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Survey of Active Acoustic Monitoring (AAM) Technologies

Volume I: Survey Results

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Defence R&D Canada – Atlantic

External Client Report

DRDC Atlantic ECR 2009-002

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Canada

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This report has been completed for International Association of Oil and Gas Producers (OGP) under contract JIP22 08-06.

Abstract

Under the International Association of Oil and Gas Producers (OGP) 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.

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. 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. Finally, a survey was conducted of commercially available sonar equipment by collecting data from sonar vendors through an on-line form. The sonars were then ranked as to their suitability for AAM based on the factors identified as important during the earlier study of potential AAM performance.

This document is Volume I of four volumes; it provides an overview of the study and the results of the AAM system survey. Overall the study found that an AAM capability for monitoring marine mammals in E&P activities and environments should be available from industry and through further development in refining requirements and field trialing AAM systems a specific recommendation for an AAM capability could be made.

Résumé

Dans le cadre du programme de l'OGP (Association internationale des producteurs de gaz et de pétrole) portant sur l'impact du bruit causé par les activités d'exploration et de production sur la vie marine, une recherche a été effectuée sur la faisabilité de la surveillance acoustique active (SAA) des mammifères marins. Le but d'une telle surveillance serait la détection des mammifères marins dans les régions océaniques où sont menées des activités d'exploration et de production, ce qui permettrait l'application du principe de diligence raisonnable à l'atténuation rapide des répercussions potentielles de ces activités. L'étude n'a pas comporté d'expérimentation directe.

Tout d'abord, on a circonscrit le problème par un survol des activités d'exploration et de production extracôtières et des environnements océaniques dans lesquelles ces activités sont menées. De manière à rendre l'analyse plus réaliste, on a sélectionné six zones océaniques pertinentes pour de telles activités et on a décrit leurs propriétés. Par la suite, on a évalué la performance potentielle de la SAA par une étude paramétrique de l'équation du sonar intégrant les connaissances disponibles sur la technologie du sonar et les effets de l'environnement. On a mis un accent particulier sur l'évaluation de l'indice de réflexion des mammifères marins, car on ne dispose que de peu de connaissances scientifiques à ce sujet pour le moment. L'analyse paramétrique incluait plusieurs exemples génériques et elle a été appliquée aux six zones océaniques précisées. Finalement, on a effectué une enquête sur l'équipement sonar offert sur le marché en recueillant des renseignements obtenus auprès de vendeurs de sonars ayant rempli un formulaire en ligne. Les sonars ont été classés en fonction de leur utilité pour la SAA selon les facteurs jugés importants au cours de l'évaluation de la performance potentielle de la SAA.

Ce document est le volume un de quatre; il donne un aperçu de l'étude des SSA et de ses résultats. Globalement, l'étude a constaté qu'une capacité de SAA en vue de la surveillance des mammifères marins dans le cadre des activités d'exploration et de production et dans le milieu où ces dernières ont lieu pourrait être obtenue auprès de l'industrie et qu'il serait possible, en effectuant d'autres travaux d'amélioration de la définition des besoins et d'essais sur le terrain, de formuler une recommandation spécifique portant sur la capacité de SAA.

Executive summary

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

J. Theriault; E. MacNeil; B. Maranda; L. Gilroy; J. Hood; DRDC Atlantic ECR 2009-002; Defence R&D Canada – Atlantic; February 2012.

Background: Under the International Association of Oil and Gas Producers (OGP) 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.

This document is Volume I of four volumes; it provides an overview of the study and the results of the AAM system survey.

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. The most significant noise generating offshore E&P activities were identified as the use of air guns, explosives, impact pile driving and vessel operations. To facilitate the evaluation of AAM systems, these activities were grouped by factors that influence the performance of an AAM system, including platform type (ship-based, autonomous and fixed) and general E&P applicability, which applies to all activities and captures factors like cost, system maturity and ability to integrate with other systems. To focus the study, six specific ocean environments of relevance to E&P were considered. The variety of marine mammals found within these six environments was sufficiently large that the AAM system evaluations could not practically be done for each species, so to facilitate the system evaluations the marine mammals were grouped by size (small, medium and large) and diving characteristics (shallow and deep). The six environments also have an impact on the regulatory requirements for marine mammal monitoring. For the purposes of this study 500 to 1000 m was considered as the mitigation zone (minimum detection range).

Second, 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.

Third, a survey of AAM systems was conducted, resulting in responses from thirteen production active sonar systems that may be appropriate for the task. These thirteen systems were evaluated for their suitability of use in marine mammal monitoring (based on marine mammal size and

diving characteristics) and suitability of use in E&P activities (based on platform type and general E&P applicability). To provide consistent results, a common evaluation template was used for each system, which ranked the responses to each survey question using a simple scale of green (suitable), yellow (possible) and red (unsuitable). Overall, the majority of the systems surveyed were found to be suitable for the applications being evaluated or could be made suitable with some modification or changes. This indicates that an AAM capability for marine mammal monitoring during E&P activities should be available from industry. Very few systems were found unsuitable, except for the autonomous platform application, which many manufacturers did not indicate as an application of their product and for which power consumption and maximum depth rating are highly important.

Fourth and finally, further development areas were highlighted to continue the investigation into the use of AAM. These consist of continued modelling work on acoustic propagation; further investigating marine mammal target strength estimates; analysing the concepts of operations and requirements for AAM systems; undertaking a trade-off study to assess the practicality of the requirements; completing an environmental assessment considering the impact of using AAM systems, and finally evaluating AAM systems in field trials.

Significance: Overall the study found that an AAM capability for monitoring marine mammals in E&P activities and environments should be available from industry, and through further development in refining requirements and field trialing AAM systems, a specific recommendation for an AAM capability could be made.

Sommaire

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

J. Theriault; E. MacNeil; B. Maranda; L. Gilroy; J. Hood; DRDC Atlantic ECR 2009-002; R & D pour la défense Canada – Atlantique; février 2012.

Contexte : Dans le cadre du programme de l'OGP (Association internationale des producteurs de gaz et de pétrole) portant sur l'impact du bruit causé par les activités d'exploration et de production sur la vie marine, une recherche a été effectuée sur la faisabilité de la surveillance acoustique active (SAA) des mammifères marins. Le but d'une telle surveillance serait la détection des mammifères marins dans les régions océaniques où sont menées des activités d'exploration et de production, ce qui permettrait l'application du principe de diligence raisonnable à l'atténuation rapide des répercussions potentielles de ces activités.

Ce document est le volume un de quatre; il donne un aperçu de l'étude des systèmes de surveillance active et de ses résultats.

Résultats : L'étude des technologies de SAA comportait plusieurs groupes de travaux.

Tout d'abord, on a circonscrit le problème par un survol des activités d'exploration et de production extracôtières et des environnements océaniques dans lesquels ces activités sont menées. Les activités d'exploration et de production générant le plus de bruit ont été identifiées comme étant l'utilisation de canons à air et d'explosifs, le battage de pieux et l'exploitation des navires. Pour faciliter l'évaluation des systèmes de SAA, ces activités ont été regroupées selon les facteurs qui influent sur la performance d'un système de SAA, y compris le type de plateforme (embarqué sur des navires, autonome ou fixe) et selon l'applicabilité générale en exploration et de production, ce qui s'applique à toutes les activités et englobe des facteurs comme les coûts, la maturité des systèmes et leur capacité d'intégration avec d'autres systèmes. Pour centrer l'étude, on a pris en considération six environnements océaniques spécifiques présentant un intérêt pour l'exploration et de production. Comme la diversité des mammifères marins trouvés dans ces six environnements était suffisamment grande pour que l'on ne puisse faire des évaluations spécifiques des systèmes de SAA pour chaque espèce, afin de faciliter les évaluations des systèmes, on a groupé les mammifères marins selon leur taille (petite, moyenne et grande) et les caractéristiques de leurs plongées (superficielles ou profondes). Les six environnements ont également une incidence sur les exigences des réglementations portant sur la surveillance des mammifères marins et, aux fins de cette étude, on a choisi la plage de profondeurs de 500 à 1000 m comme zone d'atténuation (plage de détection minimale).

En second lieu, on a évalué la performance potentielle de la SAA au moyen d'une étude paramétrique de l'équation du sonar en y intégrant les connaissances disponibles sur la technologie du sonar et ses effets sur l'environnement (par exemple, la rétrodiffusion haute fréquence aux limites des océans. Cette partie de l'étude était censée relever toute restriction fondamentale s'appliquant à la SAA en raison de la technologie ou des principes physiques de base s'appliquant au problème, mais aussi de mettre en évidence les caractéristiques du sonar qui

sont d'une importance particulière pour la SAA. Des efforts particuliers ont été accordés à l'étude de l'intensité des échos des mammifères, car il s'agit d'un point faible des connaissances scientifiques à l'heure actuelle.

En troisième lieu, on a effectué une étude des systèmes de surveillance active et on a ainsi pu obtenir des résultats au sujet de treize systèmes sonar actifs commerciaux qui pourraient être adéquats pour la tâche. Ces treize systèmes ont été évalués sur le plan de leur aptitude à un usage en surveillance des mammifères marins (en fonction de la taille de ces derniers et des caractéristiques de leurs plongées) et de la pertinence de leur utilisation dans les activités d'exploration et de production (en fonction du type de plate-forme et de leur applicabilité générale dans le domaine de l'exploration et de la production). Pour fournir des résultats cohérents, on a eu recours pour chaque système à un modèle d'évaluation commun qui a classé les réponses à chaque question de l'étude à l'aide d'une simple échelle vert (technologie adaptée), jaune (possible) et rouge (impropre). La majorité des systèmes étudiés se sont révélés adaptés pour les applications en cours d'évaluation ou pourraient être adaptés avec quelques modifications ou changements. Cela indique qu'une capacité de SAA des mammifères marins au cours des activités d'exploration et de production devrait être disponible auprès de l'industrie. Très peu de systèmes ont été jugés inaptes, sauf pour l'application sur plate-forme autonome, que de nombreux fabricants n'indiquaient pas comme mode d'utilisation de leur produit et pour lesquels la consommation d'énergie et la profondeur maximale nominale sont très importantes.

Quatrièmement, des secteurs de développement supplémentaires ont été relevés en vue de la poursuite des travaux de modélisation sur la propagation acoustique, d'estimation de l'intensité des échos des mammifères marins, d'analyse des principes de fonctionnement et des exigences pour les systèmes SAA et d'étude des avantages/bénéfices afin d'évaluer la faisabilité des exigences, de réalisation d'une évaluation environnementale portant sur l'impact de l'utilisation des systèmes SAA et enfin de l'évaluation des systèmes SAA au moyen d'essais sur le terrain.

Importance : Globalement, l'étude a constaté qu'une capacité de SAA en vue de la surveillance des mammifères marins dans le cadre des activités d'exploration et de production et dans le milieu où ces dernières ont lieu pourrait être obtenue auprès de l'industrie et qu'il serait possible, en effectuant d'autres travaux d'amélioration de la définition des besoins et d'essais sur le terrain, de formuler une recommandation spécifique portant sur la capacité de SAA.

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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 Joint Industry Programme (JIP) as an industry research fund supporting research into sound produced during E&P activities and its effect on marine life.

The JIP 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 and 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 the systems described in the 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.

1.2 Document objective and structure

This report is the final report for contract JIP22 08-06. The report consists of four volumes.

- Volume I (this report) contains an overview and summary of the survey and analysis. Annex C to Volume I includes separate pdf files, with the detailed responses from each of the system suppliers, along with the evaluation.
- Volume II is a detailed description of six chosen E&P environments and the marine mammal species expected in those environments.
- Volume III is a detailed analysis of the factors affecting the performance of an AAM system.
- Volume IV is the complete contract proposal.

1.3 Introduction

As existing oil and gas fields 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 generate sound in 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 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 a variety of detection and 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 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 into 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 affected 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 kilometers. As known O&G resources are developed, exploration tends to push into areas that are more difficult to develop, 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 [7].

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 of 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 up to 4000 m.

For the study, six environments were selected as a cross section of relevant oil and gas environments. These six environments are shown in Figure 1.

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).)

Within each of these six environments 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 II.

2.4 Marine Mammals 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 II.

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 III, 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. An 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 III) shows little or no dependence of the target strength on the lungs.

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 UK Continental Shelf [4] and Gulf of Mexico [5], two well-developed oil and gas production areas; and Atlantic Canada [6], the region local to this study's authors. These areas are subject to high levels of public scrutiny and have a significant amount of 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 and during the 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 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 III, and only 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 (Continuous Wave)) and Doppler-insensitive (e.g., HFM (Hyperbolic Frequency Modulated)) 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. Within the constrained (less than sea state 6) noise-limited conditions, good detection performance can be expected.

- As presented in Volume III, 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 favourable 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 (< 100 m), 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 often limited by the acoustic scattering cross section of the targets. Volume III presents a summary of available published data along with predicted target strengths based on boundary element and analytically-based models. Predictions are compared with published results for humpback whale, gray whale, sperm whale, and a dolphin. Limited published data is available on marine mammal target strength; model predictions were developed that reasonably agreed with published results, however this is an area that warrants further investigation.

Factors affecting target strength include animal aspect, size, and biological structure. An 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 II 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 III. The examples presented in Volume III, 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 III, 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 (i.e., 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 sound-speed 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 III. 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 (i.e., 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 in order to detect target motion.

Note also that, under downward-refracting conditions, a direct path may not exist even at fairly short range (i.e., 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 25 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 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 contact, 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). These 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. Detailed responses from each of the system suppliers, along with the evaluations are contained in Annex C.

In order to provide a consistent method of evaluating the surveyed AAM systems an evaluation template was created that associated the survey questions with the two main evaluation questions: (1) is the AAM system suitable for use in detecting marine mammals, (2) is the AAM system suitable for use during E&P activities. To make this association the survey questions were sorted by the AAM system parameters that they influenced and in turn the system parameters were associated with the two main evaluation questions.

In the first stage of the evaluation, two aspects were considered in the evaluation for suitability of use in marine mammal monitoring: marine mammal size (e.g. small, medium or large) and marine mammal diving characteristics (e.g. deep or shallow). Two aspects were also considered in the evaluation for suitability of use in E&P activities: the platform type from which the system is operating (e.g. fixed, ship-based or autonomous) and general E&P applicability. These aspects were selected based on the background information on E&P activities and environments and AAM system performance (summarized in Section 2 and Section 3). Each of these aspects can be associated with one or more system parameter (see Table 5) and the system parameters are associated with one or more survey questions (see Annex B).

The answer to each survey question was then individually rated on a simple rating scale of green, yellow, or red. 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 application and that modification to make it suitable is not likely warranted.

For example: Consider the evaluation of the CodaOctopus ES-SP-0020 system for suitability of use in detecting marine mammals, with respect to marine mammal size (see Annex C). One of the associated system parameters is frequency. One survey question is associated with this system parameter: In which frequency bands can the sonar operate? The response provided by CodaOctopus to this question was >120 kHz. This survey answer was evaluated as red (unsuitable) for small, medium and large sizes mammals. The evaluation was based on the background work in Section 3 which indicates that frequencies above 100 kHz will likely not provide long enough detection ranges.

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 C.

The second stage of the evaluation used the results of the first stage to derive an overall rating for each system for the two main evaluation questions. The results of this stage are provided in

Section 5.1. A descriptive overview of each system and further explanation of ratings are provided in Section 5.2.

Table 5: Overview of criteria used in the evaluation template.

Evaluation Criteria for Suitability in Marine Mammal Monitoring
Evaluation with respect to Marine Mammals Size (Small, Medium, Large) System Parameters: Source Level Pulse Type Frequency Classification Ability Noise Rejection Reverberation Rejection
Evaluation with respect to Marine Mammal Diving Characteristics (Deep, Shallow) System Parameters: Water Column Coverage
Evaluation Criteria for Suitability of Use in E&P Activities
Evaluation with respect to Platform Type (ship-based, autonomous, fixed platform) System Parameters: Motion Compensation Installation Operating Depths Power Consumption
Evaluation with respect to General E&P Applicability System Parameters: Range Scale Scan Rate Sonar Blindspot Cost System Maturity Training Time System Automation Aural Capability Current Applications Integration

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 two main evaluation questions. 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 application and that modification to make it suitable is not likely warranted.

The survey results for the evaluation of suitability of use in marine mammal monitoring are summarized in Table 6 and Table 7.

Table 6 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 was 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 reduced, but a more detailed understanding of target strength as a function of species is required before rating systems to that level of detail.

Table 6: 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 7 shows the utility of each system for detecting marine mammals at different depths. Here the 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, which affects reverberation rejection.

Table 7: 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

The survey results for the evaluation of suitability of use in E&P activities are summarized in Table 8 and Table 9.

Table 8 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 8: 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 9 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 9: 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

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

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 Inc. – 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.

The CodaOctopus's sonar processing is reported as advanced with beam stabilization and own-Doppler nullification. A 50° by 50° beam 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 intruder 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 (maximum 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°) in 7 s. 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 with speeds over 0.5 kn. 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 (2 ms), 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° to 20°, which 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° 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, these models 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 is 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 (i.e., 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. It contains a dual-frequency sonar with the lower frequency 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 Surveillance Towed Array Sensor System/Low Frequency Active (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 s is required to scan over 360° 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° 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 m depth. This would be acceptable for shallow water operations. The nominal detection range is between 500 and 1000 m, which may not be suitable for some applications. A scan of the full field of view is possible in 2 s. The system also provides advanced target detection and automated tracking options with the capability to detect objects moving on the order of 0.1 kn. 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 $50K to over $500K, as system complexity and power increase. Given the criteria available at the time of the review even a $50K 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; and
- 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 is not 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; and
- The potential actions by the operations team following a decision to act on the information.

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 (i.e., 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 reaction to new sonar contacts, including transmission of verbal or electronic data to other systems for increased situational awareness; and
- 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. 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 prediction.

In addition, there exists Behavioural Response Study (BRS) data in the scientific community from which 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.

This document is Volume I of four volumes; it provides an overview of the study and the results of the AAM system survey. Volume II contains a detailed description of the six E&P environments considered in this study and a summary of the marine mammal species expected in those environments. Volume III contains a detailed analysis of factors affecting the performance of AAM systems. Volume IV contains the contract proposal.

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. The most significant noise generating E&P activities were identified as the use of air guns, explosives, impact pile driving and vessel operations. To facilitate the evaluation of AAM systems, these activities were grouped by platform type (moving, fixed) and by noise type (impulsive and continuous). These groups were chosen as factors that would influence the performance of an AAM system, however during the detailed performance analysis noise type was not found to be a significant factor and therefore was not considered for the survey evaluations. Instead the survey evaluations focused on platform type, which was further divided into ship-based, autonomous and fixed, and general E&P applicability, which captured factors like cost, system maturity and ability to integrate with other systems. The overview of E&P activities is contained in Section 2.

The environment has a significant impact on the performance of AAM systems, and E&P operations are being conducted in a broad cross-section of environments. To make the study more focused, six specific ocean areas of relevance to E&P were selected: Gulf of Mexico, North Sea, West Coast of Africa, Barents Sea, Persian Gulf and the Australian Northwest Shelf. The types of marine mammals in these six environments were identified and it was found that each environment covered a wide variety of mammals, including Odontocetes (toothed whales) and Mysticetes (baleen whales). The variety of mammals was sufficiently large that the AAM system evaluations could not practically be done for each species, so to facilitate the system evaluations the marine mammals were grouped by size (small, medium and large) and diving characteristics (shallow and deep). These groups were chosen as factors that would influence the performance of an AAM system. With respect to E&P environments, the survey evaluations focused on marine mammal size and diving characteristics. During the survey evaluations it became evident that with the uncertainty around marine mammal target strength it was not possible to distinguish AAM system performance differences with respect to marine mammal size; because of this the rankings for small, medium and large mammal sizes are the same across systems. The six environments also have an impact on the regulatory requirements for marine mammal monitoring. Often these requirements will specify a zone within which Operators must monitor and mitigate impacts to marine mammals; this zone identifies the minimum detection range an AAM system would require. Guidelines by Regulators for the UK Continental Shelf, Gulf of Mexico and

Atlantic Canada were consulted and the typical mitigation zone was identified as 500 m from the center of the air gun array. For the purposes of this study 500 to 1000 m was considered as the minimum detection range. The overview of E&P environments are contained in Section 2 and Volume II.

Second, 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.

Overall the detailed performance analysis found:

- The most useful sonar frequencies for the AAM problem are below about 50 Hz, while the use of frequencies greater than about 100 kHz would likely not provide long enough detection ranges.

- Classification at long range will be difficult; motion will likely be 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; in noise limited conditions, good detection performance can be expected; in reverberation-limited conditions detection performance is more problematic.

- AAM performance is predicted to be good in most deep-water sites; performance for shallow-water sites can only be predicted with confidence through computer modelling of the site.

- Limited published data is available on marine mammal target strength; model predictions were developed that reasonably agreed with published results, however this is an area that warrants further investigation.

The results from the detailed performance analysis form the basis for ranking many of the survey questions and rolling those rankings up into the overall system evaluations. The detailed performance analysis is contained in Section 3 and Volume III.

Third, a survey of AAM systems was conducted, resulting in responses from thirteen production active sonar systems that may be appropriate for the task. These thirteen systems were evaluated for their suitability of use in marine mammal monitoring (based on marine mammal size and diving characteristics) and suitability of use in E&P activities (based on platform type and general

E&P applicability). To provide consistent results, a common evaluation template was used for each system, which ranked the responses to each survey question using a simple scale of green (suitable), yellow (possible) and red (unsuitable). Based on the ranked survey questions an overall ranking was described for each system, see Table 10.

Table 10: Summary of Overall AAM System Rankings

	Number of Systems Ranked as:		
	Green	Yellow	Red
Rankings with respect to Marine Mammal size			
Small, Medium, Large	6 (46%)	6 (46%)	1 (8%)
Rankings with respect to Marine Mammal diving characteristics			
Shallow	8 (62%)	5 (38%)	0 (0%)
Deep	7 (54%)	6 (46%)	0 (0%)
Rankings with respect to E&P platform type			
Ship-based	8 (62%)	5 (38%)	0 (0%)
Fixed	10 (77%)	3 (23%)	0 (0%)
Autonomous	4 (31%)	3 (23%)	6 (46%)
Rankings with respect to general E&P applicability			
General	6 (46%)	5 (38%)	2 (16%)

Each of the surveyed systems had promising and innovative characteristics. The systems ranged in cost from less than $50,000 to in excess of $500,000; system maturity varied from not in-service to greater than 5 years in service, with as few as 1 unit or as many as 100-plus units in-service. The training time associated with these surveyed systems ranged from less than 2 days up to 2 weeks, depending on system complexity.

Overall, the majority of the systems surveyed were found to be suitable for the applications being evaluated or could be made suitable with some modification or changes. This indicates that an AAM capability for marine mammal monitoring during E&P activities should be available from industry. Very few systems were found unsuitable, except for the autonomous platform application, which many manufacturers did not indicate as an application of their product and for which power consumption and maximum depth rating are highly important.

The details related to the survey and evaluations are contained in Section 4, Annex A, Annex B and Annex C.

Fourth and finally, further development areas were highlighted to continue the investigation into the use of AAM; these are summarized below:

- Modelling of acoustic propagation for selected environments;
- Concept of operations analysis to define how an AAM system would be used and what are the requirements for the system;

- Trade-off / requirements analysis to balance the requirements against practical constraints;
- Strategic environmental assessment to consider the impact of using AAM systems;
- Field trials of several systems that meet the requirements identified in previous steps; and
- Target strength investigation (either experimentally or using Behaviour Response Study (BRS) data) to expand knowledge of marine mammal target strength.

The details related to further development areas are contained in Section 6.

Overall the study found that an AAM capability for monitoring marine mammals in E&P activities and environments should be available from industry and, through further development in refining requirements and field trialing AAM systems, a specific recommendation for an AAM capability could be made.

References

[1] Spence, J. 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 USA. http://www.soundandmarinelife.org/Site/Products/NCE07-001_TreatmentsForUnderwaterSoundFromOil.pdf (Access date: 12 April 2013).

[2] (2010), Subsea Oil and Gas Directory (Online), 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). www.subsea.org (Access date: 12 April 2013).

[3] US Geological Survey (2003). USGS World Petroleum Assessment 2000, USGS Fact Sheet FS–062–03, US Department of the Interior, US Geological Survey. http://pubs.usgs.gov/fs/fs-062-03/FS-062-03.pdf (Access date: 12 April 2013).

[4] Joint Nature Conservation Committee (2004), Guidelines for Minimizing Acoustic Disturbance to Marine Mammals from Seismic Surveys, Joint Nature Conservation Committee, Marine Advice, Aberdeen, UK. http://jncc.defra.gov.uk/pdf/seismic_survey_guidelines_200404.pdf (Access date: 12 April 2013).

[5] US Minerals Management Service (2003), Notice to lessees and operators of federal oil, gas, and sulphur leases in the outer continental shelf, Gulf of Mexico OCS Region, Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program, (OBM Control Number: 1010-0154, NTL. 2003-G08) United States Department of the Interior Minerals Management Service (MMS) Gulf of Mexico (GOM) OCS Region, http://www.ocsbbs.com/ntls/ntl03-g08.asp (Access date: 12 April 2013).

[6] Fisheries and Oceans Canada (2007), Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment, (Science Advisory Report 2010/043) Canadian Science Advisory Secretariat. http://www.dfo-mpo.gc.ca/CSAS/Csas/publications/sar-as/2010/2010_043_e.pdf (Access date: 12 April 2013).

[7] Canadian Seabed Research Ltd. (2008), Active Acoustic Methods and Procedures Undertaken During E&P Contracts, Canadian Seabed Research Ltd. Job Number: 08514. Unpublished document.

Annex A Survey Contact List

Table 11: 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	General Dynamics Canada	Peter Giles peter.giles@gdcanada.com	Contact established, referred to Marport C-Tech Ltd.
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)
10	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)

Table 12: Contact List (Continued)

	Company	Point of Contact	Comments
Other contacts			
11	Sonardyne	Eric Levitt Eric.Levitt@sonardyne.com	Contact established, however did not complete survey
12	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
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

Table 13: Contact List (Continued)

	Company	Point of Contact	Comments
Other contacts			
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

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Annex B Survey Questions

Annex B contains Survey Questions (contained in Akoostix Inc. report).

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Survey of Active Acoustic Monitoring Technologies

Volume 1, Annex B: Survey Questions

Survey Definition

DRDC Atlantic ECR 2009-002

February 2012

Document Approval

AUTHOR		
Date	Name	Signature
	Joe Hood	Original signed by Joe Hood

ENGINEERING REVIEW		
Date	Name	Signature
	George Ryan	Original signed by George Ryan

CORPORATE REVIEW		
Date	Name	Signature
	Joe Hood, President	Original signed by Joe Hood

Table of Contents

1 Survey Definition

1.1 Introduction

This document provides the recommended survey questions for the Joint Industry Programme (JIP) Active Acoustic Monitoring system survey.

The survey will be implemented using LimeSurvey so that it may be completed via the Internet. Akoostix will host the survey on one of their servers, increasing the integrity and privacy of the survey results over hosting options provided by third parties.

Those completing the survey will be sent an email with a Hypertext Mark-up Language (HTML) link containing a key. This link will be unique and associated to one instance of the survey. One survey will be completed for each system. Potential survey respondents will be canvassed ahead of time to determine the number of systems that they wish to reference, and the required number of keys will be generated.

Respondents will be presented with the survey introduction (below) prior to commencing the survey.

1.2 Survey Introduction

The following survey is designed to gather information about commercial and research oriented active sonar systems that may be able to support active acoustic monitoring of marine mammals in the vicinity of Oil and Gas Exploration and Production (E&P) activities. Generally current mitigation procedures require detection and identification of marine mammals within 500 to 1000 meters of operations. Operations include both fixed and moving platforms. An effective system would allow users to meet these mitigation requirements.

This information will be used to assess the feasibility of the active acoustic monitoring concept and determine an achievable system specification. Survey responses will be provided to the International Association of Oil and Gas Producers (OGP) JIP along with system performance predictions for a number of potential systems and environments. More information about the OGP JIP can be found at www.soundandmarinelife.org.

We have made every attempt to gather the required information efficiently, and so many of the questions are multiple-choice. Where we felt that amplifying information might be required, a text entry option is provided after the question. Participants also have the option of entering longer responses at the end of each section via text entry or email with optional attachments. Please feel free to email any information that you feel is useful, including product brochures. Use of the email option in the survey ensures that your information is correctly associated with your survey response.

If you wish to send us any additional information, such as product brochures or specification documents, you can do so using the email address surveys@akoostix.com.

There is no time limit associated with the survey. Participants are allowed to go back and change their response to any question until they finalize and submit the survey at the end. This includes saving information and coming back at a later date to complete or change answers.

All questions except 1-7 are optional, but you are encouraged to provide answers to every question. If a question remains unanswered at the end of the survey we will assume that the information is not available or known, unless an explanation is provided at the end of the section associated to the question.

Thank you for agreeing to complete this survey.

1.3 System Description

The following questions provide basic information about the subject system and its developers. Questions 1-7 are mandatory. If required please provide amplifying information in question 8 to explain a mandatory answer that doesn't present the desired option.

1. Who are the primary developers and vendors for the sonar system? (Text box < 1,000 char)
2. What is the system model number? (Text box < 100 char)
3. How many years have been spent developing the system?
    a. < 1 yr
    b. 1 – 5 yrs
    c. > 5 yrs
4. How many years has the product or product family been in service?
    a. Not in service
    b. 0 – 2 yrs
    c. 2.1 – 5 yrs
    d. > 5 yrs
5. What is the approximate number of systems in service?
    a. Not in service
    b. 1 – 10 units
    c. 11 – 100 units
    d. > 100 units
6. What are the current applications (uses) for the sonar (e.g. fish finding, diver detection, etc.)? (Text box < 1,000 char)
7. Who is the best person to contact about the sonar and what is their contact information (mailing address, telephone number, and email address)? (Text box < 1,500 char)
8. Please supply any additional information you would like to provide in the text box below. (Email to or Text box with < 10,000 characters)

1.4 Sonar Specification

The following questions pertain to the sonar components.

9. What is the sonar's maximum source level (ref 1 μPa RMS @1m)? (pick one):
   a. < 180 dB
   b. 180.0 – 200 dB
   c. 200.1 – 220 dB
   d. > 220 dB
10. Does the sonar provide multiple source level settings? (Yes / No)
11. (If yes to above) Describe or list the available source level settings. (Text box with < 500 characters)
12. Does the sonar provide output levels that are referenced to an absolute acoustic receive level (i.e. calibrated output levels)? (Yes / No)
13. In which frequency bands can the sonar operate? (choose all that apply):
   a. < 5 kHz
   b. 5.0-10 kHz
   c. 10.1-20 kHz
   d. 20.1-40 kHz
   e. 40.1-80 kHz
   f. 80.1-120 kHz
   g. > 120 kHz
14. What types of pulses can the sonar produce? (choose all that apply):
   a. Gated sinusoid. Also known as continuous wave, or CW, pulse.
   b. Linear frequency modulated (LFM).
   c. Hyperbolic frequency modulated (HFM). Also known as linear period modulated (LPM).
   d. FM pulses are available, but unsure of their exact type.
   e. Other pulse type(s). (Text box < 500 characters)
15. List the time durations of the available CW pulses. (Text box with <500 characters)
16. List the time durations and bandwidths of the available FM pulses. (Text box with < 500 characters)
17. What is the minimum operating depth (cavitation depth) of the sonar? (pick one):
   a. < 5 m
   b. 5 – 10 m
   c. > 10 m

18. What is the maximum operating depth of the sonar? (pick one):
    a. < 10 m
    b. 10 – 50 m
    c. 50.1 – 100 m
    d. 100.1 – 200 m
    e. > 200 m
19. What is the minimum detection range of the sonar? (pick one):
    a. < 10 m
    b. 10 – 50 m
    c. 50.1 – 100 m
    d. > 100 m
20. What is the maximum detection range (limit of processing and display NOT target specific) of the sonar? (pick one):
    a. < 500 m
    b. 500 – 1000 m
    c. 1000.1 – 2000 m
    d. > 2000 m
21. What range resolutions does the sonar provide? (choose all that apply):
    a. < 0.1 m
    b. 0.1 – 1.0 m
    c. 1.1 – 5.0 m
    d. > 5.0 m
22. What is the minimum transmit beam width of the sonar in azimuth (horizontal beam width measured between half power points)? (pick one):
    a. < 1 degree
    b. 1 – 3 degrees
    c. 3.1 – 6 degrees
    d. 6.1 – 10 degrees
    e. 10.1 – 20 degrees
    f. > 20 degrees
    g. Isotropic in azimuth
23. What is the minimum transmit beam width of the sonar in the vertical direction (measured between half power points)? (pick one):
    a. < 10 degrees
    b. 10.1 – 20 degrees
    c. 20.1 – 30 degrees
    d. 30.1 – 40 degrees
    e. > 40 degrees
    f. Isotropic in vertical angle

24. What is the relative power level of the highest transmit side-lobe with respect to the main lobe? (Text box with < 50 characters)
25. What is the receiver dynamic range at the receive element? (pick one):
    a. < 60 dB
    b. 60.0 – 80.0 dB
    c. 80.1 – 100.0 dB
    d. 100.1 – 120.0 dB
    e. > 120.0 dB
26. What is the minimum receive beam width of the sonar in azimuth (horizontal beam width measured between half power points)? (pick one):
    a. < 1 degree
    b. 1.1 – 3 degrees
    c. 3.1 – 6 degrees
    d. 6.1 – 10 degrees
    e. 10.1 – 20 degrees
    f. > 20 degrees
    g. Isotropic in azimuth
27. What is the minimum receive beam width of the sonar in the vertical direction (measured between half power points)? (pick one):
    a. < 10 degrees
    b. 10.1 – 20 degrees
    c. 20.1 – 30 degrees
    d. 30.1 – 40 degrees
    e. > 40 degrees
    f. Isotropic in vertical angle
28. What is the directivity index of the receiver? (pick one):
    a. < 10 dB
    b. 10.1 – 15 dB
    c. 15.1 – 20 dB
    d. 20.1 – 25 dB
    e. 25.1 – 30 dB
    f. > 30 dB
29. What is the relative power level of the highest receive side-lobe with respect to the main lobe? (Text box with < 50 characters)
30. Is the sonar capable of beam steering in the vertical direction? (Yes / No)
31. (If yes to above) Describe the vertical beam-steering capability (for example, maximum depression / elevation angles). (Text box with < 1000 characters)
32. Is there a sonar blind spot after a typical installation? (Yes / No)
33. (If yes to above) Describe the blind spot limitations. (Text box with < 2,500 characters)
34. Does the sonar provide aural listening of active acoustic returns? (Yes / No)

35. Does the sonar provide aural listening of passive acoustic signals (i.e. when not pinging)? (Yes / No)
36. Does the sonar provide passive acoustic monitoring capability that could be used to detect marine mammal vocalizations? (Yes / No)
37. Please supply any additional information you would like to provide in the text box below. (Email to or Text box with < 10,000 characters)

1.5 Processing and Advanced Functions

This section covers questions related to signal processing and advanced target detection and tracking functions.

38. What is the amount of time required to scan for targets over a 360-degree scan at all available depression angles? (Text box with < 2,500 characters)
39. Does the sonar implement beam stabilization to compensate for ship motion (pitch, roll, & yaw)? (Yes / No)
40. Does the sonar implement own-Doppler nullification to compensate for ship motion (speed of advance)? (Yes / No)
41. Does the sonar support fusion of data from multiple pings? (Yes / No)
42. Will the sonar automatically detect and highlight potential targets? (Yes / No)
43. (If yes to above) What is the maximum number of simultaneous targets that can be automatically detected? (Text box with < 256 characters)
44. Will the sonar automatically detect and highlight objects that are moving with respect to the ocean bottom? (Yes / No)
45. (If yes to above) What is the minimum target speed required to detect motion with respect to the stationary bottom? (Text box with < 256 characters)
46. Will the sonar automatically track contacts? (Yes / No)
47. (If yes to above) Must target tracks be manually initiated (an answer of No implies that target tracking is automatic based on automated detection)? (Yes / No)
48. (If yes to question 46) What is the maximum number of simultaneous contacts that can be automatically tracked? (Text box with < 256 characters)
49. What ability does the sonar provide to classify marine mammal contacts from other potential targets such as schools of fish? (Text box with < 2,500 characters)
50. Please supply any additional information you would like to provide in the text box below. (Email to or Text box with < 10,000 characters)

1.6 System Interfaces / Data Fusion Support

The following questions pertain to the capability of the system to import and export data.

51. Does the sonar have the ability to accept data from other systems for overlay on the operator display (e.g. Automatic Identification System (AIS), Global Positioning System (GPS), Depth Sounder, Radar, etc.)? (Yes / No)

52. (If yes to above) Select the appropriate data import electrical interfaces (all the apply):
    a. RS232
    b. RS422
    c. USB
    d. IR Port
    e. Ethernet
    f. Other (Text box with < 1,000 characters)
53. (If yes to question 51) Select the format standards used for data import. (all that apply)
    a. eXtensible Markup Language (XML) – GPS eXchange format (GPX)
    b. Custom XML
    c. National Marine Electronics Association (NMEA)
    d. Delimited American Standard Code for Information Interchange (ASCII) (e.g. Comma-Separated Values (CSV))
    e. Custom ASCII
    f. Proprietary
    g. Other (Text box with < 1,000 characters)
54. Does the sonar have the ability to export data to other systems for overlay on their display or use within their database? (Yes / No)
55. (If yes to above) Select the appropriate data export electrical interfaces (all the apply):
    a. RS232
    b. RS422
    c. USB
    d. IR Port
    e. Ethernet
    f. Other (Text box with < 1,000 characters)
56. (If yes to question 54) Select the format standards used for data export (all that apply):
    a. XML - GPX
    b. Custom XML
    c. NMEA
    d. Delimited ASCII (e.g. CSV)
    e. Custom ASCII
    f. Proprietary
    g. Other (Text box with < 1,000 characters)
57. Does the sonar have the ability to generate internal contact logs that can be retrieved after each mission (e.g. a binary or ASCII record of contact or operator annotation of the data)? (Yes / No)

58. (If yes to above) Select the appropriate data export electrical interfaces (all the apply):
    a. RS232
    b. RS422
    c. USB
    d. IR Port
    e. Ethernet
    f. Memory Card (specify type – Text box with < 200 characters)
    g. Other (Text box with < 1,000 characters)
59. (If yes to question 57) Select the format standards used for data export (all that apply):
    a. XML - GPX
    b. Custom XML
    c. NMEA
    d. Delimited ASCII (e.g. CSV)
    e. Custom ASCII
    f. Proprietary
    g. Other (Text box with < 1,000 characters)
60. Please supply any additional information you would like to provide in the text box below. (Email to or Text box with < 10,000 characters)

1.7 System Information

The following questions pertain to the cost of system acquisition and operation.

61. What is the cost (United States Dollars (USD)) that best applies to an installed sonar system with typical equipment options and spares? [essentially turn-key] (pick one):
    a. < $50K
    b. $50K - $250K
    c. $250.1K - $500K
    d. > $500K
62. What type of platform can the subject sonar support be used with? (choose all that apply):
    a. Ship mounted
    b. Fixed in place (moored or attached to existing equipment)
    c. Autonomous vehicle
63. What type of installation does the subject sonar support? (choose all that apply):
    a. Permanent
    b. Temporary

64. How much electrical power does the sonar require? (pick one):
    a. < 1 kW
    b. 1 – 5 kW
    c. 5.1 – 10 kW
    d. > 10 kW
65. To give an idea of the complexity of operating the sonar, what is the time required to train an operator to be competent in independently operating the sonar? (pick one):
    a. < 2 Days
    b. 2 – 6 Days
    c. 1 – 2 Weeks
    d. other (Text < 1,000 char)
66. Please supply any additional information you would like to provide in the text box below. (Email to or Text box with < 10,000 characters)

Acronyms

AIS	Automatic Identification System
ASCII	American Standard Code for Information Interchange
CSV	Comma-Separated Values
CW	Continuous Wave
DM	Data Management
DRDC	Defence Research and Development Canada
E & P	Exploration & Production
FM	Frequency Modulated
GPS	Global Positioning System
GPX	GPS eXchange format
HFM	Hyperbolic Frequency Modulated
HTML	Hypertext Mark-up Language
JIP	Joint Industry Programme
LFM	Linear Frequency Modulated
LPM	Linear Period Modulated
NMEA	National Marine Electronics Association
OGP	Oil and Gas Producers
PI	Principal Investigator
PM	Project Manager
RMS	Root-Mean Squared
USD	United States Dollars
XML	eXtensible Markup Language
μPa	micro-Pascal

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Annex C Survey Answers

Annex C contains a summary of Survey Answers. Go to the Annex C folder on the document CD for pdf files.

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Under the International Association of Oil and Gas Producers (OGP) 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.

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. 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. Finally, a survey was conducted of commercially available sonar equipment by collecting data from sonar vendors through an on-line form. The sonars were then ranked as to their suitability for AAM based on the factors identified as important during the earlier study of potential AAM performance.

This document is Volume I of four volumes; it provides an overview of the study and the results of the AAM system survey. Overall the study found that an AAM capability for monitoring marine mammals in E&P activities and environments should be available from industry and through further development in refining requirements and field trialing AAM systems a specific recommendation for an AAM capability could be made.

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Oil and Gas Industry; Active Acoustic Monitoring; Marine Mammals; Marine Mammal Monitoring; Active Sonar;

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