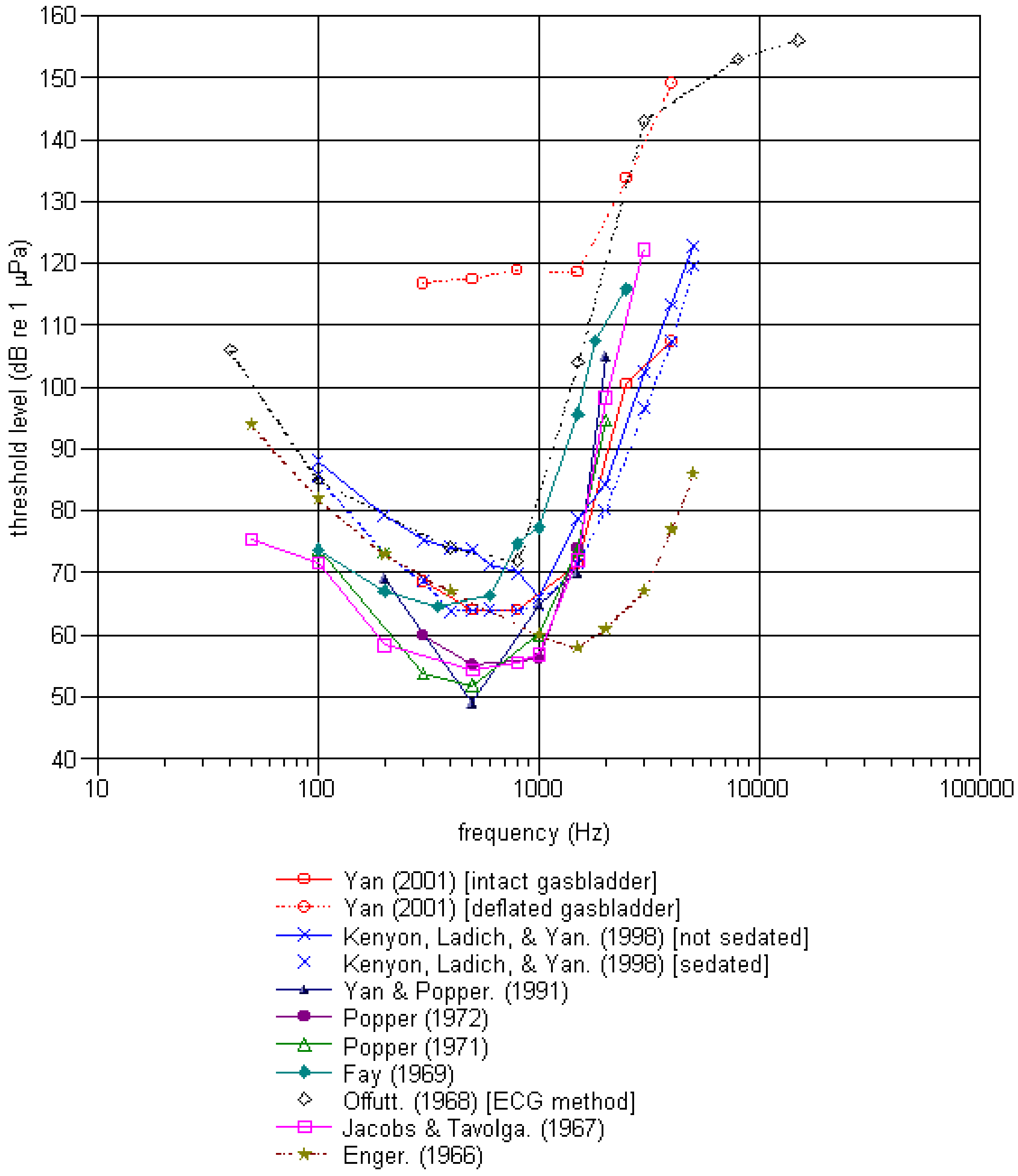
Frequency (Hz)	50	100	200	400	1000	1500	2000	3000	4000	5000
Distance 0.1m	61	58	57	56	55	55	58	64	70	90
Distance 0.2m	65	62	59	58	57	57				
Distance 1m	82	77	70	62	56	56				
Distance 2m	95	83	71	64						

Threshold levels for in-air loudspeaker in dB re 1µPa.

Frequency (Hz)	50	100	200	400	1000	1500	2000	3000	4000	5000
Distance 0.1m	94	82	73	67	60	58	61	67	77	86



Audiograms for goldfish (data of Enger only).



[Fig. ref: Goldfish01B]

Audiograms for goldfish, from a number of sources.

Database page ref: F/GouramiBlue/01.

Common name	Blue gourami.
Family	
Species	*Trichogaster trichopterus.*
Paper from which audiogram obtained	Yan, H.Y. (2001). A non-invasive electrophysiological study on the enhancement of hearing ability in fishes. Proc. I.O.A., Vol 23 Part 4, 15-26.
Paper having original audiogram data	Yan, H.Y. (2001). A non-invasive electrophysiological study on the enhancement of hearing ability in fishes. Proc. I.O.A., Vol 23 Part 4, 15-26.
Comments on methodology of getting audiogram	The ABR method was used. Experiments took place in soundproof room (2mx3mx2m). Fish clamped in mesh and held in water in tank (380x245x145mm) standing on air table, with just 1mm of top of head above water; tissue placed on head to prevent it from drying out. 2 electrodes attached to head – ref 5mm forward of recording electrode. Insonification by speaker suspended 1m above subject – 30cm speaker for frequencies below 3kHz, 12cm speaker for frequencies above 3kHz. Sound level at fish obtained from hydrophone placed near presumed 'ear' of fish. Tones and clicks played back at various levels to obtain threshold by visual inspection of averaged ABR traces. Clicks were 0.1ms in duration, presented at 38.2clicks/sec. No. of cycles in a tone burst were set to get best compromise between stimulus rapidity and peak frequency bandwidth; bursts were gated using Blackman window. Fish were sedated with Flaxedil (gallamine triethiodode) Once the baseline audiogram had been taken, the gas inside the suprabranchial chamber was flushed out with water, and audiograms taken again.
Any other comments	5 specimens were tested. In text states that gouramis hold air inside the suprabranchial chamber, which is in close proximity to the inner ear. Radiographs were taken to localise the position of the gas-holding structure.

Audiogram from Fig. 3 – **before** removal of gas bubbles. Threshold levels in dB re 1μPa. 5 specimens.

Frequency (Hz)	300	500	800	1500	2500	4000
Mean	89	78.6	75.7	85.2	102.3	124.8

Audiogram from Fig. 3 – **after** removal of gas bubbles. Threshold levels in dB re 1μPa.

Frequency (Hz)	300	500	800	1500	2500	4000
Mean	116.4	110.0	107.1	109.2	121.8	143.6

Database page ref: F/GouramiBlue/02.

Common name	Blue gourami.
Family	
Species	*Trichogaster trichopterus.*
Paper from which audiogram obtained	Ladich, F. & Yan, H.Y. (1998). Correlation between auditory sensitivity and vocalization in anabantoid fishes. J Comp Physiol A 182:737-746.
Paper having original audiogram data	Ladich, F. & Yan, H.Y. (1998). Correlation between auditory sensitivity and vocalization in anabantoid fishes. J Comp Physiol A 182:737-746.
Comments on methodology of getting audiogram	The ABR method was used. Experiments took place in soundproof room (2mx3mx2m). Fish clamped in mesh and held in water in tank (380x245x145mm) standing on air table, with just 1mm of top of head above water; tissue placed on head to prevent it from drying out. 2 electrodes attached to head – ref 10mm forward of recording electrode. Insonification by speaker suspended 1m above subject – 30cm speaker for frequencies below 3kHz, 12cm speaker for frequencies above 3kHz. Sound level at fish obtained from hydrophone (Celesco LC-10) placed near presumed right 'ear' of fish. Tones and clicks played back at various levels to obtain threshold by visual inspection of averaged ABR traces. Clicks were 0.1ms in duration, presented at 38.2clicks/sec. No. of cycles in a tone burst was set to get best compromise between stimulus rapidity and peak frequency bandwidth. All 11 specimens were given Flaxedil (gallamine triethiodode) to pacify them.
Any other comments	

Audiogram from Table 1. Threshold levels in dB re 1μPa. 11 specimens.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1500	2000	2500	3000	4000	5000
Mean	91.1	90.8	85.2	82.7	80.0	77.0	76.2	77.4	85.1	93.6	102.2	115.0	124.8	132.8
SD	4.1	5.0	4.8	4.4	6.3	4.6	6.3	6.3	4.3	2.4	3.6	7.2	3.5	3.3

Audiogram from Table 4 – by **ABR** method. Threshold levels in dB re 1μPa. (NOTE: these values differ slightly from those given in Table 1 in the paper.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1500
Mean	91.6	91.1	84.9	82.2	79.5	76.1	75.3	76.9	85.2
SD	4.1	5.2	5.0	4.3	6.5	4.0	6.1	6.5	4.6

Database page ref: F/GouramiBlue/03.

Common name	Blue gourami.
Family	
Species	*Trichogaster trichopterus.*
Paper from which audiogram obtained	Saidel, W.M. & Popper, A.N. (1987). Sound reception in two anabantid fishes. Comp. Biochem. Physiol., 88A, 37-44.
Paper having original audiogram data	Saidel, W.M. & Popper, A.N. (1987). Sound reception in two anabantid fishes. Comp. Biochem. Physiol., 88A, 37-44.
Comments on methodology of getting audiogram	Tests were done in a 900mm long vertically aligned cast iron cylinder with 7mm thick walls. Sound source was a University UW-30 underwater speaker at the base of the tube. Fish, which had been anaesthetised and injected with Flaxedil, was held at top of tube, with a surgically-made opening to the cranial cavity at the water surface. An electrode was placed adjacent to the saccule. The signal from the electrode was passed through a system with filters having a passband from 10Hz to 10kHz, and the 2nd harmonic of the stimulus was measured with a wave analyser having a filter with either a 3 or a10Hz passband centred at the stimulus frequency. Entire apparatus was placed on a vibration-isolating table in an IAC soundproof room. A PDP 11/10 computer controlled the running of the experiment (stimulus frequency, duration, amplitude, etc.). The stimulus had 5msec rise and decay times. Sound was measured with a matched pair of Celesco LC-10 hydrophones, one just below the water surface and the second 10mm below the first. The magnitude of the displacement was calculated from the 2 hydrophone readings.
Any other comments	Fish were between 50 and 90mm in total length. Ambient noise in tube was measured in a 10Hz wide band centred on each test frequency – no level exceeded 75dB re 1μPa. Because fish was held near surface of water, it was at a point where pressure was minimised and displacement was maximised. Therefore, stimulus was predominantly displacement.

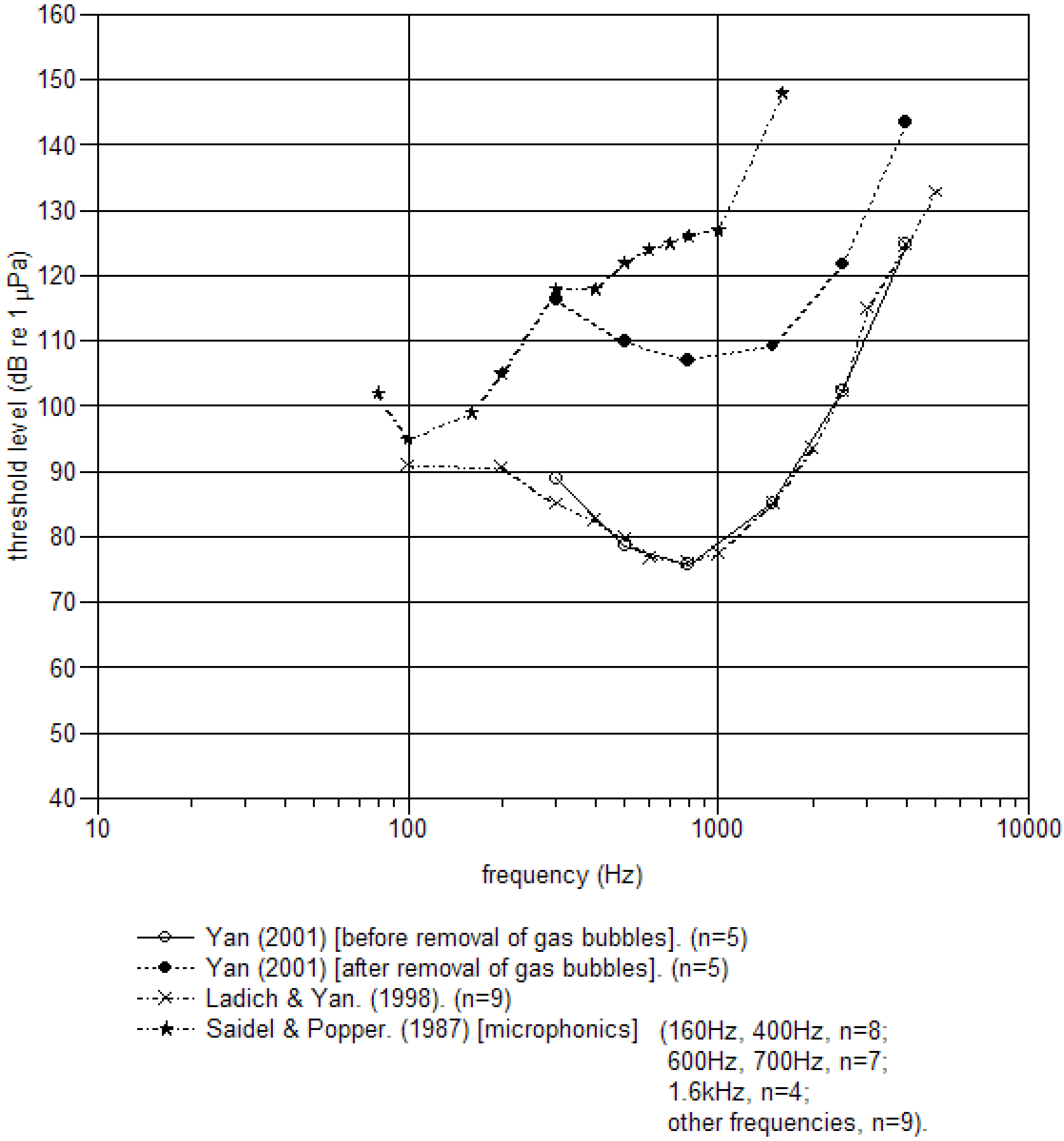
Audiogram from Table 1. Threshold levels for the *2nd harmonic of the stimulus frequency* in dB re 1μbar. The levels are those that resulted in a 1μV RMS potential above the background noise. (Note: The values in the following table are as given in the paper's Table 1. However, in Fig. 2(A) in the paper (threshold level *vs.* frequency), the frequency axis is on a log scale which is labelled unusually, *viz.* it is labelled '20', '200', '2000' where one would expect '10', '100', '1000', and the level for 80Hz (in the table) is plotted at the expected 40Hz mark, the level for 100Hz (in the table) at the 50Hz mark, etc.).

Frequency (Hz)	80	100	160	200	300	400	500	600	700	800	1000	1600
Mean	2	-5	-1	5	18	18	22	24	25	26	27	48
SD	12	11	14	7	6	9	7	9	7	7	9	4
No.	9	9	8	9	9	8	9	7	7	9	9	4

Note: For 1600Hz, 2 of the measures were estimated from subthreshold measurements, 2 were directly measured.

Threshold levels in dB re 1μPa.

Frequency (Hz)	80	100	160	200	300	400	500	600	700	800	1000	1600
Mean	102	95	99	105	118	118	122	124	125	126	127	148



[Fig. ref: BlueGourami02]

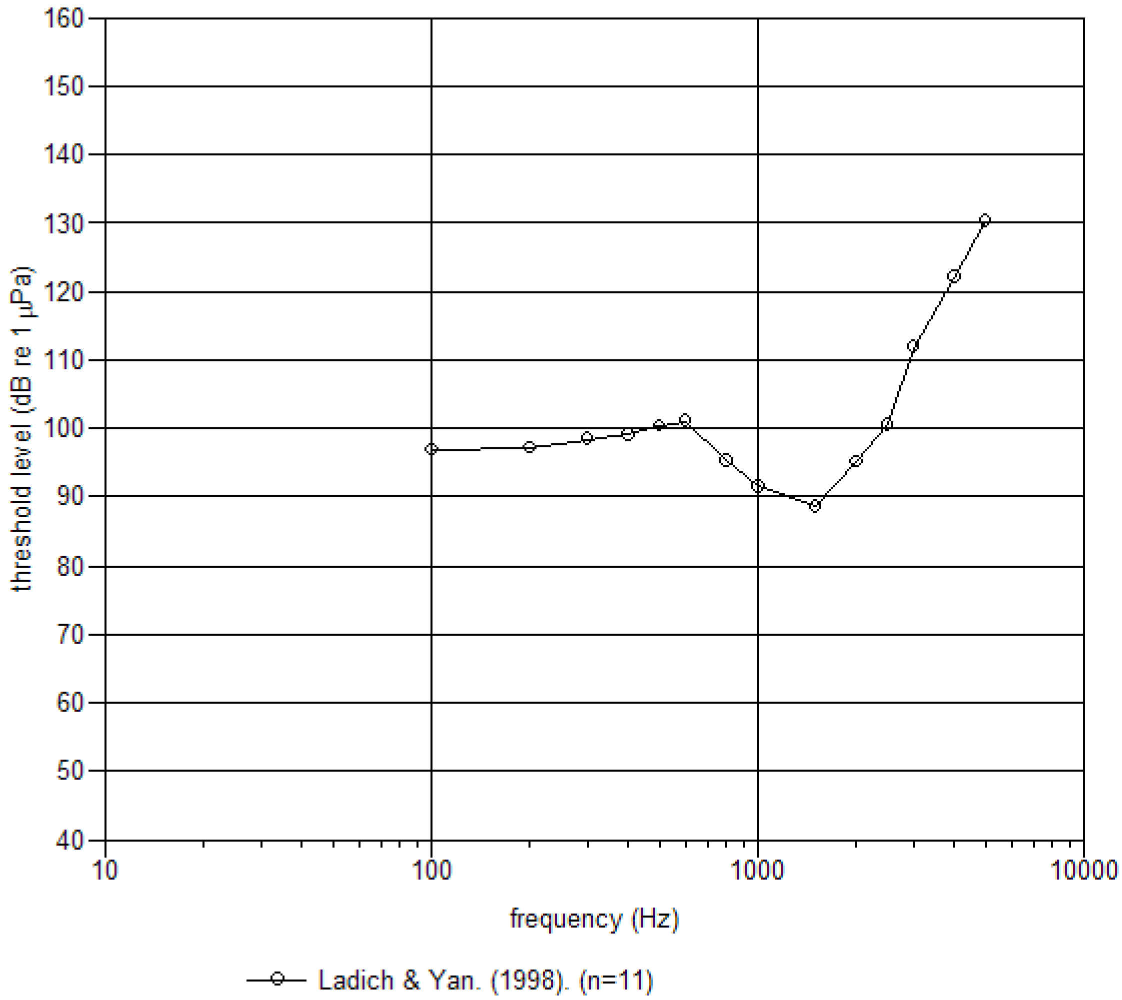
Audiogram for blue gourami.

Database page ref: F/GouramiCroaking/01.

Common name	Croaking gourami.
Family	
Species	*Trichopsis vittata*
Paper from which audiogram obtained	Ladich, F. & Yan, H.Y. (1998). Correlation between auditory sensitivity and vocalization in anabantoid fishes. J Comp Physiol A 182:737-746.
Paper having original audiogram data	Ladich, F. & Yan, H.Y. (1998). Correlation between auditory sensitivity and vocalization in anabantoid fishes. J Comp Physiol A 182:737-746.
Comments on methodology of getting audiogram	The ABR method was used. Experiments took place in soundproof room (2mx3mx2m). Fish clamped in mesh and held in water in tank (380x245x145mm) standing on air table, with just 1mm of top of head above water; tissue placed on head to prevent it from drying out. 2 electrodes attached to head – ref 10mm forward of recording electrode. Insonification by speaker suspended 1m above subject – 30cm speaker for frequencies below 3kHz, 12cm speaker for frequencies above 3kHz. Sound level at fish obtained from hydrophone (Celesco LC-10) placed near presumed right 'ear' of fish. Tones and clicks played back at various levels to obtain threshold by visual inspection of averaged ABR traces. Clicks were 0.1ms in duration, presented at 38.2clicks/sec. No. of cycles in a tone burst was set to get best compromise between stimulus rapidity and peak frequency bandwidth. All 11 specimens were given Flaxedil (gallamine triethiodode) to pacify them.
Any other comments	

Audiogram from Table 1. Threshold levels in dB re 1µPa. 11 specimens.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1500	2000	2500	3000	4000	5000
Mean	96.8	97.1	98.4	99.1	100.4	101	95.3	91.5	88.5	95.1	100.6	111.8	122.1	130.3
SD	3.5	3.9	3.0	5.5	5.3	6.9	6.2	6.4	5.5	4.9	3.5	3.4	3.7	2.9



[Fig. ref: CroakingGourami01]

Audiogram for croaking gourami.

Database page ref: F/GouramiDwarf/01.

Common name	Dwarf gourami.
Family	
Species	*Colisa lalia.*
Paper from which audiogram obtained	Yan, H.Y. (2001). A non-invasive electrophysiological study on the enhancement of hearing ability in fishes. Proc. I.O.A., Vol 23 Part 4, 15-26.
Paper having original audiogram data	Yan, H.Y. (2001). A non-invasive electrophysiological study on the enhancement of hearing ability in fishes. Proc. I.O.A., Vol 23 Part 4, 15-26.
Comments on methodology of getting audiogram	The ABR method was used. Experiments took place in soundproof room (2mx3mx2m). Fish clamped in mesh and held in water in tank (380x245x145mm) standing on air table, with just 1mm of top of head above water; tissue placed on head to prevent it from drying out. 2 electrodes attached to head – ref 5mm forward of recording electrode. Insonification by speaker suspended 1m above subject – 30cm speaker for frequencies below 3kHz, 12cm speaker for frequencies above 3kHz. Sound level at fish obtained from hydrophone placed near presumed 'ear' of fish. Tones and clicks played back at various levels to obtain threshold by visual inspection of averaged ABR traces. Clicks were 0.1ms in duration, presented at 38.2clicks/sec. No. of cycles in a tone burst were set to get best compromise between stimulus rapidity and peak frequency bandwidth; bursts were gated using Blackman window. Fish were sedated with Flaxedil (gallamine triethiodode) Once the baseline audiogram had been taken, the gas inside the suprabranchial chamber was flushed out with water, and audiograms taken again. 5 specimens were tested.
Any other comments	In text states that gouramis hold air inside the suprabranchial chamber, which is in close proximity to the inner ear. Radiographs were taken to localise the position of the gas-holding structure.

Audiogram from Fig. 6 in paper – **before** removal of gas bubbles. Threshold levels in dB re 1 μPa. 5 specimens.

Frequency (Hz)	300	500	800	1500	2500	4000
Mean	100.1	96.0	88.9	93.7	105.4	128.3

Audiogram from Fig. 6 in paper – **after** removal of gas bubbles. Threshold levels in dB re 1μPa.

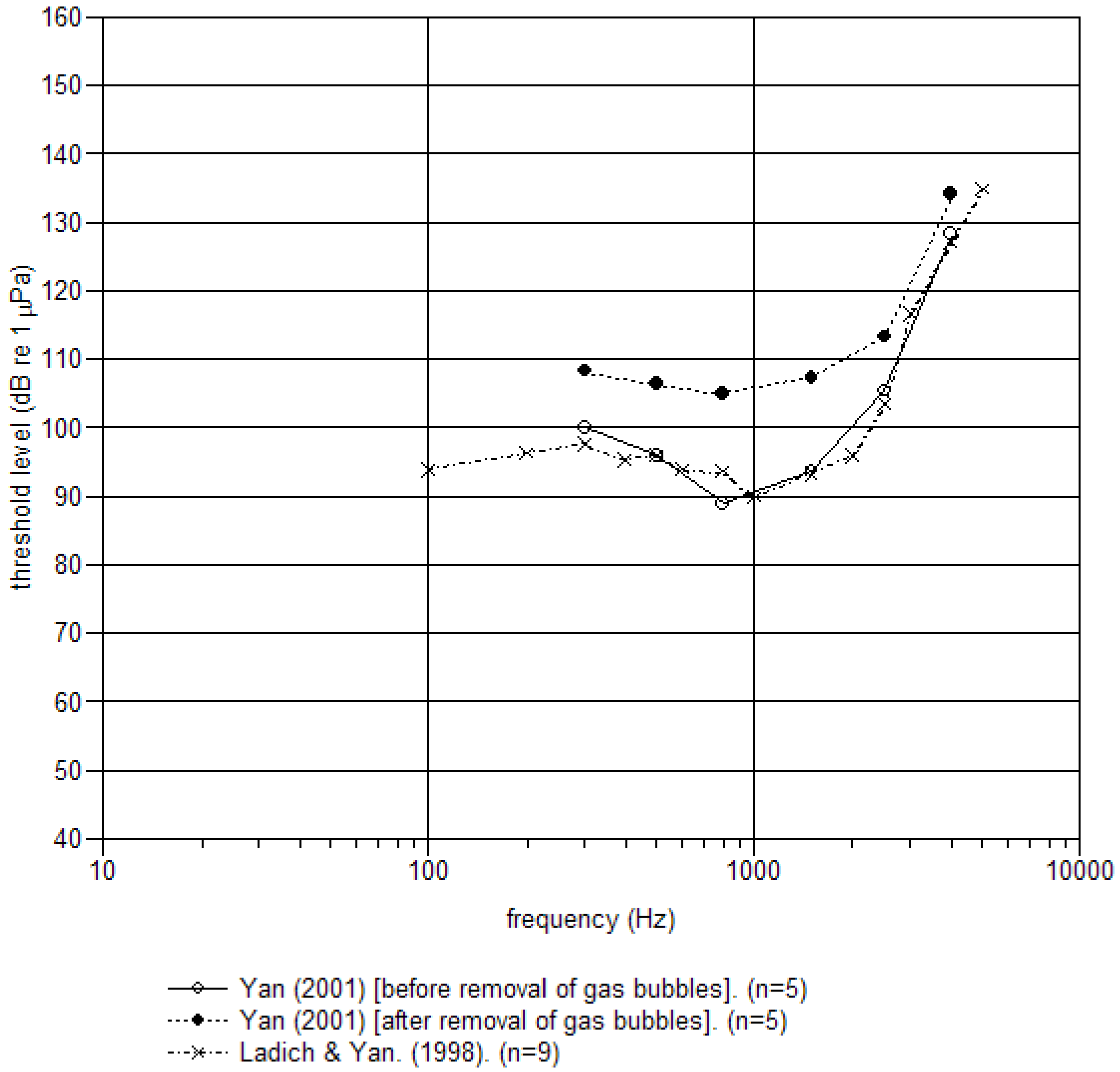
Frequency (Hz)	300	500	800	1500	2500	4000
Mean	108.3	106.5	105.0	107.3	113.3	134.1

Database page ref: F/GouramiDwarf/02.

Common name	Dwarf gourami
Family	
Species	*Colisa lalia*
Paper from which audiogram obtained	Ladich, F. & Yan, H.Y. (1998). Correlation between auditory sensitivity and vocalization in anabantoid fishes. J Comp Physiol A 182:737-746.
Paper having original audiogram data	Ladich, F. & Yan, H.Y. (1998). Correlation between auditory sensitivity and vocalization in anabantoid fishes. J Comp Physiol A 182:737-746.
Comments on methodology of getting audiogram	The ABR method was used. Experiments took place in soundproof room (2mx3mx2m). Fish clamped in mesh and held in water in tank (380x245x145mm) standing on air table, with just 1mm of top of head above water; tissue placed on head to prevent it from drying out. 2 electrodes attached to head – ref 10mm forward of recording electrode. Insonification by speaker suspended 1m above subject – 30cm speaker for frequencies below 3kHz, 12cm speaker for frequencies above 3kHz. Sound level at fish obtained from hydrophone (Celesco LC-10) placed near presumed right ‘ear’ of fish. Tones and clicks played back at various levels to obtain threshold by visual inspection of averaged ABR traces. Clicks were 0.1ms in duration, presented at 38.2clicks/sec. No. of cycles in a tone burst was set to get best compromise between stimulus rapidity and peak frequency bandwidth. All 9 specimens were given Flaxedil (gallamine triethiodode) to pacify them.
Any other comments	

Audiogram from Table 1. Threshold levels in dB re 1μPa. 9 specimens.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1500	2000	2500	3000	4000	5000
Mean	93.9	96.3	97.7	95.4	96.0	94.0	93.7	89.9	93.3	95.9	103.4	116.7	127.2	134.9
SD	8.2	4.4	5.1	6.7	7.4	6.5	6.9	7.0	6.7	9.2	8.7	6.6	5.5	4.9



[Fig. ref: DwarfGourami01]

Audiograms for dwarf gourami.

Database page ref: F/GouramiKissing/01.

Common name	Kissing gourami.
Family	
Species	*Helostoma temminckii.*
Paper from which audiogram obtained	Yan, H.Y. (2001). A non-invasive electrophysiological study on the enhancement of hearing ability in fishes. Proc. I.O.A., Vol 23 Part 4, 15-26.
Paper having original audiogram data	Yan, H.Y. (2001). A non-invasive electrophysiological study on the enhancement of hearing ability in fishes. Proc. I.O.A., Vol 23 Part 4, 15-26.
Comments on methodology of getting audiogram	The ABR method was used. Experiments took place in soundproof room (2mx3mx2m). Fish clamped in mesh and held in water in tank (380x245x145mm) standing on air table, with just 1mm of top of head above water; tissue placed on head to prevent it from drying out. 2 electrodes attached to head – ref 5mm forward of recording electrode. Insonification by speaker suspended 1m above subject – 30cm speaker for frequencies below 3kHz, 12cm speaker for frequencies above 3kHz. Sound level at fish obtained from hydrophone placed near presumed 'ear' of fish. Tones and clicks played back at various levels to obtain threshold by visual inspection of averaged ABR traces. Clicks were 0.1ms in duration, presented at 38.2clicks/sec. No. of cycles in a tone burst were set to get best compromise between stimulus rapidity and peak frequency bandwidth; bursts were gated using Blackman window. Fish were sedated with Flaxedil (gallamine triethiodode) Once the baseline audiogram had been taken, the gas inside the suprabranchial chamber was flushed out with water, and audiograms taken again.
Any other comments	5 specimens were tested. In text states that gouramis hold air inside the suprabranchial chamber, which is in close proximity to the inner ear. Radiographs were taken to localise the position of the gas-holding structure.

Audiogram from Fig. 5 in paper – **before** removal of gas bubbles. Threshold levels in dB re 1μPa. 5 specimens.

Frequency (Hz)	300	500	800	1500	2500	4000
Mean	106.0	99.4	87.4	101.0	105.2	125.2

Audiogram from Fig. 5 in paper – **after** removal of gas bubbles. Threshold levels in dB re 1μPa.

Frequency (Hz)	300	500	800	1500	2500	4000
Mean	120.3	117.0	110.1	119.4	122.6	137.4

Database page ref: F/GouramiKissing/02.

Common name	Kissing gourami.
Family	
Species	*Helostoma temincki*.
Paper from which audiogram obtained	Saidel, W.M. & Popper, A.N. (1987). Sound reception in two anabantid fishes. Comp. Biochem. Physiol., 88A, 37-44.
Paper having original audiogram data	Saidel, W.M. & Popper, A.N. (1987). Sound reception in two anabantid fishes. Comp. Biochem. Physiol., 88A, 37-44.
Comments on methodology of getting audiogram	Tests were done in a 900mm long vertically aligned cast iron cylinder with 7mm thick walls. Sound source was a University UW-30 underwater speaker at the base of the tube. Fish, which had been anaesthetised and injected with Flaxedil, was held at top of tube, with a surgically-made opening to the cranial cavity at the water surface. An electrode was placed adjacent to the saccule. The signal from the electrode was passed through a system with filters having a passband from 10Hz to 10kHz, and the 2nd harmonic of the stimulus was measured with a wave analyser having a filter with either a 3 or a10Hz passband centred at the stimulus frequency. Entire apparatus was placed on a vibration-isolating table in an IAC soundproof room. A PDP 11/10 computer controlled the running of the experiment (stimulus frequency, duration, amplitude, etc.). The stimulus had 5msec rise and decay times. Sound was measured with a matched pair of Celesco LC-10 hydrophones, one just below the water surface and the second 10mm below the first. The magnitude of the displacement was calculated from the 2 hydrophone readings.
Any other comments	Fish were between 50 and 90mm in total length. Ambient noise in tube was measured in a 10Hz wide band centred on each test frequency – no level exceeded 75dB re 1μPa. Because fish was held near surface of water, it was at a point where pressure was minimised and displacement was maximised. Therefore, stimulus was predominantly displacement.

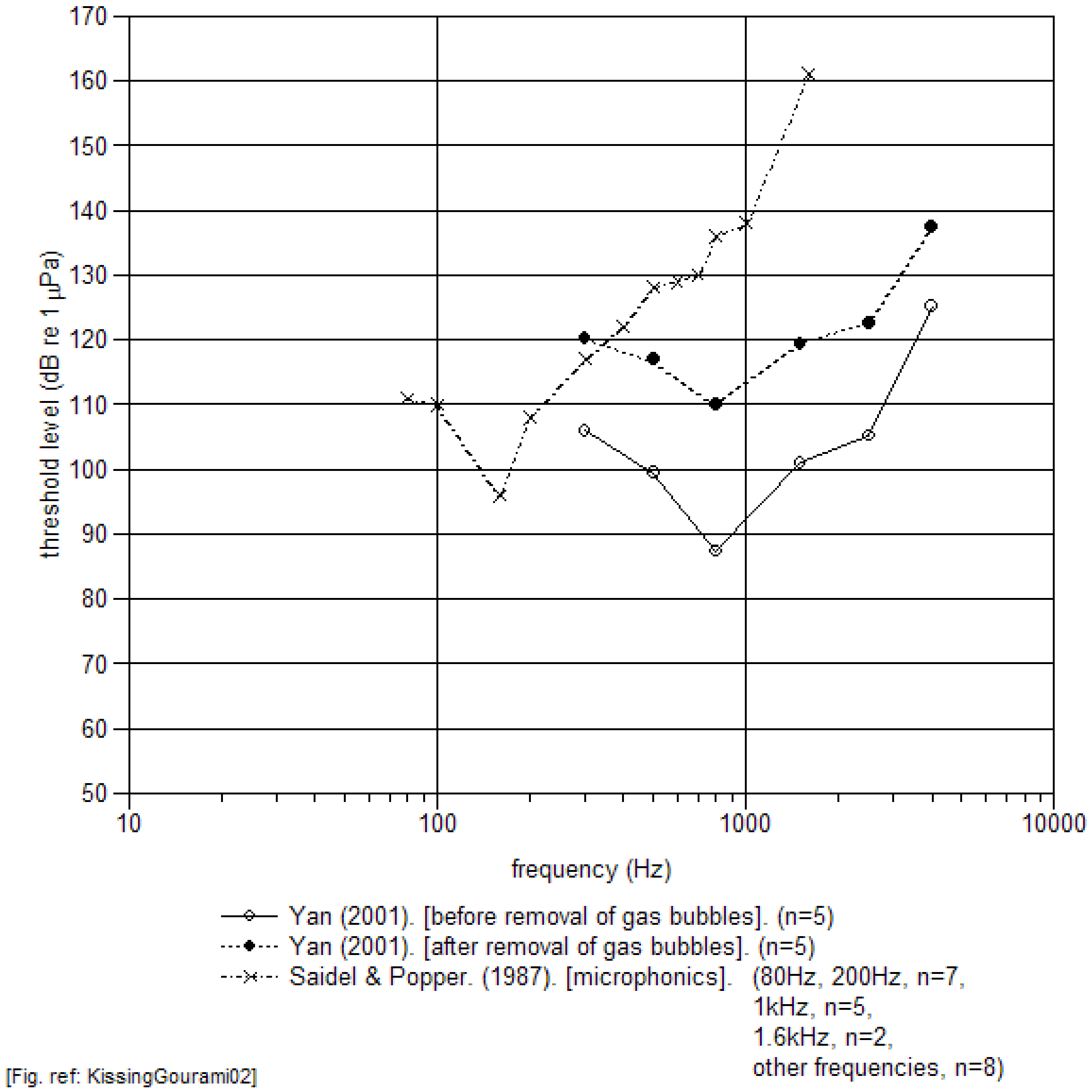
Audiogram from Table 1. Threshold levels for the *2nd harmonic of the stimulus frequency* in dB re 1μbar. The levels are those that resulted in a 1μV RMS potential above the background noise. (Note: The values in the following table are as given in the paper's Table 1. However, in Fig. 2(A) in the paper (threshold level *vs.* frequency), the frequency axis is on a log scale which is labelled unusually, *viz.* it is labelled '20', '200', '2000' where one would expect '10', '100', '1000', and the level for 80Hz (in the table) is plotted at the expected 40Hz mark, the level for 100Hz (in the table) at the 50Hz mark, etc.).

Frequency (Hz)	80	100	160	200	300	400	500	600	700	800	1000	1600
Mean	11	10	-4	8	17	22	28	29	30	36	38	61
SD	7	11	13	7	8	9	8	4	5	4	4	7
No.	7	8	8	7	8	8	8	8	8	8	5	2

Note: For 1600Hz, measures were estimated from subthreshold values.

Threshold levels in dB re 1μPa.

Frequency (Hz)	80	100	160	200	300	400	500	600	700	800	1000	1600
Mean	111	110	96	108	117	122	128	129	130	136	138	161



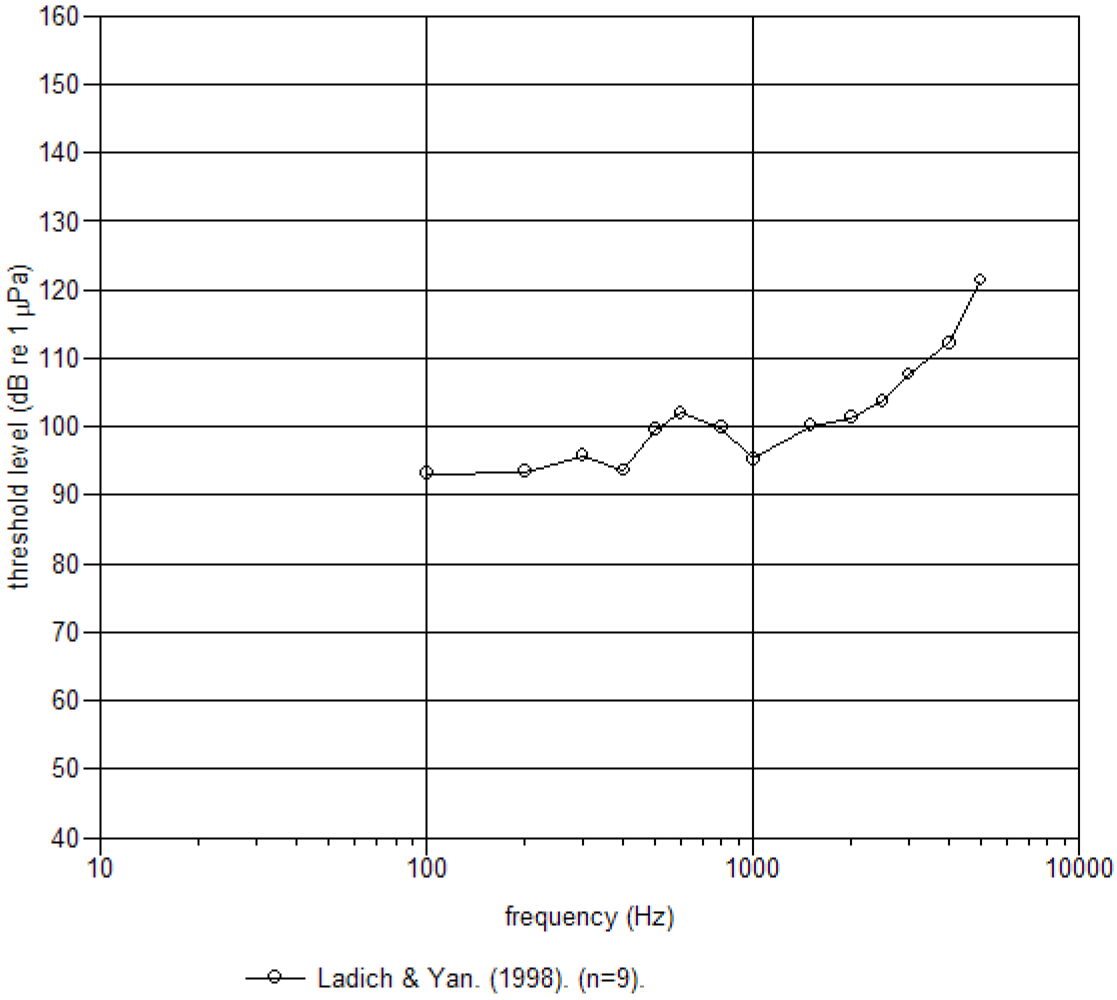
Audiogram for kissing gourami.

Database page ref: F/GouramiPygmy/01.

Common name	Pygmy gourami
Family	
Species	*Trichopsis pumila*
Paper from which audiogram obtained	Ladich, F. & Yan, H.Y. (1998). Correlation between auditory sensitivity and vocalization in anabantoid fishes. J Comp Physiol A 182:737-746.
Paper having original audiogram data	Ladich, F. & Yan, H.Y. (1998). Correlation between auditory sensitivity and vocalization in anabantoid fishes. J Comp Physiol A 182:737-746.
Comments on methodology of getting audiogram	The ABR method was used. Experiments took place in soundproof room (2mx3mx2m). Fish clamped in mesh and held in water in tank (380x245x145mm) standing on air table, with just 1mm of top of head above water; tissue placed on head to prevent it from drying out. 2 electrodes attached to head – ref 10mm forward of recording electrode. Insonification by speaker suspended 1m above subject – 30cm speaker for frequencies below 3kHz, 12cm speaker for frequencies above 3kHz. Sound level at fish obtained from hydrophone (Celesco LC-10) placed near presumed right 'ear' of fish. Tones and clicks played back at various levels to obtain threshold by visual inspection of averaged ABR traces. Clicks were 0.1ms in duration, presented at 38.2clicks/sec. No. of cycles in a tone burst was set to get best compromise between stimulus rapidity and peak frequency bandwidth. All 9 specimens were given Flaxedil (gallamine triethiodode) to pacify them.
Any other comments	

Audiogram from Table 1. Threshold levels in dB re 1μPa. 9 specimens.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1500	2000	2500	3000	4000	5000
Mean	93.1	93.4	95.8	93.6	99.6	102.0	99.9	95.3	100.2	101.3	103.8	107.7	112.2	121.4
SD	6.5	4.5	5	3.5	4.0	7.0	5.3	5.7	4.2	3.0	5.1	4.9	4.2	3.9



[Fig. ref: PygmyGourami01]

Audiogram for pygmy gourami.

Database page ref: F/GruntBlueStriped/01.

Common name	Blue-striped grunt.
Family	Pomadasyidae.
Species	*Haemulon sciurus.*
Paper from which audiogram obtained	Tavolga, W.N. & Wodinsky, J. (1965). Auditory capacities in fishes: threshold variability in the blue-striped grunt, *Haemulon sciurus*. Anim. Behav., 13:301-311.
Paper having original audiogram data	Tavolga, W.N. & Wodinsky, J. (1965). Auditory capacities in fishes: threshold variability in the blue-striped grunt, *Haemulon sciurus*. Anim. Behav., 13:301-311.
Comments on methodology of getting audiogram	Tests done in 5gal., 14inch x 8inch x10inch high, steel-framed, glass-walled aquarium tank lined on walls and floor with rubberised hair. Tank stood on cushions at its corners. A Plexiglas insert was placed in the tank at about half depth. The insert had a hurdle spanning the centre of the tank to divide the tank into two compartments. The water level was adjusted such that the fish had to swim over the hurdle to be in either of the compartments. A public address driver unit with a rubber bulb over it was placed under the hurdle to act as the sound source. Electrodes were located in the sidewalls of each compartment. An "oyster" hydrophone was placed in the water to monitor the sound level. Stimuli were continuous pure tones. Animal was trained to avoid being given a shock if it did not change compartments within 5secs of the stimulus signal being played. Staircase method was used to determine threshold, with step sizes of either 5 or 2dB. A minimum of 10, and usually between 15 and 20, reversals were used to determine a threshold.
Any other comments	This work follows on from their 1963 study, in which they had found variability in thresholds for individuals when retested at low frequencies. Tests done at laboratory in Bimini, Bahamas. 18 specimens out of original 40 were used to get almost complete audiograms. Additional 5 animals were tested at only a few frequencies. Sound field in compartments was almost uniform. Ambient noise in the tank was 10 to 20dB below any of the thresholds determined. The data presented here are the pooled results of all the animals. The paper also has a table giving the thresholds for individual animals, and some graphs comparing an animal's audiogram with the pooled average. Repeated tests of the same animal at the same frequencies resulted in progressively lower thresholds, and three successive tests were generally required to determine the lowest threshold. This variation was greatest at frequencies below 300Hz.

Audiogram from Table I. Threshold levels in dB re.1 μbar. 421 determinations.

Frequency (Hz)	50	100	150	200	300	400	500	600	700	800	900	1000
Mean	-20.84	-20.39	-22.49	-20.43	-14.47	-10.39	-6.78	0.49	8.78	24.34	27.95	38.53
S.D.	4.76	8.35	5.60	10.93	8.8.5	6.04	4.86	7.02	3.90	5.37	6.09	5.36
95% confidence interval	2.96	2.57	3.24	2.40	2.76	2.07	1.60	1.94	1.43	2.04	3.14	2.21
No. of tests	12	43	14	82	42	35	38	53	31	29	17	25
No. of animals	6	19	11	20	16	15	16	20	17	16	11	15

Threshold levels in dB re 1μPa.

Frequency (Hz)	50	100	150	200	300	400	500	600	700	800	900	1000
Mean	79.16	79.61	77.51	79.57	85.53	89.61	93.22	100.49	108.78	124.34	127.95	138.53

Database page ref: F/GruntBlueStriped/02.

Common name	Blue-striped grunt.
Family	Pomadasyidae.
Species	*Haemulon sciurus.*
Paper from which audiogram obtained	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Paper having original audiogram data	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Comments on methodology of getting audiogram	Glass tank was lined on floor and walls with 2inch layers of rubberised horsehair. Internal dimensions of tank with lining in place were 16”x7” in plan. A curved barrier, also made from horsehair and 4” high, was placed centrally in the tank, spanning its width. Water depth above top of barrier, and therefore in tank, was adjusted to cause the fish to have to exert some effort to swim over the barrier; depth ranged from 4 to 12mm. Tank was mounted on 2” thick pieces of foam rubber at its corners. Sound source was a University Model SA-HF public address unit fitted with a rubber bulb over its horn end; the entire unit was waterproofed with tar, tape and rubber. It was placed under the central barrier. A hydrophone (Chesapeake Instrument Co. Model SB-154C) was placed near the wall farthest from the sound source, but it wasn’t always used when a fish was in the tank. Electrodes for causing shock were rings of silver solder, with a pair being mounted on the tank sidewalls at each end of the tank. Avoidance conditioning test method was used. Shock was a 0.1s duration pulse repeated at about 40 pulses per minute. If fish heard sound it had to swim to other side of barrier within 10sec to avoid getting a shock. After an inter-trial interval another trial took place, with the fish having to cross the barrier in the opposite direction. Threshold determined by staircase method, starting at high level and reducing level in 2dB steps until a reversal occurred, when level was increased in 2dB steps.
Any other comments	4 specimens used. Driver unit gave distortion-free output between 200Hz and 5kHz up to 50dB re 1µbar. At lower frequencies harmonic distortion and clipping occurred above 30 to 35dB re 1 µbar. A secondary low-frequency threshold was found for repeat trials at lower frequencies after the higher frequencies had been tested.

Audiogram from Fig. 12 (authors’ mean lines). Threshold levels in dB re.1 µbar. 4 specimens.

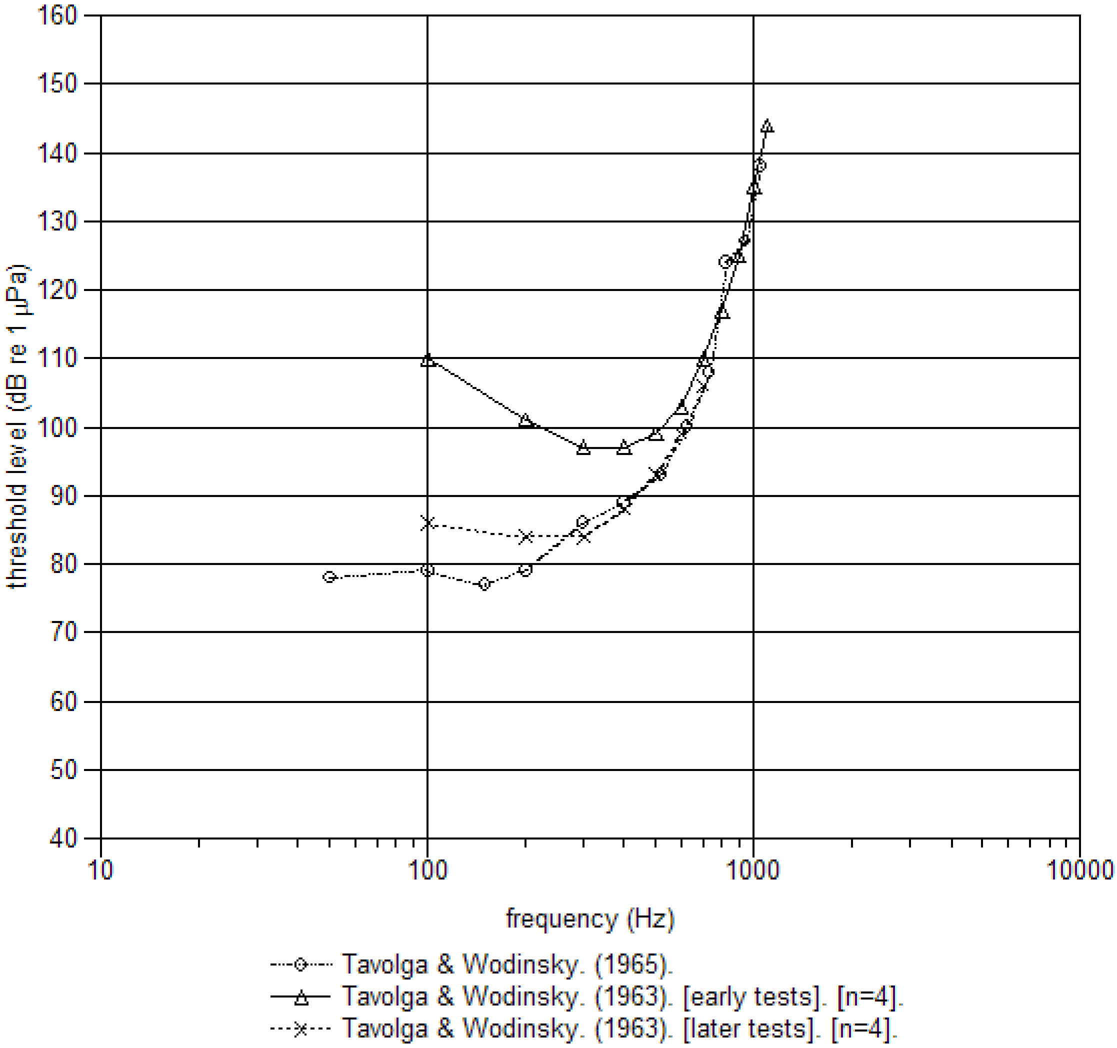
Frequency (Hz)	100	200	300	400	500	600	700	800	900	1000	1100
Mean (early tests)	10	1	-3	-3	-1	3	10	17	25	35	44
Mean (later tests)	-14	-16	-14	-12	-7	-1	6				

Threshold levels in dB re 1µPa.

Frequency (Hz)	100	200	300	400	500	600	700	800	900	1000	1100
Mean (early tests)	110	101	97	97	99	103	110	117	125	135	144
Mean (later tests)	86	84	84	88	93	99	106				

Ambient noise levels in tank.

Bandwidth (Hz)	37.5 - 75	75 - 150	150 - 300	300 - 600	600 - 1200	1200 - 2400	2400 - 4800	4800 - 9600
Level (dB re 1µbar)	-43	< -50	< -5	-43	-39	-34	-29	-20
Level (dB re 1µPa)	57	< 50	< 50	57	61	66	71	80



[Fig. ref: GruntBlueStriped02]

Audiogram for blue-striped grunt.

Database page ref: F/Haddock/01.

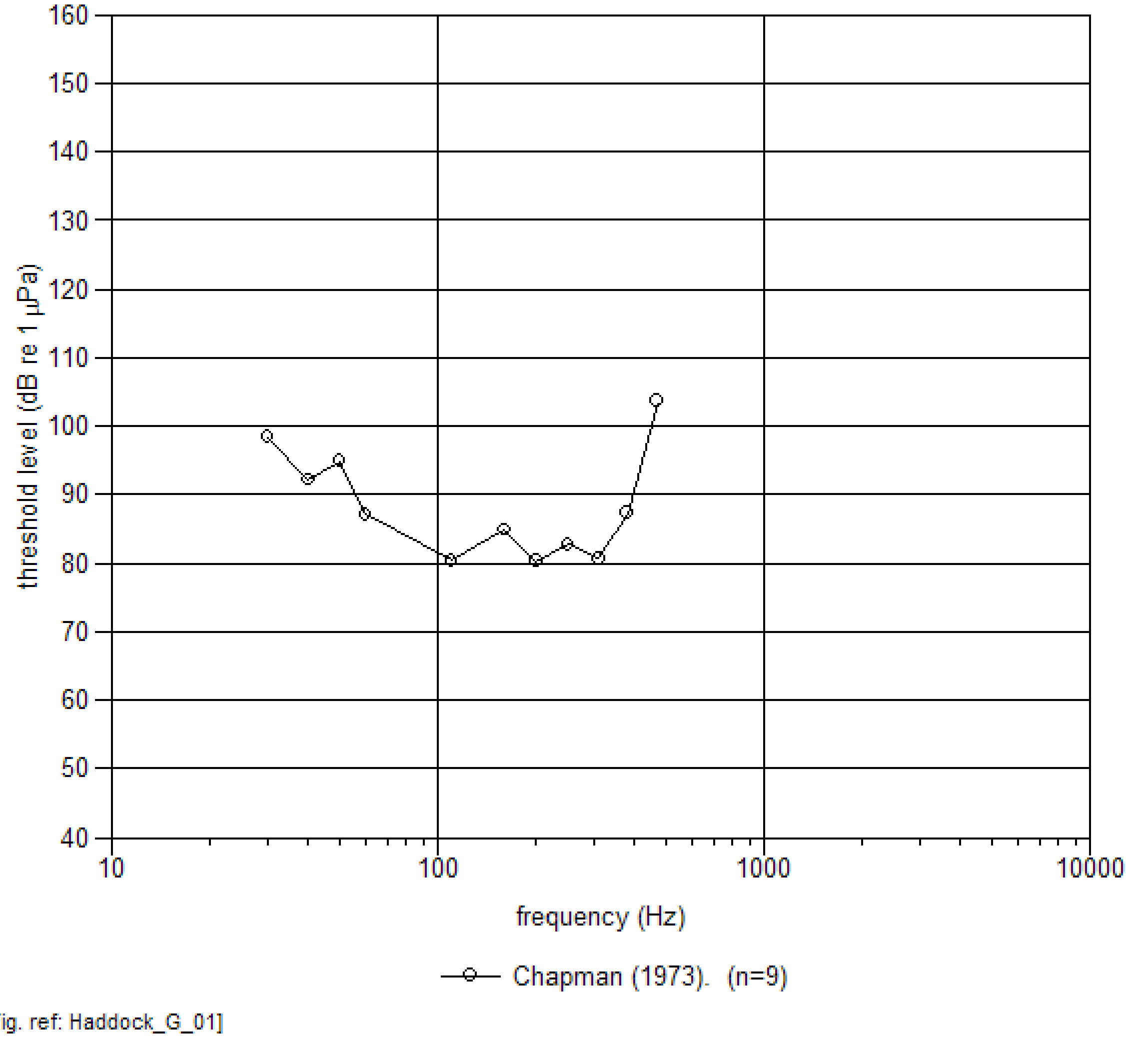
Common name	Haddock.
Family	
Species	*Melanogrammus aeglefinus.*
Paper from which audiogram obtained	Fay, R.R. (1988). Hearing in Vertebrates: A Psychophysics Databook. Hill-Fay Associates, Winnetka, Ill.
Paper having original audiogram data	Chapman C.J. (1973). Field studies of hearing in teleost fish. Helgoländer wissenschaftliche Meeresuntersuchungen, 24, 371-390.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	9 specimens tested. Thresholds below 380Hz likely to have been masked by ambient noise.

Audiogram from Table F8-0. Threshold levels in dB re 1 dyne/cm^2. 9 specimens.

Frequency (Hz)	30	40	50	60	110	160	200	250	310	380	470
Mean	-1.6	-7.8	-5.1	-12.9	-19.6	-15.1	-19.7	-17.3	-19.3	-12.7	3.7

Threshold levels in dB re 1μPa.

Frequency (Hz)	30	40	50	60	110	160	200	250	310	380	470
Mean	98.4	92.2	94.9	87.1	80.4	84.9	80.3	82.7	80.7	87.3	103.7



Audiogram for haddock

Database page ref: F/Herring/01.

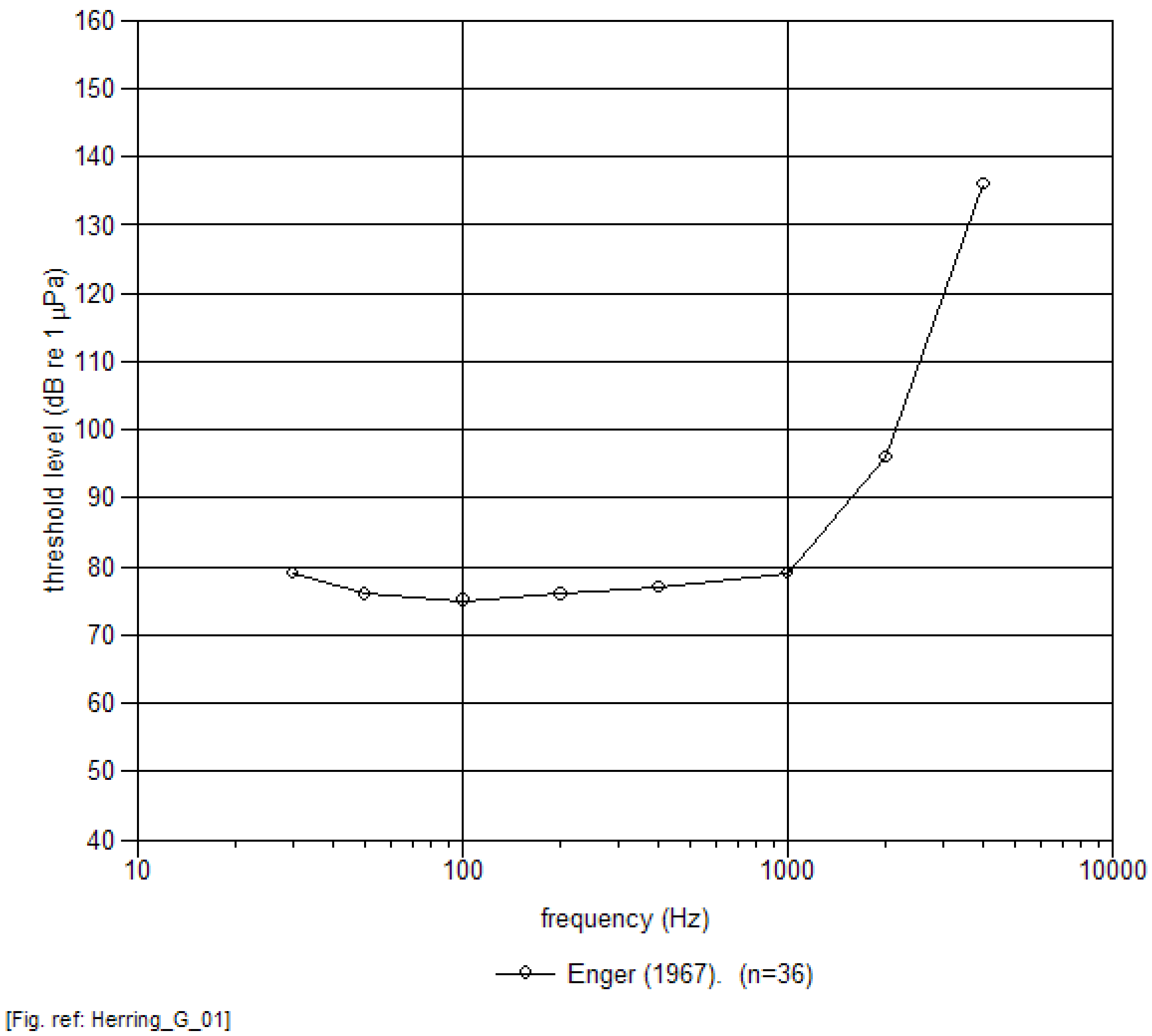
Common name	Herring.
Family	
Species	*Clupea harengus.*
Paper from which audiogram obtained	Enger, P. (1967). Hearing in herring. Comp. Biochem. Physiol., 22:527-538.
Paper having original audiogram data	Enger, P. (1967). Hearing in herring. Comp. Biochem. Physiol., 22:527-538.
Comments on methodology of getting audiogram	Monitored electrical nervous activity in acoustic region of the subjects' brains. Test tank was made from a 300mm dia. polyethylene cylinder cut lengthwise on a diameter, to give a trough 800m long with a depth of 150mm. It rested on 100mm thick foam cushions, and the sides were covered with rockwool. Subject was held in a container 10-20mm below the water surface, at approximately 150mm from, and parallel to, the membrane of the J9 underwater loudspeaker. Stimuli were sinusoids. Sound pressure was measured with an Atlantic Research Model LC34 hydrophone, placed in the position that the fish's head occupied when it was tested. The dorsal part of the skull was removed and one of three different types of electrode introduced into the brain. They were metal-filled pipettes, steel electrodes, and micropipettes filled with 4 M NaCl. Signals were amplified and displayed on a CRO and recorded on film.
Any other comments	36 specimens were used – 18 were 27-28cm long and 18 were 10-11cm long. Background noise level in the tank was –15 to –20dB re 1μbar. Author states that it was found that near-field effects did not stimulate the hearing receptors in this species, presumably because the ear with the air-filled bullae are all enclosed in the skull. Near-filed vibration will not produce pressure changes in the bullae and therefore no displacement of the prootic membrane. The swimbladder seems to play little role in hearing, probably because the duct connecting it to the ear is thin and rapid pressure changes would be highly damped.

Audiogram from Fig. 6. Threshold levels in dB re 1μbar. The figure presents a tentative audiogram for this fish; in the text the author states that this is conservative, and the frequency range may be wider and the threshold levels lower. 36 specimens.

Frequency (Hz)	30	50	100	200	400	1000	2000	4000
Mean	-21	-24	-25	-24	-23	-21	-4	36

Threshold levels in dB re 1μPa.

Frequency (Hz)	30	50	100	200	400	1000	2000	4000
Mean	79	76	75	76	77	79	96	136



Audiogram for herring.

Database page ref: F/Ling/01.

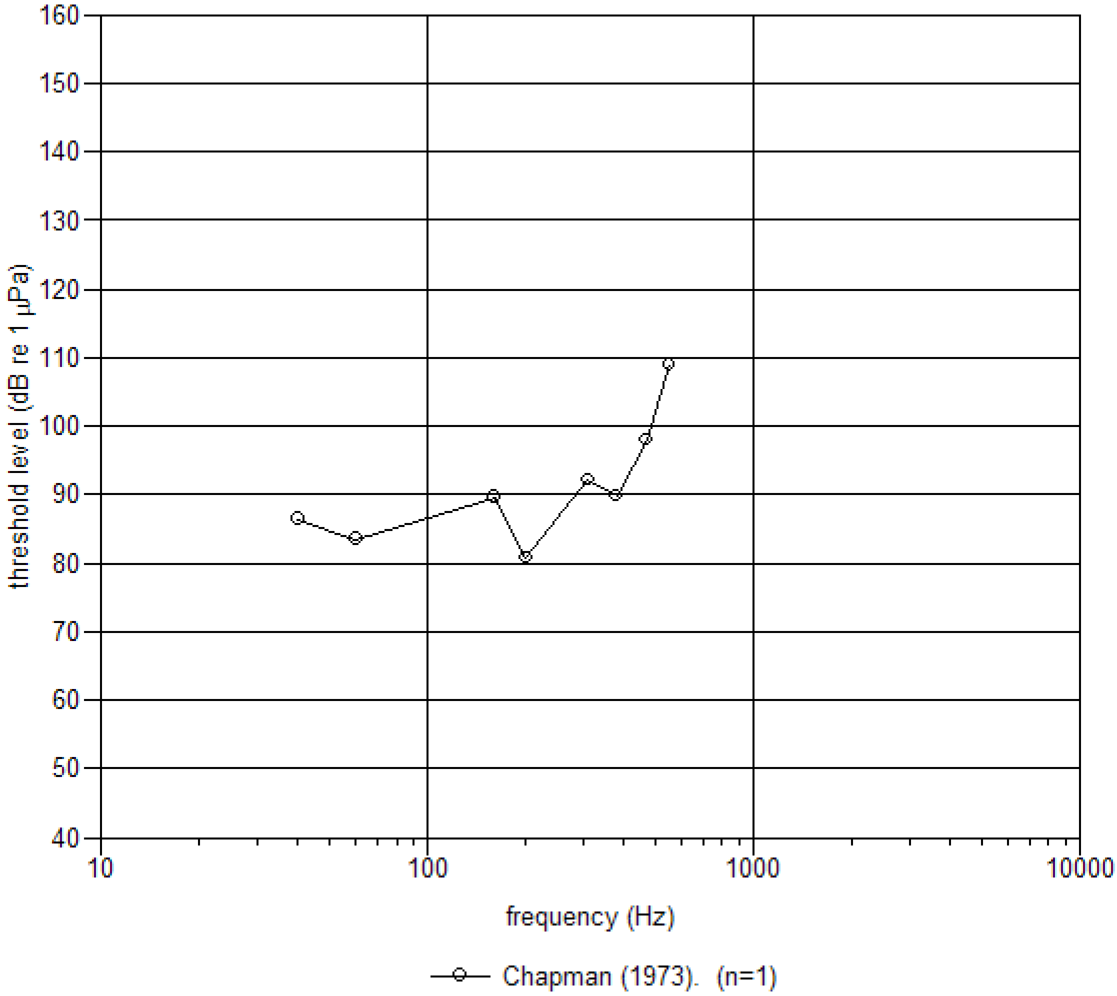
Common name	Ling.
Family	
Species	*Molva molva.*
Paper from which audiogram obtained	Fay, R.R. (1988). Hearing in Vertebrates: A Psychophysics Databook. Hill-Fay Associates, Winnetka, Ill.
Paper having original audiogram data	Chapman C.J. (1973). Field studies of hearing in teleost fish. Helgoländer wissenschaftliche Meeresuntersuchungen, 24, 371-390.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	1 specimen tested. Thresholds below 380Hz likely to have been masked by ambient noise.

Audiogram from Table F8-0. Threshold levels in dB re 1 dyne/cm^2. 1 specimen.

Frequency (Hz)	40	60	160	200	310	380	470	550
Mean	-13.6	-16.5	-10.4	-19.2	-7.8	-10.2	-2	9

Threshold levels in dB re 1µPa.

Frequency (Hz)	40	60	160	200	310	380	470	550
Mean	86.4	83.5	89.6	80.8	92.2	89.8	98	109



[Fig. ref: Ling_G_01]

Audiogram for ling.

Database page ref: F/MxcnCave/01

Common name	Mexican blind cave fish
Family	
Species	*Astyanax jordani*
Paper from which audiogram obtained	Popper, A.N. (1970). Auditory capacities of the Mexican blind cave fish (*Astyanax jordani*) and its eyed ancestor (*Astyanax mexicanus*). Anim. Behav., 18, 552-562.
Paper having original audiogram data	Popper, A.N. (1970). Auditory capacities of the Mexican blind cave fish (*Astyanax jordani*) and its eyed ancestor (*Astyanax mexicanus*). Anim. Behav., 18, 552-562.
Comments on methodology of getting audiogram	Used avoidance conditioning technique. Acrylic tank, 275mm long, 75mm wide, 110mm deep, with flat-topped barrier 45m high by 25mm long placed centrally, used. Stainless steel screen electrodes placed at ends of tank to create electric field to shock fish. The tank was placed on polystyrene foam inside a foam-lined acoustic test chamber with 100mm thick walls, with the 203mm dia. loudspeaker mounted 200mm above the water surface in the roof of the chamber, surrounded with fibreglass and polystyrene foam. The chamber was placed on flexible mounts to try to eliminate low frequency sound transmission. Thresholds were determined using up-down staircase method. If fish responded to sound and crossed barrier during the 10s period when sound alone was present, sound level was lowered by 5dB for next trial. If animal did not respond it received a shock and in the next trial sound level was increased by 5dB. Mean level of 20 of these changes constituted basis for threshold. Each fish was tested at least 3 times at each frequency.
Any other comments	3 male and 3 female specimens, 40 to 50mm in standard length, were used. Ambient noise was measured up to 3kHz – instrumentation noise precluded measurements above this frequency.

Audiogram from Table III . Threshold levels in dB re 1µbar.

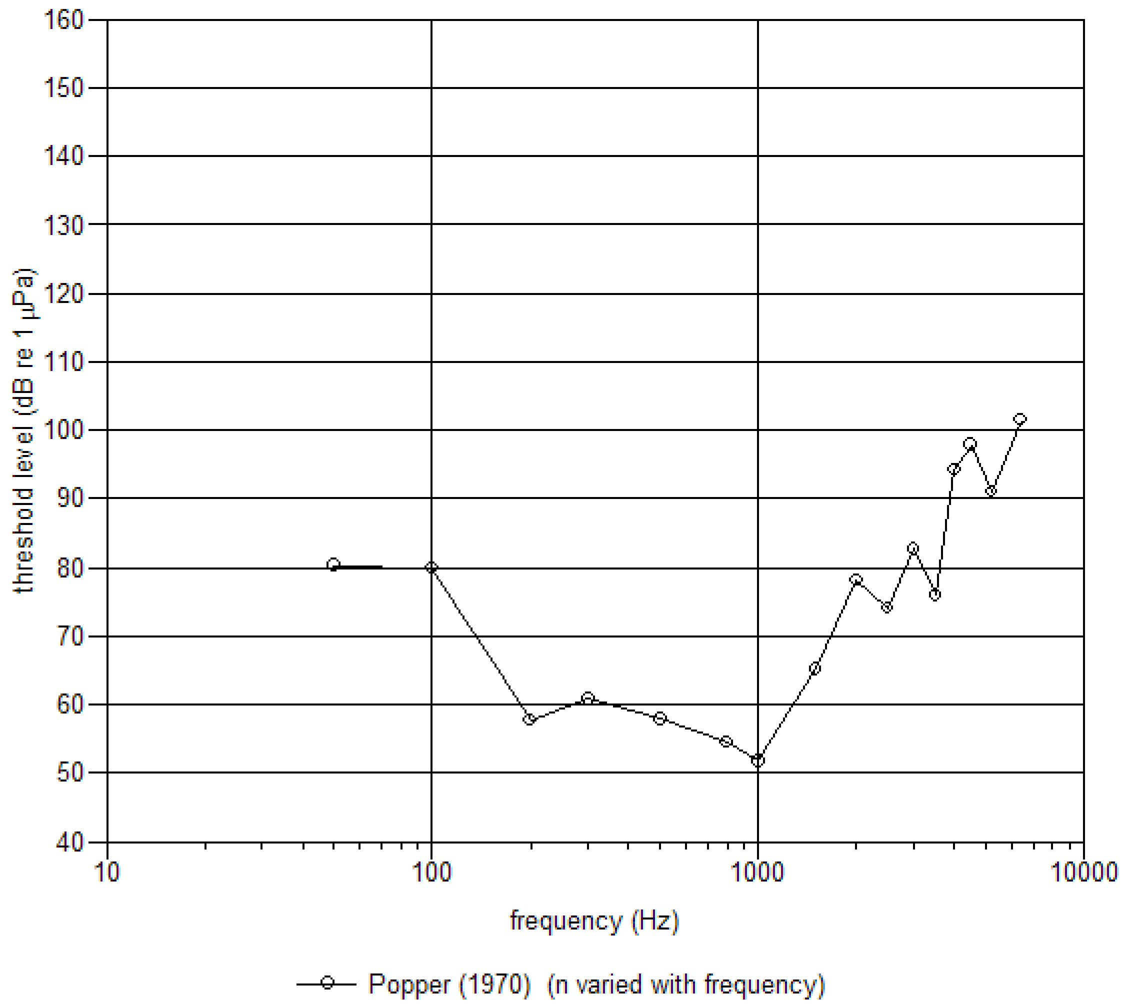
Frequency (Hz)	50	100	200	300	500	800	1000	1500
Mean	-19.7	-20.1	-42.3	-39.2	-42.1	-45.5	-48.2	-34.8
Range - upper	-15.9	-12.8	-27.1	-28.7	-35.9	-35.8	-35.1	-30.2
Range - lower	-26.3	-28.7	-58.2	-46.6	-51.2	-60.2	-56.1	-43.7
SD	3.31	4.45	9.33	4.93	3.54	5.76	6.55	3.82
No. of determinations	10	12	16	12	27	21	19	16
No. of animals	3	3	3	3	5	4	5	4
Frequency (Hz)	2000	2500	3000	3500	4000	4500	5200	6400
Mean	-21.8	-25.9	-17.3	-24.0	-5.76	-2.2	-9.0	1.5
Range - upper	-14.3	-19.5	-10.5	-15.5	-2.2	-9.2	-8.1	
Range - lower	-30.5	-36.1	-35.8	-30.9	-8.8	+6.5	+9.1	
SD	6.18	5.10	7.48	4.90	2.75	-	-	-
No. of determinations	14	9	9	8	6	4	2	1
No. of animals	4	3	3	3	3	2	1	1

Threshold levels in dB re 1µPa.

Frequency (Hz)	50	100	200	300	500	800	1000	1500
Mean	80.3	79.9	57.7	60.8	57.9	54.5	51.8	65.2
Frequency (Hz)	2000	2500	3000	3500	4000	4500	5200	6400
Mean	78.2	74.1	82.7	76.0	94.24	97.8	91	101.5

Ambient noise levels from Fig. 2.

Frequency (Hz)	50	100	200	500	800	1000	1500	2000	3000
Level (dB re 1µbar)	-42	-43	-51	-53	-55	-57	-56	-57	-58
Spectrum level (dB re 1µbar/Hz)	-57	-63	-76	-79	-83	-87	-88	-89	
Level (dB re 1µPa)	58	57	49	47	45	43	44	43	42



[Fig. ref: BlindCave_G_01]

Audiogram for Mexican blind cave fish.

Database page ref: F/MxcnRiver/01.

Common name	River Fish.
Family	
Species	*Astyanax mexicanus.*
Paper from which audiogram obtained	Popper, A.N. (1970). Auditory capacities of the Mexican blind cave fish (*Astyanax jordani*) and its eyed ancestor (*Astyanax mexicanus*). Anim. Behav., 18, 552-562.
Paper having original audiogram data	Popper, A.N. (1970). Auditory capacities of the Mexican blind cave fish (*Astyanax jordani*) and its eyed ancestor (*Astyanax mexicanus*). Anim. Behav., 18, 552-562.
Comments on methodology of getting audiogram	Used avoidance conditioning technique. Acrylic tank, 275mm long, 75mm wide, 110mm deep, with flat-topped barrier 45m high by 25mm long placed centrally, used. Stainless steel screen electrodes placed at ends of tank to create electric field to shock fish. The tank was placed on polystyrene foam inside a foam-lined acoustic test chamber with 100mm thick walls, with the 203mm dia. loudspeaker mounted 200mm above the water surface in the roof of the chamber, surrounded with fibreglass and polystyrene foam. The chamber was placed on flexible mounts to try to eliminate low frequency sound transmission. A hydrophone placed in the well of the tank measured the sound level – the level varied by about 2dB in the tank. Thresholds were determined using up-down staircase method. If fish responded to sound and crossed barrier during the 10s period when sound alone was present, sound level was lowered by 5dB for next trial. If animal did not respond it received a shock and in the next trial sound level was increased by 5dB. Mean level of 20 of these changes constituted basis for threshold. Each fish was tested at least 3 times at each frequency.
Any other comments	6 male and 5 female specimens, 40 to 50mm in standard length, were used. Ambient noise was measured up to 3kHz – instrumentation noise precluded measurements above this frequency.

Audiogram from Table I . Threshold levels in dB re 1µbar.

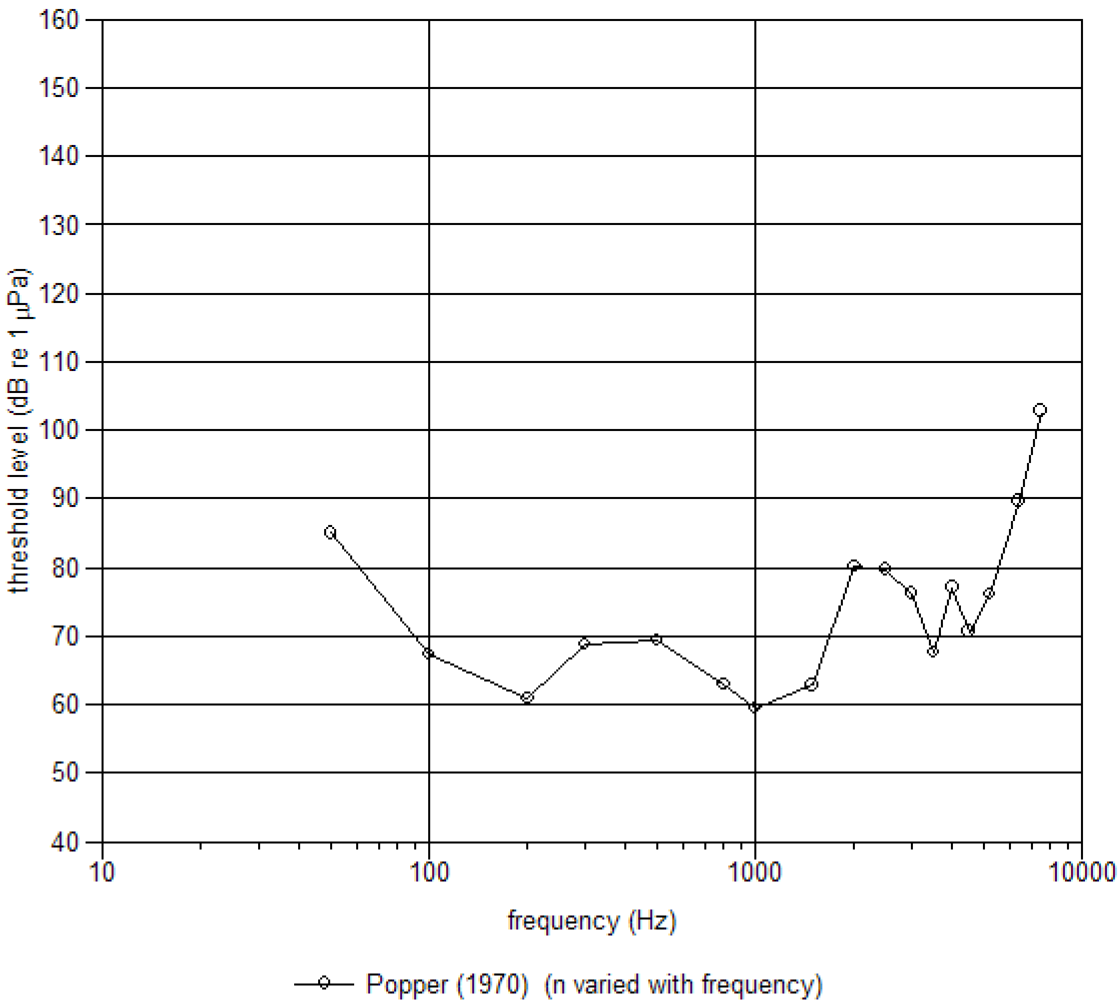
Frequency (Hz)	50	100	200	300	500	800	1000	1500	2000
Mean	-14.9	-32.7	-39.1	-31.2	-30.6	-37.0	-40.5	-37.1	-19.8
Range - upper	-8.8	-27.3	-35.5	-21.0	-23.2	-30.5	-32.1	-27.7	-7.9
Range - lower	-28.0	-37.8	-46.5	-40.0	-43.8	-44.5	-46.6	-53.3	-34.0
SD	6.41	8.88	6.10	6.61	5.85	3.75	5.13	7.49	8.52
No. of determinations	14	12	9	13	16	12	12	13	12
No. of animals	4	4	3	4	5	4	4	4	4
Frequency (Hz)	2500	3000	3500	4000	4500	5200	6400	7500	
Mean	-20.3	-23.8	-32.4	-22.9	-29.4	-23.9	-10.3	+2.8	
Range - upper	-14.9	-15.8	-18.5	-17.0	-15.8	-19.1	-8.3	-6.8	
Range - lower	-26.1	-39.0	-42.5	-28.0	-42.8	-30.8	-14.5	+9.7	
SD	5.05	6.10	8.58	3.29	6.98	3.75	2.32	3.67	
No. of determinations	15	12	18	8	11	10	9	9	
No. of animals	5	4	7	3	5	4	3	3	

Threshold levels in dB re 1µPa.

Frequency (Hz)	50	100	200	300	500	800	1000	1500	2000
Mean	85.1	67.3	60.9	68.8	69.4	63.0	59.5	62.9	80.2
Frequency (Hz)	2500	3000	3500	4000	4500	5200	6400	7500	
Mean	79.7	76.2	67.6	77.1	70.6	76.1	89.7	102.8	

Ambient noise levels from Fig. 2.

Frequency (Hz)	50	100	200	500	800	1000	1500	2000	3000
Level (dB re 1µbar)	-42	-43	-51	-53	-55	-57	-56	-57	-58
Spectrum level (dB re 1µbar/Hz)	-57	-63	-76	-79	-83	-87	-88	-89	
Level (dB re 1µPa)	58	57	49	47	45	43	44	43	42



[Fig. ref: MexicanRiver_G_01]

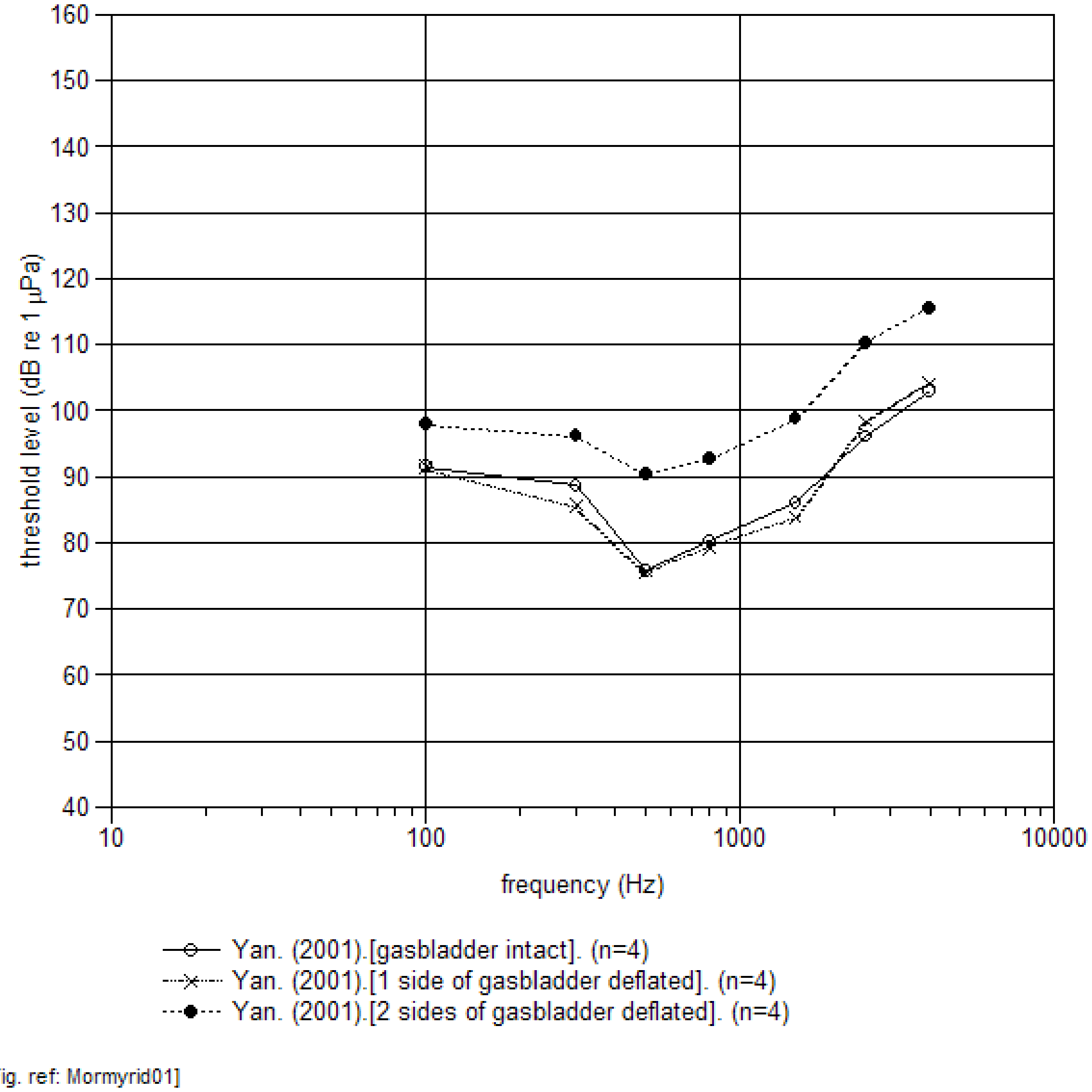
Audiogram for Mexican river fish.

Database page ref: F/Mormyrid/01.

Common name	Mormyrid (weakly electric fish).
Family	
Species	*Brienomyrus brachyistius.*
Paper from which audiogram obtained	Yan, H.Y. (2001). A non-invasive electrophysiological study on the enhancement of hearing ability in fishes. Proc. I.O.A., Vol 23 Part 4, 15-26.
Paper having original audiogram data	Yan, H.Y. (2001). A non-invasive electrophysiological study on the enhancement of hearing ability in fishes. Proc. I.O.A., Vol 23 Part 4, 15-26.
Comments on methodology of getting audiogram	The ABR method was used. Experiments took place in soundproof room (2mx3mx2m). Fish clamped in mesh and held in water in tank (380x245x145mm) standing on air table, with just 1mm of top of head above water; tissue placed on head to prevent it from drying out. 2 electrodes attached to head – ref 5mm forward of recording electrode. Insonification by speaker suspended 1m above subject – 30cm speaker for frequencies below 3kHz, 12cm speaker for frequencies above 3kHz. Sound level at fish obtained from hydrophone placed near presumed 'ear' of fish. Tones and clicks played back at various levels to obtain threshold by visual inspection of averaged ABR traces. Clicks were 0.1ms in duration, presented at 38.2clicks/sec. No. of cycles in a tone burst were set to get best compromise between stimulus rapidity and peak frequency bandwidth; bursts were gated using Blackman window. Fish were sedated with Flaxedil (gallamine triethiodode) Once the baseline audiogram had been taken, one side of the otic gasbladder was deflated was deflated and an audiogram taken. Then the both sides of the otic gasbladder were deflated and another audiogram taken. 4 specimens were tested.
Any other comments	In text states that gouramis hold air inside the suprabranchial chamber, which is in close proximity to the inner ear. Radiographs were taken to localise the position of the gas-holding structure.

Audiogram from Fig. 7. Threshold levels in dB re 1μPa. 4 specimens.

Frequency (Hz)		100	300	500	800	1500	2500	4000
Gasbladder intact	Mean	91.5	88.6	75.8	80.3	86.0	96.1	103.0
1 side of gasbladder deflated	Mean	91.5	85.6	75.6	79.3	83.8	98.4	104.2
2 sides of gasbladder deflated	Mean	98.0	96.2	90.4	92.63	98.8	110.3	115.5



Audiogram for mormyrid.

Database page ref: F/Oscar/01.

Common name	Oscar
Family	
Species	*Astronotus ocellatus*
Paper from which audiogram obtained	Kenyon, T.N., Ladich, F. & Yan, H.Y. (1998). A comparative study of hearing ability in fishes: the auditory brainstem response approach. J. Comp Physiol A 182: 307-318.
Paper having original audiogram data	Kenyon, T.N., Ladich, F. & Yan, H.Y. (1998). A comparative study of hearing ability in fishes: the auditory brainstem response approach. J. Comp Physiol A 182: 307-318.
Comments on methodology of getting audiogram	The ABR method was used. Experiments took place in soundproof room (2mx3mx2m). Fish clamped in mesh and held in water in tank (380x245x145mm) standing on air table, with just 1mm of top of head above water; tissue placed on head to prevent it from drying out. 2 electrodes attached to head – ref 5mm forward of recording electrode. Insonification by speaker suspended 1m above subject – 30cm speaker for frequencies below 3kHz, 12cm speaker for frequencies above 3kHz. Sound level at fish obtained from hydrophone placed near presumed 'ear' of fish. Tones and clicks played back at various levels to obtain threshold by visual inspection of averaged ABR traces. Clicks were 0.1ms in duration, presented at 38.2clicks/sec. No. of cycles in a tone burst were set to get best compromise between stimulus rapidity and peak frequency bandwidth; bursts were gated using Blackman window. 3 fish were given Flaxedil (gallamine triethiodode) to pacify them; however, results were insignificantly different from those for fish not given the drug, and the results for the 8 have been pooled.
Any other comments	Authors say ambient noise was measured with the hydrophone; signal was digitally filtered and spectrum levels were calculated using appropriate filter corrections and calibration factors.

Audiogram from Table 2. Threshold levels in dB re 1μPa. 8 fishes in sample.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1200	1500	2000
Mean	100.5	105.9	106.4	112.3	116.3	116.4	117.8	118.3	124.8	130.3	134.8
SD	4.6	5.8	1.9	1.8	1.8	3.2	2.6	2.9	2.0	3.5	4.9

Ambient noise spectrum level, from Fig. 6. Levels in dB re 1μPa.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1500	2000	3000	4000	5000
Mean	56	54	52	51	50	47	48	42	46	47	48	47	46

Database page ref: F/Oscar/02.

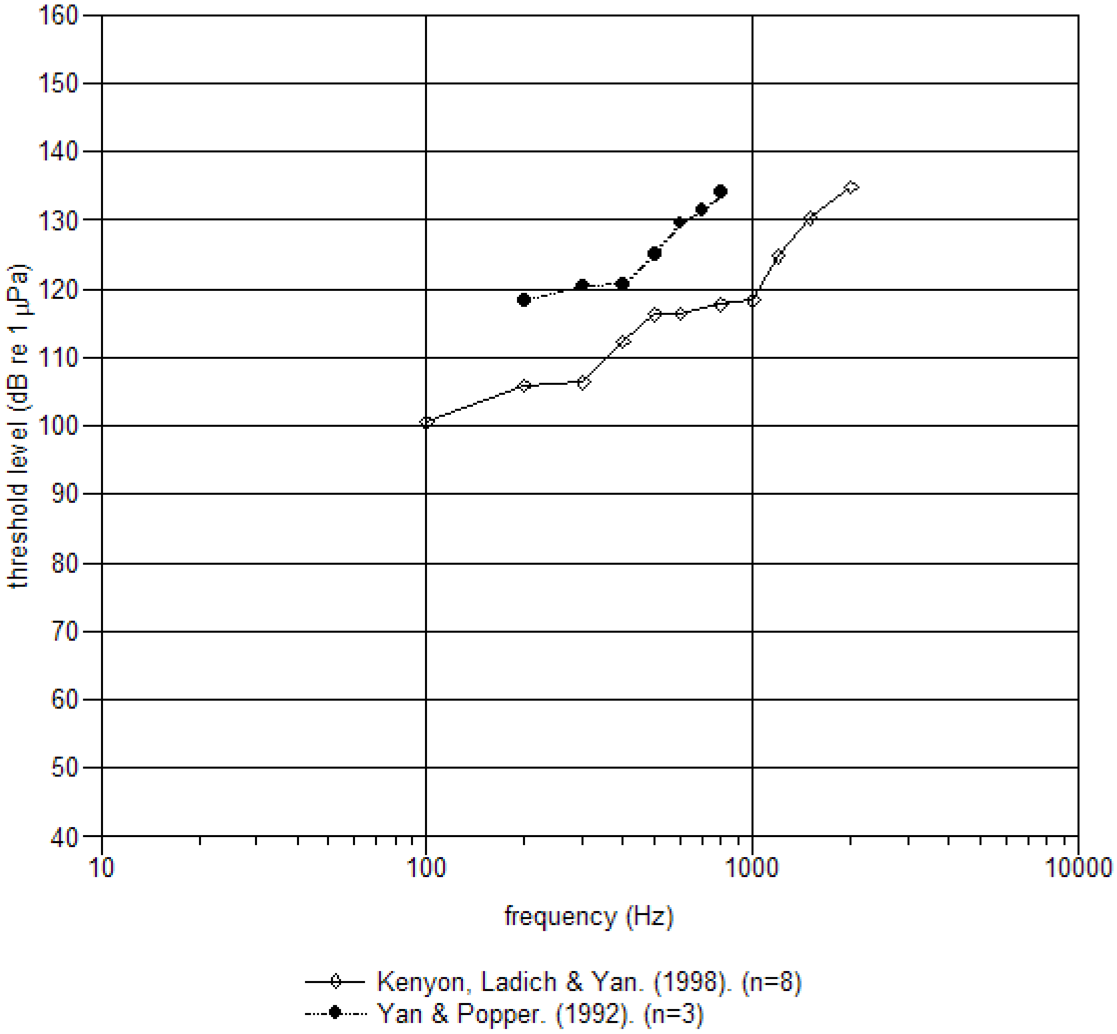
Common name	Oscar.
Family	
Species	*Astronotus ocellatus* (Cuvier).
Paper from which audiogram obtained	Yan, H.Y & Popper, A.N. (1992). Auditory sensitivity of the cichlid fish *Astronotus ocellatus* (Cuvier). J. Comp. Physiol., A 171, 105-109.
Paper having original audiogram data	Yan, H.Y & Popper, A.N. (1992). Auditory sensitivity of the cichlid fish *Astronotus ocellatus* (Cuvier). J. Comp. Physiol., A 171, 105-109.
Comments on methodology of getting audiogram	An automatic feeder was attached to the top of a Plexiglas platform which could be placed over the test tank. A vertical tube, which contacted the water surface, delivered food pellets to the fish. 2 paddles (clear plastic tubes housing 10W light bulbs, and designated the 'O-' and 'R-paddles') were suspended from the platform. The paddles sent response signals to a PC to control food delivery. An underwater speaker (University Sound UW-30) was used to present the tone signals. The fish were trained, in 5 phases, to peck the O-paddle and then to peck the R-paddle if they detected the sound signal. A correct response resulted in the fish obtaining food. Once trained, thresholds were determined using the constant stimulus method. 4 to 6 SPLs were used at each frequency. In each test run 5 replicates of a chosen SPL and 5 blank trials were randomly presented. A minimum of 2 test runs was repeated for each fish at each SPL to calculate the response rate. The response rate was calculated by dividing the number of correct responses by the total number of trials. Threshold was the level at which there was 50% correct responses.
Any other comments	3 oscars, about 60mm standard length, were tested. Experiments were carried out in an IAC soundproof chamber; the ambient in this was found never to exceed –35dB re 1μbar at each of the test frequencies, using a 10Hz wide filter. None of the fish responded to signals at 900 or 1000Hz, even at levels of 49 and 43dB respectively (the maximum outputs obtainable from the equipment). Tests wer not possible for frequencies less than 200Hz.

Audiogram from Table 1. Threshold levels in dB re 1μbar.

Frequency (Hz)	200	300	400	500	600	700	800
Mean	18.4	20.5	20.7	25.1	29.6	31.4	34.0
Range – upper	22.1	25.1	25.8	29.4	33.1	35.0	36.9
Range – lower	14.0	15.4	12.3	18.8	27.6	28.3	30.8
SD	2.8	3.0	3.9	3.5	1.8	2.1	1.9
No. of determinations	9	9	9	9	9	9	9

Threshold levels in dB re 1μPa.

Frequency (Hz)	200	300	400	500	600	700	800
Mean	118.4	120.5	120.7	125.1	129.6	131.4	134.0



[Fig. ref: Oscar01]

Audiogram for oscar.

Database page ref: F/OysterToadfish/01.

Common name	Oyster toadfish.
Family	
Species	*Opsanus tau.*
Paper from which audiogram obtained	Yan, H.Y. (2001). A non-invasive electrophysiological study on the enhancement of hearing ability in fishes. Proc. I.O.A., Vol 23 Part 4, 15-26.
Paper having original audiogram data	Yan, H.Y. (2001). A non-invasive electrophysiological study on the enhancement of hearing ability in fishes. Proc. I.O.A., Vol 23 Part 4, 15-26.
Comments on methodology of getting audiogram	The ABR method was used. Experiments took place in soundproof room (2mx3mx2m). Fish clamped in mesh and held in water in tank (380x245x145mm) standing on air table, with just 1mm of top of head above water; tissue placed on head to prevent it from drying out. 2 electrodes attached to head – ref 5mm forward of recording electrode. Insonification by speaker suspended 1m above subject – 30cm speaker for frequencies below 3kHz, 12cm speaker for frequencies above 3kHz. Sound level at fish obtained from hydrophone placed near presumed 'ear' of fish. Tones and clicks played back at various levels to obtain threshold by visual inspection of averaged ABR traces. Clicks were 0.1ms in duration, presented at 38.2clicks/sec. No. of cycles in a tone burst were set to get best compromise between stimulus rapidity and peak frequency bandwidth; bursts were gated using Blackman window. Fish were sedated with Flaxedil (gallamine triethiodode) Once the baseline audiogram had been taken, air was removed from the gasbladder with a needle attached to a syringe, and another audiogram taken. 5 specimens were tested.
Any other comments	In text states that oyster toadfish does not have any coupling between its gasbladder and inner ear, but they are in close proximity. Radiographs were taken to localise the position of the gas-holding structure.

Audiogram from Fig. 9 – **before** removal of air bubbles. Threshold levels in dB re 1 μPa.

Frequency (Hz)	100	200	250	300	400	500	600	700	800
Mean	117.2	118.1	123.4	125.8	125.4	128.4	125.4	128.5	134.0

Audiogram from Fig. 9 – **after** removal of air bubbles. Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	250	300	400	500	600	700	800
Mean	119.1	118.5	124.8	125.8	126.1	127.9	127.4	132.5	134.8

Database page ref: F/OysterToadfish/02.

Common name	Oyster toadfish.
Family	
Species	*Opsanus tau.*
Paper from which audiogram obtained	Fine, M.L. (1981). Mismatch between Sound Production and Hearing in the Oyster Toadfish. In: Hearing and Sound Communication in Fishes, Tavolga, W.N. et al (eds.), 257-263.
Paper having original audiogram data	
Comments on methodology of getting audiogram	Subjects were anaesthetised (ketamine), immobilised (Flaxedil) and clamped in a tank with the tops of their heads above water. Single fibres were then isolated from the saccular nerves. Responses to 300msec tone bursts from a speaker in air were measured. The tone bursts were phase-locked, had rise-fall times of 5msec, and were generated once per sec. The stimulus sound and background noise were measured with a Celesco LC34 hydrophone. A B&K 2508 measuring amplifier was used, and a General Radio wave analyser with a 3Hz filter.
Any other comments	106 units were isolated from 22 fish. All were sensitive to low freq. sound.

Audiogram from Fig. 13-1 in paper. Threshold levels in dB re 1dyne/sq.cm.

Frequency (Hz)	25	30	40	60	90	120	150	200	250	300	350
Mean	-14.7	-18.5	-22.1	-20.1	-23.0	-11.0	-10.4	2.5	2.6	8.5	22.3

Threshold levels in dB re 1 μPa.

Frequency (Hz)	25	30	40	60	90	120	150	200	250	300	350
Mean	85.3	81.5	77.9	79.9	77.0	89.0	89.6	102.5	102.6	108.5	122.3

Database page ref: : F/OysterToadfish/03.

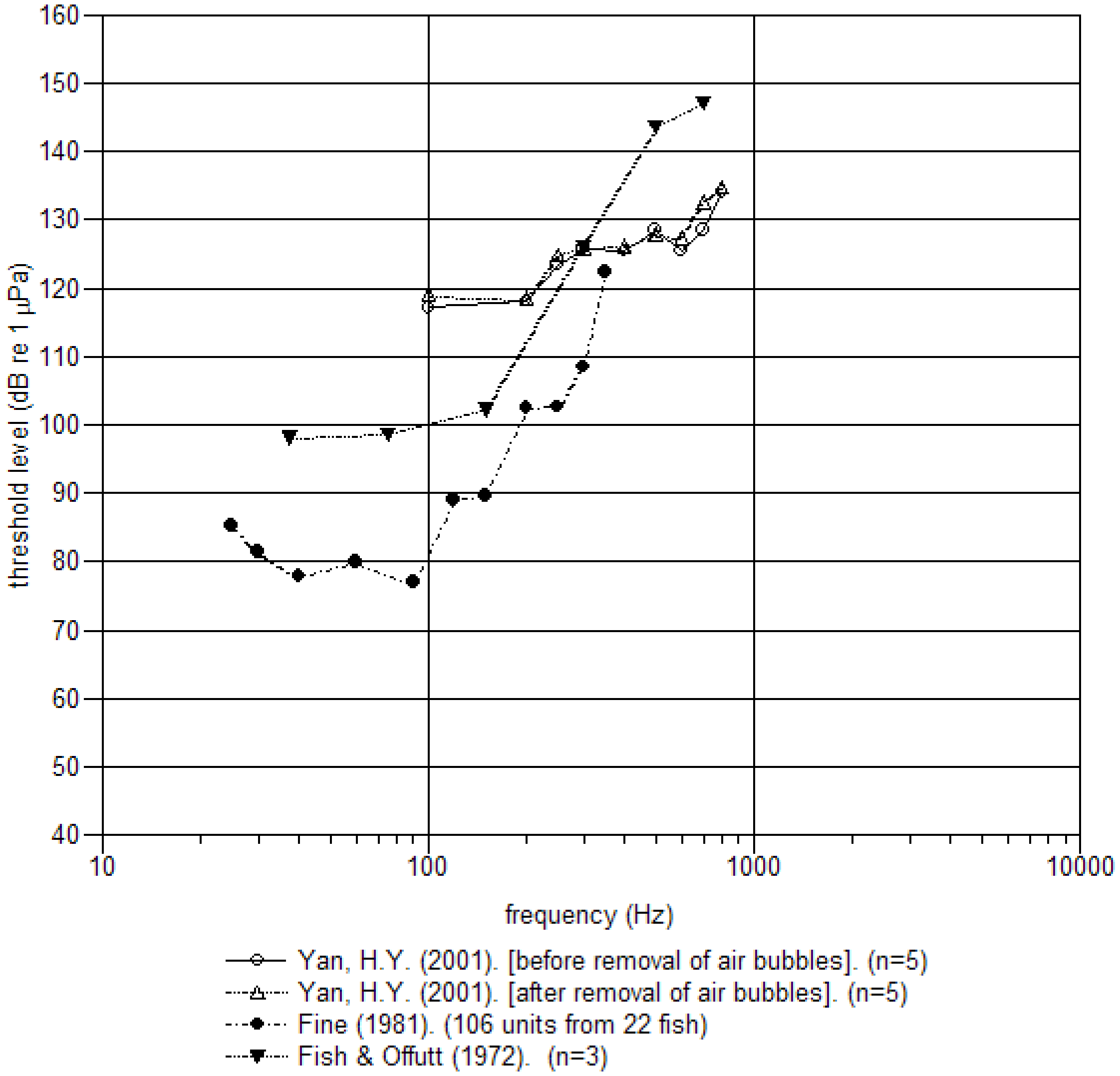
Common name	Toadfish.
Family	
Species	*Opsanus tau.*
Paper from which audiogram obtained	Fay, R.R. (1988). Hearing in Vertebrates: A Psychophysics Databook. Hill-Fay Associates, Winnetka, Ill.
Paper having original audiogram data	Fish, J.F. & Offutt, G.C. (1972). Hearing thresholds from toadfish, *Opsanu tau*, measured in the laboratory and field. JASA., 51, 1318-1321.
Comments on methodology of getting audiogram	Original source not seen. In laboratory, loudspeaker in air. Classical conditionin of the heart rate using staircase psychophysical procedure. In field, used J9 projector at1.5m and an unconditioned, sound-induced suppression of vocalization as the response.
Any other comments	3 specimens. Field threhold ranges within 3dB of laboratory thresholds at 200 and 400Hz.

Audiogram from Table F7-0. Threshold levels in dB re 1dyne/cm^2. 3 specimens.

Frequency (Hz)	37.5	75	150	300	500	700
Mean	-2	-1.5	2.2	26	43.5	47

Threshold levels in dB re 1μPa.

Frequency (Hz)	37.5	75	150	300	500	700
Mean	98	98.5	102.2	126	143.5	147



[Fig. ref: OysterToadfish01]

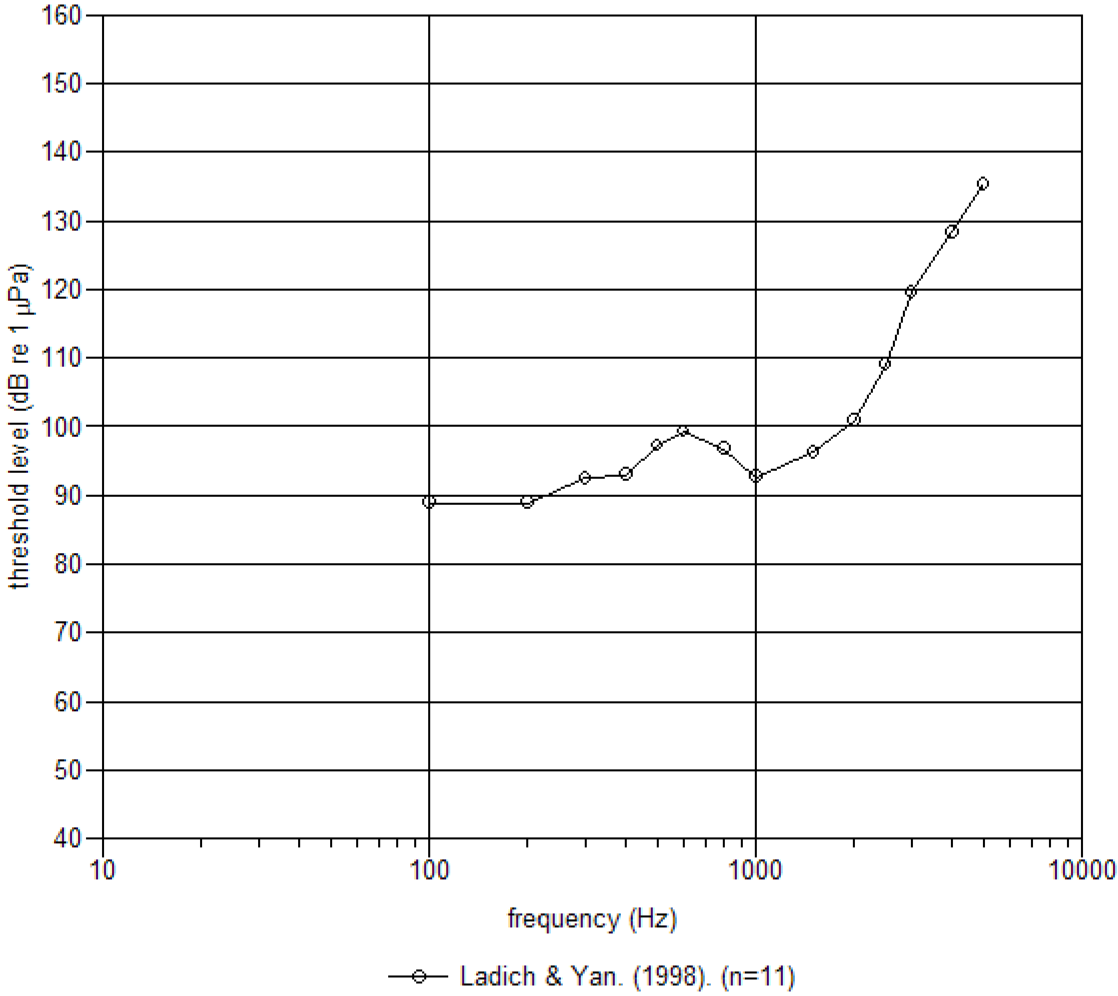
Audiograms for oyster toadfish.

Database page ref: F/Paradise/01.

Common name	Paradise fish.
Family	
Species	*Macropodus opercularis*
Paper from which audiogram obtained	Ladich, F. & Yan, H.Y. (1998). Correlation between auditory sensitivity and vocalization in anabantoid fishes. J Comp Physiol A 182:737-746.
Paper having original audiogram data	Ladich, F. & Yan, H.Y. (1998). Correlation between auditory sensitivity and vocalization in anabantoid fishes. J Comp Physiol A 182:737-746.
Comments on methodology of getting audiogram	The ABR method was used. Experiments took place in soundproof room (2mx3mx2m). Fish clamped in mesh and held in water in tank (380x245x145mm) standing on air table, with just 1mm of top of head above water; tissue placed on head to prevent it from drying out. 2 electrodes attached to head – ref 10mm forward of recording electrode. Insonification by speaker suspended 1m above subject – 30cm speaker for frequencies below 3kHz, 12cm speaker for frequencies above 3kHz. Sound level at fish obtained from hydrophone (Celesco LC-10) placed near presumed right 'ear' of fish. Tones and clicks played back at various levels to obtain threshold by visual inspection of averaged ABR traces. Clicks were 0.1ms in duration, presented at 38.2clicks/sec. No. of cycles in a tone burst was set to get best compromise between stimulus rapidity and peak frequency bandwidth. All 11 specimens were given Flaxedil (gallamine triethiodode) to immobilise them.
Any other comments	

Audiogram from Table 1. Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1500	2000	2500	3000	4000	5000
Mean	88.9	88.9	92.5	92.9	97.2	99.3	96.7	92.7	96.3	100.8	109.0	119.6	128.3	135.4
SD	3.5	3.8	1.7	4.4	4.8	3.1	6.8	6.2	5.0	5.1	4.1	4.5	4.9	3.5



[Fig. ref: ParadiseFish01]

Audiogram for paradise fish.

Database page ref: F/Perch/01.

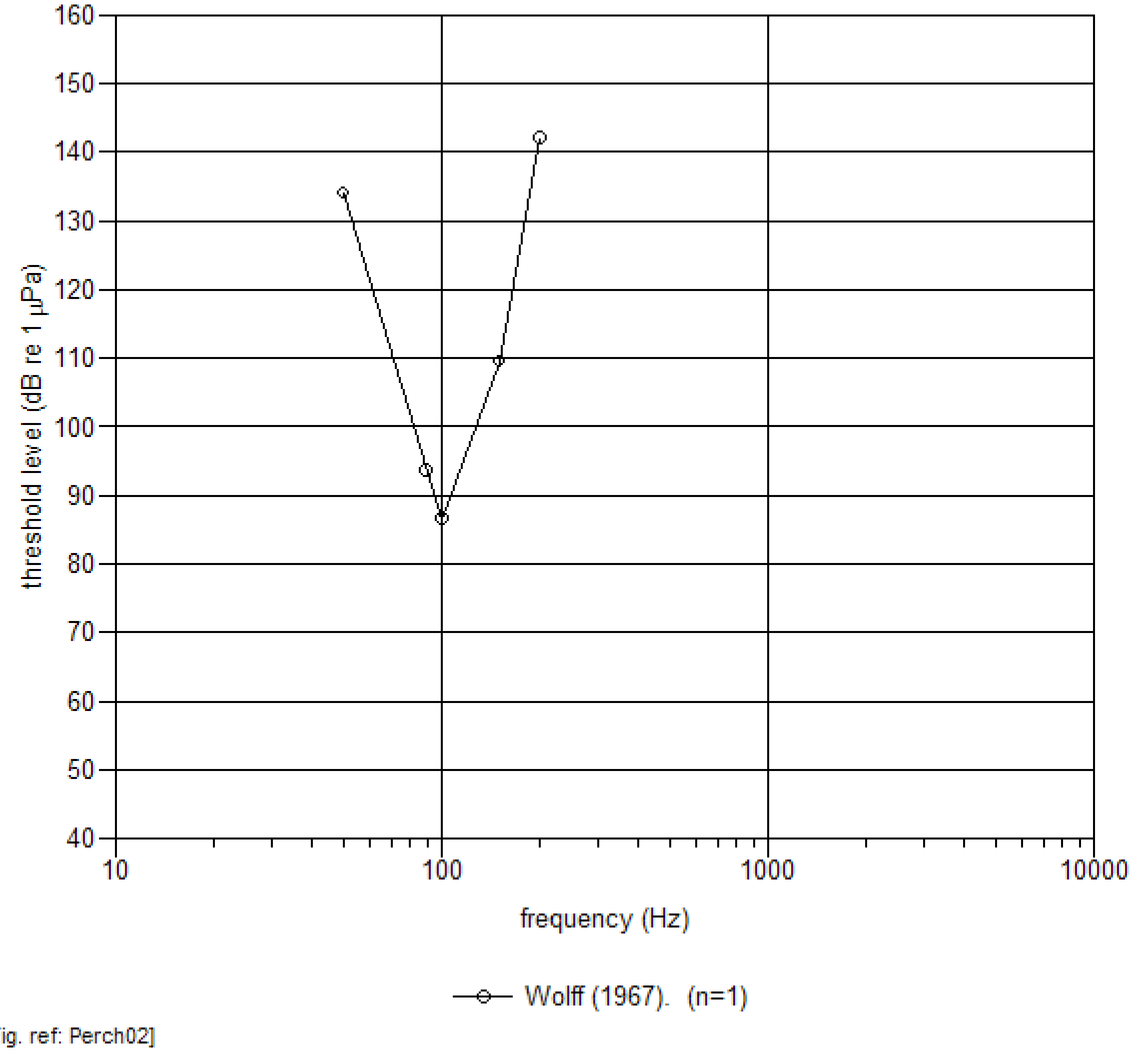
Common name	Perch.
Family	
Species	*Perca fluviatilis.*
Paper from which audiogram obtained	Fay, R.R. (1988). Hearing in Vertebrates: A Psychophysics Databook. Hill-Fay Associates, Winnetka, Ill.
Paper having original audiogram data	Wolff, D.L. (1967). Das Hörvermögen des Flussbarsches (*Perca fluviatilis* L.). Biol. Entr., 86:449-460.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	

Audiogram from Table F9-0. Threshold levels in dB re 1 dyne/cm^2. 1 specimen.

Frequency (Hz)	50	90	100	150	200
Mean	34	-6.5	-13.5	9.5	42

Threshold levels in dB re 1µPa.

Frequency (Hz)	50	90	100	150	200
Mean	134	93.5	86.5	109.5	142



Audiogram for perch.

Database page ref: F/PikePerch/01.

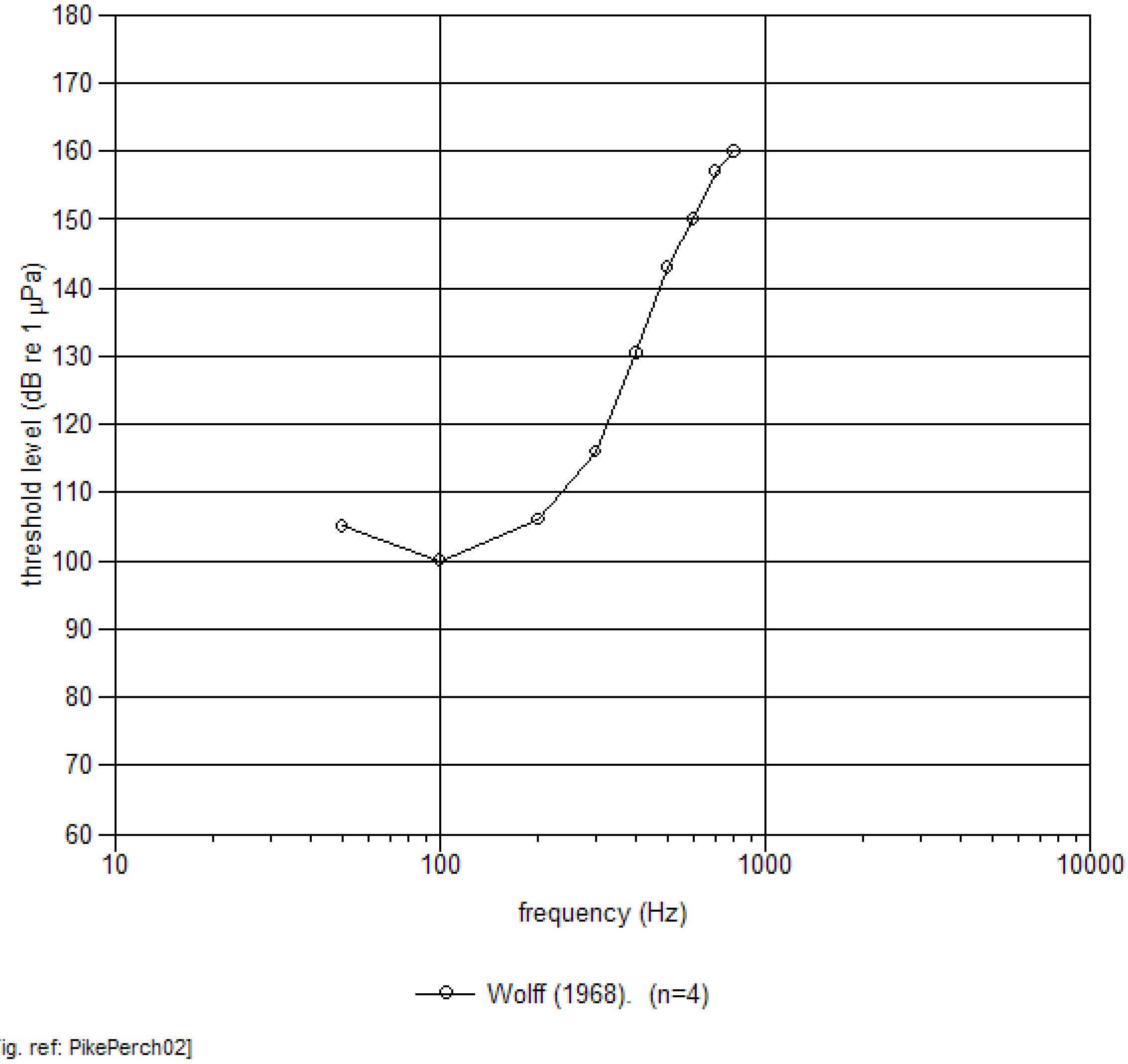
Common name	Pike perch.
Family	
Species	*Lucioperca Sandra.*
Paper from which audiogram obtained	Fay, R.R. (1988). Hearing in Vertebrates: A Psychophysics Databook. Hill-Fay Associates, Winnetka, Ill.
Paper having original audiogram data	Wolff, D.L. (1968). Das Hörvermögen des Kaalbarsches (*Acerina cernua* L.) und des Zanders, (*Luciaperca sandra* Cuv. Und Val.). Z. vergl. Physiol., 60:14-33.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	

Audiogram from Table F9-0. Threshold levels in dB re 1 dyne/cm^2. 4 specimens.

Frequency (Hz)	50	100	200	300	400	500	600	700	800
Mean	5	0	6	16	30.5	43	50	57	60

Threshold levels in dB re 1μPa.

Frequency (Hz)	50	100	200	300	400	500	600	700	800
Mean	105	100	106	116	130.5	143	150	157	160



Audiogram for pike perch.

Database page ref: F/Pinfish/01.

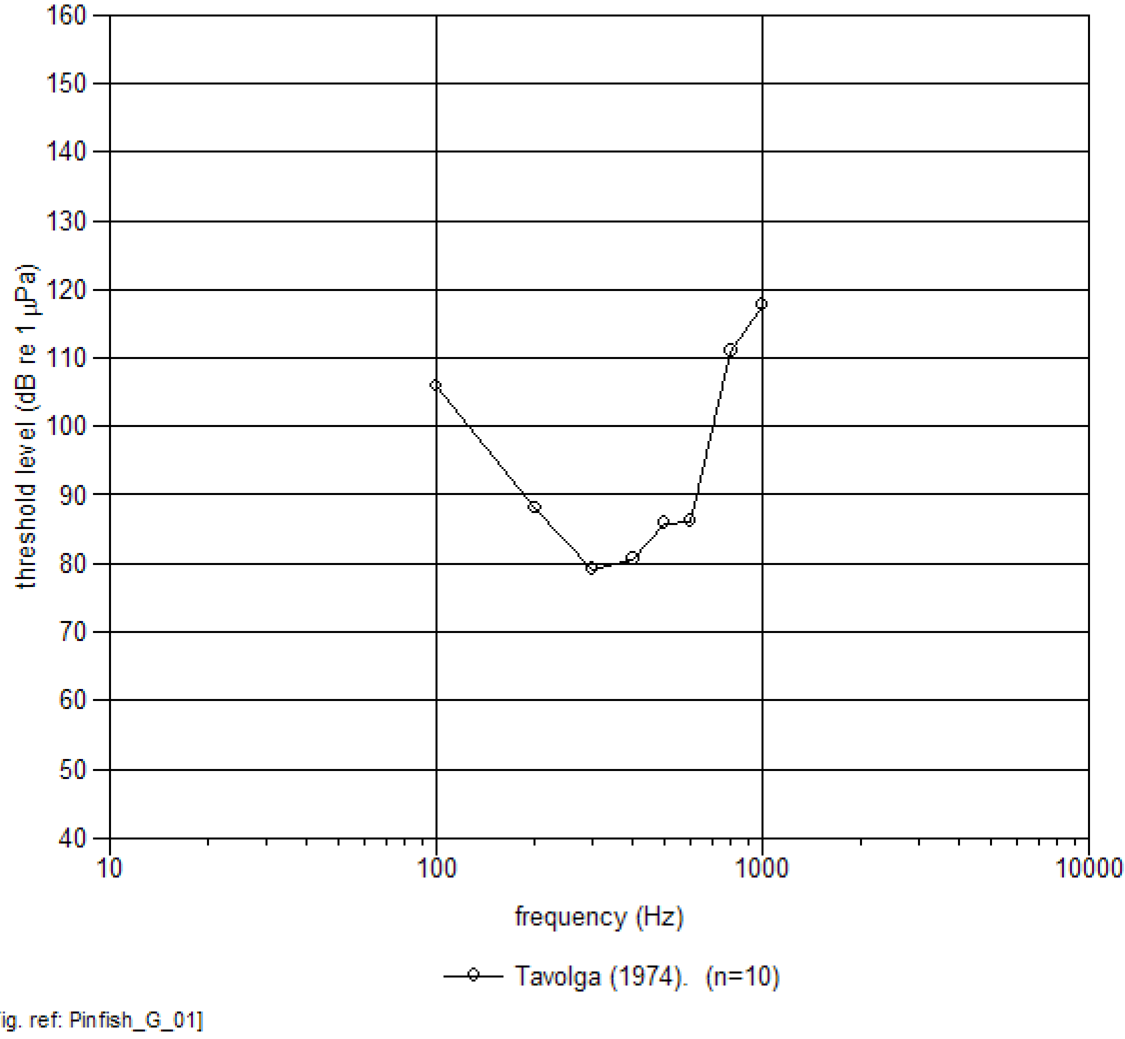
Common name	Pinfish.
Family	
Species	*Lagodon rhomboides.*
Paper from which audiogram obtained	Fay, R.R. (1988). Hearing in Vertebrates: A Psychophysics Databook. Hill-Fay Associates, Winnetka, Ill.
Paper having original audiogram data	Tavolga, W.N. (1974). Signal/noise ratio and the critical band in fishes. JASA., 55, 1323-1333..
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	

Audiogram from Table F7-0. Threshold levels in dB re 1dyne/cm^2. 10 specimens.

Frequency (Hz)	100	200	300	400	500	600	800	1000
Mean	5.9	-11.9	-20.9	-19.4	-14.1	-13.8	11	17.7

Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	300	400	500	600	800	1000
Mean	105.9	88.1	79.1	80.6	85.9	86.2	111	117.7



Audiogram for pinfish.

Database page ref: F/Pollack/01.

Common name	Pollack.
Family	
Species	*Pollachus pollachius.*
Paper from which audiogram obtained	Fay, R.R. (1988). Hearing in Vertebrates: A Psychophysics Databook. Hill-Fay Associates, Winnetka, Ill.
Paper having original audiogram data	Chapman C.J. (1973). Field studies of hearing in teleost fish. Helgoländer wissenschaftliche Meeresuntersuchungen, 24, 371-390.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	2 specimens tested. Thresholds below 380Hz likely to have been masked by ambient noise.

Audiogram from Table F8-0. Threshold levels in dB re 1 dyne/cm^2.

Frequency (Hz)	40	60	110	160	310	470
Mean	-12.6	-19	-17	-19.2	-13.5	7.7

Threshold levels in dB re 1μPa.

Frequency (Hz)	40	60	110	160	310	470
Mean	87.4	81	83	80.8	86.5	107.7

Database page ref: F/Pollack/02

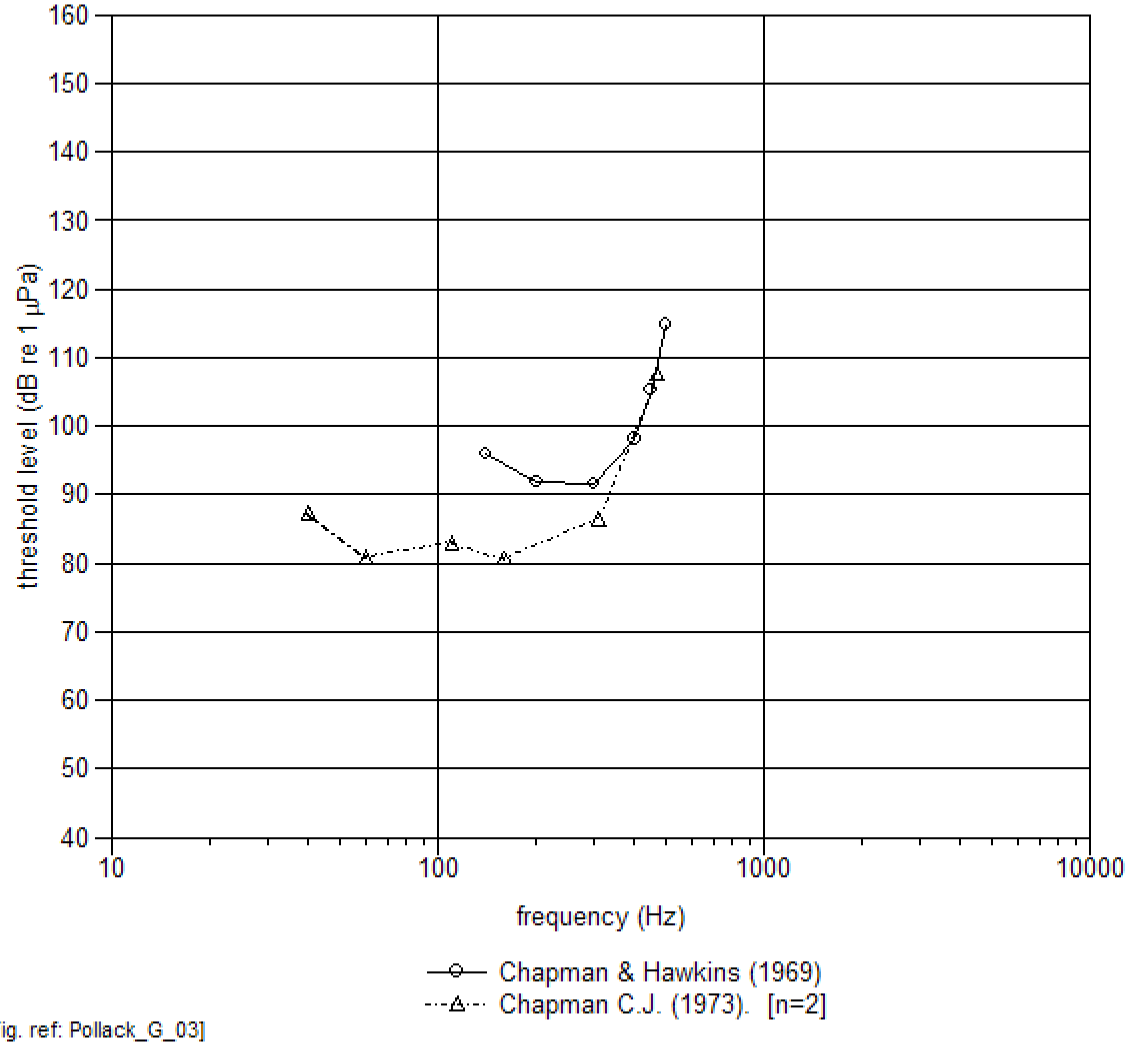
Common name	Pollack (Lythe).
Family	
Species	*Pollachius pollachius.*
Paper from which audiogram obtained	Chapman, C.J. & Hawkins, A.D. (1969). The importance of sound in fish behaviour in relation to capture by trawls. FAO Fisheries Reports, 62, Vol. 3:717-729.
Paper having original audiogram data	Chapman, C.J. & Hawkins, A.D. (1969). The importance of sound in fish behaviour in relation to capture by trawls. FAO Fisheries Reports, 62, Vol. 3:717-729.
Comments on methodology of getting audiogram	Behavioural method used. Fish in a small tank was trained to swim through an aperture on hearing sound, in anticipation of an electric shock. Sound stimulus (tone) was produced by a large loudspeaker mounted in air beneath a very thin-walled aquarium tank. Whole system was mounted inside a large container lined with sound absorbent material. Hydrophone in tank monitored stimulus sound. Staircase method used to establish threshold.
Any other comments	This paper mentions the audiogram in its discussion of the noise produced by fishing vessels and their trawls.

Audiogram from Fig. 2. Threshold levels in dB re 1μbar.

Frequency (Hz)	140	200	300	400	450	500
Mean	-4.0	-8.1	-8.4	-1.9	5.3	14.9

Threshold levels in dB re 1μPa.

Frequency (Hz)	140	200	300	400	450	500
Mean	96.0	91.9	91.6	98.1	105.3	114.9



[Fig. ref: Pollack_G_03]

Audiogram for pollack.

Database page ref: F/RedHind/01.

Common name	Red hind.
Family	Serranidae.
Species	*Epinephelus guttatus.*
Paper from which audiogram obtained	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Paper having original audiogram data	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Comments on methodology of getting audiogram	Glass tank was lined on floor and walls with 2inch layers of rubberised horsehair. Internal dimensions of tank with lining in place were 26”x10” in plan. A curved barrier, also made from horsehair and 9” high, was placed centrally in the tank, spanning its width. Water depth above top of barrier, and therefore in tank, was adjusted to cause the fish to have to exert some effort to swim over the barrier; optimum depth was found to be 90mm. Tank was mounted on 2” thick pieces of foam rubber at its corners. Sound source was a University Model MM-2 underwater speaker with a plastic expansion bulb as the driving surface. It was placed under the central barrier. A hydrophone (Chesapeake Instrument Co. Model SB-154C) was placed near the wall farthest from the sound source, but it wasn’t always used when a fish was in the tank. Electrodes for causing shock were rings of silver solder, with a pair being mounted on the tank sidewalls at each end of the tank. Avoidance conditioning test method was used. Shock was a 0.1s duration pulse repeated at about 40 pulses per minute. If fish heard sound it had to swim to other side of barrier within 10sec to avoid getting a shock. After an inter-trial interval another trial took place, with the fish having to cross the barrier in the opposite direction. Threshold determined by staircase method, starting at high level and reducing level in 5dB steps until a reversal occurred.
Any other comments	1 specimen used. Species was difficult to test. Water level at the barrier was critical; at 75mm animal had great difficulty in crossing, and a variation of 10mm around the optimum of 90mm either permitted numerous crossings or inhibited avoidances. Driver unit had slightly better frequency response and distortion level than the unit used in a smaller tank, but actual figures are not given (smaller unit was distortion-free between 200Hz and 5kHz at pressure levels up to 50dB re 1μbar).

Audiogram from Fig. 21 (authors' mean line) Threshold levels in dB re.1 µbar. 1 specimen.

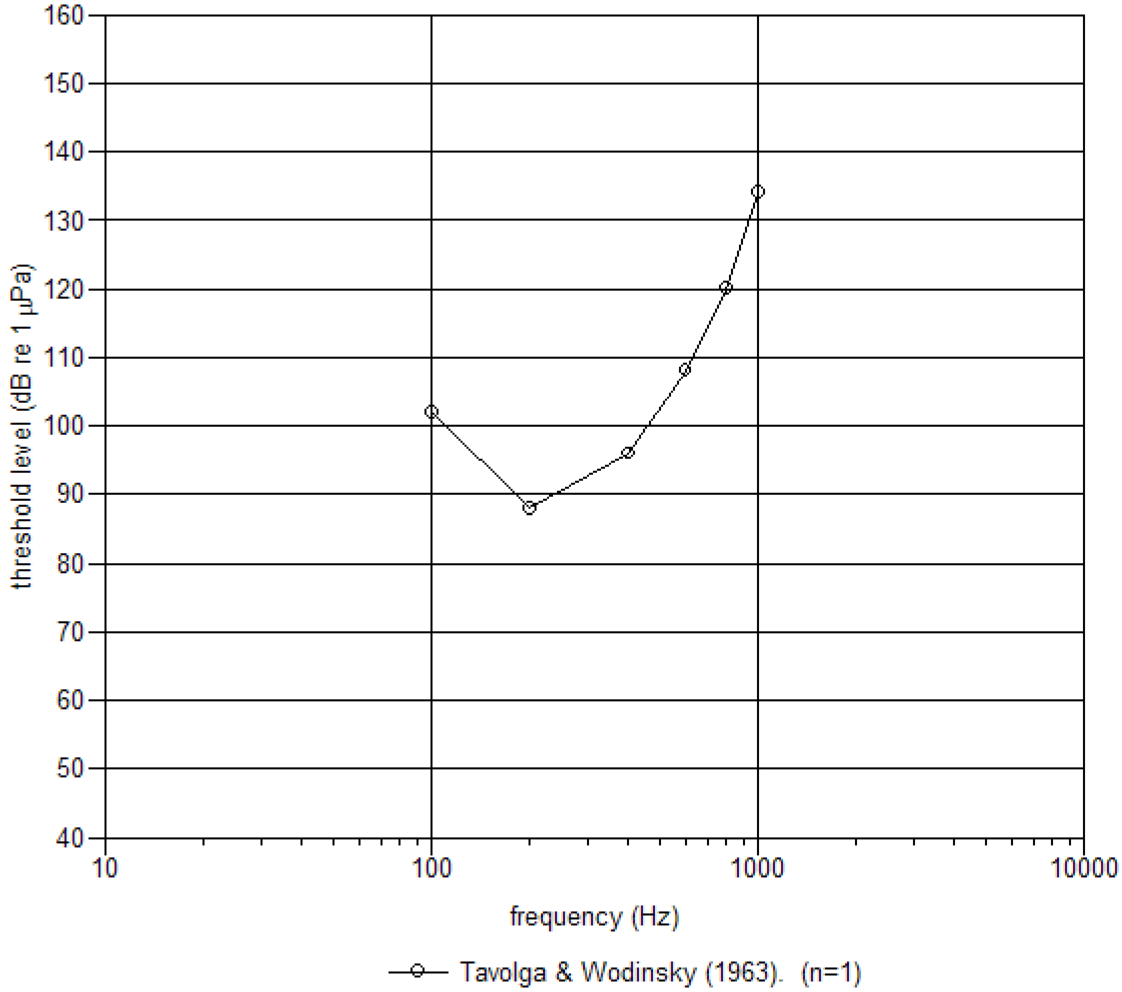
Frequency (Hz)	100	200	400	600	800	1000
Mean	2	-12	-4	8	20	34

Threshold levels in dB re 1µPa.

Frequency (Hz)	100	200	400	600	800	1000
Mean	102	88	96	108	120	134

Ambient noise levels in tank.

Bandwidth (Hz)	37.5 - 75	75 - 150	150 - 300	300 - 600	600 - 1200	1200 - 2400	2400 - 4800	4800 - 9600
Level (dB re 1µbar)	< -50	< -50	-50	-46	-43	-39	-35	-20
Level (dB re 1µPa)	< 50	< 50	50	54	57	61	65	80



[Fig. ref: RedHind_G_01]

Audiogram for red hind.

Database page ref: F/Ruff/01

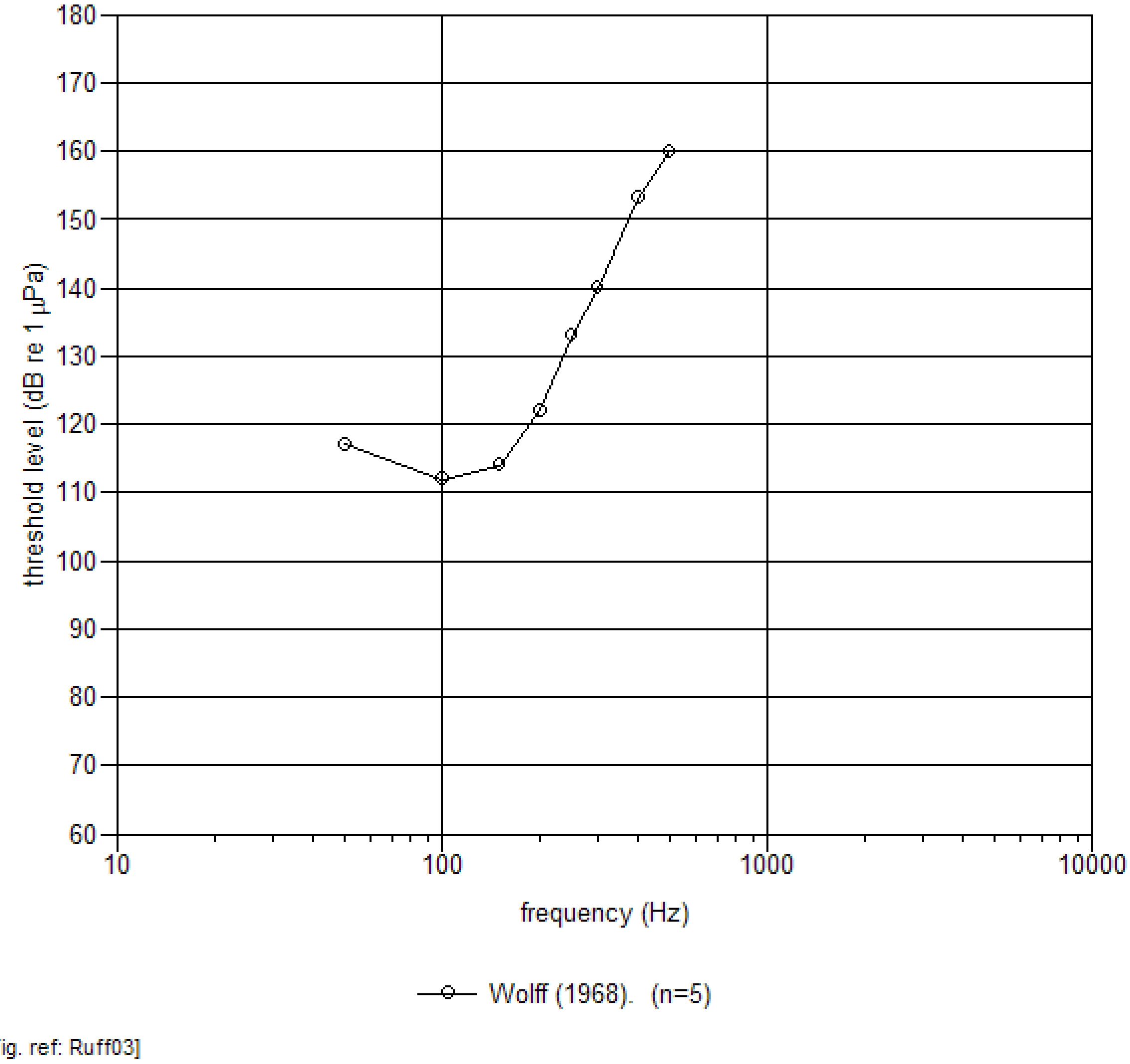
Common name	Ruff
Family	
Species	*Acerina cernua.*
Paper from which audiogram obtained	Fay, R.R. (1988). Hearing in Vertebrates: A Psychophysics Databook. Hill-Fay Associates, Winnetka, Ill.
Paper having original audiogram data	Wolff, D.L. (1968). Das Hörvermögen des Kaalbarsches (*Acerina cernua* L.) und des Zanders, (*Luciaperca Sandra* Cuv. Und Val.). Z. vergl. Physiol., 60:14-33.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	

Audiogram from Table F9-0. Threshold levels in dB re 1 dyne/cm^2. 5 specimens.

Frequency (Hz)	50	100	150	200	250	300	400	500
Mean	17	12	14	22	33	40	53.2	60

Threshold levels in dB re 1µPa.

Frequency (Hz)	50	100	150	200	250	300	400	500
Mean	117	112	114	122	133	140	153.2	160



Audiogram for ruff.

Database page ref: F/Salmon/01.

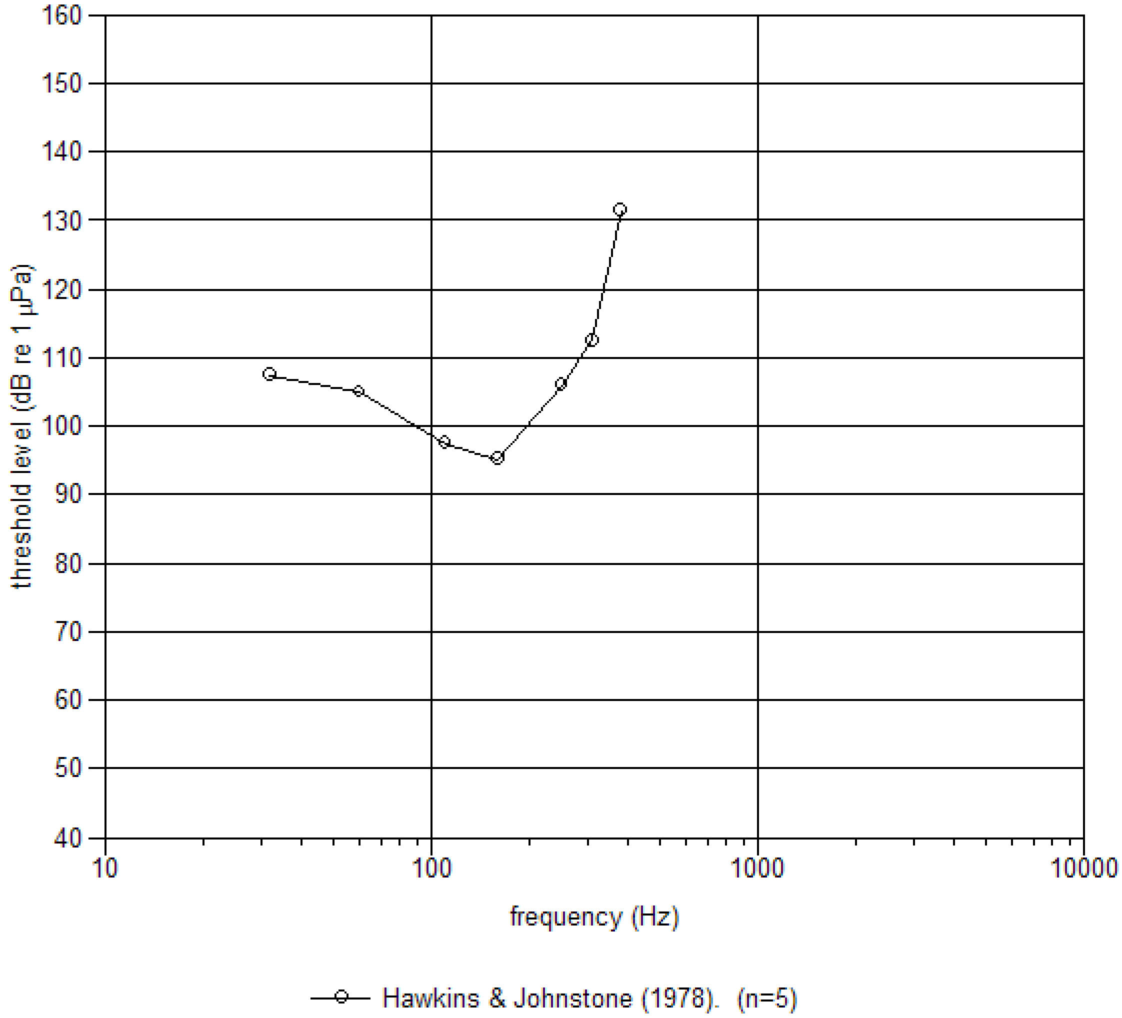
Common name	Atlantic salmon.
Family	
Species	*Salmo salar*.
Paper from which audiogram obtained	Fay, R.R. (1988). Hearing in Vertebrates: A Psychophysics Databook. Hill-Fay Associates, Winnetka, Ill.
Paper having original audiogram data	Hawkins, A.D. & Johnstone, A.D.F. (1978). The hearing of the Atlantic salmon, *Salmo salar*. J. Fish. Biol., 13:655-673.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	

Audiogram from Table F9-0. Threshold levels in dB re 1 dyne/cm^2. 5 specimens.

Frequency (Hz)	32	60	110	160	250	310	380
Mean	7.5	5	-2.5	-4.8	6	12.5	31.5

Threshold levels in dB re 1µPa.

Frequency (Hz)	32	60	110	160	250	310	380
Mean	107.5	105	97.5	95.2	106	112.5	131.5



[Fig. ref: Salmon03]

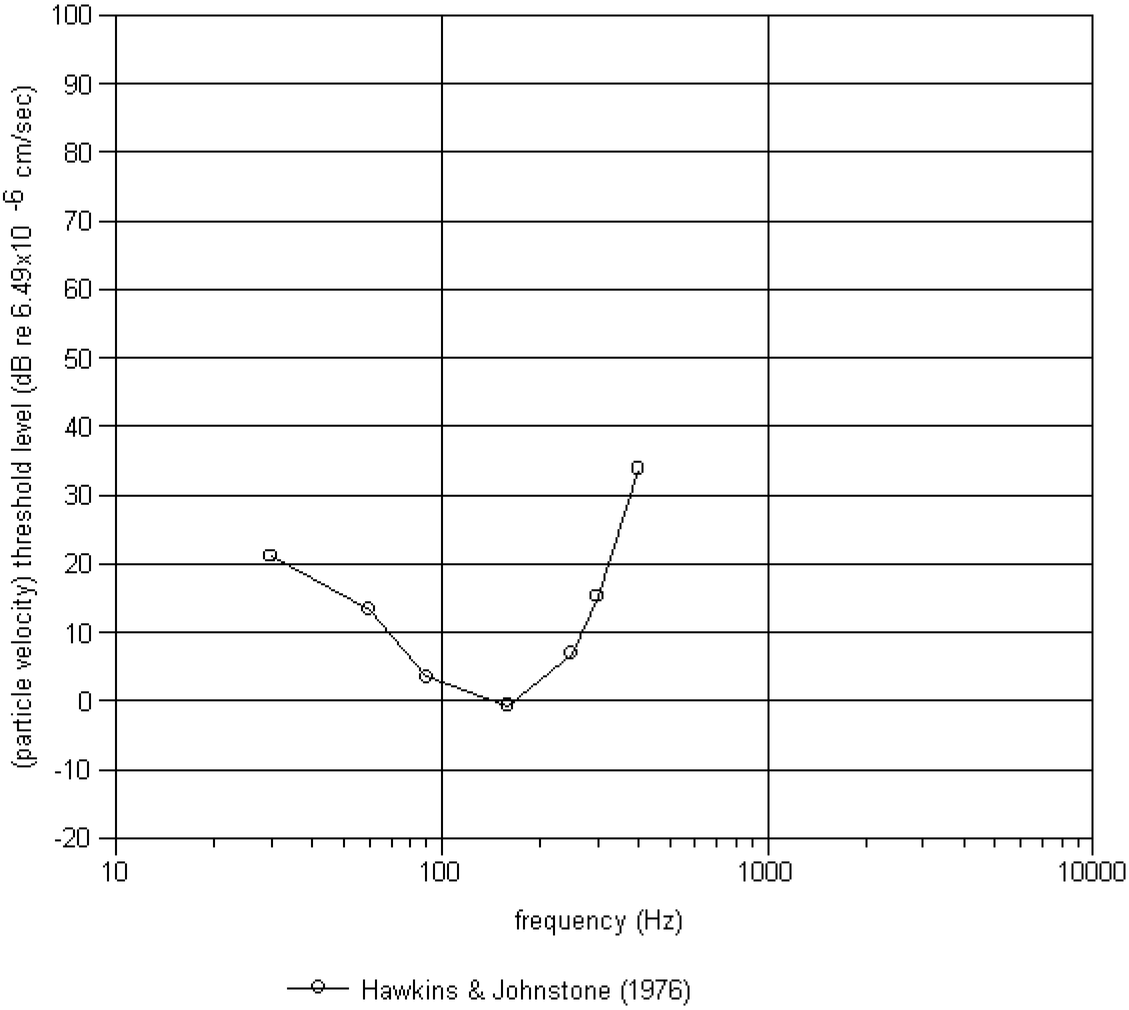
Audiogram for salmon.

Database page ref: F/Salmon/02.

Common name	Salmon
Family	Salmonidae
Species	*Salmo salar*
Paper from which audiogram obtained	Hawkins, A.D. & Myrberg, A.A. (jnr). (1983). Hearing and sound communication under water. In: Bioacoustics: a comparative approach. B. Lewis (ed.), pp. 347-405. Academic Press, New York.
Paper having original audiogram data	Hawkins & Johnstone (1976) (full details of ref. not available in photocopy of Hawkins & Myrberg seen).
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	In text, state that tests in which the ratio of particle velocity to sound pressure was varied showed that some flatfishes (e.g. *Pleuronectes platessa* & *Limanda limanda*), and the Atlantic salmon *Salmo salar* responded to particle motion rather than sound pressure. This data may be the same as in F/Salmon/01, where the data is presented in pressure units.

Audiogram from Fig. 13. Threshold levels in dB re 6.49x10^{-6} cm/sec.

Frequency (Hz)	30	60	90	160	250	300	400
Mean	21.2	13.4	3.5	-0.6	6.9	15.3	33.8



[Fig. ref: Salmon01B]

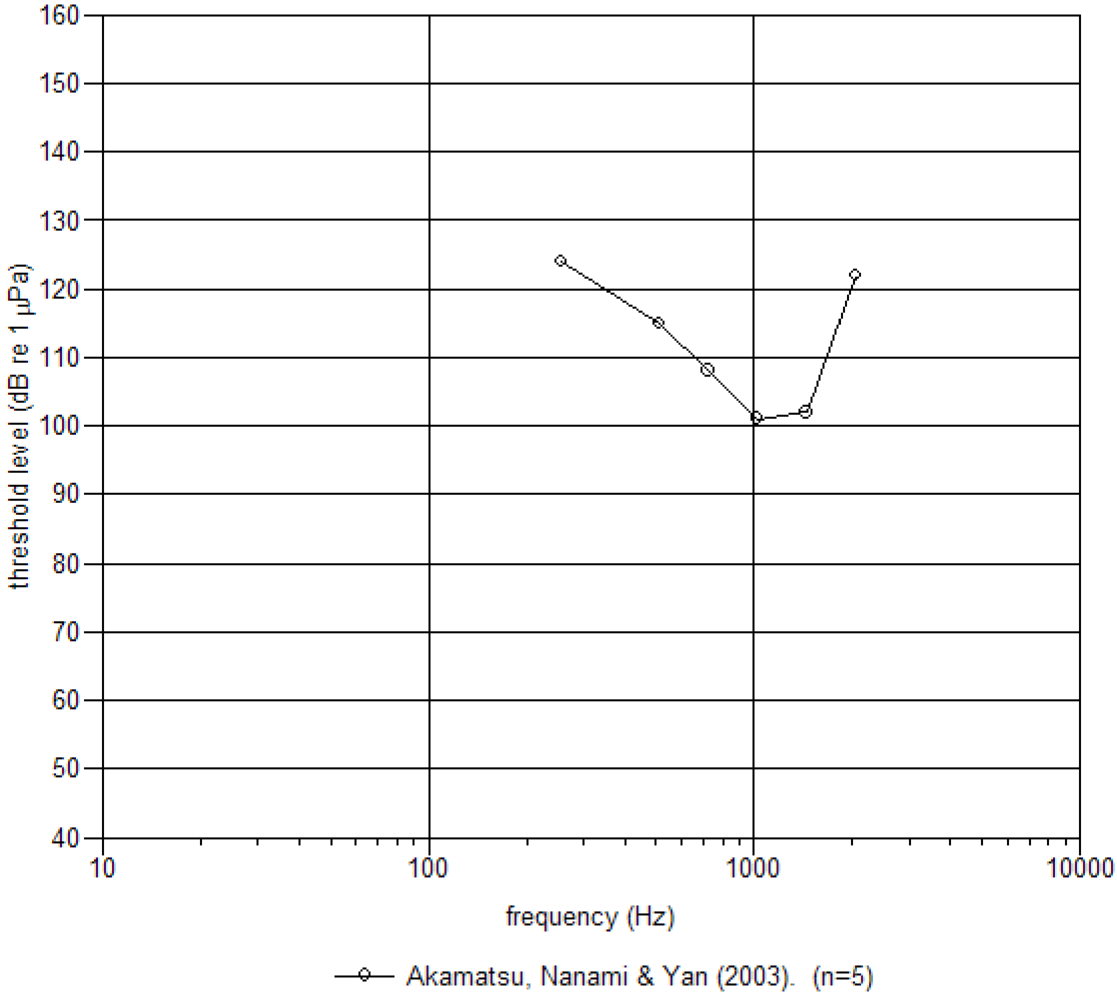
Audiogram for salmon. (Note that it is given in velocity units).

Database page ref: F/Sardine/01.

Common name	Sardine.
Family	
Species	*Sardinops melanostictus*
Paper from which audiogram obtained	Akamatsu, T., Nanami, T. & Yan, H.Y. (2003). Spotlined sardine *Sardinops melanostictus* listens to 1-kHz sound using its gas bladder. Fisheries Science; 69: 348–354.
Paper having original audiogram data	Akamatsu, T., Nanami, T. & Yan, H.Y. (2003). Spotlined sardine *Sardinops melanostictus* listens to 1-kHz sound using its gas bladder. Fisheries Science; 69: 348–354.
Comments on methodology of getting audiogram	ABR method. Tests were done in a seawater-filled plastic tub, 280x200x35mm deep, placed on a vibration isolating table in a soundproof chamber. Sound was radiated by a ceiling-mounted loudspeaker 450mm above the subject (Fostex FW108N up to 2896Hz, Fostex FT7RP at and above 4096Hz). Signals were digitally generated 5-cycle tone bursts multiplied with a Gaussian function. The PC repeated the wave file every 200ms in a loop. The sound in the water was monitored with a B&K Type 8103 hydrophone located adjacent to the subject's head. Fish was restrained in neoprene rubber, and immobilised by stainless steel plates attached to sides of the holding tub. Subject was held horizontally, the inner ear and frontal end of gas bladder kept at the same depth to ensure equal levels of incident sound pressure on both organs. Small area of skin on head exposed above the water line for placement of the electrodes. The potentials were amplified and filtered between 50Hz and 10kHz. Only 300 stimulus exposures at a frequency were used, as the sardine is rather fragile. Sound levels were varied initially in 6dB steps, and in 3dB steps nearer the threshold. Water was continually supplied to the mouth of the subject, the flow maintained by gravity to avoid the noise of an electric pump. Recording electrodes placed along the midline of the skull over the medulla region, the cables twisted to cancel out electromagnetic noise from the outside chamber.
Any other comments	5 specimens tested. Sardine is an important commercial sp. in Japan. It is thought that fishing vessel noise may alter behaviour. The resonant property of the gas bladder is considered to enhance the hearing of many fish sp. The most sensitive frequency was found to be 1kHz, well within the frequency generated by fishing trawlers.

Audiogram from Fig. 3. Threshold levels in dB re 1µPa. 5 specimens.

Frequency (Hz)	256	512	724	1024	1448	2048
Mean	124	115	108	101	102	122
SD	6	4	4	5	4	13



[Fig. ref: Sardine_G_01]

Audiogram for sardine.

Database page ref: F/Schoolmaster/01.

Common name	Schoolmaster.
Family	Lutjanidae.
Species	*Lutjanus apodus.*
Paper from which audiogram obtained	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126:177-240.
Paper having original audiogram data	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126:177-240.
Comments on methodology of getting audiogram	Glass tank was lined on floor and walls with 2inch layers of rubberised horsehair. Internal dimensions of tank with lining in place were 16"x7" in plan. A curved barrier, also made from horsehair and 4" high, was placed centrally in the tank, spanning its width. Water depth above top of barrier, and therefore in tank, was adjusted to cause the fish to have to exert some effort to swim over the barrier; depth ranged from 6 to 13mm. Tank was mounted on 2" thick pieces of foam rubber at its corners. Sound source was a University Model SA-HF public address unit fitted with a rubber bulb over its horn end; the entire unit was waterproofed with tar, tape and rubber. It was placed under the central barrier. A hydrophone (Chesapeake Instrument Co. Model SB-154C) was placed near the wall farthest from the sound source, but it wasn't always used when a fish was in the tank. Electrodes for causing shock were rings of silver solder, with a pair being mounted on the tank sidewalls at each end of the tank. Avoidance conditioning test method was used. Shock was a 0.1s duration pulse repeated at about 40 pulses per minute. If fish heard sound it had to swim to other side of barrier within 10sec to avoid getting a shock. After an inter-trial interval another trial took place, with the fish having to cross the barrier in the opposite direction. Threshold determined by staircase method, starting at high level and reducing level in 2dB steps until a reversal occurred, when level was increased in 2dB steps.
Any other comments	3 specimens used. Driver unit gave distortion-free output between 200Hz and 5kHz up to 50dB re 1μbar. At lower frequencies harmonic distortion and clipping occurred above 30 to 35dB re 1μbar. A secondary low-frequency threshold was found for repeat trials at lower frequencies after the higher frequencies had been tested.

Audiogram from Fig. 16 (authors' mean lines). Threshold levels in dB re.1 µbar. 3 specimens.

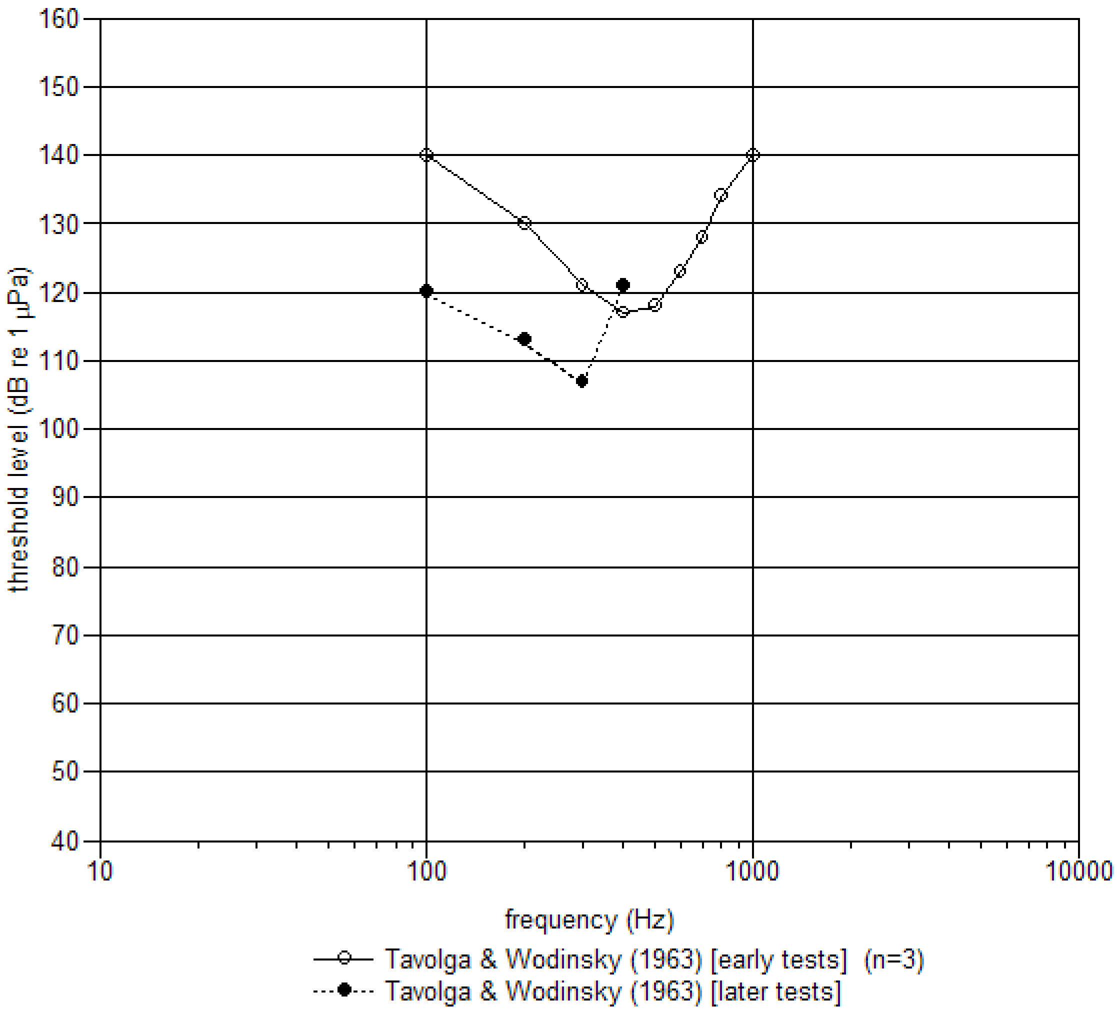
Frequency (Hz)	100	200	300	400	500	600	700	800	1000
Mean (early tests)	40	30	21	17	18	23	28	34	40
Mean (later tests)	20	13	7	21					

Threshold levels in dB re 1µPa.

Frequency (Hz)	100	200	300	400	500	600	700	800	1000
Mean (early tests)	140	130	121	117	118	123	128	134	140
Mean (later tests)	120	113	107	121					

Ambient noise levels in tank.

Bandwidth (Hz)	37.5 - 75	75 - 150	150 - 300	300 - 600	600 - 1200	1200 - 2400	2400 - 4800	4800 - 9600
Level (dB re 1µbar)	-43	< -50	< -5	-43	-39	-34	-29	-20
Level (dB re 1µPa)	57	< 50	< 50	57	61	66	71	80



[Fig. ref: Schoolmaster_G_01]

Audiogram for schoolmaster.

Database page ref: F/Skate/01.

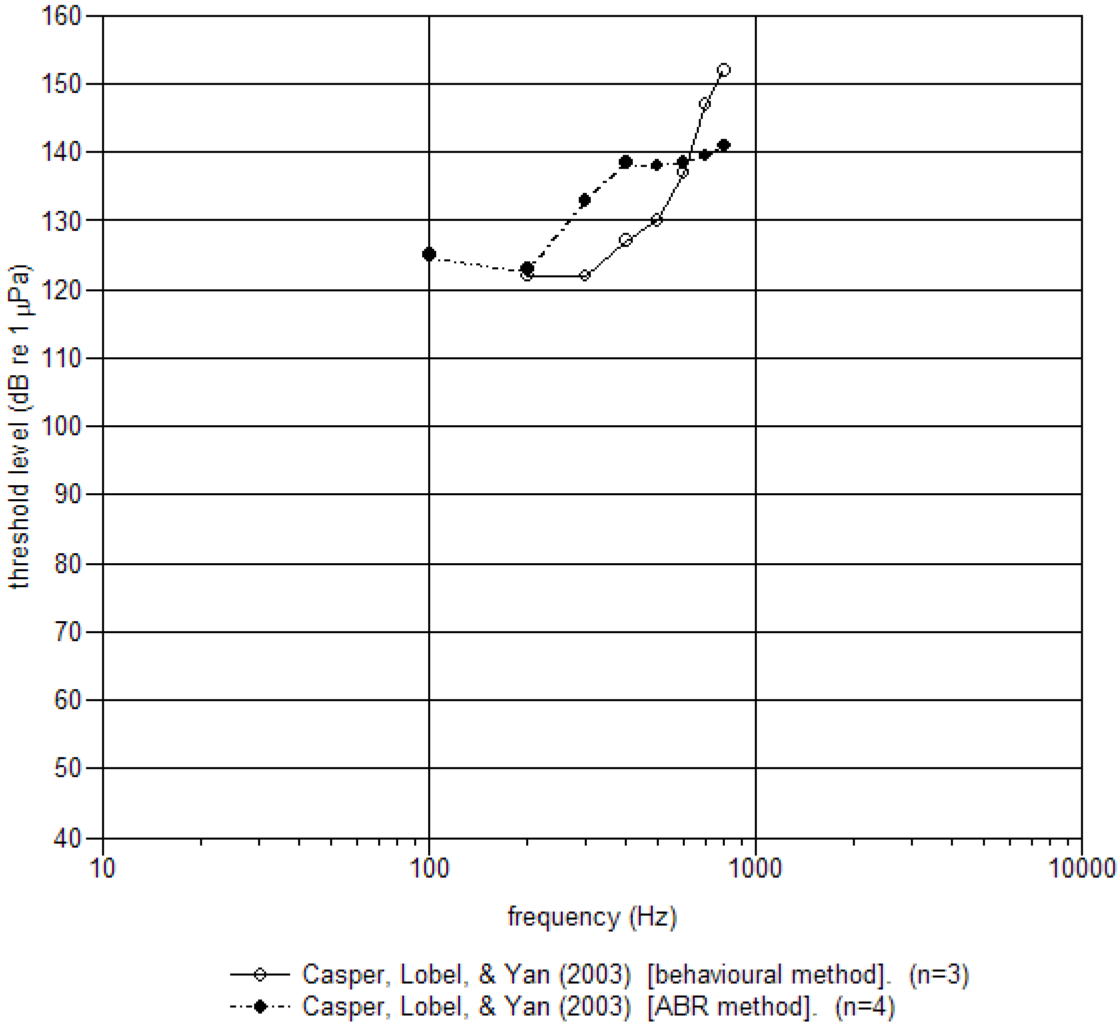
Common name	Little skate
Family	Elasmobranch
Species	*Raja erinacea*
Paper from which audiogram obtained	Casper, B.M., Lobel, P.S. & Yan, H.Y. (2003). The hearing sensitivity of the little skate, *Raja erinacea*: a comparison of two methods. Environmental Biology of Fishes. 68, 371-379.
Paper having original audiogram data	Casper, B.M., Lobel, P.S. & Yan, H.Y. (2003). The hearing sensitivity of the little skate, *Raja erinacea*: a comparison of two methods. Environmental Biology of Fishes. 68: 371-379.
Comments on methodology of getting audiogram	Audiograms obtained using behavioural and ABR methods. 1. <u>Behavioural method.</u> Tested 3 animals, in tank 1.5x1.08x0.65m. Subjects were trained using a 60s pulsed recording of brown noise, played through an underwater speaker 1m from skate's head. They were trained to associate noise with food provision. Method carried out 3-4 times per day at 3-4 hr spacing for 6 weeks. Training was considered a success if the skate showed response 10 times without the introduction of food. A positive response was acknowledged if: skate began swimming on introduction of sound stimulus, increase in respiration rate was observed. Video recording used to test reliability of observations. Following training, hearing sensitivity tests were conducted using the descending method of limits. 500ms pulsed tones were emitted from a Lubell Corp. LL-98A projector 200mm above bottom of tank, 1m from skate. An Interocean Systems Model 902 hydrophone was used to record sound pressure 150mm above skate's head. If the skate responded (either of the two behavioural responses) 5 times consecutively, it was deemed to be responding to the sound stimulus at that intensity. The pulse tone was attenuated in 5dB steps. When the subject failed to respond 5 times consecutively the sound level was raised 5dB. If it failed to respond to this level twice, the last level at which it had responded 5 times consecutively was taken as the threshold level. For this experiment 100% correct determined the value of the threshold; other experimenters have used values of 50-100% correct. For 1hr each day following testing, skate behaviour was reinforced to avoid habituation. Ambient noise was measured; it was around 114 to 116dB re 1μPa, with loudest region being between 1 and 2kHz. 2. <u>ABR method.</u> 4 subjects were tested by this method. They were immobilised with an injection of d-tubocurarine chloride and suspended in a 380x 245x145mm plastic tub, being suspended such that the entire body of the skate was immersed, with the exception of a small portion of the head region (near the medulla region), posterior to the eyes. The electrodes were placed here. The plastic tub was located on a vibration-isolating table in a sound attenuating chamber (2×3×2m). 20ms long tone bursts were played through a Pioneer 300mm speaker 1m above the subject's head. 3000 exposures were averaged at each level. The level was reduced in 5dB steps until the threshold was reached. The threshold SPL was measured with a Celesco LC-10 hydrophone placed where the subject's head was during its exposure to sound.
Any other comments	

Audiogram, for **behavioural method**, from Fig. 1. Threshold levels in dB re 1µPa. 3 specimens.

Frequency (Hz)	200	300	400	500	600	700	800
Mean	122	122	127	130	137	147	152

Audiogram, for **ABR method**, from Fig. 1. Threshold levels in dB re 1µPa. 4 specimens.

Frequency (Hz)	100	200	300	400	500	600	700	800
Mean	125	123	133	138.5	138	138.5	139.5	141



[Fig. ref: Skate0101_G_01]

Audiogram for skate.

Database page ref: F/SeaRobin/01.

Common name	Slender sea robin.
Family	Triglidae.
Species	*Prionotus scitulus.*
Paper from which audiogram obtained	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Paper having original audiogram data	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Comments on methodology of getting audiogram	Glass tank was lined on floor and walls with 2inch layers of rubberised horsehair. Internal dimensions of tank with lining in place were 16”x7” in plan. A curved barrier, also made from horsehair and 4” high, was placed centrally in the tank, spanning its width. Water depth above top of barrier, and therefore in tank, was adjusted to cause the fish to have to exert some effort to swim over the barrier; depth ranged from 10 to 20mm. Tank was mounted on 2” thick pieces of foam rubber at its corners. Sound source was a University Model SA-HF public address unit fitted with a rubber bulb over its horn end; the entire unit was waterproofed with tar, tape and rubber. It was placed under the central barrier. A hydrophone (Chesapeake Instrument Co. Model SB-154C) was placed near the wall farthest from the sound source, but it wasn’t always used when a fish was in the tank. Electrodes for causing shock were rings of silver solder, with a pair being mounted on the tank sidewalls at each end of the tank. Avoidance conditioning test method was used. Shock was a 0.1s duration pulse repeated at about 40 pulses per minute. If fish heard sound it had to swim to other side of barrier within 10sec to avoid getting a shock. After an inter-trial interval another trial took place, with the fish having to cross the barrier in the opposite direction. Threshold determined by staircase method, starting at high level and reducing level in 2dB steps until a reversal occurred, when level was increased in 2dB steps.
Any other comments	3 specimens used. All 3 died before a complete set of data could be obtained. Driver unit gave distortion-free output between 200Hz and 5kHz up to 50dB re 1μbar. At lower frequencies harmonic distortion and clipping occurred above 30 to 35dB re 1 μbar.

Audiogram from Fig. 22 (authors' mean line) Threshold levels in dB re.1 µbar. 3 specimens.

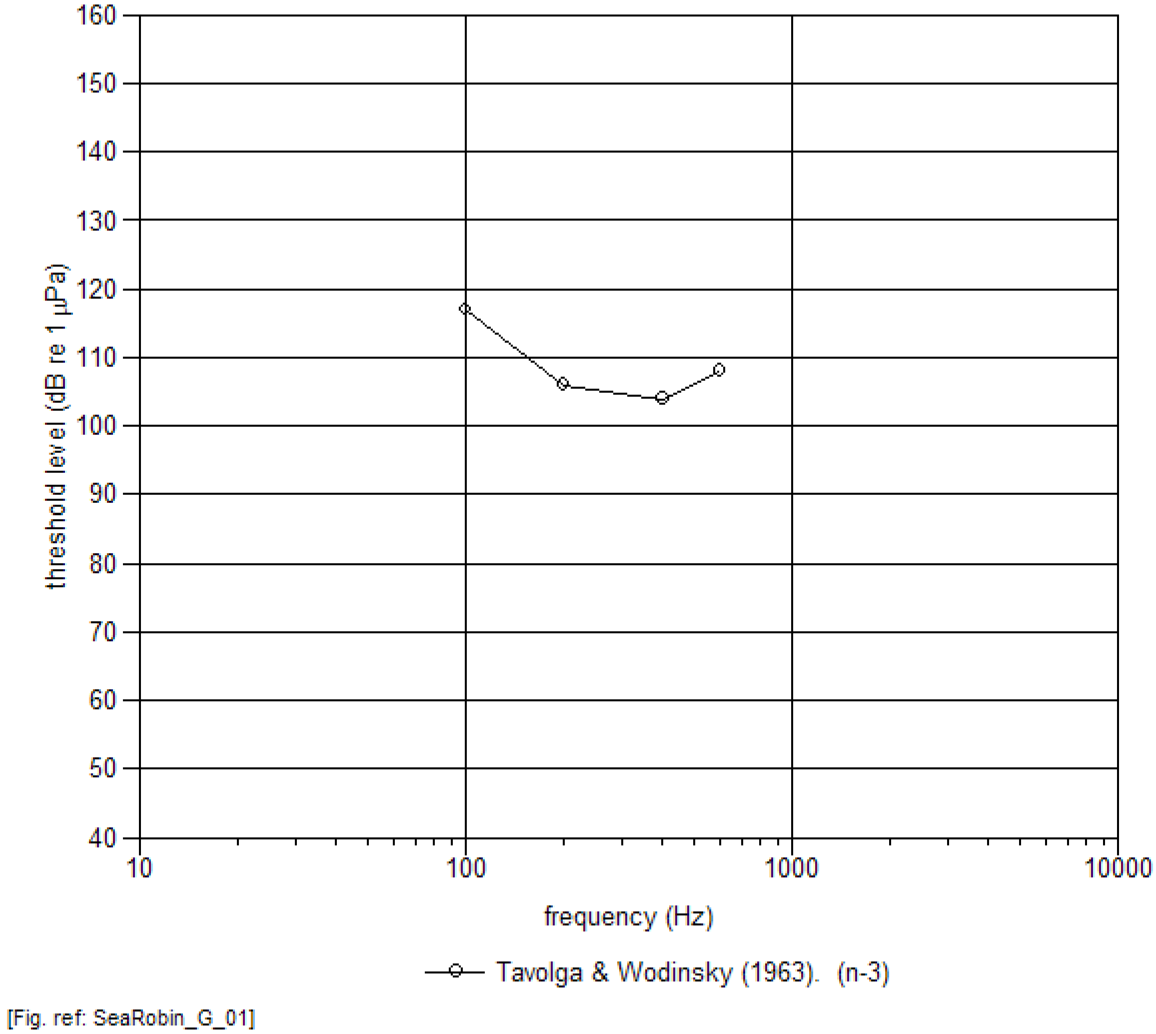
Frequency (Hz)	100	200	400	600
Mean	17	6	4	8

Threshold levels in dB re 1µPa.

Frequency (Hz)	100	200	400	600
Mean	117	106	104	108

Ambient noise levels in tank.

Bandwidth (Hz)	37.5 - 75	75 - 150	150 - 300	300 - 600	600 - 1200	1200 - 2400	2400 - 4800	4800 - 9600
Level (dB re 1µbar)	-43	< -50	< -5	-43	-39	-34	-29	-20
Level (dB re 1µPa)	57	< 50	< 50	57	61	66	71	80



Audiogram for sea robin.

Database page ref: F/SquirrelDusky/01.

Common name	Dusky squirrelfish.
Family	Holocentridae.
Species	*Holocentrus vexillarius.*
Paper from which audiogram obtained	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Paper having original audiogram data	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Comments on methodology of getting audiogram	Glass tank was lined on floor and walls with 2inch layers of rubberised horsehair. Internal dimensions of tank with lining in place were 16"x7" in plan. A curved barrier, also made from horsehair and 4" high, was placed centrally in the tank, spanning its width. Water depth above top of barrier, and therefore in tank, was adjusted to cause the fish to have to exert some effort to swim over the barrier; depth ranged from 6 to 13mm. Tank was mounted on 2" thick pieces of foam rubber at its corners. Sound source was a University Model SA-HF public address unit fitted with a rubber bulb over its horn end; the entire unit was waterproofed with tar, tape and rubber. It was placed under the central barrier. A hydrophone (Chesapeake Instrument Co. Model SB-154C) was placed near the wall farthest from the sound source, but it wasn't always used when a fish was in the tank. Electrodes for causing shock were rings of silver solder, with a pair being mounted on the tank sidewalls at each end of the tank. Avoidance conditioning test method was used. Shock was a 0.1s duration pulse repeated at about 40 pulses per minute. If fish heard sound it had to swim to other side of barrier within 10sec to avoid getting a shock. After an inter-trial interval another trial took place, with the fish having to cross the barrier in the opposite direction. Threshold determined by staircase method, starting at high level and reducing level in 2dB steps until a reversal occurred, when level was increased in 2dB steps.
Any other comments	3 specimens used. Driver unit gave distortion-free output between 200Hz and 5kHz up to 50dB re 1μbar. At lower frequencies harmonic distortion and clipping occurred above 30 to 35dB re 1 μbar.

Audiogram from Fig. 7 (authors' mean lines). Threshold levels in dB re.1 μbar. 3 specimens.

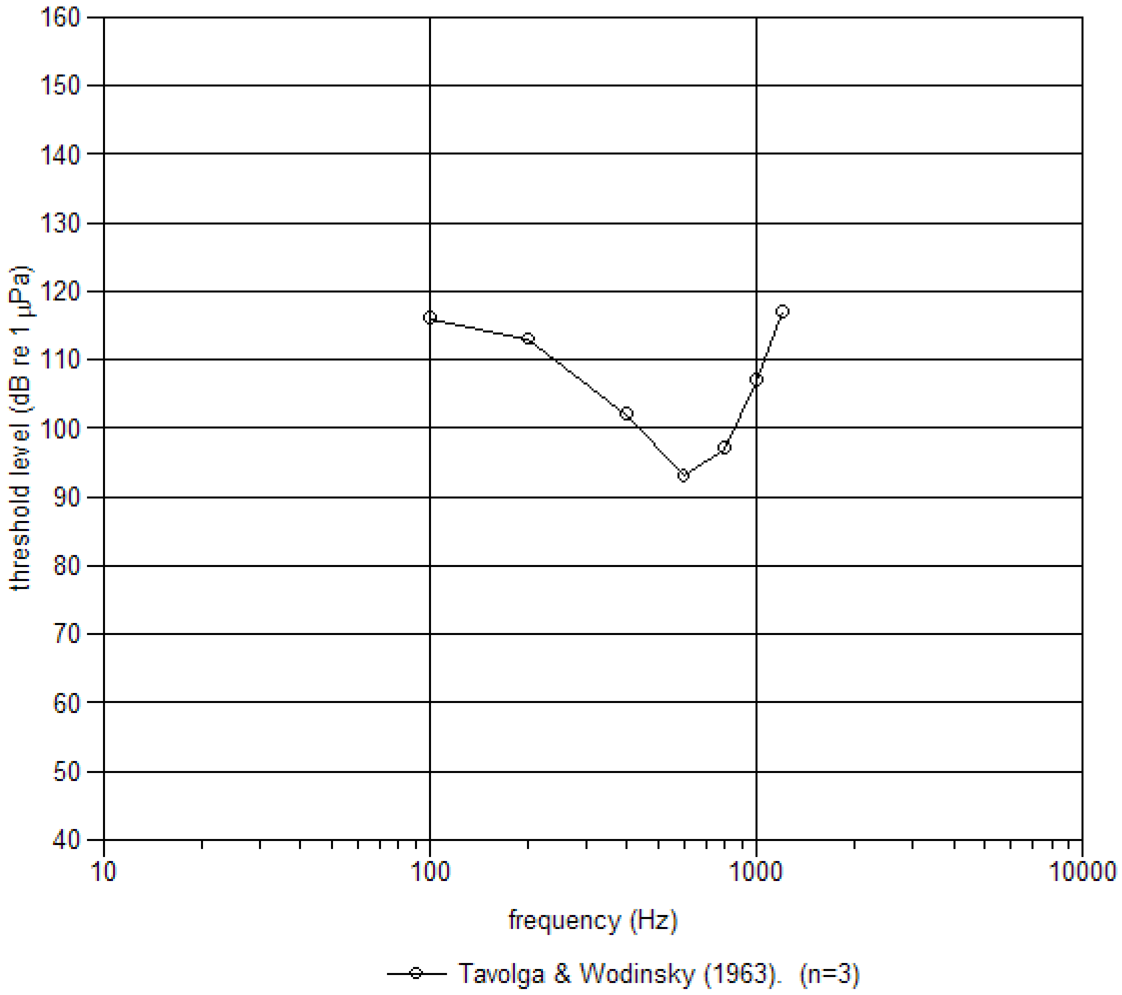
Frequency (Hz)	100	200	400	600	800	1000	1200
Mean	16	13	2	-9	-3	7	17

Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	400	600	800	1000	1200
Mean	116	113	102	93	97	107	117

Ambient noise levels in tank.

Bandwidth (Hz)	37.5 - 75	75 - 150	150 - 300	300 - 600	600 - 1200	1200 - 2400	2400 - 4800	4800 - 9600
Level (dB re 1μbar)	-43	< -50	< -5	-43	-39	-34	-29	-20
Level (dB re 1μPa)	57	< 50	< 50	57	61	66	71	80



[Fig. ref: SquirrelDusky01_G_01]

Audiogram for dusky squirrelfish.

Database page ref: F/Squirrel/01.

Common name	Squirrelfish.
Family	Holocentridae
Species	*Adioryx xantherythrus.*
Paper from which audiogram obtained	Coombs, S. & Popper, A.N. (1979). Hearing differences among Hawaiian squirrelfish (Family Holocentridae) related to differences in the peripheral auditory system. J. Comp Physiol. A, 132:203-207.
Paper having original audiogram data	Coombs, S. & Popper, A.N. (1979). Hearing differences among Hawaiian squirrelfish (Family Holocentridae) related to differences in the peripheral auditory system. J. Comp Physiol. A, 132:203-207.
Comments on methodology of getting audiogram	Tests were carried out in a 410 x 240 x 170mm Plexiglas tank situated in a sound deadened chamber. The test tones were radiated by 16 76mm dia. speakers, separated from each other by a 60mm radius, mounted on a frame which was isolated from the back wall of the chamber by foam padding. A PDP11/10 computer controlled the tests. Each sound trial consisted of a series of 600ms tone bursts, with 5ms rise and fall times, with 400ms silence between bursts. Behavioural experiments, using shock avoidance techniques, were used to measure auditory sensitivity. Fish were trained to report the presence of tone bursts by swimming across a barrier that bisected the test tank. Animals were trained using 500Hz tone bursts. During the experiment, the control system was programmed to either increase or decrease the sound level by 5dB steps depending on the animal's response to sound trials.
Any other comments	The median output of hydrophone measurements at 10 locations in the test tank were used as the level for each threshold determination. The standard deviation from the mean output, which was never more than 1 to 2dB different from the median output, ranged from 0.7dB at 100Hz to 7.5dB at 1.5kHz, and averaged approximately 4.7dB over the 14 test frequencies. Ambient noise was measured with a wave analyser with a 3Hz bandwidth, and found to be at least –90dB re 1μbar at each test frequency. This was at least 40dB below any thresholds obtained, so it was unlikely that any thresholds were masked. The authors remark that the relatively high thresholds and limited frequency range found for *Adioryx* are similar to data from fish without any obvious associations between the swimbladder and the inner ear.

Audiogram from Table 1. Threshold levels in dB re 1μbar. 3 subjects.

Frequency (Hz)	100	200	300	400	500	600	700	800
Mean	-3.5	-18.4	-23.8	-27.7	-28.5	-19.3	-4.8	-0.3
SD	3.5	8.2	6.2	6.0	8.4	3.0	5.2	4.8
No. of determinations	11	11	11	11	13	12	12	11

Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	300	400	500	600	700	800
Mean	96.5	81.6	76.2	72.3	71.5	80.7	95.2	99.7

Database page ref: F/Squirrel/02.

Common name	Squirrelfish.
Family	Holocentridae
Species	*Myripristis kuntee.*
Paper from which audiogram obtained	Coombs, S. & Popper, A.N. (1979). Hearing differences among Hawaiian squirrelfish (Family Holocentridae) related to differences in the peripheral auditory system. J. Comp Physiol. 132,203-207.
Paper having original audiogram data	Coombs, S. & Popper, A.N. (1979). Hearing differences among Hawaiian squirrelfish (Family Holocentridae) related to differences in the peripheral auditory system. J. Comp Physiol. 132,203-207.
Comments on methodology of getting audiogram	Tests were carried out in a 410 x 240 x 170mm Plexiglas tank situated in a sound deadened chamber. The test tones were radiated by 16 76mm dia. speakers, separated from each other by a 60mm radius, mounted on a frame which was isolated from the back wall of the chamber by foam padding. A PDP11/10 computer controlled the tests. Each sound trial consisted of a series of 600ms tone bursts, with 5ms rise and fall times, with 400ms silence between bursts. Behavioural experiments, using shock avoidance techniques, were used to measure auditory sensitivity. Fish were trained to report the presence of tone bursts by swimming across a barrier that bisected the test tank. Animals were trained using 500Hz tone bursts. During the experiment, the control system was programmed to either increase or decrease the sound level by 5dB steps depending on the animal's response to sound trials.
Any other comments	The median output of hydrophone measurements at 10 locations in the test tank were used as the level for each threshold determination. The standard deviation from the mean output, which was never more than 1 to 2dB different from the median output, ranged from 0.7dB at 100Hz to 7.5dB at 1.5kHz, and averaged approximately 4.7dB over the 14 test frequencies. Ambient noise was measured with a wave analyser with a 3Hz bandwidth, and found to be at least –90dB re 1µbar at each test frequency. This was at least 40dB below any thresholds obtained, so it was unlikely that any thresholds were masked. The authors remark that the low thresholds and wide frequency range found for *Myripristis* represent some of the most sensitive hearing currently known for fish, and compare quite favourably with data for the goldfish.

Audiogram from Table 1. Threshold levels in dB re 1µbar. 2 subjects.

Frequency (Hz)	100	200	300	400	500	600	1000	1500	2000	2500	3000
Mean	-12.1	-31.9	-45.0	-49.1	-44.2	-46.3	-49.8	-49.6	-45.7	-34.3	5.5
SD	10.6	5.6	6.0	4.1	4.7	4.4	4.4	5.1	7.9	4.3	8.0
No. of determinations	11	8	9	8	13	15	12	8	12	10	8

Threshold levels in dB re 1µPa.

Frequency (Hz)	100	200	300	400	500	600	1000	1500	2000	2500	3000
Mean	87.9	68.1	55.0	50.9	55.8	53.7	50.2	50.4	54.3	65.7	105.5

Database page ref: F/Squirrel/03.

Common name	Squirrelfish.
Family	Holocentridae.
Species	*Holocentrus ascensionis.*
Paper from which audiogram obtained	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Paper having original audiogram data	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Comments on methodology of getting audiogram	Glass tank was lined on floor and walls with 2inch layers of rubberised horsehair. Internal dimensions of tank with lining in place were 26"x10" in plan. A curved barrier, also made from horsehair and 9" high, was placed centrally in the tank, spanning its width. Water depth above top of barrier, and therefore in tank, was adjusted to cause the fish to have to exert some effort to swim over the barrier; optimum depth was found to be 35 to 40mm. Tank was mounted on 2" thick pieces of foam rubber at its corners. Sound source was a University Model MM-2 underwater speaker with a plastic expansion bulb as the driving surface. It was placed under the central barrier. A hydrophone (Chesapeake Instrument Co. Model SB-154C) was placed near the wall farthest from the sound source, but it wasn't always used when a fish was in the tank. Electrodes for causing shock were rings of silver solder, with a pair being mounted on the tank sidewalls at each end of the tank. Avoidance conditioning test method was used. Shock was a 0.1s duration pulse repeated at about 40 pulses per minute. If fish heard sound it had to swim to other side of barrier within 10sec to avoid getting a shock. After an inter-trial interval another trial took place, with the fish having to cross the barrier in the opposite direction. Threshold determined by staircase method.
Any other comments	5 specimens used. Water level at the barrier was critical; at 25mm crossings were greatly inhibited. Driver unit had slightly better frequency response and distortion level than the unit used in a smaller tank, but actual figures are not given (smaller unit was distortion-free between 200Hz and 5kHz at pressure levels up to 50dB re 1μbar).

Audiogram from Fig. 6 (authors' mean line) Threshold levels in dB re.1 μbar. 5 specimens.

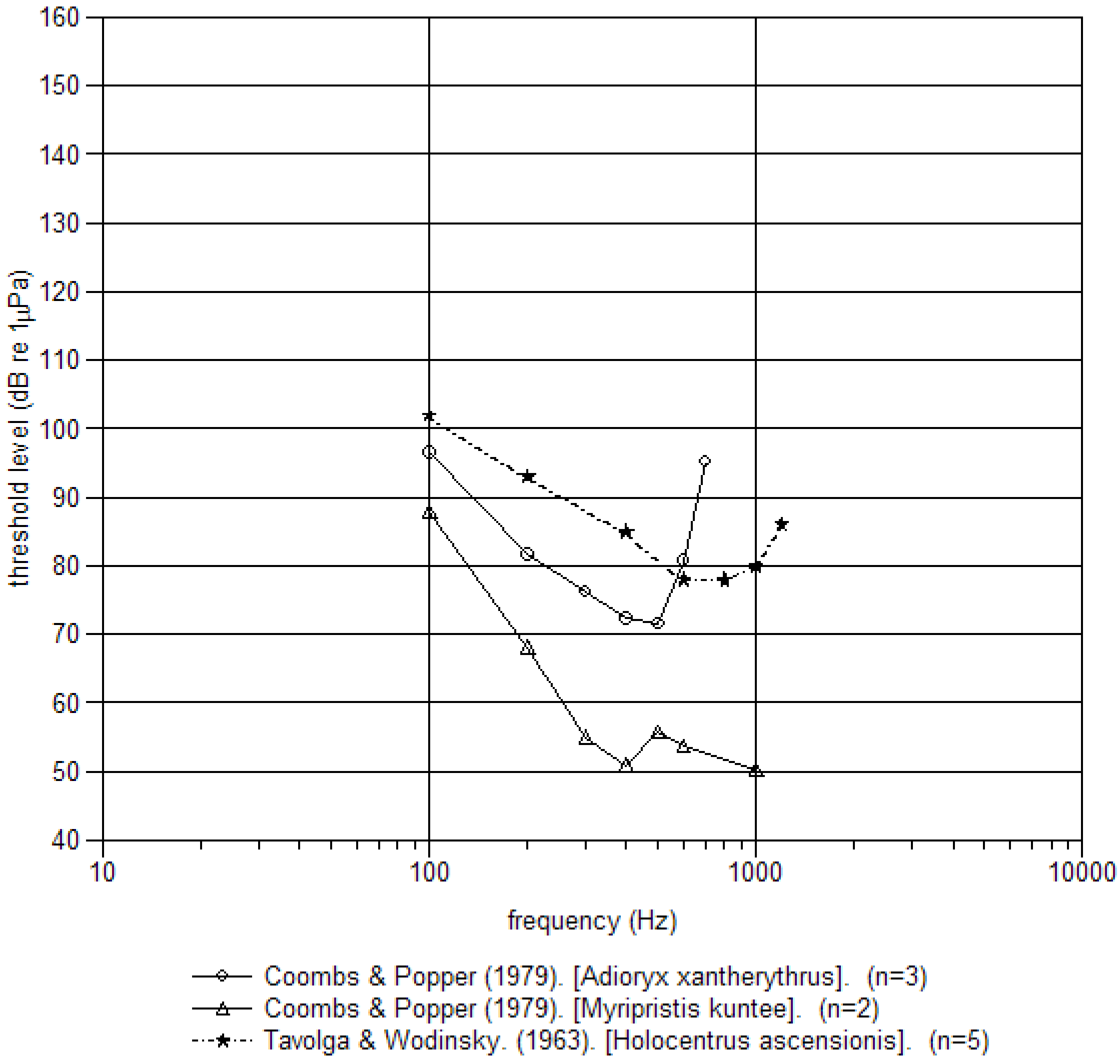
Frequency (Hz)	100	200	400	600	800	1000	1200	1400	1600	2000	2400	2800
Mean	2	-7	-15	-22	-22	-20	-14	-6	3	22	40	53

Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	400	600	800	1000	1200	1400	1600	2000	2400	2800
Mean	102	93	85	78	78	80	86	94	103	122	140	153

Ambient noise levels in tank.

Bandwidth (Hz)	37.5 - 75	75 - 150	150 - 300	300 - 600	600 - 1200	1200 - 2400	2400 - 4800	4800 - 9600
Level (dB re 1μbar)	< -50	< -50	-50	-46	-43	-39	-35	-20
Level (dB re 1μPa)	< 50	< 50	50	54	57	61	65	80



[Fig. ref: SquirrelFish02]

Audiogram for three species of squirrelfish.

Database page ref: F/Tautog/01.

Common name	Tautog
Family	
Species	*Tautoga onitis*
Paper from which audiogram obtained	Offutt, G.C. (1971). Response of the Tautog (*Tautoga onitis*, Teleost) to acoustic stimuli measured by classically conditioning the heart rate. Conditional Reflex, 6(4), 205-214.
Paper having original audiogram data	Offutt, G.C. (1971). Response of the Tautog (*Tautoga onitis*, Teleost) to acoustic stimuli measured by classically conditioning the heart rate. Conditional Reflex, 6(4), 205-214.
Comments on methodology of getting audiogram	Tests were conducted with water temp. between 16 and 19C. . (See F/Tautog/02 and F/Tautog/03 files for results at other temps.). Fish obtained in Narragansett Bay. Tested in a sealed reverberation chamber – tones produced by 16inch speaker fixed in wall. A plastic test tank was located within the rev. chamber, and fish was held in this tank in a nylon net. Heart rate obtained using electrode implanted within fish by passing laterally through the body just ventral to the pectoral fins, leaving the exposed part of the electrode wire in close proximity to the pericardial cavity. Response thresholds were determined with an up-and-down procedure with 2dB changes in stimulus level. 10 threshold crossings or reversals of conditional stimulus amplitude were used to compute a threshold point. The midpoints of all excursions were averaged to obtain the threshold point.
Any other comments	Data were obtained from 14 fish. Results on this page for Fish G. Results are lowest threshold levels obtained at a given frequency.

Audiogram from Fig. 2a. Threshold levels in dB re 1 μbar.

Frequency (Hz)	10	18.5	37.5	75	150	300	500
Mean	-7.1	-14.4	-25.6	-23.5	-26.2	-9.3	16.9

Threshold levels in dB re 1μPa.

Frequency (Hz)	10	18.5	37.5	75	150	300	500
Mean	92.9	85.6	74.4	76.5	73.8	90.7	116.9

Database page ref: F/Tautog/02.

Common name	Tautog
Family	
Species	*Tautoga onitis*
Paper from which audiogram obtained	Offutt, G.C. (1971). Response of the Tautog (*Tautoga onitis*, Teleost) to acoustic stimuli measured by classically conditioning the heart rate. Conditional Reflex, 6(4), 205-214.
Paper having original audiogram data	Offutt, G.C. (1971). Response of the Tautog (*Tautoga onitis*, Teleost) to acoustic stimuli measured by classically conditioning the heart rate. Conditional Reflex, 6(4), 205-214.
Comments on methodology of getting audiogram	Tests were conducted with water temp. between 20 and 22C. (See F/Tautog/01 and F/Tautog/03 files for results at other temps.). Fish obtained in Narrangansett Bay. Tested in a sealed reverberation chamber – tones produced by 16inch speaker fixed in wall. A plastic test tank was located within the rev. chamber, and fish was held in this tank in a nylon net. Heart rate obtained using electrode implanted within fish by passing laterally through the body just ventral to the pectoral fins, leaving the exposed part of the electrode wire in close proximity to the pericardial cavity. Response thresholds were determined with an up-and-down procedure with 2dB changes in stimulus level. 10 threshold crossings or reversals of conditional stimulus amplitude were used to compute a threshold point. The midpoints of all excursions were averaged to obtain the threshold point.
Any other comments	Data were obtained from 14 fish. Results on this page for Fish L. Results are lowest threshold levels obtained at a given frequency.

Audiogram from Fig. 2b. Threshold levels in dB re 1 μbar.

Frequency (Hz)	18.7	37.5	75	150	300	500
Mean	-1.3	2.3	-3.4	-7.7	2.7	29.1

Threshold levels in dB re 1μPa.

Frequency (Hz)	18.7	37.5	75	150	300	500
Mean	98.7	102.3	96.6	92.3	102.7	129.1

Database page ref: F/Tautog/03.

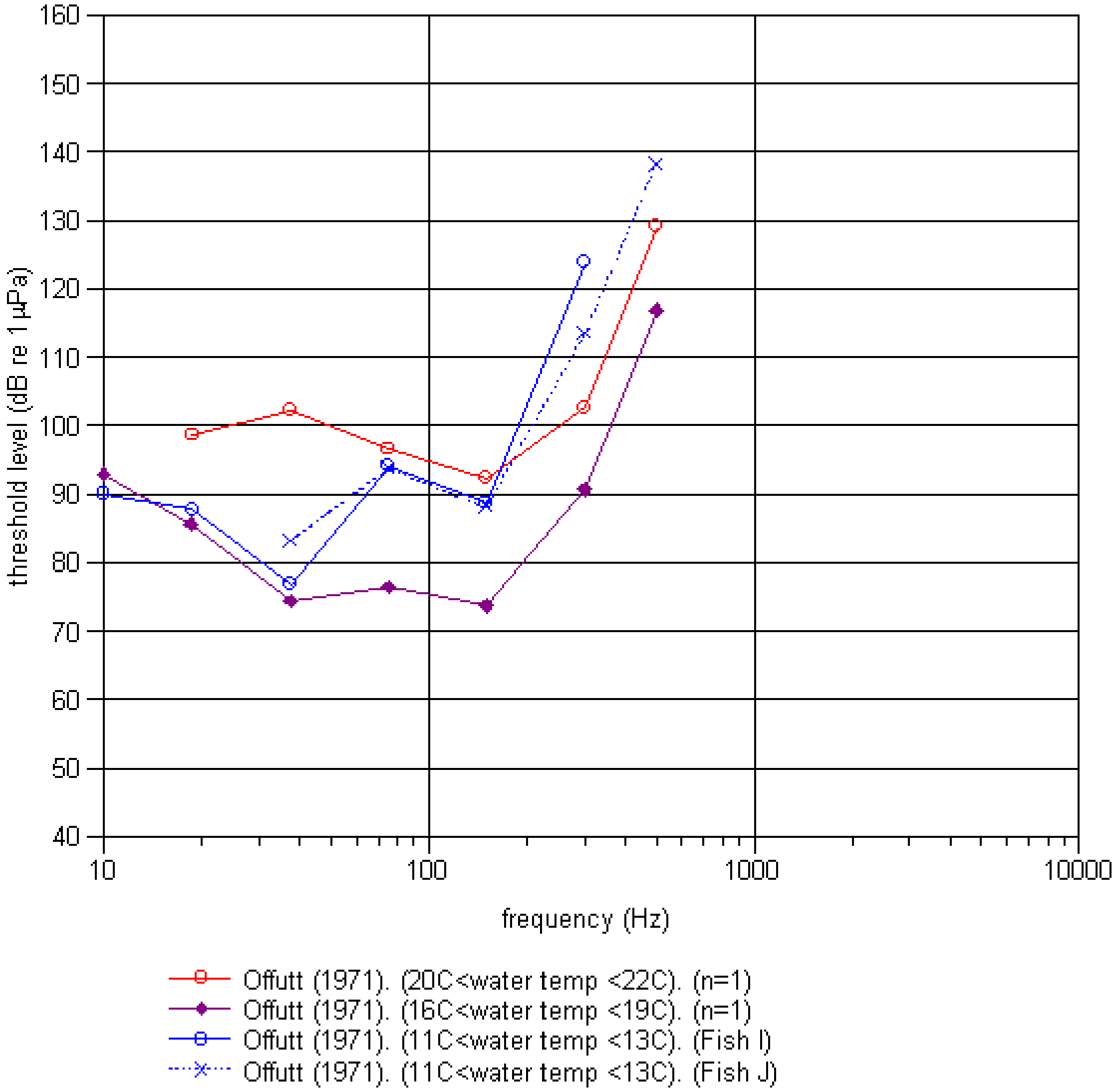
Common name	Tautog
Family	
Species	*Tautoga onitis*
Paper from which audiogram obtained	Offutt, G.C. (1971). Response of the Tautog (*Tautoga onitis*, Teleost) to acoustic stimuli measured by classically conditioning the heart rate. Conditional Reflex, 6(4), 205-214.
Paper having original audiogram data	Offutt, G.C. (1971). Response of the Tautog (*Tautoga onitis*, Teleost) to acoustic stimuli measured by classically conditioning the heart rate. Conditional Reflex, 6(4), 205-214.
Comments on methodology of getting audiogram	Tests were conducted with water temp. between 11 and 13C. . (See F/Tautog/01 and F/Tautog/02 files for results at other temps.). Fish obtained in Narrangansett Bay. Tested in a sealed reverberation chamber – tones produced by 16inch speaker fixed in wall. A plastic test tank was located within the rev. chamber, and fish was held in this tank in a nylon net. Heart rate obtained using electrode implanted within fish by passing laterally through the body just ventral to the pectoral fins, leaving the exposed part of the electrode wire in close proximity to the pericardial cavity. Response thresholds were determined with an up-and-down procedure with 2dB changes in stimulus level. 10 threshold crossings or reversals of conditional stimulus amplitude were used to compute a threshold point. The midpoints of all excursions were averaged to obtain the threshold point.
Any other comments	Data were obtained from 14 fish. Results on this page for Fishes I and J. Results are lowest threshold levels obtained at a given frequency.

Audiogram from Fig. 2c in paper. Threshold levels in dB re 1 μbar.

Frequency (Hz)		10	18.7	37.5	75	150	300	500
Mean	Fish I	-10.0	-12.2	-23.1	-5.9	-11.3	23.9	
	Fish J			-16.8	-6.1	-11.6	13.6	38.3

Threshold levels in dB re 1μPa.

Frequency (Hz)		10	18.7	37.5	75	150	300	500
Mean	Fish I	90.0	87.8	76.9	94.1	88.7	123.9	
	Fish J			83.2	93.9	88.4	113.6	138.3



[Fig. ref: Tautog01]

Audiograms for tautog.

Database page ref: F/WrasseBlueHd/01.

Common name	Blue-head wrasse.
Family	Labridae.
Species	*Thalassoma bifasciatum.*
Paper from which audiogram obtained	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Paper having original audiogram data	Tavolga, W.N. & Wodinsky, J. (1963). Auditory capacities in fishes. Bull. Am. Mus. Nat. Hist., 126, 177-240.
Comments on methodology of getting audiogram	Glass tank was lined on floor and walls with 2inch layers of rubberised horsehair. Internal dimensions of tank with lining in place were 16"x7" in plan. A curved barrier, also made from horsehair and 4" high, was placed centrally in the tank, spanning its width. Water depth above top of barrier, and therefore in tank, was adjusted to cause the fish to have to exert some effort to swim over the barrier; depth was 6mm or less Tank was mounted on 2" thick pieces of foam rubber at its corners. Sound source was a University Model SA-HF public address unit fitted with a rubber bulb over its horn end; the entire unit was waterproofed with tar, tape and rubber. It was placed under the central barrier. A hydrophone (Chesapeake Instrument Co. Model SB-154C) was placed near the wall farthest from the sound source, but it wasn't always used when a fish was in the tank. Electrodes for causing shock were rings of silver solder, with a pair being mounted on the tank sidewalls at each end of the tank. Avoidance conditioning test method was used. Shock was a 0.1s duration pulse repeated at about 40 pulses per minute. If fish heard sound it had to swim to other side of barrier within 10sec to avoid getting a shock. After an inter-trial interval another trial took place, with the fish having to cross the barrier in the opposite direction. Threshold determined by staircase method, starting at high level and reducing level in 2dB steps until a reversal occurred, when level was increased in 2dB steps.
Any other comments	4 specimens used. Driver unit gave distortion-free output between 200Hz and 5kHz up to 50dB re 1µbar. At lower frequencies harmonic distortion and clipping occurred above 30 to 35dB re 1 µbar. A secondary low-frequency threshold was found for repeat trials at lower frequencies after the higher frequencies had been tested.

Audiogram from Fig. 18 (authors' mean lines). Threshold levels in dB re 1 µbar. 4 specimens.

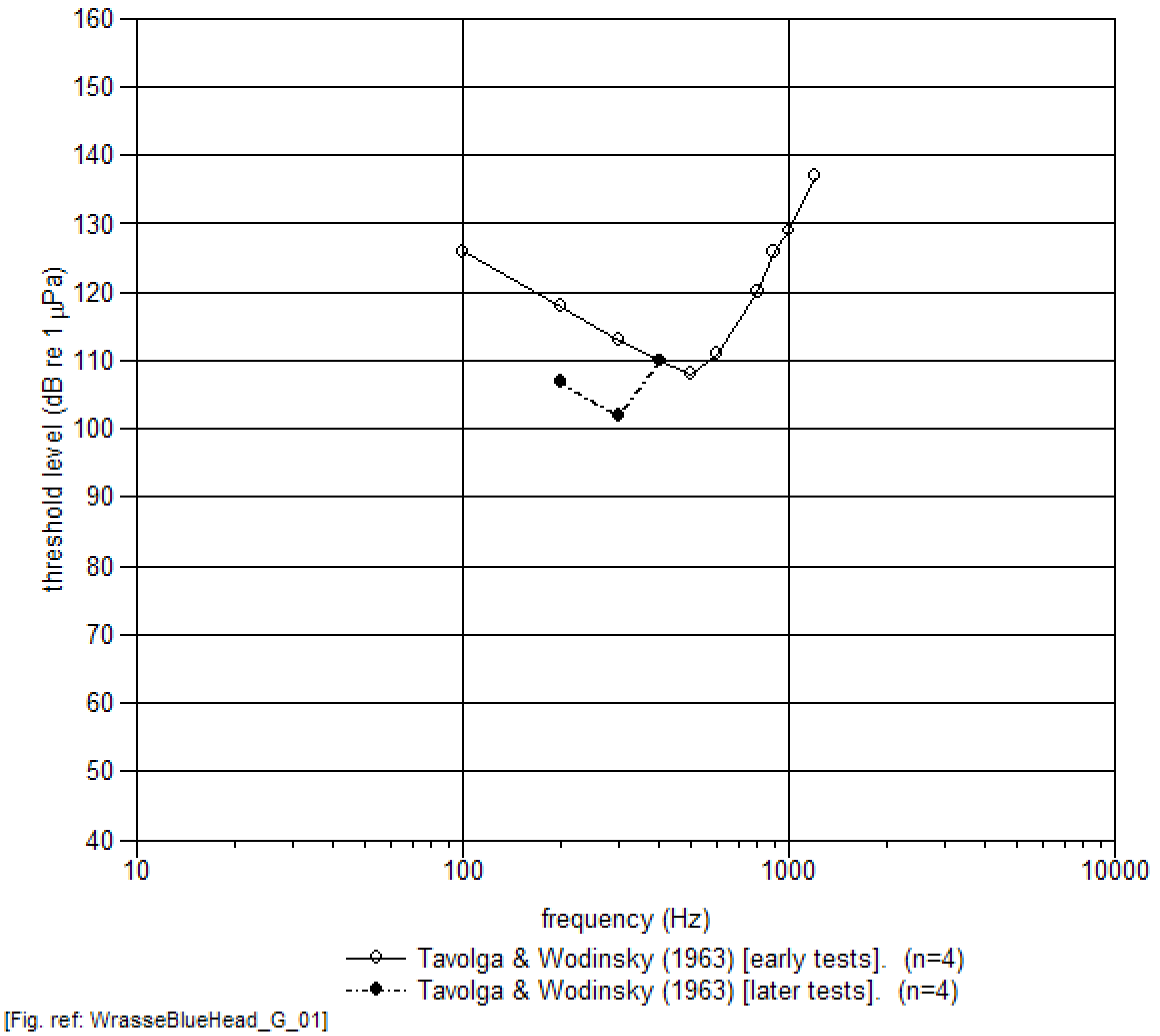
Frequency (Hz)	100	200	300	400	500	600	800	900	1000	1200
Mean (early tests)	26	18	13	10	8	11	20	26	29	37
Mean (later tests)		7	2	10						

Threshold levels in dB re 1µPa.

Frequency (Hz)	100	200	300	400	500	600	800	900	1000	1200
Mean (early tests)	126	118	113	110	108	111	120	126	129	137
Mean (later tests)		107	102	110						

Ambient noise levels in tank.

Bandwidth (Hz)	37.5 - 75	75 - 150	150 - 300	300 - 600	600 - 1200	1200 - 2400	2400 - 4800	4800 - 9600
Level (dB re 1µbar)	-43	< -50	< -5	-43	-39	-34	-29	-20
Level (dB re 1µPa)	57	< 50	< 50	57	61	66	71	80



Audiogram for blue-head wrasse.

Database page ref: F/TunaYellowfin/01.

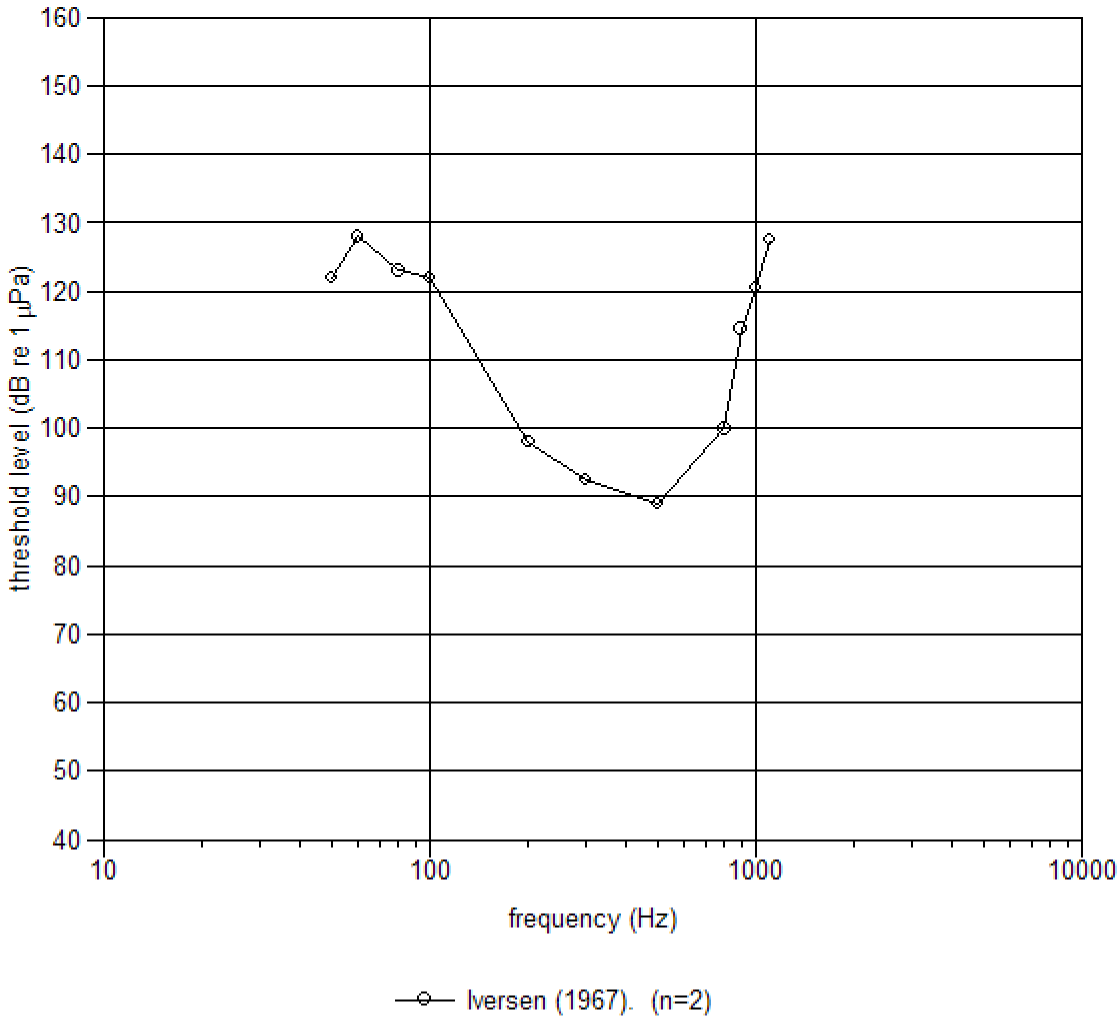
Common name	Yellowfin tuna
Family	
Species	*Thunnus albacares*
Paper from which audiogram obtained	Fay, R.R. (1988). Hearing in Vertebrates: A Psychophysics Databook. Hill-Fay Associates, Winnetka, Ill.
Paper having original audiogram data	Iversen, R. (1967). Response of the yellowfin tuna (*Thunnus albacares*) to underwater sound. In: W.N. Tavolga (ed), Marine Bio-acoustics, Vol. 2, 105-121. Pergamon Press, Oxford.
Comments on methodology of getting audiogram	Original soure not seen.
Any other comments	

Audiogram from Table F9-0. Threshold levels in dB re 1 dyne/cm^2. 2 specimens.

Frequency (Hz)	50	60	80	100	200	300	500	800	900	1000	1100
Median	22	28	23	22	-2	-7.5	-11	0	14.5	20.5	27.5

Threshold levels in dB re 1μPa.

Frequency (Hz)	50	60	80	100	200	300	500	800	900	1000	1100
Median	122	128	123	122	98	92.5	89	100	114.5	120.5	127.5



[Fig. ref: TunaYllwfn02]

Audiogram for yellowfin tuna.

Appendix 3. Marine mammal audiograms.

Common name	Database page ref.	Page number
California sea lion	M/SeaLionCalifornia/01	215
California sea lion	M/SeaLionCalifornia/02	216
California sea lion	M/SeaLionCalifornia/03	218
California sea lion	M/SeaLionCalifornia/04	219
California sea lion	M/SeaLionCalifornia/05	221
California sea lion	M/SeaLionCalifornia/06	222
Dolphin, Amazon River	M/DolphinAmazon/01	182
Dolphin, Amazon River	M/DolphinAmazon/02	183
Dolphin, beluga	M/DolphinBeluga/01	185
Dolphin, bottlenose	M/DolphinBottlenose/01	187
Dolphin, bottlenose	M/DolphinBottlenose/02	189
Dolphin, bottlenose	M/DolphinBottlenose/03	190
Dolphin, bottlenose	M/DolphinBottlenose/04	192
Dolphin, bottlenose	M/DolphinBottlenose/05	194
Dolphin, Chinese river	M/DolphinChineseRiver/01	196
Dolphin, Risso's	M/DolphinRisso/01	198
Dolphin, striped	M/DolphinStriped/01	200
Dolphin, tucuxi	M/DolphinTucuxi/01	202
Dolphin, tucuxi	M/DolphinTucuxi/02	204
Grey seal	M/SealGrey/01	225
Harbour porpoise	M/PorpoiseHarbour/01	209
Harbour porpoise	M/PorpoiseHarbour/02	211
Harbour porpoise	M/PorpoiseHarbour/03	212
Harbour porpoise	M/PorpoiseHarbour/04	213
Manatee	M/Manatee/02	207
Manatee, West Indian	M/Manatee/01	206
Seal, harbour	M/SealHarbour/01	228
Seal, harbour	M/SealHarbour/02	231
Seal, harbour	M/SealHarbour/03	232
Seal, harbour	M/SealHarbour/04	233
Seal, harbour	M/SealHarbour/05	234
Seal, harbour	M/SealHarbour/06	236
Seal, harp	M/SealHarp/01	239
Seal, Hawaiin monk	M/SealHawaiinMonk/01	241
Seal, northern elephant	M/SealNthnElephant/01	243
Seal, northern elephant	M/SealNthnElephant/02	244
Seal, northern fur	M/SealNthnFur/01	247
Seal, northern fur	M/SealNthnFur/02	248
Seal, ringed	M/SealRinged/01	252
Walrus, Pacific	M/WalrusPacific/01	254
Whale, beluga	M/WhaleBeluga/01	256
Whale, beluga	M/WhaleBeluga/02	257
Whale, beluga	M/WhaleBeluga/03	259
Whale, false killer	M/WhaleFalseKiller/01	261
Whale, killer	M/WhaleKiller/01	263
Whale, killer	M/WhaleKiller/02	265

Database page ref: M/DolphinAmazon/01.

Common name	Amazon River dolphin.
Family	
Species	*Inia geoffrensis.*
Paper from which audiogram obtained	Popov, V. & Supin, A. (1990). Electrophysiological studies of hearing in some cetaceans and a manatee. In 'Sensory Abilities of Cetaceans', 405-415. J. Thomas & R. Kastelein (eds). Plenum Press, N.Y.
Paper having original audiogram data	Popov, V. & Supin, A. (1990). Electrophysiological studies of hearing in some cetaceans and a manatee. In 'Sensory Abilities of Cetaceans', 405-415. J. Thomas & R. Kastelein (eds). Plenum Press, N.Y.
Comments on methodology of getting audiogram	Used ABR technique. Subject was placed on a stretcher in the water such that only the dorsal part of the head with the blowhole and the back were out of the water. Tests done in either a 4x0.6x0.6m bath or in a round pool. Electrodes were 0.4 to 0.6mm dia. needles inserted 3 to 5mm into the skin. The active electrode was placed on the dorsal head surface 60 to 90mm caudal from the blowhole. The reference electrode was placed on the back near the dorsal fin. The electrode signal was fed to an amplifier and to an averager of evoked potentials; the passband of the channel was 5 to 5000Hz. Sound sources were piezoceramic transducers, placed 300mm deep in the water, 1 to 2m away from the subject's head. 3 types of test signal – (1) clicks (5µsec long rectangular pulse), (2) noise (PRBS with a duration of 5µsec), (3) tone bursts (frequencies of 5 to 160kHz). Noise bursts had an abrupt rise and fall; tone bursts had linear rises and falls of 0.25msec. Parallel connection of spherical transducers of 20, 30 and 50mm dia. produced noise and clicks with a spectrum flat to within 10dB from 10 to 100kHz (-10dB). Tests showed dependence of ABR on level of stimulus. Lowest level of stimulus which exhibited ABR response taken as threshold.
Any other comments	4 subjects. Tests carried out at the Soviet-Peruvian Biostation, Pucallpa, Peru on animals caught in the Ucayaly River. Early tests established best location for active electrode was 50 to 100mm caudally from blowhole. Neither anaesthesia nor curarization required. Also did tests in which the rate of presentation of the clicks was increased. Went from 10/sec up to 1000/sec. As rate increased amplitude of ABR decreased and trace changed – peaks tended to merge. Also did tests to see directionality of hearing – most sensitive head on, with sensitivity falling by about 25dB at rear.

Audiogram from Fig. 5. Threshold levels in dB re 1mPa.

Frequency (kHz)	8	10	12.5	16	20	25	30	35
Mean	35	29	29	11	5	2	11	20
Frequency (kHz)	40	50	60	70	80	100	110	130
Mean	40	45	25	-2	5	15	34	63

Threshold levels in dB re 1µPa.

Frequency (kHz)	8	10	12.5	16	20	25	30	35
Mean	95	89	89	71	65	62	71	80
Frequency (kHz)	40	50	60	70	80	100	110	130
Mean	100	105	85	58	65	75	94	103

Database page ref: M/DolphinAmazon/02.

Common name	Amazon River dolphin or boutu
Family	
Species	*Inia geoffrensis Blainville*
Paper from which audiogram obtained	Jacobs, D.W. & Hall, J.D. (1972). Auditory thresholds of a fresh water dolphin, *Inia geoffrensis* Blainville. JASA 51(2, Pt 2), 530-533.
Paper having original audiogram data	Jacobs, D.W. & Hall, J.D. (1972). Auditory thresholds of a fresh water dolphin, *Inia geoffrensis* Blainville. JASA 51(2, Pt 2), 530-533.
Comments on methodology of getting audiogram	Tests carried out in 7m dia.x 1.5m deep tank. Water temp. ranged between 25 and 27C. Projector was located in a wooden enclosure, which was suspended in the water against the tank wall. 1yd in front of enclosure was PVC cradle on which dolphin rested its rostrum at start of test. When dolphin detected signal, it swam to paddle located on opposite side of tank. Catch trials (i.e. no signal) were included in tests. Test signal was pure tone of 5 sec duration, and was played into tank by either a J-9 or an LC-10 projector. Jellied isopropyl alcohol was applied to speaker to eliminate bubble formation on speaker. Sound measurements were taken with a CH-26B hydrophone. Ambient noise levels were measured at various locations in the tank with the dolphin removed. Test procedure was to start at a high signal level, and then reducing in 5 dB steps until subject failed to respond. Then levels were increased by 5 dB until responded again. 6 to 8 response reversals were required to complete a test. Threshold taken as midpoint of interval in which subject did and did not respond. Average of these midpoints was taken to be threshold value.
Any other comments	Data from 1 animal, captured in May 1968 and which had been used for previous echolocation studies. Authors remark that thresholds below 10kHz should be considered approximations owing to possible masking by high tank noise. Attempts were made to elicit responses above 105kHz, but no reliable response patterns were obtained. **NOTE:** Points plotted in Fig. 3 don't agree with frequency values in table.

Audiogram from Table II. Threshold levels in dB re 1dyne/cm^2.

Frequency (kHz)	1	2	3.5	5	7.5	10	20	35	50	75	90	100	105
Mean (from J-9)	-4	-26	-6	-30	-25	-40	-55	-49	-40	-53			
Mean (from J-9)	-13	-22	-9	-22	-20	-24	-46	-46	-38	-52			
Mean (from LC-10)							-43	-35	-39	-43	-49	-41	4
Mean (from LC-10)							-28	-43	-49	-54	-50	-15	8
Mean (from LC-10)							-28	-41		-48		-18	
Average of above	-7.4	-23.8	-7.4	-25.1	-22.1	-28.7	-34.6	-41.4	-40.6	-49.0	-49.5	-19.6	6.2

Audiogram from Fig. 3. Threshold levels in dB re 1dyne/cm^2.

Frequency (kHz)	1	1.1	1.3	1.7	2.5	10	11	15	17	30	50	100	105
Level	-8	-23	-13	-25	-22	-33	-40	-43	-40	-50	-49	-12	6

Audiogram from Table II, using average levels from table above. Threshold levels in dB re 1μPa.

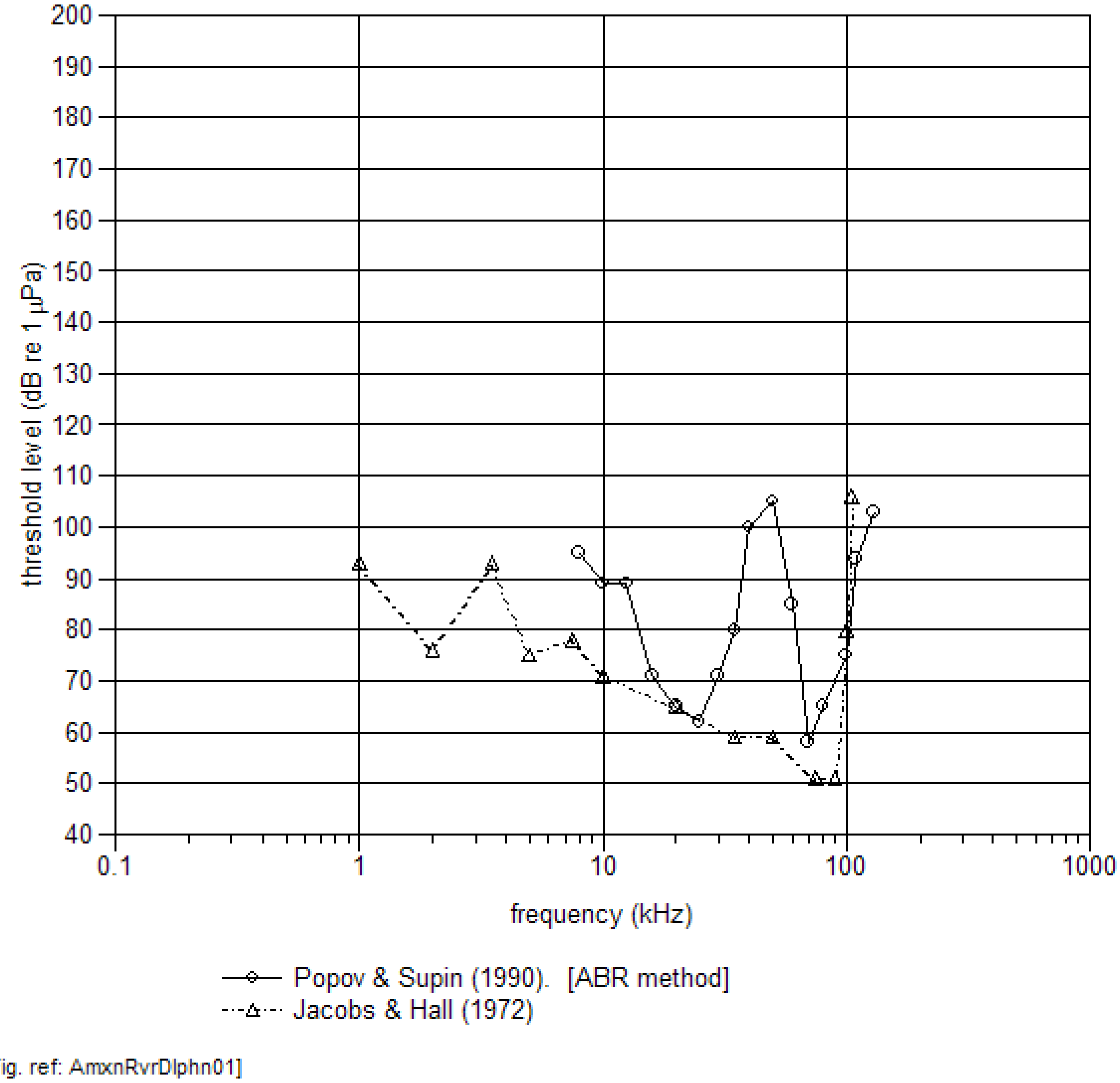
Frequency (kHz)	1	2	3.5	5	7.5	10	20	35	50	75	90	100	105
Level	93	76	93	75	78	71	65	59	59	51	51	80	106

Background noise from Table I. Levels in dB re 1dyne/cm^2/Hz.

Frequency (kHz)	0.5	1.0	2.0	5.0	10.0	15.0	20.0
Bandwidth (Hz)	213	213	213	1000	1000	1000	3000
Level	-30	-39	-41	-45	-52	-62	-66

Background noise. Levels in dB re 1µPa/Hz.

Frequency (kHz)	0.5	1.0	2.0	5.0	10.0	15.0	20.0
Level	70	61	59	55	48	38	34



Audiogram for Amazon River dolphin.

Database page ref: M/DolphinBeluga/01.

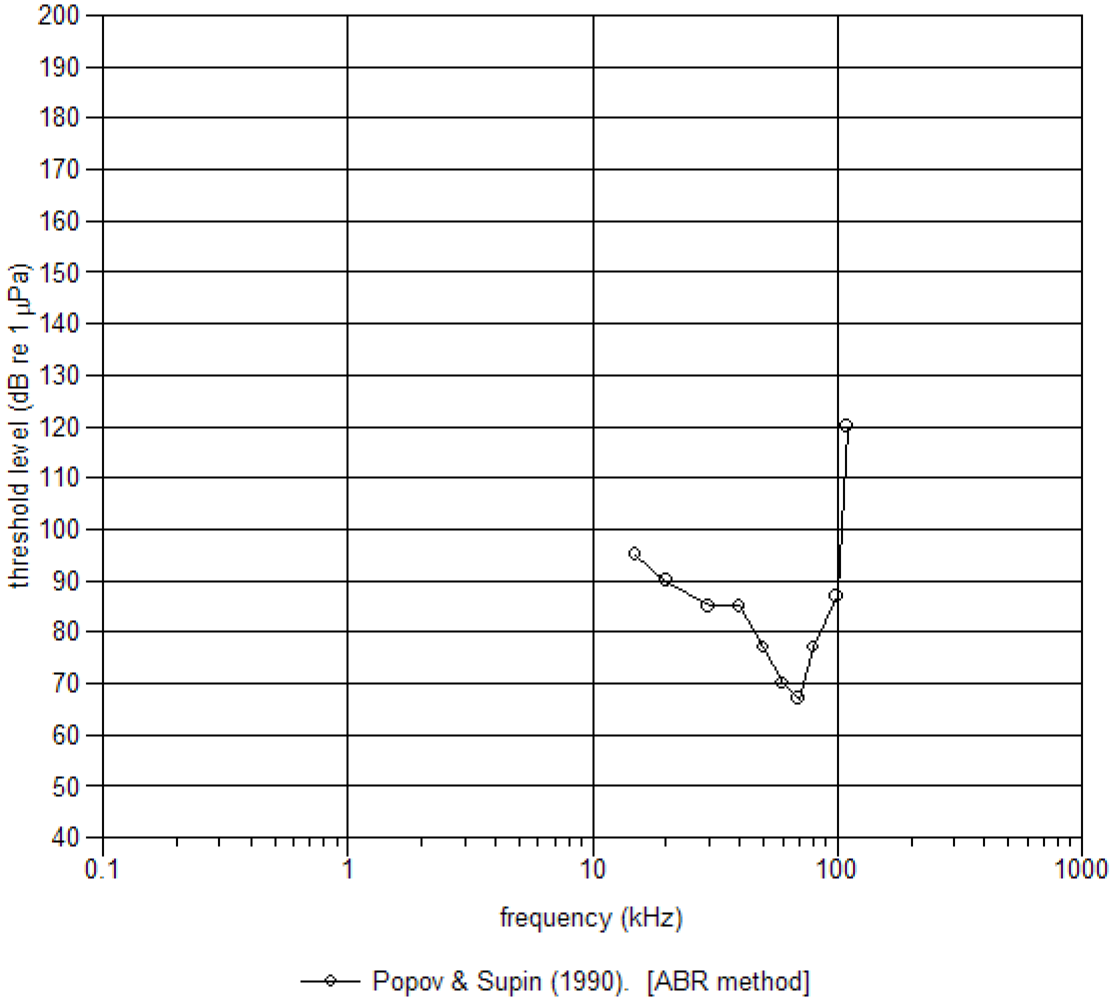
Common name	Beluga dolphin.
Family	
Species	*Delphinapterus leucas.*
Paper from which audiogram obtained	Popov, V. & Supin, A. (1990). Electrophysiological studies of hearing in some cetaceans and a manatee. In 'Sensory Abilities of Cetaceans', 405-415. J. Thomas & R. Kastelein (eds). Plenum Press, N.Y.
Paper having original audiogram data	Popov, V. & Supin, A. (1990). Electrophysiological studies of hearing in some cetaceans and a manatee. In 'Sensory Abilities of Cetaceans', 405-415. J. Thomas & R. Kastelein (eds). Plenum Press, N.Y.
Comments on methodology of getting audiogram	Used ABR technique. Subject was placed on a stretcher in the water such that only the dorsal part of the head with the blowhole and the back were out of the water. Tests done in an enclosure in a sea bay. Electrodes were 0.4 to 0.6mm dia. needles inserted 3 to 5mm into the skin. The active electrode was placed on the dorsal head surface 60 to 90mm caudal from the blowhole. The reference electrode was placed on the back near the dorsal fin. The electrode signal was fed to an amplifier and to an averager of evoked potentials; the passband of the channel was 5 to 5000Hz. Sound sources were piezoceramic transducers, placed 300mm deep in the water, 1 to 2m away from the subject's head. 3 types of test signal – (1) clicks (5μsec long rectangular pulse), (2) noise (PRBS with a duration of 5μsec), (3) tone bursts (frequencies of 5 to 160kHz). Noise bursts had an abrupt rise and fall; tone bursts had linear rises and falls of 0.25msec. Parallel connection of spherical transducers of 20, 30 and 50mm dia. produced noise and clicks with a spectrum flat to within 10dB from 10 to 100kHz (-10dB). Tests showed dependence of ABR on level of stimulus. Lowest level of stimulus which exhibited ABR response taken as threshold.
Any other comments	2 subjects. Tests carried out at the TINRO Biostation of the USSR Ministry of Fishery, on the Japan Sea. The animals were caught shortly before tests were carried out. Early tests established best location for active electrode was 50 to 100mm caudally from blowhole. Neither anaesthesia nor curarization required. Also did tests in which the rate of presentation of the clicks was increased. Went from 20/sec up to 1000/sec. As rate increased amplitude of ABR decreased and trace changed – peaks tended to merge.

Audiogram from Fig. 5. Threshold levels in dB re 1mPa.

Frequency (kHz)	15	20	30	40	50	60	70	80	100	110
Mean	35	30	25	25	17	10	7	17	27	60

Threshold levels in dB re 1μPa.

Frequency (kHz)	15	20	30	40	50	60	70	80	100	110
Mean	95	90	85	85	77	70	67	77	87	120



[Fig. ref: BelugaDlphn01]

Audiogram for Beluga dolphin.

Database page ref: M/DolphinBottlenose/01.

Common name	Atlantic bottlenose dolphin.
Family	
Species	*Tursiops truncatus*
Paper from which audiogram obtained	Brill, R.L., Moore, P.W.B. & Dankiewicz, L.A. (2001). Assessment of dolphin (*Tursiops truncates*) auditory sensitivity and hearing loss using jawphones. JASA, 109(4), 1717-1722.
Paper having original audiogram data	Brill, R.L., Moore, P.W.B. & Dankiewicz, L.A. (2001). Assessment of dolphin (*Tursiops truncates*) auditory sensitivity and hearing loss using jawphones. JASA, 109(4), 1717-1722.
Comments on methodology of getting audiogram	2 subjects – 14-yr old female and 33-yr old male housed in pens in San Diego Bay. Used 'jawphones' (suction cups formed from degassed RTV silicone rubber in which were embedded small transducers) which were fixed over the subject's pan bone (on lower jaw) to provide stimulus. 3 different jawphones used – for 10 and 20kHz frequencies used an earphone element encapsulated in an air-filled chamber; for 30, 60, 90 and 120kHz frequencies used Edo Western 6600 spherical transducer as source; for 120 and 150kHz used a B&K 8103 as source. Each jawphone was wrapped with closed-cell neoprene to restrict sound transmission from any direction other than the suction cap end. Each jawphone was calibrated for each transmitting frequency. Stimuli were pure tones, with durations of 1 sec and rise/fall times of 20msec. Procedure was to start with the stimulus level sufficiently high as to cause subject to respond. Stimulus reduced in 2dB steps until subject failed to respond, when level increased in 1dB steps until subject again responded. For the rest of a session the stimulus level was changed in 1dB steps in each direction. At start, subject stationed at a position 500mm below the water surface, where it remained for 2sec awaiting stimulus. If it detected a signal when one was presented, it should have immediately swum to press a paddle. If no signal was presented, and the subject responded correctly, it would have remained at its station until given a bridging stimulus to indicate it should return to the trainer. Free-field thresholds were also obtained for the female dolphin for 3 frequencies, using a B&K 8103 as source; this was done for each ear individually.
Any other comments	Background level in the Bay was measured.

Audiogram from Fig. 2. Jawphone threshold levels in dB re 1μPa. (This is what the figure's axis states. In the text it states that levels are spectral densities)

1) Male.

Frequency (kHz)	10	20	30	40	45	50	55	60	65
Mean (left panbone)	92	79	92	86	105	106	139	154	140
Mean (right panbone)	107	112	122	100	115	116	127	135	130

2) Female.

Frequency (kHz)	10	20	30	60	90	120	150
Mean (left panbone)	86	86	69	70	78	84	140
Mean (right panbone)	90	85	74	71	79	100	140

From Fig. 6. Female, free-field threshold levels in dB re 1μPa..

Frequency (kHz)	30	60	90
Mean	79	73	79

Background noise from Fig. 2 – selected values. Levels in dB re 1μPa.

Frequency (kHz)	1	2	4	8	16	32	64	100
Level	79	81	84	77	70	67	62	62

Database page ref: M/DolphinBottlenose/02.

Common name	Bottlenose dolphin.
Family	
Species	*Tursiops truncatus.*
Paper from which audiogram obtained	Popov, V. & Supin, A. (1990). Electrophysiological studies of hearing in some cetaceans and a manatee. In 'Sensory Abilities of Cetaceans', 405-415. J. Thomas & R. Kastelein (eds). Plenum Press, N.Y.
Paper having original audiogram data	Popov, V. & Supin, A. (1990). Electrophysiological studies of hearing in some cetaceans and a manatee. In 'Sensory Abilities of Cetaceans', 405-415. J. Thomas & R. Kastelein (eds). Plenum Press, N.Y.
Comments on methodology of getting audiogram	Used ABR technique. Subject was placed on a stretcher in the water such that only the dorsal part of the head with the blowhole and the back were out of the water. Tests done in either a 4x0.6x0.6m bath or in a round pool. Electrodes were 0.4 to 0.6mm dia. needles inserted 3 to 5mm into the skin. The active electrode was placed on the dorsal head surface 60 to 90mm caudal from the blowhole. The reference electrode was placed on the back near the dorsal fin. The electrode signal was fed to an amplifier and to an averager of evoked potentials; the passband of the channel was 5 to 5000Hz. Sound sources were piezoceramic transducers, placed 300mm deep in the water, 1 to 2m away from the subject's head. 3 types of test signal – (1) clicks (5µsec long rectangular pulse), (2) noise (PRBS with a duration of 5µsec), (3) tone bursts (frequencies of 5 to 160kHz). Noise bursts had an abrupt rise and fall; tone bursts had linear rises and falls of 0.25msec. Parallel connection of spherical transducers of 20, 30 and 50mm dia. produced noise and clicks with a spectrum flat to within 10dB from 10 to 100kHz (-10dB). Tests showed dependence of ABR on level of stimulus. Lowest level of stimulus which exhibited ABR response taken as threshold.
Any other comments	4 subjects. Tests carried out at the Utrish Sea station of the USSR Academy of Sciences, on the Black Sea coast. The animals were kept in captivity. Early tests established best location for active electrode was 50 to 100mm caudally from blowhole. Neither anaesthesia nor curarization required. Also did tests in which the rate of presentation of the clicks was increased. Went from 50/sec up to 900/sec. As rate increased amplitude of ABR decreased and trace changed – peaks tended to merge. Also did tests to see directionality of hearing – most sensitive head on, with sensitivity falling by about 35dB at rear.

Audiogram from Fig. 5. Threshold levels in dB re 1mPa.

Frequency (kHz)	5	10	20	40	60	80	100	120	130	140
Mean	22	20	14	7	9	-3	10	20	40	>60

Threshold levels in dB re 1µPa.

Frequency (kHz)	5	10	20	40	60	80	100	120	130	140
Mean	82	80	74	67	69	57	70	80	100	>120

Database page ref: M/DolphinBottlenose/03.

Common name	Eastern Pacific bottle-nosed dolphin
Family	
Species	*Tursiops* spp
Paper from which audiogram obtained	Ljungblad, D.K., Scoggins, P.D. & Gilmartin, W.G. (1982). Auditory thresholds of a captive Eastern Pacific bottle-nosed dolphin, *Tursiops* spp. JASA 72(6):1726-1729.
Paper having original audiogram data	Ljungblad, D.K., Scoggins, P.D. & Gilmartin, W.G. (1982). Auditory thresholds of a captive Eastern Pacific bottle-nosed dolphin, *Tursiops* spp. JASA 72(6):1726-1729.
Comments on methodology of getting audiogram	Behavioural method. Tests done in 7m dia, 1.8m deep circular fibreglass tank which had a trough extending from its side. Text says the trough was 0.8m wide and 3m long. (Fig. 1, sketching set-up, shows tank to be 6m i.d. and trough to be 1.8m long, 0.3m wide). A sound booth, made from plywood, was placed in the trough. The text says the booth was 1.5m long, 64cm wide and 6cm deep. The end facing towards the centre of the tank was open, to allow the subject to enter it. The booth was lined with a 5cm layer of horse hair. The closed end of the booth had a 9cm dia. hole in it through which sound projector was inserted. 1m away from the projector a 3cm dia. rubber-covered bar spanned the booth horizontally, to locate the animal's head. Method was for animal to be directed to station at the side of the tank opposite the booth, and then to go to and station in the booth, placing its rostrum on the bar. It remained on station until it heard a tone (either the test tone or a recall signal). On termination of the tone it would return to the opposite side of the tank to receive reinforcement. The test tone was of 3s duration, with a 40ms rise time and a 20ms fall time. Stationing times ranged from 7s to 30s, and were randomly chosen. Stationing time began when the dolphin was in position and ended at the termination of the test tone or the recall was delivered. Upon termination of the tone the animal had 3s to leave the booth. 'Staircase' method of testing was used – started at high level and reduced in 5dB steps until animal failed to respond. Signal then raised by 15dB, followed by stepped attenuation until it again failed to respond. A session used 4 to 6 response reversals to establish the threshold. Up to 25% of trials in a session were 'catch' trials, i.e. no test tone projected.
Any other comments	Animal was 12-yr old, 160kg male captured near Puerto Penasco, Baja California. 3 sound projectors were used – a J-9, an LC-10 and an E-27. The sound produced at the animal's head position was measured with a Naval Ordnance Test Station sound measuring set, and analysed on a Spectral Dynamics model 310 spectrum analyser. Ambient noise in the tank was measured at various positions and depths around the tank with the dolphin in the tank and the water supply shut off. Authors note that below 5kHz significant amounts of airborne sound can be transmitted through the foundation and walls of the tank into the water. This may have been masking the test signal at low frequencies.

Audiogram from Table II . Threshold levels in dB re 1μPa.

Frequency (kHz)	1	2	3	5	10	15	20	25	30	35	40	45
Level [J-9]	*	115.5	110.5	87.5	81.5	82.5	82					
Level [LC-10]				82	77	76	75	47	58	50	52	48
Frequency (kHz)	50	55	60	65	70	75	80	85	90	95	100	105
Level [LC-10]	46											
Level [E-27]	46	48	50	58	55	53	56	62	65	60	71	65
Frequency (kHz)	110	115	120	125	130	135	140					
Level [E-27]	65	68	74	85	87	98	*					

* no response.

In Fig. 3, at 1kHz threshold was > 118dB; at 2kHz the low end was 115dB; at 135kHz low end was 98dB; at 140kHz threshold was > 120dB.

Ambient noise levels in dB re 1μPa.

Frequency (Hz)	122	232	412	1160	1848	2390	5000
Level	78	73	66	64	64	68	69
Bandwidth (Hz)	16	40	44	36	100	450	320
Frequency (kHz)	1	2	3	5	10	20	
Level	77	76	76	74	66	59	
Bandwidth (Hz)	500	1100	1400	700	1200	1500	

Database page ref: M/DolphinBottlenose/04.

Common name	Bottlenose dolphin (or porpoise)
Family	
Species	*Tursiops truncates Montagu*
Paper from which audiogram obtained	Johnson, C.S. (1967). Sound detection thresholds in marine mammals. In W.N. Tavolga (ed), Marine bio-acoustics, vol. 2. Pergamon, Oxford, U.K.
Paper having original audiogram data	Johnson, C.S. (1967). Sound detection thresholds in marine mammals. In W.N. Tavolga (ed), Marine bio-acoustics, vol. 2. Pergamon, Oxford, U.K.
Comments on methodology of getting audiogram	Tests done at Point Mugu in circular wooden (redwood) tank 8.2m in dia. and 1.3m deep. At side of tank a rectangular stall-like enclosure was built – it had 2 sides, a bottom and 1 endwall, which was attached to tank side (outside dimensions were: length 1.6m, width 1.3m, height 1.1m). Open end of enclosure faced centre of tank. Stall was lined with 50mm of rubberised pig and horse hair. Sound source (Apelco TM-8A, Atlantic LC-10, or J-9), was placed near the wall, and foam-lined baffles were placed in the enclosure to concentrate the sound field. Light placed to right inside enclosure and ahead of baffle system, with lever-operated switch to left. Another lever was located on the opposite side of the tank. A fish feeder was located adjacent to the stall on the same side as the light. Animal was trained to swim into stall and wait for light to come on. When it did he pushed the lever to his left. This initiated 1 of 3 events – (1) light went off and he waited for it to come on again; (2) light went off, buzzer sounded, and fish dropped into tank from feeder; (3) light went out and a tone was emitted from the sound source. In case (3) subject left stall and pushed lever on opposite side of tank. Data taken using up-down method. Measurement of sound field near animal's head was taken with H-17 hydrophone.
Any other comments	Data for 1 animal, 8 or 9 yrs. old, about 2.3m long and weighing 160kg. Had been in captivity for about 2 yrs. Data taking was preceded by a warm-up period of 15 to 30 min. No more than 2 threshold determination runs were done on a day. In a typical run subject would have to respond to light about 100 times, receive rewards 30 times for doing so and be rewarded an additional 30 times for responding to the tones correctly. 1,2 or 3-dB steps were used. Discussion (extensive) of difficulties of measuring at high frequencies, in air as well as water, by Dr. Vernon. He had worked with bats.

Audiogram from Table 1. Threshold levels in dB re 1μbar.
In paper results are tabulated with dates for each session; some frequencies were tested more than once. Table also shows which transducer was used for each session. For a frequency where there is more than one value for threshold level, the average of the values has been calculated by the present author.

Frequency (Hz)	75	100	200	300	400	500	600	700	800	900	
Level	31.5	31.9	10.4	3.6	0.2	-1.7	4.6	-8.7	-6.3	-1.8	
Level		31.7	15.5								
Level		28.7									
Average level	31.5	30.9	13.3	3.6	0.2	-1.7	4.6	-8.7	-6.3	-1.8	
Frequency (kHz)	1	2	3	4	5	6	7	8	9	10	12
Level	-1.9	-30.8	-27.0	-27.7	-26.9	-34.4	-42.2	-34.5	-33.8	-48.6	-47.5
Level	-7.8	-25.3	-21.6	-15.8	-27.3	-29.6	-35.3		-46.2	-34.0	
Level	-2.2									-42.2	
Average level	-3.6	-27.6	-23.9	-19.9	-27.1	-31.7	-38.1	-34.5	-38.0	-39.6	-47.5
Frequency (kHz)	14	15	16	18	20	25	30	35	40	45	50
Level	-61.4	-49.9	-48.4	-50.1	-45.4	-53.2	-47.1	-56.4	-50.7	-58.0	-52.9
Level	-53.9				-46.7		-49.0				-55.1
Level					-52.5		-49.5				-58.3
Level					-51.6						-57.5
Average level	-56.9	-49.9	-48.4	-50.1	-48.5	-53.2	-48.5	-56.4	-50.7	-58.0	-55.7
Frequency (kHz)	55	60	65	70	75	80	85	90	95	100	105
Level	-51.6	-49.0	-59.2	-52.1	-45.9	-52.6	-45.4	-47.8	-49.2	-39.6	-47.0
Level		-55						-42.4		-41.7	
Average level	-51.6	-51.5	-59.2	-52.1	-45.9	-52.6	-45.4	-44.7	-49.2	-40.6	-47.0
Frequency (kHz)	110	115	120	125	130	135	140	145	150		
	-46.0	-50.8	-41.1	-37.7	-38.1	-34.8	-30.5	-3.9	33.5		
		-49.9	-40.4						37.6		
									33.4		
									37.6		
Average level	-46.0	-50.3	-40.7	-37.7	-38.1	-34.8	-30.5	-3.9	35.8		

Threshold levels in dB re 1μPa.

Frequency (Hz)	75	100	200	300	400	500	600	700	800	900	
Average level	132	131	113	104	100	98	105	91	94	98	
Frequency (kHz)	1	2	3	4	5	6	7	8	9	10	12
Average level	96	72	76	80	73	68	62	66	62	60	53
Frequency (kHz)	14	15	16	18	20	25	30	35	40	45	50
Average level	43	50	52	50	51	47	52	44	49	42	44
Frequency (kHz)	55	60	65	70	75	80	85	90	95	100	105
Average level	48	49	41	48	54	47	55	55	51	59	53
Frequency (kHz)	110	115	120	125	130	135	140	145	150		
Average level	54	50	59	62	62	65	70	96	136		

Database page ref: M/DolphinBottlenose/05.

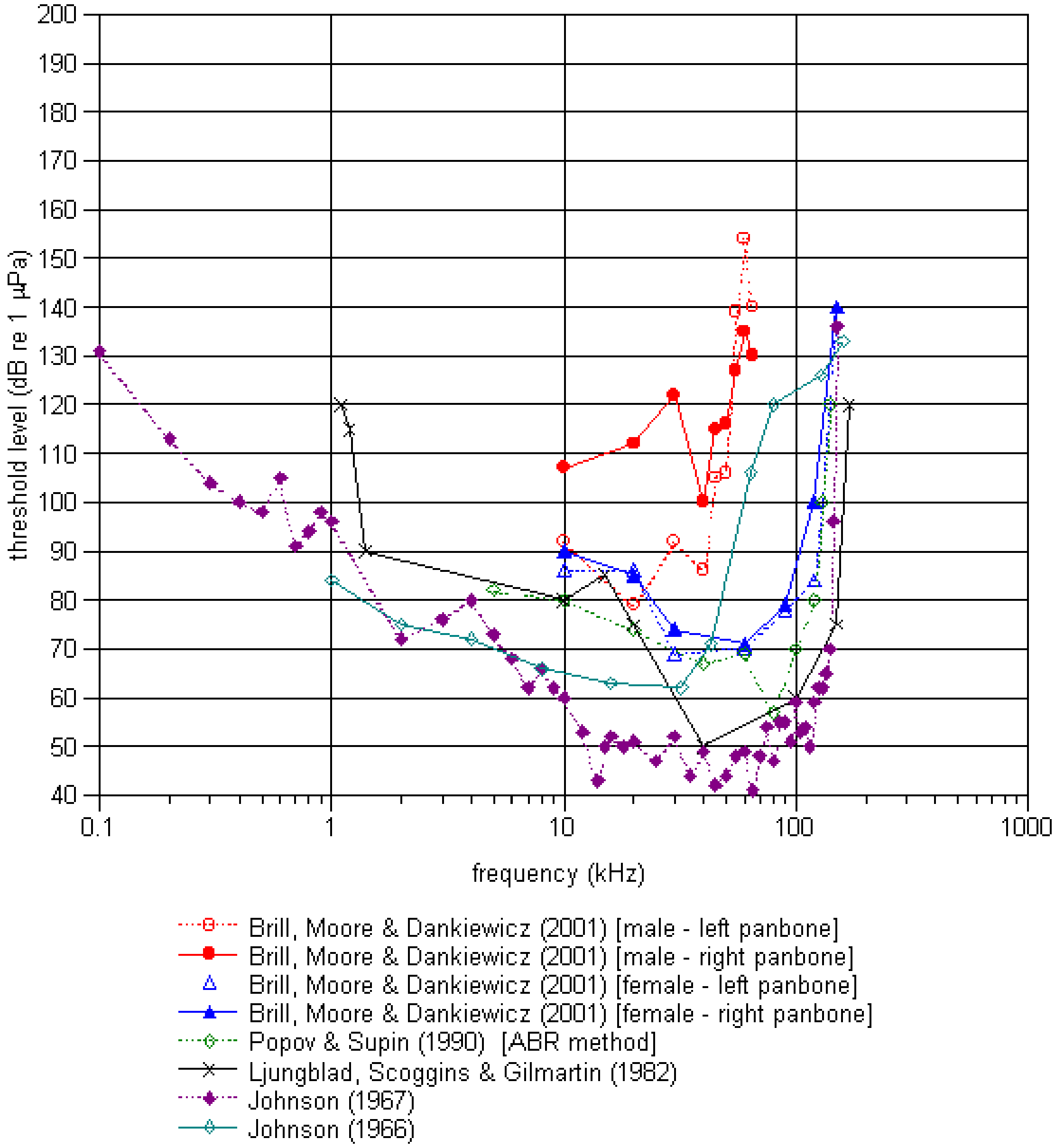
Common name	Bottlenosed porpoise.
Family	Delphinid.
Species	*Tursiops truncates.*
Paper from which audiogram obtained	Schusterman, R.J. (1975). Pinniped sensory perception. Rapp. P.-v. Reun. Cons. int. Explor. Mer, 169: 165-168.
Paper having original audiogram data	Johnson, C.S. (1966). Auditory thresholds of the bottlenosed porpoise (*Tursiops truncatus*). U.S. Naval Ord. Test Stn., Tech. Oubl., 4178: 1-28.
Comments on methodology of getting audiogram	Original paper not seen.
Any other comments	

Audiogram from Fig. 131. Threshold levels in dB re 1μbar.

Frequency (kHz)	1	2	4	8	16	32	43	64	80	128	160
Mean	-16	-25	-28	-34	-37	-38	-29	6	20	26	33

Threshold levels in dB re 1μPa.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1500	2000	3000
Mean	84	75	72	66	63	62	71	106	120	126	133



[Fig. ref: BottlenoseDolphin03]

Audiogram for Bottlenose dolphin.

Database page ref: M/DolphinChineseRiver/01

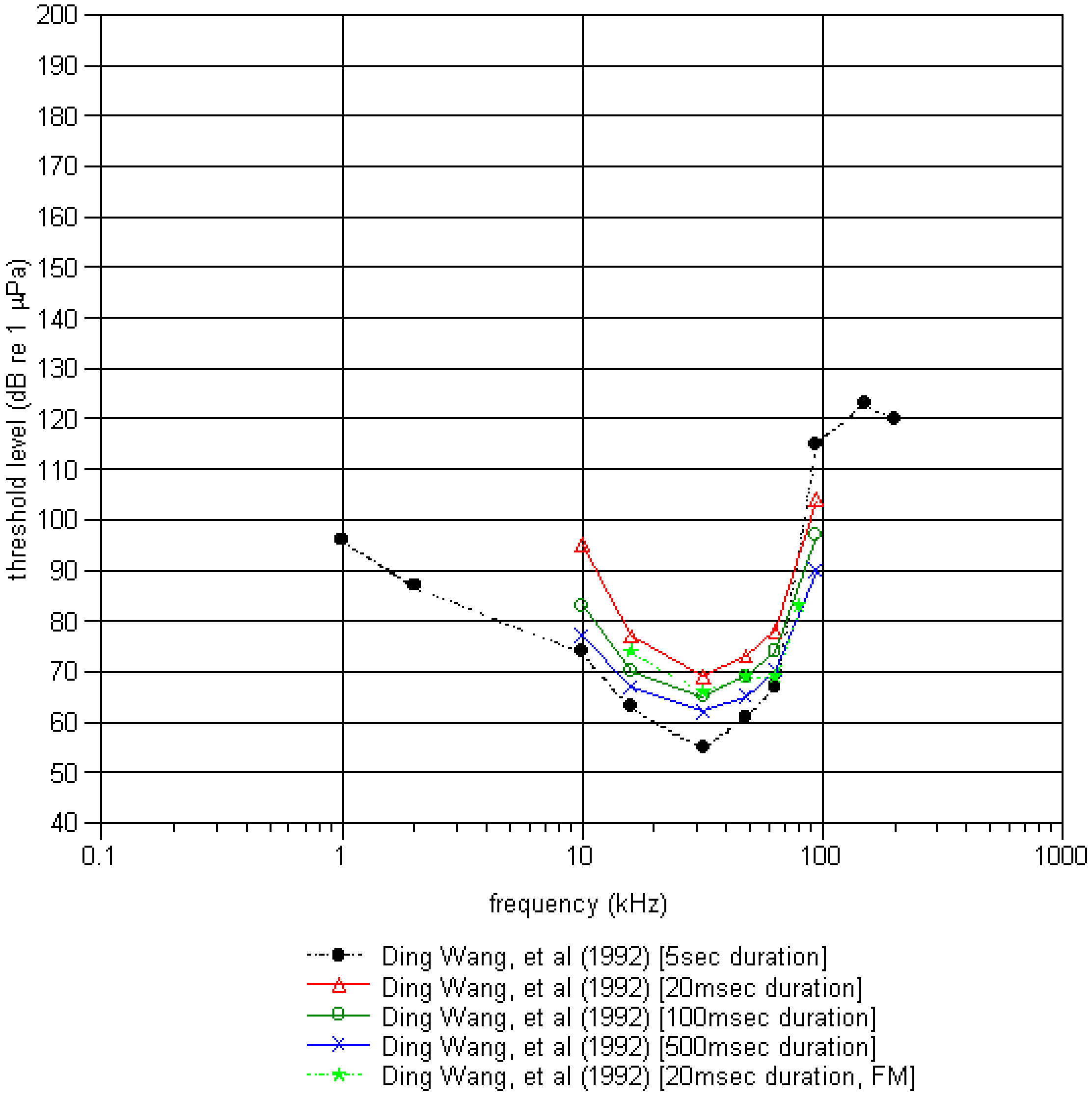
Common name	Chinese river dolphin., or baiji.
Family	
Species	*Lipotes vexillifer.*
Paper from which audiogram obtained	Ding Wang, Kexiong Wang, Youfu Xiao & Gang Sheng. (1992). Auditory sensitivity of a Chinese river dolphin, *Lipotes vwxillifer*. In: 'Marine Mammal Sensory Systems', 213-221. Thomas, J. *et al* (eds). Plenum Press, New York.
Paper having original audiogram data	Ding Wang, Kexiong Wang, Youfu Xiao & Gang Sheng. (1992). Auditory sensitivity of a Chinese river dolphin, *Lipotes vwxillifer*. In: 'Marine Mammal Sensory Systems', 213-221. Thomas, J. *et al* (eds). Plenum Press, New York.
Comments on methodology of getting audiogram	Tests done in a circular concrete tank 15m dia. x 2.5m deep. The water surface was 2m below ground level. A platform projected out over the water; the sound projector (GZF, designed by the Institute of Acoustics, Academia Sinica) was suspended below the platform, and a stationing lever (a copper pipe) was also suspended from the edge of the platform. A B&K Type 8103 hydrophone was attached to the lever to monitor the projected sound. 2 series of experiments done – in 1987 stimulus signals were tones of 5sec duration; in 1990 stimulus signals were tones of 20, 100 and 500msec duration, and also FM signals modulated up to 20% of the centre frequency. In 1987 the distance between the sound source and the hydrophone was 0.5m; in 1990 the distance was 2m. Test procedure was for animal to station when its trainer came onto the platform. If it heard a signal it raised its head out of the water to receive a reward of a piece of fish. If no signal was projected (a 'catch' trial) a whistle was sounded to indicate that the trial was over. Thresholds were established by the staircase method, with 5dB steps in level. Each session involved 10 to 20 estimations of threshold. Each frequency was tested at least 3 times, and the most sensitive frequencies 10 times.
Any other comments	1 specimen. Animal had been inadvertently caught by fisherman in the Yangtze River in 1980. It had been kept in captivity at the Institute of Hydrobiology since recovering from its injuries. Possible masking at low frequencies because of relatively high tank noise. 200kHz was highest frequency that could be tested, because of instrumentation limitations.

Audiogram from Fig. 4. Threshold levels in dB re 1μPa.

Frequency (kHz)		1	2	10	16	32	48	64	80	94	150	200
Mean	5sec duration	96	87	74	63	55	61	67		115	123	120
	20msec duration			95	77	69	73	78		104		
	100msec duration			83	70	65	69	74		97		
	500msec duration			77	67	62	65	70		90		
	FM signal; 20msec duration				74	66	69	69	83			

Background noise levels, in octave bands, in dB re 1μPa.

Frequency (kHz)	2	4	8	16
Mean	80	76	68	54



[Fig. ref: DolphinChineseRiver02]

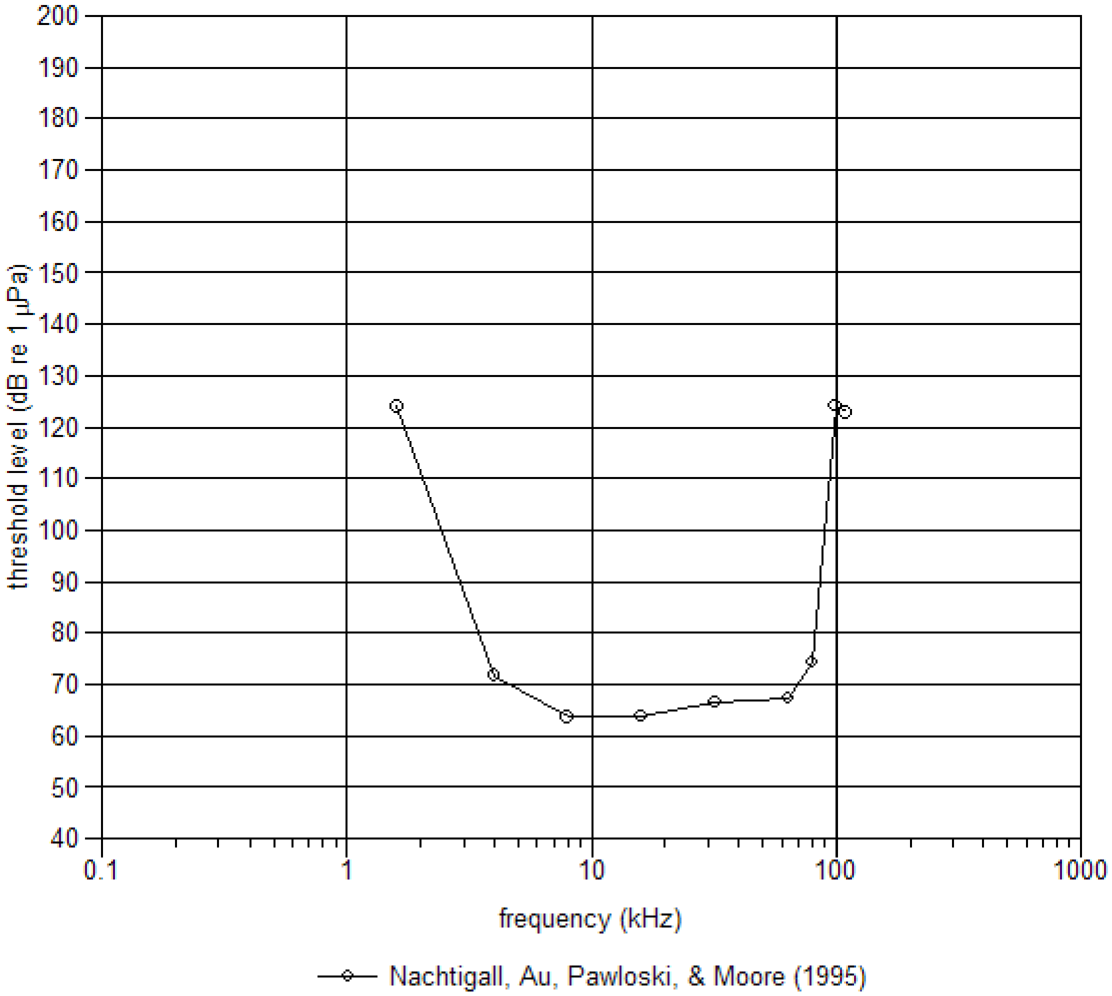
Audiogram for Chinese river dolphin.

Database page ref: M/DolphinRisso/01.

Common name	Risso's dolphin.
Family	
Species	*Grampus griseus.*
Paper from which audiogram obtained	Nachtigall, P.E., Au, W.W.L., Pawloski, J.L. & Moore, P.W.B. (1995). Risso's dolphin (*Grampus griseus*) hearing thresholds in Kaneohe Bay, Hawaii. In 'Sensory Systems of Aquatic Mammals', 49-53. R.A. Kastelein et al (eds). De Spil Publ., Woerden, Netherlands.
Paper having original audiogram data	Nachtigall, P.E., Au, W.W.L., Pawloski, J.L. & Moore, P.W.B. (1995). Risso's dolphin (*Grampus griseus*) hearing thresholds in Kaneohe Bay, Hawaii. In 'Sensory Systems of Aquatic Mammals', 49-53. R.A. Kastelein et al (eds). De Spil Publ., Woerden, Netherlands.
Comments on methodology of getting audiogram	Tests conducted in a 9.2x12.3x4.5m floating enclosure in Kaneohe Bay in water of about 5m depth with a soft mud bottom. Subject stationed in a padded circular metal hoop located in the centre of the enclosure 3m from the sound projector (EDO Western 337). Hoop was positioned to align the centre of the subject's lower jaw with the centre of the sound source. Both source and hoop were approx. 1m below surface. To reduce scattered sound from the water surface and ensure constant amplitude signal at test station a baffle (aluminium plate 610x460x16mm with cork layer on the face facing the projector) was located in the linear path between projector and hoop. Set-up calibrated by placing H-52 hydrophone at subject's lower jaw position and measuring sound levels. Sinusoidal test signal was generated by board in a portable computer. Signal was fed into shaper that attenuated it as desired and gave it linear rise and fall times of 160ms. Test procedure was a go/no-go method (i.e. if subject heard tone it would leave station and touch a ball positioned above the water; if not it would stay in the hoop). Trial consisted of 2sec of a light being illuminated, 3sec of the test tone (or silence), then 10secs of light. At the test frequency, trial started with signal level being high, and then was reduced in 4dB steps until a 'miss' occurred; then signal was increased in 2dB steps until a 'hit' occurred; thereafter signal was altered in 2dB steps until 6 to 10 reversals had been obtained. Data session was preceded by a 10 trial warm-up session; for warm-up session signal level was at a comfortable level for the subject . Threshold was defined by obtaining 2 consecutive sessions with mean amplitude levels of the reversals differing by less than 3dB.
Any other comments	Subject was older female, not used previously for experiments. Background noise, due to snapping shrimp, was comparable with threshold at subject's most sensitive frequencies.

Audiogram from Table 1. Threshold levels in dB re 1μPa.

Frequency (kHz)	1.6	4.0	8.0	16.0	32.0	64.0	80.0	100.0	110.0
Mean	124	71.7	63.7	63.8	66.5	67.3	74.3	124.2	122.9



[Fig. ref: RissoDlphn01]

Audiogram for Risso's dolphin.

Database page ref: M/DolphinStriped/01.

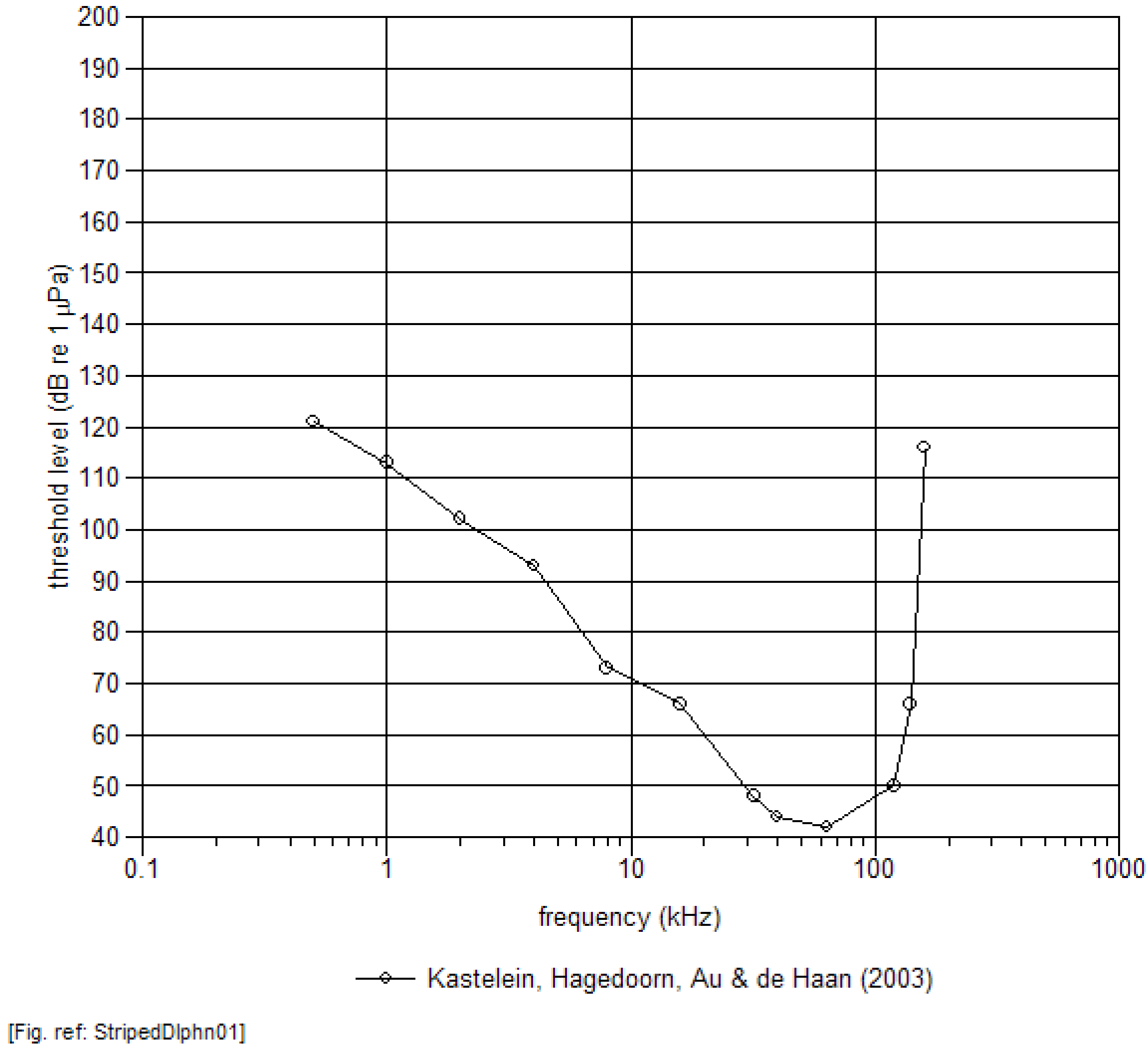
Common name	Striped dolphin.
Family	
Species	*Stenella coeruleoalba*
Paper from which audiogram obtained	Kastelein, R.A., Hagedoorn, M., Au, W.W.L. & de Haan, D. (2003). Audiogram of a striped dolphin (*Stenella coeruleoalba*). JASA, 113(2), 1130-1137.
Paper having original audiogram data	Kastelein, R.A., Hagedoorn, M., Au, W.W.L. & de Haan, D. (2003). Audiogram of a striped dolphin (*Stenella coeruleoalba*). JASA, 113(2), 1130-1137.
Comments on methodology of getting audiogram	Tests done in indoor oval concrete pool (8.6m long, 6.3m wide, 1.2m deep). Average water temp. 19.5C. During tests water pump turned off, and no one was allowed to move in the building. Projector was placed near wall at 0.6m below water surface. Dolphin station was 2.6m away, at same height. 2 baffle boards (6mm thick aluminium plates, 300mm high and 1m wide, covered in closed cell neoprene) were located on floor of tank and with top edge at water surface, 1.3m in front of projector. 2 projectors used – (1) for 500Hz to 32khz used Ocean Engineering Enterprise DRS-8 250mm piezoelectric transducer; (2) for 32 to 160kHz used custom-built transducer of piezoelectric material encapsulated in degassed polyurethane epoxy. It had an effective radiating aperture of 45mm. Test signal was sinusoidal frequency modulated signal of 2s duration, having 150ms rise and fall times. The modulation range was ±1% of centre frequency. Method was modified up-down staircase one, using 4dB steps. Session consisted of usually 12 to 25 trials. Signal amplitudes at which subject reversed its response taken as data points. Mean detection threshold defined as mean amplitude of all reversals obtained during 8 sessions per frequency after the threshold had stabilized. There were other animals in the tank, but they were kept apart during tests.
Any other comments	Subject was a female, estimated to be 6 to 7 years old, rehabilitated (and tested) at Harderwijk Marine Mammal Park, Netherlands. 500Hz was lowest frequency at which system could produce signal at sufficient amplitude without distortion. High frequency set by hearing limit of subject. Tests for uniformity of sound field around subject's head showed that SPL varied by 2 to 4dB between positions on a cubic grid (100mm spacing up to 400mm in each direction from centre). Ambient noise between 300Hz and 10kHz plotted; electronic noise prevented measurements above 10kHz. Deviations of subject's axis by more than 5° from beam axis (in any direction) was not accepted.

Audiogram from Table I. Threshold and threshold range levels in dB re 1μPa.

Frequency k(Hz)	0.5	1	2	4	8	16	32	40	64	120	140	160
Mean	121	113	102	93	73	66	48	44	42	50	66	116
Session threshold range	119-124	112-116	101-105	88-98	69-76	63-71	44-53	40-46	35-45	45-54	61-69	116

Background noise level from Fig. 3. Level in dB re 1μPa/(Hz$^{1/2}$).

Frequency k(Hz)	0.25	0.5	1	2	4	10
Mean	50	40.5	33	30	28	20



Audiogram for Striped dolphin.

Database page ref: M/DolphinTucuxi/01.

Common name	Tucuxi dolphin
Family	
Species	*Sotalia fluviatilis guianensis.*
Paper from which audiogram obtained	Sauerland, M. & Dehnhardt, G. (1998). Underwater audiogram of a tucuxi (*Sotalia fluviatilis guianensis*). JASA, 103(2): 1199-1204.
Paper having original audiogram data	Sauerland, M. & Dehnhardt, G. (1998). Underwater audiogram of a tucuxi (*Sotalia fluviatilis guianensis*). JASA, 103(2): 1199-1204.
Comments on methodology of getting audiogram	Tests done in concrete tank about 20x10x4m deep. Projector mounted in corner of pool, with positioning hoop 2.5m away from it. Lights positioned at either side of subject, on pool walls, and within sight of subject. Projectors were B&K 8104 (4 & 8kHz) and B&K 8103 (16 to 135kHz). Hydrophones were about 2m below water surface. Test signal was sinusoid with rise and fall times of 150ms and a duration of 2s. Procedure was for subject to start at side of tank by trainer, and on signal to go to hoop. Experimenter then switched on lights for 15s. After 3s delay test signal was projected for 2s. When lights went out end of trial signalled by trainer by a whistle. If subject heard signal it left hoop and swam to trainer. If it didn't hear a signal it stayed at the hoop. For correctly identifying a signal it was rewarded with a fish; for correctly identifying a catch trial it was rewarded with half a fish. Signals were presented randomly, with half being catch trials. At test frequency started with signal at high level, and decreased in 2dB steps until not heard; then increased level in 2dB steps until again detected. Levels at which reversals occurred taken as data points. Threshold estimated as average of levels at 10 consecutive reversals. After data collected at all test frequencies, repeated tests at 5 frequencies – interval between initial and repeat tests was between 1 month and more than a year.
Any other comments	2 adult males, about 20 yrs old, kept at the Dolphinarium Münster, where tests were conducted. They had been caught in 1977 off Colombia, and been at the dophinarium since 1991. They took part in 3 to 5 shows daily, except in the winter. Present experiments were carried out once per day, 3-5 days per week, from Sept 93 to Jan 95. 24 to 36 trials per day, with 2 to 6 being reversals. Initially considerable variation in signal level at subject's position, believed due to reflections from walls and water surface. Adjusted height of hydrophones to minimise, and placed projector in polystyrene hemisphere 210mm dia and 20mm thick; fluctuations reduced to 5dB max. Also, water circulation pumps left running while tests were conducted – measurements had shown that, although there was considerable background noise below 1kHz, it did not affect the animal's performance. Background noise measured:- results for 4, 8 and 16kHz given in figure; above 16kHz instrumentation noise was dominant. Only 1 reliable threshold value obtained for 2nd subject – tests with it abandoned.

Audiogram for 'Paco' from Table 1. Threshold levels in dB re 1μPa.

Frequency (kHz)	4	8	16	32	64	85	95	105	125	135
No. of reversals	30	40	50	50	40	40	40	40	40	40
Mean threshold	76	81	67	67	59	50	58	59	66	104
Range of threshold means	74-77	78-85	65-70	66-69	57-60	48-52	57-59	57-61	65-68	101-108
Mean threshold in repeat test		79		64		56		61		102
False alarm rates (%) (from Fig. 3)	9.6	3.3	10.8	8.3	3.3	3	3.3	0.5	0.7	4.4

Threshold level for 'Coco' from text and Fig. 2. Threshold level in dB re 1μPa.

Frequency (kHz)	8
Mean threshold	83

Background noise, from Fig. 2. Levels in dB re 1μPa. (In text state that used 1/1 octave filter set, and levels are in dB/($Hz^{1/2}$).

Frequency (kHz)	4	8	16
Level	65	56	52

Database page ref: M/DolphinTucuxi/02.

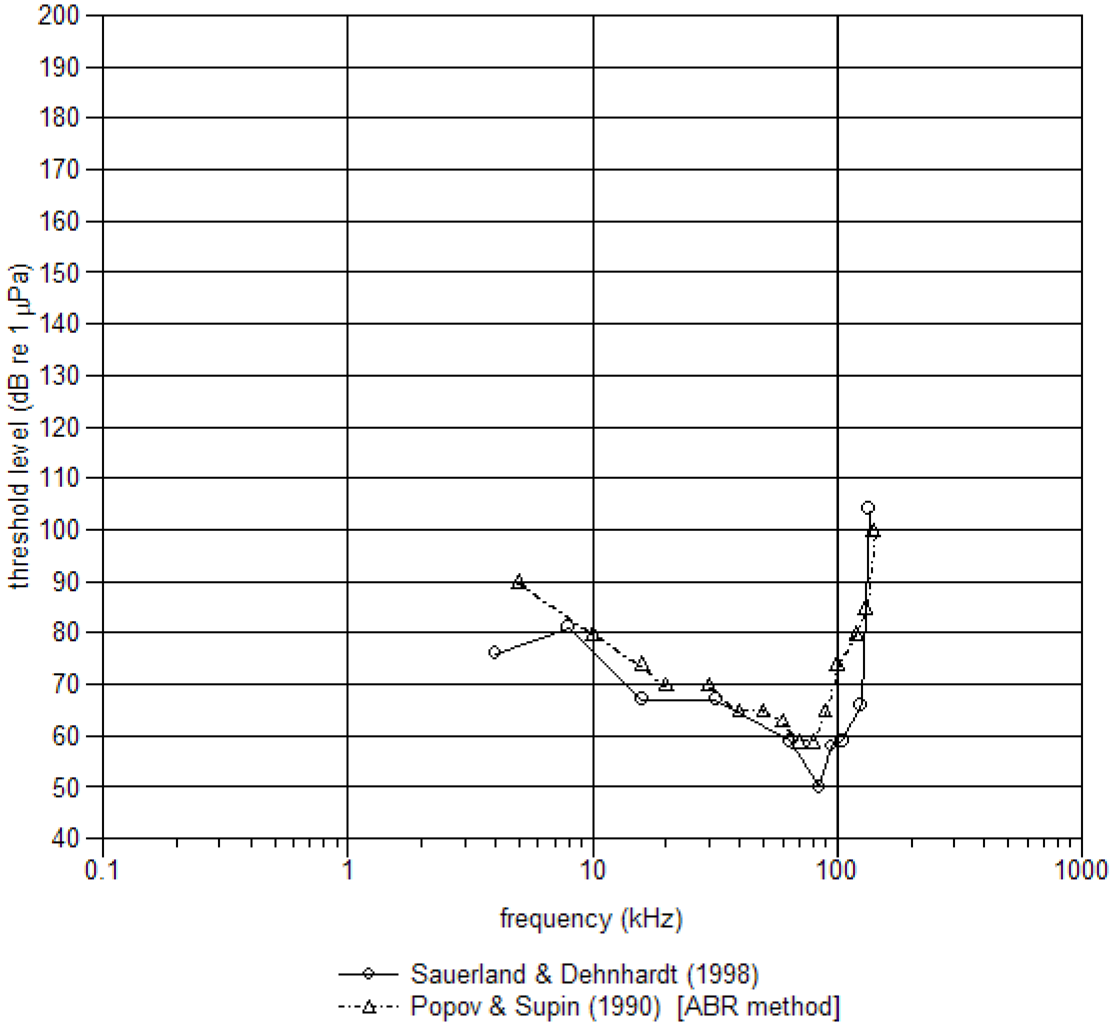
Common name	Tucuxi dolphin
Family	
Species	*Sotalia fluviatilis.*
Paper from which audiogram obtained	Popov, V. & Supin, A. (1990). Electrophysiological studies of hearing in some cetaceans and a manatee. In 'Sensory Abilities of Cetaceans', 405-415. J. Thomas & R. Kastelein (eds). Plenum Press, N.Y.
Paper having original audiogram data	Popov, V. & Supin, A. (1990). Electrophysiological studies of hearing in some cetaceans and a manatee. In 'Sensory Abilities of Cetaceans', 405-415. J. Thomas & R. Kastelein (eds). Plenum Press, N.Y.
Comments on methodology of getting audiogram	Used ABR technique. Subject was placed on a stretcher in the water such that only the dorsal part of the head with the blowhole and the back were out of the water. Tests done in either a 4x0.6x0.6m bath or in a round pool. Electrodes were 0.4 to 0.6mm dia. needles inserted 3 to 5mm into the skin. The active electrode was placed on the dorsal head surface 60 to 90mm caudal from the blowhole. The reference electrode was placed on the back near the dorsal fin. The electrode signal was fed to an amplifier and to an averager of evoked potentials; the passband of the channel was 5 to 5000Hz. Sound sources were piezoceramic transducers, placed 300mm deep in the water, 1 to 2m away from the subject's head. 3 types of test signal – (1) clicks (5μsec long rectangular pulse), (2) noise (PRBS with a duration of 5μsec), (3) tone bursts (frequencies of 5 to 160kHz). Noise bursts had an abrupt rise and fall; tone bursts had linear rises and falls of 0.25msec. Parallel connection of spherical transducers of 20, 30 and 50mm dia. produced noise and clicks with a spectrum flat to within 10dB from 10 to 100kHz (-10dB). Tests showed dependence of ABR on level of stimulus. Lowest level of stimulus which exhibited ABR response taken as threshold.
Any other comments	2 subjects. Tests carried out at the Soviet-Peruvian Biostation, Pucallpa, Peru on animals caught in the Ucayaly River. Early tests established best location for active electrode was 50 to 100mm caudally from blowhole. Neither anaesthesia nor curarization required. Also did tests in which the rate of presentation of the clicks was increased. Went from 10/sec up to 1700/sec. As rate increased amplitude of ABR decreased and trace changed – peaks tended to merge. Also did tests to see directionality of hearing – most sensitive head on, with sensitivity falling by about 30dB at rear.

Audiogram from Fig. 5. Threshold levels in dB re 1mPa.

Frequency (kHz)	5	10	16	20	30	40	50	60	70	80	90	100	120	130	140
Level	30	20	14	10	10	5	5	3	-1	-1	5	14	20	25	40

Threshold levels in dB re 1μPa.

Frequency (kHz)	5	10	16	20	30	40	50	60	70	80	90	100	120	130	140
Mean	90	80	74	70	70	65	65	63	59	59	65	74	80	85	100



[Fig. ref: TucuxiDlphn01]

Audiogram for Tucuxi dolphin.

Database page ref: M/Manatee/01.

Common name	Manatee, West Indian
Family	
Species	*Trichechus manatus*
Paper from which audiogram obtained	Gerstein, E.R., Gerstein, L., Forsythe, S.E. & Blue, J.E. (1999). The underwater audiogram of the West Indian manatee (*Trichechus manatus*). JASA, 105(6), 3575-3583.
Paper having original audiogram data	Gerstein, E.R., Gerstein, L., Forsythe, S.E. & Blue, J.E. (1999). The underwater audiogram of the West Indian manatee (*Trichechus manatus*). JASA, 105(6), 3575-3583.
Comments on methodology of getting audiogram	An 8- and a 9-yr old manatee were studied at Lowry Park Zoo in Tampa, Florida. Tests were conducted in 1 of 5 irregular-shaped pools which were in-ground. Pool used had 492050 litres capacity, and varied in depth between 1 and 3m. Tests were conducted at mid-depth in the 3m depth part. Should be no contamination by background noise as tests done in early morning or late afternoon. Subject started test by being positioned with its head in a hoop, so that it was 1.5m away from the sound projector at 1.5m below the water surface. It could see a strobe light – when light flashed subject backed out of hoop and went to 1 of 2 paddles. Choice of which paddle was determined by whether or not subject had heard the test tone. Test signal was sinusoid with 100ms rise, 300ms steady level, 100ms fall, repeated twice per second for 4s. Hydrophone monitored sound near subject's head. Sessions consisted of 30-80 trials lasting 1-2hrs. Used "warm-up" and "cool-down" trials to decide if data was valid. Test method was to start with signal level above expected threshold, then reduce level in 3dB steps until got incorrect response, then increase level in 1dB steps until subject responded correctly. Subsequent.level steps were ±1dB. Results from 7962 trials were used to estimate the hearing thresholds of both subjects.
Any other comments	Looked at hearing below 400Hz as well. 1 subject was able to detect sound at less than 400Hz only after months of repeated trials. Authors speculate that subject may have switched detection strategy from hearing to feeling. Ambient noise was measured, and is given in the tables in dB re 1μPa for a 1Hz band.

Audiogram from Table I – subject 1 ('Stormy'). Threshold levels in dB re 1μPa.
The values below 400Hz are believed by the authors' to be vibrotactile responses.

Frequency (Hz)	15	50	100	200	400	500	800	1600	3000	6000
Mean	111	98	93	93	102	102	82	72	67	58
SD	1.46	2.62	2.25	1.53	1.84	2.20	1.84	2.55	1.97	1.98
Std. error	0.28	0.47	0.39	0.44	0.34	0.39	0.35	0.37	0.37	0.45
Ambient noise	68	68	43	36	43	43	41	25	25	26
Frequency (Hz)	10000	12000	16000	18000	20000	26000	32000	38000	46000	
Mean	56	52	50	50	58	66	77	88	112	
SD	2.52	1.60	3.25	3.01	1.68	1.90	2.83	3.29	1.94	
Std. error	0.45	0.29	0.56	0.52	0.31	0.53	0.52	0.59	0.49	
Ambient noise	26	27	28	25	26	31	31	32	33	

Audiogram from Table II – subject 2 ('Dundee'). Threshold levels in dB re 1μPa.

Frequency (Hz)	500	1600	3000	6000	12000	18000	26000	38000
Mean	101	76	67	63	55	53	68	94
SD	3.27	4.70	2.23	1.96	3.05	2.70	2.35	3.28
Std. Error	0.52	0.75	0.44	0.42	0.44	0.45	0.40	0.52
Ambient noise	43	25	25	26	29	25	31	31

The ambient noise levels are for 1Hz bands.

Database page ref: M/Manatee/02.

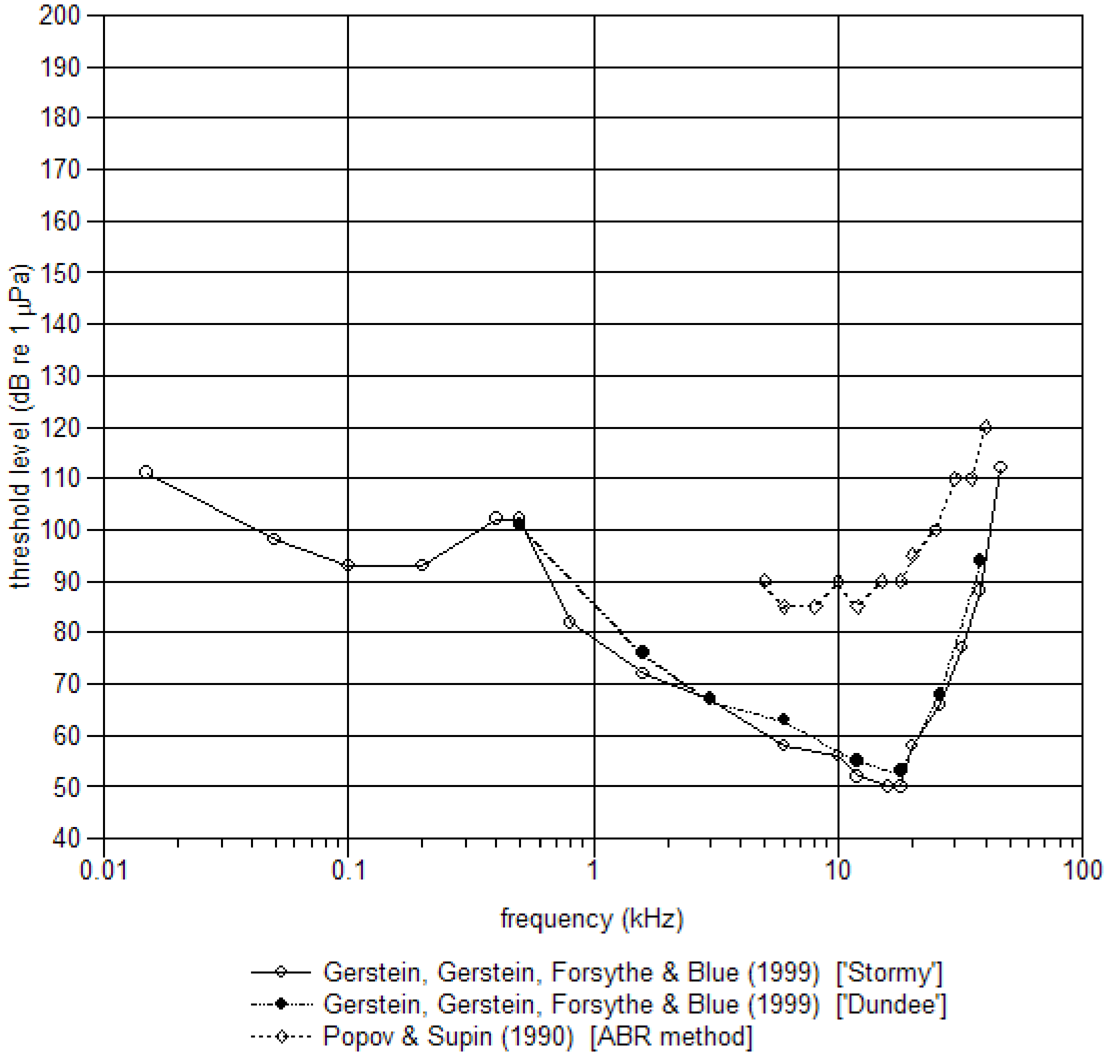
Common name	Manatee.
Family	
Species	*Trichechus inunquis.*
Paper from which audiogram obtained	Popov, V. & Supin, A. (1990). Electrophysiological studies of hearing in some cetaceans and a manatee. In 'Sensory Abilities of Cetaceans', 405-415. J. Thomas & R. Kastelein (eds). Plenum Press, N.Y.
Paper having original audiogram data	Popov, V. & Supin, A. (1990). Electrophysiological studies of hearing in some cetaceans and a manatee. In 'Sensory Abilities of Cetaceans', 405-415. J. Thomas & R. Kastelein (eds). Plenum Press, N.Y.
Comments on methodology of getting audiogram	Used ABR technique. Subject was placed on a stretcher in the water such that only the dorsal part of the head with the blowhole and the back were out of the water. Tests done in either a 4x0.6x0.6m bath or in a round pool. Electrodes were 0.4 to 0.6mm dia. needles inserted 3 to 5mm into the skin. The active electrode was placed on the dorsal head surface 60 to 90mm caudal from the blowhole. The reference electrode was placed on the back near the dorsal fin. The electrode signal was fed to an amplifier and to an averager of evoked potentials; the passband of the channel was 5 to 5000Hz. Sound sources were piezoceramic transducers, placed 300mm deep in the water, 1 to 2m away from the subject's head. 3 types of test signal – (1) clicks (5µsec long rectangular pulse), (2) noise (PRBS with a duration of 5µsec), (3) tone bursts (frequencies of 5 to 160kHz). Noise bursts had an abrupt rise and fall; tone bursts had linear rises and falls of 0.25msec. Parallel connection of spherical transducers of 20, 30 and 50mm dia. produced noise and clicks with a spectrum flat to within 10dB from 10 to 100kHz (-10dB). Tests showed dependence of ABR on level of stimulus. Lowest level of stimulus which exhibited ABR response taken as threshold.
Any other comments	1 subject. Tests carried out at the Biostation of the Institute of Investigation of Peruvian Amazony (IIAP), Iquitos, Peru. Neither anaesthesia nor curarization required. Also did tests in which the rate of presentation of the clicks was increased. Went from 10/sec up to 150/sec. As rate increased amplitude of ABR decreased and trace changed – peaks tended to merge.

Audiogram from Fig. 5. Threshold levels in dB re 1mPa.

Frequency (kHz)	5	6	8	10	12	15	18	20	25	30	35	40
Level	30	25	25	30	25	30	30	35	40	50	50	60

Threshold levels in dB re 1µPa.

Frequency (kHz)	5	6	8	10	12	15	18	20	25	30	35	40
Level	90	85	85	90	85	90	90	95	100	110	110	120



[Fig. ref: Manatee01]

Audiogram for Manatee.

Database page ref: M/PorpoiseHarbour/01.

Common name	Harbour porpoise
Family	
Species	*Phocoena phocoena.*
Paper from which audiogram obtained	Kastelein, R.A., Bunskoek, P., Hagedoorn, M., Au, W.L.W. & de Haan, D. (2002). Audiogram of a harbor porpoise (Phocoena phocoena) measured with narrow-band frequency-modulated signals. JASA, 112(1), 334-344.
Paper having original audiogram data	Kastelein, R.A., Bunskoek, P., Hagedoorn, M., Au, W.L.W. & de Haan, D. (2002). Audiogram of a harbor porpoise (Phocoena phocoena) measured with narrow-band frequency-modulated signals. JASA, 112(1), 334-344.
Comments on methodology of getting audiogram	Tests done in indoor oval concrete pool (8.6m long, 6.3m wide, 1.2m deep). Average water temp. 19.5C. During tests water pump turned off, and no one was allowed to move in the building. Projector was placed near wall at 0.6m below water surface. Dolphin station was 2.6m away, at same height. 2 baffle boards (6mm thick aluminium plates, 300mm high and 1m wide, covered in closed cell neoprene) were located on floor of tank and with top edge at water surface, 1.3m in front of projector. 2 projectors used – (1) for 250Hz to 32khz used Ocean Engineering Enterprise DRS-8 250mm piezoelectric transducer; (2) for 32 to 180kHz used custom-built transducer of piezoelectric material encapsulated in degassed polyurethane epoxy. It had an effective radiating aperture of 45mm. Test signal was sinusoidal frequency modulated signal of 2s duration, having 150ms rise and fall times. The modulation range was ±1% of centre frequency. Method was go/no-go (if it heard a signal it moved to side of pool, if not it stayed at station) and modified up-down staircase one, using 4dB steps. Session consisted of usually 29 trials. Signal amplitudes at which subject reversed its response taken as data points. There were other animals in the tank, but they were kept apart during tests.
Any other comments	Subject was 2-yr old male, raised and tested at Harderwijk Marine Mammal Park, Netherlands. Study started with pure tones, but measurements at subject's head location gave levels varying up to 15dB between sessions – thought to be due to interference effects, therefore went to FM signal. At 130kHz the width of the beam from transducer(2) was 15.6°, which gave a beam 390mm in dia. at 2m, which is wider than the subject's head. Background noise was also measured, but only up to 8kHz as above that frequency instrumentation noise was dominant. Also had 2 video cameras filming subject. 1 camera was underwater, looking horizontally, while other was mounted on ceiling of building and looked vertically down. Latter was used to calculate the time it took the subject to move from its station to a 440mm dia. circle drawn on tank floor, to give movement time as a function of signal frequency and level.

Audiogram from Table 1. Threshold and range levels in dB re 1μPa.

Frequency (kHz)	0.25	0.5	1	2	4	8	16	32	50
Mean	115	92	80	72	67	59	44	37	36
Threshold range	112-118	89-96	76-86	66-78	64-72	56-62	39-49	28-42	33-39
Frequency (kHz)	64	80	100	120	130	140	150	160	180
Mean	46	37	32	33	35	36	60	91	106
Threshold range	40-51	36-40	29-35	31-37	28-40	32-41	57-63	87-97	97-111

Table also gives number of sessions, total no. of reversals, and false alarm rate for each frequency.

Ambient noise, from Fig. 4. Levels in dB re 1μPa/($Hz^{1/2}$).

Frequency (kHz)	0.25	0.5	1	2	4	8
Level	51	46	38	38	38	39

Database page ref: M/PorpoiseHarbour/02.

Common name	Harbour porpoise.
Family	
Species	*Phocoena phocoena.*
Paper from which audiogram obtained	Bibikov, N.G. (1992). Auditory brainstem responses in the harbour porpoise (*Phocoena phocoena*). In: 'Marine Mammal Sensory Systems', 197-211. Thomas, J. *et al* (eds). Plenum Press, New York.
Paper having original audiogram data	Bibikov, N.G. (1992). Auditory brainstem responses in the harbour porpoise (*Phocoena phocoena*). In: 'Marine Mammal Sensory Systems', 197-211. Thomas, J. *et al* (eds). Plenum Press, New York.
Comments on methodology of getting audiogram	ABR method. For tests animal was loosely restrained in a bath 2.5mx0.6mx0.65m lined with sound absorbing rubber material and filled with seawater. Dorsal part of head and body, with the active and reference electrodes, was above the water surface. Sound projectors were piezo-electric spheres located underwater 200 to 300mm ahead of the animal. Stimuli were clicks or tone bursts. Some experiments used implanted electrodes – needles located near the dura mater surface or screws located in the porous bone. 3 animals were tested in this way. 1 animal was tested with a 10mm dia. silver disc (the active electrode) placed on the skin surface above the muscles overlying the vertex and a needle inserted into the skin near the dorsal fin as the reference electrode. For the intercranial and bone electrode positions the evoked potentials were amplified and filtered between 50Hz and 4kHz. For surface electrode positions the signals were amplified and filtered between 200Hz and 5kHz. Threshold estimated as the intersection point of the amplitude-intensity curve with the abscissa. For tone burst tests, signal was of 5msec duration, repeated at a rate of 10/sec.
Any other comments	Also did experiments with masking. Comments that this species has excellent echolocation abilities and high frequency narrowband signals for active sonar. Electrophysiological evidence is that it has the highest upper frequency limit of all those investigated.

Audiogram from Fig. 4. Threshold levels in dB re 1µPa (ref. pressure not stated; but believed to be µPa).

Frequency (kHz)	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190
Mean	42	43	42	42	37	32	28	20	9	13	24	25	32	45	47

Database page ref: M/PorpoiseHarbour/03.

Common name	Harbour porpoise.
Family	
Species	*Phocoena phocoena.*
Paper from which audiogram obtained	Popov, V.V., Ladygina, T.F. & Supin, A.Ya. (1986). Evoked potentials of the auditory cortex of the porpoise, *Phocoena phocoena*. J. Comp. Physiol., 158:705-711.
Paper having original audiogram data	Popov, V.V., Ladygina, T.F. & Supin, A.Ya. (1986). Evoked potentials of the auditory cortex of the porpoise, *Phocoena phocoena*. J. Comp. Physiol., 158:705-711.
Comments on methodology of getting audiogram	Tests done in a 3.5 x 0.6 x 0.6m bath filled with seawater. Animal was supported on a stretcher, with the greater part of its body under water. Electrode had been implanted in animal's brain earlier. Immobilisation of the subject was not necessary. The output from the electrode was amplified and filtered between 300Hz and 1kHz and averaged. Stimuli were clicks, pure tones and noise – the clicks were 5μsec pulses and the noise was quasi-white noise. A hydrophone near the animal's head monitored the sound reaching the animal.
Any other comments	4 animals tested, with the electrode at 24 positions in the brain. Also did tests with FM and abrupt changes of level.

Audiogram from Fig. 5B. Threshold levels in dB re 1mPa.

Frequency (kHz)	10	20	30	50	70	100	125	150
Mean	28	22	1	20	16	15	0	43

Threshold levels in dB re 1μPa.

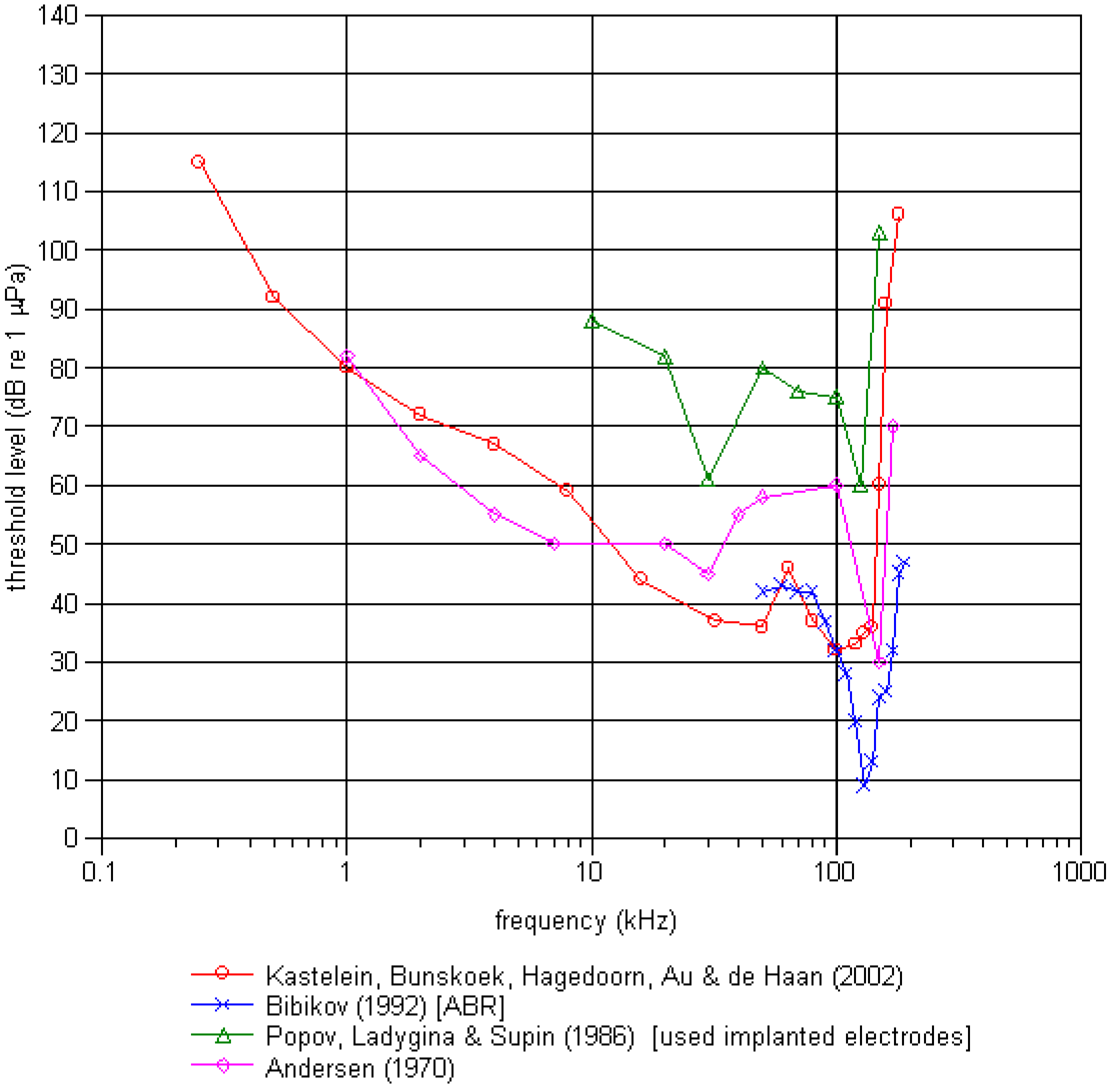
Frequency (kHz)	10	20	30	50	70	100	125	150
Mean	88	82	61	80	76	75	60	103

Database page ref: M/PorpoiseHarbour/04.

Common name	Harbour porpoise
Family	Odontocetes
Species	
Paper from which audiogram obtained	‘Marine Mammals and Noise’, p.209, Fig. 8.1 (A).
Paper having original audiogram data	Andersen, .S. (1970). Auditory sensitivity of the harbour porpoise *Phocoena phocoena*. Invest. Cetacea, 2, 255-259.
Comments on methodology of getting audiogram	Behavioural method. Original source not seen.
Any other comments	Data for 1 animal.

Threshold levels in dB re 1μPa.

Frequency (Hz)	1000	2000	4000	7000	20000	30000	40000	50000	100000	150000	170000
Mean	82	65	55	50	50	45	55	58	60	30	70



[Fig. ref: HarbourPorpoise03]

Audiogram for Harbour porpoise.

Database page ref: M/SeaLionCalifornia/01.

Common name	California sea lion
Family	
Species	*Zalophus californianus*
Paper from which audiogram obtained	Kastak, D. & Schusterman, R.J. (2002). Changes in auditory sensitivity with depth in a free-diving California sea lion (*Zalophus californianus*). JASA, 112(1), 329-333.
Paper having original audiogram data	Kastak, D. & Schusterman, R.J. (2002). Changes in auditory sensitivity with depth in a free-diving California sea lion (*Zalophus californianus*). JASA, 112(1), 329-333.
Comments on methodology of getting audiogram	Subject was 12-yr old male, housed in an open pen at San Diego. Training was done in Bay, and deep tests done in water 250m deep and 10km off the coast. Apparatus was constructed around 310mm dia PVC tube, which was suspended by cable from a research vessel. A horizontal bite plate projected from the bottom of the vertically aligned cylinder. The response paddle was an aluminium plate positioned to the left of the plate. A dive light was positioned in front of the plate. Sound projector was a hydrophone (ITC 1032) fixed in tube in front of subject (there was an aperture in the side of the tube), and an identical hydrophone was located to the side of the plate to sense signal. Video camera was mounted above bite plate to allow monitoring of experiment. Test signals were tones of 500ms duration with 5ms rise and fall times. Procedure was blind – experimenter couldn't see when response was made, and trainer didn't know when signal was triggered. Tests were go/no-go and staircase method. Tests done by starting with level well above threshold, and reducing in 4dB steps until a miss; thereafter steps were 2dB up or down. Required between 7 and 10 reversals to determine threshold, which was mean of reversal points..
Any other comments	Training procedure described fairly fully. Between 2 and 6 sessions were used at each depth/frequency combination. The thresholds determined by the staircase procedure were transformed to constant *d'* thresholds, which adjusted the threshold value to take account of the number of false alarms per session. Notes that subject's response bias changed with depth during training and testing. False alarm rates were double for sessions conducted at 10m depth compared to those at 50 and 100m depth. However, although thresholds were obtained at 100m depth for 2.5 and 6kHz, because there were only a small number of reversals and high variability, these results have been excluded. Authors conclude that subject had a clear tendency to withhold responding at depth

Audiograms from Fig. 3. Threshold levels in dB re 1μPa.

1). At 10m depth.

Frequency (Hz)	2500	6000	10000	35000
Mean	81	79	84	102
SD	±4	±2	±4	±2
No. of trials	2	5	6	4

2). At 50m depth.

Frequency (Hz)	2500	6000	10000	35000
Mean	85	90	100	93
SD	±7	±8	±4	±2
No. of trials	4	4	6	3

Database page ref: M/SeaLionCalifornia/02.

Common name	California sea lion.
Family	
Species	*Zalophus californianus*
Paper from which audiogram obtained	Kastak, D. & Schusterman, R.J. (1998). Low-frequency amphibious hearing in pinnipeds: Methods, measurements, noise and ecology. JASA, 103(4), 2216-2228.
Paper having original audiogram data	Kastak, D. & Schusterman, R.J. (1998). Low-frequency amphibious hearing in pinnipeds: Methods, measurements, noise and ecology. JASA, 103(4), 2216-2228.
Comments on methodology of getting audiogram	1 subject (Rocky) was tested in both air and water, and a second (Rio) was tested in water only. In both air and water cases the response apparatus was a PVC box (450x450x630mm in air, 430x1350x1000mm in water) containing a paddle, which the subject pressed if it heard the test signal. Each box had an aperture in 1 face; this aperture was covered by an opaque Plexiglas cover sliding in grooves; the cover could be raised by a rope to expose the paddle. A chin station was fixed to the box in front of the sliding cover. <u>Aerial tests</u>: earphones secured to neoprene harnesses were placed over the subject's ears. A probe microphone measured the sound level at the opening of the subject's external meatus. Pure tones, of 500ms duration with 40ms rise and fall times, were played to the subject. For a trial, the box cover was raised for between 5 and 7secs. If signal was to be presented, it was sent between 2 and 4secs after the cover was opened. Some 'no-signal' trials were done. Test method was to start with signal at high level and decrease it in 4dB steps until first failure, then raise and lower in 2dB steps. After 3 to 5 sessions in which consistent reversals occurred, a threshold was estimated as the average between the upper and lower limits of the reversals. <u>Underwater tests</u>: were done in a 7.6m pool, which had been acoustically 'mapped' to locate regions where the sound intensity was nearly constant. Subject was stationed in such a volume. Pure tones, of 500ms duration with 40ms rise and fall times, were projected by a J9 transducer placed 1.35m away from the pool wall and 1.57m below the pool rim on an axis shared by the stationing arm, approx. 5m away from the station. Sound pressure levels were measured at the stationing device by a hydrophone. Testing method was similar to that used in air.
Any other comments	Subjects were Rocky (f) {air & water}, Rio (f) {water}. Background noise spectra given in figures; measurements were made in 1/3 octave bands using PC sound card sampling at 22kS/s. Authors note that, in air, placement of earphones reduced ambient noise at the meatus by approx. 7-15dB.

Audiogram from Table I (aerial) and Table II (underwater).

1). **Aerial** - threshold levels for Rocky, in dB re 20μPa.

Frequency (Hz)	100	200	400	800	1600	3200	6400
Mean	77.5	57.5	59.2	63.1	56.9	48.1	31.4
False alarms (% of catch trials)	15.0	17.3	10.5	13.3	3.3	8.8	5.4

2). **Underwater** - threshold levels for Rocky, in dB re 1μPa.

Frequency (Hz)	75	100	200	400	800	1600	6400
Mean	120.6	119.4	103.7	100.0	105.6	78.7	79.8
False alarms (% of catch trials)	13.3	6.6	4.0	11.1	3.3	6.5	3.3

threshold levels for Rio, in dB re 1μPa.

Frequency (Hz)	75	100	200	400	800	1600	6400
Mean	111.9	116.3	100.1	88.9	84.2	69.3	57.1
False alarms (% of catch trials)	3.9	10.0	12.0	4.7	2.9	8.0	10.2

Background noise spectrum levels, **in air**, from Fig. 1. Levels in dB re 20μPa^2/Hz.

Frequency (Hz)	100	200	400	800	1600	3200	6400
Level	12	14	4	0	-5	-10	-7

Background noise spectrum levels, **in water**, from Fig. 2. Levels in dB re 1μPa^2/Hz.

Frequency (Hz)	100	200	400	800	1600	3200	6400
Level	62	54	48	39	34	29	20

Database page ref: M/SeaLionCalifornia/03.

Common name	California sea lion.
Family	
Species	*Zalophus californianus.*
Paper from which audiogram obtained	Kastak, D. and Schusterman, R.J. (1995). Aerial and underwater hearing thresholds for 100 Hz pure tones in two pinniped species. In: 'Sensory Systems of Aquatic Mammals', R.A. Kastelein et al (eds). De Spil Publ., Woerden, Netherlands.
Paper having original audiogram data	Kastak, D. and Schusterman, R.J. (1995). Aerial and underwater hearing thresholds for 100 Hz pure tones in two pinniped species. In: 'Sensory Systems of Aquatic Mammals', R.A. Kastelein et al (eds). De Spil Publ., Woerden, Netherlands.
Comments on methodology of getting audiogram	**In-air**: Tests were done on a haul-out area adjacent to a pool. The subject was fitted with close-fitting earphones in neoprene harnesses. The sound level at the external meatus was measured with an Etymotic ER-7C clinical probe microphone. The response apparatus was an approximately cubical frame which had a sliding door on one of its vertical sides. Behind the door (inside the frame) was a paddle, and to one side of the frame was the stationing position for the subject. When the subject had stationed correctly, the door was raised for between 5 and 7secs, and the test signal was played to the subject between 2 and 4secs after the door was raised (if the trial required the presentation of a signal; 50% of trials were 'catch' trials). If it heard the signal the subject pressed the paddle, if not it stayed at station. Correct responses were rewarded with a piece of fish. The test signal had a duration of 500ms and rise and fall times of 40ms. **Underwater**: The tests were carried out in a 7.6m dia. concrete pool. The response apparatus was similar to that used in air, but a little larger. The subject's stationing position was 1.35m away from the pool wall and 1.57m below the pool rim. Signals were projected by a J9 transducer. Sound levels at the stationing device were measured with an H56 hydrophone. Tests were done in the same way as in air. **Procedure**: Two types of testing were done. (1) A staircase method, in which the signal level was decreased in 4dB steps until the subject failed to detect the signal. Thereafter the level was increased and decreased in 2dB steps to establish a series of reversals. After 3 to 5 sessions in which consistent reversals occurred a threshold value was calculated as the average between the upper and lower levels of the reversals. (2) A constant stimulus method, in which a series of 6 levels (separated by 4dB) from a 20dB range spanning the estimated threshold level were used. In a session, which consisted of 60 trials (50% with signal, 50% catch trials), 5 trials of each level were randomly presented. After 5 days using this method, the percentage of correct detections at each sound level was calculated, and the level which had 50% correct detections was taken to be the threshold level.
Any other comments	Subjects were Rocky, a 17-year old female, and Rio, a 7-year old female. In air, noise levels (measured with earphones on) at 100Hz ranged from 35 to 40dB re 20μPa, which was 15 to 20dB lower than typical ambient noise levels without earphones. In water, the ambient noise level was 71dB re 1μPa.

Threshold level **in air**: 78dB re 20μPa (Rocky).

Threshold levels **in water**: 119dB re 1μPa (Rocky); 116dB re 1μPa (Rio).

Database page ref: M/SeaLionCalifornia/04.

Common name	California sea lion.
Family	
Species	*Zalophus californianus*
Paper from which audiogram obtained	Moore, P.W.B. & Schusterman, R.J. (1987). Audiometric assessment of northern fur seals, *Callorhinus ursinus.* Marine Mammal Science, 3(1), 31-53.
Paper having original audiogram data	Moore, P.W.B. & Schusterman, R.J. (1987). Audiometric assessment of northern fur seals, *Callorhinus ursinus.* Marine Mammal Science, 3(1), 31-53.
Comments on methodology of getting audiogram	Obtained in-air audiogram for 1 subject. Tests conducted in wooden box divided into testing and experimenter's areas. Testing chamber was 2.9x1.5x1.8m internally, and lined with 85mm thick convoluted acoustic foam. Experimenter's area was at one end of box (with access via door in outside wall) and with observation and feeding ports in dividing wall. Subject stationed in a nose cup 510mm above floor and 250mm away from exterior wall and 730mm from dividing wall. Nose cup was 90mm dia cylinder of Plexiglas with a cone-shaped hollow centre. Embedded in the cup were 3 small lamps that acted as a trial warning light. Response paddle was a 115mm Plexiglas disc mounted 530mm above the floor, 1m away from the nose cup. Test signal was projected by a Jensen Model 41moving coil and tweeter combination for frequencies of 500Hz to 8kHz, or a Lansing Model 075 tweeter for frequencies of 16 to 32kHz. The Jensen speaker was 1.13m away from the nose cup, on the opposite side to the paddle. The Lansing speaker was 650mm away from the cup, 1m above the floor and pointing down towards the cup. When subject was in position with nose in cup, trial was started – lights in nose cup illuminated for 6sec. If trial was one in which signal was to be played, a 0.5sec duration tone, with 40msec rise and fall times, was played 2sec after cup light came on. If no signal, subject should have remained at cup. Correct responses rewarded with piece of fish. Procedure was up-down one – started at a high level and decreased in 2dB steps until a 'miss', then increased in 1dB steps until 'hit' occurred. Thereafter changes were in 1dB steps. Session started with 20 'warm-up' trials, then at least 50 'threshold' trials (if warm-up period had been satisfactory), then 10 'cool-off' trials. Warm-up and cool-off levels were at least 10-15dB above threshold. Threshold taken to be mean value of all reversals. Minimum number of runs for a threshold estimate at a given frequency was set at 20 – this required 2 or 3 daily sessions.
Any other comments	Subject (Rocky) was tested early in the morning, and fed in the afternoon, so it wasn't fed for about 18hrs prior to testing. Signal and ambient noise level measured at start of experiment with B&K 2203 Precision Sound Level Meter with 4145 or 4135 microphone capsule and 1613 octave filter set. Krohn-Hite 3550 filter set used for 24, 28 and 32kHz measurements. 10 readings taken, and average taken to be noise level. Ambient noise values given in text; measurements were in octave bands, and results given are:– Frequency (kHz): 0.5, 1, 2, 4, 8, 16, 32 Level (dB re 0.0002dynes/cm^2): 16, 14, 10, 9, 9, 1, – Authors state that levels beyond 2kHz are more likely peak levels because of limitations of instrumentation. (No indication why discrepancy between number of bands and levels). Also, background noise level curve, in 1/3 octave bands, given in Fig. 3.

Frequency (kHz)	0.5	1	2	4	8	16	32
Level (dB re 0.0002dynes/cm^2)	16	14	10	9	9	1	

Audiogram, **in-air**, from Table 1.

Frequency (kHz)	1.0	2.0	4.0	8.0	16.0	24.0	32.0
Mean threshold level (dB re 0.0002dynes/cm^2)	41	19	26	16	28	37	61
SD	3	3	2	2	3	3	2
False alarms (%)	4	5	8	10	7	7	6
Mean threshold level (db re 20µPa)	41	19	26	16	28	37	61

Background noise levels, in 1/3 octave bands, from Fig. 3.

Frequency (kHz)	1.25	2	4	8
Level (dB re 0.0002dynes/cm^2)	9	5	4	5
Level (db re 20µPa)	9	5	4	5

NOTE: Authors state in discussion section that earlier results {Schusterman, JASA, 75(6), 1248-1251. (1974)} may have been masked below 18kHz.

Database page ref: M/SeaLionCalifornia/05.

Common name	California sea lion
Family	*Phocidae.*
Species	*Zalophus californianus.*
Paper from which audiogram obtained	Schusterman, R.J. (1974). Auditory sensitivity of a California sea lion to airborne sound. JASA, 56, No. 4, 1248-1251.
Paper having original audiogram data	Schusterman, R.J. (1974). Auditory sensitivity of a California sea lion to airborne sound. JASA, 56, No. 4, 1248-1251.
Comments on methodology of getting audiogram	Tests were done in the evening in an outdoor 4.6x9.1x1.8m oval-shaped redwood tank. Water level in tank was such that the whole of subject's head, including its meatal orifice, was in air while the rest of its body was in water. Sound source was JBL Model 75 tweeter, mounted on the rim of the tank and directly facing the headrest position. Subject's head was approx. 1.1m from speaker, 2m from the sides of the tank, and 0.8m from the top of the tank. A trial consisted of a light that was turned on for 2.5sec; with a tone projected for the last 0.5sec in those trials that involved a signal. The tone had rise and fall times of 100msec. A 'correct' response was defined as either emitting a burst of clicks within 1.5sec of tone onset, or remaining silent for 3.5sec after light presentation. In tests tone intensity was decreased by 4dB if subject made 7 or more correct responses in 10 successive trials. If this criterion was not met, tone intensity as increased by 12dB. For each frequency, threshold was defined as the interpolated dB value at which subject responded correctly 75% of the time. Thresholds were obtained at least twice for each frequency – variability between measurements never exceeded ±1dB.
Any other comments	Subject was a 5 to 6 yr old male, which had previously been used to establish an underwater audiogram (Schusterman (1972)). In those experiments subject had been trained to emit a burst of clicks when it heard a pure tone preceded by a warning light, and to remain silent if it didn't hear a tone following the warning light. In these in-air tests the same procedure was used. Vocalisations made by sea lions with their mouths closed and out of water may still be projected underwater by the larynx and sensed by a hydrophone. Tests at 1 and 2kHz were considered to be affected by the somewhat high ambient noise, so results presented for only 4kHz and upwards. (**NOTE:** In a later paper (Moore & Schusterman (1987)) the authors state that they later came to think that values below 18kHz may have been affected by ambient noise).

Audiogram from Fig. 1. Threshold levels in dB re 0.0002dynes/cm^2.

Frequency (kHz)	4	8	16	24	28	32
Mean	31	35	37	37	40	51

Threshold levels in dB re 20µPa.

Frequency (kHz)	4	8	16	24	28	32
Level	31	35	37	37	40	51

Database page ref: M/SeaLionCalifornia/06.

Common name	California sea lion.
Family	Otariid
Species	*Zalophus*
Paper from which audiogram obtained	Schusterman, R.J. (1975). Pinniped sensory perception. Rapp. P.-v. Reun. Cons. int. Explor. Mer, 169: 165-168.
Paper having original audiogram data	Schusterman, R.J., Balliet, R.F. & Nixon, J. (1972). Underwater audiogram of the California sea lion by the conditioned vocalization technique. J. Exp. Anal. Behav., 17:339-350.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	

1). **In water.** Audiogram from Fig. 131. Threshold levels in dB re 1μbar.

Frequency (kHz)	1	2	4	8	16	25	27	32	35	43	64
Level	-4	-17	-4	-17	-23	-17	-15	-3	27	38	45

Threshold levels in dB re 1μPa.

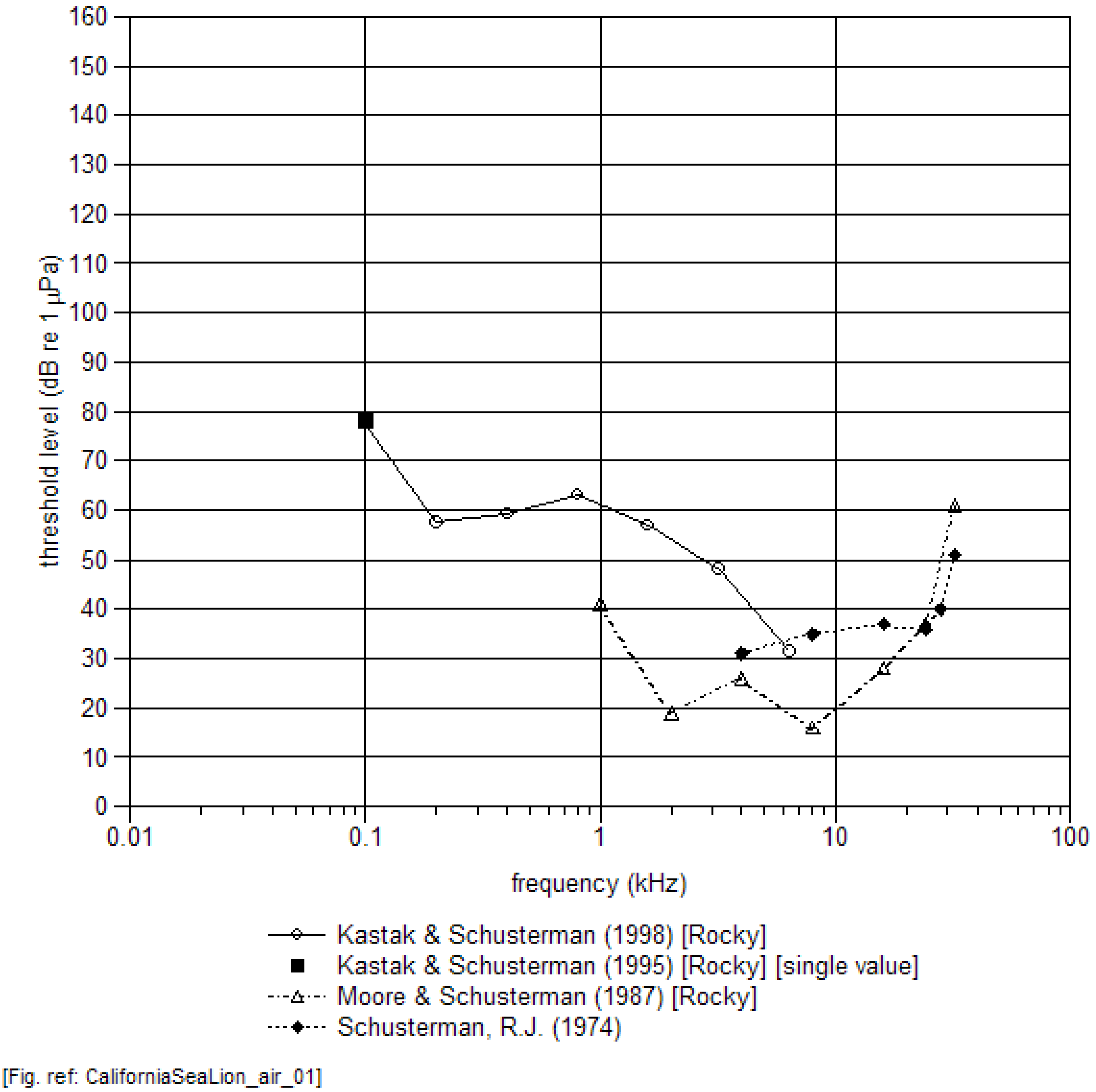
Frequency (kHz)	1	2	4	8	16	25	27	32	27	38	64
Level	96	83	96	83	77	83	85	97	127	138	145

2). **In air**. Audiogram from Table 16. Threshold levels in dB re 0.0002dynes/cm^2.
This is data which is described as ‘unpublished’.

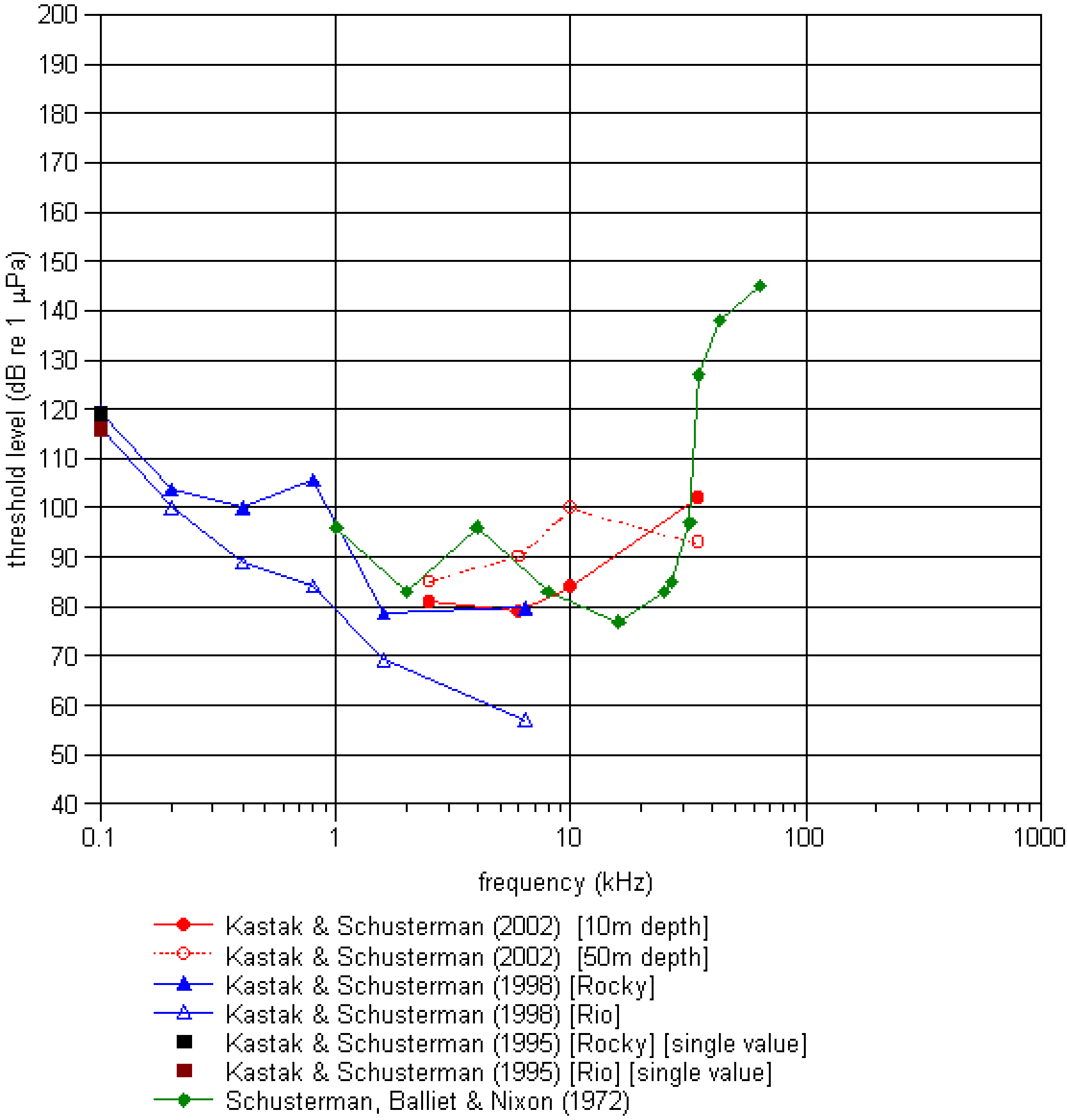
Frequency (kHz)	4	8	16	24	28	32
Level	31	35	36	36	40	51

Threshold levels in dB re 20μPa.

Frequency (kHz)	4	8	16	24	28	32
Level	31	35	36	36	40	51



Audiogram for California sea lion, for air.



[Fig. ref: CaliforniaSeaLion_water_01]

Audiogram for California sea lion, for water.

Database page ref: M/SealGrey/01.

Common name	Grey seal.
Family	
Species	*Halichoerus grypus.*
Paper from which audiogram obtained	Ridgway, S.H. & Joyce, P.L. (1975). Studies on seal brain by radiotelemetry. Rapp. P.-v. Reun. Cons. Int. Explor. Mer, 169, 81-91.
Paper having original audiogram data	Ridgway, S.H. & Joyce, P.L. (1975). Studies on seal brain by radiotelemetry. Rapp. P.-v. Reun. Cons. Int. Explor. Mer, 169, 81-91.
Comments on methodology of getting audiogram	Used cortical evoked response method. Electrodes and transmitter were fixed to the subject's head, which was able to swim as normal afterwards. 1 subject had a 3-channel telemetry system, while other 3 had 1-channel systems, fitted. Sound stimuli were tone bursts of 100ms duration with rise and decay times of 10ms. Tones were projected at rate of 1/sec. Output of EEG decoder was fed to a signal averager – response to 100 bursts averaged for each record. Subject was tested in water tank (about 2x1x1m, but this is unclear from the text) with its chest on the tank floor and its tail resting on the lip of the tank. The sound projector was located adjacent to the wall opposite the subject. For tests in water, F-33 hydrophone was used. For tests in air the tank was left empty and an 8-inch speaker used for frequencies of 250Hz to 5kHz, and a tweeter for frequencies of 5 to 30kHz. For in-air case sound field in vicinity of subject's head was measured with a B&K 0.25-inch microphone.
Any other comments	4 subjects (2 males, 2 females). Had been born on islands off coast of Iceland, probably in Sept. 1970. They were collected in late Oct., and flown to Cambridge, U.K. in Nov. They were about 18 months old when experiments took place. In-air evoked responses obtained from all subjects, but a complete audiogram was obtained for only 1 subject as the subjects climbed out of the pool as soon as it was drained. In discussion section, authors note that subjects were most sensitive, in water, at about 20 to 25kHz, and, in air, at about 4kHz. They surmise that this may be due to animal's ability to close its external auditory meatus when it submerges.

Audiogram from Fig. 47. Threshold levels.

1). **In water.**

a). Seal 6 (female).

Frequency (kHz)	2	5	10	20	30	40	50	75	110	130	150
Level (dB re 1μbar)	-16	-20	-20	-38	-33	-20	-9	18	26	32	48
Level (dB re 1μPa)	84	80	80	62	67	80	91	118	126	132	148

b). Seal 8 (female)

Frequency (kHz)	1.4	4	10	20	25	30	40	60	90	120	140
Level (dB re 1μbar)	-17	-16	-27	-35	-39	-30	-16	-3	27	45	90
Level (dB re 1μPa)	83	84	73	65	61	70	84	97	127	145	190

2). **In air**

a). Seal 6 (female)

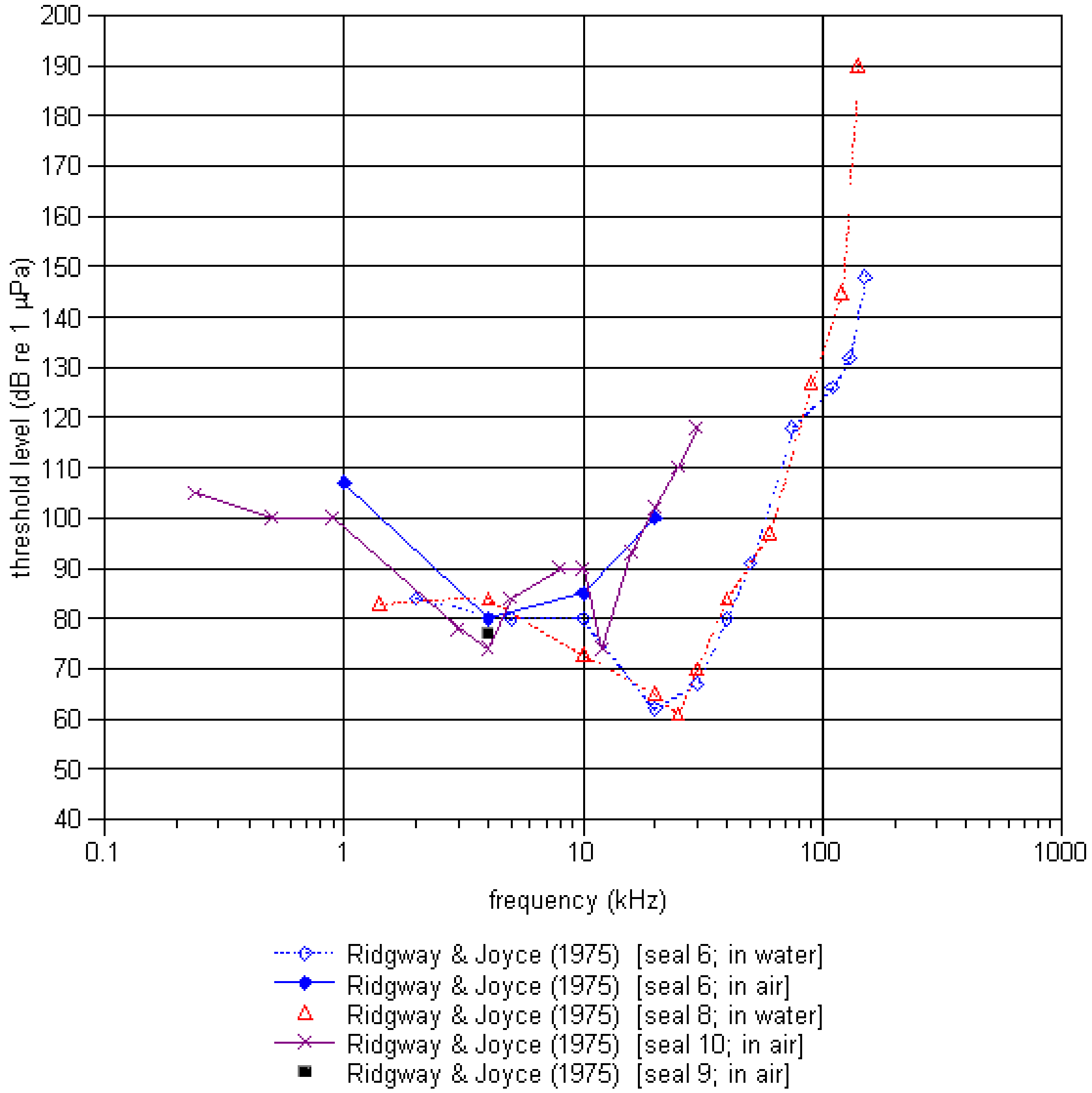
Frequency (kHz)	1	4	10	20
Level (dB re 1μbar)	7	-20	-15	0
Level (dB re 1μPa)	107	80	85	100

b). Seal 9 (male)

Frequency (kHz)	4
Level (dB re 1μbar)	-23
Level (dB re 1μPa)	77

c) Seal 10 (male)

Frequency (kHz)	0.24	0.5	0.9	3	4	5	8	10	12	16	20	25	30
Level (dB re 1μbar)	5	0	0	-22	-26	-16	-10	-10	-26	-7	2	10	18
Level (dB re 1μPa)	105	100	100	78	74	84	90	90	74	93	102	110	118



[Fig. ref: GreySeal01]

Audiogram for the Grey seal.

Database page ref: M/SealHarbour/01.

Common name	Harbour seal.
Family	
Species	*Phoca vitulina.*
Paper from which audiogram obtained	Wolski, L.F., Anderson, R.C., Bowles, A.E & Yochem, P.K. (2003). Measuring hearing in the harbor seal (*Phoca vitulina*): Comparison of behavioral and auditory brainstem response techniques. JASA, 113(1), 629-637.
Paper having original audiogram data	Wolski, L.F., Anderson, R.C., Bowles, A.E & Yochem, P.K. (2003). Measuring hearing in the harbor seal (*Phoca vitulina*): Comparison of behavioral and auditory brainstem response techniques. JASA, 113(1), 629-637.
Comments on methodology of getting audiogram	(1) – **Behavioural methods**. Subject entered a box 1.78x0.76x0.76m made from 13mm thick plywood and 52.5mm thick Sonex acoustic foam. The box reduced sound level by 20 to 30dB from ambient between 200Hz and 30kHz. Test signal was presented by 2 Polk M4 speakers used in parallel. 1 speaker was mounted above and to the side of the seal's head (along one of the upper edges of the box, and approx. 1m away from animal's ear), and the other was mounted on the roof of the box 1.2m behind the seal's head. Sound level around the subject's head varied by <±2dB. The sound level at each test frequency was measured before and after each trial block; the test before the trial block was done with a dummy seal head in position and a microphone at the subject's meatus position. There were 2 target stations at the end of the box. Subject stationed on one ('RT'), and, if a stimulus was presented and she heard it, she moved to touch the 'yes' target ('YT') and then returned to RT. The seal had to move within 2s after the tone was played to score a 'hit'. If seal moved at any other time from RT to YT it was deemed a false alarm. 2 to 5 testing blocks were conducted each day, each block consisting of 26 trials (70% signal-present, 30% signal-absent). 2 ways of presenting the stimuli were used. (i) **constant stimulus**. 30% of the 3699 behavioural trials were of this sort. A testing block consisted of a tone at a single frequency being presented at various amplitudes, with catch trials interspersed (30% of trials). Minimum difference between any 2 stimulus amplitudes was set to 5dB. Each frequency was tested in at least 4 testing blocks, totalling approx. 80 trials per frequency. The tones were of 500ms duration with 0.5ms rise time and were Blackman filtered. To arrive at threshold value, the percentage of positive responses for each sound level presented during that day's session was calculated, and the lowest level at which the animal responded positively 70% of the time was deemed to be the threshold. Trial blocks in which the false response rate and/or the false alarm rate were above 10% were excluded. (ii) **staircase method**. 70% of the behavioural trials were of this sort. Starting from a high level, the sound level was reduced in 5dB steps until seal failed to respond. The next tone was increased by 10dB. If seal scored a 'hit' at this level the level was reduced in 5dB steps until another miss was scored. 5 such series of descending intensity levels were performed in each trial block. For each descent the mid-value between the lowest level at which the seal scored a hit and the level at which it failed to respond was taken as the intermediate threshold value. There were thus 5 intermediate threshold values per block, and the final threshold value was arrived at by taking the average of these 5. (2) – **ABR method**. Subject was placed on a restraint board fitted with 2-inch nylon straps and a neck board, and was sedated with diazepam to reduce muscle activity. Dosage was such that it was unlikely that ABR morphology or amplitude was affected. ECG, EOG and EMG were measured at same time.

	ABRs were measured using a turnkey measurement system (Bio-Logic Traveller SE computer running the Evoked Potential (EP) programme) which generates stimulus waveforms and simultaneously acquires evoked responses. 3 platinum-iridium electrodes were inserted subdermally on the seal's head – ref. electrode between right auditory meatus and mastoid, active electrode at vertex of head along the plane of the ref. electrode, and a ground at the nape of the neck. Both tone bursts and clicks (wideband signals) were used as stimuli. Tone bursts were 5 cycles in length, with 2 cycles each for rise and fall and 1 cycle at plateau. Rise and decay were Blackman filtered. Both types of stimulus were presented at rate of 29.3/s. Sound signals were radiated by a Polk M-4 Studio Tweeter. Levels were calibrated with 2 ACO 7013 microphones, 1 ('ear microphone') near the seal's meatus location, the other ('ref. microphone') 300mm from the tweeter and 700mm from the animal's head. Sound levels were calibrated for the ear microphone position and the corresponding ref. microphone level noted. For each frequency stimulus level was reduced in 10dB steps until the most prominent peak was reduced in amplitude. From this point the stimulus level was reduced in 5dB steps until the peak could no longer be detected. 2 to 5 repeats were made at each stimulus level for each frequency. Threshold values were deemed to be the lowest levels at which the most prominent peak was detectable, repeatable in replicates, and above the background noise. **Comparison of results**. To compare audiograms obtained using auditory stimuli of different durations a normalizing procedure has been used. Time waveforms for each stimulus were recorded and the RMS sound pressure (Pa) for each stimulus intensity was calculated. These values were expressed as levels in dB re 20μPa. The duration of the stimulus was then used to calculate the energy level in db re 20μPa^2.s).
Any other comments	Subject was adult female, 4yrs old and naïve to testing procedures when study began. She was a beached, rehabilitated animal at the Wild Arctic facility at SeaWorld, San Diego. Behavioural testing took place between Aug. 1998 and Sept. 1999, following 6 months of training in the procedures. ABR testing was done in 1 day, 30 Aug. 1999. For *method of constant stimuli*, 13 of 79 testing blocks had false alarm rates above 10% and were not included in analysis. False response rates were <9% during catch trials. For *staircase method*, only 4 out of 100 blocks were discarded because of high false alarm rates. False response rates were <6% during catch trials. For *ABR method*, click and tone burst stimuli produced similar ABR waveforms. The latencies of the ABR peaks increased as the intensity of the stimulus was reduced.

Audiogram from Table I. **Method of constant stimuli**. Threshold levels in dB re reference quantities noted.

Frequency (kHz)	0.25	0.50	1.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0
Mean (dB re 20μPa^2.s) RMS	61.0	51.8	45.8	42.0	31.5	23.1	22.9	20.8	14.7	20.2
SD (dB re 20μPa^2.s) RMS	4.2	4.5	4.8	7.4	5.0	4.9	7.4	6.3	4.0	5.4
Mean (dB re 20μPa)	64.0	54.8	48.8	45.0	34.5	26.1	25.9	23.8	17.7	23.2
Total no. of trials	97	67	69	107	207	150	126	162	51	75

Audiogram from Table II. **Staircase method** Threshold levels in dB re. reference quantities noted

Frequency (kHz)	0.25	0.50	1.0	1.50	2.0	3.0	4.0	6.0	8.0
Mean (dB re 20μPa^2.s) RMS	44.5	34.5	27.8	35.3	39.6	26.1	26.8	10.9	8.1
SD (dB re 20μPa^2.s) RMS	3.3	2.6	2.7	1.0	4.9	2.2	2.9	2.3	2.4
Mean (dB re 20μPa)	47.5	37.5	30.8	38.3	42.6	29.1	29.8	13.9	11.1
No. of reversals	23	28	24	32	52	25	24	28	32
Total no. of trials	137	130	132	133	231	133	139	142	162
Frequency (kHz)	10.0	12.0	14.0	16.0	18.0	20.0	22.0	25.0	30.0
Mean (dB re 20μPa^2.s) RMS	12.8	10.1	23.1	24.3	27.7	25.0	25.6	29.3	39.9
SD (dB re 20μPa^2.s) RMS	3.0	1.2	2.4	2.4	3.6	3.6	3.7	2.0	2.9
Mean (dB re 20μPa)	15.8	13.1	26.1	27.3	30.6	28.0	28.6	32.5	42.9
No. of reversals	27	25	33	30	28	29	28	28	27
Total no. of trials	139	137	157	134	137	141	135	137	132

Audiogram from Fig. 3. **ABR method, using tone bursts**. Threshold levels in dB re. reference quantities noted

Frequency (kHz)	2.0	4.0	8.0	16.0	22.0
Mean (dB re 20μPa^2.s) RMS	45	32	(15)	(17)	28

NOTE: The values at 8 and 16kHz are **not** threshold values; they are the lowest intensities at which a positive ABR was generated before the test stimulus dropped into the noise floor.

Database page ref: M/SealHarbour/02.

Common name	Harbour seal.
Family	
Species	*Phoca vitulina.*
Paper from which audiogram obtained	Kastak, D. & Schusterman, R.J. (1998). Low-frequency amphibious hearing in pinnipeds: Methods, measurements, noise and ecology. JASA, 103(4), 2216-2228.
Paper having original audiogram data	Kastak, D. & Schusterman, R.J. (1998). Low-frequency amphibious hearing in pinnipeds: Methods, measurements, noise and ecology. JASA, 103(4), 2216-2228.
Comments on methodology of getting audiogram	Subject was tested in both air and water. In both cases the response apparatus was a PVC box (450x450x630mm in air, 430x1350x1000mm in water) containing a paddle, which the subject pressed if it heard the test signal. Each box had an aperture in 1 face; this aperture was covered by an opaque Plexiglas cover sliding in grooves; the cover could be raised by a rope to expose the paddle. A chin station was fixed to the box in front of the sliding cover. Aerial tests: earphones secured to neoprene harnesses were placed over the subject's ears. A probe microphone measured the sound level at the opening of the subject's external meatus. Pure tones, of 500ms duration with 40ms rise and fall times, were played to the subject. For a trial, the box cover was raised for between 5 and 7secs. If signal was to be presented, it was sent between 2 and 4secs after the cover was opened. Some 'no-signal' trials were done. Test method was to start with signal at high level and decrease it in 4dB steps until first failure, then raise and lower in 2dB steps. After 3 to 5 sessions in which consistent reversals occurred, a threshold was estimated as the average between the upper and lower limits of the reversals. Underwater tests: were done in a 7.6m pool, which had been acoustically 'mapped' to locate regions where the sound intensity was nearly constant. Subject was stationed in such a volume. Pure tones, of 500ms duration with 40ms rise and fall times, were projected by a J9 transducer placed 1.35m away from the pool wall and 1.57m below the pool rim on an axis shared by the stationing arm, approx. 5m away from the station. Sound pressure levels were measured at the stationing device by a hydrophone. Testing method was similar to that used in air.
Any other comments	Subject was Sprouts (m). Background noise spectra given in figures; measurements were made in 1/3 octave bands using PC sound card sampling at 22kS/s. Authors note that, in air, placement of earphones reduced ambient noise at the meatus by approx. 7-15dB.

Audiogram from Table I (aerial) and Table II (underwater).

1). **Aerial** - threshold levels in dB re 20μPa.

Frequency (Hz)	100	200	400	800	1600	3200	6400
Mean	65.4	57.2	52.9	26.1	42.8	30.2	19.2
False alarms (% of catch trials)	6.0	11.9	3.3	6.7	11.6	4.1	2.8

2). **Underwater** - threshold levels in dB re 1μPa.

Frequency (Hz)	75	100	200	400	800	1600	6400
Mean	101.9	95.9	83.8	83.9	79.8	67.1	62.8
False alarms (% of catch trials)	2.3	5.3	7.9	8.8	10.1	3.3	6.0

Background noise spectrum levels, **in air**, from Fig. 1. Levels in dB re 20μPa^2/Hz.

Frequency (Hz)	100	200	400	800	1600	3200	6400
Level	12	14	4	0	-5	-10	-7

Background noise spectrum levels, **in water**, from Fig. 2. Levels in dB re 1μPa^2/Hz.

Frequency (Hz)	100	200	400	800	1600	3200	6400
Level	62	54	48	39	34	29	20

Database page ref: M/SealHarbour/03.

Common name	Harbour seal.
Family	
Species	*Phoca vitulina.*
Paper from which audiogram obtained	Kastak, D. and Schusterman, R.J. (1995). Aerial and underwater hearing thresholds for 100 Hz pure tones in two pinniped species. In: 'Sensory Systems of Aquatic Mammals', R.A. Kastelein et al (eds). De Spil Publ., Woerden, Netherlands.
Paper having original audiogram data	Kastak, D. and Schusterman, R.J. (1995). Aerial and underwater hearing thresholds for 100 Hz pure tones in two pinniped species. In: 'Sensory Systems of Aquatic Mammals', R.A. Kastelein et al (eds). De Spil Publ., Woerden, Netherlands.
Comments on methodology of getting audiogram	**In-air**: Tests were done on a haul-out area adjacent to a pool. The subject was fitted with close-fitting earphones in neoprene harnesses. The sound level at the external meatus was measured with an Etymotic ER-7C clinical probe microphone. The response apparatus was an approximately cubical frame which had a sliding door on one of its vertical sides. Behind the door (inside the frame) was a paddle, and to one side of the frame was the stationing position for the subject. When the subject had stationed correctly, the door was raised for between 5 and 7secs, and the test signal was played to the subject between 2 and 4secs after the door was raised (if the trial required the presentation of a signal; 50% of trials were 'catch' trials). If it heard the signal the subject pressed the paddle, if not it stayed at station. Correct responses were rewarded with a piece of fish. The test signal had a duration of 500ms and rise and fall times of 40ms. **Underwater**: The tests were carried out in a 7.6m dia. concrete pool. The response apparatus was similar to that used in air, but a little larger. The subject's stationing position was 1.35m away from the pool wall and 1.57m below the pool rim. Signals were projected by a J9 transducer. Sound levels at the stationing device were measured with an H56 hydrophone. Tests were done in the same way as in air. **Procedure**: Two types of testing were done. (1) A staircase method, in which the signal level was decreased in 4dB steps until the subject failed to detect the signal. Thereafter the level was increased and decreased in 2dB steps to establish a series of reversals. After 3 to 5 sessions in which consistent reversals occurred a threshold value was calculated as the average between the upper and lower levels of the reversals. (2) A constant stimulus method, in which a series of 6 levels (separated by 4dB) from a 20dB range spanning the estimated threshold level were used. In a session, which consisted of 60 trials (50% with signal, 50% catch trials), 5 trials of each level were randomly presented. After 5 days using this method, the percentage of correct detections at each sound level was calculated, and the level which had 50% correct detections was taken to be the threshold level.
Any other comments	Subject (Sprouts) was a 5-year old male. In air, noise levels (measured with earphones on) at 100Hz ranged from 35 to 40dB re 20μPa, which was 15 to 20dB lower than typical ambient noise levels without earphones. In water, the ambient noise level was 71dB re 1μPa.

Threshold level, **in air**, 65 dB re 20μPa.

Threshold level, **in water**, 96 dB re 1μPa.

Database page ref: M/SealHarbour/04.

Common name	Harbour seal.
Family	
Species	*Phoca vitulina.*
Paper from which audiogram obtained	Terhune, J.M. (1988). Detection thresholds of a harbour seal to repeated underwater high-frequency, short-duration sinusoidal pulses. Can. J. Zool., 66: 1578-1582.
Paper having original audiogram data	Terhune, J.M. (1988). Detection thresholds of a harbour seal to repeated underwater high-frequency, short-duration sinusoidal pulses. Can. J. Zool., 66: 1578-1582.
Comments on methodology of getting audiogram	Tests were carried out in a 4.5m dia, 1m deep tank. A 'stimulus switch', to be pushed by the subject, was located at the centre of the tank, 0.5m from the sound source (a B&K 8100 hydrophone) and 0.5m above the tank bottom. While switch was pressed a signal was emitted (if not a catch trial), and if subject heard it it was trained to push a response 'yes' switch some distance away. If it did not hear a signal it pushed another response 'no' switch on the opposite side of the tank. Correct responses were rewarded with a fish; incorrect responses got no reward and a lamp was lit. A signal, controlled by the seal's pushing of the stimulus switch, was generated and its level adjusted as desired. Sinusoidal pulses of 1 to 64kHz (in octave steps) for durations of 500, 100, 50, 10, 5, 1 and 0.1ms were produced; their production rates were:- 1/s (500ms duration), 4/s (100 and 50ms) and 10/s. The signal began and ended at volts. The signal, after having had its level set, was passed through a filter set to pass 1 octave above and below the centre frequency before being fed to the transmitter. Signal pressure at subject's ear was measured by B&K 8100 in absence of seal – there was some variation in the field. Procedure was to present signal (at given frequency and duration) at high level for first trial, and a catch trial for second. Usually third trial was a 'with-signal' one at an intermediate level. Thereafter presented 10 signal trials (all at same level) and 10 catch trials intermingled. At each freq/durn. pair first session was at above threshold level; for subsequent sessions signal level was decreased in 4dB steps, until a session occurred where subject's summed signal and catch trials were 50% correct. Next session had signal increased by 2dB, and thereafter level was increased by 4dB. The data from the lowest 3 to 6 signal levels were used to calculate threshold level.
Any other comments	Subject was a 5-yr old seal housed in the test tank. Training or test sessions were normally held 3 times a day, at least 2hrs apart, 5 or 6 days a week. Levels for ambient noise given as:- at 1kHz, below 53dB re 1μPa/Hz$^{1/2}$; at 2kHz, below 52dB re 1μPa/Hz$^{1/2}$; between 4 and 64kHz, below 51dB re 1μPa/Hz$^{1/2}$ (the self-noise of the equipment).

Audiogram from Fig. 1. Values for 500ms duration pulses Threshold levels in dB re 1μPa.

Frequency (kHz)	1	2	4	8	16	32	64
Mean	67	71	69	56	60	73	113

Also from Fig. 1 of this (Terhune) paper, audiogram from Mohl (1968). Auditory sensitivity of the common seal in air and water. J. Aud. Res., 8:27-38. Threshold levels in dB re 1μPa.

Frequency (kHz)	1	2	4	8	16	32	64
Mean	83	75	73	66	63	62	106

Database page ref: M/SealHarbour/05.

Common name	Common seal.
Family	
Species	*Phoca vitulina vitulina.*
Paper from which audiogram obtained	Møhl, B. (1968). Auditory sensitivity of the Common seal in air and water. Jnl. of Auditory Research, 8, 27-38.
Paper having original audiogram data	Møhl, B. (1968). Auditory sensitivity of the Common seal in air and water. Jnl. of Auditory Research, 8, 27-38.
Comments on methodology of getting audiogram	Tests were conducted in a wire mesh pen 8x10x3m deep which was located in an old harbour no longer open to traffic. There was a small raft in the pen for the seal to haul out on. Procedure was for subject to press a lever, which caused a pure tone signal to be emitted by the projector (for cases which were not catch trials). Subject then had to press either of 2 levers depending on whether or not it had heard the signal. The signal had rise and fall times of 80msec, but its duration was determined by the subject – it was emitted for as long as the lever was pressed. A session consisted of 20 trials, half of which were catch trials. A correct response was rewarded with a piece of fish; an incorrect response was rewarded with a blast of air in the subject's face. In **water** Dyna Empire TR 127 (1 to 16kHz) and TR129 (32 to 180kHz) transmitters were used. Another pair of these was used as receiving hydrophones. The projector was located in a corner of the pen and was aligned at 45º to the pen's wall. The monitoring hydrophone and signal initiation lever were located along the same axis 1.829m (2yds) away. Projector and monitoring 'phone were at a mean depth of 800mm below the surface. In **air** a Peerless MI 25 loudspeaker was used for frequencies of 1 to 16kHz, and a TR129 emitter for 22.5kHz. The monitoring microphone was a Melodium Model 88. The loudspeaker, and initiation lever with adjacent microphone, were mounted at each end of and 300mm above a 1m long rockwool-covered raft – this gave a close approximation to a free-field situation. Also took background noise measurements, although self-noise of the system did not allow measurements at all the frequencies at which threshold tests were carried out.
Any other comments	Subject was male, presumed to be 3 or 4 years old, came from Copenhagen zoo. Previously had been used in experiment on pitch discrimination, in same facility. Author notes that the interference between the direct and surface-reflected waves affected the variance of the results in the **water** case. Also notes that the subject would stop if the background noise increased markedly (e.g aircraft passing), and usually repeated low level signal and catch trials 1 or 2 times before deciding on a response. Regarding the in-air audiogram, author comments that dip at 2kHz is believed to be a genuine property of the seal's hearing in air and not an artefact of the experimental procedure – an extensive examination of the sound field was made with a sound level meter. Background noise was measured, in air, using a B&K 2203 SLM with 1613 1/1 octave filter set, and, in water, a TR127 hydrophone and calibrated amplifier.

Audiograms from Table II.

1). **In water**. Threshold levels.

Frequency (kHz)	1	2	4	8	16	32	45	64	90	128	180
Mean level (dB re 1μbar)	(-16)	(-25)	-27	-33	-36	-37	-28	6	20	25	(33)
SD	9	5	7	4	5	5	3	5	4	(4)	2
No. of catch trials	67	78	63	60	68	76	66	82	50	66	74
% correct catch trials	96	96	100	98	94	95	98	96	100	100	97
Mean level (dB re 1μPa)	(84)	(75)	73	67	64	63	72	106	120	125	(133)

NOTE: The threshold levels at 1, 2 & 180kHz are based on extrapolations; the values at the 2 lower frequencies are considered by the author to be reasonable; the value at 180kHz is considered to be indicative only.

2). **In air**. Threshold levels in dB re $2x10^{-4}$μbar.

Frequency (kHz)	1	1.42	2	2.83	4	8	11.25	16	22.5
Mean	36	34	19	22	26	19	16	26	(58)
SD	4	5	3	5	4	4	5	2	4
No. of catch trials	64	47	64	57	50	52	48	70	39
% correct catch trials	97	100	94	98	96	100	100	100	87
Mean level (dB re 20μPa)	36	34	19	22	26	19	16	26	(58)

Background noise spectrum levels from Table I.

1). **In water.**

Frequency (kHz)	1	2	4	8	16	32
Level (dB re 1μbar)	≤ -55	-62	-69	-77	≤ -82	-87
Level (dB re 1μPa)	≤ 45	38	31	23	≤ 18	13

2). **In air.**

Frequency (kHz)	1	2	4	8	16
Level (dB re $2x10^{-4}$μbar)	10	0	-10	-25	-29
Level (dB re 20μPa)	10	0	-10	-25	-29

Database page ref: M/SealHarbour/06.

Common name	Harbour seal.
Family	Phocid
Species	*Phoca vitulina.*
Paper from which audiogram obtained	Schusterman, R.J. (1975). Pinniped sensory perception. Rapp. P.-v. Reun. Cons. Int. Explor. Mer, 169: 165-168.
Paper having original audiogram data	Mohl, B. (1968). Hearing in seals. In 'The Behaviour and Physiology of Pinnipeds', ed. Harrison, R.J. *et al*. pp. 172-195. Appleton-Century-Crofts, N.Y.
Comments on methodology of getting audiogram	
Any other comments	This data may be the same as in Mohl (1968), 'Auditory sensitivity of the common seal in air and water', in J. Aud. Res., 8:27-38. (That paper is in this database under M/SealHarbour/05).

1). **Underwater**: Audiogram from Fig. 131. Threshold levels in dB re 1μbar.

Frequency (kHz)	1	2	4	8	16	32	43	64	80	125	160
Mean	-16	-25	-28	-34	-37	-38	-29	8	20	26	33

Threshold levels in dB re 1μPa.

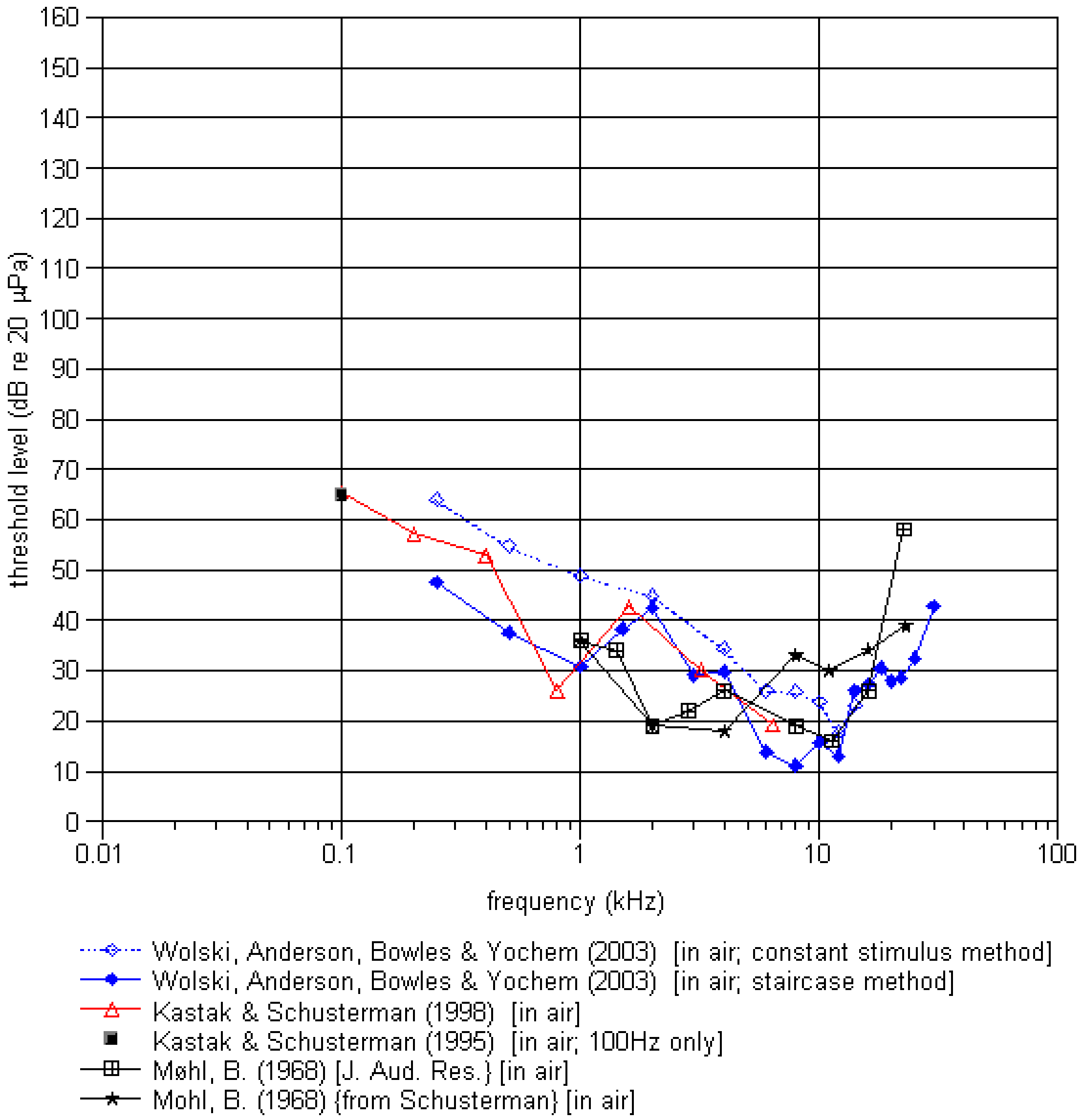
Frequency (kHz)	1	2	4	8	16	32	43	64	80	125	160
Mean	84	75	72	66	63	62	71	106	120	126	133

2). **In air**: Audiogram from Table 16. Threshold levels in dB re 0.0002dynes/cm^2.

Frequency (kHz)	1	2	4	8	11	16	23
Mean	36	19	18	33	30	34	39

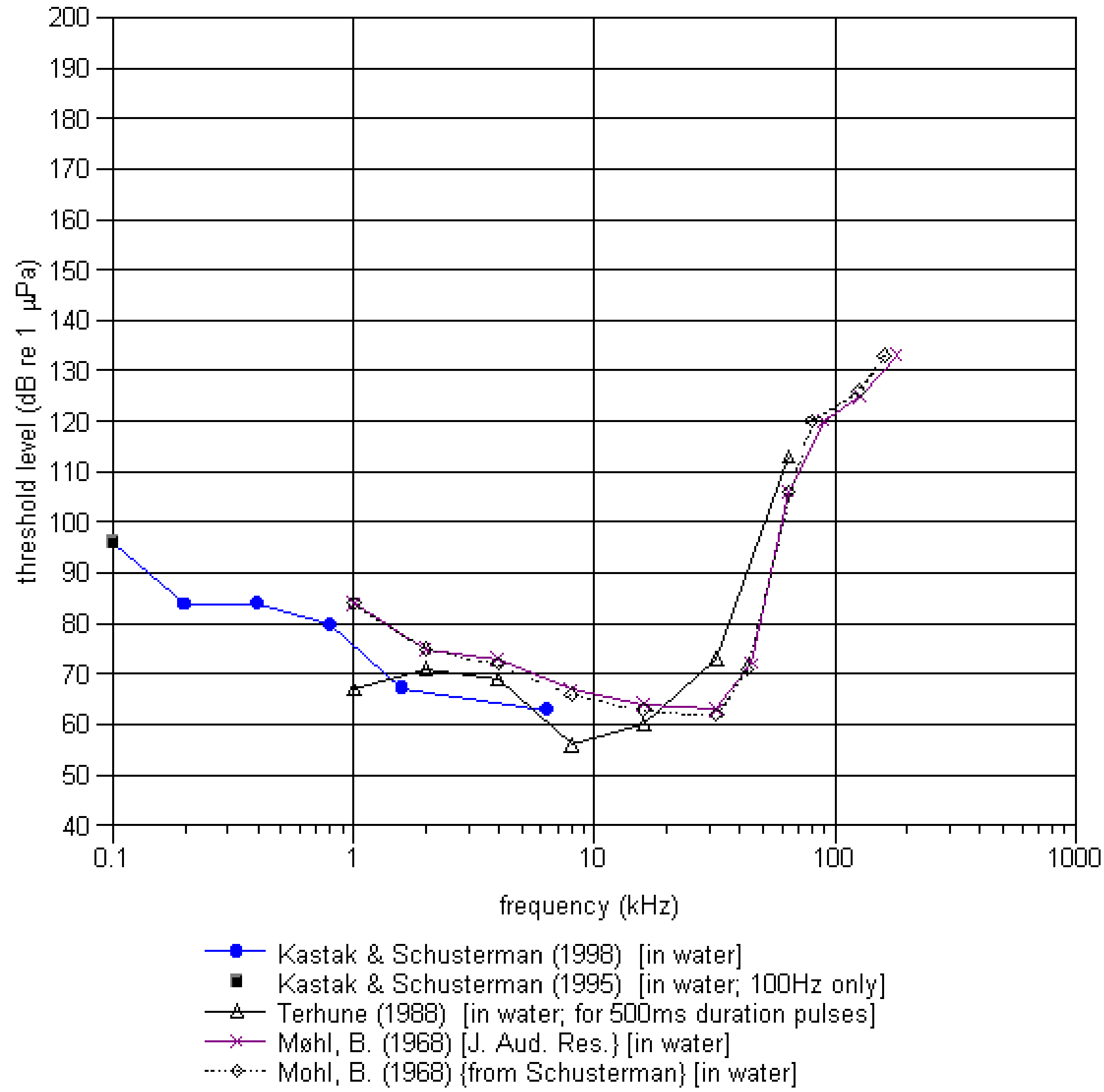
Threshold levels in dB re 20μPa.

Frequency (kHz)	1	2	4	8	11	16	23
Mean	36	19	18	33	30	34	39



[Fig. ref: HarbourSeal_air_01]

Audiogram for the Harbour seal, in air.



[Fig. ref: HarbourSeal_water_01]

Audiogram for the Harbour seal, in water.

Database page ref: M/SealHarp/01.

Common name	Harp seal.
Family	
Species	*Pagophilus groenlandicus* (Erxleben, 1777).
Paper from which audiogram obtained	Terhune, J.M. & Ronald, K. (1972). The harp seal, *Pagophilus groenlandicus* (Erxleben, 1777). III. The underwater audiogram. Can. J. Zool. 50: 565-569.
Paper having original audiogram data	Terhune, J.M. & Ronald, K. (1972). The harp seal, *Pagophilus groenlandicus* (Erxleben, 1777). III. The underwater audiogram. Can. J. Zool. 50: 565-569.
Comments on methodology of getting audiogram	Tests were done in a plastic resin-coated wooden tank 3x5x1.5m deep. A Plexiglass switch was located at the centre of the tank with its lower end 0.5m below the water surface. 0.6m away from this was an Atlantic Research LC-32 hydrophone, used as the signal transmitter. 2 other switches were also located in the tank some distance away from the first switch. When subject pushed the first switch a tone was played through the transmitter. If the seal had heard the sound it would push one of the latter switches, if not the other. Correct response was rewarded with a piece of fish; incorrect response resulted in seal having a blast of air blown in its face. Procedure was to start with signal at high level and reduce it in 2dB steps until seal gave incorrect response, thereafter the signal level was increased in 2dB steps until the seal again responded correctly. 6 reversals used to calculate threshold, by averaging the high and low values at each reversal. Chances of signal-present or catch trial were equal; max. number of similar presentations was 2. Level and waveform at seal's head position was measured after each trial using another LC-32 hydrophone.
Any other comments	4-yr old immature female weighing 90kg was subject. She had previously been used to establish an in-air audiogram. There were 2 testing sessions per day, each of which involved between 50 to 100 trials. At all frequencies standing waves and reflections caused a 10- to 20dB variation in the sound field, but calibrations of the sound field were repeatable to ±3dB. Calibration of the 100kHz threshold is subject to some error because of slight distortion of the waveform by the receiving amplifier. Seal sometimes moved its head horizontally at 45º when pressing the initiating switch. Also it sometimes pressed the initiating switch twice before choosing which response switch to press.

Audiogram from Table 1. Threshold levels in dB re 1μbar.

Frequency (kHz)	0.76	1.0	1.4	2.0	2.0†	2.8	4.0	5.6	8.0	11.3	16.0
Mean	-23	-22	-31	-32	-31	-32	-25	-26	-31	-31	-29
SD	2.0	2.2	1.6	1.8	3.3	2.4	2.3	3.0	2.0	2.1	2.6
Ambient noise*	-60	-64	-67	-70	-70	-73	-75	<-77	<-78	—	—
Catch trials (% correct)	71	68	81	80	89	83	88	97	83	95	92
Frequency (kHz)	22.9	22.9†	32.0	32.0†	44.9	55.0	64.0	90.0	90.0†	100.0	
Mean	-37	-30	-27	-25	-24	-19	3	14	14	56	
SD	2.4	2.1	2.5	2.1	1.6	2.5	2.0	2.2	2.2	2.8	
Catch trials (% correct)	100	93	89	82	91	78	83	79	77	77	

* At the spectrum level.

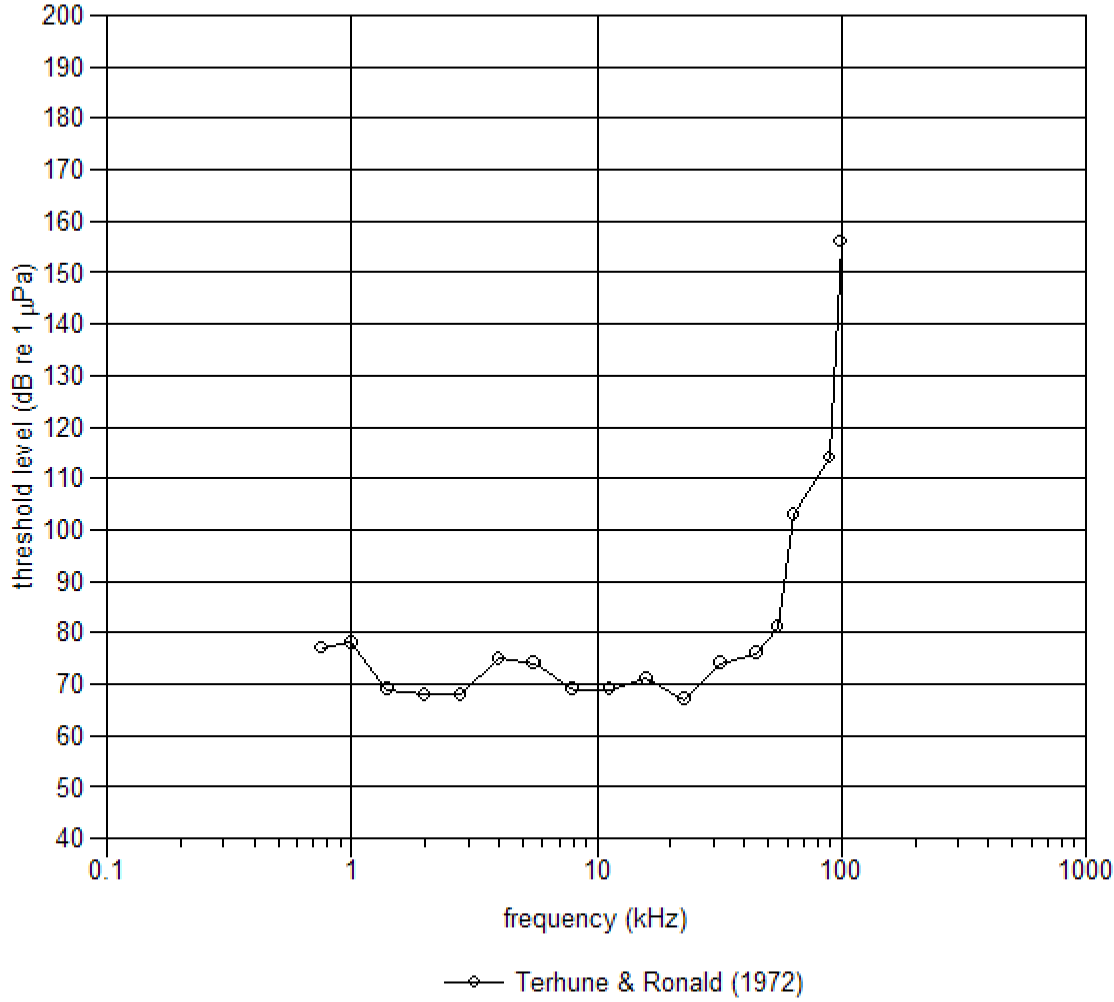
Threshold levels in dB re 1μPa.

Frequency (kHz)	0.76	1.0	1.4	2.0	2.0†	2.8	4.0	5.6	8.0	11.3	16.0
Mean	77	78	69	68	69	68	75	74	69	69	71
Frequency (kHz)	22.9	22.9†	32.0	32.0†	44.9	55.0	64.0	90.0	90.0†	100.0	
Mean	63	70	73	75	76	81	103	114	114	156	

† Repeats.

Background noise. Level in dB re 1μPa (spectrum level)

Frequency (kHz)	0.76	1.0	1.4	2.0	2.0†	2.8	4.0	5.6	8.0
Level	40	36	33	30	30	27	25	<23	<22



[Fig. ref: HarpSeal01]

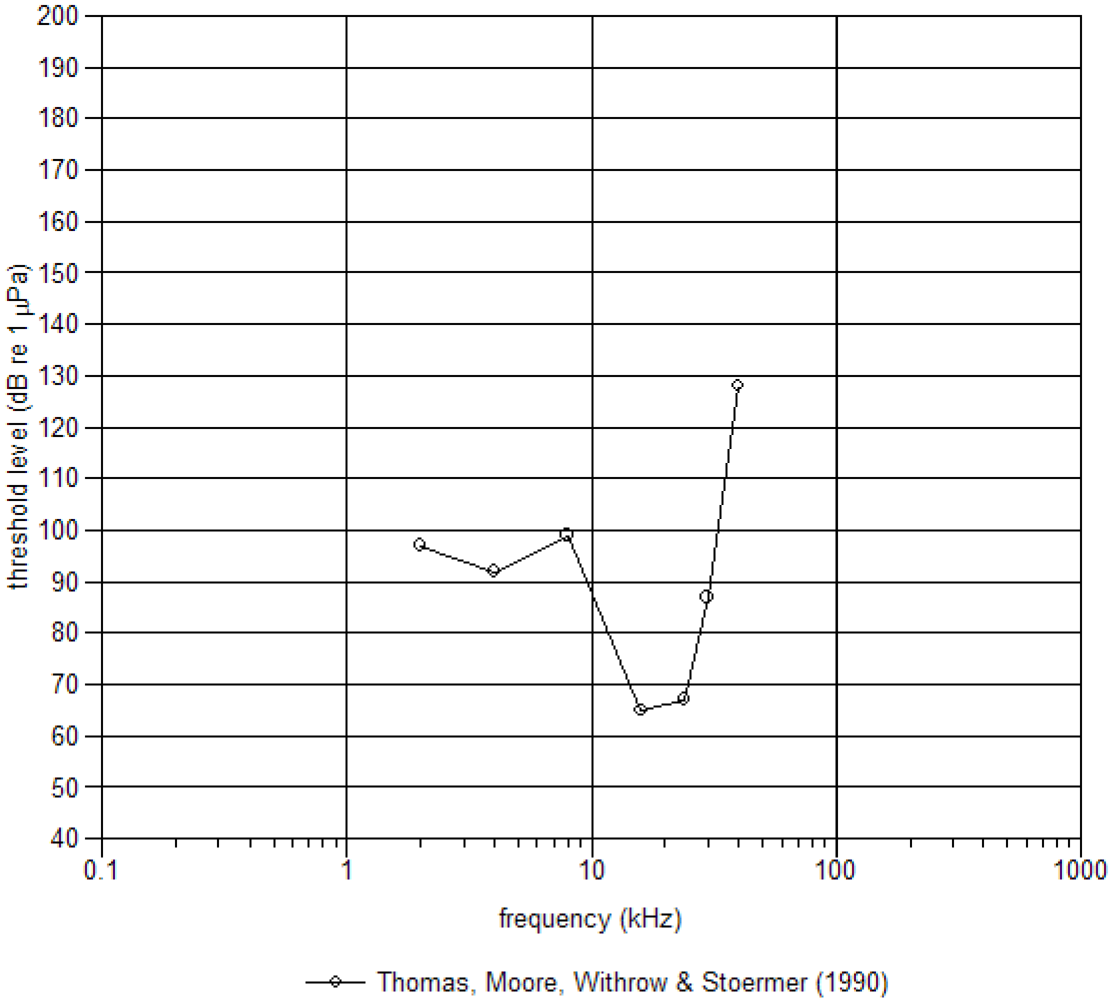
Audiogram for Harp seal.

Database page ref: M/SealHawaiinMonk/01.

Common name	Monk seal.
Family	
Species	*Monachus schauinslandi.*
Paper from which audiogram obtained	Thomas, J., Moore, P., Withrow, R & Stoermer, M. (1990). Underwater audiogram of a Hawaiin monk seal (*Monachus schauinslandi*). JASA, 87(1), 417-420.
Paper having original audiogram data	Thomas, J., Moore, P., Withrow, R & Stoermer, M. (1990). Underwater audiogram of a Hawaiin monk seal (*Monachus schauinslandi*). JASA, 87(1), 417-420.
Comments on methodology of getting audiogram	Tests done in 6.1m dia, 1.2m deep, glass fibre pool, which had a slatted redwood platform just above the water surface over about 1/3rd of its planform. The sound projector, a J9, was attached to the edge of the platform and located at mid-depth. The seal was stationed by a tripod stand, affixed to the pool bottom, which had a rim shaped to the seal's lower jaw contour, and which located the subject at mid-depth and 2m from the projector. A response paddle was fixed to the pool wall to the right of the headstand. Test signal was a tone burst of 2s duration with rise and fall times of 160ms. Sound level at seal's head position was measured with a B&K 8103. Procedure was for trainer to cue seal to go to headstand. When it was ready, the experimenter initiated the trial. For a signal-present trial, if the seal heard the signal it went to push the response paddle. For a signal-absent trial the seal remained at its station and the trainer signalled the end of the trial after 5s by blowing a whistle. Reward was a fish for a correct response. If seal failed to respond in a signal-present trial the trainer tapped a pipe on the platform to signal the seal to surface; no fish was given. Session consisted of 10 warm-up trials, data trials to obtain 10 reversals, and 10 cool-off trials. 50% of the trials were signal-absent. During data trials signal was reduced in 1dB steps until seal missed a signal-present trial. Level then increased in 1dB steps until seal again responded to the signal. Number of trials determined by requirement of 10 reversals – ranged from 36 to 87 trials. Session threshold calculated as average of the 10 reversal levels. When had 2 consecutive sessions with session thresholds within 3dB, calculated overall threshold level for that frequency as average from the 20 reversal levels.
Any other comments	Subject was 3yr old male, which, at end of study, was 1.6m long, weighed 120kg and had been in captivity for 2yrs at Sea Life Park in Hawaii, where tests were conducted. Tests were done twice a day between Dec. 1987 and Feb. 1988. Pool's water inlet was shut off before a test; ambient noise of pool was below the measurement limits of the equipment at all frequencies, and the authors consider that there was little chance of masking having occurred. Sound level at subject's station had variations of up to 3dB at all frequencies except 32kHz – used 30kHz instead.

Audiogram from Table I. Threshold levels in dB re 1μPa.

Frequency (kHz)	2	4	8	16	24	30	40	48
Mean	97	92	99	65	67	87	128	
Range of session means	1 session	102-92	109-95	66-65	68-67	87-86	129-127	No response
No. of sessions	1	6	9	2	2	2	2	



[Fig. ref: HawaiinMonkSeal01]

Audiogram for Hawaiin monk seal.

Database page ref: M/SealNthnElephant/01.

Common name	Northern elephant seal
Family	
Species	*Mirounga angustirostris.*
Paper from which audiogram obtained	Kastak, D. & Schusterman, R.J. (1999). In-air and underwater hearing sensitivity of a northern elephant seal (*Mirounga angustirostris*). Can. J. Zool., 77, 1751-1758.
Paper having original audiogram data	Kastak, D. & Schusterman, R.J. (1999). In-air and underwater hearing sensitivity of a northern elephant seal (*Mirounga angustirostris*). Can. J. Zool., 77, 1751-1758.
Comments on methodology of getting audiogram	Apparatus for use in air and in water was similar - PVC frame with a moveable sliding door which separated a chin station and a response paddle. In water frame was mounted along the side of a 7.5m dia, 2.5m deep tank. The chin station was positioned 1.5m from wall of tank and approx. 1.5m below water surface. In both media test signal was pure tone of 500ms duration with 40ms rise and fall times. <u>In air:</u> test signal fed through Telephonics TDH-39 headphones fitted in neoprene harness positioned on subject's head over meatal openings. Signal and ambient noise measured at opening of subject's meatus by probe microphone. <u>In water:</u> test signal fed through J-11 (for 75Hz), J-9 (for 0.1 to 18kHz) or B&K 8104 (for 4kHz and >18kHz) transducers. Projectors were 5m away from and in same horizontal plane as subject's head. Signal and noise measurements were made using H-56 hydrophone. Sound field was 'mapped' to find a volume in which variation of level was no more than ±3dB. In both air and water experiments method was for subject to be stationed and for door of apparatus to be raised for 4 to 6secs. Subject pressed paddle if she had heard test tone. Correct responses rewarded. 2 methods to determine thresholds. (1) For 75Hz to 6.4kHz range, used 5 or 6 discrete signal levels presented randomly in a series of 60-trial sessions. This done until pooled data resulted in a threshold with 95% confidence limits within ±3dB, determined by probit analysis. Above 6.4kHz up-down method used – started at high level, and reduced in 4dB steps until a miss occurred, thereafter in- or decreased in 2dB steps. Minimum of 6 reversals used to determine threshold, which taken as 50% correct detections.
Any other comments	False alarm rates were <12% and averaged 4% for in-air and underwater tests combined.

In air. Audiogram from Fig. 2. Threshold levels in dB re 20μPa.

Frequency (Hz)	100	200	400	800	1600	3200	6400	9000	16000	20000	25000	30000
Mean	78	72	69	57	55	53	43	44	52	50	59	67

Underwater. Audiogram from Fig. 3. Threshold levels in dB re 1μPa.

Frequency (Hz)	75	100	200	400	800	1600	3200	4500
Mean	99	90	73	75	74	74	73	68
Frequency (Hz)	6400	8500	16000	20000	30000	45000	63000	
Mean	58	60	63	65	58	70	100	

Database page ref: M/SealNthnElephant/02.

Common name	Northern elephant seal.
Family	
Species	*Mirounga angustirostris*
Paper from which audiogram obtained	Kastak, D. & Schusterman, R.J. (1998). Low-frequency amphibious hearing in pinnipeds: Methods, measurements, noise and ecology. JASA, 103(4), 2216-2228.
Paper having original audiogram data	Kastak, D. & Schusterman, R.J. (1998). Low-frequency amphibious hearing in pinnipeds: Methods, measurements, noise and ecology. JASA, 103(4), 2216-2228.
Comments on methodology of getting audiogram	Subject was tested in both air and water. In both cases the response apparatus was a PVC box (450x450x630mm in air, 430x1350x1000mm in water) containing a paddle, which the subject pressed if it heard the test signal. Each box had an aperture in 1 face; this aperture was covered by an opaque Plexiglas cover sliding in grooves; the cover could be raised by a rope to expose the paddle. A chin station was fixed to the box in front of the sliding cover. Aerial tests: earphones secured to neoprene harnesses were placed over the subject's ears. A probe microphone measured the sound level at the opening of the subject's external meatus. Pure tones, of 500ms duration with 40ms rise and fall times, were played to the subject. For a trial, the box cover was raised for between 5 and 7secs. If signal was to be presented, it was sent between 2 and 4secs after the cover was opened. Some 'no-signal' trials were done. Test method was to start with signal at high level and decrease it in 4dB steps until first failure, then raise and lower in 2dB steps. After 3 to 5 sessions in which consistent reversals occurred, a threshold was estimated as the average between the upper and lower limits of the reversals. Underwater tests: were done in a 7.6m pool, which had been acoustically 'mapped' to locate regions where the sound intensity was nearly constant. Subject was stationed in such a volume. Pure tones, of 500ms duration with 40ms rise and fall times, were projected by a J9 transducer placed 1.35m away from the pool wall and 1.57m below the pool rim on an axis shared by the stationing arm, approx. 5m away from the station. Sound pressure levels were measured at the stationing device by a hydrophone. Testing method was similar to that used in air.
Any other comments	Subject (Burnyce) was a female, aged 1-3 years during testing. She had developed an infection confined to the right external meatus prior to the testing. It is unlikely that treatment for this caused hair cell damage. Background noise spectra given in figures; measurements were made in 1/3 octave bands using PC sound card sampling at 22kS/s. Authors note that, in air, placement of earphones reduced ambient noise at the meatus by approx. 7-15dB.

Audiogram from Table I (aerial) and Table II (underwater).

1). **Aerial** - threshold levels in dB re 20µPa.

Frequency (Hz)	100	200	400	800	1600	3200	6400
Mean	78.6	72.0	68.8	57.3	55.3	52.7	43.5
False alarms (% of catch trials)	3.3	2.5	9.5	5.7	11.1	3.2	4.1

2). **Underwater** - threshold levels in dB re 1µPa.

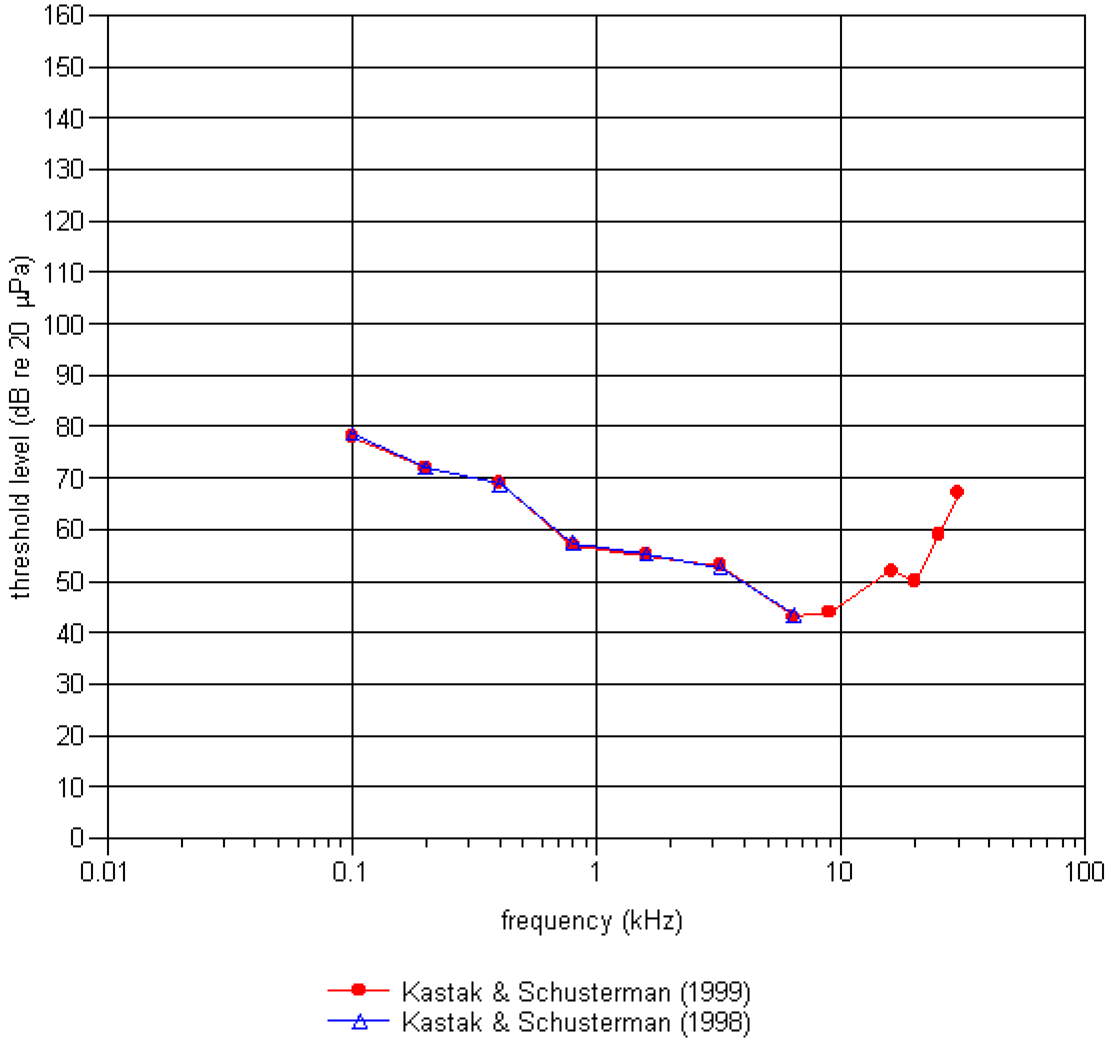
Frequency (Hz)	75	100	200	400	800	1600	3200	6300
Mean	98.3	89.9	72.8	74.9	73.5	73.4	73.3	59.0
False alarms (% of catch trials)	1.1	2.6	3.9	4.1	3.6	2.2	3.4	2.7

Background noise spectrum levels, **in air**, from Fig. 1. Levels in dB re 20µPa^2/Hz.

Frequency (Hz)	100	200	400	800	1600	3200	6400
Level	12	14	4	0	-5	-10	-7

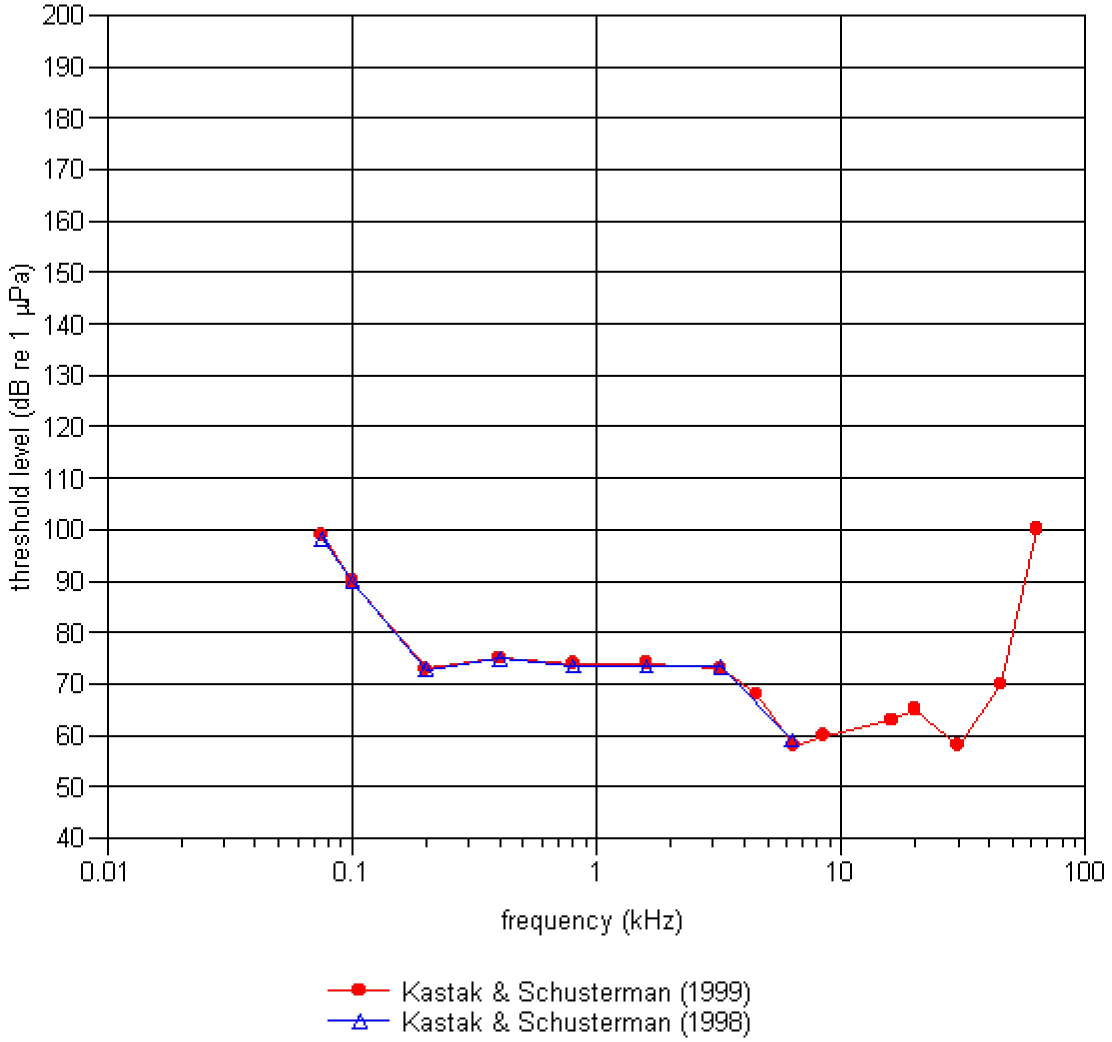
Background noise spectrum levels, **in water**, from Fig. 2. Levels in dB re 1µPa^2/Hz.

Frequency (Hz)	100	200	400	800	1600	3200	6400
Level	62	54	48	39	34	29	20



[Fig. ref: NthnElphntSeal_air_01]

Audiogram for Northern elephant seal, in air.



[Fig. ref: NthnElphntSeal_water_01]

Audiogram for Northern elephant seal, in water.

Database page ref: M/SealNthnFur/01.

Common name	Northern fur seal
Family	
Species	
Paper from which audiogram obtained	'Marine Mammals and Noise', p.212, Fig. 8.2(B).
Paper having original audiogram data	Babushina, Ye.S., Zaslavskii, G.L. and Yurkevich, L.I. (1991). Air and underwater hearing characteristics of the northern fur seal: Audiograms, frequency and differential thresholds. Biophysics, 36(5), 909-913.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	Data from 1 animal.

Threshold levels in dB re 1μPa.

Frequency (Hz)	500	1000	1600	2000	3000	15000	20000	30000	40000
Mean	75	112	110	80	70	60	70	90	133

Database page ref: M/SealNthnFur/02.

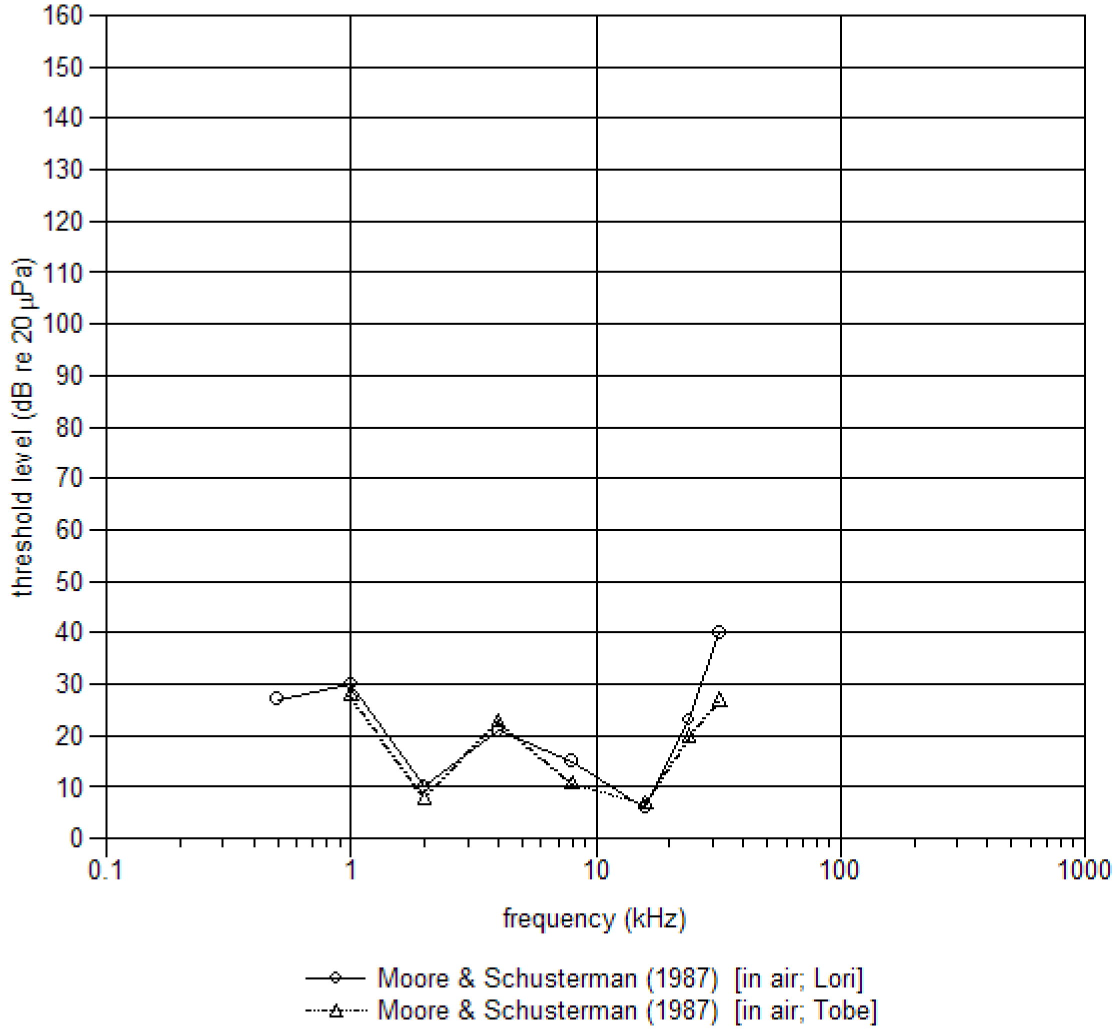
Common name	Northern fur seal.
Family	
Species	*Callorhinus ursinus*
Paper from which audiogram obtained	Moore, P.W.B. & Schusterman, R.J. (1987). Audiometric assessment of northern fur seals, *Callorhinus ursinus.* Marine Mammal Science, 3(1), 31-53.
Paper having original audiogram data	Moore, P.W.B. & Schusterman, R.J. (1987). Audiometric assessment of northern fur seals, *Callorhinus ursinus.* Marine Mammal Science, 3(1), 31-53.
Comments on methodology of getting audiogram	Obtained both in-air and underwater audiograms. For **aerial** work, tests conducted in wooden box divided into testing and experimenter's areas. Testing chamber was 2.9x1.5x1.8m internally, and lined with 85mm thick convoluted acoustic foam. Experimenter's area was at one end of box (with access via door in outside wall) and with observation and feeding ports in dividing wall. Subject stationed in a nose cup 510mm above floor and 250mm away from exterior wall and 730mm from dividing wall. Nose cup was 90mm dia cylinder of Plexiglas with a cone-shaped hollow centre. Embedded in the cup were 3 small lamps that acted as a trial warning light. Response paddle was a 115mm Plexiglas disc mounted 530mm above the floor, 1m away from the nose cup. Test signal was projected by a Jensen Model 41moving coil and tweeter combination for frequencies of 500Hz to 8kHz, or a Lansing Model 075 tweeter for frequencies of 16 to 32kHz. The Jensen speaker was 1.13m away from the nose cup, on the opposite side to the paddle. The Lansing speaker was 650mm away from the cup, 1m above the floor and pointing down towards the cup. When subject was in position with nose in cup, trial was started – lights in nose cup illuminated for 6sec. If trial was one in which signal was to be played, a 0.5sec duration tone, with 40msec rise and fall times, was played 2sec after cup light came on. If no signal, subject should have remained at cup. Correct responses rewarded with piece of fish. Procedure was up-down one – started at a high level and decreased in 2dB steps until a 'miss', then increased in 1dB steps until 'hit' occurred. Thereafter changes were in 1dB steps. Session started with 20 'warm-up' trials, then at least 50 'threshold' trials (if warm-up period had been satisfactory), then 10 'cool-off' trials. Warm-up and cool-off levels were at least 10-15dB above threshold. Threshold taken to be mean value of all reversals. Minimum number of runs for a threshold estimate at a given frequency was set at 20 – this required 2 or 3 daily sessions. For **underwater** work, tests conducted in 3.5x11.1x1.2m above-ground concrete tank. Water level was 910mm. Sound projectors were either J-9 or F-41 transducers. 150W lamp mounted alongside projector, both being 430mm above bottom of tank and 1.73m from the sides of the tank. Subject placed nose in nose cup (same as used for in-air tests). Sound field at subject's head position was measured with an H-23 hydrophone. Tests used tones of 0.5sec duration with 40msec rise and fall times. Test procedure was same as for in-air tests. If signal was projected and detected by subject, it swam to press paddle about 2m away. Inter-trial interval was approx. 10-15sec.

Any other comments	2 subjects, (Lori (f), Tobe (f)), were 2 or 3-yrs old, and experimentally naïve. They were tested early in the morning, and fed in the afternoon, so they weren't fed for about 18hrs prior to testing. In air, signal and ambient noise level measured at start of experiment with B&K 2203 Precision Sound Level Meter with 4145 or 4135 microphone capsule and 1613 octave filter set. Krohn-Hite 3550 filter set used for 24, 28 and 32kHz measurements. 10 readings taken, and average taken to be noise level. Results for **in-air** ambient noise given in text are:- Octave band centre freq. (kHz): 0.5, 1, 2, 4, 8, 16, 32 Level (dB re 0.0002dynes/cm^2): 16, 14, 10, 9, 9, 11, – Level (db re 20µPa): 16, 14, 10, 9, 9, 11, – Authors state that levels beyond 2kHz are more likely peak levels because of limitations of instrumentation. (No indication why discrepancy between number of bands and levels). **In-air** background noise levels, in 1/3 octave bands, are also plotted in Fig. 3. The values are:– Frequency (kHz): 1.25, 2, 4, 8 Level (dB re 0.0002dynes/cm^2): 9, 5, 4, 5 Level (db re 20µPa): 9, 5, 4, 5 For **underwater** tests, ambient noise in the tank was measured in 1/3 octave bands from 1kHz to 20kHz. The levels decreased from -27 to -34dB re 1µbar over this range; the corresponding *spectrum levels* decreased from -50 to -71dB re 1µbar. Also did tests to determine critical ratios for the 2 subjects. Tests used 3 levels of masking noise (white noise mixed with tone).

Inner tables from the cell above:

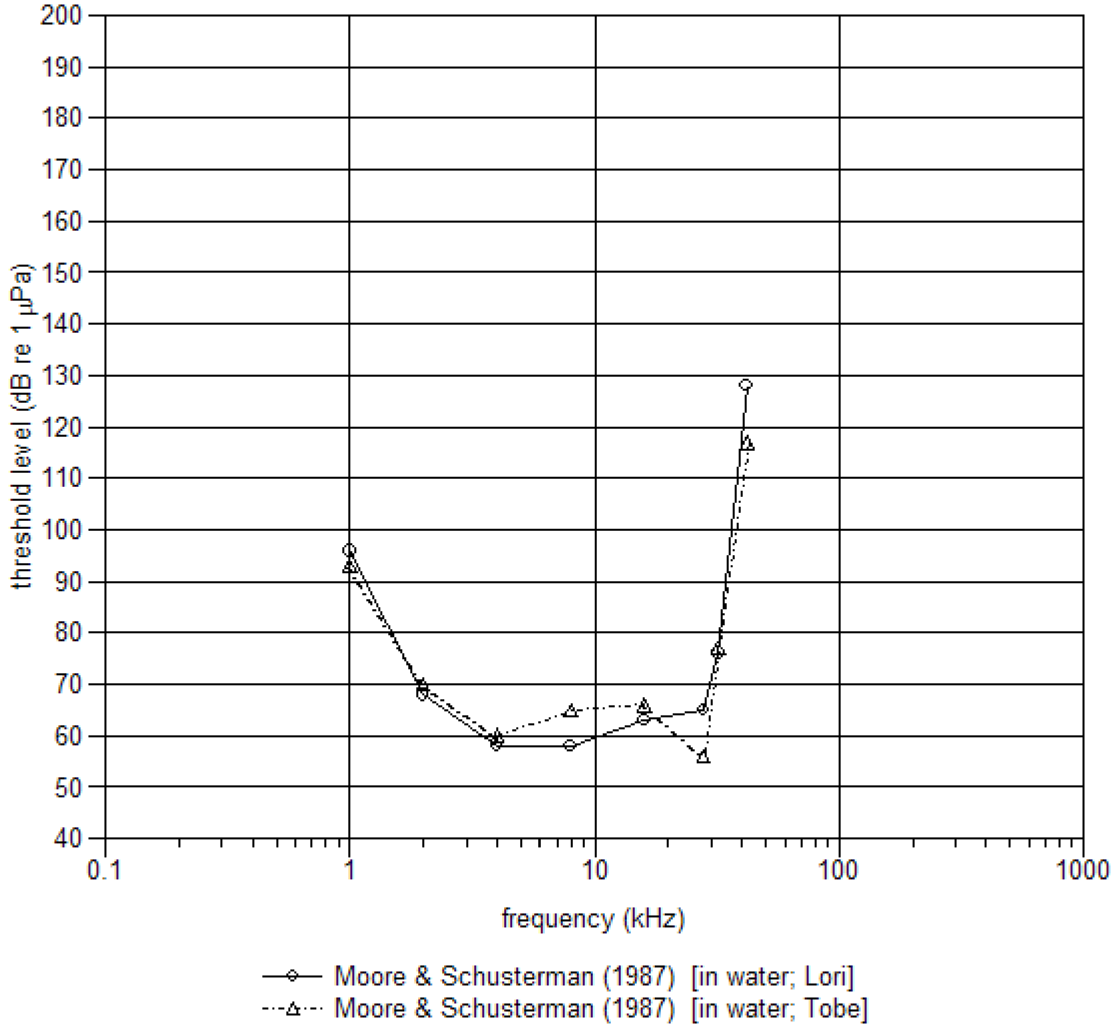
Octave band centre freq. (kHz)	0.5	1	2	4	8	16	32
Level (dB re 0.0002dynes/cm^2)	16	14	10	9	9	11	
Level (db re 20µPa)	16	14	10	9	9	11	

Frequency (kHz)	1.25	2	4	8
Level (dB re 0.0002dynes/cm^2)	9	5	4	5
Level (db re 20µPa)	9	5	4	5



[Fig. ref: NthnFurSeal_air_01]

Audiogram for Northern fur seal, in air.



[Fig. ref: NthnFurSeal_water_01]

Audiogram for Northern fur seal, in water.

Database page ref: M/SealRinged/01.

Common name	Ringed seal.
Family	
Species	*Pusa hispida.*
Paper from which audiogram obtained	Terhune, J.M. & Ronald, K. (1975). Underwater hearing sensitivity of two ringed seals (*Pusa hispida*). Can. J. Zool., 53: 227-231.
Paper having original audiogram data	Terhune, J.M. & Ronald, K. (1975). Underwater hearing sensitivity of two ringed seals (*Pusa hispida*). Can. J. Zool., 53: 227-231.
Comments on methodology of getting audiogram	Tests done in indoor plastic resin-coated wooden tank 4x3x1.2m deep. Tank was divided by a nylon net into 2 areas, each 2x3m in size. One seal and a set of 3 switches were located in each area. Sound source was an Atlantic Research LC-32 hydrophone, centrally supported at a depth of 0.5m by the net. Test signal was a sinusoid. Signal was initiated by the subject pushing, with its nose, a 'stimulus' switch, which was located 0.5m from the sound source, 0.5m below water surface and at 1.5m from a tank wall. Source signal was broadcast for as long as the seal pressed the switch. If the seal heard a signal it would press another switch ('Y') located some distance away. If it didn't hear a signal it pushed another switch ('N') located near Y. For a correct response the seal was rewarded with a piece of fish; for an incorrect response there was no reward and a lamp, visible to the seal, was lit. Procedure was to start at a high signal level and decrease it in 1.5 or 2dB steps until seal didn't hear signal. Level was then increased in 1.5 or 2dB steps until seal again responded correctly. Level was then again reduced until incorrect response. This was done for 10 descents. Threshold was calculated by averaging the max. and min. values of each run. The seal had an equal chance of being presented with a signal-present or a catch trial, with proviso that there be no more than 4 consecutive signal or catch trials.
Any other comments	Two 3-yr old seals (a male and a female) were the subjects. Each subject was tested once per day. Each test of 10 runs required 75 to 100 trials. The upper and lower frequency limits of the results were set by the apparatus, not by the seals. At all frequencies standing waves and reflections caused 5- to 10dB variations in the sound field. In discussion authors note that they made an effort not to preferentially influence the responses of the seal when it was presented with a catch trial, i.e. it was not punished (e.g. by stopping the session early) if it made a high number of catch trial errors. This was done so the seals would not be encouraged to establish a criterion which would bias their responses toward a catch trial response. They state that such a situation may have occurred in many marine mammal psychophysical threshold determinations and may have resulted in underestimating the subject's threshold.

Audiogram for **female** from Table 1. Threshold levels in dB re 1μbar.

Frequency (kHz)	1.0	1.4	2.0	2.8	4.0	5.6	8.0	11.3	16.0	22.9	32.0	44.9	55.0	64.0	90.0
Mean	-26	-22	-19	-20	-25	-23	-20	-32	-32	-27	-21	-25	-11	15	(18)
SD	3.1	4.0	3.0	3.5	2.9	2.2	2.5	6.2	7.8	3.2	2.8	4.8	4.9	3.7	(5.1)
Catch trials (% correct)	53	61	64	73	80	86	77	44	68	76	87	55	69	58	61

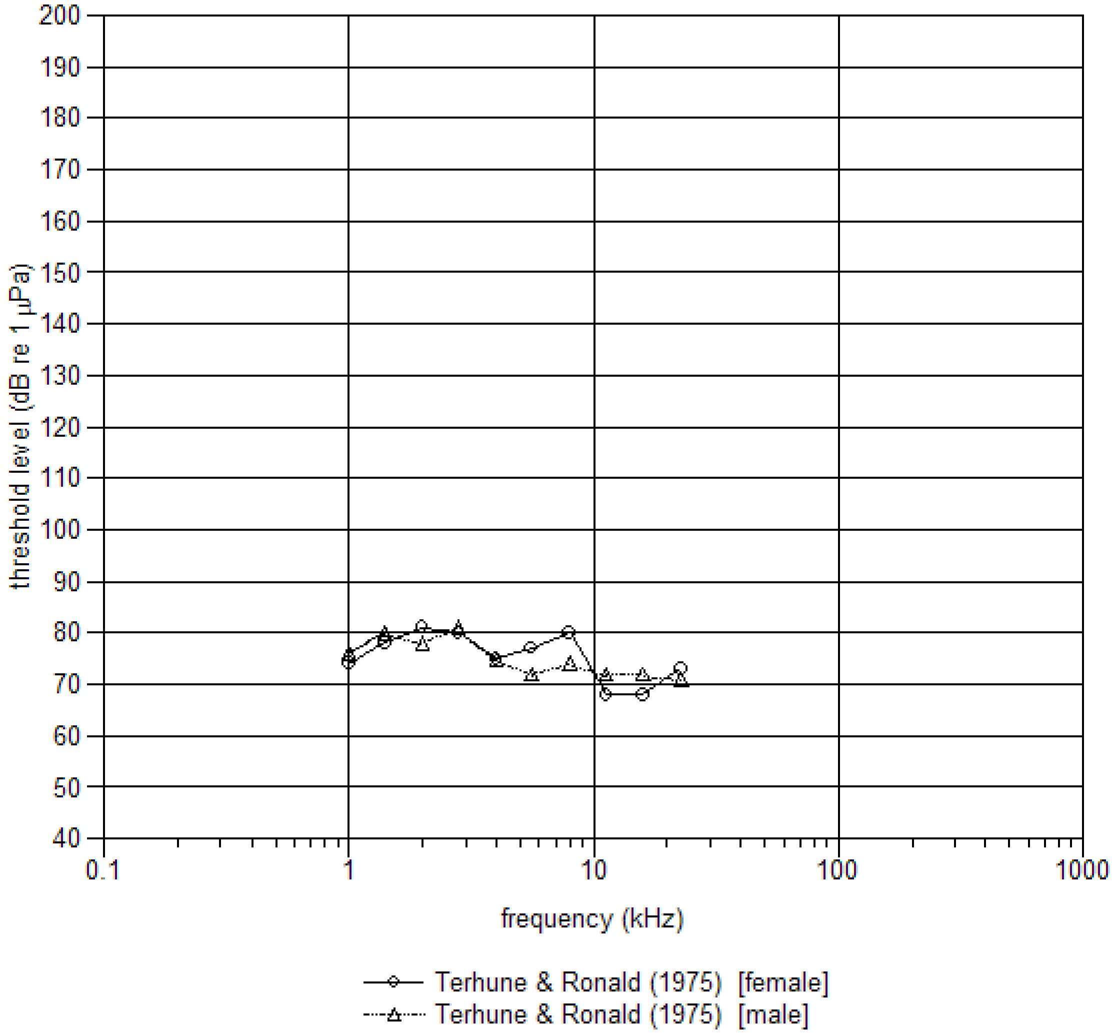
Audiogram for **male** from Table 1. Threshold levels in dB re 1μbar.

Frequency (kHz)	1.0	1.4	2.0	2.8	4.0	5.6	8.0	11.3	16.0	22.9	32.0	44.9	55.0	64.0	90.0
Mean	-24	-20	-22	-19	-25	-28	-26	-28	-28	-29	-29	-31	-14	4	12
SD	3.1	2.7	3.0	3.1	2.5	4.8	2.8	7.6	5.7	7.0	2.6	2.9	4.1	3.6	3.0
Catch trials (% correct)	68	80	73	91	86	77	78	50	49	67	83	85	100	80	66

Threshold levels in dB re 1μPa.

Frequency (kHz)	1.0	1.4	2.0	2.8	4.0	5.6	8.0	11.3	16.0	22.9	32.0	44.9	55.0	64.0	90.0
Mean (**female**)	74	78	81	80	75	77	80	68	68	73	79	75	89	115	(118)
Mean (**male**)	76	80	78	81	75	72	74	72	72	71	71	69	86	104	112

NOTE: The threshold for the female at 90kHz could not be accurately measured because in this instance the maximum sound level produced by the equipment was only barely above her threshold.



[Fig. ref: RingedSeal01]

Audiogram for Ringed seal.

Database page ref: M/WalrusPacific/01.

Common name	Pacific walrus.
Family	
Species	*Odobenus rosmarus divergens.*
Paper from which audiogram obtained	Kastelein, R.A., Mosterd, P., van Santen, B., Hagedoorn, M. & de Haan, D. (2002). Underwater audiogram of a Pacific walrus (*Odobenus rosmarus divergens*) measured with narrow-band frequency-modulated signals. JASA, 112(5), Pt.1, 2173-2182.
Paper having original audiogram data	Kastelein, R.A., Mosterd, P., van Santen, B., Hagedoorn, M. & de Haan, D. (2002). Underwater audiogram of a Pacific walrus (*Odobenus rosmarus divergens*) measured with narrow-band frequency-modulated signals. JASA, 112(5), Pt.1, 2173-2182.
Comments on methodology of getting audiogram	Tests done in outdoor concrete kidney-shaped pool (20m long, 12m wide, on average 3m deep) with a haul-out space. Water pump was switched off for test. Projector was mounted on wall of tank, with subject 6.5m away. Subject's head, and projector, was about 1m below water surface. For 200Hz to 32kHz signals used Ocean Engineering Enterprise DRS-6 piezoelectric transducer; for 125 and 200Hz signals used Ocean Engineering Enterprise DRS-12 transducer placed in front of DRS-6. Low limit was set by transducer's capabilities. Test signal was sinusoid, in most cases frequency modulated to ±1% of the centre frequency with a modulation frequency of 100Hz. Tests at 125 and 200Hz, and 1 test at 250Hz, used a pure sinusoid. Test signal was 1.5s in duration, with 50ms rise and fall times. Found that subject didn't respond to 16kHz and 32kHz signals at highest level projector capable of. For tests 1 frequency presented per session. Method was go/no-go one – if subject heard signal it returned to start and response point. Modified up-down staircase technique, with test signal level varied in 5 dB steps, used. 20 trials per session. Order of testing of frequencies mixed. Threshold taken as mean amplitude of all reversals of response obtained in 10 sessions after the mean session thresholds levelled off (usually after 2 or 3 sessions).
Any other comments	Subject was male , 18-yrs old, kept (and tested) at Harderwijk Marine Mammal Park, Netherlands. A second experiment, done after main experiment, used frequencies of 250Hz, 1, 8 and 14kHz with a signal duration of 300ms and rise and fall times of 50ms to determine thresholds. 3000 trials used to obtain thresholds in 1.5s duration tests, and 160 trials in 300ms duration tests. Ambient noise between 125Hz and 8kHz plotted; couldn't measure above 8kHz. Uniformity of field around subject's head tested by taking SPL measurements (in absence of subject) on a cubic grid (100mm spacing for up to 500mm from centre in each direction) – for 2kHz signal variations of up to 6dB found. In discussion authors note that ambient noise may not be neglected. At a centre frequency of 1kHz ambient noise PSD level was 60dB re 1µPa/√Hz. Assuming critical band is 10% wide, noise intensity in critical band will be 80dB re 1µPa, which is close to the found threshold value. Speculate that sharp insensitivity at 2kHz possibly due to ageing of animal, and the whistle it produced at around 1.1kHz, with an almost equally strong 1st harmonic at around 2.2kHz.

1). Audiogram from Table I. Tests with 1.5s duration signal. Threshold and threshold range levels in dB re 1μPa.

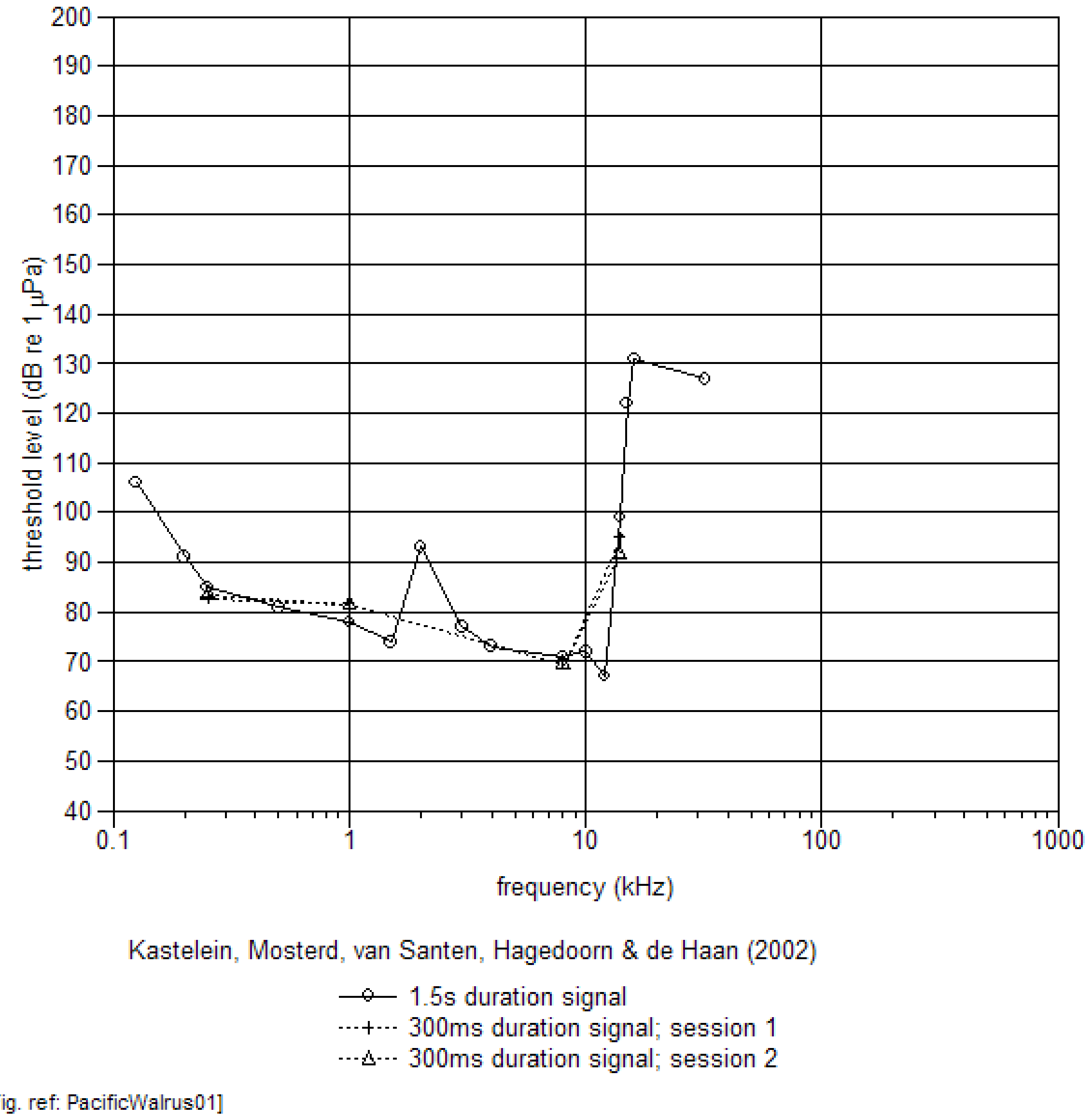
Frequency (kHz)	0.125	0.2	0.25	0.5	1	1.5	2	3
Mean	106	91	85	81	78	74	93	77
Mean threshold range	101-111	86-98	79-89	74-87	72-83	70-80	86-96	74-82
Frequency (kHz)	4	8	10	12	14	15	16	32
Mean	73	71	72	67	99	122	>131	>127
Mean threshold range	69-76	69-75	66-74	63-75	92-104	116-126		

2). Audiogram from Table II. Tests with 300ms duration signal. Threshold levels in dB re 1μPa.

Frequency (kHz)	0.25	1	8	14
Mean (session 1)	83	82	70	95
Mean (session 2)	84	82	70	92

Ambient noise from Fig. 3. Levels in dB re 1μPa/($Hz^{1/2}$).

Frequency (kHz)	0.125	0.2	0.25	0.5	1	1.5	2	3	4	8
Level	58	54	54	52	35	35	32	34	30	30



Audiogram for Pacific walrus.

Database page ref: M/WhaleBeluga/01.

Common name	Whale, beluga
Family	
Species	*Delphinapterus leucas*
Paper from which audiogram obtained	Johnson, C.S., McManus, M.W. & Skaar, D. (1989). Masked tonal hearing thresholds in the beluga whale. JASA, 85(6), 2651-2654.
Paper having original audiogram data	Johnson, C.S., McManus, M.W. & Skaar, D. (1989). Masked tonal hearing thresholds in the beluga whale. JASA, 85(6), 2651-2654.
Comments on methodology of getting audiogram	Test pen was located in San Diego Bay. Subject held bite plate in her mouth. Plate was suspended in water by a PVC pipe at 1m below water surface, and pipe was pivoted at its upper end. When subject heard test signal she pushed plate forward to touch a disk 150mm ahead of plate. 3 speakers used to generate sound – (1) for 40Hz to 1kHz a Cerwin-Vega 188EB mounted in a steel garbage can whose bottom had been removed – can was suspended in air above plates; (2) for 500Hz to 110kHz a J-9 projector; (3) for 30kHz to 115khz a transducer from a fathometer (make unknown, but had resonance at 200kHz). For last two, projectors were 2m ahead of bite plate. Calibrations done using B&K 8103 mounted on bite plate when calibrating. Data collected using staircase method – used 5db steps, with at least 5 up-down reversals at threshold, and 4 or more repetitions of a measurement. Absolute thresholds at 32 frequencies from 40Hz to 125kHz measured first – between 5kHz and 100kHz threshold masked by Bay noise. Thresholds from 40Hz to 4khz were not masked (and are in table below). Upper limit found to be 125khz, at which threshold was 99±4dB re 1μPa.
Any other comments	Subject was female who was about 2 yrs old when captured in 1980. She had been used in other experiments. Authors comment on difficulties in obtaining threshold values – other experimenters had found values taken on different days to differ by 5dB or more. Conclude that number of repetitions is as important as step size in determining threshold. Also have graph giving critical ratios~frequency.

Audiogram from Table 1. Threshold levels in dB re 1μPa.

Frequency (Hz)	40	50	60	80	100	300	400	500	600	800	1000	1500	2000	3000	4000
Mean	140	139	131	133	127	108	107	105	100	103	102	96	95	83	81
Tolerance	±3	±3	±4	±5	±4	±4	±4	±4	±4	±4	±4	±3	±3	±6	±3

Database page ref: M/WhaleBeluga/02.

Common name	Beluga whale
Family	
Species	*Delphinapterus leucas*
Paper from which audiogram obtained	Awbrey, F.T., Thomas, J.A. & Kastelein, R.A. (1988). Low-frequency underwater hearing sensitivity in belugas, *Delphinapterus leucas*. JASA, 84(6), 2273-2275).
Paper having original audiogram data	Awbrey, F.T., Thomas, J.A. & Kastelein, R.A. (1988). Low-frequency underwater hearing sensitivity in belugas, *Delphinapterus leucas*. JASA, 84(6), 2273-2275).
Comments on methodology of getting audiogram	Tests done in pool at Sea World, San Diego – 13mx13mx4m. Whale was trained to a station with its rostrum against a target that was 0.5m below the water surface. Loudspeaker suspended in air 1.9m above animal's station. Test sinusoid had 50ms rise and fall times, and 500ms duration. Subject was trained to remain at station unless it heard the test signal or was recalled by its trainer. Two 30- to 45-min sessions were conducted each weekday for a month. In a session each of 3 whales was given 10 test series. For each of 4 different frequencies an ascending series of at most 6 amplitudes was presented in 2-dB steps. The 10 test series included 2 silent catch series. The order of the frequencies and catch series was random. Actual threshold was assumed to be midway between the level at which the subject first responded and the immediately lower level at which it did not respond.
Any other comments	Authors comment that adult male's hearing was slightly less sensitive at 4 and 8kHz than when tested in 1978. A comparison was also made with previous studies – agreement good for 4kHz and above. Had 11dB difference at 2kHz – reason unknown, but author's suspect they had a standing wave or constructive interference problem. The calibration tone was consistently 10dB higher for a given voltage than those an octave above and below it. Ambient noise was measured using a signal analyser having a 75Hz bandwidth. Results are plotted in figure.

Audiograms from Table 1. Threshold levels in dB re 1μPa.
1). For adult male (same as was used by White, *et al* in 1978).

Frequency (Hz)	125	250	500	1000	2000	4000	8000	Catch
Mean	124	126	108	102	99	78	66	
Range	121=127	135-127	104-112	97-111	97-99	76-80	65-67	
N	2	2	18	20	7	8	3	28

False alarms 4.

2) For adult female.

Frequency (Hz)	125	250	500	1000	2000	4000	8000	Catch
Mean	122	122	109	102	103	76	65	
Range	121-123	121-123	94-116	97-107	101-111	76-78	63-67	
N	7	3	14	7	6	5	5	25

False alarms 2.

3) For juvenile male.

Frequency (Hz)	125	250	500	1000	2000	4000	8000	Catch
Mean	118	114	106	100	101	77	65	
Range	115-121	111-121	100-114	97-107	99-103	76-78	63-67	
N	7	9	13	18	11	5	7	30

False alarms 3

Ambient noise levels from Fig. 1. Levels in dB re 1μPa, for 75Hz bandwidth.

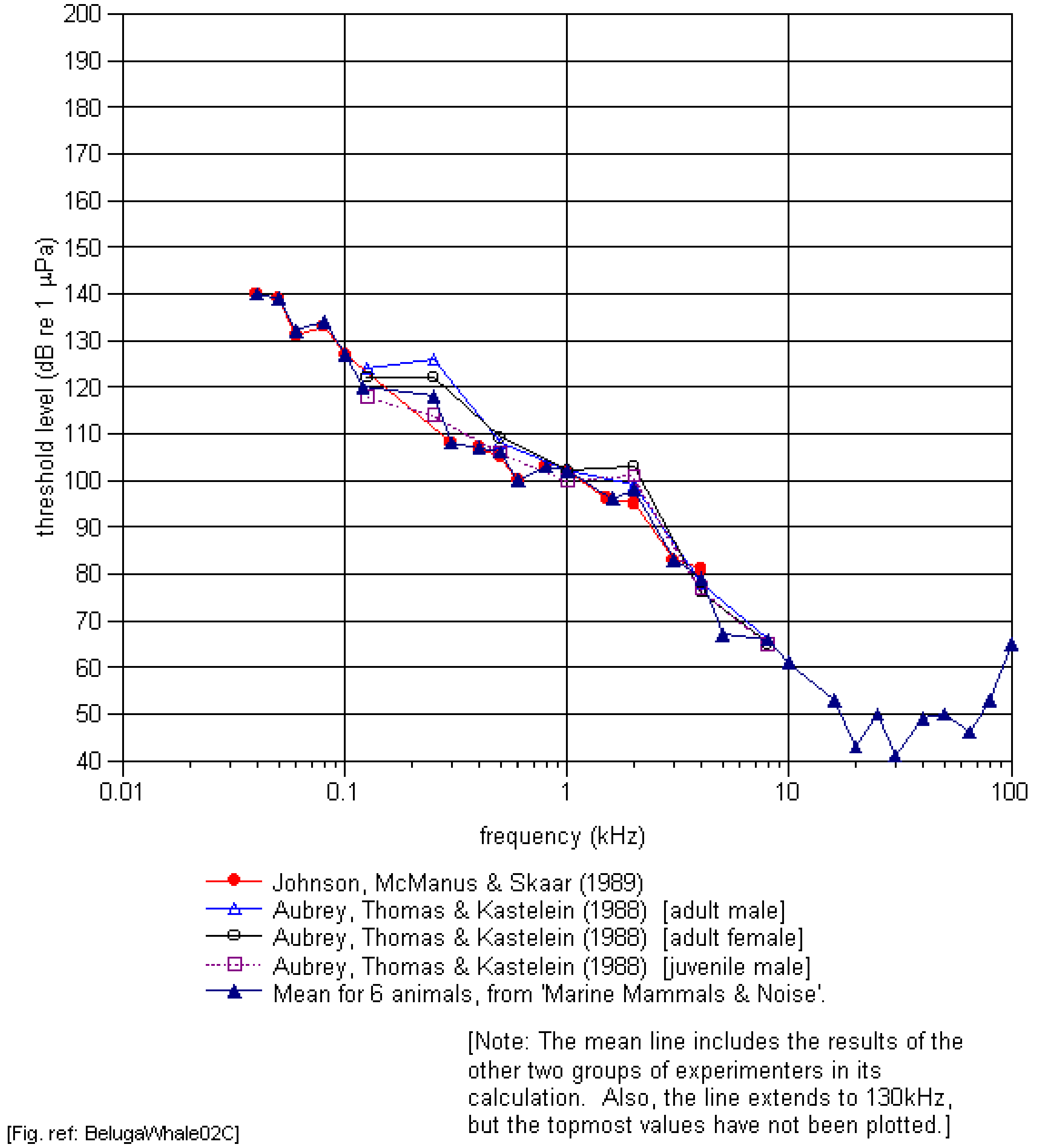
Frequency (Hz)	125	250	500	1000	2000	4000	8000
Level	83	83	74	83	81	71	59

Database page ref: M/WhaleBeluga/03.

Common name	Beluga whale
Family	
Species	*Delphinapterus leucas*
Paper from which audiogram obtained	
Paper having original audiogram data	White, M.J. (jnr), Norris, J., Ljungblad, K. & di Sciara, G. (1978). Auditory thresholds of two beluga whales (*Delphinapterus leucas*). HSWRI Tech. Rep. 78-109. Hubbs Sea World Res. Inst., San Diego, CA.
Comments on methodology of getting audiogram	Original source not seen.
Any other comments	Data from J. Gordon's spreadsheet. (Originally from MM&N (Richardson *et al)*, probably Fig. 8.1(A). It is the averaged audiogram for 6 animals, and includes data from Awbrey *et al* (1988) and Johnson et al (*1989*) as well as White *et al*'s data as above.)

Threshold levels in dB re 1μPa. Mean values of 6 animals.

Frequency (Hz)	40	50	60	80	100	120	250	300	400	500	600	800
Mean	140	139	132	134	127	120	118	108	107	106	100	103
Frequency (kHz)	1	1.6	2	3	4	5	8	10	16	20	25	30
Mean	102	96	98	83	79	67	66	61	53	43	50	41
Frequency (kHz)	40	50	65	80	100	120	130					
Mean	49	50	46	53	65	80	108					



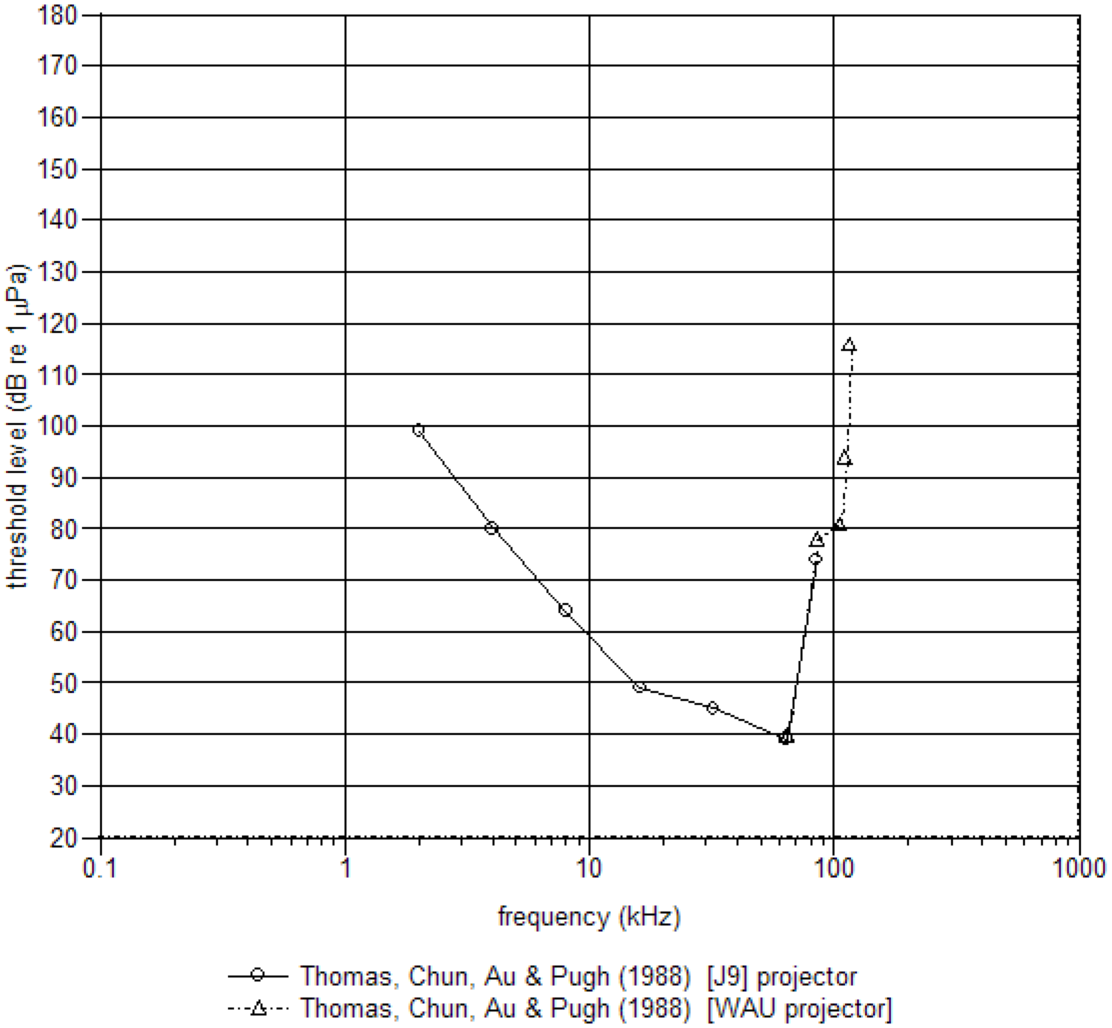
Audiogram for Beluga whale.

Database page ref: M/WhaleFalseKiller/01.

Common name	False killer whale.
Family	
Species	*Pseudorca crassidens.*
Paper from which audiogram obtained	Thomas, J., Chun, N., Au, W. & Pugh, K. (1988). Underwater audiogram of a false killer whale (*Pseudorca crassidens*). JASA, 84(3), 936-940.
Paper having original audiogram data	Thomas, J., Chun, N., Au, W. & Pugh, K. (1988). Underwater audiogram of a false killer whale (*Pseudorca crassidens*). JASA, 84(3), 936-940.
Comments on methodology of getting audiogram	At site main pool is separated from a holding pool – tests were done in holding pool, which was of irregular shape with max. dimensions of 15x7x4m deep. Aluminium plank projected out over water, and was propped at end by 2 posts resting on pool bottom. Horizontal bar, with bend in centre for animal to rest its thorax on, spanned the posts to station the animal at 1m below the water surface. Projector (J9 for lower frequencies, WAU (made by one of the authors) for higher frequencies) was located near pool wall 3.2m ahead of stationing bar. 2 lights were located ahead of the animal, at a short distance either side of the projector. 2 baffle plates, of 6mm thick aluminium and 0.8m wide with 6mm thick neoprene rubber glued to them, were placed between the projector and the subject to reduce signal level variations (up to 15dB initially, reduced to 3dB by baffles). Baffle on pool bottom was 0.7m high, and one at surface was 0.9m high but broke surface so that only approx. 0.7m was in water. Also small transducer above subject's head for training tone projection. Procedure was for trainer to cue animal to go to station by sounding a 0.5s long 3kHz tone through training projector. When animal was in place experimenter initiated test, which started with the lights being lit and, 2sec later, the test signal being projected for 2sec. After a further 10sec the light were switched off, and a 0.5sec long 7kHz tone, through the training projector, signalled the end of the trial. The test signal was a sinusoid with 160ms rise and fall times. If subject heard signal it immediately backed away from its station, if not it stayed there until the trainer gave the release tone. Rewards o animal were: (1) no fish for improper response, (2) 2 fish for correct response to signal-present trial, (3) 4 fish for correct response to signal-absent trial. Started with signal at above threshold level and reduced in 2dB steps until subject failed to hear signal. Then increased level in 2dB steps until subject again hard signal. This repeated until had 10 reversals, to complete a session. 50% of trials were signal-absent ones. Sessions ranged from 24 to 69 trials. Session threshold was computed as average of the 10 reversals. Required 2 consecutive sessions to have threshold estimates within 3dB, and then computed overall threshold for that frequency.
Any other comments	Subject was adult male, about 4.5m long and weighing approx. 700kg, kept at Sea Life Park, Hawaii since 1974. Tests conducted at the Park. Animal was at least 18yrs old, but its hearing was believed to be normal. Pool had skimmer filtration system (no pumps). Subject performed 3 to 5 shows per day; it was tested once per day between June and Dec. 1986. Note that animal turned and tilted its head during signal-absent or below-threshold trials, presumably to optimise reception. Authors believe there was little likelihood of masking at any of the test frequencies. The ambient noise level in the pool was well below the test signal amplitude at all test frequencies; only results are statement that level declined from 85dB/($Hz^{1/2}$) at 2kHz to 35dB/($Hz^{1/2}$) at 115kHz. They did get some large deviations of some session thresholds from others at same frequency. They conclude that these were probably due the animal being ill or socially stressed.

Audiogram from Table I. Threshold levels in dB re 1μPa.

Frequency (kHz)	2	4	8	16	32	64		85		105	110	115
Transducer	J9	J9	J9	J9	J9	J9	WAU	J9	WAU	WAU	WAU	WAU
Mean	99	80	64	49	45	39	40	74	78	81	94	116
Range of session means	95-101	80-81	62-67	44-55	42-49	38-42	37-47	72-76	76-79	77-84	90-98	111-119
No. of reversals tested	50	30	40	60	50	60		50		40	50	50



[Fig. ref: FalseKillerWhale01]

Audiogram for False killer whale.

Database page ref: M/WhaleKiller/01.

Common name	Killer whale
Family	
Species	*Orcinus orca.*
Paper from which audiogram obtained	Szymanski, M.D., Bain, D.E., Kiehl, K, Pennington, S., Wong, S. & Henry, K.R. (1999). Killer whale (*Orcinus orca*) hearing: Auditory brainstorm response and behavioral audiograms. JASA, 106(2): 1134-1141.
Paper having original audiogram data	Szymanski, M.D., Bain, D.E., Kiehl, K, Pennington, S., Wong, S. & Henry, K.R. (1999). Killer whale (*Orcinus orca*) hearing: Auditory brainstorm response and behavioral audiograms. JASA, 106(2): 1134-1141.
Comments on methodology of getting audiogram	Test pool, filled with seawater, was 15m in dia and about 4m deep. Subject was trained to remain stationary alongside pool wall with the apex of the melon of its head at a target and its blowhole breaking the water surface. If subject moved more than 100mm off target trial was abandoned. For **ABR tests** the projector (ITC Model 1042 spherical hydrophone, (35mm dia.)) was positioned 1m ahead of the subject's rostrum and 1m below water surface. Monitoring hydrophone (Sea Systems Model 1000r) was positioned 0.5m lateral to subject, 1m below water surface, in line with the lower jaw at the approx. level of the pan bone. Test signal was cosine-gated tone burst of 1ms duration (1 & 2kHz) or 0.5ms duration (all other frequencies). Bursts were presented at 30/sec, in blocks of 350 stimuli. In a trial the trainer placed 2 gold Grass EEG electrodes embedded in suction cups on subject's head; 1 was 170mm caudal of the blowhole, the other was near the dorsal fin, 750mm caudal of the blowhole along the midline. Both electrodes were above the water surface. The signal between the electrodes was differentially amplified 10^5 times and bandpass filtered from 100Hz to 3kHz. The AEPs were averaged in 30ms epochs from 350 responses sampled at 200KS/s and stored for off-line analysis. Procedure was to start with level about 50dB above threshold, and reduce level in 10dB steps until ABR response was no longer visually detectable in 2 consecutive trials. Stimuli were then increased in 5dB steps until ABR reappeared. Delphinid ABR wave IV was used as measure of threshold because it had the largest pk-to-pk amplitude. Auditory threshold was defined as the minimum amount of stimulus power needed to evoke a response greater than background EEG noise. In **behavioural experiments** (done in 1991-93) signal projector was an LC32 hydro-phone and monitor a B&K 8105. Go/no-go method was used. Subject was trained to station with the apex of its melon against a bar 1m below the water surface. A 2sec tone was played between 1 and 10secs later, and the whale had 4sec to respond. Signal levels were reduced by 6 to 8dB when signal was detected, and increased by 6 to 8dB after signal was not detected. Threshold was defined as 2 detections at one intensity level and 2 failures to detect the tone level below.

Any other comments	Tests conducted on 2 adult female killer whales at Marine World Africa USA in California in 1995-96. Both subjects previously participated in behavioural and evoked potential experiments. Yaka was 26 to 28-yrs old (she came originally from the resident A5 pod off the coast of British Columbia in 1969), and Vigga was 16 to 18-yrs old (she came from Icelandic waters in 1980). Stimuli were calibrated daily at frequencies being tested (before whale was in position), the monitoring 'phone being placed at the approx. site where the whale's pan bone would be. Signal level was also calibrated with whale in position and found to fluctuate between 6 and 10dB re 1μPa. When whale was in position and electrodes were attached it was possible to collect 2 averaged waveforms, a procedure which lasted 2 to 3mins. Ambient noise was measured with a signal analyser having a bandwidth of 238Hz, between 2kHz and 10kHz. Results plotted in figure.

Overall audiograms for both animals, from Table I. Threshold levels in dB re 1μPa.

Frequency (kHz)	1	2	4	8	12	16	20	32	45	60	80	100
Mean threshold (behavioural)			61	57	45	46	34	46	48	53	65	75
Mean threshold (physiological)	105	72	75	52	60	50	37	40	45	65	78	116

Ambient noise from Fig. 5c. Analyser had bandwidth of 238Hz. Levels in dB re 1μPa
NOTE: Selected values to get representative shape of curve.

Frequency (kHz)	2	2.2	2.5	3.2	3.5	4.2	4.6	5.4
Level	58	47	58	54	30	44	36	47
Frequency (kHz)	6.1	7	7.2	7.8	8.2	8.8	10.0	
Level	23	40	23	40	24	33	25	

Database page ref: M/WhaleKiller/02.

Common name	Killer whale
Family	Odontocetes
Species	*Orcinus orca*
Paper from which audiogram obtained	Hall, J.D. and Johnson, C.S. (1972). Auditory thresholds of a killer whale *Orcinus orca* Linnaeus. JASA, 51(2), 515-517.
Paper having original audiogram data	Hall, J.D. and Johnson, C.S. (1972). Auditory thresholds of a killer whale *Orcinus orca* Linnaeus. JASA, 51(2), 515-517.
Comments on methodology of getting audiogram	Used tank 13m in diameter and 2.5m deep at Sea World , San Diego. 1 subject – subadult male 5m long weighing 1820kg which had been in captivity for 3 yrs. At start of trial whale went to a stall and placed its head partially in it. It waited until a light was switched on for 15 sec as a precursor to the auditory signal, which was played for 8 sec. If subject heard signal, it would back out of stall and swim to a paddle, which it pushed. Tests included 'catch trials', i.e. no signal. Used up-down (or staircase) method. Levels were changed in 4dB steps – with a 1dB step size, once a 'no-tone' response was obtained it would often take 3 or 4 trials before a 'yes-tone' response. For frequencies between 500Hz and 7kHz used a Pioneer UL-3 projector; for frequencies between 7 and 31kHz used Atlantic Research LC-10 projector; and repeated this frequency range using Pioneer UL-3. Sound pressure at anterior tip of animal's rostrum was measured using U.S. Naval Ordnance Test Station sound measuring set and HP wave analyser. Tank noise level established by taking measurements at a number of locations within the tank.
Any other comments	Upper limit of threshold was 31kHz; during 8 months of training and testing whale responded only 3 times to a 32kHz tone, and never responded to tones above 32kHz. Couldn't test below 500Hz because of high ambient noise levels, and authors remark that thresholds below 10kHz were probably noise masked. **NOTE:** Richardson ('MM&N') remarks that this animal probably had impaired hearing as other, later, work had shown that this species had an upper limit around 120kHz.

Audiogram from Fig. 3. Threshold levels in dB re 1 dyne/cm^2.

Frequency (Hz)	500	1000	2000	5000	7000	10000	15000	20000	25000	28000	31000
Level	0	13	-4	-31	-54	-55	-68	-53	-58	-60	-15
Level							-73	-58	-62	-62	-18
Level								-63	-67	-65	
Average level	0	13	-4	-31	-54	-55	-70	-57	-62	-62	-16

NOTE: Some values around 30kHz have been omitted, as the curve is rising very steeply here and it is very difficult to estimate values.

Threshold levels in dB re 1µPa.

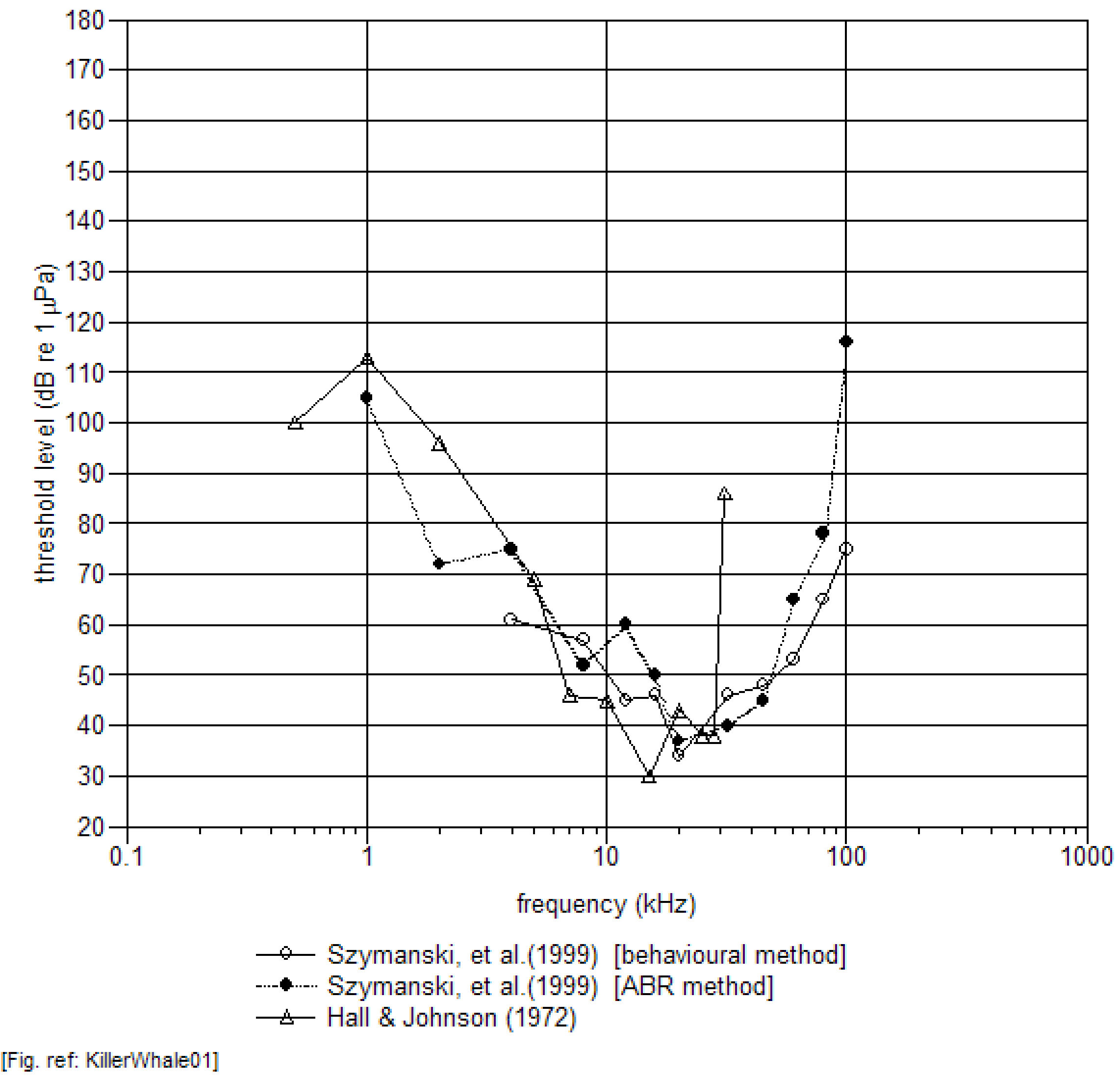
Frequency (Hz)	500	1000	2000	5000	7000	10000	15000	20000	25000	28000	31000
Average level	100	113	96	69	46	45	30	43	38	38	86

Tank noise level from Fig. 3. Levels in dB re 1 dyne/cm^2.

Frequency (Hz)	200	500	1000	2000	5000
Level	-14	-7	-11	-26	-53

Tank noise levels in dB re 1µPa.

Frequency (Hz)	200	500	1000	2000	5000
Level	86	93	89	74	47



Audiogram for Killer whale.

Appendix 4. Miscellaneous data

Common name	Database page ref.	Page number
Dolphin, bottlenose	X/DolphinBottlenose/01	268
Seal, harbour	X/SealHarbour/01	273
Seal, harbour	X/SealHarbour/02	275

Database page ref: X/DolphinBottlenose/01.

Common name	Bottlenose dolphin.
Family	
Species	*Tursiops truncates*
Paper from which audiogram obtained	Turl, C.W. (1993). Low-frequency sound detection by a bottlenose dolphin. JASA, 94(5), 3006-3008.
Paper having original audiogram data	Turl, C.W. (1993). Low-frequency sound detection by a bottlenose dolphin. JASA, 94(5), 3006-3008.
Comments on methodology of getting audiogram	Behavioural method used. Tests done in 6x6m floating pen at San Clemente Island, California. Enclosure had nylon mesh around its sides and bottom. Water depth below pen approx. 10m. Subject was adult female, which had received previous operant conditioning training, but not taken part previous experiments. Signal was sine wave of 1s duration with rise and decay to avoid switching transients. Signal was projected by J-11 projector. At beginning of each test session sound levels and ambient noise levels at subject's position 1m ahead of projector was measured. 2nd and 3rd harmonics were also measured. Procedure was go/no-go method. At start of trial animal positioned on experimenter's hand 350mm below water surface. After experimenter's hand was removed, tone was played (if trial was tone one) and animal had to move to either of two paddles. Half the trials were catch trials. Staircase method used for signal presentation – level reduced in 3dB steps until no response to test signal, then increased again in 3dB steps until animal again responded correctly. At least eight consecutive reversals obtained to complete session.
Any other comments	Two response patterns were observed. In the first, at 200 and 300Hz, there was a plateau around threshold level (Tables A4.1 and A4.2 and Fig. A4.1 below). In the second, at 60 and 100Hz, after 3 to 5 reversals the animal again responded to lower level signals, down to ambient noise level (Tables A4.3 and A4.4 and Figs. A4.2 and A4.3 below). In his discussion, the author states that the separation between animal and sound projector was 1m, which was within the projector's nearfield for frequencies <200Hz. He speculates that the animal may have been responding to particle velocity at the lower frequencies. He cites authors who have found that a dolphin's skin is highly innervated and sensitive to vibrations and small pressure changes in the areas surrounding the eye, blowhole and head region.

Table A4.1. Signal levels, at 200Hz, in dB re 1μbar. From Fig. 2(a) of paper.

Trial no.	1	2	3	4	5	6	7	8	9	10	11	12
Level	29	26	23	20	17	14	10	7	5	11	8	11
Trial no.	13	14	15	16	17	18	19	20	21	22	23	24
Level	8	11	8	11	8	11	8					

Ambient noise level was -8dB re 1 μbar

Table A4.2. Signal levels, at 300Hz, in dB re 1μbar. From Fig. 2(a) of paper.

Trial no.	1	2	3	4	5	6	7	8	9	10	11	12
Level	30	26	25	20	16	14	12	10	7	4	2	6
Trial no.	13	14	15	16	17	18	19	20	21	22	23	24
Level	2	0	2	6	3	6	3	6	3	6	3	

Ambient noise level was -8dB re 1 μbar

Table A4.3. Signal levels, at 100Hz, in dB re 1μbar. From Fig. 2(b) of paper.

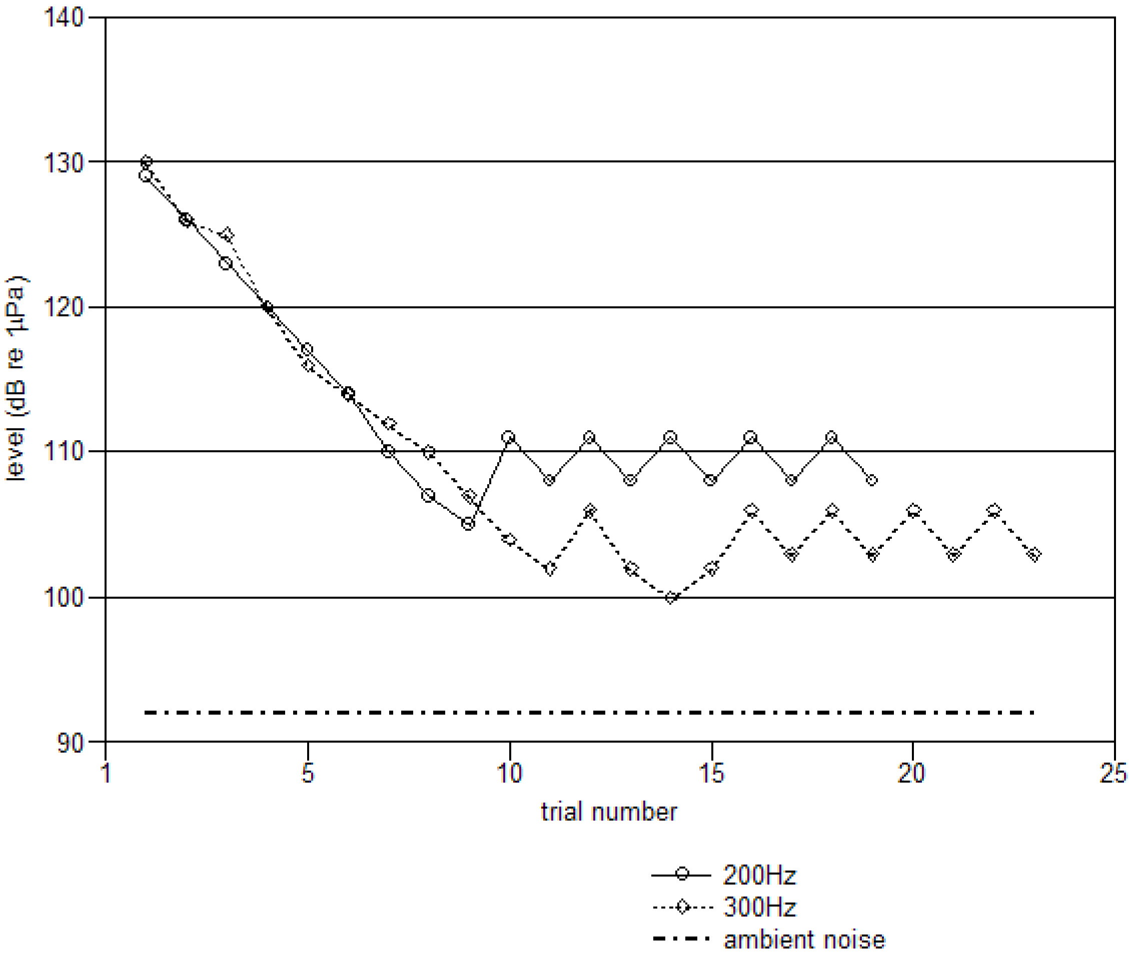
15 Nov	Trial no.	1	2	3	4	5	6	7	8	9	10	11	12
	Level	30	20	16	19	16	19	16	19	16	19	16	13
	Trial no.	13	14	15	16	17	18	19	20	21	22	23	24
	Level	10	7	4									
30 Nov.	Trial no.	1	2	3	4	5	6	7	8	9	10	11	12
	Level	30	27	24	20	17	13	17	13	17	13	17	13
	Trial no.	13	14	15	16	17	18	19	20	21	22	23	24
	Level	17	13	10	7	4	3	0	-3	-6			
18 Dec	Trial no.	1	2	3	4	5	6	7	8	9	10	11	12
	Level	30	23	20	17	13	11	14	11	14	11	14	11
	Trial no.	13	14	15	16	17	18	19	20	21	22	23	24
	Level	8	5	2	-1	-4	-7						

Ambient noise level was -8dB re 1 μbar

Table A4.4. Signal levels, at 60Hz, in dB re 1μbar. From Fig. 2(c) of paper.

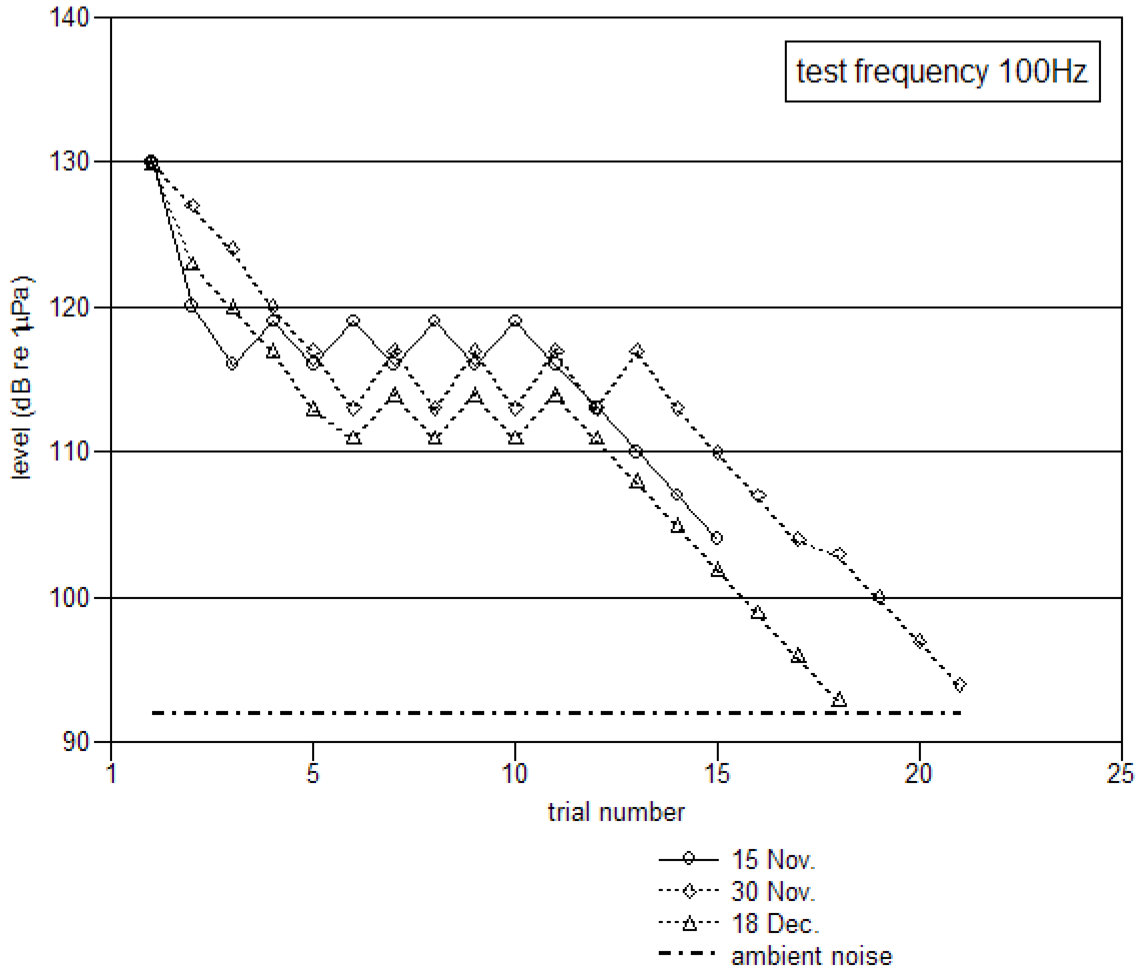
1 Nov	Trial no.	1	2	3	4	5	6	7	8	9	10	11	12
	Level	30	24	21	15	18	15	18	15	18	15	18	15
	Trial no.	13	14	15	16	17	18	19	20	21	22	23	24
	Level	12	9	6	3	0	-3	-6	-9	30	24	21	18
	Trial no.	25	26	27	28	29	30	31	32	33	34	35	36
	Level	15	18	15	18	15	12	15	18	15	12	9	7
	Trial no.	37	38	39	40								
	Level	4	1	-2	-5								
19 Dec	Trial no.	1	2	3	4	5	6	7	8	9	10	11	12
	Level	30	20	17	20	17	20	17	20	17	14	11	8
	Trial no.	13	14	15	16	17	18	19	20	21	22	23	24
	Level	5	2	-1	-4	-7							

Ambient noise level was -8dB re 1 μbar



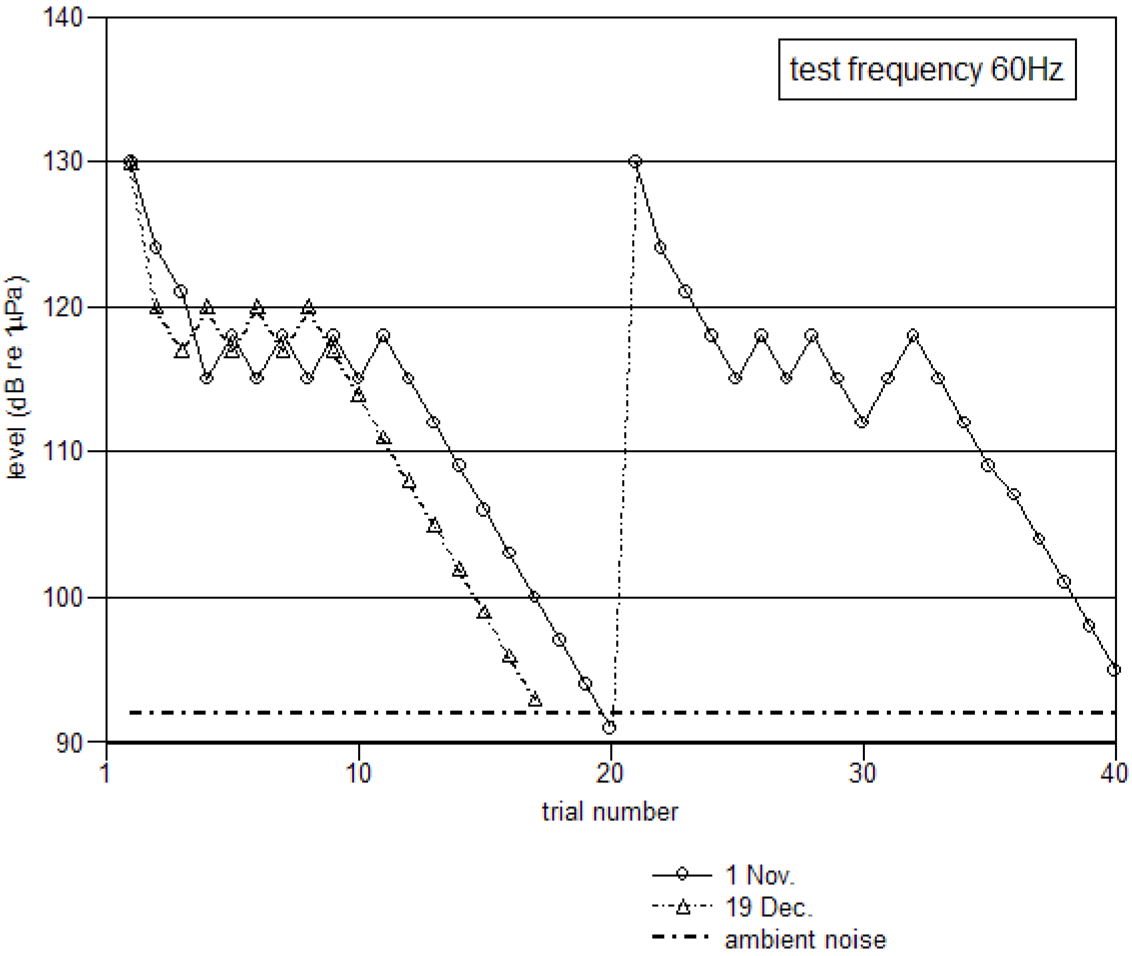
[Fig ref: DolphinBottlenose_G_02_A01]

Fig. A4.1. Examples of sessions in which plateau was observed.



[Fig ref: DolphinBottlenose_G_02_B01]

Fig. A4.2. Examples of sessions in which a temporary plateau was observed.



[Fig ref: DolphinBottlenose_G_02_C01]

Fig. A4.3. Examples of sessions in which a temporary plateau was observed.

Database page ref: X/SealHarbour/01

Common name	Harbour seal.
Family	
Species	*Phoca vitulina.*
Paper from which audiogram obtained	Terhune, J.M. (1989). Underwater click hearing thresholds of a harbour seal, *Phoca vitulina*. Aquatic Mammals, 15(1), 22-26.
Paper having original audiogram data	Terhune, J.M. (1989). Underwater click hearing thresholds of a harbour seal, *Phoca vitulina*. Aquatic Mammals, 15(1), 22-26.
Comments on methodology of getting audiogram	Tests conducted in indoor 4.5m dia. by 1m deep tank. Stimulus switch was placed at centre of tank, 0.5m from bottom and 0.5m from sound source (B&K 8100). Subject indicated if it had or had not heard a sound by pressing either of 2 switches (‘yes’ or ‘no’) after it had pressed the stimulus switch. Signal generator was triggered when subject depressed switch; in catch trial case circuit was opened to prevent signal generator from triggering. Each testing session consisted of 2 or 3 warm-up trials followed by 10 signal trials (all of same level) interspersed in 10 catch trials. Signal level in subsequent sessions was reduced in 4dB steps until subject’s correct responses to both signal and catch trials (summed) was 12/20 or less. Signal level of next session was increased by 2dB, and, if appropriate, a final session 4dB louder was conducted. Data from 3 to 6 stimulus levels (2dB apart, 10 signal and 10 catch trials per level) were used in the threshold calculation. The thresholds (50% correct, signal and catch trial responses summed) were calculated using a constant stimulus method. 2 sets of signals were presented to subject. (1) single 8, 16, 31 or 63μsec rectangular pulses at a rate of 10/sec. (2) 16kHz sine wave pulses of lengths 1600, 160, 16, 8, 4, 2 or 1 cycles at a rate of 10/sec (4/sec for 1600 cycles).
Any other comments	Subject was 5 yrs old. 3 testing sessions per day, at least 2 hrs apart, were conducted for 5 to 6 days per week. Loudness of a click can be can be described in terms of peSPL (peak equivalent sound pressure level), which is defined as the RMS SPL of a continuous pure tone having the same amplitude as the click.

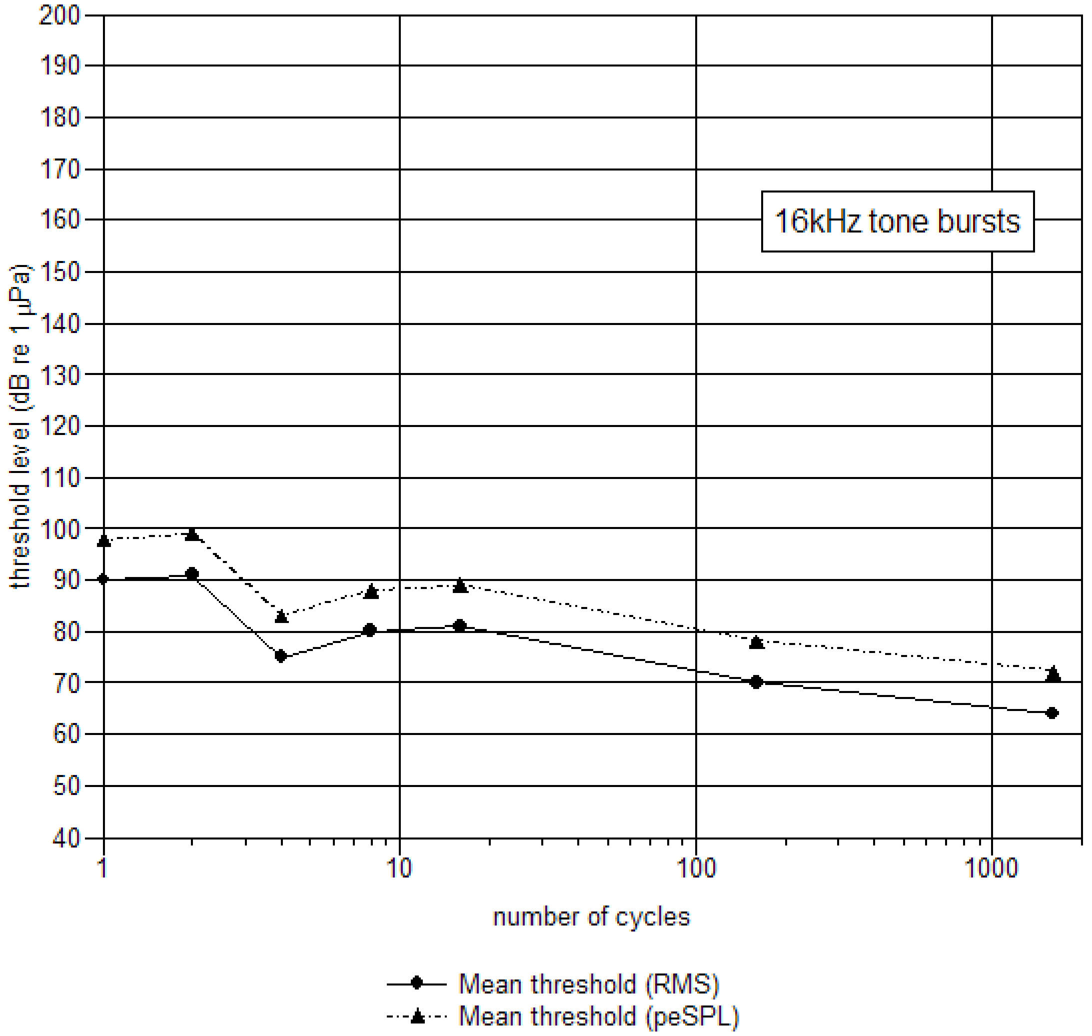
Data from Table 1.

1). Rectangular pulses (1 cycle). Threshold levels (peSPL) for short duration sounds in dB re 1μPa.

Pulse length (μsec)	8	16	31	63
Mean threshold (peSPL)	93	95	95	93
SD	±4	±4	±5	±3

2). 16kHz tone burst. Threshold levels (RMS and peSPL) for short duration sounds in dB re1μPa.

Number of cycles	1600	160	16	8	4	2	1
Mean threshold (RMS)	64	70	81	80	75	91	90
SD	±2	±2	±4	±14	±19	±4	±5
Mean threshold (peSPL)	72	78	89	88	83	99	98
SD	±2	±2	±4	±14	±19	±4	±5



[Fig. ref: HarbourSeal_water_16k_tone_01]

Variation of threshold level with number of cycles of a 16kHz tone burst, for a harbour seal.

Database page ref: X/SealHarbour/02.

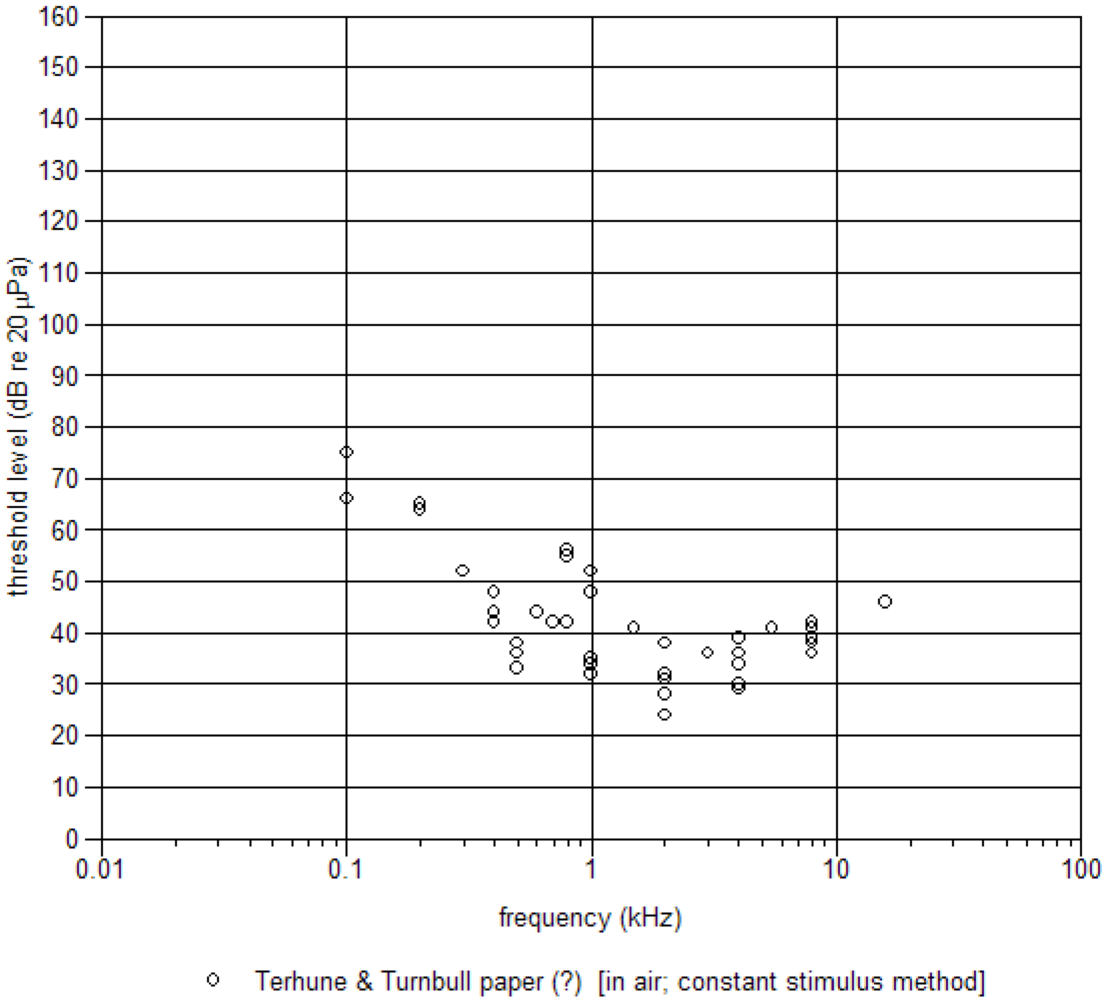
Common name	Harbour seal
Family	
Species	*Phoca vitulina*
Paper from which audiogram obtained	Terhune, J. & Turnbull, S. (?)Variation in the psychometric functions and hearing thresholds of a harbour seal. ?.
Paper having original audiogram data	Terhune, J. & Turnbull, S. (?)Variation in the psychometric functions and hearing thresholds of a harbour seal. ?.
Comments on methodology of getting audiogram	Method had been to get subject to push a stimulus switch, and then to go to either of 2 response paddles. Stimulus presentation was constant stimulus method – started at high level, then reduced level in 4dB steps until subject's response was correct in only 50-60% of trials at a particular level. Then raised level by 2dB, and then by 4dB for final session. 20 trials in a session for first three sets of experiments, and 30 trials in a session for fourth set of experiments. For all sessions, half of trials were signal-present trials, and half catch trials.
Any other comments	Re-analysis of data obtained in 174 hearing detection measurements over 8 years from 1 subject. Used studies of Terhune (1988) {"Detection thresholds of a harbour seal to repeated underwater high-frequency, short-duration sinusoidal pulses"}, Terhune (1989) {"Underwater click hearing thresholds of a harbour seal, *Phoca vitulina*"}, Turnbull & Terhune (1990) {"White noise and pure tone masking of pure tone thresholds of a harbour seal listening in air and underwater"}, and Turnbull & Terhune 1993) {"Repetition enhances hearing detection thresholds in a harbour seal (*Phoca vitulina*)"}. Authors state in summary of paper that, "rather than using the lowest thresholds per subject, a broad brush approach to general trends of data sets should be used when interpreting results of phocid hearing studies'.

In air unmasked hearing thresholds from Fig. 6. Levels in dB re 20µPa.

Frequency (kHz)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1	1.5	2	3	4	5.5	8	16
Level	75	65	52	48	38	44	42	56	52	41	38	36	39	41	42	46
Level	66	64		44	36			55	48		32		36		41	
				42	33			42	35		31		34		39	
									34		28		30		38	
									32		24		29		36	

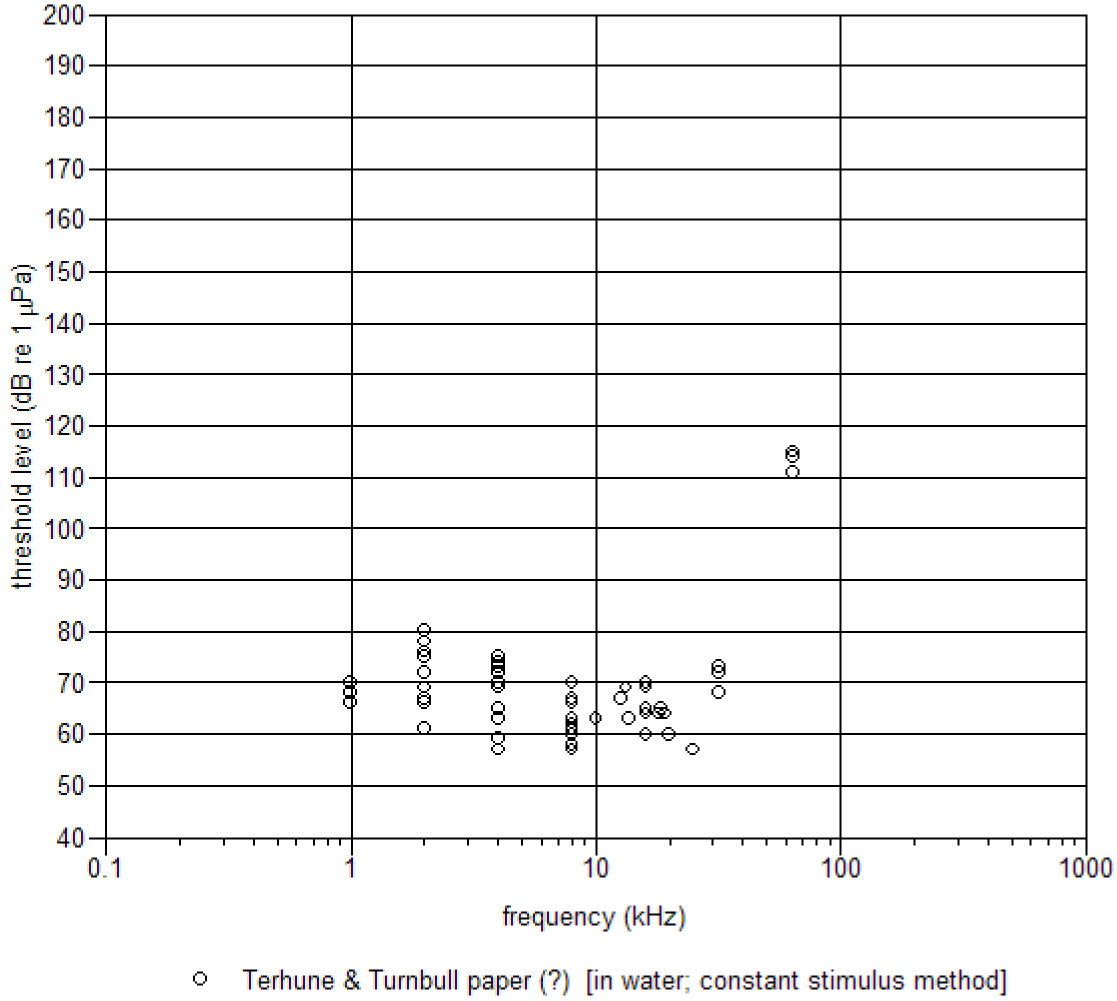
Underwater unmasked hearing thresholds from Fig. 5. Levels in dB re 1µPa.

Frequency (kHz)	1	2	4	8	10	12.6	13.3	13.6	16	18	18.5	19.2	20	25	32	64
Level	70	80	75	70	63	67	69	63	70	64	65	64	60	57	73	115
Level	68	78	74	67					69				60		72	114
Level	66	76	73	66					65						68	111
Level		75	72	63					64							
Level		72	70	62					60							
Level		69	69	61												
Level		67	65	60												
Level		66	63	58												
Level		61	59	57												
Level			57													



[Fig. ref: HarbourSeal_air_Misc01]

In air unmasked hearing threshold levels



[Fig. ref: HarbourSeal_water_Misc01]

Underwater unmasked hearing threshold levels

Appendix 5. Record of changes.

1. This is a controlled document.
2. Additional copies should be obtained through the Subacoustech Librarian.
3. If copied locally, each document must be marked "Uncontrolled Copy".
4. Amendment shall be by whole document replacement.
5. Proposals for change to this document should be forwarded to Subacoustech.

Issue	Date	Details of changes
534R0201	5/12/03	First draft, by B.E.
534R0202	12/12/03	Second draft, by B.E.
534R0203	19/12/03	Third draft, by B.E.
534R0204	7/1/2004	Fourth draft, by B.E.
534R0205	20/1/2004	Fifth draft, by B.E.
534R0206	6/2/2004	Sixth draft, by B.E.
534R0207	11/2/2004	Seventh draft, by J.R.N.
534R0208	11/2/2004	Eight draft, by J.R.N.
534R0209	11/2/2004	Ninth draft, by J.R.N.
534R0210	18/2/2004	Tenth draft, by B.E.
534R0211	3/3/2004	Eleventh draft, by J.R.N.
534R0212	11/3/2004	Twelfth draft by B.E.
534R0213	29/3/2004	Thirteenth draft issued by email by JRN
534R0214	3/9/2004	Report issued.

1. Originator's current report number	534R0214
2. Originator's Name & Location	J.R.N., Subacoustech
3. Contract number & period covered	534;
4. Sponsor's name & location	
5. Report Classification & Caveats in use	UNCLASSIFIED; UNLIMITED DISTRIBUTION.
6a. Date written	
6b. Pagination	
6c. References	
7a. Report Title	Fish and Marine Mammal Audiograms: A summary of available information
7b. Translation / Conference details (if translation give foreign title / if part of conference then give conference particulars)	
7c. Title classification	UNCLASSIFIED
8. Authors	Nedwell, J.R., Edwards, B., Turnpenny, A.W.H., & Gordon, J.
9. Descriptors / Key words	audiogram
10a. Abstract Compendium and review of audiograms of underwater animals, including a brief overview of the methods used to obtain them and fuller details of the method used for each experiment.	
10b. Abstract classification	UNCLASSIFIED; UNLIMITED DISTRIBUTION.