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THE SAFEGUARDING OF MARINE MAMMALS DEVELOPMENT OF DETECTION METHODS IN A BLAST ENVIRONMENT

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Abstract

This paper describes the selection of a preferred method for the detection of marine mammals in the vicinity of a construction site where underwater blasting will be taking place. This is in response to the need to minimize underwater noise and shock on these animals.

The impact on marine mammals from underwater blasting varies but depends primarily on the size of the blast, the proximity of the animal to the explosion site and the size of the mammal.

The advantages and disadvantages of underwater acoustics and alternative monitoring techniques such as infra-red imaging and visual sighting from aircraft or unmanned airborne vehicles (UAVs) are investigated. A Systems Engineering approach is used to select a preferred configuration of acoustic arrays and UAVs.

1. INTRODUCTION

Extensive research has been conducted on the effects of noise impacts on mammals. Reference [1] presents an excellent on this research. Pressure pulses from blasts have higher peak levels than any other man-made source with very rapid rise-times, often resulting in shock waves. A scale of effects from underwater blast noise on marine life is presented in Figure 1. The right hand side of the graph represents the source of the explosion.

- Primary effects (Lethal): cause life threatening physical injuries (death, physical injury). These are often associated with the impulse of a blast wave, although peak pressure is also a factor.
- Secondary effects (Sub-lethal): causes non-life threatening physical injuries such as auditory damage. This is often associated with the peak pressure of the blast.
- Tertiary (Behavioural): causes behavioural change, the most common being the future avoidance of the location.

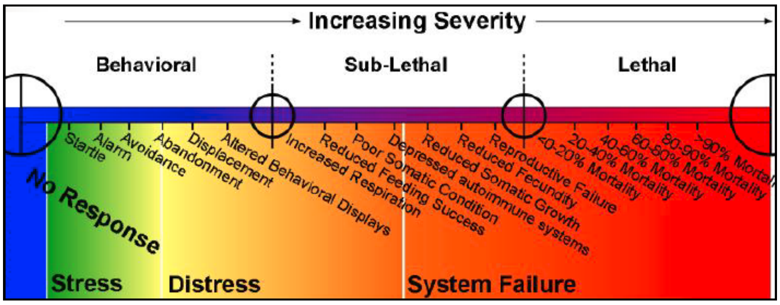

Figure 1. Scale of effects from underwater noise on marine life [7].

Figure 1 represents the result of blast effects on mammals as a function of distance. A safe distance or an exclusion zone must be established before blasting takes place. This will depend on the charge strength and local acoustic conditions. The ability to monitor mammal movement is fundamental to ensuring that mammals do not enter the exclusion zone before or during blasting operations.

2. EFFECTS OF UNDERWATER BLASTING ON MARINE MAMMALS

2.1. Physiological Effects

Research on blast damage to animals suggests that the mechanical impact of a short duration pressure pulse (positive acoustic impulse) can be correlated with organ damage.

Marine mammals may be killed or injured as a result of an explosive underwater detonation due to the response of air cavities in the body, such as the lungs and bubbles in the intestines. Effects are likely to be most severe in near-surface waters where the reflected shock wave creates a region of negative pressure called “cavitation”. An animal in this region will experience near total physical trauma and would not be expected to survive [1].

A second possible cause of mortality or lethal injury is the onset of extensive lung haemorrhage. Extensive lung haemorrhage is debilitating and potentially fatal. Suffocation caused by lung haemorrhage is likely to be the major cause of marine mammal death from underwater shock waves. The onset of extensive lung haemorrhage for marine mammals will vary depending upon the animal's weight, with the smallest mammals having the greatest potential hazard range.

Dolphins and whales, having much greater mass than fish, can presumably withstand blasting at closer distances, but the lack of any direct evidence should encourage a cautious approach.

2.2. Acoustic Effects

The same sharp, impulsive sounds that cause the broadest range of physiological damage in terrestrial and marine mammals can harm the ear. For mammals close to a blast site, the small bones, or ossicles, that carry sound waves from the eardrum to the inner ear may suffer damage, bringing on permanent deafness; or worse, the oval window that protects the inner ear may rupture, causing a fatal loss of cerebrospinal fluid. Farther from the blast, the animal may experience other debilitating effects such as disruptions in its equilibrium and hearing.

Hearing thresholds may be degraded by exposure to high-intensity sound. Hearing losses are classified as either temporary threshold shifts (TTS) or permanent threshold shifts (PTS), where repeated TTS may lead to PTS. The extent of hearing loss is related to the sound power spectrum, the hearing sensitivity, and the duration of exposure. High-intensity, impulsive blasts can damage cetacean (whales, dolphins and porpoises) ears. Hearing losses may result in poor co-specific communication, lessened abilities for echolocation and foraging and erratic migratory and mating behaviour. It may result in stranding and increased vulnerability to predators. For cetaceans which are highly dependent on their acoustic sense, both TTS and PTS must be considered serious.

2.3. Summary of Criteria and Thresholds

Table 1 summarises the impact category, criteria and thresholds applicable to marine mammals that have been developed for:

- Mortality ([2])
- Injury ([3])
- Non-injurious harassment and behavioural modification ([4], [5], [6])

Table 1. Blasting impact criteria and thresholds.

Impact Category	Criteria	Threshold
Mortality	Onset of extensive lung haemorrhage	210 kPa.ms (impulse)
Injury	(i) Onset of slight lung haemorrhage (ii) 50% probability level for a rupture of the tympanic membrane (TM).	(i) 205 dB re. 1 μPa^2.s (PSD) (ii) 175 kPa.ms (impulse)
Disruption of hearing-based behaviour	Temporary threshold shift (TTS)	(i) 182 dB re. 1 μPa^2.s (PSD) (ii) 83 kPa (peak pressure)

3. MARINE MAMMAL MONITORING TECHNIQUES

3.1. Passive acoustics

Passive acoustic detection refers to the detection of animals by listening to the sounds that they make. The past decade has brought extensive growth in the application of passive acoustic sensing of marine mammals together with automated signal processing tools for localisation purposes. Marine mammals use underwater sounds to navigate, feed and communicate. These sounds can be detected with towed hydrophone arrays, stationary hydrophones deployed from ships or shore, autonomously recording bottom hydrophones, or drifting radio-linked sonobuoys deployed and monitored from ships or aircraft.

Most cetacean species make sounds and one advantage of acoustics is that these sounds can be detected when the animals are submerged or out of range of visual observers. One disadvantage is that sound production is voluntary and many cetaceans may be silent for long periods of time. Species identification from vocalisations is easier for some cetacean species than others. Baleen whales, in particular, appear to make very stereotyped calls that can be used to distinguish them. Dolphin whistles are more variable, echolocation clicks can be used to identify sperm whales with certainty and the repetition rate (frequency) can be used to distinguish clicks made by different species.

Each monitoring system has unique advantages and disadvantages. The optimal system choice depends on the frequency spectrum of the sounds of interest, the depth at which the animals vocalise, and the logistics of mitigation (a stationary hydrophone might be inappropriate for a moving sound source, and a sea bottom recorder is not appropriate for real-time monitoring). Localisation of cetaceans typically requires more than one hydrophone.

The system assessed in this paper is based on two fixed small aperture hydrophone arrays. They are used to detect a range and bearing of selected marine mammal calls including clicks, sweeps, and whistles. The system's detection algorithm uses advanced signal processing techniques including cross-correlation, time differences of arrival, triangulation and hyperbolic tracking algorithms.

The performance of the system is constrained by the ocean environment. Multiple sound paths in shallow water and/or high background noise levels will limit performance. Preliminary studies and acoustic surveys would be required to determine the ambient anthropogenic (man-made) and natural underwater noise levels prior system selection.

3.2. Aircraft

It is common knowledge that the surveillance of fish and marine mammals using aircraft or helicopters has proven to be very successful in Australia. It is now an everyday occurrence, as can be seen from the number of helicopters employed on Australian beaches for surveillance of sharks in shallow waters.

Marine mammal observation from an aircraft is to simply ensure relies on visual contact with the mammals on the surface or underwater. In shallow waters and in weather conditions exhibiting moderate sea-states, this is generally sufficient. However, no real time data is accumulated and stored for post viewing or movement analysis. Viewing is restricted to relatively good weather conditions, clear waters and the availability of aircraft when needed.

Real time video data acquisition which includes infra-red detection and telemetry for downloading is expensive to implement in an aircraft. Although the capability is available, it requires the use (and availability) of a special aircraft (special surveillance avionics, data link and video) to be dedicated to the task, resulting in expensive budgets ($1000's per hour).

3.3. UAVs

As an alternative to aircraft, UAVs are specifically designed to replace aircraft in dangerous, difficult or advantageous circumstances. UAVs are now being considered for surveillance missions for purely economic reasons.

The most applicable UAVs for this role are "small" UAVs which are used by tactical echelons in the armed forces (and special operations forces) to gather intelligence "over the hill" and "around the corner". These platforms are simple to operate, can be launched from "the shoulder", can fly one to two hour missions covering a pre-planned route and/or respond to specific requests from an operator. They are very quiet, being powered by an electrical motor.

These small platforms are highly sensitive to vibration caused by buffeting and wind gusts and require electronic stabilisation to provide good video imagery. New stabilised payloads specially developed for such small UAVs have emerged, which are equipped with power zoom lens (both visual and IR). They are capable of providing quality images and detailed information.

An issue of concern is obstacle avoidance. Mini-UAV's fly at low altitudes (500 feet, dependent on the system's Field Of View), and special measures must be taken to ensure that gantry, conveyor and ship structures are avoided during take-off and landing phases.

The ability to retrieve and store data is a positive step in the prediction of future mammal movements.

Mini-UAVs of the type extensively used by the armed forces are now exhibiting exhibit product maturity. They can be deployed to fly a grid pattern over the blast exclusion zone for up to two hours. A second UAV can then be deployed while the first aircraft has its battery changed, and so on.

4. MONITORING SYSTEM ANALYSIS

4.1. Review of Monitoring Methods

To set the scene and to qualify sensor capabilities, Table 2 presents the benefits and disadvantages of each of the monitoring methods.

Table 2. Marine mammal monitoring techniques.

Method	Benefits	Disadvantages
Acoustic Tracking	a. Simple to deploy, relatively low maintenance b. Continuous monitoring, day and night c. Single operator d. Discriminates targets e. Relatively low-cost f. Reasonable reliability in most circumstances g. On-shore real time acquisition and processing h. Proven off-the-shelf techniques for marine mammal tracking i. Can simultaneously provide extra information on underwater construction noise and blast pressure levels	a. Dependant on mammals vocalisation b. Signal sensitivity to background levels including weather conditions c. Signal sensitivity to multiple paths in shallow water d. Limited coverage over large distances
Aircraft	a. Easy visualization of mammals b. Number of service suppliers high c. Cost effective if only visual observation d. Can provide complete analysis and storage from specially equipped aircraft	a. Weather limited b. Aircraft availability c. Expensive for “special” aircraft d. Requires support staff e. Difficult to visualize mammals in murky waters f. Transit and turnaround times g. Only daylight surveillance for simple configuration h. Requires approval from the Civil Aviation Safety Authority (CASA) i. Lengthy preparation for flight
UAV’s	a. In good weather, provides accurate detection of mammals in shallow water b. Easy to use c. Provides video and IR detection and storage d. Single operator e. Easier to provide continuous monitoring, day and night (via IR) f. Can be deployed from any location g. 5 minutes preparation for flight and deployment h. Instantaneous deployment – flexible i. Flies itself j. Can remain around specific location of interest and fly pre-determined, fixed patterns k. Operationally not expensive	a. Maybe expensive to procure complex UAVs b. UAV solution is geared towards advanced system c. Risk of damage d. Requires CASA approvals

4.2. Probability Determination

The prime system indicator chosen to differentiate methods of surveillance is the probability of detection. This assessment assumes that, in the case of reasonable weather conditions (i.e. moderate wind, moderate sea-state, reasonable clarity in the water, etc), the detection probability of mammals using any of the systems discussed in section 3 would be high and we assign it a value of 0.99.

We then postulate a test case involving whales traversing the location of interest and introduce windy conditions and relatively high levels of background noise. The estimated probability of detection using the different systems is presented in Table 3. Note that this Table presents parameters that are considered most important to acoustic detection and doesn't attempt to capture all the issues involved in detection probability and does not attempt to signify a quantifiable position.

Table 3. Probability of detection techniques.

Probability Factors	Acoustic Tracking System	Aircraft (non special aircraft, only observer onboard)	Aircraft (with special equipped CCD and IR instruments)	UAVs
Detection of at least one whale (based on the mammals communication and echolocation sound in a ambient (background) noise field	0.99	0.99	0.99	0.99
Weather influence on detection (rain and higher sea-state)	0.80[1]	0.50[3]	0.99	0.99
Detection in anthropogenic (dredging, blasting & construction) noise	0.25[2]	0.99	0.99	0.99
Location influence on detection (shallow or site specific lower loss factor due to cylindrical spreading)	0.99	0.99	0.99	0.99
Detection in murky conditions	0.99	0.50[3]	0.99	0.99
Total probability of detection	0.20	0.25	0.95	0.95

Notes: The probabilities in Table 3 are based on data presented in reference [1] for whales covering sounds over a frequency band of 20-2kHz and acoustic levels in the range 128-190dB re 1µPa at 1 m. The test case for the computation assumed a charge weight of 50kg for which a safe distance of 700m is required. Reference [1] indicates that source data is insufficient and that some species exhibiting low source levels may be detectable only within a few meters!

1. Approximately over 80% of the mammals listed [1] have a source signal high enough to be detected.

2. The background noise spectrum from construction activities raises approximately 20dB [1].

3. Assumes observer has reduced capability to visually distinguish whales near the surface under rough or murky condition. This is assumed to be in one out of two cases.

4.3. Ranking and Weighting Criteria

A generally used industrial method to assess system options is to employ a ranking matrix which considers key issues. The ranking criteria are listed in Table 4 for each system and a score assigned to each criterion. The score ranges from Good (10) to No-Good (1). Significant criteria are weighted.

Table 4. Ranking criteria for the marine mammals monitoring techniques presented.

Criteria	Weighting	Method			
		Acoustic Array	Aircraft Non Special	Aircraft Special	UAVs
Cost (<AU$100k good)	2.0	20	14	6	6
Ease of Use	1.5	15	12	9	14
Probability of detection	4.0	8	10	36	36
Onsite Set-Up and preparation	1.5	6	12	8	13
Reliability (Salt Water Env.)	1.0	6	9	9	9
Flexibility	1.0	7	7	7	10
Continuous 24 hr surveillance	2.0	20	6	10	18
Data storage	1.5	15	2	14	14
Real time information	2.0	20	6	18	18
Post trials analysis	1.0	10	1	9	9
Support (personnel)	1.5	13	8	5	14
Value added for future deployments	1.0	10	8	8	10
Weighted Total		**150**	**97**	**139**	**171**

4.4. System Assessment

On the basis of the above ranking, the preferred system to monitor marine mammals would appear to be the adoption of UAVs - this is based on a combination of its detection probability and its flexibility of operation. It appears to provide a low risk solution. Specially equipped surveillance aircraft provide similar performance but suffer from greater regulatory requirements, a large support staff (with attendant cost) and inflexibility of use. Experience shows that UAV systems that fly themselves via a pre-programmed GPS based system and are equipped with stabilised optics are preferred.

The results infer that an acoustic system may still be chosen ahead of the UAV, especially if larger arrays can be used to increase gain. An acoustic solution has the advantage that it can be "tuned" and used stand-alone once sufficient data is obtained for a site.

An alternative option is to consider an acoustic system to augment the UAV. Combined with the UAV system, acoustic monitoring will add significant assurance and confidence in detection in murky or poor visibility conditions. One scenario sees the acoustic system used to provide continuous monitoring with the UAV deployed immediately preceding blast events.

5. CONCLUSIONS

This assessment recommends that UAV surveillance is complemented with passive acoustic tracking to provide a high level of confidence in marginal acoustic and weather conditions. The benefits of UAVs include:

- excellent detection capabilities employing visual and infra-red focusable optics.
- low altitude surveillance or monitoring.
- "shoulder" launch capability for flexible operational use.
- autonomous UAV tracking, either pattern or waypoint directed overflight.
- use in all but severe weather.
- deployable at any time, day or night, subject to flight permissions, and
- requires small team for operations and support.

The back up acoustic array system can be utilized to:

- perform noise control (management of noise from other construction activities) and blast monitoring,
- monitor approaching mammals, especially during night time periods, and
- provide the trigger for the deployment of UAVs.

This combined system significantly increases the efficacy of meeting the surveillance and monitoring requirements for the conservation of the marine mammal population.

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