Agenda Item 14.5.2

Implementation of the ASCOBANS Triennial Work Plan (2007-2009)

Review of New Information on Pollution, Underwater Sound and Disturbance

Acoustic Disturbance

Document 45

Possible Impact of Personal Watercraft (PWC) on Harbor Porpoises (*Phocoena phocoena*) and Harbor Seals (*Phoca vitulina*)

Action Requested

- take note of the information submitted
- comment

Submitted by

GSM

ASCOBANS

NOTE:
IN THE INTERESTS OF ECONOMY, DELEGATES ARE KINDLY REMINDED TO BRING THEIR OWN COPIES OF DOCUMENTS TO THE MEETING

Possible Impact of Personal Watercraft (PWC) on Harbor Porpoises (*Phocoena phocoena*) and Harbor Seals (*Phoca vitulina*)

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SUMMARY

In light of the plans by an investor to open a part of the Neustadt Bight (German part of the Baltic Sea) to the use of Personal Watercraft (PWC) and discussions about a ban of PWC in certain protected areas such as national parks or special areas of conservation under the EU habitats directive, this study seeks to summarize and assess possible risks these craft cause to harbor porpoises and harbor seals. PWC are small, jet-powered plastic boats that can reach speeds of up to 120 km/h.

Harbor porpoises and harbor seals are likely to be highly sensitive to disturbance by PWC. The noise caused by these craft, their erratic movement (rapid changes in direction and speed), high speeds and the fact that they are used primarily in shallow coastal waters hold a considerable potential for disturbance and carry a risk of collision.

Under water, cavitation (the formation of bubbles and their collapse due to changes in pressure, causing a hissing sound) causes considerable sound pressure levels over a broad frequency range. Levels measured were significantly above the auditory thresholds of harbor porpoises and harbor seals. Cavitation, and hence the noise intensity, is increased by wave motion. In addition to causing direct disturbance, this noise can mask biologically significant sounds, such as communication sounds emitted by conspecifics or the sounds made by prey or predators. Masking can negatively affect the natural behavior of these animals. Due to the loud, broadband sound emissions of PWC it is likely that they mask communication sounds of seals and harbor porpoises in a similar frequency range even at great distances.

Speed boats cause harbor porpoises to flee even at considerable distances. Their reactions are particularly noticeable when the boats change course and move towards the animals. No systematic studies of harbor porpoise behavior relative to PWC exist. Information on effect mechanisms and possible behavioral patterns can however be derived from studies carried out on bottlenose dolphins (*Tursiops truncatus*), since both species show similar behavioral reactions when interacting with speed boats.

PWC dramatically influence the behavior of bottlenose dolphins. Compared to other types of boats, approaching PWC were found to lead to very pronounced changes in behavior. Several studies found that characteristic escape reactions occurred. These consisted in changes in dive patterns, with animals spending more time underwater, decreased interanimal distance, increased swimming speed and changes of direction away from the craft. Frequently the animals even abandoned the study area as a reaction to increased power boat traffic.

The erratic movements of PWC, which are unpredictable for the animals, intensified observed escape reactions. Moreover, the avoidance behavior of females with calves is especially pronounced, possibly due to the fact that the slow-moving juveniles limit their ability to maneuver. Furthermore, the observed behavioral reactions to boats and PWC are particularly strong in shallow waters, since the animals cannot escape downwards but only horizontally.

Additionally, acoustic phenomena (”shallow water effect“) make it more difficult to locate the PWC, increasing the overall risk of collision.

In addition to these short-term effects of PWC for individual animals or groups of animals, there may be long-term risks for the populations of marine mammals. Long-term effects on populations and cumulative effects of disturbance caused by water craft have not yet been studied. It can be assumed that boat traffic and, in particular, the intensive disturbance caused by the operation of PWC has a negative effect on the energetic requirements of marine mammals. As a result, the population may suffer long-term damage due to increased parasite infestation, diseases or reduced reproductive success.

INTRODUCTION

In light of the plans by an investor to open a part of the Neustadt Bight (German part of the Baltic Sea) to the use of Personal Watercraft (PWC) and discussions about a ban of PWC in certain protected areas such as national parks or special areas of conservation under the EU habitats directive, this study seeks to summarize and assess possible risks these craft cause to harbor porpoises and harbor seals. PWC operating off bathing beaches are considered to cause disturbance and their use is prohibited in many places along the German Baltic and North Sea coasts. Noise, interference and collisions from boat and jet ski activity may also injure marine mammals or inhibit their natural behaviour. On the basis of the relevant literature, this study aims to assess the susceptibility of two native species, harbor porpoises and harbor seals, to sound emissions in relation to their hearing abilities, natural behavior and possible collision risk.

DEFINITION

The watercraft covered by this study are plastic boats, between 2 m and 4.5 m long and powered by an inboard engine driving a pump jet[1]. Their top speeds range from 60 to 120 km/h. They are frequently referred to as “jetskis”. Since *Jetski* is a brand name coined by Kawasaki Heavy Industries Ltd., the term personal watercraft (PWC) will be used in this study. This comprises both smaller, one person “stand-ups” and the bigger “sit-down” models for up to four riders.

HEARING OF HARBOR SEALS AND HARBOR PORPOISES

The hearing of harbor porpoises and harbor seals has been studied by various authors using operant conditioning, i. e. increasing a behavior captive animals were trained to show as a reaction to a certain sound using positive reinforcement. If animals take the correct decisions they are rewarded with a fish. In the course of the tests, the sound pressure level and the frequency of the sounds is varied. The received level leading to a random decision (50% wrong decisions) of the test animal is considered to mark the auditory threshold at the frequency concerned (Kastak & Schusterman 1998;Kastelein et al. 2002). Tests of this kind lead to so-called behavioral audiograms depicting the auditory threshold of the animals studied at various frequencies.

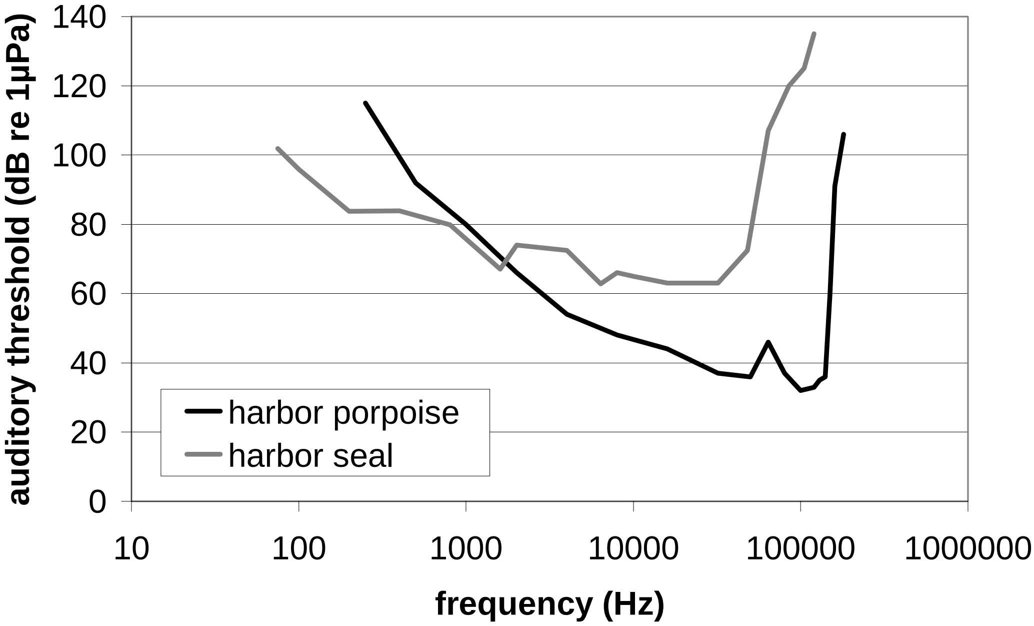

***Figure 1** Audiograms of a harbor seal (black) and a harbor porpoise (grey). The table depicts the minimum auditory threshold as indicated by Andersen (1970) and Kastelein et al. (2002) for the harbor porpoise, respectively Terhune & Ronald (1974) and Kastak & Schusterman (1998) for the harbor seal. The lower the curve progression the better the hearing at the corresponding frequency.*

A conservative estimate of the effects of sound must be based on the most sensitive individuals (presumably the juveniles) in a given population. Figure 1 therefore depicts the

[1] Information provided by Jets Marivent Deutschland GmbH, Burscheid, Germany

minimum auditory threshold of two behavioral studies for each species in order to take account of the fact that in all studies only one individual animal was studied. Kastelein et al. (2002) complemented the harbor porpoise audiogram established by Andersen (1970) by providing data in particular for the low-frequency range. Kastak & Schusterman (1998) were able to add low-frequency data to the behavioral audiogram of harbor seals initially examined by Terhune & Ronald (1974).

The sensitivity of both species is low in the low-frequency range, rises at medium and high frequencies and drops again at very high frequencies resulting in a typical u-shaped hearing curve. The audiograms of harbor porpoises and harbor seals differ at various frequencies: the hearing of harbor porpoises is far more sensitive in the high frequency range of their own echolocation signals (110 to 140 kHz), whereas the hearing of harbor seals is better than that of harbor porpoises at frequencies below approximately 1 kHz.

SOUND EMISSIONS OF PWC

Sound in air

The producers of PWC only provide data on the sound levels of their craft in air. To name one example, measurements taken at a distance of 25 m from a craft with a 2-stroke engine running at 95% of full power yielded a sound level in air of 74,8 dBA (re 20 µPa, weighted to the human audiogram)[2]. Measurements taken by Evans et al. (1992) yielded a sound level of 83 dBA at low speeds and 90 dBA at high speeds (*Kawasaki Jetski* 650 ccm). These differences may be due to technical progress or to different methods of measuring. Sound in air may be relevant for seals resting on their haul-outs. However, this study concentrates on effects of underwater sound. Unfortunately, information on underwater sound cannot be deduced from sound in air as the sources of noise differ. Thus, noise heard on the surface is primarily engine noise and the sound of the hull slapping down on the surface, whereas the sound of the hull's passage through the water and cavitation[3] contribute to the spectrum of emissions under water (Evans et al. 1992;Richardson et al. 1995).

Underwater sound

Generally speaking, the sound level and frequency of the sound in water of boats is roughly correlated to the size of the boat and its speed. However, there are considerable variations between various classes of boats (Richardson et al. 1995). Sound emissions of boats primarily derive from cavitation and the sound of the hull's passage through the water. Cavitation is the dominant source of noise in propeller-driven vessels. Due to the high speeds at which PWC travel, jet propulsion also causes cavitation, leading to a broadband, high intensity noise (Homm[4], personal communication). This is the case especially when waves repeatedly cause the jet stream to be interrupted for short intervals. This causes the sound emissions to rise and drop.

In the literature, only one specific underwater sound measurement for PWC was found (Evans et al. 1992). Figure 2 reflects the spectrum measured for a *Kawasaki Jetski* (650 ccm), compared to a lobster fishing vessel (5 ft., 240 HP inboard engine), a speed boat (17 ft., 90 HP outboard engine) and an inflatable dinghy (7 ft., 6 HP outboard engine). In the given conditions the PWC was significantly less noisy than the propeller-driven vessels (Figure 2). However, since the test took place in a yacht harbor, presumably at constant speed and with no waves, the sound level under normal conditions in the Baltic Sea needs to be corrected upward. Due to stronger cavitation higher sound emissions are to be expected.

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[2] According to information provided by Jets Marivent Deutschland GmbH, Burscheid, Germany

[3] The formation of air bubbles and their collapse due to changes in pressure in water, which leads to a clearly audible hissing sound.

[4] Anton Homm, Wehrtechnische Dienststelle für Schiffe und Marinewaffen - WTD 71, Akustikzentrum 340, Berlinerstr. 115,

24340 Eckernförde, Germany

Moreover, Evans et al. (1992) do not indicate the speed of the PWC at time of measurement. Speed is, however, crucial to the extent of cavitation and, therefore, the maximum sound level.

All sound levels (measured at 3 m distance) indicated in Fig. 2 are significantly higher than the auditory threshold of bottlenose dolphins (*Tursiops truncatus*, the target species of their study), harbor porpoises and harbor seals. The spectrum measured by Evans et al. (1992), however, only extends from 2 kHz to 20 kHz. The noise caused by cavitation and the hull's passage through the water covers a much wider range from a few Hz to approximately 100 kHz (Richardson et al. 1995). Maximum sound pressure levels of boats (and presumably also of PWC) typically can be measured between 50 and 150 Hz. Considerable parts of the PWC frequency spectrum are audible to marine mammals even at great distance. Evans et al. (1992) calculated that with ambient noise typical of sea state 3, bottlenose dolphins can hear the PWC studied up to a distance of 450 m. In the frequency range studied by Evans et al. the auditory threshold of harbor porpoises is lower than that of bottlenose dolphins, so that harbor porpoises would be able to perceive the noise at even greater distances (cf. Au 1993).

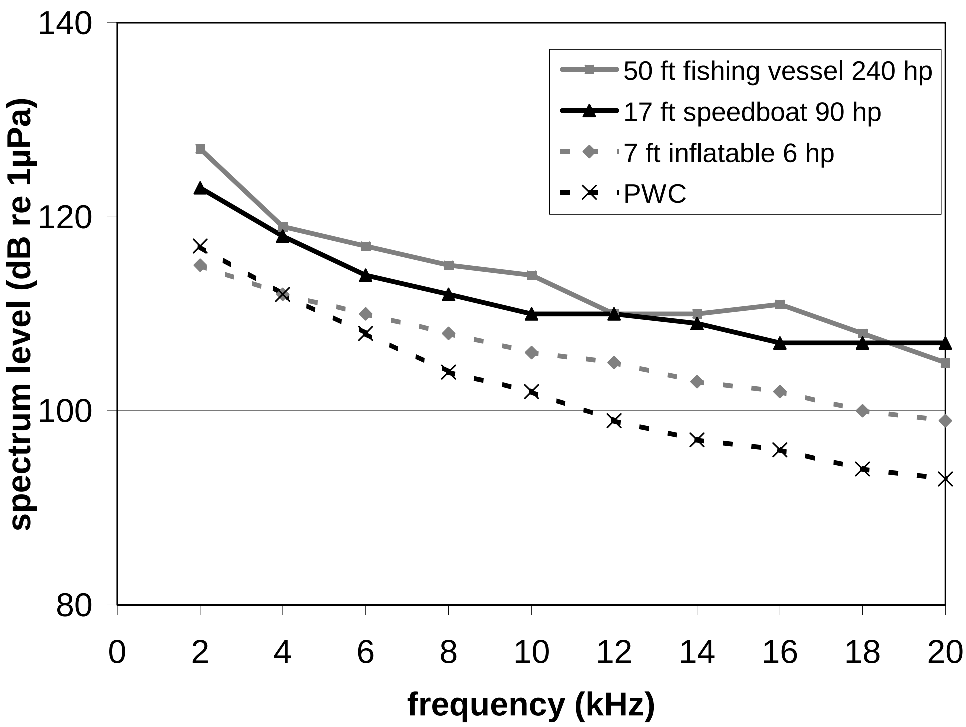

Figure 2 *Sound spectra of various watercraft (measured at 3 m distance); measuring range from 2 to 20 kHz. Redrawn from Evans et al. (1992).*

SUSCEPTIBILITY OF MARINE MAMMALS TO DISTURBANCES BY BOATS AND PWC

Information from harbor seal studies

No systematic studies of harbor seal reactions to fast boats or PWC exist. Seals may habituate to the sound of boats and ships. E. g., Thompson et al. (1998) reported distinct avoidance behavior to unknown vessels, but animals tolerated a familiar research vessel. Seals stopped calling for 15 min during breeding season as a reaction to strange vessels, but continued calling in the presence of an extremely loud but familiar high-speed catamaran.

Information from harbor porpoise studies

Harbor porpoises react in different ways to various types of boats and ships. It is reported that they may be attracted to sailboats, and that they maintain a minimum distance of only 50 m to ships operating regularly and on a straight course such as ferries (Kinze 1986). In the case of a research vessel they were usually observed outside of a 100 m radius (Kinze 1990). This avoidance behavior typical of harbor porpoises was also documented by Scheidat (1996) from another research vessel. Harbor porpoises avoid fast-moving motor boats at even greater distances: in different studies escape behavior was documented at a distance of approx. 150 m (Kinze 1986) to an average of 233 m (Evans et al. 1994).

In general, pronounced escape or avoidance behavior shown by a significant increase in dive time and a change of direction away from the boat similar to the behavior documented for harbor porpoises (Evans et al. 1992) became evident as a response to boats. Motor boats trigger avoidance behavior more often (100% of observations) compared to slower motor yachts (60%) or ferries on a regular course (22%). And even more distinct reactions occurred when boats changed their courses towards the animals (Evans et al. 1994). This indicates that apart from their speed, the “behavior” of approaching watercraft is crucial.

Information from bottlenose dolphin studies…

A study by Allen & Read (2000) in Florida, proved noticeable effects of boat traffic on bottlenose dolphins’ choice of habitats. During times of intense boat traffic (power vessels including PWC) primary feeding grounds were abandoned.

PWC have a dramatic influence on the behavior of dolphin groups (Mattson et al. 2005). Their study of bottlenose dolphins in South Carolina revealed very marked behavioral changes when PWC approached the animals, compared to other types of boats. Most groups interrupted their activities, dived and left the study area. Lemon et al. (2006) found a change in surface behavior and direction of travel of indo-pacific bottlenose dolphins orienting away from an approaching boat (5.6 m, 90 hp two-stroke outboard engine). Hastie et al. (2003) further found an increased breathing synchrony in bottlenose dolphins when boats were present in the Cromarty Firth (Scotland) which they interpret as possible type of antipredatory response.

A systematic study of bottlenose dolphin behavior towards fast-moving watercraft (boats with outboard engines and PWC) was conducted by Nowacek et al. (2001). In their experiments, a speed boat (5.8 m, 115 hp two-stroke outboard engine), and a PWC (*Yamaha WaveRunner III*) were steered towards groups of bottlenose dolphins in Florida. The behavior of the animals at different speeds and in response to different “behaviors” of the boat or PWC (directed vs. erratic movements) was documented. Behavioral changes observed were changes of animals’ heading, increase in interbreath intervals, increase in swimming speed as well as decrease in interanimal distance.

Nowacek et al. (2001) conclude that the following factors influence the avoidance reaction of bottlenose dolphins: (1) the predictability of the boat’s movement, (2) the speed, (3) the presence of juveniles (4) the water depth.

(1) Predictability of the boat’s movement

Behavioral changes were most distinct when a PWC approached with erratic movements (rapid changes of direction and speed), compared to a boat or PWC on a straight course, as these erratic movements typical of PWC are unpredictable for the animals (Nowacek et al. 2001). This corresponds to the results obtained by Sini et al. (2005) who found that small boats moving in variable directions elicited a negative response of bottlenose dolphins in Aberdeen harbor more often than boats on a straight course. In another study, in which boat noise was simulated using recorded sounds, a similar effect became apparent (Evans et al. 1992): sudden high volume boat sounds simulating erratic movements lead to particularly pronounced escape reactions of bottlenose dolphins.

(2) Speed

Sini et al. (2005) recorded only negative responses (prolonged dives or avoidance) of bottlenose dolphins to fast moving vessels in Aberdeen harbor, whereas near slower boats negative, neutral and positive responses occurred with the same frequency. In contrast, Nowacek et al. (2001) found that reactions to watercraft following a straight line were more pronounced at lower speeds (17 km/h for the boat and 28 km/h for the PWC) than at higher speeds (57 km/h for the boat and 65 km/h for the PWC). According to the authors this may be due to the fact that in their study area in Florida dolphin watchers usually follow the animals at lower speeds and for longer periods, whereas boats traveling faster commonly stay on course, for instance in the shipping lane, making their “behavior” more predictable for the animals. A similar effect was also described by Janik et al. (1996), who report that an observation boat in the Moray Firth (Scotland) caused bottlenose dolphins to show stronger avoidance reactions than any other motor boats.

(3) Presence of juveniles

The study by Nowacek et al. (2001) also showed that mother-calf pairs of females which had successfully raised a calf before increased their dive times (interbreath intervals) more pronounced compared to “inexperienced” females with or animals without calves. This is interpreted as a sign of acquired avoidance behavior towards watercraft.

(4) Water depth

Furthermore, behavioral reactions of bottlenose dolphins to boats and PWC were more pronounced in shallow water than in deeper water (Nowacek et al. 2001). Since PWC can be used in very shallow water, it can be assumed that the potential for disturbance is very high in particular in such waters. There are a number of possible reasons for this. In shallow water, the animals cannot escape downwards but only horizontally. Moreover, the animals are probably particularly susceptible to disturbance during certain critical activities taking place in shallow water (e.g. feeding, calving, nursing). Another explanation for the pronounced reactions in shallow water may be the existence of physical effects. Thus, multiple sound reflections at the surface and the sea floor lead to unpredictable interference patterns ("shallow water effect", see Koschinski 2002a). Phase shifts of the direct sound waves and the reflected sound waves result in an addition or a subtraction of sound energy, leading to localized but considerable differences in received sound levels at the ears of the animals, which make it impossible to detect the source of the sound.

… and their possible implications for harbor porpoises

Since systematic studies of the behavior of harbor porpoises in relation to PWC do not exist, effect mechanisms and possible behavioral patterns must be derived from research conducted on the better-studied bottlenose dolphins. This is possible, since both species show similar behavioral reactions in case of interaction with sports boats (not including PWC). Porpoises, however, show these reactions at greater distances to the boats (150 to 233 m; Kinze 1986;Evans et al. 1994) compared to bottlenose dolphins or indo-pacific bottlenose dolphins (*Tursiops aduncus*) (<100 m; Nowacek et al. 2001;Lemon et al. 2006) and therefore appear to be more sensitive.

Since no whale watching trips take place in the Baltic Sea, it can be assumed that (unlike bottlenose dolphins in Florida) harbor porpoises show more pronounced responses to fast vessels and PWC, since in general slower vessels are more predictable than fast ones. This is confirmed by the findings of Evans et al. (1994), who showed that in the coastal waters of the Shetland Islands (an area without whale watching trips) faster boats caused more pronounced reactions in harbor porpoises compared to slower vessels.

Based on the findings above it can be assumed that harbor porpoises are highly susceptible to disturbance by PWC. The erratic maneuvers of these craft, their high speed and their use in shallow water have a high potential for disturbance.

COLLISION RISK

Erratic movements at high speed in shallow waters also increase the risk of collision. In order to escape in time, marine mammals need to receive sufficient acoustic information from the craft to be able to determine in which direction and at what speed it is moving. But the erratic maneuvers typical of PWC and “shallow water effects” make this difficult since the audibility of the craft and predictability of its course are reduced substantially (Nowacek et al. 2001;Koschinski 2002a). Evans[5] (personal communication) assumes that for harbor porpoises the risk of collision with PWC is considerably higher than the risk of collision with other watercraft that travel on a directed course. Wells & Scott (1997) have documented a number of injuries of bottlenose dolphins by fast motor boats.

Even though experienced bottlenose dolphin females with calves show particularly pronounced reactions to PWC or speed boats (Nowacek et al. 2001) the potential for collision with fast boats or PWC in particular for females accompanied by calves is higher than for other groups (Wells & Scott 1997). Due to the slow-swimming juveniles, it is considerably more difficult for them to get out of the way of watercraft increasing the vulnerability of both mother and calf.

Moreover, in shallow waters a downward escape is practically impossible. The risk of collision is increased by the long periods spent at or near the surface.

In the Baltic Sea, harbor porpoises are usually born between May and July. During this and the following nursing period, the animals are particularly vulnerable (Koschinski 2002b).

MASKING

One of the most pervasive and significant effects of noise may be the reduction in the animals’ ability to detect, interpret and respond to biologically important signals in the presence of noise, a phenomenon called masking. Masking occurs when both the masking noise and the signal have similar frequencies and overlap or occur very close together in time (National Research Council 2003). However, very intense sounds can mask signals even if the signal frequency lies outside the spectrum of masking noise (Richardson et al. 1995). Structured signals such as echolocation click trains or complex calls may be better detected in noise because their frequency content and temporal features differ from those of the background noise.

Indirect evidence for masking of marine mammal signals is the development of antimasking behavior. In a number of odontocete species this has been demonstrated by lengthening or increasing source level or number of calls or adaptation in echolocation frequency (Au et al. 1985;Buckstaff 2004;Foote et al. 2004;Morisaka et al. 2005). Such antimasking behavior may compensate to a certain extent for a loss of information.

Biologically significant sounds for marine mammals can be communication or echolocation sounds emitted by their own species or the sounds produced by predators or prey. Harbor porpoises use stereotypic narrow-band high-frequency (110 to 140 kHz) clicks to echolocate on prey organisms and to orientate (Au 1993;Au et al. 1999;Verboom & Kastelein 1995). Frequency components of between 30 kHz and 60 kHz which may be a by-product of producing the high-frequency clicks were measured (Verboom & Kastelein 1995).

Since the main energy in the expected PWC frequency spectrum is concentrated in the low-frequency range of a few hundred Hertz and broad-band elements all remain below 100 kHz, masking of echolocation sounds by PWC noise is therefore unlikely.

However, low-frequency communication and social calls of harbor porpoises and seals can be masked by noise emissions of PWC in similar frequency-bands. During mating, male harbor seals emit air bubbles, causing low-frequency (<4 kHz) underwater pulses of approx.

[5] Peter G. H. Evans, Department of Zoology, University of Oxford, South Parks Road, Oxford OX1 3PS, UK

20 ms. Furthermore grunting noises and roars and the beating of flippers on the water's surface are used as acoustic signals during mating (Van Parijs et al. 1997;1999). Most of the males' underwater calls occur between July and August. Social underwater calls of harbor seals recorded by Richardson et al. (1995) and Van Parijs et al. (1997;1999) are within a frequency range of 100 Hz to 4 kHz. Juveniles emit contact vocalizations of around 350 Hz. Sound levels are estimated at approximately 105 dB and are, therefore, relatively low and may be subject to masking (Southall et al. 2000). Masking also concerns the lower-intensity click components of harbor porpoises in a broadband range between 13 kHz und 100 kHz and between 1,4 und 2,5 kHz (source level 116 dB re 1µPa at 1m) measured in harbor porpoise clicks (Verboom & Kastelein 1995). Whether these have a function in communication is unclear. If harbor porpoises use low-frequency sounds to communicate, masking of these sounds would have a detrimental effect on the animals.

Presumably broadband sound emissions of PWC can mask low-frequency sounds of harbor porpoises and seals. Whether or not masking occurs depends on the exact sound spectrum and the sound energy within the expected masking range. In critical habitat, the use of PWC should not be authorized prior to a more in-depth examination of this phenomenon.

FINAL ASSESSMENT

The main problems marine mammals are faced with when an area is opened for PWC are noise, high speeds, and erratic movement of the craft. Related problems are difficulty in localizing the craft, higher risk of collision, as well as disturbance resulting in increased and more pronounced avoidance behavior and increased stress.

Short-term reactions to boat traffic and PWC have been documented in several studies mentioned above, but there may also be long-term risks for marine mammal populations (National Research Council 2005).

Short-term effects of PWC operation comprise, for instance, escape and avoidance reactions which can lead the animals to abandon an area. This was proven in particular for bottlenose dolphins. An increased risk of collision, especially in shallow water, can lead to injury or death of individuals (z. B. Wells & Scott 1997). Even at great distances, noise may cause further problems. Background sound levels can mask social vocalizations of harbor seals and harbor porpoises which would have short-term negative impacts on their behavior.

Long-term effects at population level and cumulative effects of disturbance caused by watercraft have yet to be studied (Janik & Thompson 1996). Vessel traffic can, however, have a negative influence on behavior, distribution, habitat use and energy requirements of marine mammals, which may lead to long-term effects (Wells & Scott 1997;Allen & Read 2000). Thus, the fitness of the animals may be reduced in the long term if they are forced to relocate to sub-optimal feedings grounds, in particular if there are additional negative anthropogenic influences (e.g. overfishing, ship traffic, seismic operations, aggregate extraction activities, construction of wind farms etc.). Chronic stress can suppress immune function or reproduction, inhibit growth or alter metabolism. Reliable techniques to identify indicators of stress caused by acoustic immissions in free-ranging marine mammals have yet to be developed (National Research Council 2005). Decreased fitness may result in increased infestation with parasites, weakened resistance to diseases or reduced reproductive rates.

Nowacek et al. (2001) have demonstrated that in the case of bottlenose dolphins mothers with calves are especially susceptible to disturbance. Unpublished own data indicate a similar tendency in harbor porpoises. In the long run, frequent disturbance to females with calves can reduce their fitness and, consequently, the survival rates of juveniles.

The same holds true for masking of biologically relevant sounds (e. g. contact vocalizations, social vocalizations). Long-term effects to be expected at population level may be lower reproductive rates or lower survival rates of juveniles if disturbance occurs on a regular basis during the mating season or during the rearing of the young. The mating season of harbor porpoises and harbor seals is around July and August (Koschinski 2002b;Van Parijs et al. 1997). This is also the main vacation period, and thus the period in which the greatest number of PWC and speed boats are presumably in operation.

LITERATURE

Allen, M. C., & A. J. Read. 2000. Habitat selection of foraging bottlenose dolphins in relation to boat density near Clearwater, Florida. Mar. Mamm. Sci. 16: 815-825.

Andersen, S. 1970. Auditory sensitivity of the harbour porpoise *Phocoena phocoena*. In [ed.], G. Pilleri. Investigation on Cetacea, Vol. II. Institute of Brain Anatomy. Berne. p. 255-259

Au, W. W. L. 1993. Sonar of dolphins. Springer. New York. 277 pp.

Au, W. W. L., D. A. Carder, R. H. Penner, & B. L. Scronce. 1985. Demonstration of adaptation in beluga whale echolocation signals. J. Acoust. Soc. Am. 77: 726-730.

Au, W. W. L., R. A. Kastelein, T. Rippe, & N. M. Schooneman. 1999. Transmission beam pattern and echolocation signals of a harbor porpoise (*Phocoena phocoena*). J. Acoust. Soc. Am. 106: 3699-3705.

Buckstaff, K. C. 2004. Effects of watercraft noise on the acoustic behavior of bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. Mar. Mamm. Sci. 20: 709-725.

Evans, P. G. H., P. J. Canwell, & E. Lewis. 1992. An experimental study of the effects of pleasure craft noise upon bottle-nosed dolphins in Cardigan Bay, West Wales. European Research on Cetaceans 6: 43-46.

Evans, P. G. H., Q. Carson, P. Fisher, W. Jordan, R. Limer, & I. Rees. 1994. A study of the reactions of harbour porpoises to various boats in the coastal waters of southeast Shetland. European Research on Cetaceans 8: 60-64.

Foote, A. D., R. W. Osborne, & A. R. Hoelzel. 2004. Whale-call response to masking boat noise. Nature 428: 910.

Hastie, G. D., B. Wilson, L. H. Tufft, & P. M. Thompson. 2003. Bottlenose dolphins increase breathing synchrony in response to boat traffic. Mar. Mamm. Sci. 19: 74-84.

Janik, V. M., & P. M. Thompson. 1996. Changes in surfacing patterns of bottlenose dolphins in response to boat traffic. Mar. Mamm. Sci. 12: 597-602.

Kastak, D., & R. J. Schusterman. 1998. Low frequency amphibious hearing in pinnipeds: methods, measurement, noise, and ecology. J. Acoust. Soc. Am. 103: 2216-2228.

Kastelein, R. A., P. Bunskoek, M. Hagedoorn, W. W. L. Au, & D. De Haan. 2002. Audiogram of a harbor porpoise (*Phocoena phocoena*) measured with narrow-band frequency-modulated signals. J. Acoust. Soc. Am. 112: 334-344.

Kinze, C. C. 1986. On the distribution of the harbour porpoise (*Phocoena phocoena*) in Danish waters. ICES council meeting 1986 (collected papers). Copenhagen (Denmark). 13 pp.

Kinze, C. C. 1990. Chapter 6: The behaviour of freeranging harbour porpoises (*Phocoena phocoena*) in inner Danish waters. PhD. University of Copenhagen.39 pp.

Koschinski, S. 2002a. Ship collisions with whales. Information document presented at the eleventh meeting of the CMS scientific council. 14-17 September 2002, Bonn/Germany. UNEP/ScC11/Inf.7. 19 pp.

Koschinski, S. 2002b. Current knowledge on harbour porpoises (*Phocoena phocoena*) in the Baltic Sea. Ophelia 55: 167-198.

Lemon, M., T. P. Lynch, D. H. Cato, & R. G. Harcourt. 2006. Response of traveling bottlenose dolphins (*Tursiops aduncus*) to experimental approaches by a powerboat in Jervis Bay, New South Wales, Australia. Biol. Conserv. 127: 363-372.

Mattson, M. C., J. A. Thomas, & D. St Aubin. 2005. Effects of boat activity on the behavior of bottlenose dolphins (*Tursiops truncatus*) in waters surrounding Hilton Head Island, South Carolina. Aquat. Mamm. 31: 133-140.

Morisaka, T., M. Shinohara, F. Nakahara, & T. Akamatsu. 2005. Effects of ambient noise on the whistles of indo-pacific bottlenose dolphin populations. J. Mamm. 86: 541-546.

National Research Council. 2003. Ocean noise and marine mammals. The National Academies Press. Washington D. C. / USA. 192 pp.

National Research Council. 2005. Marine mammal populations and ocean noise. The National Academies Press. Washington D. C. / USA. 126 pp.

Nowacek, S. M., R. S. Wells, & A. R. Solow. 2001. Short-term effects of boat traffic on bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. Mar. Mamm. Sci. 17: 673-688.

Richardson, W. J., C. R. Greene, C. I. Malme, & D. H. Thomson. 1995. Marine mammals and noise. Academic Press. San Diego. 576 pp.

Scheidat, M. 1996. Bestandserfassungen bei Walen (Cetacea): mögliche Fehlerquellen bei der "Line-Transect"-Methode. Diplom. Institut für Meereskunde an der Christian-Albrechts-Universität zu Kiel.

Sini, M. I., S. J. Canning, K. A. Stockin, & G. J. Pierce. 2005. Bottlenose dolphins around Aberdeen harbour, north-east Scotland: a short study of habitat utilization and the potential effects of boat traffic. J. Mar. Biol. Ass. UK 85: 1547-1554.

Southall, B. L., R. J. Schusterman, & D. Kastak. 2000. Masking in three pinnipeds: underwater low frequency critical ratios. J. Acoust. Soc. Am. 108: 1322-1326.

Terhune, J. M. & K. Ronald. 1974. Underwater hearing of phocid seals. ICES C.M.1974/N:5. International Council for the Exploration of the Seas. 11 pp.

Thompson, D., C. D. Duck, & B. J. McConnell. 1998. Biology of seals of the north-east Atlantic in relation to seismic surveys. In [eds.], M. L. Tasker and C. Weir. Proceedings of the seismic and marine mammal workshop London 23-25 June 1998.

Van Parijs, S. M., P. M. Thompson, D. J. Tollit, & A. Mackay. 1999. Geographical variation in temporal and spatial vocalisation patterns of male harbour seals in the mating season. Anim. Behav. 58: 1231-1239.

Van Parijs, S. M., P. M. Thompson, D. J. Tollit, & A. Mackay. 1997. Distribution and activity of male harbour seals during the mating season. Anim. Behav. 54: 35-43.

Verboom, W. C., & R. A. Kastelein. 1995. Acoustic signals by harbour porpoises (*Phocoena phocoena*). In [eds.], P. E. Nachtigal, J. Lien, W. W. L. Au, and A. J. Read. Harbour porpoises - laboratory studies to reduce bycatch. De Spil. Woerden. p. 1-39

Wells, R. S., & M. D. Scott. 1997. Seasonal incidence of boat strikes on bottlenose dolphins near Sarasota, Florida. Mar. Mamm. Sci. 13: 475-480.