Survey of Active Acoustic Monitoring (AAM) Technologies

Volume 1: Survey Results

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Abstract

Under the Exploration and Production (E&P) Sound and Marine Life Programme, a research study was carried out on the feasibility of the Active Acoustic Monitoring (AAM) of marine mammals. The purpose of such monitoring would be to detect marine mammals in those ocean areas where E&P activities are being conducted, in order to allow due diligence in mitigating any potential impact of these E&P operations. The study did not include any direct experimentation.

The AAM study encompassed multiple work components. First, the problem domain was delineated in an overview of offshore E&P activities and of the ocean environments in which they are conducted. To make the analysis more concrete, six specific ocean areas of relevance to E&P were selected and their properties described. Next, the potential performance of AAM was investigated via a parametric study of the sonar equation, incorporating available knowledge of sonar technology and environmental effects (e.g., high-frequency backscattering from the ocean boundaries). This part of the study was intended to identify any fundamental limitations to AAM as imposed by technology or by the basic physics of the problem, and also to pinpoint those sonar features that are of key importance for AAM. Special effort was dedicated to investigating the target strength of marine mammals, as this is an area in which scientific knowledge is sparse at present. The parametric analysis included several generic examples, and was also applied to the six specific ocean areas; however, computer modeling of the six environments was beyond the scope of the study.

This report (Volume I) provides an overview of the study and summary results. Volumes II through IV provide supporting background material.

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Executive summary

Survey of Active Acoustic Monitoring (AAM) Technologies: Volume 1: Survey Results

J. Theriault; E. MacNeil; B. Maranda; L. Gilroy; J. Hood; Canadian Seabed Research Ltd.; DRDC Atlantic ECR 2009-002; Defence R&D Canada – Atlantic; March 2010.

Background: Under the Exploration and Production (E&P) Sound and Marine Life Programme, a research study was carried out on the feasibility of the Active Acoustic Monitoring (AAM) of marine mammals. The purpose of such monitoring would be to detect marine mammals in those ocean areas where E&P activities are being conducted, in order to allow due diligence in mitigating any potential impact of these E&P operations. The study did not include any direct experimentation.

Results: The AAM study encompassed multiple work components. First, the problem domain was delineated in an overview of offshore E&P activities and of the ocean environments in which they are conducted. To make the analysis more concrete, six specific ocean areas of relevance to E&P were selected and their properties described. Next, the potential performance of AAM was investigated via a parametric study of the sonar equation, incorporating available knowledge of sonar technology and environmental effects (e.g., high-frequency backscattering from the ocean boundaries). This part of the study was intended to identify any fundamental limitations to AAM as imposed by technology or by the basic physics of the problem, and also to pinpoint those sonar features that are of key importance for AAM. Special effort was dedicated to investigating the target strength of marine mammals, as this is an area in which scientific knowledge is sparse at present. The parametric analysis included several generic examples, and was also applied to the six specific ocean areas; however, computer modeling of the six environments was beyond the scope of the study.

This Volume provides an overview of the study. The survey received responses from thirteen production active sonar systems that may be appropriate for the task. Each of the systems has promising and innovative characteristics and individuals.

Significance: The study documents the feasibility of using AAM technologies for mitigating potential impacts of E&P acoustic emissions on marine mammals. There exist technologies that could provide a basis for actively detecting marine mammals between 500 and 1000 m.

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1 Introduction

1.1 Background

The International Association of Oil and Gas Producers (OGP) established the Exploration and Production (E&P) Sound and Marine Life Programme as an industry research fund supporting research into sound produced during E&P activities and its effect on marine life.

The JIP (Joint Industry Programme) has funded a proposal by Defence R&D Canada Atlantic, in partnership with Akoostix Inc., to deliver this study which has completed a review and inventory of current active acoustic methods and technologies and has identified potential further development areas for the detection of marine mammals during E&P activities offshore. The study has been approached as a three phase project; during the first phase background information was gathered on E&P activities / environments and a general assessment was done on the performance capabilities of active acoustic technology. In the second phase a survey of manufacturers of active systems was conducted. During the third phase these survey responses were evaluated for suitability of use in monitoring marine mammals at sea during E&P activities and recommendations were made on further development areas.

The study proposal details are contained in response to Request for Proposals JIP08-05.

1.2 Document Objective and Structure

This report is the final report for contract JIP08-05. The report consists of five volumes.

- Volume I (This report) contains an overview and summary of the survey and analysis. Annex B to Volume I includes a Microsoft Excel file, with the detailed responses from each of the system suppliers, along with the evaluation.

- Volume II is the complete contract proposal.

- Volume III is the complete sub-contract report from Canadian Seabed Research on E&P Operations.

- Volume IV is a detailed description of six chosen E&P environments and the marine mammal species expected in those environments.

- Volume V is a detailed analysis of the factors affecting the performance of an AAM system.

1.3 Introduction

As existing oil and gas developments become depleted, new E&P opportunities are increasingly found offshore, often in remote or environmentally sensitive areas. The increasing number of offshore developments means there is an increasing number of offshore E&P activities which

may contribute sound into the marine environment. In recent years, the oil and gas industry has gained significant attention from the public and governments related to the environmental impact of offshore activities on marine mammals. As a result in many areas regulatory requirements have been put in place that require monitoring for marine mammals during E&P activities and mitigations to be employed when marine mammals are found. In areas where regulations do not exist, there remain public scrutiny and corporate due diligence requirements to undertake monitoring and mitigation methods to reduce the impacts of E&P activities on marine mammals.

The capability to monitor marine mammals in the areas where offshore E&P activities are being conducted is essential to meeting these requirements. Currently, visual monitoring and Passive Acoustic Monitoring (PAM) methods are used. These methods have some inherent limitations that may impact the ability to conduct E&P activities; therefore the JIP (Joint Industry Programme) is investigating alternative methods, such as active acoustic monitoring (AAM), that could address these limitations.

Visual monitoring methods typically involve a trained observer who monitors the area in which E&P activities are being conducted for marine mammals surfacing. The use of visual methods has limitations such as visibility, due to weather or light conditions, and it requires mammals to have a surface presence. These limitations can be significant in specific environments and in particular seasons which, for example, may have a high probability of fog or reduced daylight hours. This limitation can also be significant for particular species of marine mammals that have a reduced surface presence either normally or during specific periods.

PAM methods involve passively listening for marine mammal vocalizations in areas where E&P activities are being conducted. The use of PAM methods has limitations for mammals that have low vocalization rates and in areas with high ambient noise levels (for example due to ongoing E&P activities or environmental conditions).

AAM methods involve actively monitoring for marine mammals by emitting pings (sound pulses) in the area where E&P activities are being conducted and listening for return echoes from the pings reflecting off marine mammals. Use of AAM is not limited by visibility conditions and is not dependant on vocalization or surface presence of the marine mammals. AAM methods are currently in use for in a variety of detection / monitoring applications, such as fish finders used by commercial fisheries for location of fish schools and in sonar used on naval platforms for location of underwater targets.

Under this study a general review of the E&P specific requirements for marine mammal monitoring has been conducted and an evaluation was done to generally assess the potential performance of AAM methods for detection of marine mammals. Based on this background information, the important parameters impacting the performance of AAM systems in this application were outlined. Following this a survey was conducted of commercially available AAM systems. The survey results were evaluated against the important parameters established earlier, and general rankings were made for AAM systems suitability in this application. A list of recommendations on further development areas was also assembled.

2 E&P Activities and Environments

2.1 Introduction

To complete a realistic evaluation on the suitability of an AAM system for use in Marine Mammal Monitoring, it is necessary to have a general understanding of the requirements that must be met by a system employed for this purpose during offshore E&P activities.

To develop this general understanding a review was done on the types of offshore activities carried out by the oil and gas (O&G) industry, the environments where these activities are occurring and the types of regulatory requirements that are in place governing marine mammal monitoring.

2.2 E&P Activities

The type of activity has some effect on the requirements for an AAM system, as it may influence the platform from which the system will be operated and the potential performance of the system. A system which may be suitable for use in one activity may not perform as well in another.

The oil and gas industry engages in a wide variety of E&P related activities in offshore areas. These activities span exploration, construction, production, and demobilization. Within a particular activity there also exists considerable variation in the methods and procedures used to conduct the activity. As it would not be practical to evaluate each AAM system surveyed against all possible activities, the approach was taken to develop a small number of 'concepts of use' that represent the most significant activities. The concepts of use are essentially scenarios in which an AAM system could be employed for monitoring marine mammals. The surveyed AAM systems will be evaluated against these concepts of use to provide insight on their suitability for use in E&P activities.

2.2.1 Identifying E&P Activities

The first step in outlining the concepts of use was to identify the E&P activities. The activities of interest for this study are those that are a significant source of underwater noise. This is obviously an area of significant interest to the O&G industry, and one in which the JIP has previously funded research. Reference [1] includes a general list of E&P activities and a ranking of their significance as a source of underwater noise. The ranking is based on overall source level, detectable range and duration of sounds. The activities ranked as the most significant were associated with seismic exploration (air guns, explosives), construction activities (impact pile driving, explosives) and vessel operations. Production activities, aside from vessel operations, were ranked as less significant.

Of these significant activities, the use of air guns for seismic exploration is typically the activity that gains the most attention from non governmental organizations and by government regulators. Air guns are the most common method used to conduct seismic surveys. In general, this activity is conducted from a main survey vessel, which tows streamer arrays (underwater sound receivers) and air gun arrays (impulsive noise sources). The main survey vessel is often accompanied by a

number of support vessels. The air guns direct acoustic energy into the seabed, some of which reflects off rock layers beneath the surface back into the water column and is received by the streamer arrays. This returned energy is processed and used to produce a map of the subsea structure. Seismic source arrays are commonly activated every 25-50 m during conventional seismic surveys, along pre-defined sail lines after which the source is stopped or in some areas reduced to a minimum while the vessel moves from the end of one sail line to the next. As well as turns between sail lines, overall survey duration is also effected by other factors such as obstructions, tides, weather, fishing or other vessels. Therefore, although a seismic vessel is able to operate on a 24-hour basis, the seismic source is not active 24 hours a day every day. Surveys are conducted over areas as large as hundreds or thousands of square kilometres. As known O&G resources are developed, exploration tends to push into more difficult to develop areas, including sensitive environmental areas, deeper water areas and areas with political, social or economic instability.

Other significant activities include construction impact pile driving, the use of explosives and vessel operations. Construction impact pile driving is a mechanical process which uses an impact hammer to drive large piles into the seabed to anchor infrastructure in place. Explosives are used both in construction activities, for site preparation and rock / obstacle removal, and at times for exploration activities where air guns are not effective. Vessel operations cover a broad range of activities, including support and supply vessels for offshore platforms, tankers transporting hydrocarbons, a variety of vessels used in construction and explorations activities (survey vessels, support vessels, drilling rigs, heavy lift vessels, barges, pipelay vessels) and even ice breakers used in Polar areas.

Further details on E&P noise generating activities are outlined in [1] and Volume II of this report.

2.2.2 Grouping E&P Activities

Focusing on only the most significant activities identified above, these were generally grouped by the type of platform from which they are conducted (moving or non-moving / fixed location) and by the type of noise (impulsive or continuous). These groups are outlined in Table 1.

These two groupings were selected as they provided a convenient method to narrow down the activities and it was thought that platform type and noise type would be significant influences on the requirements for an AAM system. As the evaluation progressed, it was found that while platform type was a significant influence on the requirements for an AAM system, the noise type was not particularly significant for the high level evaluation performed under this study.

Table 1: General grouping of the most significant noise generating activities by platform type and by noise type

Platform Type		**Noise Type**	
Moving	**Non-Moving or Fixed Location**	**Impulsive**	**Continuous**
• air guns • explosives used in exploration activities • vessel operations	• impact pile driving • explosives used in construction activities	• air guns • explosives • impact pile driving	• vessel operations

2.2.3 Concepts of Use

Based on the activity groupings, three concepts of use were outlined describing how an AAM system would be used during an offshore E&P activity. Table 2 provides a summary of the concepts of use.

Table 2: Summary of Concepts of Use for AAM Systems in E&P Activities

Concept of Use	Description	Example
Concept of Use 1	AAM system is used during an E&P activity that is conducted from a moving platform and which generates impulsive underwater noise.	Seismic survey using air guns.
Concept of Use 2	AAM system is used during an E&P activity that is conducted from a moving platform and which generates continuous underwater noise.	Vessel operations: tankers, supply or support vessels, pipelay vessels, icebreakers.
Concept of Use 3	AAM system is used during an E&P activity that is conducted from a non-moving or fixed location platform and which generates impulsive underwater noise.	Construction activities using impact pile driving or explosives.

A fourth concept of use for an AAM system used during an E&P activity on a non-moving or fixed location platform and which generates continuous noise was not included as the activities in this category (such as production operations) were not ranked as the most significant noise generating activities [1].

The discussion of the suitability of the surveyed AAM systems for these concepts on use is included in Section 5.

2.3 E&P Environments

The environment has a major impact on the potential performance of an AAM system and has implications on the type of AAM system that could be used. The water depth, water column conditions (including surface and bottom) and the type of marine mammals present all impact system performance and are highly variable between environments. Even within a given environment there may be large variations in marine mammals and conditions, for instance due to changing seasons or weather. The impact of environmentally related factors on system performance is investigated in detail in the potential performance assessment, Section 3.

Due to the broad range of environments in which E&P activities are conducted, the approach was taken to generally characterize a small number of environments that represent a cross section of relevant areas.

The first step taken was to identify general areas/regions with a significant number of offshore developments. A number of well established areas were identified, such as the Gulf of Mexico and the UK Continental Shelf [2]. In well-established areas much of the O&G resources have been developed and new projects are typically in harder to develop areas, such as very deep water or more remote, harsher environmental areas. Numerous other areas were also identified as having a significant number of developments, including the West Coast of Africa, Barents Sea, Brazil, Indonesia, South China Sea, Atlantic Canada and North West Bank of Australia [2].

In addition to areas with existing offshore developments, consideration was also given to areas which may be future development areas. The assessment of world petroleum reserves by the United States Geological Survey estimates that the former Soviet Union and the Middle East / North Africa region contain the bulk of the world's undiscovered O&G resources [3]. In the assessment a number of offshore areas were indicated as potential locations of significant offshore resources, these include the West Coast of Africa, offshore Brazil, East Coast of Greenland, West Siberian Basin, Caspian Sea, Persian Gulf, and North Sea. The assessment also notes that a significant portion of undiscovered O&G resources are offshore, in water depths out to 4000 m.

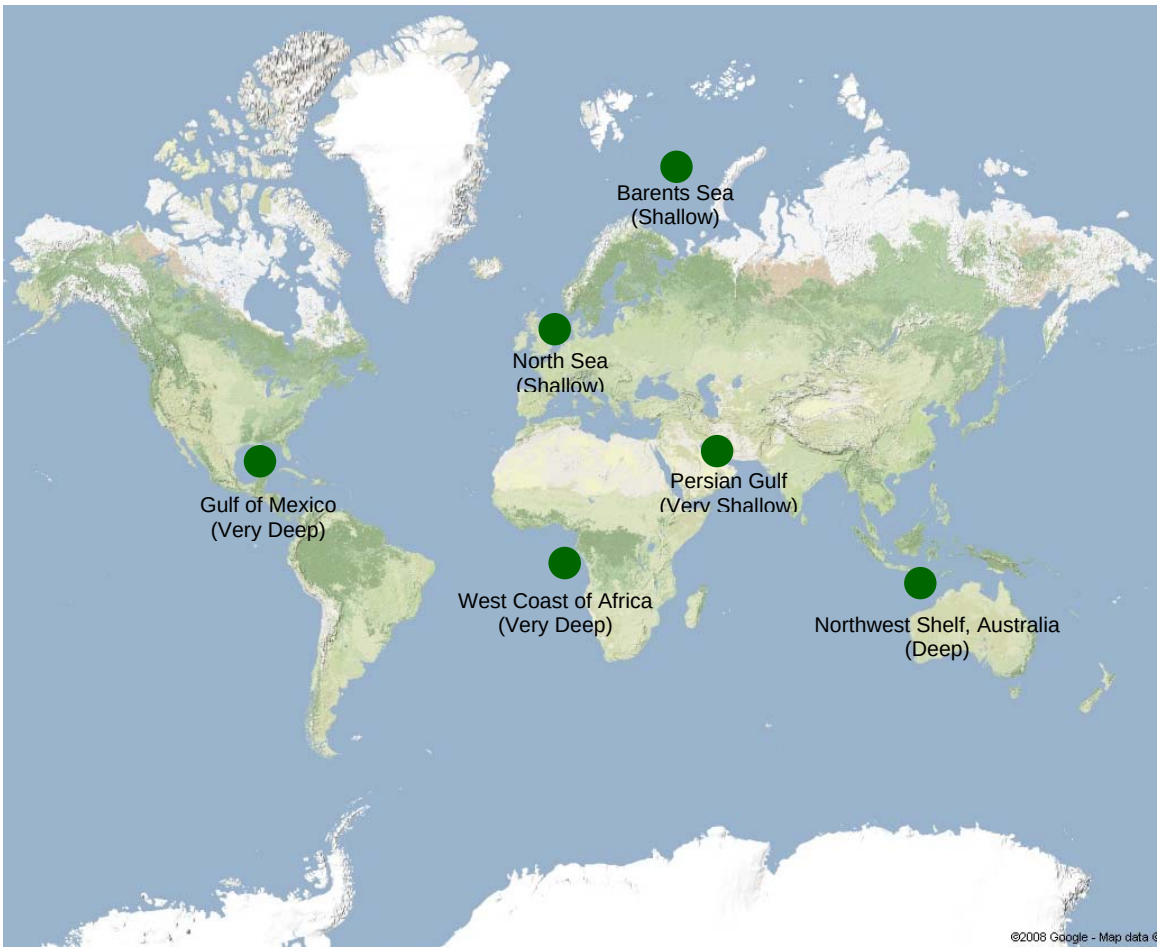

Figure 1: World Map showing locations for Six O&G Relevant Environments (Water depths defined as Very Shallow (<100m), Shallow (100-400 m), Deep (1000-2000 m), and Very Deep (> 2000 m).)

As previously mentioned, within each of the environments identified above there are large variations in water depth, water column conditions and marine mammals. To complete a detailed assessment of the performance of each of the surveyed AAM systems in each of these environments, the specific environmental parameters would be required (e.g. Water depth, sound-speed profile, bottom type). To determine these environmental parameters a specific location and a specific time of year would need to be selected. For the general evaluation being conducted under this study it was not practical to select individual locations and times within each environment. The approach taken was to select one water depth for each environment and to provide a general evaluation of AAM performance for each environment. The discussion of the AAM performance in these environments is included in Section 3.2. A detailed description is included in Volume IV.

2.4 Marine Mammal within E&P Environments

To develop an understanding of the types of marine mammals in the six environments above, a list of 86 species of marine mammals and their habitat was cross referenced with the six locations. This list, which also references marine mammal size and diving characteristics, is contained in Volume IV.

From the list, it can be seen that a wide variety of marine mammals are present in these six environments. As it would not be practical to evaluate the performance of the surveyed AAM systems against each species in each environment, the approach was taken to group the mammals in terms of size (see Table 3) and in terms of diving characteristics (deep, shallow). These groupings were chosen as they provided a convenient way of narrowing down the evaluation and, based on the performance factors results presented in Volume V, were thought to be the parameters that would most likely influence the AAM performance. The size influences roughly the target strength of the animal and the diving characteristics influence where in the water column an animal may be detected. A hypothesis had been put forward that the acoustic target strength of an animal may change with depth as lung volume decreases, but a modelling study (presented in Volume V) shows little or no dependence of the lungs on target strength.

Table 3: Marine Mammal Grouping by Size

Size Grouping	Marine Mammals
Small	Small Odontocetes (toothed whales)
Medium	Large Odontocetes (toothed whales)
Large	Mysticetes (baleen whales)

The evaluations of the surveyed AAM systems for use with these marine mammal groupings are discussed in Section 5.

2.5 Regulatory Requirements

A general understanding of the regulatory requirements which impact E&P activities offshore is required to ensure the evaluation of AAM systems is relevant to the current monitoring requirements under which the oil and gas (O&G) industry operates. The regulatory requirements impact the desired performance requirements for an AAM system (e.g. detection range) and the way in which a system is operated.

To establish the general regulatory requirements, a review of practices, guidelines and mitigation measures was done, focusing on two well developed oil and gas production areas, UK Continental Shelf [4] and Gulf of Mexico [5], and the region local to this study's authors, Atlantic Canada [6]. These areas are subject to high levels of public scrutiny and have significant

experience in offshore oil and gas developments and as such were thought to be a good generalization of regulatory requirements.

These areas all have issued practices or guidelines that aim to mitigate the impact of seismic surveys on marine mammals. In general the guidelines require a zone to be established, in which an observer must monitor for marine mammals before commencing and during use of air gun arrays. If marine mammals are observed in this zone action must be taken, generally to delay or cease activities until the mammals have left the zone. The typical range for the zone is 500 m from the center of the air gun array. The guidelines require visual monitoring only, although the Canadian and Gulf of Mexico practices make reference to the use of PAM systems in low visibility conditions. The guidelines generally require a gradual ramp up of power when commencing operations to encourage mammals to leave the zone.

A detection range of 500 – 1000 m will be considered as the desired AAM system performance for the latter stages of this study. This range covers the general regulatory requirement of 500 m, found in the references above, and allows for potential increases to the regulatory requirement, for example as technology advances. Considering detection ranges out to 1000 m is also useful for systems which may be operating at an offset from the center of the airgun array (e.g. vessel mounted) and/or could provide some advance warning of marine mammals advancing towards the 500 m zone.

3 Potential performance of AAM systems

3.1 Introduction

The potential performance of AAM was investigated via a parametric study of the sonar equation, incorporating available knowledge of sonar technology and environmental effects (e.g., high-frequency backscattering from the ocean boundaries). This part of the study was intended to identify any fundamental limitations to AAM as imposed by technology or by the basic physics of the problem, and also to pinpoint those sonar features that are of key importance for AAM. Special effort was dedicated to investigating the target strength of marine mammals, as this is an area in which scientific knowledge is sparse at present. The parametric analysis included several generic examples, and was also applied to the six specific ocean areas; however, computer modeling of the six environments was beyond the scope of the study.

3.2 Active Sonar Performance Factors

The fundamental limits on how well such systems can perform are determined by the laws of physics, but there are also softer constraints imposed by engineering and operating costs, ethical considerations (e.g., allowable active-signal levels to be used against marine mammals in an AAM system), concepts of operation, etc. To outline the potential performance of AAM systems a high level investigation was carried out, guided largely by the physics, taking into account the practical lessons learned at DRDC Atlantic through many years of experience with sonar. The details of this investigation are contained in Volume V, a summary of key performance factors is provided below.

Sound absorption in seawater increases with frequency, and therefore higher sonar frequencies generally result in shorter maximum detection ranges. The most useful sonar frequencies for the AAM problem are below about 50 kHz, while the use of frequencies greater than about 100 kHz would likely not provide long enough detection ranges.

Classification at long range will be challenging. Typical azimuthal beamwidths will not allow the angular resolution of target structure at such ranges, and the range structure will usually be too ambiguous for classification purposes. This leaves motion as the only reliable clue to classification at long range.

The sonar should be capable of transmitting and processing both Doppler-sensitive (e.g. CW) and Doppler-insensitive (e.g., HFM) waveforms. The capability of Doppler processing to reject seabed clutter is most important for shallow-water sites.

At the frequencies of interest for AAM, the ambient noise is largely dependent on the wind speed, although at very high frequencies the thermal-noise component can dominate. In noise-limited conditions, good detection performance can be expected.

Detection performance in reverberation-limited conditions is more problematic. Surface reverberation alone should not be a problem at low wind speed, but might become important at higher wind speed (high sea state). Detection in bottom-reverberation looks to be difficult in all

but the most favorable circumstances, although Doppler processing can help to detect objects that are moving at high enough speed.

AAM performance is predicted to be good in most deep-water sites, as bottom reverberation is ruled out by the geometry of the detection scenario. Standard values of vertical beamwidth should be sufficient to avoid bottom reverberation out to 1000 m range in water of depth 150 m or even slightly shallower. In very shallow water, however, bottom reverberation would become a factor. AAM performance in shallow water can be predicted with confidence only through the computer modeling of the specific sites of interest.

3.2.1 Target Strength (TS)

AAM performance is limited by the acoustic scattering of the targets. Volume V presented a summary of available published data along with predicted target strengths based on boundary element and analytically-based models. Predictions were compared with published results for humpback whale, gray whale, sperm whale, and a dolphin.

Factors effecting target strength include animal aspect, size, and biological structure. A hypothesis had been considered, where lung collapse due to dive depth may decrease the target strength, however modelling results did not support the hypothesis.

3.3 Potential Performance of AAM in specific areas

As part of the analysis conducted for this report, the potential performance of AAM was assessed for six areas of interest for E&P operations. Section 2.3 and Volume IV describe the six areas and provide a succinct description of each one; a map showing their locations was given in Figure 1. Most of the areas are of such wide geographic extent that they encompass regions of quite different oceanographic features and for the purpose of assessment only a single location was considered for each area.

The first step of the assessment was to extract, from publicly available sources, more detailed information on the ocean environments for the areas; of most importance are such parameters as the water depth, sound-speed profile (SSP), bottom type, etc. It should be noted that the sound-speed profile changes with the season of the year, which therefore introduces a time dimension to the problem. The second step was to assess how the environmental parameters would affect the potential performance of AAM in each area, drawing on material presented in Volume V. The examples presented in Volume V, along with their associated graphs and tables, are particularly useful in helping to gauge the importance of different environmental effects.

The assessment is qualitative rather than quantitative, since quantifying the potential AAM performance would require extensive computer modeling that was considered beyond the scope of the report. The shallow-water sites are quite distinct from one another, and there is uncertainty in the performance assessments. The deep-water sites, on the other hand, are very similar in their nature, and the assessments are more straightforward. Therefore if any numerical computer modeling is to be performed subsequently, the shallow-water sites should be treated individually, whereas it should be adequate to model only one deep-water site.

3.3.1 Barents Sea

The water is moderately shallow in the Barents Sea, and a site of depth 300 m has been chosen for analysis. One of the most important criteria in selecting an AAM sonar for this area is that the vertical beamwidth should be narrow enough to avoid bottom reverberation. As shown in Volume V, with the sonar located near the surface, even fairly wide vertical beams can avoid reverberation from a 300-m bottom for straight-line propagation (as would occur in isovelocity conditions). During the winter, the SSP is almost isovelocity or perhaps slightly upward refracting, which should provide the best opportunity for detection throughout much of water column while avoiding bottom interaction. More detailed analysis would be required to determine if high surface reverberation would result from winter storms. The conditions are much different during the summer, when the SSP is downward-refracting due to surface heating. In this case, better vertical directivity would be required to avoid bottom reverberation as compared to isovelocity conditions; however, at a range of 1000 m the effect of refraction is usually no greater than a few tens of meters, and so the impact on equipment specifications is not severe.

Also, if the sonar were placed too close to the surface in the downward-refracting conditions, a shadow zone could form at fairly close range. Because one of the goals would be to avoid insonifying the seabed, detections would not be made in a shadow zone through a bottom-bounce path.

3.3.2 Gulf of Mexico

Water depths in the Gulf of Mexico range from very shallow to very deep, and the prediction of AAM performance in the different areas of the Gulf is beyond the scope of this report. Here we consider only the deep-water area of the Gulf (at least several kilometres deep). A representative SSP does not exhibit much variability with season, except in the upper 100 m of the water column. The SSP has the classic shape of a deep sound-channel profile: the sound speed decreases with depth (e.g., is downward-refracting) until the channel axis is reached, and then increases until the bottom is reached. Depending on the season, the water very close to the surface (upper 30 or 40 m) may be upward-refracting, but with a very weak gradient.

The ocean environment in the selected region of the Gulf of Mexico appears favourable for the use of AAM. The deep water implies that bottom reverberation would not be a concern, as the distance to the bottom is well beyond the 1000-m range of interest. Even if bottom reverberation spilled over from one ping cycle to the next, it would be greatly attenuated owing to the propagation loss. (Also, a prudent approach to sonar operation would be to always allow enough “channel clearing time” between ping cycles.) The effect of surface reverberation would depend on the sea state, but this is generally favourable in the lower latitudes except during short-lived storms.

When specifying AAM equipment for deep water, it would be desirable to have the capability of vertical beam steering, in order to ensure adequate detection coverage of deep-diving mammals.

3.3.3 North Sea

The North Sea is a generally shallow body of water, and a depth of 150 m was assumed for the AAM assessment. The SSP for a representative site has a form that is seen in many shallow-water areas, being almost isovelocity or slightly upward-refracting for much of the year, but becoming downward-refracting near the surface during the summer.

The vertical directivity required to avoid bottom reverberation in 150 m of water is more stringent than that required in the 300-m water of the Barents Sea: A vertical beamwidth of at most 17° (or ±8.5°) could be used in isovelocity water as shown in Volume 5. A more careful analysis must account for the sonar depth (e.g., if the sonar were 10 m deep, it would be 140 m above the bottom) and possible downward refraction; the upshot is that the vertical beamwidth would have to be narrowed a few more degrees. This tighter specification is available in some commercial sonars, but certainly limits the choice of equipment. The consequence of using a wider beamwidth, say 20°, is that bottom reverberation would be received near the end of the 1000-m range scale; depending on the reverberation level, detection performance would be sacrificed beyond about 750 m.

Surface reverberation would be unavoidable at this site, and would likely constitute the limiting factor on AAM performance. To quantify the effect on detection performance would require assembling specific information on the temporal distribution of wind speeds throughout the North Sea areas of interest.

As a comment on the directivity requirements, it should be noted that vertical directivity would be needed on transmit as well as on receive to mitigate bottom reverberation. If the signal were transmitted omni-directionally, the fathometer return (e.g., the return from directly under the sonar) from a 150-m bottom would be at such a high level that it would come in strongly through the side-lobes of the receiver beampattern and degrade even close-in detection performance.

3.3.4 West Coast of Africa

The area chosen for evaluation off the west coast of Africa is a deep-water site (3000 m). The SSP in this area has the classic deep-water shape described previously in the analysis of the Gulf of Mexico (see above). Since bottom properties are of little import for AAM in these deep-water areas, the assessment made for the Gulf of Mexico is valid for the west coast of Africa as well.

3.3.5 Northwest Shelf, Australia

The water depth off the coast of northwest Australia ranges from shallow to very deep as one moves outward from the coastal shelf to the deep abyssal plain. The water depth chosen for assessment, 1000 m, puts the site on the outer shelf and slope region.

The SSP in this deep-water region has little seasonal variation except for the upper 100 m, and shows a downward-refracting contour with a gradient that weakens with depth but that does not turn around to become upward-refracting. (Intuitively speaking, it appears that the water isn't deep enough for the SSP to turn around, as it invariably does when isothermal conditions are

reached and pressure becomes the dominant factor in determining the SSP.) The profile in the upper 100 m appears to be approximately isovelocity or slightly downward-refracting.

As for the other deep-water sites, AAM performance is predicted to be good. Bottom reverberation should not be a factor, as the 1000 m depth is equal to the maximum range scale. If the sonar were looking downward for part of the time, reverberation from one ping cycle could cause interference in the next ping cycle if inadequate dead time was allocated between pings.

3.3.6 Persian Gulf

The Persian Gulf is very shallow, with only 50 m of water at the selected site, and therefore represents a difficult area for AAM. The SSP appears to be approximately isovelocity during the fall and winter, and downward-refracting during the spring and summer. This suggests that bottom reverberation would be unavoidable even at fairly short ranges at all times of the year. The reverberation level would be moderated by the favourable environmental conditions: the bottom is mainly fine mud or sandy mud (having a low backscattering strength) and the grazing angles would be small. As for the other shallow-water sites, however, computer modeling would have to be carried out to obtain quantitative results. Nevertheless, one should anticipate being reverberation-limited; hence the sonar set should be equipped with wideband FM (Frequency Modulated) signals, and also be able to Doppler process CW (Continuous Wave) signals (producing some sort of moving-target indication, in the ideal case).

Note also that, under downward-refracting conditions, a direct path may not exist even at fairly short range (e.g., there is a shadow zone), but in such shallow water there is often a reliable bottom-bounce path. To explore such issues quantitatively would require again numerical modelling, as the geo-acoustic parameters of the bottom would have an important influence on the acoustic propagation. Depending on the waveguide parameters, transmission loss could be better or worse than spherical spreading.

4 Survey of AAM Systems

The objective of the survey was to gather information on a large variety of AAM systems, in a consistent, unbiased manner. To facilitate consistent information collection, an online survey questionnaire was developed that requested information on: system description, sonar specifications, processing and advanced functions, system interfaces / data fusion support, general system information. The questions were chosen to facilitate the system evaluations and included the system parameters that were highlighted as important during the potential performance assessment (Section 3). The survey questionnaire is contained in Annex B.

A list of potential survey contacts was identified which included 24 companies who manufacture sonar for applications such as fish finding, naval / anti-submarine warfare, swimmer / diver detection, mine or obstacle avoidance, maritime security, marine research, and whale strike avoidance. The survey contact list is contained in Annex A.

Of the 25 companies identified, survey responses were submitted by eight (with entries for a ninth company completed by DRDC); eight were identified as not having a system suitable for this application; two companies did not find an opportunity to complete the survey; and a point of contact could not be established for six others. The survey response level was slightly below what was hoped for, however the most suitable contact to complete the survey was often the technical contacts, and the survey was likely a lower priority for them. Attempts were made during the survey to increase the number of survey responses, by providing additional time to the survey points of contact and by completing website searches for potentially suitable systems. Through the website searches two systems were identified and sufficient information was contained in the online specification brochure that DRDC Atlantic was able to complete survey submissions for these two products. A list of the survey responses is outlined in Table 4.

A class of sonars not generally included in the survey responses were Military Anti-Submarine Warfare systems (with the exception of the UEMS response). The systems are usually in the forefront of target classification, tracking, and data fusion, but tend to have operation frequencies lower than the systems surveyed. A critical issue for the scope of this study is that they generally require consideration at the outset of vessel design and tend to have higher costs than the thirteen systems presented in Table 4. The manufacturers of ASW Systems that were approached, either did not respond or referred the project to manufacturers of high-frequency, lower cost systems.

Table 4: Summary of Survey Responses

No.	Company	System Model
1	CodaOctopus Products Inc.	ES-SP-0020
2	C-Tech Ltd.	CSDS-85
3	FarSounder Inc.	FS-3DT, FS-3, FS-3DT-B (Bistatic), FS-3DT-N (Network Version), FS-3DT-BN
4	FarSounder Inc.	FS-3ER, FS-3ER-N (Network Version), FS-3ER-B (Bistatic Version), FS-3ER-BN
5	Kongsberg Mesotech Ltd.	SM 2000 & DDS 9000
6	Simrad, Kongsberg Maritime AS	SX90 (20-30kHz)
7	Simrad, Kongsberg Maritime AS	SH90 (114kHz)
8	Ultra Electronics Maritime Systems (UEMS)	UEMS has a family of high power, low frequency acoustic projectors and receivers and systems.
9	Furuno Electric Co Ltd (Survey entered by DRDC Atlantic based on website spec sheet)	FSV-30
10	Furuno Electric Co Ltd (Survey entered by DRDC Atlantic based on website spec sheet)	CH-300
11	Qinetiq	Cerberus
12	Scientific Solutions	HF/M3
13	Scientific Solutions	SDSN

5 Evaluation of Survey Responses

The thirteen systems listed above were evaluated for their suitability of use for marine mammal monitoring and their suitability of use in E&P activities. The evaluation was performed in two stages.

In the first evaluation stage, the survey questions were sorted according to the primary use case affected by the answer (e.g. marine mammal size, diving characteristics, platform type, and general E&P applicability). The answer to each question was then individually rated according to how the answer would contribute to the primary use case. A simple rating scale of green, yellow, or red was used. Here a rating of green was used to indicate that the response was supported the use case and didn't require system changes. Yellow indicates that the response could be suitable, but that it could be improved for full benefit to be realized. Finally, red indicates that the response was not considered suitable for the subject use case. Care was taken to ensure that the evaluations were consistent across all systems, drawing on technical detail from Section 3 to provide an objective evaluation where appropriate. These detailed responses and their resulting evaluation are provided in Annex B.

The second evaluation stage used the results of the first stage to derive an overall rating for each primary evaluation category. The overall evaluation score was created by weighting the various related responses according to their impact on overall performance for that category. The results of this stage are provided in Section 5.1. A descriptive overview of each system and further explanation of ratings by use case are provided in Section 5.2.

5.1 Survey Results

The tables below provide an overview of the survey results showing how each of the surveyed systems was rated against the primary use cases. Here a rating of green is used to indicate that the system was found suitable for the application without any major modification. Yellow indicates that the system could be suitable, but an element of its design may need to be addressed before full benefit is realized. Finally, red indicates that the system was not considered suitable for the subject use case and that modification to make it suitable is not likely warranted.

Table 5 shows the utility of each system for detecting marine mammals of various sizes. While detection range is a function of target strength, the fidelity of the models used to evaluate the survey responses were not high enough to discriminate between the various categories of marine mammal. The primary factors used to differentiate between systems were operating frequency and the pulse energy supported by the system. Of course the detection range of animals with lower target strength would be more limited, but a more detailed understanding of target strength as a function of species is required before rating systems to that level of detail.

Table 5: Summary of System Rankings with respect to Marine Mammal Size

System		Ranking with respect to Marine Mammal Size		
		Small Size (Sm. Odontocetes)	**Medium Size (Lg. Odontocetes)**	**Large Size (Baleen)**
1	CodaOctopus ES-SP-0020	r	r	r
2	C-Tech CSDS-85	y	y	y
3	FarSounder FS-3D	y	y	y
4	Farsounder FS-3E	y	y	y
5	Kongsberg SM2000 & DDS9000	y	y	y
6	Simrad SX90	g	g	g
7	Simrad SH90	y	y	y
8	UEMS	g	g	g
9	Furuno FSV-30	g	g	g
10	Furuno CH-300	g	g	g
11	QinetiQ Cerberus	y	y	y
12	Scientific Solutions HF/M3	g	g	g
13	Scientific Solutions SDSN	g	g	g

Table 6 shows the utility of each system for detecting marine mammals at different depths. Here primary factors used for evaluation included beam steering and beam width. The two systems rated yellow for deep divers only had limited beam steering options to illuminate targets requiring a high depression angle. A limiting factor for shallow detection was beam width that affects reverberation rejection.

Table 6: Summary of System Rankings with respect to Marine Mammal Diving Characteristics

System		Ranking with respect to Marine Mammal Diving Characteristics	
		Shallow	**Deep**
1	CodaOctopus ES-SP-0020	y	g
2	C-Tech CSDS-85	g	y
3	FarSounder FS-3D	g	g
4	Farsounder FS-3E	g	g
5	Kongsberg SM2000 & DDS9000	g	y
6	Simrad SX90	g	g
7	Simrad SH90	g	g
8	UEMS	y	y
9	Furuno FSV-30	g	g
10	Furuno CH-300	g	g
11	QinetiQ Cerberus	y	y
12	Scientific Solutions HF/M3	y	y
13	Scientific Solutions SDSN	y	y

Table 7 shows the applicability of each system to the candidate platform types. Ship based deployment was limited by beam stabilization features, while autonomous and fixed platform options were most often limited by maximum transducer depth. The autonomous platform suitability was rated as red when the manufacturer did not indicate that it was suitable, though power consumption and maximum transducer depth were also major factors.

Table 7: Summary of System Rankings with respect to E&P Platform Type

System		Ranking with respect to E&P Platform Type		
		Ship Based	**Fixed Platform**	**Autonomous**
1	CodaOctopus ES-SP-0020	g	g	g
2	C-Tech CSDS-85	y	g	r
3	FarSounder FS-3D	g	y	y
4	Farsounder FS-3E	g	y	y
5	Kongsberg SM2000 & DDS9000	y	g	r
6	Simrad SX90	g	g	r
7	Simrad SH90	g	g	r
8	UEMS	y	g	r
9	Furuno FSV-30	y	g	r
10	Furuno CH-300	g	g	g
11	QinetiQ Cerberus	y	y	y
12	Scientific Solutions HF/M3	g	g	g
13	Scientific Solutions SDSN	g	g	g

Finally Table 8 shows a more general ranking of E&P applicability. Here maximum detection range was one major factor that resulted in a poorer rating, while system cost was another.

Table 8: Summary of System Rankings with respect to General E&P Applicability

System		Ranking with respect to General E&P Applicability
1	CodaOctopus ES-SP-0020	r
2	C-Tech CSDS-85	g
3	FarSounder FS-3D	r
4	Farsounder FS-3E	y
5	Kongsberg SM2000 & DDS9000	g
6	Simrad SX90	g
7	Simrad SH90	g
8	UEMS	y
9	Furuno FSV-30	g
10	Furuno CH-300	g
11	QinetiQ Cerberus	y
12	Scientific Solutions HF/M3[1]	y
13	Scientific Solutions SDSN	y

5.2 Overview of System Evaluations

This section provides a descriptive overview of each system that was included in the survey. The text is intended to provide an explanation of the ratings established in Section 5.1.

5.2.1 CodaOctopus Products In. – Model ES-SP-0020

The CodaOctopus system is unique among the survey respondents and is used as an imaging and search sonar for a variety of domains. It operates above 120 kHz and is capable of high resolution imaging. The system provides good source level, but limited information was available to assess the total pulse energy and available pulse types. Though the sonar would likely be excellent at imaging marine mammals at short range, the combination of its high frequency and assumed lower total pulse energy would prevent it from detecting marine mammals at the ranges required for mitigation. (The sonar system limits detection processing to < 500 m.) With a broad vertical beamwidth and no indication of beam steering options, it may need improvement to detect animals near the surface.

[1] See Section 5.2.12 for comment regarding E&P applicability evaluation.

The CodaOctopus's system's sonar processing is reported as advanced with beam stabilization and own Doppler nullification. A 50 degree by 50 degree area is ensonified each time a ping is transmitted. The system also supports multi-ping processing, automated detection, and target motion detection. Its low power consumption and the wide range of depth options support use on all possible platform types. It also supports a number of data interfaces that could simplify integration. The system is reported as mature both in terms of development time and units in service. Regardless, the system's limited detection range caused it to be rated as unsuitable for E&P AAM.

5.2.2 C-Tech Ltd – Model CSDS-85

The C-Tech system is used to support diver and submerged intrusion detection, operating at high frequency (> 80 kHz). Though most system parameters are amenable to marine mammal detection the low total pulse energy is limited by its short pulse length (Max 2 ms). This would limit the maximum detection range, especially at high frequency where environmental attenuation is problematic.

This system was most likely designed for shallow water and is not currently capable of illuminating targets requiring a high depression angle, which may present a problem in deep water scenarios. The sonar will ping all available depression angles (± 24 degrees) in 7 seconds. The system would also benefit from motion compensation to improve performance on moving platforms, though it was found suitable for fixed platform installation in its current state. It does however provide advanced target detection and tracking functions, including moving target detection for targets over 0.5 Kts. The system would prove beneficial for environmental mitigation from fixed platforms in shallow water, if detection range were improved. Data interfaces are provided that use a number of standard electrical and logical standards that could simplify integration. The system is reported as mature in terms of development time, but has relatively few units in service.

5.2.3 FarSounder Inc – Models FS-3DT, FS-3, FS-3DT-B (Bistatic), FS-3DT-N (Network Version), FS-3DT-BN

These FarSounder models are used to support navigation and obstacle avoidance, including marine mammal avoidance. The system is designed with a forward-looking beam and for short-range detection (<500 m). If used for AAM, it would require modifications to increase the effective range and further adjustments to reduce blind spots. The operating frequency is amenable to AAM (40-80 kHz), but the pulse lengths are quite short (2ms), reducing the total pulse energy and therefore maximum detection range in ambient noise limited conditions. (The sonar system limits detection processing to < 500 m.) The system is also reported to have a horizontal receive beamwidth of 10-20 degrees that reduces its effectiveness against reverberation and its resolving capability for classification and tracking, though this appears to be contradictory to the brochure. The survey respondents reported the maximum operating depth at <10 m, which would make autonomous and fixed platform usage difficult in many scenarios.

The system family provides beam stabilization and consumes relatively little power for an active sonar system. The sonar will cover 90 degrees in vertical (full coverage in azimuth) with each ping. Other positive features of this system include its price, system maturity, training time,

automatic target detection and standard interfaces. Regardless, its limited detection range caused it to be rated as unsuitable for E&P AAM.

5.2.4 FarSounder Inc – Models FS-3ER, FS-3ER-N (Network Version), FS-3ER-B (Bistatic Version), FS-3ER-BN

These FarSounder models are the extended range versions of the prior systems. Though not in service yet, it will process to a maximum range between 500 and 1000 m, which may be suitable in some E&P environments, depending on regulatory requirements. Other features are reported as identical to the previous model.

5.2.5 Kongsberg – Models SM 2000 & DDS 9000

These Kongsberg sonars are used for diver detection and marine mammal research. Operating at high frequency (80-120 kHz), they would be subject to considerable environmental attenuation, which would reduce their performance at long range over lower frequency sonar. Other sonar design parameters are amenable to active marine mammal detection. This system was most likely designed for shallow water and is not currently capable of illuminating targets requiring a high depression angle, which may present a problem in deep water scenarios.

The system appears optimized for fixed platforms and should have some form of motion compensation added to improve its effectiveness on moving platforms. Though it is one of the higher cost systems, it provides advanced processing functions including multi-ping processing, automated detection and tracking, and motion detection. The system also provides standard logical formats for data exchange, though data input must be via an RS232 connection, which may not be readily available on some modern systems and computers. The system is reported as mature both in terms of developmental time and units in service.

5.2.6 Simrad, Kongsberg Maritime AS – Model SX90

This Simrad model is used in both fishery and military applications. The system parameters were found suitable for AAM, though the system may benefit from improved horizontal beam width. Improvements in maximum operating depth may also improve its applicability to deeper deployment on fixed or autonomous platforms. The moderate procurement cost, low power consumption, and wealth of processing features make it an attractive option. Advanced processing includes beam stabilization, motion compensation, multi-ping processing and automatic target tracking. This system is one of the only systems surveyed that is reported to provide both active and passive aural monitoring capability, which could be used to augment AAM with PAM. The system also provides a variety of data interface options including standard electrical and logical formats. The system is reported as mature both in terms of developmental time and units in service.

5.2.7 Simrad, Kongsberg Maritime AS – Model SH90

This system is reported as very similar to the SX90 model. The one major difference is the higher operating frequency (114 kHz). High environmental attenuation at this frequency makes it less suitable for AAM.

5.2.8 Ultra Electronics Maritime Systems (UEMS) – Family of systems

The UEMS system family of systems operates at the lowest frequency of those surveyed and are currently used for anti-submarine warfare (ASW). Though the sonar frequency is most likely suitable for AAM not enough information was provided about pulse length options to determine the overall utility of the system. There may be issues with minimum detection range and range resolution that would best be addressed prior to procurement. The system's vertical beam widths and beam steering options may prove problematic for detection of marine mammals throughout the water column, especially in shallow water. The system could also benefit from beam stabilization if fixed to the hull, but does provide automatic compensation for own-Doppler. The minimum operating depth is reported at >10 m, which would also need to be adjusted for most ship based installations.

Though the sonar was the most expensive and highest power consumer of those surveyed, the survey response indicated that advanced processing functions including multi-ping processing, automatic detection and automatic tracking were available. The system can be designed to provide full area coverage with a single ping. The survey also reported that the system includes an aural listening capability that may support concurrent PAM. The system was reported as using standard electrical and logical interfaces. The system is also reported as mature both in terms of developmental time and units in service.

5.2.9 Furuno – Model FSV-30

This model of Furuno sonar is used primarily for commercial fish finding. The information used herein was taken from openly available literature and resulted in a number of survey questions being left unanswered. The information that was available indicated that the sonar could be suitable for use in AAM, though the receive beamwidth could be improved to increase classification and reverberation rejection ability.

The sonar provides a high degree of beam steering allowing for full coverage of the water column, though a single ping will only cover a small area (e.g. one azimuth and depression angle). It also provides beam stabilization functions, though it appears to use significant power. (It was not considered suitable for autonomous vehicles due to its weight and power consumption.) The system appears mature and its cost is in the lower range of the systems reviewed. Standard NMEA interfaces are provided for data import / export, though the electrical interfaces were not specified.

5.2.10 Furuno – Model CH-300

This model of Furuno sonar is used primarily for commercial fish finding. The information used herein was taken from openly available literature and resulted in a number of survey questions

being left unanswered. This system is smaller and consumes less power than the FSV-30, though a single ping will still only cover a small area (e.g. one azimuth and depression angle). It contains a dual-frequency sonar with the lower most suitable for AAM. The higher frequency may prove beneficial for higher resolution classification requirements, if the contact appeared at close range. This sonar provides two search beam patterns and both can be scanned over the entire water column. Advanced functions including beam stabilization and automatic target tracking are also available. The system appears mature and its cost is in the lower range of the systems reviewed. Standard NMEA interfaces are provided for data import / export, though the electrical interfaces were not specified.

5.2.11 QinetiQ – Cerberus

The Cerberus sonar was developed by QinetiQ for diver detection. Though many of the sonar specifications are desirable for marine mammal detection, the very high frequency of the sonar is seen as a limitation for some applications, with a detection range of less than 1 km. The sonar is also limited by the absence of a vertical beam steering option, which may limit effectiveness in deep water. The sonar does however provide beam stabilization and automated target motion detection and tracking. It could, however, benefit from the addition of own-Doppler nullification if mounted on a moving platform. The higher than average system cost and proprietary data exchange formats may also limit utility for E&P applications.

5.2.12 Scientific Solutions – HF-M3

This system was developed by Scientific Solutions for use in marine mammal mitigation on SURTASS/LFA platforms. It is one of the few systems that was purpose built and is implemented on a towed, variable-depth sonar. Most of the sonar specification was found suitable for marine mammal detection, though it does not provide beam stabilization, own-Doppler nullification, and vertical beam steering options. The requirement for stabilization is not as important because the system is not mounted directly to the hull. The sonar would therefore experience less motion in high seas if at depth (below the effects of surface motion). The system offers automatic target detection, which may assist inexperienced operators. The sonar provides good detection range at a reasonable cost, but sales have been limited to SURTASS/LFA users, and 45 seconds is required scan over 360 degrees if searching out to 2000 m. Some work would likely be required to integrate this towed system for seismic operations, and potential customers would want to ensure that no export restrictions are in place. Overall the system and manufacturer is interesting because of the current application, which is clearly relevant to mitigation for E&P applications.

5.2.13 Scientific Solutions – SDSN

This system was also developed by Scientific Solutions, though its intended application is as fixed, swimmer-detection sonar. Typical systems consist of an array of sonar nodes that communicate to provide area coverage. Each node covers a 54 degree arc for an approximate cost of USD$100K. Much of the sonar specification is amenable to marine mammal detection from a fixed location, though it lacks vertical beam steering, and is limited to between 10 and 50 metres depth. This would be acceptable for shallow water operations. The nominal detection

range is between 500 and 1000 meters, which may not be suitable for some applications. A scan of the full field of view is possible in 2 seconds. The system also provides advanced target detection and automated tracking options with the capability to detect objects moving on the order of 0.1 Knots. System integration is possible using the TENA (Test and Training Range Enabling Architecture) US Department of Defence architecture, though bridge interfaces would be required on E&P platforms.

6 Further Development Areas

The survey of AAM technologies indicates that the foundation for an AAM capability should be available from industry. It also showed that candidate systems range in cost from $20K to over $500K, as system complexity and power increases. Given the criteria available at the time of the review even a $20K system *could* provide the required capability, but it is difficult to state this with any certainty without a more comprehensive evaluation. The primary recommendation for further development is to conduct a structured evaluation of promising systems against defined JIP AAM requirements.

One of the big differentiators between the surveyed systems is how they could be used to scan for contacts. The range of options for coverage from a single pulse includes:

- Full water column coverage with a receiver capable of beamforming in all directions simultaneously
- Coverage of a specific look direction or depression angle, with one pulse required per depression angle to get full coverage.
- Coverage of a single beam (spotlight) with many pulses required for each depression angle

The time to cover the entire water column is therefore highly variable – seconds to minutes. Of course the most expensive system provides the quickest detection and the best simultaneous multi-target coverage, but it may not be required for AAM to be effective. It may also be reasonable to have gaps in single-ping-cycle coverage with the expectation that the target or vessel motion will provide the required coverage over more than one cycle. The cycle period requirement is one aspect that merits further analysis.

Another aspect that isn't covered in the initial survey is team coordination and system integration. Many of the surveyed systems have the ability to exchange data with other systems. The capability could be exploited to increase the team's situational awareness, providing more effective and efficient AAM. The coordination processes required to integrate with existing E&P operations should be explored. Other important factors may also be revealed and better accounted for if the recommended follow-on process is adopted.

The following subsections describe a process whereby the technical data assembled during the initial survey can be used to determine the final selection criteria for an AAM capability. The survey succeeded in highlighting a number of potential systems and the desirable *sonar* characteristics. This next stage would further refine the list of systems and define the desirable *operational* characteristics. It would also involve conducting more focused and detailed system evaluations, further improving the criteria for, and increasing the confidence in the targeted AAM capability. Other areas for further development include investigations of target strength estimates for marine mammals and the environmental impact of using AAM system for this application.

Modelling: Computer modelling of the acoustic propagation, particularly in shallow-water areas, would be of benefit in refining the general analysis conducted in this study. This work would

entail identifying appropriate models for the high frequencies involved in AAM, and then running the models on selected environments.

Concept of Operations Analysis: The first step in furthering capability development should be to define the concept of operations and requirements for an AAM operation. This will help to better understand what level of system is required (e.g. minimum scan rate), and therefore the practical range of system cost. These analyses will not only help to define required and desirable options in the AAM sonar, but also how that system and its operator will integrate with the rest of the operations team. It should attempt to constrain the solution to fit within the practical limitations of current technology and physics (e.g. detection range) revealed during the subject technology survey, considering factors like:

- Anticipated operator training and experience
- Receiver and target motion
- Acceptable delay in target detection
- The required communication path after initial detection (sensor operator up to operations chief) and the acceptable delay in initial communication of new contact.
- The expected steps once initial contact is gained (e.g. contact investigation / classification, options analysis, option selection, and option activation) and the acceptable delay in completing these tasks.
- The potential actions following activation of an option.

Consideration of delays in decision making is important as it leads to a minimum detection range. The require mitigation range is typically 500 to 1000 meters, but this along with reasonable delays and target-receiver motion will lead to the minimum detection range (e.g. the range that allows decision making processes to be completed before critical mitigation action is required).

The concept of operations would define specific elements of how the system would be operated including:

- The proposed process used for scanning, including gaps in single-cycle coverage.
- The proposed approach to contact, including transmission of verbal or electronic data to other systems for increased situational awareness.
- The types of analysis tools, operator aids, and communication aids that the team would employ.

This type of analysis might be facilitated by an engineering professional, but should also include those that will conduct operations ensuring the relevance of the output and following steps. This work might also involve site visits and equipment demonstrations to better understand current systems and their proven concepts of use for other applications such as fish finding.

Trade-off / Requirements Analysis: This step would transform the concept of operations to system requirements. The requirements would be written ensuring that the AAM system would support all elements of the concept of operations, or if a resulting requirement is anticipated to be too expensive or impractical, result in a change to the concept of operations.

Once the requirements are defined they should be mapped to the surveyed systems to determine which systems are closest to reaching compliance. This effort should also result in a more precise determination of the level of system that would be required (e.g. cost).

Strategic Environmental Assessment: A consideration in the implementation of AAM systems as an impact mitigation measure during E&P operations is the potential for direct impact by an AAM system on the environment. Like seismic survey activities, the use of active sonars has received significant scrutiny with regard to its impact on marine life in recent years. It may be prudent to undertake a Strategic Environmental Assessment based on a proposed Concept of Operations before undertaking sea tests.

Field Trials: Ideally two or three systems would be selected and tested to validate the perceived concept of operations and their ability to meet the resulting requirements as built. Data would be collected in realistic environments for analysis during the next step.

Target Strength: An important factor in determining the performance of an AAM system is the Target Strength of the animals. Though the modeling results presented in this report are favourable, there is little data available to validate the modeled predictions. An experimental program to measure the Target Strength of real (or synthetic) animals would greatly increase the confidence of the ability of AAM systems to be effective in an E&P environment. In particular, an experimental approach to addressing the lung collapse hypothesis would add significant confidence to the model predication.

In addition, there exists Behavioural Response Study (BRS) data in the scientific community where it may be possible to extract target strength data without subjecting animals to additional experimentation.

7 Summary

Under the Exploration and Production (E&P) Sound and Marine Life Programme, a research study was carried out on the feasibility of the Active Acoustic Monitoring (AAM) of marine mammals. The purpose of such monitoring would be to detect marine mammals in those ocean areas where E&P activities are being conducted, in order to allow due diligence in mitigating any potential impact of these E&P operations. The study did not include any direct experimentation.

The AAM study encompassed multiple work components. First, the problem domain was delineated in an overview of offshore E&P activities and of the ocean environments in which they are conducted. To make the analysis more concrete, six specific ocean areas of relevance to E&P were selected and their properties described. Next, the potential performance of AAM was investigated via a parametric study of the sonar equation, incorporating available knowledge of sonar technology and environmental effects (e.g., high-frequency backscattering from the ocean boundaries). This part of the study was intended to identify any fundamental limitations to AAM as imposed by technology or by the basic physics of the problem, and also to pinpoint those sonar features that are of key importance for AAM. Special effort was dedicated to investigating the target strength of marine mammals, as this is an area in which scientific knowledge is sparse at present. The parametric analysis included several generic examples, and was also applied to the six specific ocean areas; however, computer modeling of the six environments was beyond the scope of the study.

This document is one of five Volumes. It provides an overview of the study. The survey received responses from thirteen production active sonar systems that may be appropriate for the task. Each of the systems has promising and innovative characteristics and individuals.

The study documents the feasibility of using AAM technologies for mitigating potential impacts of E&P acoustic emissions on marine mammals. There exist technologies that could provide a basis for actively detecting marine mammals between 500 and 1000 m.

References

[1] J. Spence et al. (2007) Review of Existing and Future Potential Treatments for Reducing Underwater Sound from Oil and Gas Industry Activities. NCE Report 07-001, Noise Control Engineering Inc., Billerica, MA.

[2] Subsea Oil and Gas Directory. www.subsea.org. Summary of Offshore Oil and Gas Projects. (note: a portion of the list of project was cross referenced with O&G company websites to confirm project and locations were valid).

[3] USGS World Petroleum Assessment 2000. US Department of the Interior, US Geological Survey.

[4] Guidelines for Minimizing Acoustic Disturbance to Marine Mammals from Seismic Surveys (2004). Joint Nature Conservation Committee, Marine Advice, Aberdeen, UK.

[5] Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program (2007). United States Department of the Interior Minerals Management Service (MMS) Gulf of Mexico (GOM) OCS Region. OBM Control Number: 1010-0154.

[6] Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment (2007). Government of Canada, Department of Fisheries and Oceans.

Annex A Survey Contact List

Table 9 Contact List

	Company	Point of Contact	Comments
Survey Responses Received			
1	Romor / CodaOctopus	Darrin Verge, Romor dverge@romor.ca	One survey completed (ES-SP-0020)
2	C-Tech	Bob Fraser, Marketing bob.fraser@c-techltd.com	One survey completed (CSDS-85)
3	Far Sounder	Ian Bowles www.farsounder.com ian.bowles@farsounder.com	Two surveys completed (FS-3DT and FS-3ER)
4	Kongsberg Mesotech Ltd	Nick Burchill nick.burchill@kongsberg.com	One survey completed (SM 2000 and DDS 9000)
5	Simrad, Kongsberg Maritime AS	Fred Reier Knudsen frank.reier.knudsen@simrad.com	Two surveys completed (SX90 and SH90)
6	Ultra Electronics	Linas Siurna lsiurna@ultra-uems.ca	One survey completed (family of products)
7	Furuno	www.furuno.com	Point of contact not established, several applicable products identified in website search by DRDC. DRDC completed two surveys based on information contained in online specifications (FSV-30 and CH-300)
8	QinetiQ	Andy Webb, Chief Engineer UW System Sea, UK abwebb@QinetiQ.com	One survey completed (Cerberus)
9	Scientific Solutions Inc. (SSI)	Peter Stein pstein@scisol.com	Two surveys completed (HF/M3 and SDSN)
Other contacts			
10	Sonardyne	Eric Levitt Eric.Levitt@sonardyne.com	Contact established, however did not complete survey
11	Reson	Mike Mutschler, Sales Rep, San Diego, Hydrographic Applications michael.mutschler@reson.com Canadian Rep: Ken McMillian, McQuest Marine info@mcquestmarine.com	Contact established, however did not complete survey
12	General Dynamics Canada	Peter Giles peter.giles@gdcanada.com	Contact established, referred to Marport C-Tech Ltd.
13	Thales	TUS@thales-underwater.com	Contact established, however no

			applicable products
14	Lockheed Martin	Steven Marsden steven.marsden@lmco.com	Contract established, however no applicable products
15	Humminbird	www.humminbird.com	Point of contact not established, no applicable products identified in website search by DRDC.
16	Garmin	www.garmin.com	Point of contact not established, no applicable products identified in website search by DRDC.
17	Eagle (a Lowrance company)	www.eaglenav.com	Point of contact not established, no applicable products identified in website search by DRDC.
18	Lowrance	www.lowrance.com	Point of contact not established, no applicable products identified in website search by DRDC.
19	Vexilar	Greg Bleck greg@vexilar.com	Contract established, however no applicable products
20	Marport	sales@marport.com	Point of contact not established
21	Atlas Elektronik		Point of contact not established
22	DSIT		Point of contact not established
23	L3 Communications		Point of contact not established
24	Marine Sonic Technology Ltd		Point of contact not established
25	Neptune		Point of contact not established

Annex B Survey Questions and Answers

The survey questions and responses are contained under separate cover: The results are included as a Microsoft Excel file.

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This report (Volume I) provides an overview of the study and summary results. Volumes II through IV provide supporting background material.

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