Development of Environmental Mitigation Measures for the Sound Sources of Autonomous Underwater Vehicles (AUVs)

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Synopsis

Autonomous Underwater Vehicles (AUVs) will be vital to support future Marine Research and enhance Defence capabilities. As these new technologies emerge it is important to ensure all possible environmental impacts have been assessed and appropriately mitigated. Unmanned Underwater Vehicles (UUVs) and Autonomous Underwater Vehicles can comprise of a wide variety of acoustic sensors as can the accompanying survey ship. National and European legislation is in place to protect habitats and species from harm which includes the disturbance to marine mammals (The Conservation of Offshore Marine Habitats and Species Regulations, 2017; The Habitats Directive, 1992). Emission of impulsive sound from acoustic sensors have the potential to adversely impact marine mammals (Finneran, 2015; Harris, et al., 2016). These impacts can range from general disturbance to hearing damage when certain thresholds of the received sounds are breached. In the most severe cases, permanent shifts to hearing thresholds can occur (Southall, et al., 2019). Understanding the environmental impact and developing appropriate mitigation measures for UUVs and AUVs will therefore ensure these new Defence capabilities are minimising the impact to marine mammals whilst ensuring Defence operations are not at risk. A first screening and scoping study determined the environmental aspects and impacts related to the sensors onboard AUVs procured in Defence. Further analysis is being conducted to inform the extent of the impact and to determine if any existing mitigation strategies could be adopted and integrated into the Standard Operating Procedures for planned AUV use and exercises e.g. running bespoke Sonar Risk Assessments ahead of deployments together with temporal (seasonal) and/or spatial planning of operations. This paper explores the environmental management techniques adopted to understand the environmental impact and introduce mitigation measures for future challenges related to the deployment of AUVs such as the cumulative effects of multiple AUVs functioning together and the deconfliction of other anthropogenic sound sources.

Keywords: Autonomous Underwater Vehicles, Environmental impact, acoustic sensors, mitigation measures

Author Biography:

Dr Delphine Byford started her career conducting research on the effects of offshore wind farms on the seabed. She moved into the Defence sector as Maritime Environmental Protection Adviser for Navy Command, followed by five years as environmental manager in DE&S. Delphine is now lead Environmental consultant in the ITS SED team in DE&S.

Harriet Rushton has three years experience advising Navy Command on maritime environmental protection including how to minimise risks to marine mammals from sonar and explosive activities. Harriet is now working as an Environmental Manager within DE&S, on various projects including platforms with underwater noise capabilities.

1. Introduction

During the next 50 years the UK Royal Navy (RN) will be adapting its capabilities to incorporate a wide range of autonomous off-board systems, thus creating a modern, high-tech and automated Navy (UKNEST, 2019). By adopting innovation, focusing on Research & Development and introducing cutting-edge technology, the UK Ministry of Defence (MOD) is ensuring it sustains an operational advantage in a changing environment and geopolitical scope with continuously evolving global threats (MOD, 2021). A range of autonomous vehicles will shape the future fleet and will include autonomous surface vessels, unpropelled (submarine gliders) and propelled autonomous underwater vehicles (AUVs) in various shapes, sizes and lengths of endurance.

As these new technologies emerge it is important to ensure all possible environmental impacts have been identified, assessed and appropriately mitigated, so far as reasonably practicable (POEMS, 2021; Secretary of State for Defence, 2020). The oceans contain vast amounts of marine life which have various levels of legal protection due to increasing anthropogenic pressures arising from maritime activities. The importance of marine ecosystems is reflected in UN Sustainable Development Goal 14 ‘Life Below Water’ where the goal is to conserve and sustainably use the world’s oceans, seas and marine resources. Anthropogenic noise is one environmental impact caused by sources such as shipping, construction (e.g. pile driving), seismic surveys and sonar use and can be divided into impulsive and continuous sound (Merchant, et al., 2016; Thomsen, et al., 2021). Anthropogenic marine noise is further recognised as negatively impacting the marine environment in the UK Marine Strategy Regulations (The Marine Strategy Regulations, 2010). Introduction of noise into the marine environment is defined as a form of pollution which may hinder achievement of Good Environmental Status through deleterious impacts upon living resources, marine ecosystems and biodiversity.

Autonomous vehicles can comprise of a wide range of acoustic sensors which have the potential to adversely impact marine mammals (Finneran, 2015; Harris, et al., 2016; Wynn, et al., 2014). This paper focuses on the environmental assessment and mitigation measures related to the acoustic sensors onboard Commercially of the Shelf (COTs) procured AUVs and the accompanying host platform (mothership).

2. Acoustic Sensors on Autonomous Underwater Vehicles

Autonomous Underwater Vehicles (AUVs) are unmanned, self-propelling, robotic vehicles which are pre-programmed with parameters ahead of their (untethered) deployment into the ocean, typically from a research vessel (Trembanis, et al., 2021; Wynn, et al., 2014). Depending on their battery life, AUVs currently available on the market can be deployed for missions from a few hours to several days, covering a range of hundreds of kilometres at depths ranging up to 6000m (Figure 1).

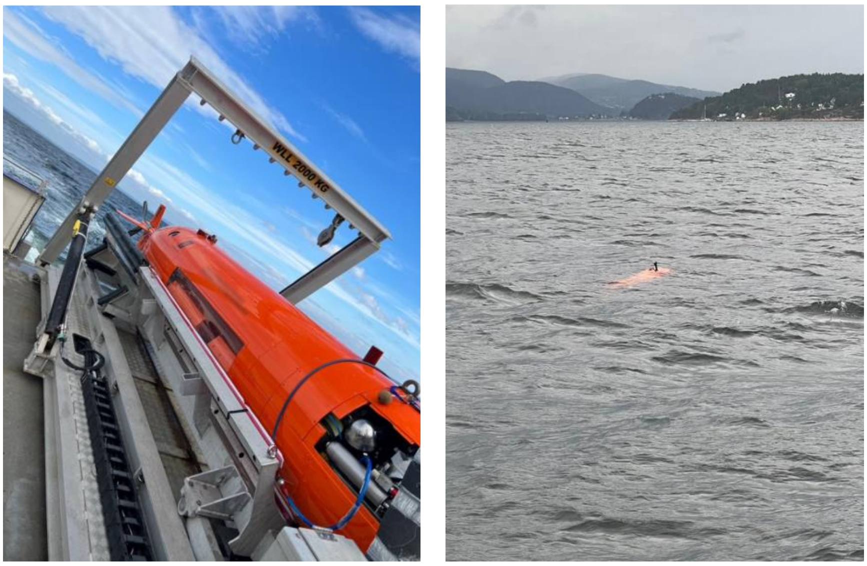

Figure 1. Example of Autonomous Underwater Vehicle ready for launch on the survey vessel (Left) and after launch on the sea surface (Right) (Kongsberg Maritime)

AUVs can contain various acoustic sensors such as synthetic aperture sonar, side-scan sonar, sub-bottom profilers and high resolution multibeam echosounders and are capable of operating close to the seabed (Wynn, et al., 2014). Side-scan sonar and multibeam echosounders generally direct sonar signals towards the seabed, sub-bottom profilers are highly directional sound sources, often with high sound levels and a varying range of frequencies (Thomsen, et al., 2021).

Traditional active military sonar operates in the low (< 1 kHz) and medium frequency ranges (1 kHz – 10 kHz) whereas the sonars onboard the COTs AUVs procured in Defence are mostly categorised in the medium and high-frequency range (> 10 kHz).

3. Marine Mammal Science

Emissions of impulsive sound from acoustic sensors have the potential to adversely impact marine mammals (Finneran, 2015; Harris, et al., 2016). How underwater sound causes behavioural and physical impacts in marine mammals depends upon multiple factors including frequency (Hz) and source level (dB) of the sound and the physical properties of the water into which the sound is emitted (Southall, et al., 2007). These factors influence how the sound propagates within the water column and thus levels and frequencies received by marine mammals should they be located within the ensonified area. Behavioural responses and / or physical harm could then result depending upon the hearing sensitivities of the marine mammals present and how loud the received levels of sound are (Gomez, et al., 2016). The most severe risk is that marine mammals could be subjected to physically damaging levels of sound, which harm their inner ears and cause permanent threshold shift (PTS). If subjected to lower levels of sound, this damage could be temporary (temporary threshold shift; TTS) and could also disturb their activities (Southall, et al., 2019). Disturbance has further implications as it can cause a stress response, deter marine mammals from important foraging grounds, disrupt social interaction or mask sounds of predators or hazards to name but a few (Southall, et al., 2021; National Marine Fisheries Service, 2018). This can then impact feeding, increase predation and disrupt dive patterns which can in turn cause physical harm.

Southall et al (2019) categorised marine mammals in accordance with the frequencies of sound to which they are most sensitive. In the case of cetaceans (whales, dolphins and porpoises), these are low (LF), high (HF) and very high frequency (VHF). The authors also modelled the frequencies and sound levels at which these groups of cetaceans may suffer TTS.

Assessing impacts of sonar upon marine mammals is further complicated because in some species behavioural responses have been found to cause physical damage (Tyack, et al., 2006). A case in point are beaked whales, which are highly adapted for life at depth and manage their nitrogen levels through specific dive patterns whereby multiple, relatively short, shallow “bounce” dives are undertaken in between longer, deeper foraging dives, in order to manage nitrogen levels within their tissues and blood. Therefore, disruptions to their dive profiles, for example by initiating a startle response from loud, impulsive sounds, could have impacts upon nitrogen management in their tissues, potentially causing physical harm such as gas emboli formation in their tissues when they cannot manage pressure through their usual dive patterns (Tyack, et al., 2006).

However, studies have yet to agree how to identify what may constitute a significant enough behavioural response to cause physical damage, let alone quantify what levels of sound may cause such responses under what conditions and when (Gomez, et al., 2016). Therefore, the threshold for measuring risk to marine mammals is generally accepted to be TTS. This also complicates management of impact of sound on marine mammals as legislation requires activities do not significantly “disturb” cetaceans (see Section 4). When coupled with the mobile nature of marine mammal populations and difficulties in accurately determining population numbers, locations and seasonal movements, this further underlines the complexities in assessing impacts of sonar operations and effectively mitigating these impacts.

4. Legislation and Regulations

National and European legislation is in place to protect habitats and species from harm which includes the disturbance to marine mammals (The Conservation of Offshore Marine Habitats and Species Regulations, 2017; The Habitats Directive, 1992).

The EU Habitats Directive 1992 is transposed into UK legislation by the Conservation of Offshore Marine Habitats and Species Regulations (2017) in the offshore area. The MOD has no derogation, exemption or disapplication from this legislation, which requires that competent authorities (including government departments and thus MOD) do not “deliberately” capture, injure, kill or disturb wild animals categorised as European protected species (EPS), which includes all species of cetacean. “Disturbance” is here defined as impairing the ability to survive, breed, reproduce or rear or nurture young, or to migrate or significantly affect the local distribution or abundance.

It is a defensible case to have not "deliberately" impacted marine mammals (as EPS') in the aforementioned ways. "Deliberate" is interpreted to mean that *"(...) actions will most likely lead to an offence against a species"* and therefore *"(...) by following appropriate mitigation measures and/or using alternative methods, the risk of certain activities causing an offence may be reduced to negligible levels"* (Joint Nature Conservation Committee, Natural England and Countryside Council for Wales, 2010). This means that it is defensible if it can be proven that risk was assessed, and all available and appropriate mitigation measures were implemented and therefore that if harm to EPS occurred, all best efforts were employed to prevent it. It is therefore important to understand the risk and implement effective mitigation measures to abide by the requirements of legislation.

As alluded to in Section 3, "significant" disturbance of marine mammals is difficult to measure and the science has yet to quantify what may constitute significant disturbance, neither have the nature conservation bodies released specific advice on the matter. JNCC issued guidance on assessing significance of noise disturbance on resident Harbour porpoise populations within UK SAC (Joint Nature Conversation Committee, 2020)[1]. However, these guidelines are specific to Harbour porpoise SAC and thus may not be accurately extrapolated to be relevant to all cetaceans in all waters.

5. Environmental Assessment

The UK MOD has a legal requirement to assess the environmental impacts of its equipment, systems, platforms and operations. Defence Equipment & Support (DE&S) delivers the through life procurement and support of equipment for the UK MOD. Within DE&S, the Project Oriented Environmental Management System (POEMS) is applied which is a bespoke Environmental Management System based on the international standards ISO 14001 and ISO 14040 (POEMS, 2021), incorporating an assessment throughout the life cycle of the equipment (Galante, et al., 2017).

5.1 Environmental Screening and scoping Study

As part of the POEMS process, an initial environmental screening and scoping study (EISS) identified the environmental aspects (causes) and impacts (effects) related to the AUV and associated platform for the in-service and disposal phase. The causes both covered embodied (inputs into the system) and emitted (outputs) environmental aspects as illustrated in Figure 2.

The EISS process ensures delivery teams can focus their efforts on the most important environmental aspects and impacts associated with their equipment. During the process, the significance of the effect on the environment is determined by using an environmental impact significance matrix with agreement by a SQEP (Suitably Qualified and Experienced Personnel) panel. Each environmental impact is then given a priority score (high, medium or low) by weighing the significance against other criteria such as the potential risk to MOD operations, potential breach of legislation and the ability to implement operational controls (POEMS, 2021).

The noise disturbance (impact) to marine mammals due to the use of AUVs generating underwater acoustic noise was one environmental impact which was given a high priority score, thus requiring further nvironmental assessment.

[1] These guidelines advise that noise disturbance within an SAC is considered to be "significant" if it excludes harbour porpoise from more than (1) 20% of the relevant area of the site in any given day or (2) an average of 10% of the relevant area of the site over a season (see the full report for definitions of "relevant area", "any given day" and a "season").

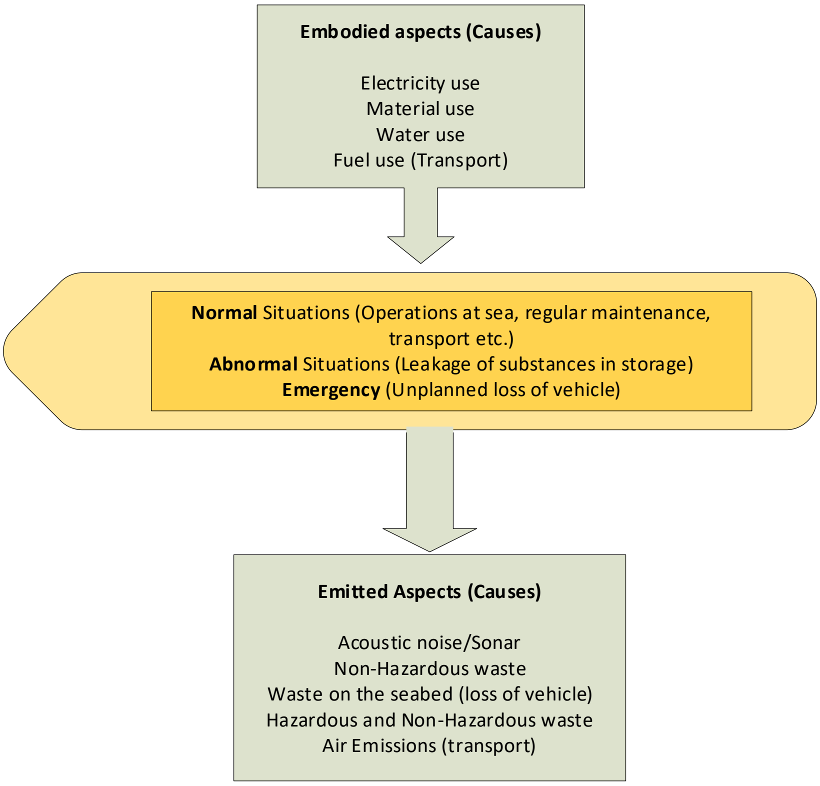

Figure 2. Example of a Context Diagram illustrating some of the embodied aspects (inputs into the system) and emitted aspects (outputs from the system) related to the in-Service and Disposal phase of AUVs (yellow).

5.2 Sonar Risk Assessment

As the primary user of sonar within MOD, the Royal Navy uses a Sonar Risk Assessment (SRA) software to determine risk of sonar use upon marine mammals. This software uses the physical properties of the sound source and the water at the time of sonar use and the latest marine mammal hearing thresholds and abundance data. This is employed for the mid frequency active sonar (MFAS) traditionally used by RN surface ships undertaking anti-submarine warfare activities.

The high frequency sonars traditionally used by AUVs can be within the hearing thresholds of cetaceans categorised in the HF / VHF hearing groups by Southall et al (2019). These high frequency sonars are unlikely to cause as widespread ensonification of the water column as MFAS due to the comparatively fast absorption rates of high frequency sounds in water (Neighbors, 2017). This absorption causes more significant propagation loss than for less readily absorbed lower frequency sounds. Therefore, although the sound source levels and frequencies of such sonars may be within the hearing thresholds of HF / VHF cetaceans, these cetaceans would likely need to be much closer to the sonar itself to suffer TTS / PTS, than would be the case for MFAS which have the potential to ensonify a larger area of water with damaging levels of sound. These different ranges of damaging levels of sound are known as Stand-Off Ranges (SORs).

As high frequency sonars are not included in the database of the RN sonar risk assessment software, as part of the Environmental Impact Assessment (EIA), a general SRA is being conducted to calculate the SORs for the acoustic emitters which emit sounds within the hearing ranges of marine mammal species as described in Section 3, the outcome of the SRA was not yet available on publication of this paper. The SORs will inform the extent of the impact from the different sound sources and inform appropriate mitigation measures.

5.3 Operational Mitigation Measures

Traditionally, the "mitigation action zone" (MAZ)[2] for high frequency sonars is generally relatively small due to the short SORs of high frequency sound sources. The MAZ can therefore be effectively monitored, and mitigation measures can be implemented to reduce the risk of harming marine mammals.

Identification of marine mammals within the MAZ allows operators to adjust sonar use (by amending source level / frequency or switching off / not using the sonar) to prevent ensonification of the marine mammals. As yet, no effective mitigation measures for preventing harm to marine mammals from unmanned equipment have been suggested by the UK nature conservation bodies as effective mitigation traditionally relies upon there being marine mammal observers (MMOs) or passive acoustic monitoring (PAM) capabilities undertaken in-situ in real-time. Therefore how / whether the MAZ could be monitored and effectively mitigated remains to be determined for AUVs.

Use of MFAS by the RN is undertaken in accordance with standard operating procedures (SOP). These include running SRAs and using a specific sonar book of reference, which instructs operators on how to use sonar in a manner which is the lowest risk to marine mammals whilst maintaining operational / training output. This includes monitoring the MAZ before, during and after sonar use and adjusting sonar use depending upon whether marine mammals are sighted (using MMOs / PAM) within the MAZ.

These existing mitigation measures are being applied to the AUV operations ahead of each deployment from the mothership, however the sonar risk management software does not include COTs AUVs and therefore a bespoke SRA is being conducted based upon the specific emitters of the AUV (security allowing), and generic physical water column data.

Due to the autonomous nature of AUVs, bespoke mitigation measures are currently being explored. The SRA will inform if existing mitigation strategies incorporated into the SOPs of AUVs are sufficient to reduce the risk of harming marine mammals from planned operations and exercises. Depending on SRA results, which would be specific for different types of COTs procured AUVs, these mitigation measures could include:

- Running bespoke SRAs ahead of operations to calculate specific SORs based on the location of the operation and which acoustic emitters are going to be used.
- Temporal (seasonal) and/or spatial planning of operations. As part of the EIA process, the distribution of marine mammals that are likely to be present around the AUV operating areas will be determined e.g. If the SRA identified the acoustic sound could influence a specific marine mammal species, operations could (if possible) be planned around the seasonal migration of these species and/or avoid the most sensitive areas during certain times of the year.

5. Conclusion

An initial EISS study concluded that the high frequency sonars traditionally used by AUVs can be within the hearing thresholds of cetaceans categorised in HF / VHF hearing groups (Southall, et al., 2019). As these sonars are not included in the database of the RN SRA software, a bespoke EIA is being carried out, including a SRA to calculate the SORs for the acoustic emitters. The SORs will inform the extent of the impact from the different sound sources and inform appropriate mitigation measures. As there remains no formal advice on effective mitigation measures for prevention of harm and / or disturbance to marine mammals for autonomous systems from regulators or conservation bodies, MOD is taking the first step by assessing the potential impact.

With the future ambition to incorporate more and larger autonomous surface and subsurface vehicles to the RN fleet there will be an increasing need to (1) understand the behavioural responses of marine mammals to sonar (Gomez, et al., 2016; Tyack, et al., 2006) and (2) ensure cumulative impacts from multiple sound sources are assessed, monitored and mitigated appropriately, not only for MOD activities but also between all marine industries (Hague, et al., 2022). The work described in this paper will contribute to ensuring appropriate mitigation measures are developed for future autonomous systems thus avoiding hinderance of MOD operations whilst minimising harm to marine mammals.

[2] The area within which effective mitigation can be implemented to minimise risk of marine mammals being exposed to harmful levels of sound. If the MAZ diameter exceeds the SOR for TTS and can be effectively monitored using MMOs or PAM, the area at risk of harming marine mammals can be effectively mitigated.

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