Telemetry studies in harbour porpoises – An overview of the technical and practical state of the art

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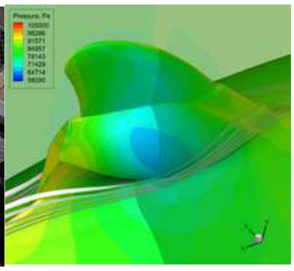

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Summary

Information on the life functions and ecology of harbour porpoises is still scarce. Only a limited number of animals are available for research in controlled situations. Satellite tracking allows to gather information on individual movements of harbour porpoises, hence providing direct insight into the individual lifestyle of a free-ranging animal. Moreover, satellite telemetry is a powerful method for directly identifying the cause-effect relationship between anthropogenic activities and the animal's behaviour. Harbour porpoises have been tagged with satellite transmitters already for almost two decades.

This document is intends to provide a comprehensive overview of the relevant aspects of telemetry studies in harbour porpoises in Dutch waters and also give an overview of the latest technical developments in this field. Based on this information the strategy for further development and use of telemetry in harbour porpoises can be shaped.

Today a range of telemetry tags are available for a multitude of different usage. The following components are evaluated in this report: Positioning tags, recorders for diving behaviour, acoustic tags, releasers, retrieving equipment and new developments. Important aspects considered are the size of the tag in relation of the size of the target animal, the attachment method in relation to longevity of the data recording, and the data sampled in relation to project objective.

It is evident that results derived from 'classic' telemetry studies provide detailed information on the behaviour of the animal without allowing to assess which and to what extent external factors have influenced the behaviour. Controlled behaviour experiments on the other hand allow assessing the cause-effect relationship between underwater sound and the animals' behaviour under semi-controlled conditions, but will not provide sufficient insight into the behaviour of the animals. Only acoustic telemetry is able to provide a comprehensive data set allowing to assess which type of underwater sound events leads to what kind of reactions at which level and in which behavioural context.

The technology to conduct these studies is already available and only needs to be adjusted to the specific requirements of working with harbour porpoises. But whatever approach or technology will be chosen, it always has to be considered that the behaviour of marine mammals is highly complex and context specific. A completely novel approach to the design and attachment of tags will not only reduce the effect on the animal, it will as well reduce artefacts caused by the tag and the tagging procedure itself.

1. Introduction

Harbour porpoises(*Phocoena phocoena*) are small toothed whales (odontocetes) with an elusive lifestyle. Most of the time they are submerged and only coming to the surface to breathe. Moreover, compared to other odontocete species such as dolphins who are known to accompany ships, harbour porpoises are rather shy and neophobic. With mainly their small dorsal fin being visible above the surface during the very brief surfacing to breathe these animals are difficult to detect visually and even harder to follow under water.

At the same time information on their life functions and ecology is still scarce. Only a limited number of animals are available for research in controlled situations. Information on free-ranging animals mainly derives from aerial or boat-based visual surveys, acoustic surveys with towed hydrophones or passive acoustic monitoring (PAM) using data-loggers or controlled exposure experiments. This information provides valuable but somewhat limited answers to the research and management questions as it gives only indirect insight and is restricted to either a small spatial or temporal scale. This is perfectly worthwhile for monitoring e.g. population trends or the effects of certain activities on these animals. Satellite tracking on the other hand allows to gather information on the individual movements of harbour porpoises, hence providing direct insight into the individual lifestyle of a free-ranging animal. Moreover, satellite telemetry is a powerful method for directly identifying the cause-effect relationship between anthropogenic activities and the animal's behaviour.

Harbour porpoises have been tagged with satellite transmitters since 1994 (Read and Westgate 1997). All taggings has been conducted in either the Bay of Fundy, Canada (Read and Westgate 1997, Johnston et al. 2005) or in Danish waters (Teilmann et al. 2007, Sveegaard et al. in press). In these areas, national fishing methods (herring weir in Canada and pound nets in Denmark) permit capture of the porpoise in bowl-shaped nets that allow the porpoise to breathe. Furthermore, the mesh size of these nets is too small for the porpoises to get entangled.

Satellite tracking of harbour porpoises can provide information on the individual porpoise e.g. detailed movement patterns (Read and Westgate 1997), diving behaviour (Otani et al. 1998, Teilmann et al. 2007), seasonal movements, home range and distribution (Sveegaard et al., in press). Sveegaard (2011) provides the most comprehensive and up-to-date information on satellite telemetry studies on harbour porpoises. As she points out, this method has recently been used for identifying high-density areas (Sveegaard et al., in press) and suitable habitats (Edren et al. 2010) of harbour porpoises.

2. Assignment

Several important research questions can be addressed with satellite telemetry:

1. The habitat use and in particular the migration routes of harbour porpoises. Without knowing where harbour porpoises are spending their time any management plan being developed is limited in its effectiveness. The animals might e.g. face certain threats at different times of the year at different areas while these threats are either managed only on a spatial or a temporal scale, these efforts will provide only limited protection to the harbour porpoises. In the context of bycatch of harbour porpoises one hypothesis is that the Dutch porpoises move to German waters in the summer to reproduce, but this is not known and almost impossible to find out with the current research methods. Satellite telemetry can provide the relevant information of their movements on the appropriate temporal and spatial scale which will allow determining the most efficient management and protection measures.

2. Investigation of behaviour and impact of noise on marine mammals, especially the harbour porpoise: The latest technical improvement is the development of acoustic telemetry, i.e. in addition to the classical telemetry devices a sound recorder can be integrated into the unit. Even though this results in an increase in the dimensions of the tags (weight and size), it represents an important improvement in terms of the insight that can be gained into the cause-effect relationship between anthropogenic noise and the animal's behaviour. Anthropogenic noise has been identified as a major stressor for marine mammals as it has the potential to disturb or even injure animals. The perception of underwater sound and a healthy hearing system is of vital importance for harbour porpoises . Acknowledging the importance of this factor, underwater sound has been listed by the EU as descriptor 11 in the Marine Strategy Framework Directive. Besides the potential physical impact that underwater sound can have on the animals (TTS/PTS, i.e. a damage to the hearing system of the animals) the behavioural effects of noise on marine mammals has been identified as an important aspect. While we have first data on the physical effect of sound on harbour porpoises (TTS test conducted in Denmark, published in a peer-reviewed journal: Lucke *et al.* 2009), the behavioural aspect is still poorly understood. The National Research Council has identified this aspect as another major lack of knowledge and a lot of research effort is put worldwide into understanding the cause-effect relationships and to assess its relevance for individual marine mammals as well as effects on a population level.

3. Investigating the success of rehabilitation of stranded harbour porpoises: Each year a number of life-stranded harbour porpoises is rehabilitated by the Stichting SOS Dolfijn in Harderwijk. Most of the animals are released into the North Sea a few months after their initial stranding. However, so far the survival of these animals and hence the success of the rehabilitation can't be assessed unless an animal strands again alive or is found dead on the beach. Satellite telemetry would provide the information necessary to assess how the animals are doing once they're released. This would give researchers as well as the experts from SOS Dolfijn important insight into the behaviour and well-being of rehabilitated animals.

This document is intended to provide a comprehensive overview of the relevant aspects of telemetry studies in harbour porpoises in Dutch waters and also give an overview of the latest technical developments in this field. Based on this information the strategy for further development and use of telemetry in harbour porpoises can be shaped.

3. Materials and Methods

The following components are evaluated:

1. Positioning tags
    - Argos (smaller, less accurate, transmitting locations, months-year duration)
    - Fastloc GPS (larger, more accurate, recording only, weeks-months duration, need retrieval)
2. Recording diving behaviour
    - Time-Depth-Recorder (small, high resolution, recording data, weeks duration)
    - Accelerometers and compass in 2-D or 3-D (small, detailed body movements, feeding behaviour, avoidance behaviour, recording data, days-weeks duration)
    - Satellite linked dive recorder (small, low resolution, histograms or sample of dives, transmitting, months-year duration)
3. Acoustic tags
    - A-tag (echolocation event recorder, small, recording data, days duration)
    - D-Tag (full bandwidth recorder, small, recording data, hours duration, includes dive recorder, accelerometers and VHF)
    - Bioacoustic probe (full bandwidth recorder up to 20 kHz, small, depth, temperature and 2D acceleration, recording data, hours duration)
4. Releasers (pins or suction cup)
    - Timed (small, predictable)
    - Corrosive metals (small, less predictable)
    - Acoustic releaser (bigger, predictable)
5. Retrieving equipment
    - VHF transmitter (small, only for retrieval of tags)
    - VHF receiver radio (necessary for finding a tag in open sea)
6. New developments

4. Results

Initially telemetry studies involved transponders which were sending out radio signals. By using a directional antenna it was then possible to track the movements of a tagged individual. With advancing technology the range of parameters that could be measured increased, but more importantly the potential to store data in the telemetry unit (the "tag") arose. This allowed to no longer having to follow the tagged animal but to retrieve the stored data once the tag detached itself (either actively or passively).

Today a range of telemetry tags are available for a multitude of different usage. The use of such tags on diving animals such as the harbour porpoise, however, require to make the units waterproof and pressure resistant. Moreover, there are two principal options with regard to data retrieval: if the amount of data can be limited to the position where the animal surfaces and some basic dive parameters (such as depth) this information can be transmitted via satellite; the advantage of this approach is that the tags do not have be buoyant as they are not retrieved after they detached. If the aim of the tagging is to study the movements of the animal in more detail the tags have to buoyant to ensure that they float at the surface once they're detached. This results in an increase in size and volume of the unit to an extent of several times the size of the sensors and data logger.

Attaching sensors directly to the animal allows to monitor and record various physical parameters such as the animal's swimming speed, the pressure (= depth), temperature, 3-dimensional position and acceleration of the animal. This provide enough information to reconstructing the animals behaviour (so-called "dead reckoning") once the data have been retrieved.

The size and hydrodynamic shape of the unit as well as the position on the animals body dictates the influence the tag has on its carrier. With an average maximum body size of 1.5 m for an adult male harbour porpoises and 1.6 m for female harbour porpoises (Olafsdóttir *et al*. 2003) and an average swim speed of 1.5 m/s (Lucke *et al*. 2000) this species is one of the smallest cetacean species and a rather slow swimming species.

As all cetaceans harbour porpoises have evolved a streamlined body shape reducing the drag and possibly even special adaptations of their skin which reduce the drag caused by vortices along their skin as the animals move through the water.

But nevertheless, harbour porpoises are supposed to have a high metabolic rate. Any additional energetic demand as it would be caused by the drag caused by an telemetry unit being attached externally to their body could have a negative effect on the animal. Moreover, while being put onto the animal to study its behaviour in detail, the tag itself could potentially alter the animals behaviour if it's too big.

One of the biggest problems besides the technological issues of optimising the technical issues (sensor technology, memory capacity and power requirements) and hydrodynamic shape is the attachment method. The attachment should cause no or as little harm to the animal as possible but at the same provide the most secure attachment possible. Harbour porpoises, alike all whales studies so far, shed their upper skin layer constantly, most likely to avoid or reduce the growth of 'Aufwuchs' which prohibits the use of any adhesive agent. Baleen whales have a subdermal fat layer ("blubber") which can reach a thickness of up several tens of centimeter. These large whales are commonly tagged using units attached to darts which are shot with a crossbow into the blubber and ideally get stuck with a barb hook. This attachment method can result in a tag deployment period of several months and is considered to be of little negative impact for the baleens (little to no reaction of the whale to deployment, additional drag considered to be negligible due to size animal/ tag size ratio). With the small body size and a blubber layer thickness of only a few centimeters this technology is evidently no option for telemetry on harbour porpoises.

The attachment method which is currently predominantly used for tagging harbour porpoises involves bolts to keep the tag in place. These bolts are either corrosive (magnesium) or can be released by a dedicated release mechanism. As the latter usually involves additional space and weight (battery power), this approach is less suited when trying to minimize the tag dimensions (both in weight and size). Hence, the most appropriate method is to locally anaesthetize a small region of the dorsal fin of an animal and drill a hole through it in preparation for the attaching the bolts through the hole. After inserting the bolts through the hole the devices can be attached and locked on both sides. This technique allows to securely attach the tag to the animal and ensure that the tag doesn't begin to move or oscillate due to the current when the animal is swimming. Even though the dorsal fin of harbour porpoises consists to large extent of tough connective tissue, this body region is nevertheless innervated and contain blood vessels. In order to avoid/reduce the amount of pain from this procedure for the animals the dorsal fin is being locally anaesthetised before the tagging is conducted. It has been shown that animals tagged with this method do not suffer from negative long-term effects (re-sighting of tagged animals accompanied with calves), but a wild animal would be clearly stressed from being handled and might suffer from other short-term effects.

Acoustic telemetry

Harbour porpoises have been proven to echolocate, i.e. to emit acoustic signals to detect, localise and characterise their prey items as well as for orientation and most likely also for communication (Clausen et al. 2010). They also have a very sensitive hearing and can perceive acoustic stimuli of frequencies up to 160 kHz (Andersen 1970, Kastelein et al. 2010). With all other forms of energy being attenuated underwater much faster this represents again a highly specialised adaptation to their marine environment. The acoustic sense has evolved to be their most important sensory modality. Consequently acoustic cues are the most important trigger for behavioural reactions to external stimuli.

Over the past decades the amount of anthropogenic activities has increased in many parts of the world' s oceans. This development in linked, either intentionally or unintentionally as a by-product, with the emission of sound into the marine environment. On average this has led per decade to a doubling in terms of sound energy which is being introduced into the water. With the development of offshore renewable energies especially in European waters the need to assess the impact of the correlated sound emissions on harbour porpoises has been identified as a major scientific and regulatory requirement. Existing data on soundscapes at sea as well as telemetry data from telemetry studies using conventional devices would allow to model this aspect, but the cause-effect correlation would remain very weak. Controlled exposure experiments can shed some more light on this issue, but can only be conducted at a small number of specific sights which provide the required porpoise density and e.g. elevated vantage points.

However, the most efficient approach is the combined attachment of a conventional telemetry unit with a underwater noise recorder. There are a number of technical aspects to consider to make this effort worthwhile, but the benefit of this approach is that the behavioural reactions identified through the telemetry data can directly be linked to any acoustical event which is recorded by the noise logger. This allows to identify and quantify the effect of underwater sound on marine mammals in general and of specific anthropogenic sound sources on harbour porpoises in particular.

The biggest disadvantage is of course the increase in tag-size. With a second unit being added this approach can only be conducted in a justifiable way if each of the components is reduced to its absolute minimum. The complete tag must be of a sensible size and create only an acceptable amount to drag for the animal and only large, adult animals should be tagged in beginning. Moreover, the tagging process as well as the presence of the tag itself has the potential to alter the animals' behaviour. Due to this, behavioural data of the time immediately after the tagging should not be included into the analysis. With the decreased size of tags the risk of long-term behavioural effects is minimised as can also be seen from the re-sighting of tagged animals accompanied with calves.

The following aspects have to be considered in relation to acoustic telemetry:

1. Access to animals
2. Validation of effect of tagging
   - In relation to existing tags (i.e. at smaller size)
   - In relation to untagged animals (only inferred from sound exposure studies), problem that behaviour is highly complex
3. Requirements:
   - Small size
   - Optimised hydrodynamic shape
   - Large data storage and low power consumption
   - Long life time
   - Multitude of sensors including acoustic receiver
   - Benign attachment method
   - Data transfer while attached or floating
   - Reusable

Best available technique

The following review of technical aspects of tags is based to a wide extent on the market analysis conducted by Teilmann and Siebert (2011). Based on available literature, contact with manufactures and 20 years of field experience with tagging Teilmann and Siebert (2011) describe availability of the electronic components for a tag combination for porpoises and seals that can record movements, dives and acoustics. These include the Argos satellite transmitters, Fastloc GPS, 2D or 3D behavioural data loggers, high frequency and low frequency recorders, releasers, VHF transmitters and tracking equipment. Of particular consideration is the adjustment of the selected combination's size to make it acceptable to the target animal. Some of the available units have to date been used mostly on larger whales or seals, thus a decrease in size must be achieved. The various components, to be selected will be embedded in a common housing having sufficient buoyancy to float and be retrieved. The housing must be small enough to attach easily to the dorsal fin or the back of a harbour porpoise or seal.

1. Positioning tags

1a) Argos system
Argos satellite transmitter has been widely used in the past ca. 15 years for porpoises (Read and Westgate 1997, Teilmann et al. 2007, Sveegaard et al. 2011) and for about 25 years on seals (e.g. Heide-Jørgensen et al. 1992, Teilmann et al. 1999). These instruments have been specially designed to withstand pressure from deep diving animals. An Argos transmitter transmits to several satellites that orbit around the globe. Argos locations are calculated by measuring the Doppler shift on the transmitter signals. This is the change in frequency of a wave when a transmitter and a satellite are in motion relative to each other. The classic case is when an observer notices a change in the sound when a train approaches and moves away. Similarly, when the satellite "approaches" a transmitter, the frequency of the transmitted signal measured by the satellite is higher than the actual transmitted frequency, and

opposite when it moves away. Each time the satellite instrument receives a message from a transmitter, it measures the frequency and time-tags the arrival. The Argos processing centres placed in several countries around the world compute the location of the transmitter. The advantage of this system is that it only requires the transmitter to be in the air for ¼ of a second to transmit to the satellite and that the researcher will have locations of the animal within 30 min. This is ideal for getting locations from swimming cetaceans and for seals in the waters. The short transmission and no need for data processing in the transmitter also permit very long battery life (up to 1,5 years for porpoises (Teilmann unpubl. data) and 1 year for seals (e.g. Born et al. 2004)). The backside of this system is that the accuracy of locations are a few hundred meters up to several kilometres. This is not necessarily a problem in open ocean but to analyse detailed behaviour in relation to the environment or a noise source a higher location precision is preferable.

Argos transmitters for marine mammals are produced by order in many configurations. The main producers are Wildlife Computers (http://www.wildlifecomputers.com/, Seattle, USA), Telonics (http://www.telonics.com/, Arizona, USA), SMRU (http://smru-inst.st-andrews.ac.uk/pageset.aspx?psr=339, St. Andrews, Scotland) and Sirtrack (http://www.sirtrack.com/, New Zealand).

1b) GPS system
The GPS system is widely used by humans to locate moving objects like e.g. ships, planes and people. In the past decade this system has also been developed for terrestrial animals. The system is fundamentally different from the Argos system as it is a receiving system rather than a transmitting system. The signals from the satellites are received and a location is calculated and stored inside the GPS tag. Therefore the unit needs to be retrieved from the animal or another system needs to transmit the GPS locations to a receiver on land. The Argos system or the GSM mobile network can do this. However, the Argos system has limited transmission capacity and can only transmit a fraction of the recorded GPS locations and the GSM network needs long time to connect to the network. Furthermore the traditional GPS system requires 30-60 sec to record a location, which does not work for marine mammals in the water. Since no system exists for accurately locating objects under water, a new system called Fastloc GPS was developed a few years ago. This system can provide accurate locations from marine mammals that only briefly expose a tag to the air (e.g. Patterson et al. 2010). The advantage of the Fastloc GPS is accurate locations almost every time an animal surface but the challenge is to make it small enough to be carried by porpoises and seals as well as release the tag and get it back. The longevity of the Fastloc GPS on animals are in principle the same as for the Argos, but due to the higher battery consumption the size of equivalent tags are larger.

Fastloc GPS units for marine mammals are produced by order in many configurations, e.g. alone or in connection to an Argos or GSM transmitter. The main producers are Wildlife Computers (Seattle, USA), SMRU (St. Andrews, Scotland) and Sirtrack (New Zealand).

2. Dive recorders

2a) Time-Depth-Recorders (TDR)
For several decades TDR’s have been used to record time and dive depths for marine mammals. These instruments record data at user defined intervals, usually every one or few seconds and have to be recovered to get the data back. Additional sensors have been added to these instruments depending on the objective of the study, like temperature, light level and salinity.

TDR units for marine mammals are produced by order in many configurations. Some of the main producers are Wildlife Computers (Seattle, USA) and Star-Oddi (Iceland).

2b) Accelerometers etc.
In the more advanced loggers also swimming speed, 3D compass and 2D or 3D accelerometers have been added to be able to get detailed tracks of animals under water to analyse e.g. dead reckoning, feeding behaviour or response to noise (e.g. Madsen et al. 2006, Wilson et al. 2008, Akamatsu et al. 2010).

These specialised loggers for marine mammals are mostly developed by researchers for specific projects. They may be available for other researchers from the following Producers/researchers: Little Leonardo/Tom Akamatsu (http://cicplan.ori.u-tokyo.ac.jp/UTBLS/Home.html, Japan), JUV Elektronik (Germany)/Rory Wilson (http://www.swan.ac.uk/staff/academic/environmentsociety/biologicalsciences/wilsonroryp/, UK), Woods Hole Oceanographic Institution/Mark Johnson (USA/UK).

2c) Satellite linked dive recorders (SLDR)
Depth and other sensor data can also be recorded and relayed through Argos satellite transmitters (e.g. Teilmann et al. 2007). However, the limited number of transmissions and the limited capacity per transmission prevent detailed behavioural studies.
SLDR transmitters for marine mammals are produced by order in many configurations. The main producers are Wildlife Computers (Seattle, USA), and SMRU (St. Andrews, Scotland).

3. Acoustic tags

Johnson et al. (2009) provide an excellent review of the present knowledge on “behaviour and sensory ecology of marine mammals using acoustic recording tags”. This review is authored by the designer and users of the D-tag, but also describes other tags and future perspectives of the technology to better understand the detailed behaviour of marine mammals in relation to the increasing concern about effects from anthropogenic sources.

3a) A-tag
This recorder is specially designed to record high frequency echolocation signals from small cetaceans like the harbour porpoise (Akamatsu et al. 2005). Due to its stereo hydrophones, it is capable of distinguishing between signals emitted by the animal carrying the transmitter and those of other animals. The tag functions like an ultrasonic event recorder and records the sound pressure (peak to peak (p-p) re 1 μPa) along with the exact time of detection at each hydrophone. Signals are band pass filtered (55 to 235 kHz) and a hardware detection threshold is set at 142 dB (p-p re 1 μPa) to avoid too much noise. The sampling frequency of 2 kHz provide a time resolution and shortest click interval of 0.5 ms. The total recording time is battery limited to 60-70 h continuous recording. Duty cycle can be set to extent the period over which recordings are made. The instrument fit into a cylindrical waterproof housing measuring 21 x 122 mm and weighing 77 g. The A-tag has to be imbedded in a float for positive buoyancy after detachment from the animal. A VHF transmitter also needs to fit into the float for locating the float after detachment. The A-tag has been deployed on several Danish harbour porpoises since 2005 (Akamatsu et al. 2007, Linnenschmidt in prep., Teilmann, unpublished data).

3b) D-Tag
This acoustic recorder is combined with TDR, accelerometer and compass sensors described in 2a and 2b to be able to relate the acoustic recordings to the behaviour of the animal.

Furthermore, the D-tag is built into a hydrodynamic floating house with four suction cups that can be released with a timer. For retrieval a VHF tag emits from the rear end. The D-tag has provided unique results for frequencies up to 45 kHz with stereo hydrophones (Madsen et al. 2006). The D-tag is a full bandwidth recorder from about 50 Hz to 45 kHz that can be set by the user. The memory and battery capacity is designed to last for up to 48 hours depending on sampling frequency and whether one or two sound channels are used. A new version of the D-tag is being developed to be able to record high frequency echolocation activity from e.g. the harbour porpoise. Besides the sensors mentioned above a Fastloc GPS and an Argos transmitter is considered to be part of this new "all in one" instrument.

3c) Bioacoustic probe (AcousondeTM)
This acoustic tag is developed for large whales or seals that use lower frequency vocalisation or for recordings of background noise (Burgess 2008). In its latest version (March 2012) it optionally records up to 114 kHz and has depth, temperature, 3D compass, 3D tilt and ambient light sensors. The tag can be applied with two suction cups and retrieved by a VHF transmitter and a strobe light (www.acousonde.com).

4. Releasers

4a) Timed releasers
A reliable releaser is essential for retrieving instruments with high probability. Therefore a timed releaser is ideal. The timed releaser can either be attached to a small explosive that detach a cable tire holding the tag on the animal (Linnenschmidt et al. in prep.) or a wire that burn over when strong current is passing through inside the tag (e.g. like in the Wildlife Computers Pop-Up tags where a string will lose the tag from the animal or in the D-tag where air is released into the suction cups so they lose the grip).

4b) Corrosive metals
If many low cost tags are deployed or the tag recovery rate is not a high priority, corrosive metals can be used as a cheap releaser. For short term (hours/days) deployments magnesium has been used and are commercially available (http://www.underseareleases.com/research.htm). The release time is dependent on salinity and temperature, but quite certain if these conditions are known. For long term deployments other metals like iron may be used.

4c) Acoustic releaser
An acoustic releaser will detach when a specific signal is transmitted through air or water over short distances. This option is ideal to release the tag when the tag is in sight, however, this is seldom the case, and may not be very successful when tagging animals with unpredictable behaviour like the harbour porpoise. It may work better for seals but it requires that the seal haul out at a place where it can be observed at close range. This type of releaser is often used for equipment placed on the sea floor where a float will take it to the surface when a ship is ready to take it up (e.g. http://www.sonardyne.com/Products/index.html).

5. Retrieving equipment

5a) VHF transmitter
For all tags that collect large data amounts it is not feasible to transmit data and therefore it is necessary to retrieve it for downloading the data. When the tag is detached from the animal it should float to the surface where a VHF transmitter should start transmitting to facilitate short range tracking. A VHF signal can be heard 5-10 km from a smaller boat or at longer ranges from an airplane depending on the transmitter strength and receiver equipment.

If the animal has not been tracked from tagging to tag detachment, it is impossible to find the tag from a boat. Either the general area of the tag has to be found from an airplane or an Argos transmitter can give the position of the tag. Recent experience have shown that it is feasible to have a very small Argos transmitter as part of the tag containing A-tag, depth logger, 2D accelerometers and a timed releaser (Teilmann pers. comm.). This way of tracking and retrieving the tag has proven very efficient and also gives the flexibility to avoid bad weather where tracking may be impossible.

5b) VHF receiver radio
The basic equipment for tracking a VHF transmitter is a radio with the right frequencies and a directional antenna designed for VHF signals. The principle is to turn the antenna around and find the direction of the strongest signal which is equivalent to the direction of the transmitter. The higher above sea level and the larger the antenna is the longer the tracking range is. It is therefore important to have several types of antennas. Often the wind and radio noise prevent listening to weak signals, therefore noise cancelling headphones is a great advantage. When tracking transmitter within 100 meters the signal must be attenuated to get the direction. If the radio does not have a sufficient internal attenuator an extra attenuator can be mounted on the cable between the radio and the antenna. To help tracking tagged animals or find detached tags a new instrument has been developed called the Digital Direction Finder (DDF, ASJ Electronics Design and LKARTS-Norway). This instrument greatly improves the tracking by giving a visual cue of the direction of the tag by means of a circle of diodes.

6. New developments

Development of a hydro-dynamically optimized (“friendly”) tag
As described above the standard method of attaching a tag to porpoises is by using bolts which are placed through the dorsal fin of the animals. Even though the dorsal fin of porpoises (as dolphins) consists mainly of connective tissue and is not strongly innervated or vascularised, ethical concerns have been repeatedly raised about this attachment method. Moreover, the negative hydrodynamic effect of attaching an tag to animals has been criticised.
In order to develop a “friendly”, less invasive attachment method, a completely new approach has to be taken by Pavlov and Rashed (2011). They developed a less invasive way of tracking dolphins for long-term behavioral research. The results of their study, which relied heavily on computational fluid dynamics (CFD), support the theory that biotelemetry tags can be held in place on a dolphin’s dorsal fin by hydrodynamic force. The development of effective hydrodynamic tags could eliminate or minimize the need to pierce the fins of dolphins. Pavlov and Rashed examined the viability of using hydro-dynamically designed tags for telemetry studies. They theorized that a properly designed hydrodynamic tag would remain securely attached to the dorsal fin for long periods of time, while minimizing drag on the dolphin’s body and allowing the animal to propel itself naturally through the water.

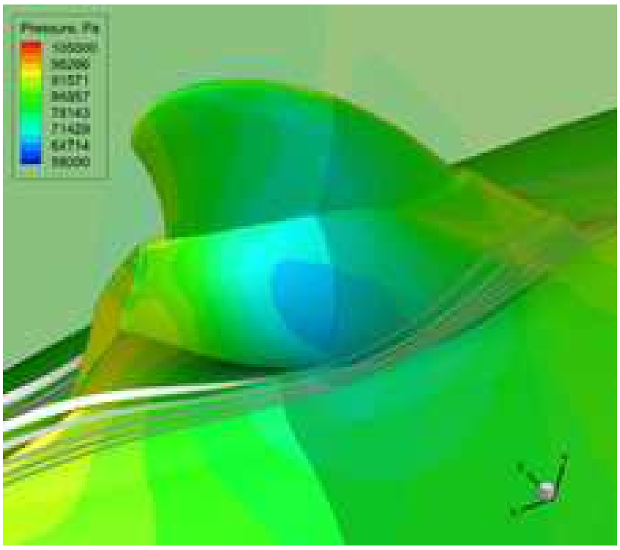

Figure 1: Visualization of a hydro-dynamically shaped tag placed over the dorsal fin of a dolphin and basic flow around the dorsal fin. Image Credit: Dr. Vadim Pavlov, ITAW.

Developing and testing a hydrodynamic tag specifically designed for harbour porpoises would include basic steps of Computer-aided design (CAD), CFD testing, making the prototypes, testing them in water channel and finally, selection of the best models and testing them on porpoises in captivity (first) and at a later stage, on free-ranging animals. In terms of time and funding such a project would last 2.5 – 3 years and require approx. 450k € of funding.

The aim of this development is a telemetry tag design which matches the natural hydrodynamics of harbour porpoise with minimized impact on the tagged animal. Different techniques can be envisaged to ensure that the tag will stay on the dorsal fin of the harbour porpoise for an extended period of time (weeks); small suction cups might provide enough adhesion to keep the tag in place if e.g. the animal is not moving thus reducing the hydrodynamic force which is the principal component the tag design is based on. If suction cups compromise the hydrodynamic properties of the tag a single bolt could be drilled through the animal’s dorsal fin keeping the tag for a pre-defined period in place. A single pin would reduce the stress for the animal (thus representing a compromise between the practical requirements and ethical concerns) and at the same time ensure the tag stays hydro-dynamically stable without any risk of long-term injury.

5. Conclusions

In a kind of general overview, results derived from classic telemetry studies will provide detailed information on the behaviour of the animal without allowing to assess which and to what extent external factors have influenced the behaviour. Controlled behaviour experiments on the other hand allow assessing the cause-effect relationship between underwater sound and the animals' behaviour under semi-controlled conditions, but will not provide sufficient insight into the behaviour of the animals. Only acoustic telemetry will be able to provide a comprehensive data set allowing to assess which type of underwater sound events leads to what kind of reactions at which level and in which behavioural context.

But whatever approach or technology will be chosen, it always has to be considered that the behaviour of marine mammals is highly complex and context specific. In addition, as with all scientific studies it is essential to have a sufficiently large sample size to derive general conclusions or even threshold values, but every data point gained from such an acoustic-telemetry study would already significantly improve the current situation of evaluating the effect of man-made sound on harbour porpoises.

The technology to conduct these studies is already available and only needs to be adjusted to the specific requirements of working with harbour porpoises. The design and technology will have to be improved during a pilot study and furthermore, but all means are existing to begin this effort. Access to harbour porpoises exists in Denmark, might become available through dedicated catches in German waters, but can ideally be used on rehabilitated animals from Stichting S.O.S. Dolfijn in Harderwijk. A completely novel approach to the design and attachment of tags will not only reduce the effect on the animal, it will as well reduce artefacts caused by the tag and the tagging procedure itself.

This report gives an overview of available electronic devices relevant for telemetry on harbour porpoises. It is encouraging that the recent development in low power computer processing and increasing memory capacity has provided the opportunity to record sounds and movements in almost any spatial and temporal context. In addition developments in tag attachment and tag size makes it realistic to meet the ambitious requirements of such an approach. However, the following considerations must be discussed before a decision can be made on what tag components to develop or use:

1) Size of the tag in relation of the size of the target animal

(different tags to different size animals?)

The size and hydrodynamic drag of the tag should always be limited to a minimum, however, with the ambition to record detailed movements and acoustics, the tag will inevitably increase in size. All products except the D-tag provide either recordings of movements or acoustics. It may be an advantage to be able to combine the different units relevant for a specific study, but a reliable and well integrated and designed system will always be smaller in size and drag.

2) Attachment method in relation to longevity of the data recording

(suction cups or bolt attachment for porpoises?)

This is a very important question relevant to both animal ethics and reliability of the data. Suction cups can be deployed very fast and with little stress on harbour porpoises. However, the longevity is only some hours, possibly up to 48 hours. Whether the stress induced by catching, handling and tagging influence the natural behaviour in the first hours is unknown. Any data collected for more than 48 hours require attachment of pins through the dorsal fin. Satellite tags have recorded locations of porpoises for up to 1.5 years in Danish waters and no physiological effects have been found on tagged (hydrodynamic design) porpoises bycaught in a gillnet after 1 year (Sonne et al. in press).

This experience shows that it is possible to tag porpoises with pins with little or no effect on the natural behaviour of the animal. Also a captive porpoise showed little behavioural alterations after pin tagging (Geertsen et al. 2004).

The issue of tagging method can be further studied on captive porpoises and by analysing existing data from wild animals.

3) Data sampled in relation to project objective

(e.g. movements in relation to known noise sources or detailed behavioural response to specific noise levels?)

If we had a full knowledge of the noise in our waters we could analyse the response to noise simply by correlating movements of the animals with noise maps. However, noise mapping is still in its infancy. Therefore, a more direct method is to record noise from the swimming animal's perspective and see how it responds to it. This can be done by attaching the recorder of sounds and movements on the animal. As these recordings can only be made for a short duration and since some knowledge exists on noise sources in the sea, we may consider deploying both longer term movement tags and short-term acoustic/3D movements tags. This way we will get an understanding of the response to each specific sound but also an overview of the general movements in relation to e.g. areas where noise mapping exists, wind farms, ship lanes, harbours etc.

4) The aim of the study is of principal importance in order to define the type of tag to be used: Using small non-floating satellite tags they will provide long term data (months to a year) on movements, with lower resolution. This would provide data on migration patterns. Tags that collect vast amounts of data (acoustic, dive behaviour) would be attached for a relatively short time (days to weeks) and need to be retrieved. The choice of the right type of tag is crucial in order to reduce the impact on the animal to a minimum.

Recommendations (for a telemetry study in the Netherlands):

Suggestions for the acoustic/3d movement tags could be:

Porpoise tag including: acoustic recordings (background noise and echolocation), depth, 3D accelerometers, 3D compass, Fastloc GPS, VHF/Argos, releaser.

The D-tag version-3a, which is under development, will be the smallest and most advanced tag on the market with the following specifications:

a) Full bandwidth 50 Hz-180 kHz (may be further limited by flow noise).

b) 500 kHz sample rate with two hydrophones

c) 100 Gb unfolded data can be stored.

d) Due to the enormous data amounts, recordings are limited to 48 hours with one hydrophone and 24 hours with two hydrophones (two hydrophones are only needed for detailed studies on feeding and social behaviour).

e) The rather short recording time makes suction cups the best way of attachment, this will limit the stress during tagging and subsequently increase reliability of data.

6. Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

References

Akamatsu, T., Matsuda, A., Suzuki, S., Wang, D., Wang, K., Suzuki, M., Muramoto, H., Sugiyama, N. and Oota, K., 2005. New stereo acoustic data logger for free-ranging dolphins and porpoises. Mar. Technol. Soc. J. 38: 6-12.

Akamatsu, T., Teilmann, J., Miller, L. A., Tougaard, J., Dietz, R., Wang, D., Wang, K., Siebert, U. and Naito, Y., 2007. Comparison of echolocation behaviour between coastal and riverine porpoises. Deep Sea Res. II 54: 290-297.

Akamatsu, T., Wang, D., Wang, K., Li, S. and Dong, S., 2010. Scanning sonar of rolling porpoises during prey capture dives. J. Exp. Biol. 213: 146-152.

Born, E.W., Teilmann, J., Acquarone, M. and Riget, F.F., 2004. Habitat Use of Ringed Seals (*Phoca hispida*) in the North Water Area (North Baffin Bay). Arctic 57 (2): 129– 142.

Burgess, W.C., 2008. A miniature acoustic recording tag: applications to assess marine wildlife response to sound. Technical Report GS0105A-0801. Greeneridge Sciences, Inc., 4512 Via Huerto, Santa Barbara, CA, 93110. http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA480428

Cetacean Research Technology: http://www.cetaceanresearch.com/hydrophone-systems/underwater-recording/acousonde/index.html

Edren, S. M. C., Wisz, M. S., Teilmann, J., Dietz, R., and Soderkvist, J., 2010. Modelling spatial patterns in harbour porpoise satellite telemetry data using maximum entropy. Ecography 33: 698-708.

Geertsen, B.M., J. Teilmann, R.A. Kastelein, H.N.J. Vlemmix & L.A. Miller 2004. Behaviour and physiological effects of transmitter attachments on a captive harbour porpoise (*Phocoena phocoena*). Journal of Cetacean Research and Management 6(2): 139-146.

Heide-Jørgensen, M.P., Stewart, B.S. and Leatherwood, S., 1992. Satellite tracking of ringed seals *Phoca hispida* off northwest Greenland. Ecography 15: 56-61.

Johnson, M., Aguilar de Soto, N. and Madsen, P.T., 2009. Studying the behaviour and sensory ecology of marine mammals using acoustic tags: a review. Mar. Ecol. Prog. Ser. 395: 55-73.

Johnston, D. W., Westgate, A. J., and Read, A. J., 2005. Effects of fine-scale oceanographic features on the distribution and movements of harbour porpoises *Phocoena phocoena* in the Bay of Fundy. Mar. Ecol. Prog. Ser. 295: 279-293.

Linnenschmidt, M., Teilmann, J., Akamatsu, T., Dietz, R. and Miller, L.A. In Prep. Biosonar, dive and foraging activity of satellite tracked harbour porpoises (*Phocoena phocoena*). Suibmitted to Mar. Mamm. Sci.

Madsen, P.T., Johnson, M., Miller, P.J.O., Aguilar Soto, N., Lynch, J. and Tyack, P., 2006. Quantitative measures of air-gun pulses recorded on sperm whales (*Physeter macrocephalus*) using acoustic tags during controlled exposure experiments. J. Acoust. Soc. Am. 120: 2366–2379

Olafsdottir D., Vikingsson G.A., Halldorsson S.D. and Sigurjonsson, J.. 2003. Growth and reproduction in Harbour Porpoises (*Phocoena phocoena*) in Icelandic waters. In: Haug T., Desportes G., Vikingsson G.A. & Witting L. (eds.) Harbour Porpoises in the North Atlantic. NAMMCO Sci. Publ. 5: 195-210.

Otani, S., Naito, Y., Kawamura, A., Kawasaki, M., Nishiwaki, S., and Kato, A. 1998. Diving behavior and performance of harbor porpoises, *Phocoena phocoena*, in Funka Bay, Hokkaido, Japan. Marine Mammal Science 14: 209-220.

Patterson, P.A., McConnell, B.J., Fedak, M.A., Bravington, M.V. and Hindell, M.A., 2010. Using GPS data to evaluate the accuracy of state–space methods for correction of Argos satellite telemetry error. Ecology 91(1): 273–285.

Read, A.J., and Westgate, A.J., 1997. Monitoring the movements of harbour porpoises (*Phocoena phocoena*) with satellite telemetry. Mar. Biol. 130: 315–322.

Sonne, C., Leifsson, P.S., Teilmann, J., and Dietz, R. (In press). Case study of tissue healing processes after satellite transmitter attachment in two pound net by-caught Danish harbour porpoises (*Phocoena phocoena*). Mar. Mamm. Sci.

Sveegaard, S., Teilmann, J., Tougaard, J., Dietz, R., Mouritsen, K.N., Desportes, G. and Siebert, U., 2010. High-density areas for harbor porpoises (*Phocoena phocoena*) identified by satellite tracking. Mar. Mam. Sci. 27: 230-246.

Sveegard, S., 2011. Spatial and temporal distribution of harbour porpoises in relation to their prey. PhD Thesis, National Environmental Research Institute, Aarhus University, Denmark, 128 pp.

Teilmann, J, Born, E.W. and Aquarone, M., 1999. Behaviour of ringed seals tagged with satellite transmitters in the North Water polynya during fast-ice formation. Can. J. Zool. 77: 1934-1946.

Teilmann, J., Larsen, F. and Desportes, G., 2007. Time allocation and diving behaviour of harbour porpoises (*Phocoena phocoena*) in Danish and adjacent waters. J. Cetacean Res. Manage. 9: 201-210.

Teilmann, J. and Siebert, U. (2011): Market survey of tag availability and proposed developments - combined report. Report for BMU, Pos. 6 & 9 / Prod. 1., 12 pp.

Wilson R.P., Shepard E.L.C. and Liebsch, N., 2008. Prying into the intimate details of animal life: use of a daily diary on animals. End. Spec. Res. doi: 10.3354/esr00064.

Justification

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The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Dr. M. Scheidat
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Date: 13th March 2013

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Head of department Ecosystems

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Date: 13th March 2013