Workshop on technology requirements to investigate the effects of sound on marine wildlife

Sponsored by the International Association of Oil and Gas Producers Joint Industry Programme on Sound and Marine Life

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EXECUTIVE SUMMARY

The workshop took place over 2½ days and involved 45 participants who were mainly users of technology or developers of technology. The workshop reviewed different aspects of the technology required by the OGP Joint Industry Programme on Sound and Marine Life (referred to as the OGP-JIP Research Programme in the remainder of this document) and assessed the gaps in technology that is likely to be relevant to this OGP-JIP Research Programme.

Workshop objectives

- Using the innovators in the field, to provide an authoritative overview of the data requirements related to the need to make behavioural measurements from marine mammals as part of the OGP-JIP Research Programme.
- To identify appropriate available techniques and technology and any required development options, and produce a definitive description of the requisite development programme and the resources required.
- Provide recommendations for future funding.

Summary of recommendations

The following recommendations are given in order of priority but, whatever the OGP-JIP decides to fund, it is essential that it considers ways to ensure there is greater strategic collaboration between players, especially between the commercial suppliers and the academic community, so that technology solutions can be transferred quickly and efficiently into production items.

(i) Consider funding development of improved power supplies for animal-borne instruments. Power is the ultimate factor that limits most aspects of tag capability, e.g. attachment, longevity, data transmission. Power limitations determine the size and shape of most tags and the trade-off that exists between longevity and the information that is collected and then transmitted. This is achievable with some level of innovation through power robbed from the movement of the animal.

(ii) Issue an RFP for alternatives to using sparse data (from a few tags) to address individual and population-scale processes. In many species, tags will always present limits and, especially with cetaceans, we are currently under-achieving on our technical ability to gather behavioural data using remote observation, especially using passive acoustics. For example, a specifically-designed sonobuoy that can be deployed into sensitive areas in a grid will open up a wide range of experimental options for rapid, reliable and relatively cheap data acquisition at high volumes[1] from some species.

(iii) Issue an RFP for a coordinated approach to be taken between some of the main players in instrument development and academia to overcome current constraints and foster innovation. This could include a feasibility assessment for design of a modular tag but in assessing the proposals that

[1] Recent developments of the AUTEC and SCOR grids operated by the US Navy illustrate the power there is for passive acoustic grids to provide much of the essential information required to measure behavioural responses to sounds.

come forward it is important to understand some of the dynamics involved between the groups. The OGP-JIP may have to actively manage this process.

(iv) Improve ability to attach instruments particularly for small cetaceans. Develop attachments that can last for months to years for a broad range of marine vertebrates (comparable to current capability for large cetaceans and turtles). There is some doubt if this is achievable but it definitely needs some serious work.

(v) Improve data communication, recovery or retrieval. This could include use of communications systems at long range and wide bandwidth but it could also involve the development of improved methods for remote release and recovery of archival tags or on-board data processing to reduce volume of data transmitted (including solutions like PAMGUARD). Consider involvement in developing infrastructure such a satellite communications solutions.

(vi) Develop the ability to measure behavioural/physiological response variables (e.g. heart rate and/or respiration) and relate these to important life functions. There is scope for much greater innovation at the level of behavioural and physiological sensors but progress is likely to be slow and this should not dilute the effort to make progress in some of the higher priority items.

Defining technological requirements

The workshop reviewed and prioritised requirements for data collection for measurements of marine mammal behaviour likely to be required by the OGP-JIP Research Programme.

Principal challenges for the workshop were to identify those questions that could be addressed using tagging technology and the potential need and opportunity to develop new technologies to address issues associated with E&P operations, particularly for seismic operations. Priority is being given by the industry to identifying and measuring behavioural parameters that could indicate when behavioural effects are large enough to cause substantial changes to feeding or other life functions.

It was recognized that tags have limitations in terms of parameters that can be measured, duration of deployment, and applicability to a broad range of species and circumstances and considerable discussion took place to identify parameters that could provide the most valuable data when conducting a risk assessment. Some physiological and behavioural responses that could be measured using tagging technology have the potential to indicate a dose-response relationship between received sound levels and behaviour. But alternatives to tagging, e.g. involving passive acoustic systems, also need to be considered. Lower priority was attributed to parameters that can be measured but are more difficult to relate to potential effects on life functions.

The main conclusions were:

- The workshop found a good correlation between the requirements of the OGP-JIP Research Programme with questions that the academic/scientific community viewed to be important to E&P operations.
- The ability to measure changes in behaviour during feeding is important. Displacement from feeding areas could provide valuable insights if linked to life functions using appropriate models of animal energetics
- Although highly desirable from a risk assessment perspective, there are no current technical solutions that could realistically address vital rates or many of the life functions (breeding, predator avoidance, nursing)
- It is important to improve our ability to interpolate from measurements made at the level of individuals to the level of social groups and populations
- Physiological parameters such as heart rate and breathing have the potential to inform how animals sense and react to sound, and indirectly could provide an assessment of the significance of different exposure levels.

Defining priorities

It is important to prioritise the technology required against the needs of the OGP-JIP Research Programme. The outputs from previous exercises to develop models of the underlying rationale for studying the effect of underwater noise on marine wildlife[2] had done much to define the major questions to be addressed by the OGP-JIP Research Programme. Recognising that many questions will be difficult to answer and that E&P activities will continue even in the absence of definitive answers in many cases, the rationale for prioritising different types of technology was structured in a manner that addressed a risk assessment approach to managing the effects of E&P activtities on marine wildlife and to assess its biological significance.

This analysis identified the need to measure the received levels of noise and the response of individual animals to these levels as a very high priority. The capacity to titrate the effects of sound was seen to be important but current capability to do this using basic physiological measurements (e.g. auditory brainstem response) is limited and is also of limited utility. This is because peripheral physiological responses and behavioural responses to sound are likely to be of greater biological importance than a simple measurement of what sounds an animal can hear. It is important to have the capacity to titrate these responses against received sound levels in a broad range of different species and circumstances.

The types of technological approaches available were matched to the variables that need to be measured (see Table ES1). This analysis suggested that considerable progress could be made by investment in the development of animal-borne instruments but also that passive acoustics also offers options that could be easier to implement and that is less dependent on fundamentally new technology. The workshop focussed most of its attention upon tagging but also recognised that remote methods including passive acoustics and visual methods would benefit from technological innovation and would also provide considerable information about dose-response. In addition, in some circumstances the high data volumes available using remote measurement could make

[2] The *source-pathway-receiver* model and the PCAD model from the US National Academy of Sciences. Also a workshop on *The effects of anthropogenic sound on marine mammals: a draft research strategy*. Tubney House, Oxford, 5-9 Oct 2005.

up for the reduction of data quality associated with remote measurement as opposed to measurements made using animal-borne instruments.

Table ES1: Matching the general capacity of improved technological approaches to address the critical questions given in the source-pathway-receiver model (Fig. 1) and the PCAD model (Fig. 2) as a way of prioritising the activities of the workshop and focussing on issues that are likely to be most productive.

		Variable	**Level of technological innovation possible/likely**	**Type of technology approach**	**Comment**	**Priority for the industry**
Source-Sound-Pathway- Receiver model	**PCAD model**	Audiogram	Low	(1) Auditory brain stem response	Although the technology needed to develop improved traditional audiograms using ABR is relevant, audiograms may be a poor reflection of the response of animals as transducers of sound energy;	Low
			High	(2) Other behavioural/physiological variables	ABR may be less relevant than developing another form of titration response involving a physiological variable such as heart rate or breathing rate that can be used routinely in free-ranging animals.	High
		Demographic	Low	Long-term marking methods using transponders or natural marks	Demographic variables, including vital rates, are not generally measurable to sufficient unbiased accuracy in marine mammals, even under long-term observation, to be useful for measuring anything other than very large changes in vital rates. Has been achieved in relatively few marine mammal species to date. Transponder approaches limited by adequate attachment.	Medium
		Activity	High	Animal-borne instruments and PAM for cetaceans	Indications that an animal changes its behaviour, e.g. break points in activity such as changes in the search path, types of food being sought, changes from social interaction to directed movement or *vice versa*. PAM has a particular application here especially if used with direction hydrophone arrays and because there is increasing understanding of the behavioural context of different types of vocalization.	High
		Population status / structure	Medium	Aerial survey methods	Well-developed visual survey methods are unlikely to be superseded by technology solutions except perhaps involving use of PAM for cetacean population assessment or other detection methods including LIDAR, Radar , infra-red imaging and active sonar. There is high dependency upon statistical methods that need to be developed in conjunction with any technology solution	Low
		Movement	High	Animal-borne instruments	See “Activity”	High
		Vocalisation	High	PAM	Passive acoustics using remote grids and arrays has, in general, been overlooked as a potentially power, cheap and robust method that could be used for measuring dose-response in some species. Importantly, these are often species that are particularly difficult to tag.	High
				Animal-borne instruments	Some animal-borne instruments are already making a major contribution to the understanding of behaviour through passive acoustic monitoring of both the focal animal carrying the instrument and other members of the same social group	
		Diving	High	Animal-borne instruments	This has the potential to show deviations in feeding activity as a result of exposure to sound, particularly if measurable over a period of several weeks.	High
		Foraging / feeding	High	Animal-borne instruments	Techniques have been applied to a number of seal species, especially using stomach temperature but also using video imaging.	High
		Survival	Low	Animal-borne instruments	“Death” tags are in the process of being tested. Constrained by the long-term, low-resolution nature of the study and applicable to a narrow range of species	Medium
		Breeding	Low	None		Low
		Nurturing	Medium	Animal-borne instruments	Requirement for proximity sensors of some type to allow detection of association between parent and offspring.	Medium
		Response to predators	High	Animal-borne instruments	Probably only possible where responses to predators that produce signature vocalisations can be detected.	Medium
		Stage	Low	None		Low
		Maturation	Low	None		Low

		Reproduction	Low	Animal-borne instruments	Probably more likelihood of success with species that haul-out to breed, e.g. pinnipeds and turtles.	Medium
		Growth rates	Medium	(1) Animal-borne instruments	Instruments that measure fatness and changes in body condition. Longer-term changes in body mass are not feasible at present	Medium
				(2) Remote photogrammetry	Only applicable to a few species and only useful over long time periods	Low
		Population dynamics (elasticity, sensitivity, extinct prob.)	Low	None	This requires the measurement of vital rates as well as obtaining time-series data about the trajectory of populations with sufficient accuracy in both cases to provide a meaningful way of carrying out sensitivity analyses to small, indirect effects like changes in foraging success caused by distrurbance.	Low

A feature of this analysis that probably requires further clarification are the strengths and weaknesses of approaches involving tagging as opposed to alternatives. The strengths and weaknesses of different technological approaches to obtaining data that will address the major objective of the OGP-JIP Research Programme are summarised in Table ES2.

Table ES2. Tabulation summary of the strengths and weaknesses of general approaches that can be taken to obtaining information from free-ranging marine mammals. The assessments are presented as "Low" meaning that this is an important weakness of the approach to "Medium" meaning that there are roughly equally distributed strengths and weaknesses and then to "High" meaning that strengths greatly out-weigh the weaknesses.

	Type of approach		
Issue	**Tagging**	**Passive Acoustics**	**Visual/active acoustics**
Breadth of application (Different techniques can be applied to different extents depending upon the species)	Medium Potentially all species could be tagged but in practice tagging is only possible of relatively few because of the constraints of tag size, durability and attachment. Least for species in which passive acoustics is most useful. Received level of sound are measurable using specialised tags.	Medium Only possible to use with species that vocalize and constrained to when they vocalize. However, this means it is useful mainly for small odonticetes. Received levels of sound are measurable using real-time sound propagation model.	Medium Very useful for most pinniped species aerial photography etc). Less useful for cetaceans but still used widely across all species. Least useful for species in which passive acoustics is most useful.
Sample size (For many applications sample size is a critical attribute. Examining dose-response relationships usually requires large sample sizes to cover different circumstances and different age/sex classes of individuals)	Low Tagging tends to produce large amounts of high quality data about a small number of individuals. There will always be constraints on how well tags are able to be used to obtained unbiased samples of populations to allow the interpolation of individual behaviour to that of a population.	High Using passive acoustics it is possible to gain large sample sizes very quickly. A weakness is that it is often not possible to identify individuals within groups, although additional research may solve this for some species.	Medium There are no effective limits on sample size but, unlike passive acoustics where there are already algorithms for automated detection of targets visual and active methods mainly require manual detection thus limiting the extent to which this can be used.
Individual-level behaviour (Includes foraging/feeding and social interaction, including breeding)	High This is what tags are mainly designed to achieve. They provide a very detailed picture of individual behaviour. Poor at defining social behaviour though but very good at tracking movements of individuals.	Medium Only possible to collect information while animals are vocalizing so and there are limits to the types of behaviour that can be measured – mainly to foraging and social sounds. But more likely to give information about social	Low In general opportunities for visual observation of under-sea behaviour are very limited and in many species this also applies to surface behaviour. Only really useful on a broad scale for pinnipeds while they are on land.

		behaviour than tagging in appropriate species. Some utility for tracking the movements of individuals depending upon species and the ranges involved.	
Group/population-level behaviour or dynamics (Includes population trends, habitat use, group dynamics, e.g. group size, structure and social interaction)	Low Sample size limits this application of tags as well as the ability to sample a reasonably random selection of the population. Interpolation from the detailed behaviour to population level requires robust stratified sampling of the population. There is probably no example of where this has been achieved for tags even in the most malleable species. However, can be used to show habitat usage for some sections of a population. Almost no information about social interaction in groups	Medium The issues with random sampling of the population that exist for tagging only arise if different classes of individuals have different vocalization behaviour. Even then, it is possible to calibrate a passive acoustic system for this. Can be used to provide long-term, area-based assessments of habitat usage by cetaceans by both monitoring regions and by . Useful for developing a view about social interaction. Passive acoustics is now being developed as a tool for population assessment.	Medium Visual methods are now standard for measuring cetacean populations. This also provides information about group size and course-scale information about habitat use. Limited mainly by the need for expensive assets and skilled observers
Physiology (Includes the measurement of the internal environment of individuals and how this changes in response to external stimuli)	Medium Tags have been developed with limited capabilities in this direction but there will always be large constraints because of the general need for invasive intervention to place transducers within the body.	Low Very little that can be said about physiology based upon vocalizations.	Low Almost no physiological information for visual observations. The only possible exception might concern heat flux using infra-red cameras.
Surrounding environment (Includes the measurement of the potential prey field or indicators of environmental productivity to may be key to understanding species distribution and abundance)	Medium Tags can provide information about the physical and biological features of the ocean surrounding the focal animal. Constraints include the power needed to collect data and the ability to transmit and recover the data from the tag.	Low Passive acoustics in themselves provide little information about the environment except in that vocalizations from animals feeding suggest something about the extent of the prey field. These methods probably need a greater input of information about the environment (e.g. temperature structure) than they can provide.	Low Only visual methods using remote sensing platforms for, e.g. ocean color or sea surface temperature are likely to be useful.
Ethical (All measurements of animals have the potential to affect them in various ways. These effects need to be calibrated and/or minimised and a judgement needs to be made about whether the balance of benefit is proportionate to the cost to the animal)	Low In general, tagging is one of the most invasive forms of data collection. Different species respond in different ways but it is important to assess the potential effects of tagging when assessing approaches to be adopted.	High Passive acoustics is non-invasive and can involve measurements at sufficient range that the subjects have no concept of human presence and there is, in effect, no disturbance. An exception to this is when a vessel is carrying passive acoustic gear but most of this can be overcome with relatively simple technologies.	Medium The need to place an observe close enough to animals to gather meaningful data carries a risk of disturbance. Active acoustics could be potentially very disturbing, and even dangerous, if it is within the auditory range of the animal being observed.

<u>Current technology capabilities.</u>

The most appropriate tagging options and methods (if any) were identified for each research topic. The workshop also summarised the capabilities and accessibility of currently available tagging technologies matched to the requirements.

Technological capability has advanced on a broad front during the past two decades but not all types of technology has received equal amounts of development investment. In general, the major innovations have been led by increased memory capacity and processing power, reduced power requirements for instrument components and improvements in sensor technologies. The field has used extant technologies and moved forward at a speed dictated mainly by the availability of components. However, innovation specific to the field includes the methods used to package and attach instruments and the way in which instrument packages, involving several different types of sensor, are controlled and transmit their data.

The following brief assessment is of where the current state-of-the-art lies but does not make a distinction between technologies that have been tested on only a few species from those that have been used widely (see Appendix 2 for more detail).

- Availability of sensors and off-the-shelf instruments available to researchers. Sensors include: depth (pressure), temperature, location (GPS and ARGOS), speed, orientation, acceleration, light level, sound (up to 100 kHz), salinity, water chlorophyll (under development)
- It should be noted that all combinations of sensors are not possible due to size and power constraints and ultimately limitations on the rates of data transmission from tags.
- Data Telemetry
    - Most of these involve the use of some form of radio telemetry to transfer data but a small number use acoustics for communication.
    - The ARGOS satellite system has been an essential tool but is in need of updating.
    - Cellphone networks are beginning to be used for data transmission in appropriate regions
- Archival instruments, because of their greater simplicity, are manufactured by a broad range of suppliers but are also used in situations where very large data volumes are collected, especially for sound recording.
- Localisation methods have recently been enhanced by the capacity to collect and transmit GPS data from animals that surface only briefly and this can provide high-resolution tracks of individuals. This capability is likely to become routinely available from most manufacturers in the next few years.

Gap analysis

Matching between the OGP-JIP Research Programmeme and the most appropriate techniques was addressed in a gap analysis.

Figure ES1 is a schematic of the process used for the gap analysis. This exercise identified areas important to the OGP-JIP Research Programme where current capabilities were deficient. This shows that the process is driven by the research questions. These define the functions required which define the sensor and technology capability required. The principal research questions were pre-defined using assessments made at previous workshops and these are listed in Appendix 3. The gap analysis consisted of a comparison between the desired set of sensors and technology and the senors and technology that is actually available.

Table ES3 summarises current technology capabilities with respect to measuring responses to sound produced by E&P activities. Although some variables are classified as operational, in most cases this applies only in specific circumstances. These circumstances are described in more detail in Section 6 of this report.

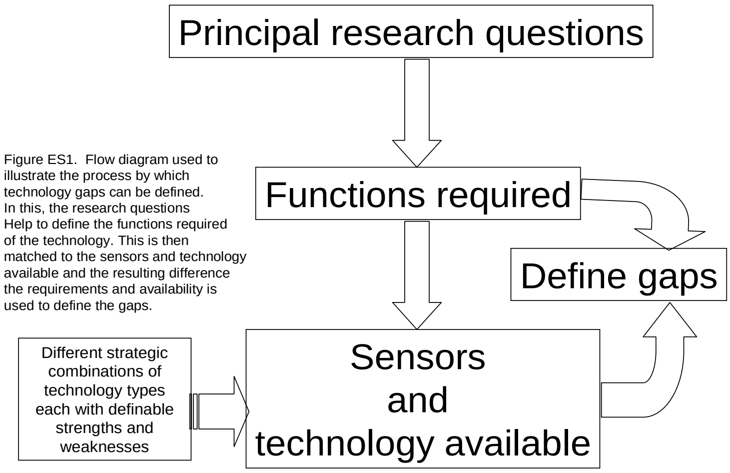


Figure ES1. Flow diagram used to illustrate the process by which technology gaps can be defined. In this, the research questions Help to define the functions required of the technology. This is then matched to the sensors and technology available and the resulting difference the requirements and availability is used to define the gaps.

Table ES3: Summary of current capabilities with respect to the capacity to measure various potential responses to sound.

<u>Short term effects</u>

Note: Priority (1=high, 3=low)

Variable	Pinniped	Cetacean	Priority
HR	*Operational*	*None*	*1*
Temperature	*Operational*	*Operational*	*3*
Respiration	*Operational*	*None*	*3*
Behavioural	*Operational*	*Operational*	*1*
Feeding	*Operational*	*Operational?*	*1*
Speed/stroking	*Operational*	*Operational*	*2*
Orientation	*Operational*	*Operational*	*3*
Vocalization	*Operational*	*Operational*	*1*
Haul out	*Operational*	-	*1*
Social	*None*	*None*	*1*
Sleep	*None*	*None*	*1*
Heart flux	*Operational*	*None*	*3*

<u>Long-term effects</u>

Variable	Pinnipeds	Cetaceans	Solution
Location	*Operational*	*Operational*	
Condition (e.g. blubber, morph. Index)	*Operational. Easier in some sp. E.g. elephant seals. IR thermo remote video (obs)*	*Harder to measure, especially if from remote location.*	*Telemetry (ultrasound measure, B/A)*
Growth (mass)	*Operational*	*Difficult. (L/W data video)*	*? important measure!*
Survival	*Operational*	*Operational*	*Life history transmitters and pit tags*

			(imbedded). Continue developing
Reproduction	*Operational*	*Operational*	*Biopsies. Recal (hormones)*

There were relatively few gaps in terms of sensors but there were very significant technology gaps in several critical areas. Applications of technology are very restricted because of a need to (i) overcome several generic constraints concerning our ability to attach instruments and communicate data and (ii) develop our ability to measure behavioural/physiological response variables to tritrate effects, mainly because sample sizes are very small[3]. In particular the gap analysis showed that there is a need to:

- Develop fundamentally new approaches to supplying power to instruments
- Develop better attachments, particularly for small cetaceans
- Improve the rate of data transfer and retrieval from tags
- Develop a coordinated approach between some of the main players in instrument development and between research groups to produce a modular tag design.

Most constraints co-vary with one another, i.e. solving one without solving the other may not result in a step-change in capability. For example, solving the problem of providing a long-term power supply will not help unless methods of attachment are improved at the same time.

There are additional non-technical constraints that will limit progress if they are not addressed:

- Organisational challenges. The current developer community is occupied by a number of small units with little incentive to cooperate or innovate and, in general, there is much overlap in the capability of the instruments they supply.
- Much the same could be said about the research community. Strategic collaboration is needed but this is not a general feature of the community. Collaboration needs to be fostered to overcome some of the larger challenges.
- A strong stimulus needs to be provided to some developers in the academic community to work with those who can make their new forms of technology available to the broad research community.

[3] For example, on average it takes a large team up to a week to place a single tag on a beaked whale that will supply detailed behavioural data for 17 hours. This represents a very large investment for a small return in terms of a sample size that can be used to titrate behavioural or physiological responses against different types of sound.

INTRODUCTION, BACKGROUND, RATIONALE AND WORKSHOP STRUCTURE

1. Introduction

1.1 The workshop was constituted for the International Association of Oil and Gas Producers (OGP) Joint Industry Programme (OGP-JIP Research Programme), a consortium of 14 oil and gas companies plus the Oil International Association of Geophysical Contractors (IAGC) that had been formed to consider ways of supporting research into the effects of seismic sound sources on marine wildlife but, in particular, on marine mammals. The workshop was held over a period of 2½ days at the Rufflets Hotel in St Andrews, UK. It was hosted by the Sea Mammal Research Unit, a specialist research institution at the University of St Andrews.

1.2 There were 45 participants from a wide range of institutions (see Appendix 1 for a list of attendees and their affiliations). Attendees were representative of a much larger community than could be hosted at the workshop and delegates were asked wherever possible to represent their community rather than their own interests. Delegates were drawn from across the research and technology development sector to include those who used and applied technology, those who both used and built technology and those who designed and supplied technology on a commercial basis to the researchers working in the field.

1.3 The general objectives of the workshop were to

- provide an authoritative overview of the data requirements related to the need to make behavioural measurements from marine mammals as part of the OGP-JIP Research Programme;
- to identify appropriate available techniques and technology and any required development options
- Provide recommendations for future funding.

1.4 It was always anticipated that most discussion would center around telemetry and tagging technology, in part because this is an area where most technical challenges lie. Other modalities, including visual and acoustic methods for measuring behaviour were discussed briefly. However, they were viewed as essential elements within a suite of methods that could be used to address the research questions being addressed by the OGP-JIP Research Programme. Reasons for not considering them in detail were because of a combination of time constraints and the need to address some of the more difficult and possibly most urgent problems associated with collecting data by tagging marine mammals and then recovering these data. The following diagram (Fig. 1) attempts to show the relative importance of different types of technology to the major areas of biological activity of interest to the assessment of the effects of seismics on marine wildlife. While visual and photographic methods have an important part to play, the greatest future progress will be made in the development of better technology based upon micro-electronics to allow the remote observation of animals. This includes tagging and other electronic systems such as those used to monitor cetaceans using passive acoustics.

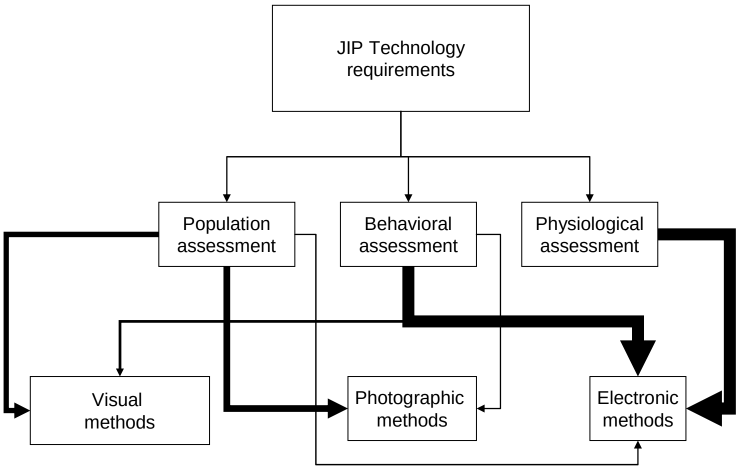


Figure 1. A flow diagram that summarises the relationship between the need for technological support for the JIP to support its mission, the types of biological assessments that will be required, and the types of technology that are likely to be used to support those assessments. The relative strength of the lines is used as a guide to the importance of the linkage.

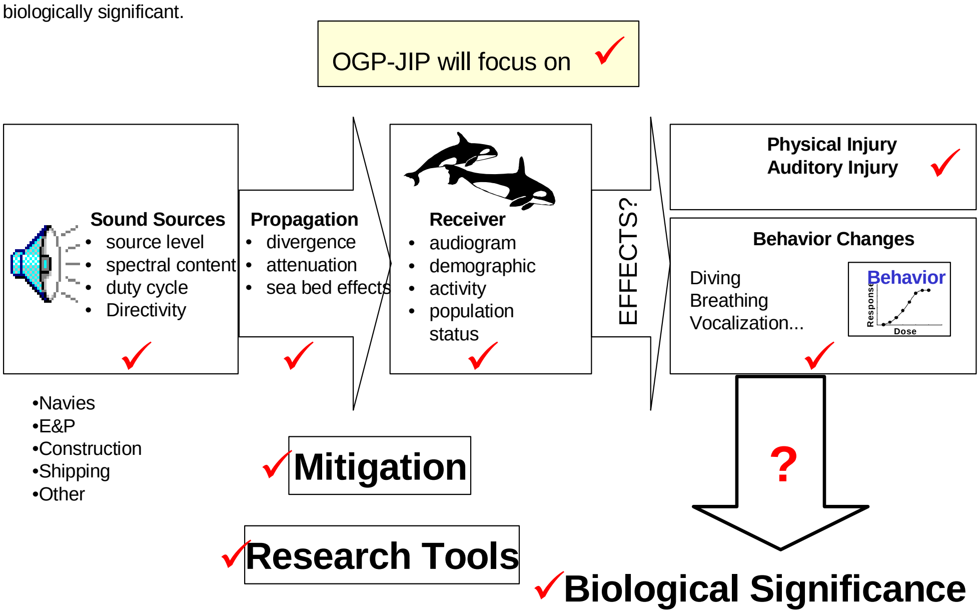
1.5 Consequently, specific aims were to:

1. Review and prioritise requirements for data collection for measurements of marine mammal behaviour likely to be required by the OGP-JIP Research Programme. (see Section 2)
2. Describe the telemetry techniques and visual and acoustic detection and localisation methods required to fulfil the aspirations of the OGP-JIP Research Programmeme, identifying the most appropriate techniques and methods for each research topic.
3. Describe the capabilities and accessibility of currently available technologies matched to the requirements identified in 1 and 2.
4. Review of the capabilities and current status of systems under development, with specific reference to the requirements identified in 1.
5. Describe the availability of tools for analysis, visualisation and databasing of telemetry and other data.
6. Describe potential solutions to the gaps in capability and availability identified above.

2. Background and rationale

2.1 The approach being taken by the OGP-JIP Research Programme can be summarised by two conceptual models, the source-pathway-received model (Fig. 2) and the PCAD model (Fig. 3). In Figure 2, ticks show the areas that are of particular interest to the OGP-JIP Research Programme.

Figure 2. The source-pathway-receiver model. The diagram shows the basic features of the problem being investigate. Sound sources produced by different users of the marine environment propagate sound depending upon characteristics of the sound source and environmental condition. This sound could be received by marine mammals depending upon the biolgocial features of the receiving animal and its distribution and abundance. This may elicit behavioral changes or could cause injury. A major question being addressed is the extent to which these effects are biologically significant.



2.2 The source-pathway-receiver model (Fig.2) is a heuristic way of defining the relative importance of different parts of the process that should be understood in order to constrain the uncertainty surrounding the possible effects of sound on marine mammals. It defines areas of particular interest to the OGP-JIP Research Programme. The National Academy of Sciences Population Consequences of Acoustic Disturbance (PCAD) model provides a view of the relative state of current knowledge and research capability (Fig. 3).

2.3 There is a need to develop a high-level environmental risk assessment procedure for marine mammals that can be integrated with other risk assessment activities undertaken by the E&P industry. Section 3 of this report deals with this in more detail as a basis upon which it is possible to make further judgements about the development of technology in a manner that specifically addresses the needs of the E&P industry. An objective should be to frame the issues of marine sound and its effects upon wildlife in the context of an environmental risk management procedure.

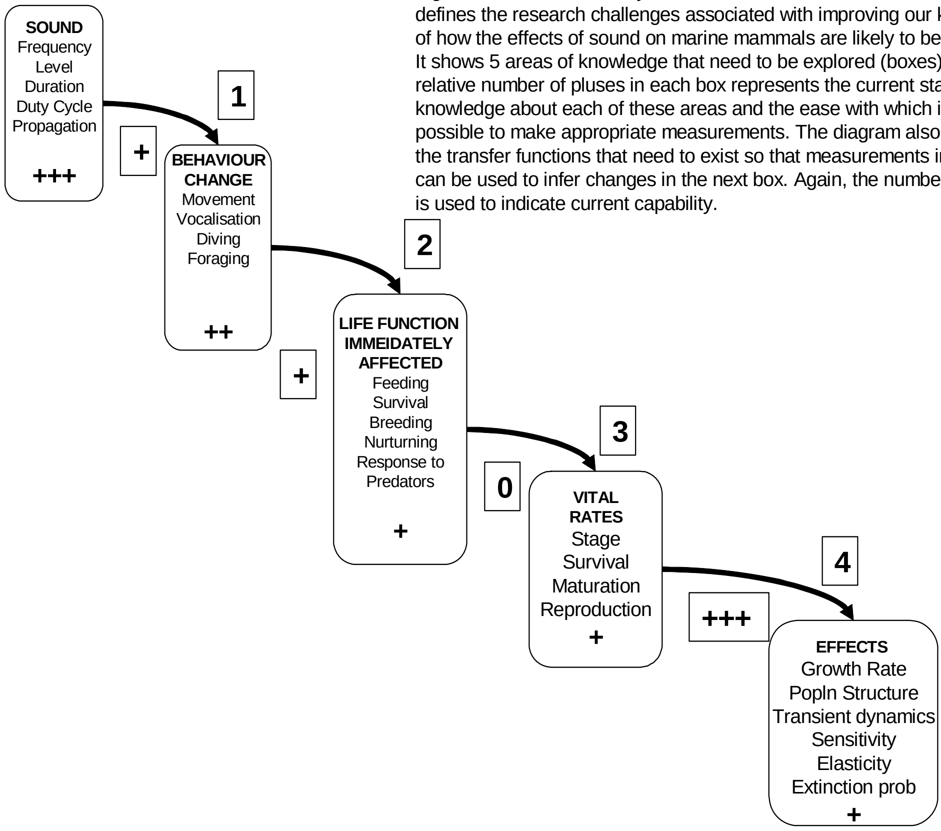


Figure 3. National Academy of Science PCAD model. The model defines the research challenges associated with improving our knowledge of how the effects of sound on marine mammals are likely to be generated. It shows 5 areas of knowledge that need to be explored (boxes) and the relative number of pluses in each box represents the current state of knowledge about each of these areas and the ease with which it is possible to make appropriate measurements. The diagram also summarises the transfer functions that need to exist so that measurements in one box can be used to infer changes in the next box. Again, the number of pluses is used to indicate current capability.

2.3 The PCAD model shows that we have a much greater capacity to measure sound sources and the propagation of sound than we have to measure the important biological variables. In particular, while we have the capacity to measure some behavioural and physiological changes there are progressively greater challenges associate with using these to infer changes in the life functions of individuals. The National Academy even suggested that we have, in effect, little or no capacity to infer population vital rates from knowledge of the underlying animal biology. Consequently, they saw the transfer from box 2 to box 3 as the greatest challenge to inferring biologically significant effects from simple measures of behaviour. Since the PCAD model focuses on Consequences of a disturbance, industry is evaluating ways to incorporate this general structure into qualitative risk assessment approaches.

2.4 While it is likely that only effects on populations (box 4, Fig. 3) are biologically significant, because they are likely to be the only effects that could jeopardise the existence of species, many stakeholders take a view that inferring effects from source to populations is not possible with our current state of knowledge. In general terms, if oil and gas operations can be conducted without affecting vital rates such as reproduction or adult survival, impacts on populations should not occur. However, it is broadly recognized that measuring effects on these parameters is complex. In turn, if effects on life functions can be reduced, the likelihood of impact on a vital rate should also be reduced. Consequently, the Exploration and Production (E&P) sector of the oil and gas industry has generally taken the view that reducing effects upon life functions will lead to the protection of populations. Thus, the effect of our inability to quantify the difficult transfer function between boxes 2 and 3 of the PCAD model (Fig. 3) can be minimised by taking such an approach. As a result, the industry would place a higher priority on a sensor that has the capacity to measure a parameter that could be compared to the level of change in a life function that could in turn affect a vital rate. Tools that measure fine scale changes in behaviour would have a lower priority.

2.5 Consequently, the workshop focused to a large extent on tags that provided data on behaviours that could affect feeding or other life functions (box 2 and portions of box 1 of the PCAD model).

Workshop participants recognized that improved knowledge of behaviour and physiology in marine mammal species is challenging for three main reasons:

- Access to animals in their natural, undisturbed state is particularly difficult and varies between taxonomic groups – small odontocetes are more difficult than myticetes and some large odontocetes which are more difficult than pinnipeds. Accessing some other marine wildlife such as turtles is at least as difficult as pinnipeds and, for some age and sex classes is probably more difficult than any of the marine mammals.
- Building data sets that encompass most of the natural variability of a species requires sufficient sample size to allow appropriate statistical inference about the presence of abnormal behaviour or physiology in response to a sound stimulus. Sufficient information is available for very few marine mammal species, and probably no turtles, to allow these types of statistical inferences. Those species for which sufficient information is available are relatively accessible and have been studied over many decades.
- The context of exposure is critical. If an animal reacts to a higher sound exposure level generated by bringing the source closer, it is important to separate out the effect of the received sound level and the proximity of the vessel deploying the sound source.

2.6 This challenge is one that can be met by the application of technological solutions. There are already a wide range of different technologies applied to measuring the behaviour and physiology of marine mammals (box 1, Fig. 3) but there has been no recent assessments of the technical capabilities against the requirement of the kind of programmeme being established by the OGP-JIP Research Programme. This, therefore, was the rationale for gathering a representative group of technology-users (researchers) and developers to develop a better understanding of the strengths of current technologies and the technological gaps that currently exist.

2.7 Consequently, the workshop focussed upon the technology needed to measure changes in life function (box 2, Fig. 3) or behaviour and physiology changes (Fig. 1; box 1, Fig. 3) that have the best chance to provide a measure of a change in a life function. Priority was given to parameters that could inform the effects of sound on feeding. This does not mean that technology cannot be developed to help resolve other issues (boxes 3 and 4, Fig. 3) but many of these do not lend themselves to technological solutions or to solutions that are within the range of current technology or technology likely to be available in the short to medium term. Table 1 summarises the extent to which technology may be able to assist with biological variables mentioned in Figures 2 and 3. The broad conclusion of the tabulation is that developments in animal-borne instrumentation could bring the most constructive benefits to the OGP-JIP Research Programme.

Table 1: Matching the general capacity of improved technological approaches to address the critical questions given in the source-pathway-receiver model (Fig. 1) and the PCAD model (Fig. 2) as a way of prioritising the activities of the workshop and focussing on issues that are likely to be most productive.

		Variable	Level of technological innovation possible/likely	Type of technology approach	Comment	Priority for the industry
Source-Sound-Pathway- Receiver model	PCAD model	Audiogram	Low	(1) Auditory brain stem response	Although the technology needed to develop improved traditional audiograms using ABR is relevant, audiograms may be a poor reflection of the response of animals as transducers of sound energy;	Low
			High	(2) Other behavioural/physiological variables	ABR may be less relevant than developing another form of titration response involving a physiological variable such as heart rate or breathing rate that can be used routinely in free-ranging animals.	High
		Demographic	Low	Long-term marking methods using transponders or natural marks	Demographic variables, including vital rates, are not generally measurable to sufficient unbiased accuracy in marine mammals, even under long-term observation, to be useful for measuring anything other than very large changes in vital rates. Has been achieved in relatively few marine mammal species to date. Transponder approaches limited by adequate attachment.	Medium
		Activity	High	Animal-borne instruments and PAM for cetaceans	Indications that an animal changes its behaviour, e.g. break points in activity such as changes in the search path, types of food being sought, changes from social interaction to directed movement or *vice versa*. PAM has a particular application here especially if used with direction hydrophone arrays and because there is increasing understanding of the behavioural context of different types of vocalization.	High
		Population status / structure	Medium	Aerial survey methods	Well-developed visual survey methods are unlikely to be superseded by technology solutions except perhaps involving use of PAM for cetacean population assessment or other detection methods including LIDAR, Radar , infra-red imaging and active sonar. There is high dependency upon statistical methods that need to be developed in conjunction with any technology solution	Low
		Movement	High	Animal-borne instruments	See "Activity"	High
		Vocalisation	High	PAM Animal-borne instruments	Some animal-borne instruments are already making a major contribution to the understanding of behaviour through passive acoustic monitoring of both the focal animal carrying the instrument and other members of the same social group	High
		Diving	High	Animal-borne instruments	This has the potential to show deviations in feeding activity as a result of exposure to sound, particularly if measurable over a period of several weeks.	High
		Foraging / feeding	High	Animal-borne instruments	Techniques have been applied to a number of seal species, especially using stomach temperature but also using video imaging.	High
		Survival	Low	Animal-borne instruments	"Death" tags are in the process of being tested. Constrained by the long-term, low-resolution nature of the study and applicable to a narrow range of species	Medium
		Breeding	Low	None		Low
		Nurturing	Medium	Animal-borne instruments	Requirement for proximity sensors of some type to allow detection of association between parent and offspring.	Medium
		Response to predators	High	Animal-borne instruments	Probably only possible where responses to predators that produce signature vocalisations can be detected.	Medium
		Stage	Low	None		Low
		Maturation	Low	None		Low
		Reproduction	Low	Animal-borne instruments	Probably more likelihood of success with species that haul-out to breed, e.g. pinnipeds and turtles.	Medium
		Growth rates	Medium	(1) Animal-borne instruments	Instruments that measure fatness and changes in body condition. Longer-term changes in body mass are not feasible at present	Medium

				(2) Remote photogrammetry	Only applicable to a few species and only useful over long time periods	Low
		Population dynamics (elasticity, sensitivity, extinct prob.)	Low	None	This requires the measurement of vital rates as well as obtaining time-series data about the trajectory of populations with sufficient accuracy in both cases to provide a meaningful way of carrying out sensitivity analyses to small, indirect effects like changes in foraging success caused by distrurbance.	Low

3. Workshop structure

3.1 The workshop was divided into 7 major sections and these were considered within dedicated session using a format involving breakout groups that reported back to the plenary group at the end of each session. The main subjects considered were:

(i) Localising animals
(ii) Monitoring the acoustic environment and passive acoustic monitoring
(iii) Measuring responses to sound and their consequences
(iv) On-board sensors
(v) Attachment techniques
(vi) Communications
(vii) User-supplier interactions

With respect to each subject area, the break-out groups were asked to consider:

(a) The current state of the technology, i.e. where are we now expressed in terms of both current capability and accessibility of technology;
(b) What are the challenges?
(c) What are the solutions?
(d) How can we implement the solutions - by whom, with what and where?

3.2 In addition to these, two groups were established to develop the rationale for identifying the technology gaps. The first group was tasked with defining the functions that were required in order to address the main research questions and the second was to define the technology that was available in terms of what it was capable of sensing and measuring. The differences between the outputs of the “functions” group and the “sensors” group (see conceptual model of the process below) should define the gap between current capability and the requirements of the research field.

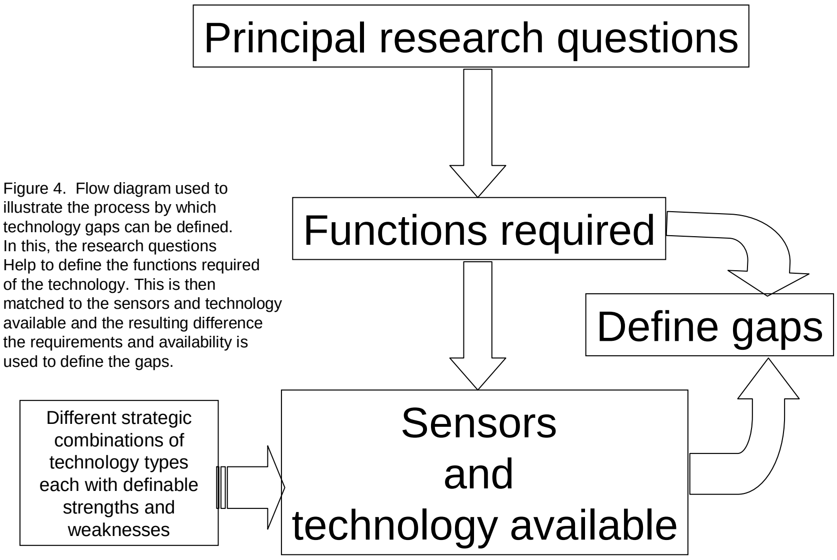


Figure 4. Flow diagram used to illustrate the process by which technology gaps can be defined. In this, the research questions Help to define the functions required of the technology. This is then matched to the sensors and technology available and the resulting difference the requirements and availability is used to define the gaps.

3.3 The principal research questions in this case were taken from the output of the meeting sponsored by the European Science Foundation that took place in Oxford in 2005[4]. These research questions had been structured to address the problem of sound and its affects upon marine mammals within a risk assessment framework. The full list of research questions is given in Appendix 3 and these are allocated to different parts of the risk assessment process that has the following form:

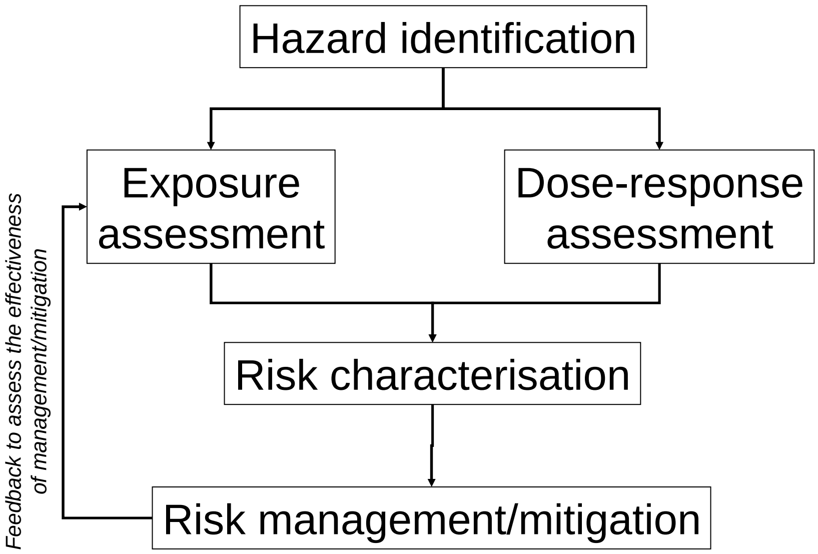


Figure 5. Flow diagram illustrating the environmental risk assessment process. Modified from that provided by the US National Academy of Sciences

3.4 The outcome of the Oxford meeting was an assessment of the relative importance of the research questions. This assessment was based upon the need, in many cases, to

[4] The effects of anthropogenic sound on marine mammals: a draft research strategy. Tubney House, Oxford, 5-9 Oct 2005.

answer some questions before others, because our ability to respond to some research questions was perceived to depend upon responses to a smaller subset of questions. Responses to questions such as "where are the marine mammals?" or "what are the received sound characteristics?" were viewed as being in more urgent need of action than many others because the answers to these were a pre-requisite to being able to answer other question.

3.5 Many of the questions requiring most urgent attention were within the *exposure assessment – dose-response assessment – risk characterisation* parts of the risk assessment framework. This happens to match well with the priorities described in Figure 1. However, it was also recognised that the field needs to advance on all parts of the risk assessment process simultaneously if the uncertainties associated with the final outcome are to be kept within reasonable boundaries. This includes incorporation of the context of the exposure and other confounding factors within the range of natural variability.

IDENTIFYING PRIORITY TECHNOLOGY NEEDS

4. Technology gap analysis

4.1 Table 2 summarises the outputs from the analyses of the required technology functions when assessed against the research questions (See Appendix 4 for a more detailed analysis) and matches this with current technological capability (See Appendix 3 for a more detailed analysis). The process by which both the detailed analyses was carried out involved identifying a set of variables that could, or needed to, be measured. These are listed down the left hand column of the table. The demand for measurement of these variables was derived from the analysis of the research questions and assessed in terms of its relevance. Gaps in capability occur where the table shows that there is a high demand but low current capacity. Those parts of the table showing that a variable is in high demand ("high priority" in the table) by where there is current low capacity, a perceived need for development work to be done and a high likelihood of success are highlighted in the table.

Table 2: Summary of the gap analysis conducted as described in Paragraph 3.2. Rating low (L) in "present status" means that the measurements has not been made in free-ranging individuals; Medium (M) means that there has been some limited success; and High (H) means that the method has been used extensively. N means not known. Shaded boxes highlight those variables where the present capability is poor, the development need is high and the probability of success is high. These could be seen as important gaps in essential capability with high priority for future investment.

	Demand			Current capacity								
Variable	Duration	Temporal resolution	Priority	Present status			Development Needed			Probability of success		
				Odontocete	Mysticete	Pinniped	Odontocete	Mysticete	Pinniped	Odontocete	Mysticete	Pinniped
Physiology												
Heart rate	Weeks-months	Seconds-minutes	High	L	N	M	H	H	M	H	H	H
Temperature (body)	Weeks-months	Hours	Medium	L	L	M	M	M	M	L	L	H
Energy consumption	Weeks-months	Minutes-days	High	L	L	M	H	H	H	L	L	M
Heat flux	Hours-weeks	Minutes	Low	M	N	M	H	H	H	L	L	L
Respiration	Minutes-months	Seconds-minutes	High	L	L	L	H	H	H	H	H	H
Condition/growth	Months-years	Days-weeks	High	L	L	M	H	H	H	H	H	H
Behaviour												
Location & movement	Months to years	Minutes-days	High	M	M	H	H	H	M	H	H	H
Diving	Weeks-months	Minutes-hours	High	L	M	H	H	M	L	H	H	H
Feeding	Hours-weeks	Minutes-hours	High	L	M	M	H	H	H	H	H	H
Speed	Hours-	Minutes-	High	L	M	M	H	H	H	H	H	H

	weeks	hours										
Stroking	Hours-weeks	Seconds-minutes	High	L	M	M	H	H	H	H	H	H
Acceleration	Hours-weeks	Seconds-minutes	High	L	M	M	H	H	H	H	H	H
Orientation	Hours-weeks	Seconds-minutes	High	L	M	M	H	H	H	H	H	H
Vocalisation	Weeks-years	Seconds-minutes	High	H	H	H	M	M	M	M	M	M
Haul-out	Hours - weeks	Minutes-days	Medium	-	-	H	-	-	L	-	-	H
Social	Minutes-weeks	Minutes-hours	High	M	M	L	H	H	H	M	M	M
Sleep	Days-Wks	Min	Low	N	N	L	H	H	H	L	L	L
Population												
Survival	Years	Months	High	L	L	L	H	H	H	L	L	L
Reproduction	Years	Months	High	L	L	L	H	H	H	L	L	L
Environment												
Ambient sound	Weeks-years	Days-weeks	High	M	M	M	H	H	H	H	H	H
Received sound level	Days-Wks	Minutes-Hours	High	M	M	H	H	H	M	H	H	H
Prey field	Days-weeks	Minutes-hours	High	N	N	M	H	H	H	L	L	H
Bio Oceanog (e.g. ocean colour)[1]	Days	Minutes	Medium	N	N	M	M	M	M	H	H	H
Phys Oceanog (e.g. conductivity, salinity)[1]	Days	Minutes	High	N	N	M	H	H	H	H	H	H

[1]Consideration was only given to the measurements that could be made using instruments developed for studying marine animal biology. This excluded the technology normally associated with standard oceanography.

4.2 An additional analysis of technology gaps was carried out by asking the attendees at the end of the meeting to provide a list of their 5 top technology issues that required further development specifically to address the needs of the E&P industry. This was done in an attempt to provide an alternative integration of the technology needs. With the benefit of hindsight it might have been useful to have conducted this pole both at the beginning and the end of the meeting to assess the extent to which discussion at the meeting itself had influenced the views of participants. The results will reflect the balance of the community present at the meeting although it can also be expected that, while some individuals would take a narrow view, others will have attempted their own personal integration of the results emerging from the meeting. The detailed results are given in Appendix 5 and summarised in the following table.

Table 3: Listing of the main technology issues identified by workshop participants together with the frequency with which each issue was mentioned. The frequency represents a weighting within the group of respondents.

Technology issue	Frequency[1]
Attachment	33
Communications	23
Sensors	21
Availability	11

(i.e. how easy is it to access current technology)	
Data analysis (on-board)	10
Power	8
Multi-functional, multimodal tag	8
Size	7
Cost	5
Data analysis (post-hoc)	3
Separate pinniped/odontocete/mysticete requirements	2
Long-term, low-cost tags	2
Additional, unclassified comments	28

[1]The frequency represents the number of comments classified into some general categories

4.3 Attachment gained the greatest weight in this analysis. However, this also included an acknowledgement that attachment was most challenging in cetaceans and in small-medium sized species in particular. Included under attachment was also the need to have improved release systems. This also reflects the need for control over the deployment duration so that short-medium term deployments could occur on the same duration as a seismic survey (periods of a few weeks to 2-4 months). Although some respondents suggested that longer tagging duration was desirable, this was generally interpreted as an issue for attachment rather than memory or battery life.

4.4 There was a high level of covariation between several of the technology issues. In particular, *attachment*, *size* and *power* involve several trade-offs. There tends to be a set of dependencies that leads from power → size → attachment → longevity. Power supply is limited by battery technology and this ultimately limits the size of attached instruments as well as the sampling by sensors, and the bandwidth of communication. All these affect longevity and result in the general trade-off between longevity and functionality. The limits imposed by this general trade-off can possibly be overcome to an extent by better on-board data compression and processing or by considering the needs of the different taxonomic groups as being distinct and designing tags that are specific to each of these groups.

4.5 The result of this analysis suggests that there is a need to focus attention upon improving methods to enable on-board data processing within tags during deployment. However, there was also a strong feeling that other methods needed to be considered, in addition to tagging. For example, passive acoustics for detecting and studying cetacean behaviour would benefit from technology development and the same could be said for visual surveys. Both of these methods provide advantages over tagging in some circumstances.

4.6 The Group agreed that tagging technology should be led by the research questions but that, in some cases, the recent record had shown that research questions were being modelled around the tools that were available. While this is a pragmatic approach, it could mean that research is constrained by the commercial needs of manufacturers rather that the research questions. Again, a balance needs to be struck between tags that are closely aligned with the needs of researchers, which are likely to be costly, bulky and less reliable, and tags that are mass-produced to a standard design at comparatively low cost. Some researchers saw a need for a modular tag that had, at its core, a specific control and power unit that could then be used to carry a wide variety of sensors and communications devices. Others saw a need for a low-cost, low-capability tag that could be deployed in large numbers. Matching the researcher needs between both ends of this spectrum, is perhaps the single greatest challenge for the technology developers. However, a minority of participants, who were mainly drawn from the commercial developers present at the meeting, felt that the concept of a modular tag was unlikely to fulfil expectations and that a more appropriate solution would be for the research community to provide specifications for tags that were specific to particular sets of requirements. It is noted, however, that this view came from the group who took a commercial view of tag development rather than one that sought to respond to the OGP-JIP needs.

4.7 Overall, it was concluded that there is a need for a generic type of tag that can be produced in large numbers and at low cost but which could then be modified to take different forms of sensors and shapes and sizes. Such a tag would need to be modular and programmemable in a way that made it smart. The requirements for the future are systems that will maximise flexibility in terms of what a tags is required to do and minimise costs and size.

4.8 Consideration of large-scale strategic investments beyond the boundaries of the OGP-JIP research programme may be central to the success of future OGP-JIP Research Programme investment in technology. This is particularly important in two areas:

- The supply of a global observation systems to replace or upgrade ARGOS. Although the proposed Ocean Tracking Network (OTN, see para. 9.1) promises much, it may take years to build this network and its coverage will always be constrained to some regions of continental shelf and it may not cover regions of specific interest in the context of seismic exploration.
- The production of the technology required to make a step change from the current systems that are available to a new set of systems with substantially greater capability may be unlikely to emerge naturally from the current community. Consequently, it may be most productive to focus funding in a way that brings about the development of strategic alliances that may lead to a restructuring of the community of commercial developers and researchers. This is based on the idea that common technologies that need to be mass-produced require a consolidation of the supply chain, to ensure that the demand is focussed on specific designs, while modification of this basic technology (e.g. by adding sensors, power supplies and communications systems) for particular applications can be carried out by particular developers as a way of providing added value.

5. Economic constraints upon step-changes in technology

5.1 The meeting suggested that there were conflicting needs between researchers and the developers' capacity (or willingness) to deliver tags that meet those needs. While recognising that there will always be a dynamic process between developers and researchers, with some researchers sometimes benefiting from a special relationship with a developer, there is clearly a requirement for a more flexible approach to the development of tagging systems than has been available hitherto. Development of a low-cost, high-volume tag that could be expanded, in a modular fashion, to meet specific research needs would appear to be a priority, although there was little appetite amongst the developers for such a move. The reasons for this were never explicitly explored at the meeting, mainly because they inevitably involve issues of commercial and intellectual property.

5.2 Consequently**, an important recommendation emerging from this workshop will be to conduct a feasibility study into the technical issues involved with the production of a modular tag.** This could take place over a period of a few months before any final decisions are likely to be made about research investment. Included in the feasibility study could be arrangements for the licensing of the intellectual property associated with such a tag to ensure that developers can develop this further in future. This recommendation emerges from the issue that no individual developer may be willing to commit to the R&D investment required to make a step-change in current technical capability and that the current structure of the commercial supply side of this industry is probably not optimised to ensure that there is an appropriately responsive R&D sector.

5.3 Most companies operating within this sector are relatively small (<100 employees) and, because of the way in which the sector has developed, each tends to service a particular part of the research community, sometimes with duplicate technologies. The degree of cooperation between these commercial operators varies but, in general, the meeting showed that there is little tendency for them to combine their resources to further generic technology development.

5.4 The interaction between the commercial and academic sector was highlighted as one area where more could be done to stimulate development. Fellowships and internships involving individuals from the academic sector working directly with developers were suggested as ways of tackling this (see Appendix 5). However, while the OGP-JIP Research Programme may wish to consider bids for such schemes, these would be most productive if they were part of a planned approach to stimulating new development that was aimed at the specific needs of the seismic industry. An alternative approach would be to **stimulate technology research and development within academic environments with explicit partnerships with commercial developers**.

REPORTS FROM BREAKOUT GROUPS

6. Measuring response to sound

6.1 Important responses to sound are those that carry through to consequences on the population and/or species (see 2.2 and Fig. 2). These responses include avoidance, changes in feeding success, reproductive success and survival. The lack of any behavioural avoidance to sound may lead to physiological responses that may be both adaptive or non-adaptive[5]. If there is no avoidance (i.e. change of distribution) then what are the physiological changes, if any?

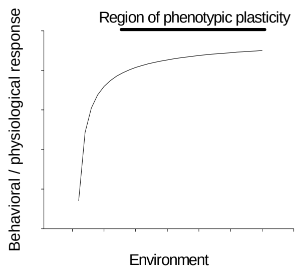
6.2 Conditioning to sound, through processes of habituation or sensitisation, is recognised as an important variable that is difficult to measure and that will contribute to the variance in any response to sound that may be used to titrate an effect. Moreover, sound may have a cumulative effect so measurement of the sound exposure history of animals would be important but is technologically challenging. It is generally recognised measuring exposure histories directly in marine mammals is probably not currently technically feasible, at least over time scales of years to lifetimes, and this points to a need for more proficient statistical modelling of likely sound exposure histories.

6.3 Responses to sound were considered under several categories and the types of variables that could be measured to quantify these responses are listed:

6.3.1 Avoidance

- May occur on short- and long-time scales;
- Over short time scales this may represent a behavioural change and the quantification of this is dealt with in the next section;
- Over the long-term (months to years) tracking individuals, using tags attached to animals or using photographic identification are the most appropriate technological solutions. However, changes in distribution as an indication of avoidance can probably be tracked most effectively at

[5] The term "adaptive" is used here in the same sense as it is used in evolutionary biology, i.e. responses that are either behavioural or physiological which are within the normal repertoire of responses are adaptive because they allow the animal to adjust to changes within their environment. Behavioural or physiological responses that are adaptive represent phenotypic plasticity and allow animals to respond to environmental change with costs to fitness. All animals show some level of phenotypic plasticity that can normally be represented as a reaction norm illustrated as follows for changes in, for example, the reproductive response of a pinniped or seabird to changes in their food supply:



In theory, long-lived species, like marine mammals, should have a more extensive region of phenotypic plasticity. An important conclusion from this is that, depending upon the state of the environment as viewed by an individual, one is likely to observe highly variable responses among individuals. This is because some individuals will be closer to the steep part of the curve than others and will be less capable of adapting their behaviour and physiology to changes in their environment.

the regional and population levels using visual surveys of populations using distance sampling. Technological innovations concerning distance sampling could involve the use of non-visual methods to detect the presence of animals including passive acoustics, active acoustics involving sonars, HF radar to detect surfacing or infra-red visualisation.

6.3.2 Behavioural Change

- Orientation, movement, location, and startle: note FASTLOK has the capability of measuring these movements on medium scales (minutes to days), as well as tags that contain movement sensors on short-medium time-scales (second-hours).
- Breathing: possible to see and/or hear in cetaceans. Possible to hear in pinnipeds at the surface.
- Vocalisation: Measure using hydrophone tags and passive acoustics.
- Diving behaviour: changes in swim and dive behaviour TDR/PIT etc.
- Mother infant associations: Measure using visual, passive acoustic and double tagging methods.
- Heart rate: EEG has been used in pinnipeds but remains a difficult technique to apply to free-ranging animals. It may be possible to develop a 'stethoscope tag' to measure heart rate in cetaceans, but this is difficult to implement with unrestrained animals and it may also require complex signal processing to subtract ambient noise that could mask heart rate.

6.3.3 Life Function

- Migration (long term – weeks to months): Satellite tags, photo-id
- Feeding: Possible for seals and some cetaceans. (i) Measuring defecation rates and (ii) echolocation signals, although there are problems defining when echolocation behaviour results in successful foraging but some sounds, such as buzzes used by odontocetes in the final approach to prey capture, may be used as proxies for feeding; (iii) buoyancy studies indicators of feeding success over periods of weeks to months; (iv) stomach temperature measures may also be used, although evidence suggests variable reliability between species and the method needs more research. Stomach temperature as a proxy of feeding success is much more difficult with cetaceans.
- Breeding: Suitable well-practiced methods for some species using visual/photographic survey. Not clear how one would develop a technology solution to provide additional information.
- Predator responses: Suitable visual/photographic methods for some species and circumstances. Otherwise there may be some technological solutions to detect predation (e.g. some form of specialised mortality tag – see below) but this would need substantial development work both in terms of tag technology and attachment/implantation with a low likelihood of success.

6.3.4 Vital Rates

- Survival/mortality tags: Development is needed in this field. Life-long implantable loggers that are released on the death of the animal are in the process of development. Long term mark-recapture studies are likely to be at least as useful but ethically appropriate and reliable marking methods have not been developed. The use of implantable PIT tags that can remotely record presence and absence data is a possibility but there are substantial technical challenges to be overcome using this method.

- Maturation/growth/body composition: Mass changes can be estimated by drift dives (currently only in elephant seals), acoustics (e.g. size measurement of some cetaceans), blubber (ultrasound). Intelligent use of accelerometers to resolve the buoyancy component from an animal's movement is technically feasible but demands a sophisticated type of tag.
- Reproduction: Some traditional methods are available to measure reproductive condition using reproductive hormone assays. Suggested development of hormone biopsies (blood spot in elephant seals), possibly using the apparent chorionic gonadotrophins present in pinnipeds and some cetaceans. The assays would require to be species- or taxon-specific but are feasible to develop and would be more reliable (fewer false positives/negatives) than traditional reproductive steroid hormone assays.

6.4 The foregoing assumes that the objective is to measure a range of variables in response to seismic surveys or experimental situations where seismic sound is simulated. However, it is also recognised that ambient noise could be used as a tool to understand whether animals avoid noisy environments or environments with particular sound signatures. This could be tested using long-term (months-yrs) tags to assess and log noisy environments in combination with ocean sound monitoring from fixed locations.

6.5 Responses to sound can be short term or long term. Short-term effect studies may guide resources to examine long-term studies, while the cumulative effect of a number of short term effects may be important. To understand the consequences and effects of sound on an animal/population there needs to be a prior knowledge of relevant behavioural ecology of species of concern.

6.7 Challenges and solutions

6.7.1 One of the most important challenges will be the relatively high variance in the kinds of responses that will be observed to different sound stimuli. Overcoming this will require large sample sizes. The technological solutions to overcoming this constraint are dealt with repeatedly throughout this report and involve the need for more efficient, less invasive attachment/detachment, which covaries with the need for small size which covaries with the need for low power or improved power supply (battery constraints), which covaries with the production volume and which covaries with cost. There needs to be a concerted effort across all of these constraints simultaneously if the constraint of small sample size is to be truly overcome.

6.7.2 Tagging itself is a challenge in the sense that it will have some possible behavioural effect on the animal, either as a result of the process of tagging (restraint, pursuit, vessel approach etc) or the effect on the attached tag itself. These effects can be reduced by minimising the size and attachment duration of the tags, as well as reducing the impact of the process of tag attachment and tracking where possible. Being realistic about the amount of data actually needed could also help to reduce both disturbance of the animal/population being studied as well as requiring simpler tags that will cost less to design and manufacture.

6.7.3 As described in paragraph 6.2, determining exposure history is a substantial challenge and is important because it could determine the response of animals. Measuring this through the use of tags, at least over useful time scales, is probably not technically feasible at present or in the near future because of the need to simultaneously overcome the challenges of long-term attachment, high data storage capacity and high data transfer rates. **An alternative is to support wider-scale development of ocean sound observation technologies by investing in basic observation technologies** and supporting the development of statistical algorithms that build exposure budgets for animals following particular distribution and migration tracks (which could themselves be derived from shorter-term tracking – see paragraph 9).

6.7.4 **An important development would be the provision of a method to allow the titration of short-term behavioural/physiological responses that does not have to rely upon the use of auditory brainstem response (ABR) to assess an effect**. ABR cannot be used in free-ranging animals. For example, a heart rate tag for cetaceans, a 'stethoscope tag', could be used to measure heart rate as a behavioural and physiological proxy of the effect of sound. Heart rate has several advantages over many other potential variables: (i) it has already been used as a proxy for energy consumption in a range of higher vertebrates and since changes in energy consumption are likely to have direct effects on vital rates, it has value as a proxy for responses that may affect vital rates; (ii) heart rate in its own right is a physiological response; (iii) in marine mammals, where there appears to be a high level of autonomic control of the heart, it may even be used as a behavioural variable and; (iv) there is already a considerable body of literature that examines heart rate as a stress response in vertebrates. Breathing rate also has many of these qualities and could be measured alongside heart rate but has the disadvantage that it only has relevance to animals when at the surface. Both heart rate and breathing rate could be used to titrate for cumulative effects, at least over short (minutes to hours) durations.

6.7.5 As already outlined in section 4 of this report, there will be a strong interaction between the researcher needs and the manufacturers and developers of tags who need to know what the market is and what the user community require. There is a need for a generic type of tag that can be produced in large numbers and at low cost but which could then be modified to take different forms of sensors and shapes and sizes. Such a tag would need to be modular and programmemable in a way that made it smart. The requirements for the future are systems that will maximise flexibility in terms of what a tags is required to do and minimise costs and size. This type of compromise may not produce the best or most elegant design for a particular circumstance but it might make the development possible because the alternative, i.e. production of specific tags for specific circumstances, will lead to impracticality because of prohibitive cost and narrowness of application.

7. Attachment Techniques

7.1 Current attachment techniques

- Pinnipeds: Tags are attached/glued to hair meaning that tag duration is thus dependent on time to the next moult. Longer-term tags can be attached/clipped to flippers and tusks (walrus), though flipper tags can rip through the webbing of the flippers and there is no current electronic tag small enough to be used effectively in this format on pinnipeds.
- Small Cetaceans: Short-term (hours to days) attachment to dolphins and porpoises can be achieved using suction cups by remotely operated methods. Longer-term attachment of tags requires implantation or clipping to the dorsal fin but both these methods requires capture. Remote attachment can be achieved with trans-dermal barbs. Harnesses can be used if animals can be captured and some of these could involve a tethered tag within a harness.
- Large Cetaceans: Remotely attachable suction cups are also used in large cetaceans, though again these are shot-term attachments (hours to days). Longer-term attachments need to be implanted in the blubber or muscle using a projectile fired into the whale.

7.2 Challenges and Developments

- Tag size:
  There was general agreement that tags should be as small as possible to reduce drag, thereby reducing the effects of tagging on animal behaviour and also likely increasing the period of attachment. But there is a trade-off between tag size and the level of functionality of the tag.
- Tag attachments:
  The attachment method is closely linked with deployment duration. There are concerns about the impact of invasive tag attachments and new and creative ways or attaching tags includes the use of harnesses for small cetaceans (requires capture). Some small cetacean tags being developed that do not require capture include trans-dermal barbs, fin clips and fin darts. There was also some uncertainty mentioned about the pros and cons of anti-bacterial substances used in association with invasive tags. More research is required into the tissue response to different materials.
- Tag duration:
  Suggestions for the improvement of the length of time pinniped tags stay attached include improvements in the type of glue used to attach to fur (current glues tend to heat the hair on curing and can cause the hair to become brittle), materials for attachment that are more flexible than current glues so that they flex with changes in body movement, and methods for reducing the attachment area. A trade-off exists between the longevity of a given tag and the invasiveness of the attachment.
  There is a lack of intermediate-duration tags (days to weeks) and development in this area would be beneficial. Improving suction-cup capabilities may be the solution for this because current suction cups have

been borrowed from off-the-shelf products and not developed specifically for attachment to marine mammals. Problems with suction cups being used for deployments of more than a few days come from restriction of circulation in region under the suction cup. A possible solution is an attachment system with multiple suction cups each one of which could then be loosened in turn and moved to a new patch of skin while other cups remain attached and so forth. Such a system would be an engineering challenge but it could help overcome ethical concerns with the use of suction cups and how they affect the animals' skin.

- Tag recovery:
  The recovery of tags can be a challenge, especially if it involves the recapture of the animal concerned. The development of controlled remote-release tags would be very useful. There is also a need to develop methods to recover implanted tags humanly, with as little impact on the animal as possible. Ethical considerations require the development of systems that will detach all of the tag and not just the tag itself while leaving the mounting in place.

- Some other challenges mentioned include, the development of attachment methods that can be used in higher sea states and the need to design parts to minimise hydrodynamic drag.

8. Monitoring Acoustic Environments (including passive acoustic monitoring)

8.1 Monitoring acoustic environments is a complex problem with many different approaches and applications beyond those being considered in this report. For the purpose of this report, and in relation to the interaction between seismics and marine wildlife, the problem was approached by sub-dividing the applications across two axes, namely taxonomic and spatio-temporal scale. The taxa were sub-categorised as pinnipeds, odontocetes and mysticetes and the spatio-temporal scales were categorised into *Presence*, *Avoidance*, *Short-term responses* and *Long-term effects*. The E&P industry is interested in whether animals are present in a given area, how often they are there, the relative importance of different habitats or regions and the effects that seismic activity may have upon these distributions over periods from minutes to years. Current capability includes an number of fundamental methods that can be applied in different ways to address questions relating to *presence*, *avoidance*, *short-term responses*, and *long-tem effects*:

- Presence: Present methods for characterising the acoustic environment are built around physical sound propagation models. These rely heavily upon data about the water column structure and bottom type and topography. Ambient noise prediction is used commonly in the military. Otherwise, current technique focussing on marine wildlife mainly include passive acoustics using moored or ship-based arrays. Passive acoustics can include bottom-mounted localization, periodic acoustic surveys with towed arrays from mobile platform and tags (long-term acoustics). All have the potential to integrate background broad-band noise levels as well as noise in the bands used for communication by cetaceans. All these are more highly developed for cetaceans than pinnipeds and are most easily applied in the context of mysticetes but rely upon animals to vocalise in order to be of any use. Monitoring methods would probably need to be adjusted depending upon the species of interest. For example, visual and PAM methods are of little use for pinnipeds and tagging is the most effective tool. Conversely, odontocetes are likely to be surveyed most effectively using towed arrays from moving platforms (depending upon the size of the area in question) and mysticetes are likely to be surveyed effectively using bottom-mounted systems or moorings.

- Avoidance: The same range of techniques can be used as for the measurement of presence but with these need to be measured over longer time periods and in relation to actual use of seismic, but this will require sufficient base-line data to measure the variance in "presence" during unexposed periods so that statistical analysis of "effects" can be carried out. This will demand long-term monitoring. Current acoustic sound propagation models can be used to estimate received levels (RLs) of sound but may only be measured accurately using RLs measure on the animals using a tag.
- Short-term response/controlled exposure: Short-term responses can be measured using visual observations during seismic surveys by marine mammal observers and data probably already exists to estimate these effects, but they are probably measured most effectively using tags that record behavioural and physiological variables (see Appendix 4). Towed arrays using PAM or analyses of specific vocalisation behaviours may augment or replace visual observations systems. Active acoustics may provide an alternative method of visualising and measuring behaviour in specific circumstances but these are mainly only applicable over short ranges (a few hundred metres).
- Long-term effect: There are no examples of systems currently monitoring of the acoustic environment in the long-term (years to decades). Long-term background monitoring is important to helping answer questions about avoidance and short-term effects because it provides a context within which to assess the statistical significance of an effect against background variation in noise levels. Relevant questions emerging from this include how acoustic 'budgets' could be measured and in what currency, and what parts of the acoustic spectrum are likely to be relevant.

8.2 Challenges and Solutions

- Presence: Detection range for PAM systems and the variable vocalisation behaviour (particularly if the animal ceases to vocalize due to sound)of cetaceans is a fundamental constraint and monitoring systems need to be multimodal to some extent in order to help overcome these constraints, or they need to be designed with these constraints taken into account. Range will also depend upon the level of background noise and this will vary between geographical regions. Bandwidth, disk space and classification all pose major challenges but these could be overcome with appropriate development. The challenge of how to cope with false negatives and the resulting possible biases in absence/presence data as well as sex and age ratios. **Real time acoustic data transmission from tags or remote stations, including PAM buoys deployed in grids or arrays, would be important developments.** An advantage of using PAM systems, such a grids of buoys is that most of the technology is already available and it is simply a matter of assembling the systems. These also do not have many of the constraints of tags associated with, for example, power supply, size, or attachment.

- Avoidance: Measuring the acoustic environment using tags and the associated received levels of sound will depend upon tagging methods and tag capability – especially memory and transmission bandwidth. Small sample size, which is typical of trials carried out to date, is a challenge in the case of all three taxa. There is a trade-off between tagging (less false negative biases) and passive acoustic monitoring (larger sample size vs. higher false negative). PAM systems are under development or, in some cases, are already in an advanced state of development with experience of widespread use. While there remain technical challenges with PAM systems, which can be overcome, **the development of long-term sound-recording tags for attachment to marine mammals is an essential step towards reducing some of these challenges.**
- Short-term: The challenges and solution are similar to those associated with measuring avoidance.
- Long-term chronic effects: There is a need to capture the acoustic background. **The challenge is to develop an acoustic monitoring system at low cost that could be deployed in regions of likely future seismic operations that could both examine the cumulative and peak levels of background noise and collect PAM data from cetacean vocalisations.** Even if these PAM data cannot be used to establish species distribution and abundance, they may provide a basis for a proxy of changes in these variables in future. The compression of acoustic data would help to reduce the challenge of longer term surveys.

8.3 Over-all Challenges

- There may be a need for *acoustic standardisation* involving the development of standard procedures that will channel effort into the most productive areas using methods that have been validated by appropriately qualified and experienced individuals. This may also help to ensure that biologists who have little experience of dealing with marine acoustics can operate within and environment where they can be confident of the validity of their techniques.
- Developing an appropriate algorithm for quantifying detection probability which includes both propagation and behaviour.
- Long-term acoustics packages that address the issue of the need for high bandwidth, the telemetry/power trade-off as well as constraints from energy/power and memory size.
- Post-hoc data management presents a considerable challenge because of the very large data sets that are associated with acoustics. There is a need to address the issue of how to manage and store these data sets effectively.
- Although the ability to detect sound in data sets is well developed, there is the challenge of using acoustic records to effectively predict population parameters.
- Flow Noise in acoustic recordings is a significant issue for researching acoustics because it can mask the signals of interest and saturate the recorder. The effects of flow noise can be reduced by stream-lining tags as much as possible, reducing its size, minimise moving parts and having multiple hydrophones. However, this, once again points to the need for tags that can be optimised for the trade-off between tag size and tag capability.
- Ability to sort out the effects of sound vs. context (activity of the animal and proximity, relative direction of the vessel… approaching or going past)

9. Determining location

9.1 Current capability: Location techniques vary in effectiveness and suitability across the marine mammals as a group. The overall capabilities can be summarised as follows:

- Visual: For example, thoedolite location of marine mammals, in good conditions animals can be localised over 7km offshore, although the range for visual observation is normally much less and depends greatly upon atmospheric conditions, sea-state, platform height and type of optics. Species/population range can be localised using video and binocular data but this is only effective for large cetacean species and those which associate into large aggregations. Visual methods also have short duration (hours) unless there is a structured approach to sampling visually across a region and through time.
- Acoustic Telemetry: Localisation using the Ocean Tracking Network (OTN)[6] with 6000+ receivers will be a possibility in future, assuming this is successful. This has the potential to service applications for marine mammals and the marine mammal research community needs to take an active part in its development. It is at an early stage of development but the associated tags for tracking are low cost. It has the potential to provide high location accuracy, but will be restricted in its capacity to track animals to specific regions of continental shelf. Further investigation would be required to establish its potential for transmitting data.
- Passive acoustics are effective at small to medium scales in time and space. Data are collected over short duration (hours). It has limited application even for small cetaceans and very limited applications for pinniped. It is useless for species or age/sex classes that do not vocalise including turtles and most pinnipeds (see Section 8).
- Active acoustics involves the use of sonars to actively track individuals or groups. This method has been used in specific circumstances (e.g. tracking killer whale foraging in Norwegian fjords and spotted dolphin foraging in Hawaii). Its main constraints are (i) its limited range (100-200 m maximum); (ii) poor definition in situations where there are air bubbles in the water as is common in most high energy environments; (iii) most of these sonars produce significant levels of sound within the hearing range of many cetaceans and this could alter behaviour. However, data collected in this way can provide fine-scale location information. Examples include Fish Aggregation Devices as Instrumented Observatories. However, these have very specific applications to investigating pelagic fish schools and may have little application to marine mammals except if platforms are being deployed that could host other types of instruments of more direct relevance.
- Telemetry Devices have different pros and cons associated with each device. These devices include: (i) VHF which is not very effective as a locating tool but is useful when actively tracking individual animals; (ii) System Argos is effective as a method of localising animals on a course scale over long periods of time (weeks to years). It is effective on pinnipeds and some cetacean species. (iii) GPS has

[6] The Ocean Tracking Network (OTN), a $168-million conservation project, which deploy an acoustic tracking network within most of the major the shelf-seas. It has the potential to track thousands of marine animals around the world - from fish to birds to polar bears. It also has application to measurements concerning climate change.

very fine scale location and is effective world wide and it is potentially effective over long time duration (years). There is a possible new development in which the aging Argos system will be replaced with alternative satellites[7] that have higher data transfer capacities. Unlike the OTN, this would have global cover.

- Geolocations systems using light level are very cheap and energy efficient but give very poor precision. Some combination of geolocation and AGROS or GSM (cellphone) data transmission may be a useful combination that could provide a small, relatively inexpensive type of tag for tracking animals over long time periods at comparatively low resolution.
- Dead reckoning has been used for short-term tracking and may emerge as an increasingly useful method for longer-term tracking. Errors are cumulative but improved accuracy of solid state inertial and compass sensors, together with hybrid instruments that may be able to ground-truth dead reckoning from occasional position fixes, for example using GPS, could be developed.
- General issues with all tag devices are the problems of attachment to the animal and tag size for use in smaller species.

9.2 Challenges and solutions

- Many challenges and solutions associated with the localisation of animals reflect those already described in preceding sections, namely, those associated with increasing the sample size, especially of species that are difficult to tag. A large number of the technical challenges associated with providing information about location at appropriate spatial and temporal scales have been solved, e.g. the solution to obtaining GPS-quality information for diving species. However, the problems associated with attaching instruments, keeping them patent for long periods (months to years) and communicating the information they collect mostly remain to be solved. Only in some large whales has there been success with long-term deployment of tags. For small cetaceans in particular we need a step change in our knowledge of how distribution and abundance changes through time for a broad range of species, populations and individuals in different states (reproductive, non-reproductive, fasting, feeding, resting…).

- Two-way transmission between tags and System Argos satellites could help to save power – thereby increasing the endurance of the tag or reducing its size, although this could be offset by the need for tags to carry and power receiver units. This has been in development for some time and is likely that it will become available in the near future.

- Some aspects of determining location could be tackled through improved statistical algorithms for interpolating between sparse data points. This has already been applied to time-series data of animal locations to refine animals track.

- Data analysis and processing from location information collected at a broad range of levels of accuracy has received much recent attention and a great deal of progress has been made using statistically validated methods for, for example, building highly serially-correlated location data from individuals tracked using

[7] Although still embryonic, there is a current initiative from ONR to develop such a capability.

the ARGOS system into an unbiased representation of the distribution of the population as a whole. This has been achieved by combining across highly non-specific data collected at the level of populations with highly specific data from a small sample of the population. **Additional work needs to be done to examine the statistical methods that will allow data about distribution and abundance collected at a broad range of spatial and temporal scales to be used within single analytical frameworks.**

- New global observation systems are needed to allow data collection at high data rates. The ARGOS system is no longer fit for purpose. It is possible that new satellite networks could become available for ocean observation, including animal tracking, in the next few years.

- Many of these issues apply equally across all marine mammal groups but, in general, the easier access to pinnipeds and the easier method of attachment has meant that much more location information has been collected for pinnipeds than cetaceans. The ability to embed instruments in the blubber of large mysticetes has also led to a rapid recent increase in knowledge of location information for them but, apart from a few isolated special cases, the small odontocetes present the greatest challenge.

10. Acoustic Tag Technology

10.1 There are two biological goals of acoustic tags: (i) to measure external stimuli and (ii) to measure animals' vocal behaviour. In general, there is a trade-off in acoustic tags between band width and recording life. This is a constraint brought on by the limitations of memory capacity. Different tags have been designed to exploit different parts of this trade-off and this determines how useful they are for different applications.

10.2 Current Capabilities

- General purpose broadband tags with a range from approx. 10 Hz up to 2 kHz are currently available or used to measure animal/social/echolocation signals. Broadband tags include the D-tag (micro-processor, 4 channels, ~500 Hz to 96 kHz measurement => short duration (hours), collaborative only), the B-probe (micro-processor, 1 channel, 4-10 kHz => duration of hours-days, commercially available), the Crittercam (tape, collaborative only) and Mozart (collaborative only).
- Detectors e.g. the A-tag produced by Little Leonardo's is a collaborative tag transitioning to commercial availability.

10.2 Challenges and Solutions

- There is a possible evolutionary path from the broadband general acoustic tags available now, to hybrid tags with compressed data and decision criteria (about what to record and not record), and also to special purpose tags in the future.
- Acoustic tags generate large volumes of data (Gbts) making it impractical to download remotely with current bandwidth capability. As a result the tags must

be retrieved in order to obtain the data, or the tag itself needs to undertake most data processing on-board with pre-programmemed algorithms. **Therefore, retrieval techniques are an important constraint on acoustic tags**.

- VHF is most commonly used to search for tags that are being recovered. It is possible that specialised tags with smarter VHF receivers could solve the problem of data transmission.
- Another major challenge is that of power and tag endurance. This is affected by battery size (physics vs. endurance) and storage capacity (B-probe can hold 1Gb-8Gb), D-tag can store 8Gb). There is a choice between long-term, low frequency or short-term, high frequency sampling because all tags are ultimately limited by their memory capacity. A possible solution is to move to specialised detector tags, but this requires specific biological goals for acoustic detecting tags.
- Flow Noise in acoustic recordings is a significant issue for researching acoustics, masking the signals of interest and saturating the recorder. The effects of flow noise can be reduced by stream-lining the tag as much as possible, reducing its size, minimise moving parts and having multiple hydrophones. There is then a trade-off between the amount of information the tag can record, the ease of its retrieval and how hydrodynamic it can be made.
- A major technical goal is compression of data. This can possibly be achieved by (i) Spectral averaging- ambient/chrome exposure; (ii) Event/peak detection; (iii) Recording triggers based on, e.g. depth, proximity, time, orientation, acceleration/startle, temperature and position. There is still a power trade-off associated with this. Compression of this type will facilitate communication by which may extend tag life.

11. Communication

11.1 The rate and manner of data transmission from instruments carried on animals is an important constraint on how useful various types of technology are in different circumstances. A number of different features affect the choice and effectiveness of different types of communication. This includes the data transfer rate, range, energy cost and financial cost. As with many other factors in the development of these technologies, the communications system of choice will involve a trade-off between, for example, size and power.

11.2 Current capability: The systems reported in the Table 5 show the current options available for communication of data. This shows that there is no ideal system. Perhaps the most widely used system is the ARGOS satellite system but this is being augmented by the capacity for much higher data transfer rates at lower power using cellphone networks when available.

11.3 Constraints: There are a limited number of modalities for the communication of data and these are often constrained by physics and practicality, e.g. attenuation of radio waves within salt water, poor transmission of acoustics in air, but there are sometimes licensing and bureaucratic issues concerning different forms of radio communications that are also constraints.

11.4 Overcoming constraints will be achieved by improving basic technologies, such as increasing the data rate available for the ARGOS satellite system, but this is probably beyond the scope, or influence, of the current research community.

Instead, overcoming constraints will rely upon improving algorithms that compress data before transmission or that carry out on-board data analysis so that only processed data are then transmitted. Improved power supplies within tags may help to increase the frequency of transmission, range and the transmission duration in some cases.

11.5 Challenges: The main challenges were seen as those associated with increasing data rates; achieving handshaking and 2-way communication; a capacity for frequency hopping and building systems that are adaptable to different circumstances. Making more use of Iridium may make a step change in data transfer rates and this method may be able to benefit from systems designed to use cellphone networks. Improvements in antenna design could also help to reduce the size and increase the capabilities of tags.

Table 5: Listing of different modes by which data can be communicated together with an assessment of the characteristics of each.

Technology	**Data rate**	**Range**	**Energy cost**	**Financial**	**Latency**	**Duplex**	
Archival	*Depends on recovery interval*		*Low*	*Low*	*No*		*Risk of loss*
Argos	*Very low*	*No limit*	*High ??*	*High*	*Hours/ days*	*No*	
Global Star	*Medium/ High*	*?*	*Medium*	*Medium*	*Seconds, low*	*Yes*	
Mobile phone	*High*	*Restricted*	*Low (10-100 times less)*	*Low*	*Days*	*Yes*	*Many rigs ?*
Mobile phone with own cell	*Medium*	*Line of sight*	*Low*	*Very high*	*Very low (seconds)*	*Yes*	*Many bureaucratic problems*
Real-time Argos via LUT	*Medium*	*Line of sight*	*Medium high*	*Moderate*	*10's seconds*	*No*	
Real-time Argos via SATCOMS	*High*				*Hours*	*No*	
UHF. Spread spectrum	*Very high*	*8km*	*Low*	*Very low*	*Seconds to minutes*	*Yes*	*Telomics and others*
Blue 7000 wifi wimax	*Very high*	*Too low*	*Too ?*	*Low*	*Days*	*Yes*	*?? on beach*
VHF	*Medium*	*Higher than UHF*	*Low*	*Very low*	*Real time*	*Yes*	*Nothing off shelf. Licence issues*
Acoustic modems	*Low but continuous.*	*100's meters. Very ???*	*2-3 ??? per GB*	*Low*	*React real time. Or days*	*Yes*	*ANMAC responce*

RECOMMENDATIONS

The following tabulation of recommendations has emerged from the discussions at the Workshop and the gap analysis. It includes additional post-workshop assessment of the OGP-JIP Research Programme requirements, especially for technology that will help it to improve the industry's environmental risk assessments. Priority levels are notional but are assessed upon a set of criteria including the likelihood of success, the extent to which outputs are likely to make a step change in capability and the relevance to the OGP-JIP Research Programme objectives.

	Recommendation	Justification	Priority	Likelihood of success	Relevance
(i)	Develop a method for remote power generation on animal-borne instrumentation	Delegates pointed out that the ultimate constraint on almost all aspects of remote data acquisition involves the management of scarce power resources. A solution will probably require consideration of new and perhaps novel technologies used to generate power from, for example, the body heat of the animal or pressure changes caused during diving. Hydrodynamics solution may also be considered but these suffer from the need to be externalised on the animals and there should be a focus upon technologies that will allow internalised tags.	High (1)	High	This is a generic problem that will affect the OGP-JIP Research Programme’s ability to respond to a broad range of questions that require the remote collection of data from marine mammals, including information about dose-response in the long- and short-term and biological significance. Solving this problem will augment attachment, tag longevity, data transmission rates and on-board processing/sensor selection.
(ii)	Carry out a feasibility study to understand the advantages and disadvantages, as well as the obstacles, to modular tag designs	Unless tags become more modular each manufacturer is likely to produce their own bespoke design that will allow them to optimise across their perceived market. This means the manufacturer’s needs are dictating tag capabilities. It is important to move away from this constraint by allowing researchers to “build” tags to their specification so that they can control the form of the tools required. If this leads to a CFP for modular tags development, the OGP-JIP Research Programme should be looking for proposals in which there are strong strategic partnerships between developers and researchers.	High (2)	High	Tagging has been identified as a significant method to be used to collect data relevant to the OGP-JIP Research Programme’s mission. However, there is still uncertainty about the trade-offs, both technical and commercial, involved in different approaches to tag design. Modularity may be the one-stop shop answer. If an appropriate strategic approach was taken to developing a modular tag, this could provide economy combined with flexibility by ensuring the core modules were manufactured in high volumes for low cost with add-on modules providing the additional functionality desired by researchers and the added value and diversity required by different manufacturers.
(iii)	Improved communication and high bandwidth data transfer, possibly by buying in to extant strategic infrastructure projects	Current systems cannot cope with high data volumes, especially from sensor that sample at high frequency including those that sample for sound levels and acceleration both of which are highly relevant. New strategic systems are likely to become available (Ocean Tracking Network using acoustics or new high volume satellite networks).	High (3)	Medium	The OGP-JIP Research Programme needs to consider whether funding assistance for large-scale strategic infrastructure is an appropriate us of funds but if applied appropriately this could lead to a step change in capability
(iv)	Support the development of wider-scale ocean sound observation technologies that can be deployed into focussed regions where E& P activities are planned	This development is important as a means of providing data for statistical algorithms that build exposure budgets for animals following particular distributions and migration tracks, which could themselves be carrying tracking tags. This would be essential as a measure to estimate received levels of sound given that the developments required to monitor received levels from tags on the animals themselves are probably not feasible in the short- to medium term. The method also has great potential to collect dose-response data from certain species for which tagging is not a feasible option, or where tagging will not produce the required,	High (4)	High	Environmental sound characterisation before, during and after seismic surveys, including the measurement of the relative abundance of cetaceans in a proposed survey region is an important part of the environmental risk assessment. There is a need for an inexpensive PAM system that can be deployed within survey regions and in which the PAMGURAD system could be used to provide real-time feedback via UHF or satellite linkage for

		statistically-robust result.			planning and mitigation purposes.
(v)	Develop systems that allow long-range (>1 km) remote controlled release of instrument packages attached to animals	Part of the process of data recovery needs to involve the use of archival tags that can be released on command. Since archival tags are probably at the most advanced state of development and are comparatively easy to build, this could lead to a rapid improvement in capability. One constraint will be that the smallest possible residue of any tag should remain on the animal after tag release. Despite much effort various developers have been unsuccessful with developing such a system to date because it requires very high levels of reliability.	High (5)	Medium/Low	The OGP-JIP Research Programme needs deployment and attachment systems that will operate over the time scale of weeks to months (approximately the duration of a seismic survey). Remote release systems will probably be required to gain greater control over deployment than is currently possible. This has a strong linkage with recommendation (iv)
(vi)	Make better use of the data collected from tags by developing statistical and mechanistic frameworks for analysing data in the context of broader-scale, lower-resolution data	Even a step-change in technology may not lead to an equivalent change in our ability to obtain appropriate sample sizes to gain enough statistical power to draw robust conclusions about effects. It is important to develop a strong understanding of the statistical power that can be developed by combining low volume, highly detailed data with high volume data of lower quality.	High (6)	High	Large data sets already exist and more data will be collected, much from different types of technology, that can be applied to answering the critical research questions being addressed by the OGP-JIP Research Programme. It would seem sensible to maximise the efficiency of data use in these circumstances.
(vii)	Develop new methods of instrument attachment	Remote observation is impossible without appropriate attachment methods and these are not well developed for many species, especially small cetaceans. Likelihood of success in this case has been classed as "low" because this has received a lot of attention to date and approaches not yet attempted are highly speculative.	High (7)	Low	Tagging has been identified as the main method to be used to collect data relevant to the OGP-JIP Research Programme's mission.
(viii)	Develop sensors for heart rate that can be used reliably in systems involving remote attachment	Heart rate was identified as an appropriate response variable for titrating the effects of received sound. It has the important property in marine mammals of being both a physiological and behavioural variable.	High (8)	Medium	The OGP-JIP Research Programme needs to be able to assess dose-response characteristics, as well as habituation and sensitisation responses. Although some of this could be done with movement sensors (which are already reasonably well developed) heart rate has the advantage that is is a variable that is comparatively simple to interpret.
(ix)	Real-time (or near real-time) data transmission from tags	Any dose-response experiment or in-situ monitoring of responses to real surveys will require rapid feedback from instrumented animals as part of the risk assessment process so that an adaptive approach could be taken.	High (9)	Medium	A short latency in feedback between seismic source and response of animals can allow a much more rapid accumulation of information about the response of animals under different circumstances than would be possible if studies were to be conducted "blind" until data was recovered after studies had ended.
(x)	Development of a sensor for breathing rate that can be used reliably in systems involving remote attachment	Probably not as useful as heart rate but can be measured for the same reasons.	Medium (10)	Medium	See (iv)

APPENDICES

Appendix 1

Aims and agenda

The following summary is taken from an introductory slide provided by Russell Tait and it shows an overview of what the OGP-JIP Research Programme saw as its objectives.

Tagging Developments / Opportunities

- **Exposure of animals will not always be avoidable**
  - **Assessment of exposure**
- **Fine scale behavioral effects are virtually impossible to link to higher level effects, especially population level effects**
  - **Transfer functions will take a long time to develop**
  - **Will always lead to additional questions that cannot be answered**
- **If operations focus on managing risks at the vital rate level, tools are needed to establish effects at the life function level and relate how these could affect reproduction and/or survival**
  - **How do you assess levels of change in feeding? How long does it take before affected animals resume feeding?**
  - **How much change in migration route is needed to become consequential to reproduction or survival?**
  - **What do demographics tell us?**

OGP

International Association of Oil & Gas Producers www.ogp.org.uk

www.soundandmarinelife.org/site/

Aims of Workshop: To provide an authoritative overview of the data requirements related to the need to make behavioural measurements from marine mammals as part of the OGP-JIP Research Programme, to identify appropriate available techniques and technology and any required development options, and produce a definitive description of the requisite development programmeme and the resources required. We anticipate that most discussion will centre around telemetry, in part because this is an area where technical development may be required. However, visual and acoustic methods for measuring behaviour will also be reviewed and discussed.

Specifically aims:

1. Provide an overview and prioritise requirements for data collection for measurements of marine mammal behaviour likely to be required by the OGP-JIP Research Programme.
2. Provide a detailed description of the telemetry techniques and visual and acoustic detection and localisation methods required to fulfil the aspirations of the OGP-JIP Research Programme research programmeme, identifying the most appropriate techniques and methods for each research topic.

3. Provide an authoritative description of the capabilities and accessibility of currently available technologies matched to the requirements identified in 1 and 2.
4. Provide an overview of the capabilities and current status of systems under development, with specific reference to the requirements identified in 1.
5. Consider availability of tools for analysis, visualisation and databasing of telemetry and other data.
6. Consider potential solutions to the gaps in capability and availability identified above.

The workshop was organised by the Sea Mammal Research Unit and held at the University of St Andrews in Scotland. SMRU hosted the successful 2nd International BioLogging conference in June 2005 which attracted most of the biological and commercial expertise in development and application of the appropriate telemetry techniques. This workshop will be an obvious extension of that gathering, but will involve a smaller, more focussed group. In addition, it will incorporate experts on acoustic tracking and monitoring using passive acoustic methods.

Workshop structure

Duration: 3 days to allow time for in-depth discussions and production of report

Days 1 & 2 will consist of a series of **short** presentations providing up-to-date summaries of the current state of each of six technology themes. Each will be followed by extended discussions in break out groups with short plenary sessions to collate the insights from each group. Rough draft reports from each theme will be compiled and will be discussed and agreed on the final day. The second day will end with a plenary session to debate and agree the list of technological priorities for the OGP-JIP Research Programme. The morning of the third day will be spent discussing how such developments can be implemented, concentrating on how to get novel devices out into the user community. We aim to have a draft report including an agreed list of priorities by the end of **Day 3.**

Workshop Agenda

Day One.

8:30 coffee available at meeting room

8-50 Welcome address (Ian Boyd- SMRU)

9-00 Requirements of the OGP-JIP (Industry perspective) (30min). Russell Tait ExxonMobil
Summary of the outputs of the Halifax meeting: this will provide an outline of the problems and requirements, as we currently understand them

9-30 Requirements of the OGP-JIP (Academic perspective) (30min) Jonathan Gordon- ECOLOGIC.
Based on the output from the Oxford and Halifax meetings, this will provide a summary of the information required to address the scientific objectives of the OGP-JIP Research Programme.

10-00 Plenary Discussion of OGP-JIP Research Programme requirements, plus agreeing format of the meeting, defining sub-group structure and expected outcomes.

10-45 COFFEE

11-00 Localising animals (20min) Presenter—Mike Fedak, SMRU
current state of satellite linked data telemetry, cell phone technology, GPS location technology,+ where next.
11-20 break-out session Open discussion (minuted)
12-30 short plenary (30min) Presentations from sub-group raporteurs

13-00 to 14-00 LUNCH

14-00 Monitoring Acoustic environment (20min) Presenter—Chris Clark Cornell Uni.
current state of on board acoustic recording technologies and of real time monitoring of noise levels and modelling, + where next
14-20 break-out session Open discussion (minuted)
15-30 short plenary (30min) Presentations from sub-group raporteurs

16-0 Afternoon tea.

16-15 Measuring responses to sound and their consequences (20min) Dave Thompson SMRU
current abilities to detect, record & measure short & medium term responses to transient stimuli, estimation of medium & long term costs and consequences
16-35 break-out session Open discussion (minuted)
17-45 short plenary (30min) Presentations from sub-group raporteurs

18-30 onwards informal pre-dinner discussion (possibly in the bar)---open forum, an opportunity to discuss new and emerging ideas that are not likely to come under the 6 topic headings (e.g. new wonder power sources, new telemetry systems…….) or to simply expand on some aspects of the day's work.

Day Two.

8:30 coffee available at meeting room

09-00 On board sensors (20min). Roger Hill : Wildlife Computers
current state of on-board sensors: Behavioural; physiological and environmental, what is being developed and what might be feasible
09-20 break-out session Open discussion (minuted)
10-30 short plenary (30min) Presentations from sub-group raporteurs

11-00 COFFEE

11-15 Attachment techniques (20min) Bruce Mate : Oregon State University
current state of attachment techniques, in hand &remote, implantable & external, improvements in longevity, reduction of harm etc.
11-20 break-out session Open discussion (minuted)
12-30 short plenary (30min) Presentations from sub-group raporteurs

13-00 to 14-00 LUNCH

14-00 Passive Acoustic Monitoring and localisation (20min) Doug Gillespie IFAW
current state of PAM, localisation, species id, behavioural information, next developments etc.
14-20 break-out session Open discussion (minuted)
15-30 short plenary (30min) Presentations from sub-group raporteurs

16-00 Afternoon tea.

16-15 PLANARY SESSION – structured panel discussion to identify and prioritise development needs (1 ¼ hr) (minuted)
17-30 Adoption of an agreed list of priorities, discuss report structure and allocate writing tasks

18-00 Close day 2. Informal pre-dinner discussion (possibly in the bar)---open forum, an opportunity to discuss new and emerging ideas that are not likely to come under the 6 topic headings (e.g. new wonder power sources, new telemetry systems…….) or to simply expand on some aspects of the day's work.

Day 3

09-00 Ensuring availability of novel methods (20min). Ian Boyd
making the developments available in a timely and cost effective way to ensure that they are used appropriately. Production capacity, pricing issues etc..
09-20 break-out session Open discussion (minuted)
10-30 short plenary (30min) Presentations from sub-group raporteurs

11-00 coffee

11-30 Break out sessions to refine report.

13-00 Lunch

14-00 Any remaining business.
15-00 Concluding remarks (Russell Tait).

Appendix 2

Assessment of current technological capability

An assessment of current technological capability based upon different sensors and instruments. The tabulation is divided into two parts; part 1 summarises the current technology in relation to variables that are measured and part 2 summarises the current instruments that are available and their capabilities.

PART 1

Variable	Technology	Detail / resolution	Sampling interval	Spatial scale	Current drain	Current experience
A. Current capabilities						
Temperature	Thermistor (oceanography)	0.01°C	~ 1s	km	Very small	High
	Thermistor (body temp)	0.1°C	Seconds-minutes			High
Depth	Pressure sensor	Log-scale accuracy	Seconds	Defined by dive depth	Small	High
Speed	Turbines Diff. pressure Bending vane Thermistor Doppler	0.1 ms^{-1} (defined by stall speed)	~ 1s	< 1 m	Very small Very small Very small Large Large	High
Salinity	Conductive or inductive	0.01 psu	Seconds	Defined by dive depth	Large	High
Density	Optical or mechanical vibration	?				Low
Acceleration (3D)	Strain gauges	0.1 ms^{-2}	Case-dependent		Large	High
Surfacing	Conductive Capacitive Optical	~1 s	<<1 s		Small	High
Orientation	Magnet Acceleration	1°	<1s		Large	High
Light level	Photo diode	High (every surfacing)	<1s		small	High
Respiration	Acoustics Magnets	Seconds	<1s		?	Low
Heart rate	ECG Acoustic Magnet Oxygen pulse	<1s	<<1s		Very small ? ? Large	Medium

Blood	pO_2 pCO_2	?	Minutes	Whole animal	Very large	Very low
Body composition & mass	Acceleration Ultrasound Magnets	0.1 kg 1%	Days	Whole animal	Very small	Medium
B. Aspirational capabilities						
Sociality & inter-specific interaction	Camera Acoustics Radio TDR synchrony Double tagging	Group size dependent	Minutes	Metres-kilometres	Unknown	Low
Food proxies	Chlorophyll On-animal sonar Camera					
Feeding	Stomach temp. Acoustics Magnets Acceleration Camera pH sensor					
Water chemistry	Turbidity Pollutants O_2					
Death	Acceleration Temperature Heart rate Activity/movement		All need to be measured over very long time scales			

PART 2

Instrument/manufacturer	Sensors available	Likely new capability	Data recovery	Species						
				Large cetacean	Small cetacean	Pinniped	Penguin	Turtle	Sirenian	Polar bear
A. Satellite telemetry										
Wildlife Computers M10-A	Depth, Temperature, Speed, Light level, GPS_f	Conductivity	Argos	Y	Y	Y		Y		
Wildlife Computers Spot	Temperature		Argos	Y	Y	Y	Y	Y	Y	Y
Telonics ST 20	Depth, temperature, GPS_s	GPS_f, Acceleration	Argos	Y	Y	Y	Y	Y	Y	Y
Telonics ST 24	Depth, temperature		Argos	Y	Y	Y	Y	Y	Y	Y
Sirtrack Kiwisat 101	Temperature, activity		Argos			Y	Y	Y		
Sirtrack Kiwisat 202	Temperature, activity	GPS_F, GPS_s	Argos	Y	Y	Y	Y	Y		
SMRU SRDL 9000	Depth, Speed, Temperature, GPS_F, CTD	Acceleration, fluoresence	Argos		Y	Y		Y		Y
B. Acoustic										
Vemco Vg-22	Depth, temperature, pH	Acceleration, archival, sociality	Acoustic, archive upload. Range 0.1-1 kim							
Sonotronics/Telonics	Depth	Temperature	Acoustic/VHF combination			Y				
C. Cellphones										

SMRU	Depth, GPS_F	Temperature	GSM, 32 km from shore			Y				
Sp.Sp.Tx (UHF)	Depth, Temperature, GPS_F		2-way, 10 km							
D. VHF										
Telonics implantable/external	Temperature (external and internal), Activity, Heart Rate, Mortality		Line of sight			Y				
Sirtrack	Temperature, Heart Rate, Activity, Mortality		Line of sight			Y				
ATS	No information		Line of sight			Y				
Lotek	No information		Line of sight			Y				
E. Data Loggers										
Little Leonardo M-D2GT	Depth, Accceleration, Temperature			Y	Y	Y	Y	Y	Y	
Little Leonardo W-PD2GT	Speed, Depth, Acceleration, Temperature	GPS_S								
Little Leonardo W-3MPD3GT	Magnets, Speed, Depth, Acceleration, Temperature									
Little Leodardo DSL	Depth, Temperature, Images (15 s)					Y	Y			
Wild Insight	Depth, Temperature, Images (full movie to intermittent), sound					Y				
National Geographic Crittercam	Depth, Temperature, Images (full movie), sound			Y	Y	Y	Y			
Wildlife Computers Mk 9	Depth, Temperature, Light				Y	Y	Y	Y		
Wildlife Computers Mk 10	Depth, Temperature (External & Internal), Light, Speed, GPS_F	CTD, Heart rate								
Lotek	Depth, Temperature, Light	Mianly designed for application to fish								
Star Oddi	Depth, Temperature									
CEFAS	Depth, Temperature									
Woods Hole D-tag	Depth, 3D accewleration, sound, temperature, compass	GPS_F, Speed, High frequency sound		Y	Y	Y			Y	
B-probe	Depth, Sound	3-D acceleration, compass, high-frequency		Y		Y			Y	

Appendix 3 Summary of research questions

		Research questions addressing the higher-level question "what are the effects of seismics on individuals and populations?" These questions were derived from Table 4 within the report of the meeting held at Tbney House, Oxford, in October 2005 to examine "The effects of anthropogenic sound on marine mammals".
Hazard identification	1	What is the range of frequencies, intensities and durations of exposure (that causes risk)?
	2	What is the effect of propagation conditions?
	3	Have stranding rates changed?
	4	Has seismic activity affected the distribution and abundance of any marine mammal?
	5	Does seismic survey activity affect prey availability for marine mammals?
	6	Where are the sources?
Characterise exposure	7	Where are the marine mammals?
	8	What is the overlap of marine mammal distribution with sound sources?
	9	How do behavioural changes modulate exposure?
	10	What are the received sound characteristics?
Characterise dose-response relationship	11	Are there physiological responses?
	12	Do airguns have a direct physical effect?
	13	What is the behavioural response?
	14	Is there habitat displacement and over what temporal and spatial scales?
	15	How do we assess the significance of observed habitat shifts?
	16	Does sensitivity vary between individuals?
	17	How are populations and their vital rates affected?
Risk charact eisation	18	What is the probability of impacts on individuals?
	19	What is the probability of adverse population impacts?
Risk mitigation	20	What is the effect of changing the acoustic source, operational characteristics and location of the source?
	21	Is ramp-up an effective mitigation measure?
	22	How can marine mammals be detected within the operational zone in real time?
	23	How to reduce risk of overlap between marine mammals and seismic surveys?
	24	How to design MPAs to minimize risk to animals in areas where seismic exploration is likely?

Appendix 4

Assessment of the technological requirements

Assessment of the technological requirements based upon the major questions defined in Appendix 3 and expressed as variable that need to be measured.

	Variable	Research question	Duration[1]	Detail (resolution)	Priority / utility	Practicality	Spatial scale	PCAD Ref.
Physiology								
	Heart rate	11	Min-mon	High	High	High	N/A	B, T1, (T2)
		13	Min-days	Low-high	Med	High	Any	
		16	Days-wks	High	High	High	Any	
	Temperature	11	Wks-mon	Low	Low	Med	Any	T1, L
		16	Wks-mon	Low	Low	Med	Any	
	Energy consumption	11	Wks-mon	High-med	High	Med-low	Any	T1, (T2)
		16	Wks-mon	High-med	Low	Med-low	Any	
	Heat flux	11	Days-mon	High	Low	Low		T1, (T2)
		16	Days-mon	High	Low	Low		
	Respiration / breathing	11	Min-mon	High	High	High		T1, (T2), L
		13	Min-days	Low-high	Med	High		B
		16	days	Low-high	Low	High		
	Condition / growth	11	Days-yrs	High	High			T2, (V)
		15	Days-yrs	High	High	Low	Large	T2, (V)
		16	Days-yrs		Low	Low		
		17	Yrs	High	High	Low		(V)
Behaviour								
	Location & movement	1	High (< 1km)	High	High	High	Small	A
		7	Med (1-10 km)	High	High	High	Med-large	A, B, L
		8	High	High	High	High	Med-large	A, B, L
		9*	High	High	High	High	Small	A, B
		10	High	High	High	High	Med-large	A
		13	High-low	High	High	High	Small-large	B
		14	High-low	High	High	High	Small-large	L, B, T1
		16	High-low	High	High	Conditional	Small-large	
	Diving	7	Days-mon	High	High	High	Small-med	A, B, L
		8	Days-mon	High	High	High	Small-med	A, B, L
		9*	Hrs-wks	High	High	High	Small-med	A, B
		13	Hrs-wks	High	High	High	Small-med	A
		14	Hrs-wks	High	High	High	Small-med	B
		16	Hrs-wks	High	High	High	Small-med	L, B, T1
	Feeding	13	Hrs-wks	High	High	Variable	Small-med	L, B, T1
		16	Hrs-wks	High	High	Variable	Small-med	
	Speed & orientation	9*	Hrs-wks	High	High	High	Small-med	A, B
		13	Hrs-wks	High	High	High	Small-med	B
		16	Hrs-wks	High	High	High	Small-med	
	Vocalisation	13	Days-wks	High	High	High	Large	B, L
		16	Days-wks	High	High	High	Large	B, L
	Haul-out	9	Hrs-days	High	Med	High	Small	A, B, T0
		13	Hrs-days	High	Med	High	Small	A, L
		16	Hrs-days	High	Med	High	Small	A, L
	Social behaviour	13	Days-Wks	High	High	Med-low	Small	B, T1, L, (V)
		16	Days-Wks	High	High	Med-low	Small	B, T1, L, (V)

	Sleep	13	Hrs-days	High	Low	Low	Small	B, T1, (T2)
		16	Hrs-days	High	Low	Low	Small	B, T1, (T2)
Population								
	Survival / reproduction	15	Yrs-life		High			V, T3, (P)
		16	Yrs-life		Low			
		17	Yrs-life		High			H, V
Environment								
	Received sound	1	Wks-mon	High	High	Yes (passive)[2]	Small-large	A (T0) high
		10	Wks-mon	High	High	Yes (passive)	Small-large	A (T0) high
		16	Derived from Q1; Q10 & location, response & behavioural variable for Q9					
	Ambient (background) sound (in absence of seismics)	1	Yrs	Med	Med	Yes (passive)[2]	Large	A high
		16	Yrs	Med	Med	Yes (passive)[2]	Large	All
	Prey field & biological oceano-graphy	15	Wks - yrs	High	High	Possible but difficult	Med-long	L1, T2, high
		16	Derived from Q15 and response variable					
	Physical oceano-graphy	1, 2	Wks - mon	High	High	Yes (ship)	Large	A High
		10	Wks - mon	High	High	Yes (ship)	Large	A
		15	Wks - mon	High	Med	Yes (ship or tag)	Med-large	L1, T2 Low

[*] Question 9 includes consideration of tagging effects.
[1]Duration includes pre-treatment, treatment & post-treatment
[2]Passive means can probably be achieved without tagging

Appendix 5

<u>Assessment of the main issues associated with technology relevant to marine mammals and seismic survey</u>.

Technology Issue	Workshop participant responses	Number of responses
Attachment	Long term attachment tags; Attachment/recovery; Attachments; Long-term attachment; Cheap long-term tags; Attachment/deployment/recovery techniques for medium-term experiments; Duration of tag: Potential to monitor behaviour pre, during and post survey / Attachment/capture/recovery; Attachment; Longevity at operation (medium - long, weeks/months - months/years); Attachment techniques; Longer attachment for larger recording; Tag attachment, capture, recovery techniques; Attachment; Better release systems for all taxa; Better capture techniques for small cetaceans; Attachment; Attachment; Release systems; Benign medium term attachment for cetaceans; Attachment issues; Long-term attachment to small/medium sized cetaceans; Increased longevity (6 – 8 weeks); Duration (tag) of 8 – 12 weeks; Attachment methods; Cetacean attachment; Capture, Deployment and Attachment. How do we get the tag on the animal and keep it on? Attachment/release; Attachment techniques / drop off unit to terminate the period of collection of data; Attachment and retrieval tag; Attachment/retrieval;	33
Power	Power supply; Power supply; Power Supply; Attachment and power; Power innovations in order to reduce tag size (i.e. battery size); Increased power supply; Less power consumption/more efficient batteries; Increase tag longevity; attach, power;	8
Communications	Improve accuracy of satellite communication; Communications; Accurate satellite communications; Data recovery without tag recovery for both low; density and high density data sets; Communications; Communication; Communications, real time vs. archival; Real-time telemetry at high bandwidth data; High band width remote data collection – communication; Communication (2-way); 2-way communication; Latency (real-time data transfer); Real time / two-way communication; Communication issues; Real time tags as related to real time visual and acoustic monitoring; Higher data transfer rate; More timely (e.g. near real time) data transfer; Near real time acquisition of location/behaviour data;	23

		Communication; Low latency high band = real time data transfer; Real time communication; Real time 2-way communication;	
Size		small size; Size; Small size; Small size; Small size; Small size tags to last longer with minimum ‘impact’; Small size;	7
Cost		Cheap long-term tags; Cost/sample; Cheaper tags; lots of good things already out there, but lets get costs down; Field costs;	5
Data analysis	On-board	On-board processing; On board processing ‘smart tags’; Methods of data compression for enhanced communication and/or storage (smart tag) Data compression on tag; Integration of all sources of measurement, tagging, displayed arrays, PAM, observations; Intelligent tag that records when relevant; Data compression – onboard; On-board processing (data compression); On-board processing; Compression of Acoustic data into small chunks; Real time data synthesis;	10
	Post-hoc	Data fusion and analysis; Data analyses and visualisation; Develop analytic techniques to integrate data;	3
Separate pinniped/odontocete/mysticete requirements		Define the requirements of a tag, or tag alternative, for a pinniped, odontocetes and mysticetes; Standardisation of methods separately, pinnipeds/large cetaceans/small cetaceans;	2
Availability		Transition of technologies to commercial availability; Long term acoustic recording (small, cheap, Available!); Measuring and logging acoustic sounds more easy, not enough cheap available tags for this; Commercial availability of tags rather then reliance on collaborator – controlled access; Long-term funding of experiments; know tag requirements over months/years to plan field seasons, tag acquisition; Commitment to funding long-term experiments with 1000’s tags to access overall response to sound in general; Provide time frames for the tag availability; Provide funding regime to develop newer future technologies; Move money for developing existing technology; make the most of all the amazing tools that are being massively underutilised; Purchase of large numbers of tags; Purchase large numbers of ARGOS;	11
Sensors		Sensors – basic vs. specific; Heart rate in cetaceans; Multi function integrations; Characterising sound exposure; Sensor/metric for reproduction; Acoustic measurements on tag with appropriate summerisation; Acoustic long lasting tags; Sound characterisation; GPS localisation for cetaceans; Long term monitoring of feeding events; Long term monitoring of respiration rate; Long term acoustic recording (small, cheap, Available!); Characterisation of acoustic environments at/near	21

	animals in question; Monitor dive behaviour; GPS accuracy locations; Identification and quantification of exposure, what acoustic signature needs to be recognised, how do we measure it? Monitoring condition changes – LH cycle; Habitat characterisation and preference; Small data logging 2A-3D acoustics; On board acoustics; Long-term monitoring of 'proxies of energetics';	
Long-term, low-cost tags	Long-term monitoring of survival; Methods for long-term identification of individuals e.g. small, long-life VHF/PIT tag for survival;	2
Multi-functional, multimodal tag	Tag which has/can: multi sensor, cascade detail, intelligent/responsive, multi mode data delivery, duration appropriate to LH; A data collection package (logger and transmitter or recovery package) that allows assessment of one or more variables that serve for both short-term behavioural responses and long-term vital rates (as proxies); Medium term tags (BMW); Medium term tag; Multi-mode tags. Switch between short-term high sampling and longer-term lower sampling and/or summarising; Combine Attachment, Real time and Communication to one carrier for data logging, position, control (real-time) and drop of unit; How do we get reasonably (adequately) detailed information over a 6-8 week period related to seismic exposure? Length of data gathering/size vs. capacity;	8
Additional unclassified comments	Effective assessment of vital rates (reproduction rate, fitness)	
	Establish acceptable sampling requirements for each tag required for the experiments.	
	What combination of tags/animals can be tagged to provide realistic responses that have potential to affect animals at life function level?	
	How can we characterise exposure beyond 1-2 days in context with behavioural response? What is needed to monitor and transmit data?	
	How can we characterise variables most directly affecting reproduction and survival?	
	How can we get measures to characterise long term issues from short term exposure.	
	Fund science not technologies	
	Determining acoustic (vocal) statistical behaviour of calling species from acoustic recording tags to enable more accurate population estimates from fixed-hydrophone recorders	
	Determining key acoustic parameters to enable development of appropriate acoustic compression	
	Tags that can last for a long time (years), that can also be deployed in large numbers	
	Long-term monitoring	
	Biofouling; Achilles heal for long deployment in some cases. Batteries not an issue	
	Higher data density/capacity	
	Sound exposure metrics (context OGP-JIP Research Programme specific)	
	Fund project	
	Synergism. Experimental strategies/multiple techniques	
	Standard specifications	
	Short-term behaviour at exposure	
	Long-term tracking	
	Reliability	
	Real time control for position;	
	Positioning! Control where the tagged animal is	
	Fellowships	
	Intern (a helpful one!)	
	Need to communicate project outlooks – horizon scanning	

	List-server communications	
	E-mail list at shared feasibility studies	
	Standardization of methods for each OGP operations questions	