Workshop Report:
Review of Near-Real Time Whale Detection Technologies

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WORKSHOP REPORT: REVIEW OF NEAR-REAL TIME WHALE DETECTION TECHNOLOGIES

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ABSTRACT

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Vessel strikes are one of the threats negatively affecting the recovery of two of Canada's endangered whale species: North Atlantic Right Whales (NARWs) and Southern Resident Killer Whales (SRKWs). A component of Canada's Ocean Protection Plan (OPP), referred to as the Whale Detection and Collison Avoidance (WDCA) initiative, involves investigating technologies that will enable detection of whales in and around areas where vessel activities occur in support of the development of a near real-time alert system for reducing the threat of vessel strikes. This paper reviews technologies that could be used to provide information on the presence of NARWs and SRKWs in near real-time. The goal is to identify existing or emerging technologies or systems that could be useful for detecting whales, and specifically to evaluate their suitability and likely effectiveness for detecting NARWs and SRKWs in near real-time in Canadian waters. Above water sensing systems such as basic light cameras, thermal imaging detection via infrared (IR) cameras, radio detection and ranging (RADAR), and satellite-based multispectral optical technologies; and underwater sensing systems including passive acoustic monitoring (PAM) and active Sound Navigation and ranging (SONAR) technologies are considered. Visual detection and PAM systems are currently the primary and most accurate marine mammal detection modalities being used, and substantial developments in both PAM and IR camera systems in recent years make them the most promising technologies on which to focus efforts under the OPP WDCA initiative. PAM and IR camera technologies will be tested in near shore areas off eastern and western Canada, the results of which are expected to provide insights into future development of a near real-time alert system to reduce potential NARW and SRKW vessel strikes.

RÉSUMÉ

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Les collisions avec des navires sont l'une des menaces au rétablissement de deux des espèces de baleines en voie de disparition au Canada : la baleine noire de l'Atlantique Nord (BNAN) et l'épaulard résident du sud (ERS). L'Initiative de détection et d'évitement des baleines (IDEB), qui s'inscrit dans le Plan de protection des océans (PPO), vise à étudier des technologies permettant de détecter la présence des baleines à l'intérieur et autour des zones où se déroulent des activités de navire afin de développer un système d'alerte en temps quasi réel pour réduire les collisions avec des navires. Cet article présente une revue des technologies qui pourraient servir à fournir des renseignements sur la présence de BNAN et d'ERS en temps quasi réel. Le but est de déterminer des technologies ou des systèmes existants ou émergents qui pourraient servir à détecter les baleines, et plus particulièrement, à évaluer leur aptitude et leur efficacité probable à détecter les BNAN et les ERS en temps quasi réel dans les eaux canadiennes. On y passe en revue les systèmes de détection de surface, tels que les caméras d'éclairage de base, les caméras infrarouges (IR) à imagerie thermique, les systèmes de détection et de télémétrie par radioélectricité (RADAR) et les technologies d'imagerie optique multispectrale satellitaire, ainsi que les systèmes de détection sous-marine, tels que la surveillance acoustique passive (SAP) les technologies actives de détection et télémétrie par échos sonores (SONAR). Les systèmes de détection visuelle et de SAP constituent les principales modalités de détection des mammifères marins les plus précises actuellement utilisées. Les progrès importants réalisés en matière de systèmes de caméras de SAP et de caméras IR au cours des dernières années en font les technologies les plus prometteuses sur lesquelles les efforts doivent porter dans le cadre de l'IDEB du PPO. Les technologies de caméras de SAP et de caméras IR seront évaluées dans les zones côtières de l'Est et de l'Ouest du Canada. Les résultats de ces évaluations devraient contribuer au développement futur d'un système d'alerte en temps quasi réel pour réduire les possibilités de collision entre les BNAN/ERS et les navires.

INTRODUCTION

BACKGROUND

The density of ocean-based vessel traffic has been increasing globally over the past few decades (Tournadre 2014), including in Canadian waters where endangered and threatened whale species occur. As vessel traffic has increased, so has the risk of negative impacts caused by vessels on whales and other marine species (Pirotta et al. 2019). Vessel activities can negatively impact whales by producing noise that can lead to adverse behavioural responses, displacement, increased stress, and masking of biologically important signals, all of which has the potential to negatively impact the health and survival of individuals and populations. Vessels can also strike whales, injuring or killing them.

In November 2016, the Government of Canada announced a new program to protect Canada's coasts and waterways: the Ocean Protection Plan[1]. A sub-initiative under the OPP, referred to as the OPP Whale Detection and Collision Avoidance (WDCA) initiative, is focused on evaluating and testing technologies that will enable timely detection of whale presence, accurate identification of the species and/or population, and effective tracking of whale movements. The ultimate goal of this initiative is to contribute to reducing the risk of whales being struck by vessels by testing the efficacy of near real-time alert systems that could be used to inform managers, regulators and mariners of whale presence within the vicinity of vessels or areas through which vessels are transiting. The initial focus of this work is on North Atlantic right whales (NARW; *Eubalaena glacialis*) on the east coast and Southern Resident killer whales (SRKW; *Orcinus orca*) on the west coast. Vessel strikes are recognized as an important threat to the recovery of both of these endangered species (DFO 2017a, 2017b). These species (NARW and SRKW); however, are not the only marine species threatened by vessel strikes and a more general application of the results of this work will also be useful for reducing the risk of vessel strikes for other species.

OBJECTIVES

The objective of this review is to identify existing and emerging whale detection technologies that may be used to provide information on NARW and SRKW presence in near real-time (within minutes, hours or days) in areas where there is risk of vessel strikes. Also considered will be the time scale over which these technologies can be operational and whether this will be effective for vessel alerts to prevent strikes, as detection and verification of species and/or population may differ between these two species, primarily due to differences in movement patterns and duration of site occupancy. The technologies reviewed include above water sensing systems such as such as visable light cameras, thermal imaging detection by infrared (IR) cameras, radio detection and ranging (RADAR), and satellite-based multispectral optical technologies; and below water sensing systems including a number of passive acoustic monitoring (PAM) technologies as well as active sound navigation and ranging (SONAR) technologies.

This review was conducted to inform discussions during the workshop "*Review of whale detection technologies and their applicability in Canadian waters*" hosted by Fisheries and

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[1] Ocean Protection Plan website: https://www.tc.gc.ca/en/campaigns/protecting-coasts.html.

Oceans (DFO) in Montreal, Quebec on February 20-21 2018, which included participation from DFO, the National Oceanic and Atmospheric Administration (NOAA), other government agencies, academic organizations and other experts (see Appendix A for the Terms of Reference for this meeting). It is important to note that the intent of this paper is not to provide a comprehensive review how each technology works and testing that has occurred within the context of marine mammal detection, or of specific systems available within each technology category (though in some cases specific types of systems are referenced as examples). Rather this paper seeks to provide information about the basic utility and limitations of each general type of technology that should be taken into consideration when developing a near real-time whale detection system, and much of the information presented is a slightly edited version of the working paper that was provided to meeting participants during the February 2018 meeting.

SPECIES OF FOCUS

NORTH ATLANTIC RIGHT WHALE (NARW)

NARWs are large baleen whales which grow to about 17 m in length and weigh up to 60-70 tonnes (DFO 2014). They have large heads and paddle-like flippers, but lack a dorsal fin and throat grooves. The body is stocky and black in colour with white patches sometimes present on the chin and ventral area (Figure 1). Individual NARWs are distinguished by callosities (patches of raised skin covered by whitish whale lice) on the head and chin that occur in patterns unique to individuals (DFO 2014).

NARWs range from Florida to Iceland and Norway, and generally use more southerly waters off northern Florida and Georgia for calving in the winter and move to more northern waters in the Gulf of Maine, Bay of Fundy, Scotian Shelf, and Gulf of St. Lawrence in the summer to feed and socialize (Figure 2; Reilly et al. 2012, DFO 2014, Simard et al. 2019), though they have been detected in northern areas year-round (DFO 2019). The Grand Manan Basin in the Bay of Fundy and Roseway Basin off southwestern Nova Scotia have been identified as critical habitat for NARW in Canadian waters (Figure 2; DFO 2014).

*Figure 1: North Atlantic right whale (*Eubalaena glacialis*) (source: DFO 2014; credit: Scott Landry, Provincetown Center for Coastal Studies).*

NARWs spend much of their time at or near the surface. They may be observed alone or in large groups, and surface-active groups (SAGs) consisting of 3-40 individuals have been documented (DFO 2014). When surfacing, NARWs have a distinctive v-shaped blow that can reach 7 m in height (DFO 2014).

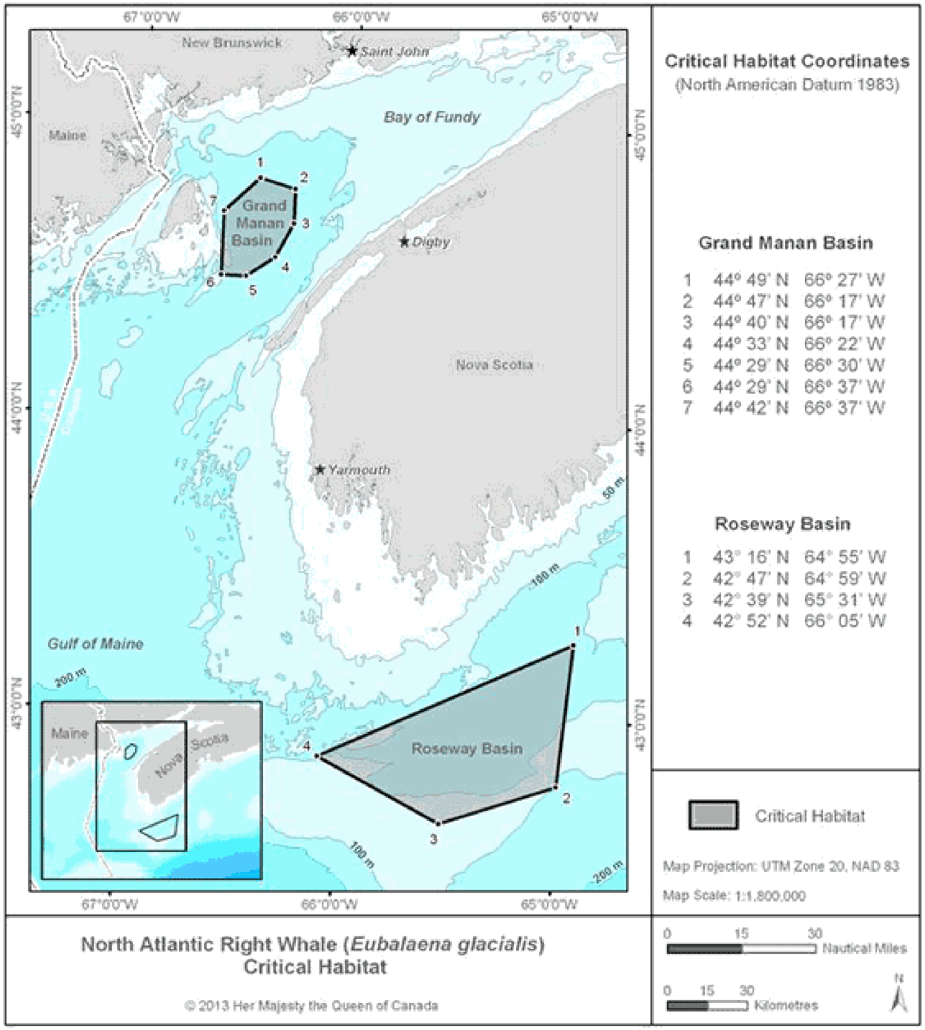

Figure 2: Critical habitat identified for North Atlantic right whales in Canadian waters (source: DFO 2014).

NARWs feed mainly on copepods by swimming through aggregations of these prey with their mouths open (Baumgartner and Mate 2003, Reilly et al. 2012). They have been observed skim feeding in surface waters and at depth (Baumgartner and Mate 2003). Based on a study of tagged animals, during feeding dives NARWs descended rapidly to a depths of 80-175 m and remained there for about 5-14 min feeding on discrete layers of zooplankton, followed by a rapid ascent. Average dive duration was 12.2 min while average dive depth was 121.2 m (Baumgartner and Mate 2003).

NARWs produce a number of different low frequency tonal calls and also some broadband calls, primarily for communication purposes including to maintain contact with one another over larger distances. The majority of their calls occur at frequencies between 50-500 Hz, though energy in some calls can extend up to 20 kHz. Most calls are short in duration, lasting from less than 5 sec and are produced at irregular or variable intervals. Some of the tonal call types described include screams, downcalls, constant low-frequency calls, moans and warbles (Laurinolli et al. 2003, Matthews et al. 2001, Parks 2003, Parks and Tyack 2005). The most commonly described NARW call type is the upcall – a 0.5-2 sec upsweep beginning around 50 Hz and sweeping up to about 200 Hz (Figure 3; Laurinolli et al. 2003, Parks 2003; Parks and Tyack 2005). Upcalls are a contact call made by all individuals in the population including males, females, adults and calves, and appear to be made in all areas in which NARWs are regularly occur, and most automated detector-classifiers that have been developed for NARWs target upcalls, (e.g., Parks 2003, Clark et al. 2010, Baumgartner et al. 2013). Gunhots are another commonly described call type and are very brief (usually < 0.2 sec), broadband (ranging between 20 Hz-20 kHz), loud calls that seem to be primarily produced by males, often when within SAGs, and likely have some sort of reproductive function, for example they may be an antagonistic signal directed towards other males (Laurinolli et al. 2003, Parks et al. 2005; Parks and Tyack 2005). There remains many knowledge gaps about NARW vocalization behaviour, including call repertoire and calling rates in different areas, during different times of year, and during different behavioral contexts (e.g., socializing,transiting, resting, etc.).

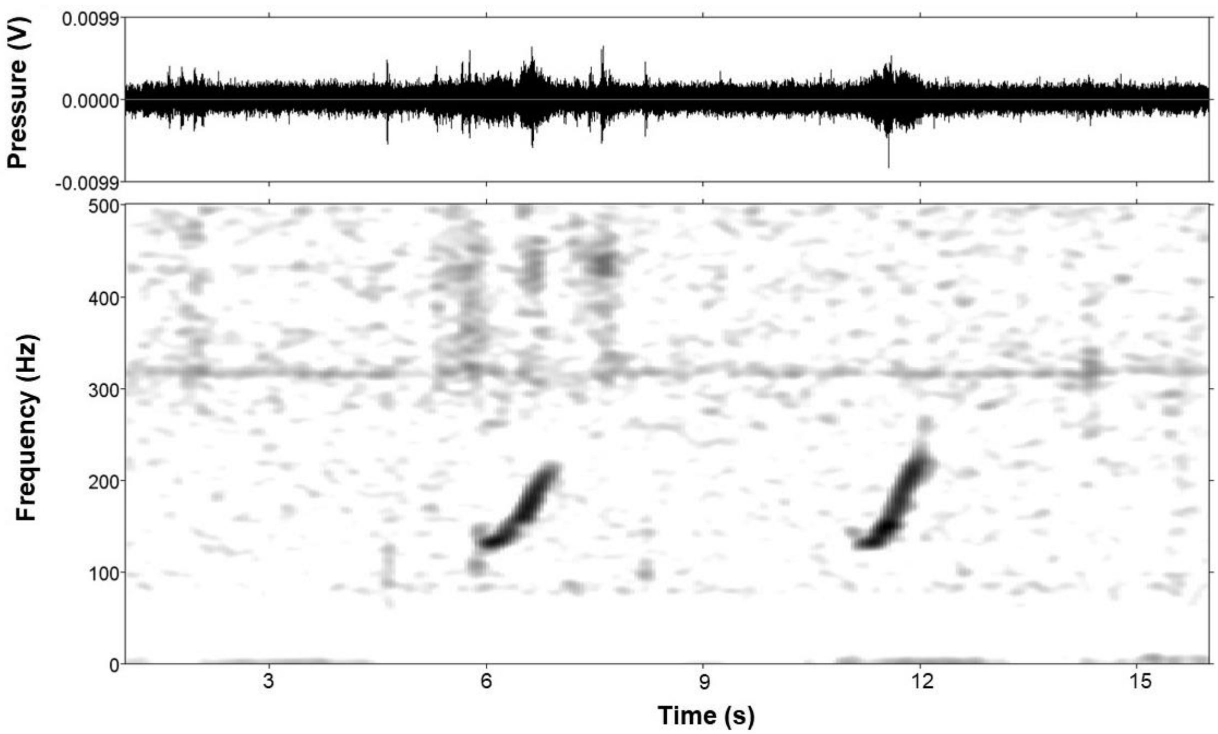

Figure 3. Waveform and spectrogram of typical North Atlantic right whale upcalls (figure produced in PAMlab, JASCO Applied Sciences).

With a population estimate of less than 450 individuals and declining (Pace et al. 2017, Corkeran et al. 2018), NARWs are considered one of the most endangered of the large whale species. The NARW Recovery Strategy (DFO 2014) and Action Plan (DFO 2016) identified vessel strikes as a primary threat to species recovery. It has been documented that on a per capita basis NARWs are more likely to be struck by a vessel than other large whale species (Vanderlaan and Taggart 2007). Figure 4 shows reported NARW mortalities from 1987 to 2017 in Canadian waters, including those attributable to vessel strikes. Reinforcing the importance of vessel strikes as a threat to NARW, an ongoing NARW Unusual Mortality Event declared by the United States (US) National Oceanic and Atmospheric Administration (NOAA) in 2017 due to the documented deaths of 30 NARWs (21 in Canada and 9 in the US) over the period of 2017-2019, the majority of which have been determined to be caused by vessel strikes and entanglements[2]. Twelve of the dead individuals in Canada were examined, eight of which were determined to be suspect or probable vessel strikes (two deaths were attributed to entanglement, while cause of death of two individuals could not be determined) (Daoust et al. 2017, Bourque et al.2020). Some mitigation measures to avoid lethal vessel strikes include implementation of dynamic vessel slow down zones based on confirmed NARW sightings (such as those implemented in the Gulf of St. Lawrence; DFO 2017a) or confirmed NARW call presence (such as those implemented off northeastern United States as part of the mariner alert system; Moller et al. 2005). Static speed restrictions have also been implemented to reduce the risk of lethal vessel strikes in the United States in right whale habitats (IMO 2003, NOAA 2008) and vessel re-routing around right whale habitats in both Canada and the United States (IMO 2003, 2006, 2008, NOAA 2006).

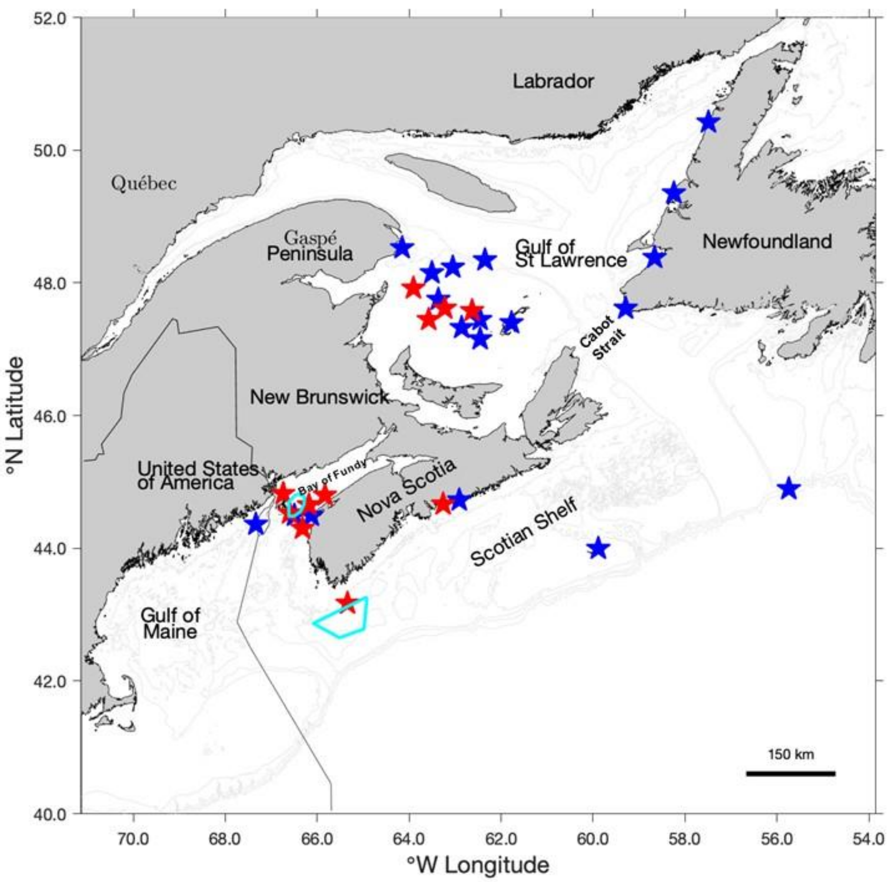

Figure 4: Bathymetric (100, 200, 500, and 1000 m isobaths) chart of Atlantic Canada illustrating the North Atlantic right whale critical habitats (light blue polygons), the known right whale mortalities in Canadian waters discovered from 1987 through 2017 with red stars depicting first observed locations of right whale carcasses where death was attributable to vessels strikes and blue stars depicting first observed locations of right whale carcasses due to fishing gear entanglements and unknown causes of death. The Canadian Exclusive Economic Zone boundary and "grey zone" polygon (dark grey line) are also depicted.

[2] https://www.fisheries.noaa.gov/national/marine-life-distress/2017-2020-north-atlantic-right-whale-unusual-mortality-event#more-information (last accessed April 22 2020)

SOUTHERN RESIDENT KILLER WHALE (SRKW)

Killer whales are the largest member of the oceanic dolphin family. They are sexually dimorphic, with males growing to about 9 m in length and weighing 5.5 tonnes and females growing to about 7.7 m in length and weighing about 4 tonnes (DFO 2018).They have a distinctive colouration pattern, mainly black on top and white underneath with white oval eye patches and a grey saddle patch behind the dorsal fin (Figure 5). Each individual killer whale has a uniquely shaped dorsal fin and saddle patch, and many have naturally acquired nicks and scars on their dorsal fin or body shanks making them individually identifiable.

Figure 5: Killer whales (Orcinus orca) (source: https://www.nps.gov/sajh/learn/nature/orca.htm).

Killer whales have a global distribution primarily in temperate and colder waters, and are found in much of Canada's waters including on both the east and west coasts (DFO 2018). Currently killer whale populations are considered to be all of the same species but many differ in size, diet, colouration, and vocal patterns which allows the division into distinct ecological types (Heyning and Dahlheim 1988, Ford et al. 2000, Barret-Lennard and Ellis 2001). Each ecotype is unique due to their choice of prey, their acoustic dialect and other socially learned behaviours. Globally, there is little variation in mitochondrial DNA, which suggests that the split in ecotypes is a recent phenomenon (Barrett-Lennard 2000, Hoelzel et al. 2002, Morin et al. 2015), yet they maintain socially and genetically isolated groups. The Canadian Pacific hosts three killer whale ecotypes, each managed as separate populations: Bigg's (formerly called Transient) killer whales, offshore killer whales, and resident killer whales. In Canadian waters the resident killer whale eco-type is represented by the northern resident killer whale (NRKW) and SRKW populations. The SRKW population is listed as endangered both in US (NMFS 2008) and in Canadian waters (DFO 2018).

SRKWs range from central California to Southern Alaska (Ford et al. 2017), but aggregate in the Salish Sea (inside waters off the coasts of Southern British Columbia and Washington State), especially during the summer (DFO 2018). SRKWs are often observed in waters of Juan de Fuca Strait and adjacent Swiftsure Bank, around the San Juan Islands (US) including Haro Strait, the waters around the Canadian Southern Gulf Islands, and the Southern Strait of Georgia up to Texada Island (Ford et al. 2017). Areas off northern Washington State and southern British Columbia including offshore areas along southwestern Vancouver Island have been identified as critical habitat for this population (Figure 6; DFO 2018).

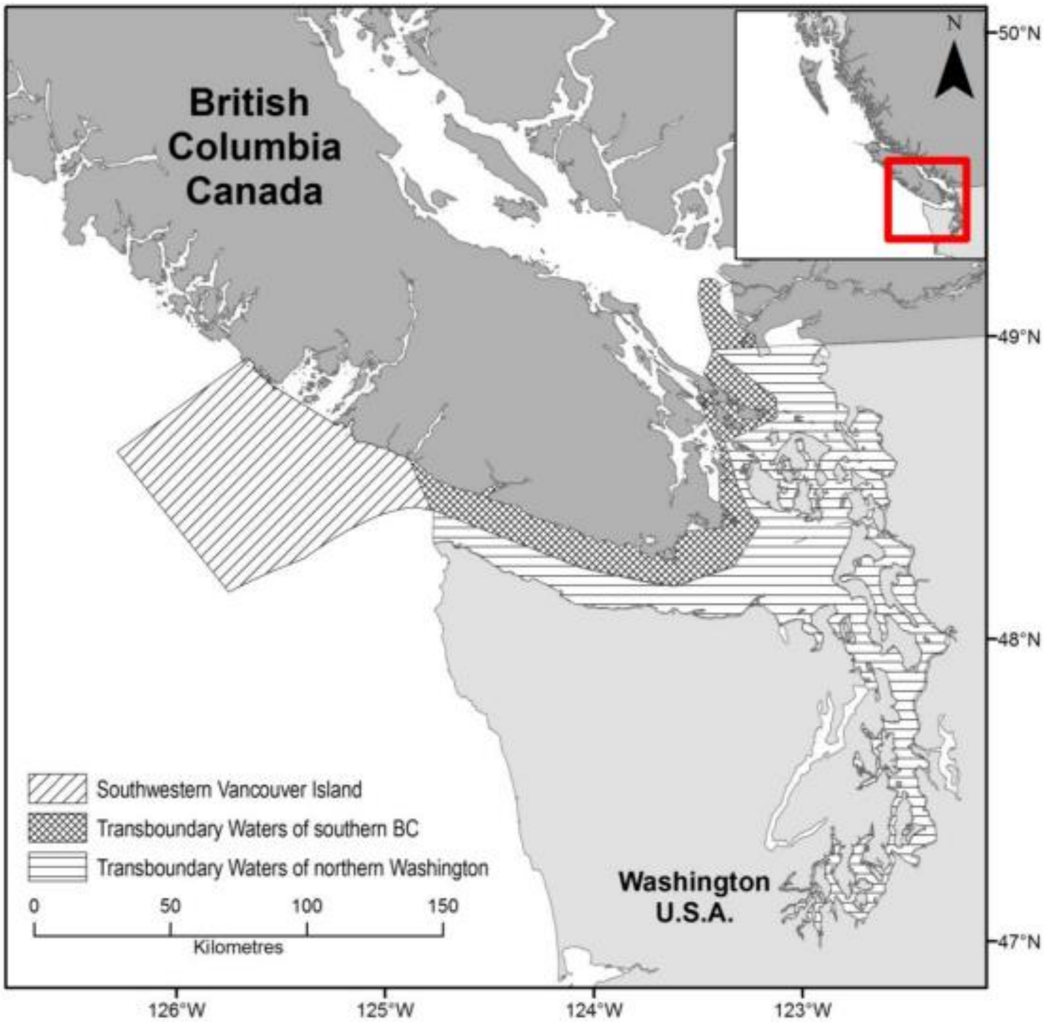

Figure 6: Critical habitat identified for Southern Resident killer whales (source: DFO 2018).

Resident killer whales (including SRKW) are fish eating specialists that travel in larger social groups and are more vocally active and display more surface active social behaviour than marine mammal specialists (such as Bigg's killer whales). Killer whales live in natal groups called matrilines that consist of a female and all her living offspring. SRKW matrilines that are closely related often swim together forming pods ranging from 15–45 animals, and sometimes pods travel together (Ford et al. 2000). The SRKW population is subdivided into three pods called J, K, and L pod. J pod is the most commonly seen pod in the Salish Sea year-round, while K and L pods often spend winter months off the outer coasts, particularly off the Washington State and Oregon coasts as well as off Vancouver Island (DFO 2018). In recent years (since 2017), the Center for Whale Research shows that during the summer all three pods have spent increasingly more time in offshore waters and around the entrance of Juan de Fuca Strait and along the west coast of Vancouver Island[3]. Further work is required to determine if this change in summer distribution is permanent, following a change in prey distribution. Although the pods have been spending less time in the Salish Sea in summer,

[3] https://www.whaleresearch.com (last accessed April 29 2020)

sightings of all three pods have occurred within these waters during winter months. More work is needed to determine the importance and regularity of use of the Salish Sea over winter.

Killer whale blows are smaller and bushier than baleen whale blows, and they are often visually identified at the surface by their tall dorsal fin rather than their blows. SRKWs always travel in groups (single or multiple pods) but tend to forage individually, and mostly on Chinook salmon (*Oncorhynchus tshawytscha*) (Hanson et al. 2010). They forage for prey at depths ranging from 10 m to over 200 m, but spend more than 75% of their time in the upper water column above 50 m depth (Wright et al. 2017).

SRKWs produce echolocation clicks to navigate and forage, narrowband whistles to communicate when within relatively close proximity of one another, and amplitude-modulated pulsed calls to maintain contact and communicate over larger distances (Figure 6; Ford 1989). SRKW pods have call dialects with repertoire sizes ranging from 7-17 distinct call types that allows for identification of the group. These calls range in frequency from 600 Hz to 40 kHz, with most sound energy between 1-15 kHz (Ford 1989, Holt et al. 2011). Calls can have two frequency components; the higher frequency component often transmits directionally out the front of the whale, while the lower frequency component is omnidirectional (Figure 6). Call types and even calls of the same type can differ in duration.The broadband sound pressure source level of calls ranges between 135 and 176 dB re. 1 uPa at 1 m, and some calls have been detected from more than 15 km away under quiet conditions (Miller 2006, Holt et al. 2011).

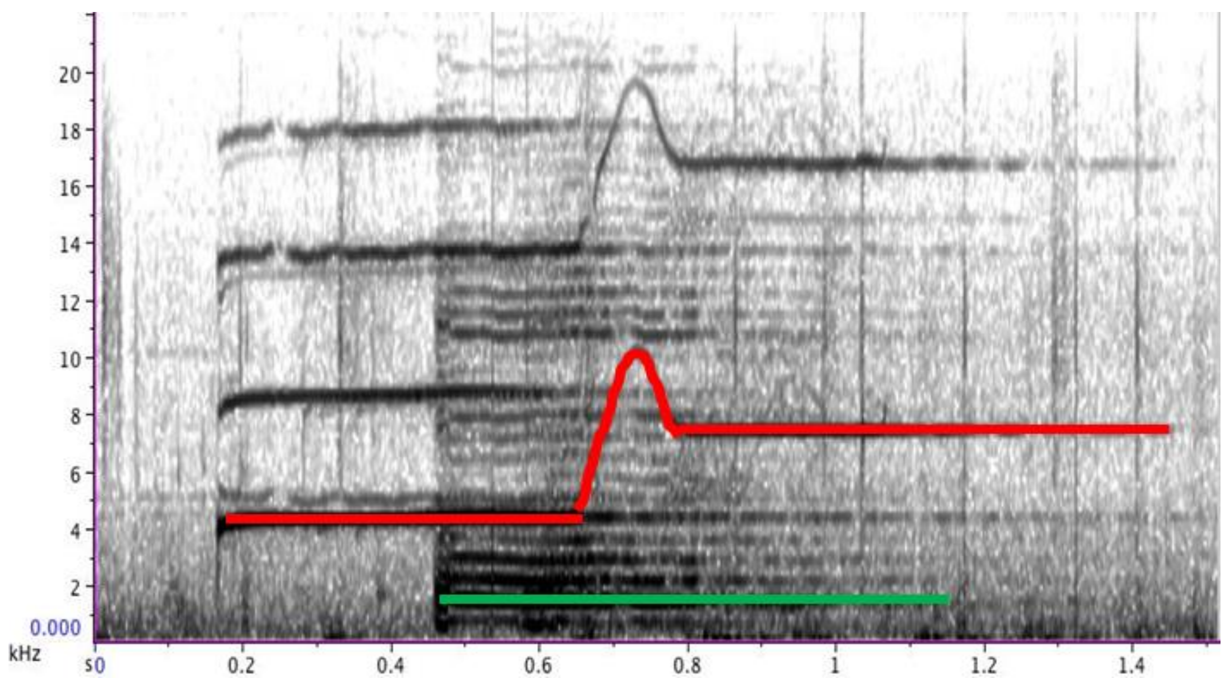

Figure 7: A spectrogram of an example Southern Resident killer whale amplitude-modulate pulsed call (figure produced in Raven Pro, TheCornellLab). These calls can have two frequency components: the higher frequency component (shown in red) often transmits directionally out the front of the whale, while the lower frequency component (shown in green) is omnidirectional.

SRKWs are an endangered population consisting of 73 animals as of January 2020[4]. Several SRKW deaths have been attributed to vessel strikes; for example, L98 was a seven year old male who was separated from his matriline for an extended period and later confirmed dead due to vessel strike, J34 was a male who died showing signs of blunt force trauma assumed to be the result of a vessel strike, and L112 was found dead on a beach in Washington State showing signs of blunt force trauma that could have been the results of a vessel strike. While these events are considered rare with only two cases of suspected vessel strikes documented in recent years, due to the very small SRKW population size, mortalities due to vessel strikes of even very few individuals can potentially lead to population decline. Vessel traffic occurs throughout most of the range of SRKWs and vessel strikes are identified as threats in both the Canadian and US recovery plans for the population (NMFS 2008, DFO 2018).

MARINE MAMMAL DETECTION SYSTEMS

DETECTION, CLASSIFICATION, LOCALIZATION, AND TRACKING (DCLT)

The process of identifying a whale (specifically a NARW or SRKW), regardless of which type of sensing technology or signal detector system is used, can be divided into four activities that will be considered as part of this review: detection, classification, localization and tracking (DCLT).

Detection refers to the identification of the presence of a whale. Is there a detectable signal (cue) from the whale of sufficient magnitude to recognize that something is there?

Classification refers to the assignment of the detection to a species or sub-species level, or determining that the noise is non-biological and coming from a noise source (such as a vessel, seismic airgun, hammer strike during pile driving, etc.). Is the detected signal (cue) recognizable as being associated with a particular animal, species or group or other important target?

Localization refers to determining the location of the whale relative to the location of the sensor. Is it possible to determine a bearing and/or distance to the detected signal (i.e., position of the whale)? In many cases, it may only be possible to determine that the target is within an estimated distance of the sensor.

Tracking refers to following the movement of the whale over time. Is it possible to derive speed and direction of the animal from the detected signals (i.e., position of the whale over time)?

It should be noted that the processing of data from these four activities sometimes overlaps. For example, a whale's localization or track parameters may provide a clue as to the classification of the target. Sometimes detection and classification are completed as a single process, and some systems are focused only on detection-classification and do not attempt to localize or track animals. With some technologies detection, localization and tracking may be available, but classification is not possible.

FEATURES OF A DCLT SYSTEM

To achieve an effective DCLT system for NARWs and SRKWs, a number of system attributes must be considered. The following was generally assessed for each technology as part of this review:

- Physical/biological cue

[4] Latest population count as indicated on the Center for Whale Research website: https://www.whaleresearch.com/orca-population (last accessed April 22 2020)

- What is the signal/cue that the system is detecting?
- What is the probability of detection? How often is the signal (cue) available for detection, or what is the probability that the individual animal is accessible for detection? For example, a visual system uses light reflected from a whale on or just below the surface for detection so the amount of time a whale spends at the surface impacts the probability that it will be detected; if the animal is not near the surface, it is dark or visability is poor (due to sea state, weather, fog, etc.), the technology will not work. Similarly, the absence of an acoustic signal does not represent the absence of a whale because vocal rates of animals sometimes differ over time, location and behavioural state.

- Sensor
  - What are the capabilities and limitations of the physical sensor?
  - Can the sensor effectively detect the signal/cue of interest and over what distance?
  - Does it provide directional or localization information?
  - Does it allow for tracking and if so over what distance and time?
- Signal processing and automated DCLT capabilities
  - What is required to transform a digitized signal time series into detection and localization information?
  - What is the performance of the system? What level of accuracy, precision and recall (number of missed signals and number of false detections) can be achieved?
- Deployment platform(s)
  - Each DCLT system needs to be mounted to a physical deployment platform. These platforms can be divided into three groups: active mobile and passive mobile (drifting) platforms, and stationary platforms. Most DCLT technologies may be deployed on multiple platforms. For example, human visual observers may be shore-based, shipborne, or airborne. However, each platform option will have limitations and strengths which will be evaluated.
  - Mobile platforms may operate in space, air, on the water's surface or below the surface. Within this context, mobile platforms have controlled mobility. Mobile platforms include satellites, manned aircraft (e.g., planes and helicopters), unmanned aircraft systems (UAS), vessels, submarines and unmanned underwater vehicles (UUV).
  - Stationary platforms may take many forms including anchored remote systems, sea bottom-mounted systems either cabled to a shore station or to buoy, land-based systems, or geo-stationary satellites.
  - Drifting systems move with wind and/or ocean currents. Generally, the only movement control which may be available to these systems is to change depth.

DETECTOR-CLASSIFIER PERFORMANCE METRICS (LOCATION AND TIME SPECIFIC METRICS)

Though a simple metric to compare the performance of different DCLT systems is desired, one is generally not available. It is difficult or nearly impossible to directly compare detection range (the range to which a system can detect a particular signal/cue) between systems without considering the probability of detection (the probability that the signal/cue will be detected by the system), which can be influenced not only by the sensor capabilities but also by environmental conditions (e.g., transmissibility of the signal in air and/or water) and behaviour of the target species. Assessing the probability of detection, and how to use these probabilities has been discussed in many previous studies (e.g., Borchers et al. 2002, Buckland et al. 2001, 2004, 2015, Seber, 1986, Thomas et al. 2010), but there are still inconsistencies and uncertainties about how to accurately assess detection probability in a standardized way. A number of studies have looked at detection probabilities and the likely spatial range to which different whale species may be detected for specific types of systems within specific contexts, but the methods applied and metrics used to evaluate the effectiveness of these systems vary considerably between studies.

Detectors-classifiers for whales can have four possible outcomes:

- True positive - when a detection/classification occurs when the whale(s) or call(s) are present within the detection range of the system (the detector-classifier is correct);
- True negative - when no detection/classification occurs when the whales or calls are not present within the detection range of the system (the detector-classifier is correct);
- False positive - when a detection/classification occurs but the whales or calls are not present within the detection range of the system, also called a false alarm (the detector-classifier is incorrect);
- False negative - when no detection/classification occurs but the whales or calls are present within the detection range of the system, also called missed detections (the detector-classifier is incorrect).

An ideal detection/classification system would have a high rate of true responses, particularly true positives (correct detections and classifications) and a low rate of false responses, particularly false negatives (missed detections and misclassifications). However, typically there is often a trade-off between these because signals travel through a dynamic environment and are affected by changes in visibility or sound speed. Introduced ‘noise’, either visually or acoustically, will influence the detection/classification process and its success. As detection thresholds are decreased, for example by adjusting how much the signal strength has to exceed environmental noise to be detected to prevent missing signals of interest, the probability of detecting signals that are not from the whale(s) but are visually or acoustically similar (erroneous detections) increases. Parameters can often be adjusted within a detector-classifier to better suit the needs of the study (for example, if it is important not to miss any true detections one could set parameters to allow for high true detection rates, at the expense of high false detection rates), also leading to variation in false positive and false negative rates for any one system.

Fully quantifying the performance characteristics of a system and how it varies with parameter settings (and with varying environmental conditions and animal behaviour) is often very difficult, which causes problems when characterizing performance in a standardized way that is comparable both within and among technologies in different environments. Further, there are other requirements beyond detection-classification performance that must also be met to be an effective DCLT system, and consideration must also be given to cost, time to acquire a DCLT solution, time to validate a DCLT solution, user training requirements, data archiving, telemetry and communications, power requirements in addition to the costs of maintenance of the system in an marine environment. This review will present information on performance metrics when available, but will take a less structured approach to evaluating overall likely effectiveness for detection-classification of SRKWs and NARWs based on a qualitative review of a variety of system requirements.

ABOVE WATER SENSING TECHNOLOGIES

MARINE MAMMAL OBSERVERS (MMO) AND LIGHT-CAPTURING CAMERA SYSTEMS

Summary: *The visual observation systems described in this section generally allow for detection and classification of whales at or near the surface, though accuracy can depend on a number of factors including experience and training of human observers, or performance metrics associated with automated detection-classification software. Detection probability, detection range and accuracy of classification varies by species and with environmental conditions that affect visibility. Localization via human observers can be very accurate as can be tracking, but these are also dependent on visibility.*

Visual DCLT is generally undertaken by trained marine mammal observers (MMOs) with or without optical aids, such as binoculars (Harwood and Joynt, 2009), on a variety of platforms such as vessels, aircraft and shore-based viewing stations. Light reflected from the animal's body, the wake that the animal creates, or exhalations (blows) at or near the surface are often used as detection aids and cues by the MMO. MMO training and experience greatly impacts detection and classification speed and accuracy; however, so does fatigue (e.g., number of hours spent on watch). Detection range and classification accuracy is also subject to environmental factors that affect visibility such as sea state and weather conditions, and the behaviour of the animal such as the amount of time spent at the surface. Evaluating MMO performance based on training, experience, fatigue, visibility and other factors is beyond the scope of this document.

Visual light-capturing basic camera systems can be deployed on a variety of platforms and are often fitted to UAS (Eggleston et al. 2015, Koski et al. 2013), but can also be fitted to buoys, manned aircraft, surface vessels, or operated from land-based platforms. Such camera systems can be equipped with automated detection or detection-classification software (image analysis software designed to analyze the video feed and pick out features similar to those of a whale), and video feeds and/or detection information can be relayed back to trained MMOs for analysis/verification. Visual camera systems operated by trained MMOs offer similar detection capability to that of trained MMOs in the field (Hodgson et al. 2017, Koski et al. 2015), but field of view may be more restricted. A benefit of having trained MMOs concurrently view and verify data from a direct video feed is that detection information can be verified instantaneously and then may be communicated within seconds or minutes of an observation with relatively low effort. In contrast to this, data being sent from remote camera systems requires significantly higher transmission effort and may be delayed in the relay of data or by the detection verification, which is generally completed by MMOs after receiving the transmission. UAS-camera systems, including capabilities and limitations of specific systems, have been reviewed in depth by Koski et al. (2010). Visual detection by any of these camera systems may be hampered by low light levels, fog, glare, rain, sea surface roughness, and hail/snow. Only animals at or near the surface can be detected visually. Visual classification and localization of the detection would also be affected by the same factors. Tracking can only occur while the animal remains at the surface (Verfuss et al. 2018), or between subsequent surfacings if dives are short enough with several surfacing events within the field of view.

An added benefit of visual detection by MMOs and basic light-capturing camera systems is that it allows for assessments of the health of observed individuals through examining body condition, scars, injuries and entanglements not observable by other means. In particular, photos and video can support more detailed analysis of injuries and entanglements, as well as more detailed health assessments, post-sighting.

NARWs and SRKWs are visually observable when each is at or near the surface. As both species are required to come to the surface to breathe, both spend much of their time at or near the surface. They have distinct surface profiles (such as the tall dorsal fin and distinctive coloration of SRWKW or lack of a dorsal fin on NARW) and surfacing behaviours (such as the v-shaped blow of NARW) that allow them to be easily differentiated from other species within the area, depending on distance and environmental conditions.

THERMAL IMAGING DETECTION (TID) VIA INFRARED (IR) CAMERAS

Summary: *Thermal Imaging Detection (TID) through use of infrared (IR) cameras offers a means for detection of whales at times when use of light capturing camera systems are limited (such as at night). Weather (such as fog or precipitation) can limit detection ranges or render detection impossible. The efficiency of IR cameras would be increased if automated detection software were integrated into the system. If height of the camera location can be accurately assessed, detection ranges can be estimated (and in some cases have been demonstrated to exceed several hundred meters). Systems may also be used to measure distances between whales and other objects on the water surface, such as vessels. Handheld IR cameras with automated detection systems will likely be of limited use due to the difficulty in interpreting the received signals and the problems in achieving accurate heights to estimate detection ranges. Many IR systems have been designed to operate from vessels or aircraft, but require camera stabilization to be integrated into the system. The are no technological constraints to operating these systems from land-based platforms. No data on classification, localization, or tracking capabilities of these systems is available.*

TID senses the part of the electromagnetic wave spectrum emitted by heat emitting objects. In the case of marine mammals, IR camera automated detection systems (Zitterbart et al. 2013, Zitterbart et al. 2015) or handheld IR monoculars/binoculars (Baldacci et al. 2005) sense the IR waves generated by the animal's body and by warm air exhaled by the animal (Cuyler et al. 1992, Butterworth 2006, Churnside et al. 2009, Horton et al. 2017). IR detection can only be made when the animal surfaces.

Background noise for an IR system consists of the energy emitted by other warm objects. Some environmental factors affecting performance are aerosols, fog, glare, light level, rain, sea state, snow, and water temperature (Verfuss et al. 2018). Wind dispersion of whale blows could be a potential limitation of this technology if used in windy areas. Like all electronic sensing equipment, IR systems can be affected by internal electrical and electronic noise.

Cuyler et al. (1992) observed that animals detected entirely due to heat emission of their body only produced short detection ranges (<150 m), likely limited by the height from which the equipment is applied. This limits the effectiveness of handheld devices. Handheld IR systems do not come with integrated automated detection software and cannot be used as an independent detection and classification tool but could be considered as an optical aid for visual observers.

Many IR systems are designed to operate from either a surface vessel or an aircraft, although vibrations or movements of the camera need to be considered when mounting on these platforms. Rotating line and planar cameras provide directional information and, depending on altitude/height of the camera system, can provide distance information. Rotating cameras can provide a view of all azimuths with multiple visits per second. Planar cameras provide single images (like a standard photographic camera) and must be augmented with pan and tilt capability or use multiple cameras to effectively capture a sufficient field of view. Planar cameras tend to be less complex, with a smaller footprint than rotating cameras. There is no technological barrier preventing systems from being mounted on land or from a shore-cabled buoy.

Energy supply and insufficient data bandwidth available to relay information to an operator (if direct relay of camera data is desired) may limit effectiveness of these systems. No references could be found discussing the effect of dried sea spray on lenses.

Verfuss et al. (2018) reviewed many of the available high performance IR systems. Several suppliers indicate their products can be used for IR detection of marine mammals (Ocean Life Survey, Seiche Measurement Limited, Toyon Research Corporation, Rheinmetall Defence). The AIMMMS (Automated Infrared-based Marine Mammal Mitigation System) by Rheinmetall Defence has been in development for a number of years. AIMMMS uses a rotating sensor and therefore provides 360^{o} coverage. Other systems exist and may be used for marine mammal detection, but there is very little information available on their performance with marine mammals. Ocean Life Survey, Toyon Research Corporation, and Seiche Measurement Limited have developed IR detection capability using cameras supplied by the same company (FLIR) (Verfuss et al. 2018). These and other systems (Polaris, RADES, Hyper-Cam and Gobi) provide self-evaluations of their performance. Polaris has estimated detection ranges between 150 and 400 m with large animals whereas Seiche has estimated minimum detection ranges for RADES at 2 km for large animals, 1.5 km for medium sized animals, and 1 km for small animals. Toyon estimated their shore-based system to have ranges from 2-5 km for large animals, 0.5–2 km for medium sized animals, and 1-3 km for small animals. Wessenberger and Zitterbart (2012) and Zitterbart et al. (2013) evaluated the performance of sensor and auto detection capability of their system and indicated large whales with large blows were detected at 5-8 km, and smaller whales were detectable at 3-5 km. Concurrent Corporation (2011) indicated that they were able to detect simulated blows (which were 3-6 m in height) at ranges of up to 2 km using a human observer. As indicated earlier, detection ranges are difficult to compare without considering the false negative and false positive statistics (Zitterbart et al. 2011, 2013). In a recent study on comparing detectability of humpback whales in Australia, Hawaii, and Canada via automated thermal imaging technology, false negative and true positive statistics were assessed (Zitterbart et al. 2020). False negative rates decreased with distance due to the larger field of vision, and at night potentially due to generally lower wind forces during this period. The authors concluded that re-training of the detection algorithm in a re-iterated fashion at each site increased detection probabilities. So far, no data on classification and localization capabilities is available. Height of the camera installation was positively correlated with detection range. As well, as IR systems are based on line of sight and localization is based on the inclination angle, localization accuracy can also be improved with increased altitude of the camera (Verfuss et al. 2018).

Graber et al. (2011) used three shore-based FLIR Thermovision A40M thermal IR systems to observe SRKW. These were mounted 13 m above sea level. SRKWs were observed from 43 m to 162 m away. Animals were detected at greater ranges (> 100 m), but only by blows and were difficult to classify to species level. No automated detection algorithm was applied.

NARWs have been observed in the Gulf of St. Lawrence using IR camera systems mounted underneath an aircraft (an L3 Wescam MX-15 mounted under a King Air B200 aircraft used for fisheries monitoring) [5]. Not only were NARWs detectable at the surface, but sub-surface detection cues were available – the surface water temperature was sometimes higher than the water directly above and behind the animal. It was hypothesized that cold water was being brought to the surface with the animals movements near the surface[2]. There is no published data on NARW detection ranges or detection probabilities for this system available.

RADIO DETECTION AND RANGING (RADAR)

Summary: *While Radio Detection and Ranging (RADAR) systems are actively being used for detecting, localizing, and tracking objects on the water, some testing that has been done for marine mammal detection specifically has demonstrated limited usefulness due to environmental interference of the signals travelling to and from the detected whale and difficulties with classifying received signals to the species-level. Effective range may only be less than 1 km for conventional RADARs, but could be as high as 6 km for optimized systems. If detection-classification problems are able to be resolved, RADAR could be used at short ranges for DCLT but likely only for larger species such as NARWs.*

Like TID, RADAR technology uses electromagnetic waves travelling through air to detect objects. However, there are some critical differences between IR systems and RADAR systems. A fundamental difference is that the IR systems are passive detection technologies whereas RADAR is an active detection technology. RADAR systems transmit electromagnetic energy through the air and then detects the energy scattered back from objects (including whales at the surface). By doing so, the whale does not need to be emitting energy (such as thermal energy). RADAR systems transmit electromagnetic radio or microwaves for detection as compared to the IR systems which passively detect light waves.

A typical RADAR system transmits electromagnetic energy and receives a return from an object or the target. Often RADAR systems have rotating highly directional components that sweep through azimuth with a relatively short revisit rate, allowing the system to determine both range and bearing to the object it's detecting. For a RADAR system to detect a marine mammal, the animal must be at the surface and have sufficient body exposure to reflect the radio wave. Reflections from nearby ocean waves may present themselves as false targets (noise or "clutter") and therefore RADAR systems are hampered by high sea states. RADAR system performance also degrades with fog, glare, rain, sea state, snow/hail, and presence of other false targets. RADAR systems may be mounted on vessels or aircraft, or can be land based. However, as the energy requirements for such an active system are significant, remote battery-operated systems may suffer from shorter operational duration than a continuously powered system.

Verfuss et al. (2018) considered the possible performance for detecting marine mammals of four surface detection RADAR systems available from three companies: RADAR Technology AS's Frequency-Modulated Continuous-Wave (FMCW) system that transmits continuously and their more conventional Magnetron pulsed system, Sea-Hawk Navigation AS's SHN X9 polarized pulsed RADAR and the National Oceanography Centre's (NOC) system (GANNET) based on a Kelvin Hughes RADAR with proprietary signal processing software. Whale detection capabilities have been demonstrated using these conventional RADAR systems though there exist a number of limitations and generally only short detection ranges (< 1 km) could be achieved even in optimal sea conditions (Verfuss et al. 2018). Verfuss et al. (2016), suggested that only high performance surface detection RADARs used for detecting large species would achieve

[5] Vanderlaan, A.S.M., 2018, personal communication.

greater detection ranges. Arête Associates and Brainlike Inc., have worked on processing time series from X-Band commercial surface RADARS for automatic detection of marine mammals (DeProspo et al. 2005, Forsyth 2008). Both studies demonstrated the challenges of limiting false positives in whale detection, but were able to successfully detect humpback, fin, and gray whales. Detections were confirmed up to 6 km in moderate sea conditions. According to Verfuss et al. (2018), the current weaknesses in RADAR for detection of whales include poor real world performance, inability to classify targets, and the limited amount of detection data available. Clutter (noise) from nearby waves makes masking of cues a potentially significant issue.

No studies that demonstrated RADAR detection of NARWs or SRKWs specifically were reviewed. One study tracking and detecting swim speeds of Atlantic killer whales using a shore-based X-band marine navigation radar reported a detection range between 1-1.5 kms (McCann and Bell 2017). The animals were visually identified as killer whales before ranging started. While RADAR systems could potentially be used to detect these species, similar to IR systems, purpose-specific automatic detection software (i.e., software specifically designed to detect a SRKW or NARW with RADAR) do not currently exist and would be required (noting that reliable classification of RADAR detections to the species level would be very difficult).

SATELITTE MULTISPECTRAL OPTICAL TECHNOLOGIES

Summary: *Satellite detection and classification has been tested with southern right whales and showed limited effectiveness due to small temporal satellite coverage of the same areas and high false negative (or missed detection) rates. Localization is limited to coverage of the satellite and tracking of animals is impossible. This technology is not likely useful as a near real-time detection tool.*

The concept of using satellite imagery to detect marine mammals (Fretwell et al. 2014, McMahon et al. 2014) began with the launch of the first high resolution (HR) imaging satellite, IKONOS 2 (Abileah 2002). Multispectral light (within and outside the visual light spectrum) from the sun is reflected from the animal and received. The reflectivity varies across the multiple light bands providing a detection cue. ICONOS 2 had 0.8 m panchromatic and 3.3 m multispectral resolutions. Its cross-track footprint (width of the strip on earth that the satellite can see) was 11-13 km with a 1 day revisit time (satellite receiving images from the same location on earth).

A newer generation of imaging satellite (Worldview2 with 50 cm in panchromatic and 2 m multispectral resolutions) has been used to detect and localize southern right whales (Fretwell et al. 2014). A single Worldview2 image covering 113 km^2, containing nine bands of information, was analyzed for presence of southern right whales. Manually detected objects of the right size and shape were assumed to be and classified as right whales. Though direct visual observations were not used as verification, the detections occurred in areas with known right whale aggregations. Automatic detection algorithms resulted in more detections than the manual annotation of images by human observers and classified fewer detections as probable or possible (i.e., inconclusive results) than the human observer. In principle, localization was feasible using the panchromatic band images (~50 cm per pixel resolution) and the images of the costal band that penetrates subsurface (~2 m per pixel resolution).

The analyzed satellite multispectral images of the southern right whales were taken on a day with a clear sky and little wave action (Fretwell et al. 2014). The introduction of wind, fog, snow, and rain would cause the performance to deteriorate. A limitation of the technology is that the mammals need to be at or just below the surface. New species-specific automatic detection algorithms would need to be developed to optimize the technology.

Higher resolution satellite imagery is now available with the launch of Worldview3 satellites in 2014. The new imagery has 34 cm in panchromatic and 1.24 m in multispectral resolution which will sharpen animal images. Depending on the data processing and detection verification process, satellite imagery may be used to determine areas of high animal presence, but long time intervals may make them less useful for real-time reporting.

This technology could be a potentially useful DCLT technology for NARW. As SRKWs are significantly smaller, it may be more difficult to effectively detect them using Satellite technology. However, it should be noted that this is the only sensing technology reviewed in this paper that yields wide-area data coverage, but the revisit time for a satellite sensing system may limit the update time and therefore utility of the information.

UNDERWATER SENSING TECHNOLOGIES

PASSIVE ACOUSTIC MONITORING (PAM)

Summary: *Passive acoustic monitoring (PAM) systems are an unobtrusive means to detect and monitor whale presence, using vocalisations as a cue of presence. Acoustic systems can be archival (recordings stored onboarduntil system retrieval) or relayed in real-time. Detector-classifier systems look for signals defined by their characteristics of frequency over time to distinguish whale calls from sounds in the background noise of recordings. If call detection is relayed in real-time, and classified by species, PAM systems can be a very useful tool for managers for dynamic management of vessel traffic passages through areas identified as important to whales and lessen the risk of vessel strikes.*

PAM systems, sometimes referred to as passive SOund Navigation and Ranging (passive SONAR) detection systems rely on detecting sound pressure waves underwater. Sound travels through water more efficiently than electromagnetic waves and therefore is easier to detect over greater distances than waves in other spectra (such as visible to infra-and/or ultraviolet light spectra). Sounds emitted from marine mammals (i.e., their calls and/or echolocation clicks) are used to communicate for social interactions (Janik and Sayigh, 2013, Quick and Janik 2012, Madsen et al. 2002, Schulz et al. 2008, Smith et al. 2008), to navigate (Payne and Webb, 1971, Verfuss et al. 2005), and to locate prey (Au et al. 2004, Madsen et al. 2005, Verfuss et al. 2009). These vocalizations provide the cue for PAM technologies.

PAM technologies are sensitive to background acoustic noise levels – either generated naturally (precipitation, wind-generated noise, seismic events/earthquakes, etc.) or by anthropogenic sources (construction, shipping, fishing, active sonars/echo sounders, seismic surveys, etc.). System self-noise (clanking chains or noise from the system's mooring, electronics, etc.) or water flow noise (a physical interference with sound pressure detection) may also introduce challenges. Acoustic propagation conditions are highly variable in space and time, and affect the capability of PAM technologies.

PAM systems come in many different forms and have been deployed on a variety of platforms (such as mobile, stationary and drifting platforms). Some examples of PAM systems include over-the-side hydrophones deployed from a stationary vessel/platform, hydrophone arrays towed by vessels, PAM packages integrated into autonomous underwater vehicles (AUVs), stationary PAM moorings, cabled hydrophone arrays, drifting buoys equipped with Pam packages, and more.

In addition to the wide range of PAM hardware and deployment platforms available, there also exist many different software options currently being used for processing PAM data. These include proprietary DCLT and acoustic display software (e.g., PAMlab and OceanObserver developed by JASCO Applied Sciences Inc.), as well as open source software (such as PAMGuard; Gillespie et al. 2008). PAMGuard is a popularly used real-time marine mammal

DCLT software for which a number of open source detectors for many species are available (especially those occurring in the Atlantic, and with a focus on toothed whales), that the user can customize or refine (Gillespie et al. 2008). Whetehr using proprietary or open-source software, a number of companies/organizations have been developing and testing detection algorithms specifcially for NARW and SRKW in recent years (e.g., Google is currently developing an artificial intelligence classifier to detect and discriminate killer whale calls from those of other whales in the Pacific).

Much of the advancement in marine mammal detection lies within PAM technologies, thus these approaches receive more attention in this document than other approaches. As this is a large field of research and many technology options exist, in the following sections general types of platforms and their strengths and limitations are discussed and some specific options available for each platform type are considered.

Mobile Platforms

Surface Vessels (Towed Arrays)

Towed hydrophone array systems may be deployed from vessels and autonomous surface vehicles (e.g., wave gliders). Vessels have the advantage of hosting operators, providing reliable power, as well as providing a base for detection verification and real-time communications. Autonomous surface vehicles have lower operating costs than vessels, but have limited power, cannot be deployed in all sea conditions and are at risk of collision with vessels.

Verfuss et al. (2018) reviewed a number of commercially available towed hydrophone arrays. The number of hydrophones in a towed hydrophone array can vary from two to hundreds. Of the reviewed systems, the Delphinis array (Sheldon-Robert et al. 2008, von Benda-Beckmann et al. 2010) developed by TNO in the Netherlands was the most capable and complex. As a research array, it has been used to track marine mammals and was designed to make marine mammal detections in three frequency bands (<12 kHz, <48 kHz, <150 kHz). The lower frequency array sections consist of 16 hydrophones each, while the 150 kHz array section has only a single hydrophone.

The WesternGeco Whalewatcher towed array also operates at multiple frequency ranges, but with more focus on the lower frequencies. The design effort has been to optimize sections to operate up to 250 Hz and to 4 kHz. A critical difference in the two array designs is that the Delphinis array was intended as a stand-alone towed system where as Whalewatcher system was designed to be integrated with a seismic streamer. The Sercel QuietSea system is also focused on the lower frequencies and is integrated with a seismic streamer. However, QuietSea includes a small number of elements which operate up to 96 kHz (Verfuss et al. 2018). These systems are significantly larger (higher number of sensors spaced over a greater distance to allow directional detection of sounds), and by using beamforming techniques outperform the 2-element towed arrays for detection and localization that are used by many researchers. Each of the discussed systems is operated using proprietary detection and display software.

There has been some effort to compare the performance of large-scale towed arrays to other types of marine mammal detection methods (e.g., visual detection methods). For example, Gordon et al. (2000) showed that there were 10 times the number of acoustic odontocete detections with a towed array as compared with visual detections by observers. Stone (2015) found the opposite to be true when reviewing the detection data from seismic surveys between 1995 and 2010. The difference in conclusions may be explained by independently influencing factors such as species, environmental conditions (acoustic propagation), visual and acoustic observer experience, and the equipment used.

There are many ways for towed arrays to localize targets. For coherently beamforming towed arrays bearings-only localization and tracking can be employed. By executing small turns, the bearings-only tracking may be extended to include distance estimates. However, many towed arrays used to detect and localize marine mammals use widely spaced hydrophones (typically 2-4 hydrophones many meters apart). In these cases, localization can be estimated by the time difference of arrival between the elements in the array. The ability to determine the time difference of arrival is related to the signal-to-noise ratio and the uniqueness of the time and frequency structure of the target vocalization.

Detection ranges vary greatly with towed hydrophone array systems and are dependent on the sensitivity of the recorders, the local environmental conditions and the signals and vocal behaviour of the target species. Detection ranges derived from data collected from combined acoustic and visual surveys may be more realistic. Based on empirical data, the effective half-strip width (the distance at which positive detections are possible and reliable) for sperm whales was measured to be 10 km (Lewis et al. 2007) in the Straits of Sicily. Abadi et al. (2015) were able to localize calling baleen whales (humpback whales) at ranges up to 26 km with a dual towed array system.

Subsurface Vessels

Subsurface vehicles used for marine mammal detection include autonomous underwater vehicles (AUVs; e.g., ocean gliders) equipped with PAM packages. Manned submarines could also fit into this category, but are beyond the scope of this discussion. Powered AUV's are either large in nature or have limited duration. One form of AUV known as "gliders" utilize changes in the center of mass and buoyancy causing the AUV to travel through the water column in a saw-toothed pattern, with slow lateral progress. Gliders have the advantage that as they travel in this saw-toothed pattern, the acoustic sensors travel through a range of depths. To communicate acoustic detections, the gliders must come to the surface where they can connect to remote communication systems to relay their detections and positions to a shore station. This does; however, put the glider at risk of collision with vessels. The data is transmitted via satellite (long-range) or other Radio Frequency (RF) communications (e.g., Freewave) over shorter distance. The delay from detection to reception can be minutes to hours depending on the surfacing intervals of the glider.

A number of options exist for gliders to detect whales acoustically, and in some cases relay detections in real-time. Currently, the Woods Hole Oceanographic Institute (WHOI) digital acoustic monitoring instrument (DMON) and Low-Frequency Detection and Classification System (LFDCS) (Baumgartner et al. 2011, 2013, Johnson and Hurst 2007) has been installed on Teledyne-Webb Slocum gliders and used for research in both Atlantic and Pacific waters. The DMON records up to 1 kHz, with the in-built LFDCS system scanning the incoming data stream for signals of interest exceeding 12 dB above ambient noise level. A distilled version of the acoustic data called 'pitch tracks' (which are classified to the species level) are sent back to a shore system via satellite. Results are available through the "Robots4Whales" online website which also provides maps of the glider tracks and location of detections[6]. Detections are classified to species, and in some cases to specific call types for a species, each associated with a date-time stamp. Manual verification is performed by an experienced analysist to confirm detection-classifications. The full dataset is available for further analysis and verification when the glider is retrieved. A desktop version of the LFDCS is available for use on archival data. This system could provide input to an early warning system for mariners of the presence of NARW,

[6] WHOI Robots4Whales website: http://dcs.whoi.edu/ (last accessed April 22 2020)

fin, sei, or humpback whales in the area (Reimer et al. 2016), and currently feeds acoustic detection-classifications made in eastern Canadian and US waters into Dalhousie University's online tool for displaying NARW visual observations and acoustic detections for this purpose: WhaleMap[7]. The same system has been deployed on moored buoys (to be discussed in the following section), on wave gliders (a type of unmanned surface vehicle), and on drifting profiling floats.

DFO has procured six Alseamar SeaExplorers gliders for which an archival PAM subsystem is available, but the effort to integrate the DMON-LFDCS into the SeaExplorer gliders would be substantial[8]. JASCO Applied Sciences has implemented their OceanObserver detection-classification software in Slocum gliders owned and operated by the Ocean Tracking Network (OTN) and Ocean Networks Canada (ONC), and some initial testing of OceanObserver has also been done with the SeaExplorer gliders[9]. OceanObserver includes a detector-classifier for killer whales that, like the DMON-LFDCS, can deliver results in near real-time. Twenty-one detector-classifiers are run simultaneously as the data is received by JASCOs Autonomous Multichannel Acoustic Recorder (AMAR) to detect and classify baleen whale calls, toothed whale calls and dolphin calls, often to the species level.

The LIDO (Listening to the Deep Ocean environment) network of acoustic sensors includes stationary sensors, autonomous surface buoys, towed arrays, gliders, and bottom-mounted sensors. It includes data provided through the ANTARES neutrino observatory (ANTARES Collaboration, France), the OBSEA shallow water test site (UPC, Technical University of Catalonia, Spain), the Neptune network operated by ONC, the Kushiro and Hatsushima observatories (JAMSTEC, Japan) and the NEMO sites (INFN, Italy). Trained Neural Networks provide the basis for auto detection-classification.

The use of glider technology to detect NARWs is feasible and has been demonstrated in near real-time using the DMON-LFDCS system. The effectiveness of such a system for detecting and clasifiying SRKWs in real-time needs to be further investigated using the OceanObserver system (as the DMON-LFDCS system is not currently designed to process higher frequency data or toothed whale calls).

Stationary Platforms

Moored Remote Systems

Remotely moored systems such as AMARs have become a common acoustic monitoring tool in Canadian waters, but in its current applications the data is only retrieved post-deployment which may be months to over a year long, making this a non-real-time PAM system. However, other options exist where moored systems, usually with a surface float equipped with a cabled or acoustic modem, can be used for near real-time detection. These have the advantage of having near real-time communications options, but careful design of the mooring system must be undertaken to reduce system self-noise. Furthermore, the buoy-based system must be robust, but often cannot be deployable in areas with regularly occurring high winds and strong currents as the system or the buoy could be damaged during storms resulting in the loss of costly recording and detection equipment, as well as any archived data.

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[7] Dalhousie University WhaleMap website: https://whalemap.ocean.dal.ca/ (last accessed April 22 2020)

[8] Baumgartner, M. 2018, personnal communication.

[9] Moloney, J. 2018, personnal communication.

The DMON-LFDCS system described above has been deployed on moored buoys at New York Bight, Nomans Land, Massachusetts, and Mount Desert Rock, Northern Gulf of Maine (Baumgartner et al. 2019). This system operates in a similar manner to the system integrated into Slocum gliders but the sensor is stationary and suspended on a compliant cable below the surface float. An Iridium satellite modem is used to transmit its data to a land-based operator on a pre-determined schedule.

Conceptually, The Cornell Laboratory of Ornithology's Bioacoustics Research Program has undertaken a similar task with its Stellwagen Bank NARW monitoring program and the Boston Traffic Separation Scheme with the Right Whale Listening Network[10] (REF). In this case, detection information from ten NARW autodetection buoys is relayed to a land-based operator every 20 min. The buoys form an array with overlapping detection ranges to localize and determine movement of whales through the system. The detection of a whale initiates a Notice to Mariners to relay information of whale presence and enforce a vessel slow-down in the vicinity of the whale. Acoustic detection information is also provided on the 'Whale Alert' application available on mobile devices[11].

OceanObserver has been integrated into moored buoys in a number of projects, such as the "Eyes on the Bay" project led by the Dublin Port Authority. JASCO's detection algorithms and viewing software PAMlab; however, have also been used successfully in number of conservation projects targeting SRKW, such as via the Underwater Listening Station (ULS), implemented together with the Enhancement of Cetacean Habitat and Observation (ECHO) program by the Vancouver Fraser Port Authority and ONC.

Seabed Cabled Systems

There are a number of examples of seabed cabled acoustic systems tethered to shore, where data is communicated to a shore site as it is collected. Either at these shore sites, or on a remote 'cloud' the data can processed through a detection-classification system it is received. The shore sites can be equipped with internet access which allows detection data from several cabled systems to be transmitted to a central location where they can be verified. The data can be processed either at the sensor site (i.e., through an integrated digital recorder detector-classifier system such as OceanObserver or LFDCS), or on land if sensors can be powered via cable and data transfer bandwidths allows for transmission of raw acoustic data. The resulting networks of sensors allow operators and decision makers to determine the presence of whales, as indicated by detections, to verify detections as they are received, track whale movements, alert vessels. This could be implemented in real-time or near real-time, with the aim that the detection and information relay processes be completed within a time frame that allows vessels to respond to whale detections and alter speed and/or direction to reduce collision risk.

The DFO Whale Tracking Network (WTN) is a multi-node system that currently runs an artificial intelligence based detector-classifier developed by Google Inc. on some of its live-streaming sensor nodes. This network should allow the acoustic detection of SRKWs and other whales in near real-time, and may be able to track them as they move through the water in which it is deployed (Figure 9). Another aim of the system is the monitoring of ambient sound levels, but the quality of the collected data is effected by the shallow depth and proximity to shore of the sensors, and often suffers from shore noise. The location of WTN sensors in relatively shallow water, may impact whale detection range due to ambient noise variation driven by surface noise (waves, precipitation, man-made noise from anchor lines, navigational buoys, etc.), as well as

[10] Right Whale Listening Network website: http://www.listenforwhales.org/ (last accessed April 22 2020)

[11] Whale Alert application website : http://www.whalealert.org/ (last accessed April 22 2020)

being heavily influenced by vessel traffic, and by ferry traffic in particular. The output of the sensor network can be mapped together with AIS tracks of vessels to allow alerts to be sent to vessels about whales currently in their paths or can be used to feed an algorithm predicting whale movements to determine locations where whales may be in the paths of vessels in the future. One particular aim of the network is to have a direct feed of whale presence to ferries transiting the area, as well as the Canadian Coast Guard. The actual number of operational WTN sensor nodes varies due to frequent maintenance requirements. Delays in equipment repair or replacement can mean a node is not operational for extended periods, with the system particularly susceptible due to the deployment locations. At the time of its original installation in the summer of 2017 a number of nodes were in areas with high ferry traffic and areas used by fishing vessels and recreational boaters (approximately 8-10 nodes) while 5-6 nodes were in areas near commercial shipping routes. Nodes can have between 1-4 digital hydrophones (icListen, Ocean Sonics) and four hydrophone nodes are tetrahedral arrays that could potentially track individual SRKW and smaller dolphins producing sounds above 1.5 kHz, given the spacing of the hydrophones. No automatic tracking algorithm is currently applied to the array data to determine location of incoming signals. The spacing of nodes would allow tracking of SRKWs and other whales through an area such as inshore waters of the Salish Sea characterized by islands, and narrow waterways, whereby detections would act as presence markers as the whales move through the waterways, although continuous tracking may be hindered by the underwater topography and land masses. The tracking ability of whales in more open water using the current system differs spatially and temporally in their signal detection ranges which are determined by ambient noise conditions and sound propagation pathways. For some nodes, under certain conditions, the detection ranges in the wider channels exceeds that of the more narrow waterways. Detection ranges vary greatly between seasons and locations and even may vary over the course of a day. Work on determining detection range variation is currently underway for the area around WTN stations and other areas with PAM stations in the Salish Sea. The functionality of the WTN as real-time vessel alert tool is greatly dependent on the ranges over which whales can be detected, and the timeliness by which vessels can be alerted. The accuracy of the detections, and any interim time needed to verify detections and the range at which the calls are being received may also delay the relay of the message of whale presence to vessels. Requests for details on the operations of the WTN need to be directed to Paul Cottrell, DFO Fisheries Management Pacific. A report on the functionality of the WTN as a vessel alert tool is currently being prepared and should be available later this year. As it is a recent installation, with the functionality and real-time capacity still to be assessed, performance statistics are not publically available.

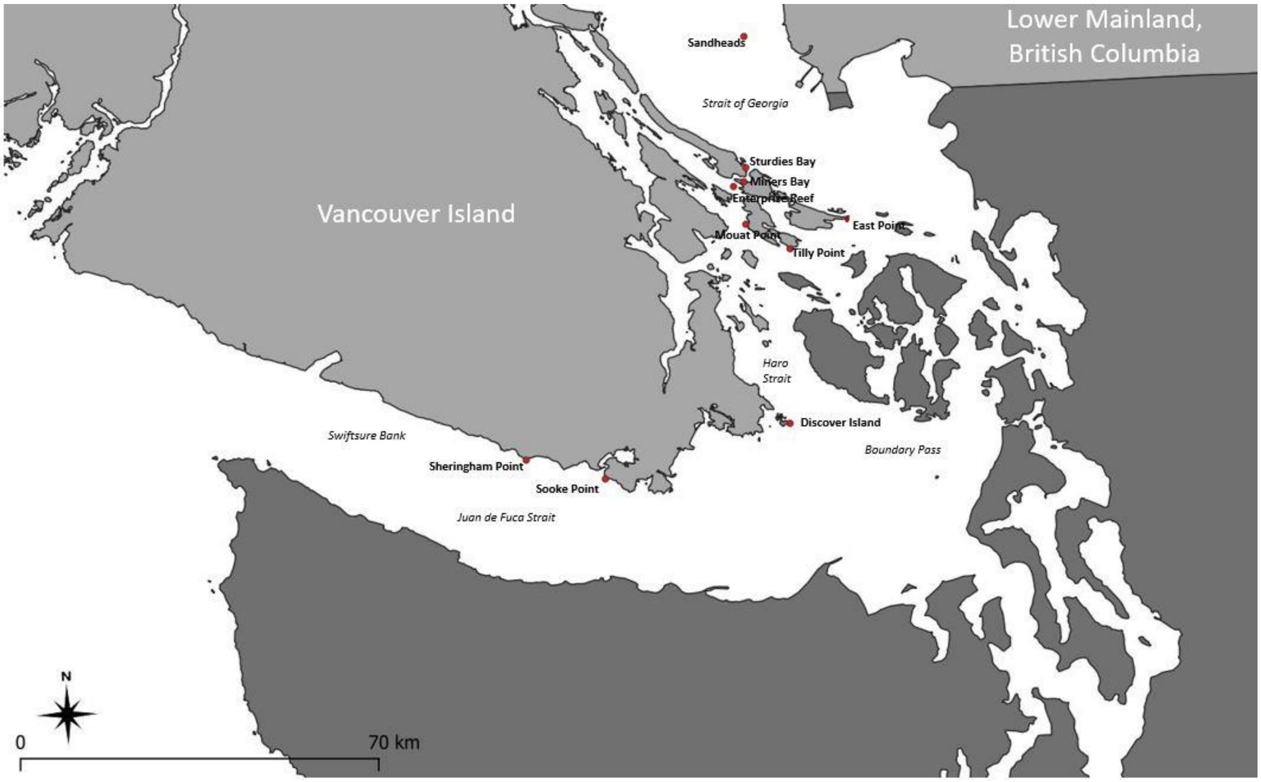

Figure 8: Location of the Whale Tracking Network acoustic nodes (red circles) in the Salish Sea, British Columbia.

Cabled PAM hydrophones (single sensors and arrays) placed as nodes on the sea floor have been installed and tested by the ONC on their Venus and Neptune observatories in the Strait of Georgia and the Neptune observatories off the west coast of Vancouver Island. Some of the hydrophones have been in place since 2007 and either employ the LIDO (SONSECTS Inc.) or the PAMlab (JASCO Applied Sciences) systems for whale detection.

Other examples of fixed cabled systems can be found worldwide. The U.S. Navy's Sound Surveillance System (SOSUS) and the U.S. Navy test ranges in the Bahamas (Atlantic Undersea Test and Evaluation Center), southern California (Southern California Offshore Range) and Hawaii (Pacific Missile Range Facility) have been in place for years.

Cabled systems have an advantage over surface tethered monitoring systems because they are not affected as much by waves and wind, and do not present a hazard to vessels. However, cabled systems have high maintenance costs, especially when installed in deeper water with limited access to any failing sensors. Shore tethered systems are also not power limited, which is a limitation of all remote systems.

Drifting Systems

Drifting Vessel Systems

Over-the-Side (OTS) hydrophones may be used for marine mammal detection. They have many of the same benefits as mobile systems such as towed arrays, but the vessel needs to be drifting or station-keeping while in use. Both vessel motion and vessel noise present potential limitations for use of these systems. Drifting ship systems are ideally deployed from smaller vessels with engines turned off during deployment, allowing the vessel to drift with the acoustic sensor.

Acoustic Surface Drift Buoys

Drift buoys with automated detector-classifiers and transmitters (satellite, Wi-Fi, 3 or 4G, *e.g.,* Coastal Ocean Buoy by SMRU Consulting) can be used to monitor areas for marine mammal presence. This can be for either short term deployments, for example during and after an activity that could impact marine mammals, or long term deployments in offshore locations where other systems may not be practical. Deployments offshore would allow the system to monitor whale presence in larger ocean areas; however, these areas would require much larger buoys. Applications in both coastal and offshore waters will be limited by on-board power supply and data storage capacity.

Sonobuoys

Passive sonobuoys provide much of the same capability of an OTS system, but have limited life (usually 8 hours) and are disposable. Military sonobuoys generally are designed to operate at higher sea states than is usually possible with an OTS system. The sonobuoy uses a radio signal to relay the acoustic data to a receiving aircraft or vessel in real-time. This can be processed and further analyzed on the receiving platform. Conceptually, any drifting surface float with a submerged acoustic sensor could be considered a sonobuoy (e.g., SMRU PAMBuoy or CAB; DASBR (Griffiths and Barlow, 2016). Multiple units can be used in conjunction to enable localization and tracking of calling animals.

Long-Term Submerged Profiling Buoys

Acoustic sensors have been added to oceanographic drifting buoys. These tend to be used in long deployments (months) and relay data in near real-time. The majority of the examples found (MetOcean Pablo, Teledyne Webb Apex) relay processed data (e.g., averaged spectra or pitch tracks) via an Iridium satellite. The WHOI DMON-LFDCS has been deployed on a profiling float.

ACTIVE SOUND NAVIGATION AND RANGING (SONAR)

Summary: *While Sound Navigation and Ranging (SONAR) systems are being used for detecting, localizing and tracking objects in the water, only very limited testing on marine mammal detection has been done. Detection range is likely to be quite small and classifying received signals to the species level will be challenging. An additional consideration for this technology are the potential impacts of the sound emissions on NARWs or SRKWs.*

Active SOund Navigation And Ranging (SONAR) technology uses similar approaches to detection as PAM systems, but with a few critical differences. Like RADAR, active SONARs transmit sound energy and detect the reflected returns from an object. This has a number of advantages and disadvantages over passive systems. Firstly, the mammal is no longer required to vocalize. The transmitted energy is reflected from either the mammal's body or from the water disturbance.

Like PAM technologies SONAR is sensitive to background noise– either generated naturally (rain, wind-generated noise, seismic events, etc.) or by anthropogenic sources (construction, shipping, fishing, echo sounders, seismic surveys, etc.). Acoustic propagation conditions are spatially and temporally highly variable and affect the capability of acoustic technologies. System self-noise (mooring chains, electronics, etc.) or flow noise may also interfere with the detections. Additionally, active technologies generate reverberation which can also limit performance. Furthermore, active acoustic technologies require significantly more electrical energy than a passive technology. This limits the application of active systems in remote battery-operated systems. Finally, the acoustic transmission of sounds via active systems may in themselves impact whales by potentially causing physiological impacts (e.g., hearing threshold shifts, stress responses), behavioural responses, and/or masking of vocalizations (depending on the characteristics of the SONAR signal used and overlap with marine mammal hearing and sound production range).

Verfuss et al. (2018) reviewed a wide range of active SONAR systems with operating frequencies from 20 kHz to 700 kHz. All of these systems were built for purposes other than detecting marine mammals and detection performance for whales is highly correlated to a number of parameters such as frequency, source level, beam shape, and waveform. Coda Octopus Echoscope has been used to detect, classify, and localize small animals, such as dolphins, at distances up to 100 m (Hastie, 2013) while the Tritech International Gemini 720 has a maximum detection range of 120 m. At the lower end of the frequency range, Pyć et al. (2016) documented the Kongsberg SX90 on the CCGS Amundsen detecting seals at distances up to 2 km in the Beauford Sea. Though not experimentally verified, the performance of the Scientific Solutions HFM3 and the Nautel C-Tech CMAS-36/39 should yield similar results. Detection range of active SONAR is limited only by sound travel time. However, while classification can be accomplished through generating an image using higher frequency systems, the lower frequency systems (which operate over longer ranges) lack the ability to directly classify a marine mammal target.

Active SONARS have been mounted and used on surface vessels and in fixed installations. With the relatively short detection range, an active SONAR solution would be best employed when mounted to vessels that frequent NARW or SRKW habitats, though there are a number of challenges that have been identified with using this technology to detect whales. No studies that have demonstrated SONAR detection of NARWs or SRKWs specifically were reviewed. While SONAR systems could potentially be used to detect these species at relatively short ranges, reliable classification of detections to the species level would be very difficult and careful consideration needs to be given to the potential impacts of SONAR sound emissions into NARW or SRKW habitat.

DISCUSSION AND WAY FORWARD

Each of the reviewed technologies showed at least some capacity for near real-time DCLT applications. All of the technologies reviewed had some demonstrated capability for detecting whales, but effectiveness varied and limitations of each must be considered. Of the reviewed technologies, visual sensing and PAM are the most operational in terms of their ability to detect whales and classify whales in general, and NARWs and SRKWs specifically, and these are likely to remain the primary marine mammal detection modalities in the coming years. These technologies will be the focus of the OPP WDCA initiative moving forward.

A wide variety of options are available for PAM systems that can be optimized for specific objectives and locations due to their extensive application in marine research. There has been a great amount of technology development in this area over the past 30 years and new PAM technologies continue to emerge even in recent years (e.g., application of acoustic underwater modems for whale detection).

Human visual observation is still by far the most applied form of whale detection and monitoring in biological research, and may be supplemented by electro-optical systems such as TID technologies using IR cameras. MMOs will likely be required to evaluate the results of associated automated detector-classifiers before IR camera systems can be used as operationally independent tools.

The OPP WDCA program will focus on testing a variety of moored, cabled, and drifting PAM systems for their effectiveness in detection-classification of NARWs and SRKWs. The effectiveness of land-based and vessel-mounted IR camera systems will also be tested for both species. The sections below describe some of the considerations for testing each of these technologies for each species.

TECHNOLOGIES FOR TESTING FOR NARW

RADAR, satellite multispectral optical imaging, and SONAR technologies are not developmentally compatible with the environmental conditons in areas where NARWs most often occur (which is often windy, foggy, rainy and/or snowy), and also have not yet been proven to be effective near real-time DCLT technologies for NARWs. Conversely, PAM has been used to effectively detect the presence of NARWs in many different studies, including in areas off eastern Canada, and IR camera technologies seem promising for detecting large whales like NARWs (and could be particularly effective for this species given their tall distinctive v-shaped blow). Capabilities for determining the presence of NARWs in near real-time of both these technologies will be investigated under the OPP WDCA initiative. While each of these technologies are considered individually below, it should be noted that a network of IR camera sensors monitoring for NARW presence within in area concurrently being monitored by PAM sensors would allow for a more direct visual-acoustic comparison to determine which of these systems perform better for detection-classification of NARWs.

Based on historical and recent NARW sightings, the following areas should be considered for testing near real-time NARW DCLT technologies: Grand Manan Basin (identified critical habitat), Roseway Basin (identified critical habitat), Cabot Strait (suspected movement corridor), southern Gulf of St. Lawrence (a relatively new aggregation area), and the Jacques Cartier Strait north of Anticosti Island (a smaller and relatively new potential aggregation area overlapping a shipping lane).

The Cabot Strait is the most likely entry point into the Gulf of St. Lawrence for NARWs, though relatively little monitoring effort has occurred in this area and many questions remain around how and when NARWs use this area. There is much interest in developing a near real-time NARW detection system in this area in particular, and the technologies being tested need to take into consideration requirements for applications in this area.

The southern Gulf of St. Lawrence has been a consistent NARW aggregation area in recent years (DFO 2019, 2020), as well as an area where a number of ship strikes and entanglements have been documented (Daoust et al. 2017, Bourque et al. 2020). It is also an area of particular interest for implementation of a near real-time detection system, and detection technology testing should also consider potential applications in this area.

PAM Technology Testing

In general, development and testing of moored, cabled and drifting PAM systems for detecting NARW presence within any given area should be considered. NARWs are highly mobile and their distribution in recent years is not fully understood but does vary from year to year (DFO 2020), and different platforms may be needed within the different areas of monitoring interest. Cabled systems are more permanent and likely to be very costly to install and should only be undertaken after careful consideration of their effectiveness within any particular area for detecting NARWs. Moored systems with surface floats and remote communications could be investigated as a more mobile alternative to cabled systems, with specific focus on reducing the impacts of mooring system noise on NARW call detection. Drifting systems such as acoustic gliders, profiling buoys, and sonobuoy-like systems could provide lower cost real-time or near real-time detection opportunities over shorter timeframes.

In the Cabot Strait area the winds are too strong for deployment of a drifting system while the currents are too strong for autonomous underwater vehicles such as gliders. Therefore, use of a stationary system, whether moored or cabled, and possibly arranged as an array or network of individual sensors (to provide more complete coverage of the area) is needed. The Ocean Tracking Network (OTN) currently has a cabled receiver system in the Cabot Strait for tracking fish movement. This may provide a potential collaboration opportunity for installation of a cabled PAM system for detecting whale presence. However, little is known of NARW calling behaviour in the Cabot Strait area. While some archival bottom-moored systems have been deployed in the area, relatively few NARW upcalls have been detected (DFO 2019), which could be due to a number of reasons – it is possible that NARWs were present but not calling in the area, that the recorders were not located close enough to the area where NARWs were transiting to detect their calls, that vessel noise from nearby shipping lanes hampers detection of NARW calls, or that NARWs do not actually occur in the area (though the latter is highly unlikely). As a first step towards developing a near real-time detection system for the Cabot Strait, a better understanding of NARW calling behaviour in the area is needed. Locations near the Cabot Strait will initially be monitored using archival recorders (e.g., AMARs) to increase understanding of NARW calling behaviour and determine if PAM will be an effective detection technology for monitoring NARW presence in the area. The archival recorders will be equipped with directional sensors to allow for an enhanced signal-to-noise ratio to be achieved, and to determine if use of directional sensors is beneficial for detecting NARWs in areas near shipping lanes that are subject to periodic loud vessel noise.

The southern Gulf of St. Lawrence is also an area of monitoring interest for NARW and testing of cabled and moored systems for this area should be investigated. Viking buoys (developed by Multi-Electronique Inc.) outfitted with a variety of oceanographic instruments have been deployed in the Gulf of St. Lawrence to relay information collected to DFO (and others) in near real-time as part of the St. Lawrence Global Observatory. DFO is undertaking testing of Viking buoys as potential platforms for PAM systems for NARW monitoring. Careful consideration must be given to the impacts of noise generated by the mooring on the effectiveness of the system as these moorings were not designed for acoustic monitoring and anchors and chains may cause too much noise to be useful in some areas. Consideration should also be given to the cost of a cabled PAM system within the southern Gulf of St. Lawrence, where there has been more persistent NARW presence and success in detecting NARWs via PAM technologies in recent years (DFO 2019, 2020). Such a system could be designed so that the cable reaches land-fall at the closest point from the aggregation area, likely the eastern end of the Gaspe Peninsula.

IR Camera Testing

IR camera testing focused on NARWs will be undertaken from land off the Nova Scotia and the Bay of Fundy coastline and/or in areas near the Cabot Strait.. The Jacques Cartier Strait may also be an appropriate area to deploy and test a land-based camera detection system for NARWs as the waterway there narrows so that the range from the land to possible animal locations is limited; however, height of the camera in this area needs to be carefully considered to determine if it is a suitable location. Since there tends to be a positive relationship between height of the camera and detection range, the land-based testing of the IR camera system to detect NARWs will be need to be conducted from a high viewpoint to reach areas out to where NARWs occur.

Restricting IR camera capability to land-based stations that can only monitor nearshore areas might not be effective for NARWs as they often occur further from land than could be detected by these systems. Vessel-based IR camera systems may thus be more suitable for NARW, and from vessels (likely in the Gulf of St. Lawrence). This will necessitate development and testing of a motion stabilization system.

TECHNOLOGIES FOR TESTING FOR SRKW

Similar to NARWs, RADAR, satellite multispectral optical imaging, and SONAR have not yet been proven to be effective near real-time DCLT technologies for SRKWs while PAM has been effectively used to detect SRKW presence and IR camera technologies also have the potential to be useful for this species, thus the OPP WDCA initiative will focus on testing these detection technologies for SRKW. These technologies are considered individually below, but monitoring of an area using IR camera and PAM sensors concurrently would be more informative for determining which of the available systems deliver the highest rate of detection.

For SRKW, known areas of overlap between habitat and shipping lanes should be priority areas for technology testing and include: Swiftsure Bank, Juan de Fuca and Haro Straits, waters around Southern Gulf Islands, Boundary Pass, and the complete Strait of Georgia. The southern parts of the Strait are included in the designated critical habitat for SRKW, whereas the northern parts have only recently gained attention as additional important habitat for SRKW.

PAM Technology Testing

A number of PAM technologies for detecting SRKWs will be investigated under the OPP WDCA initiative. These include stationary cabled and moored systems, acoustic surface drift buoys, and mobile AUVs equipped with PAM packages,

Existing cabled PAM networks such as the Whale Tracking Network (WTN) recorders should continue to operate to provide near real-time notifications of SRKW detections to British Columbia (BC) Ferries via the Marine Communication and Traffic Systems (MCTS), which can also hail vessels that are approaching the area to notify them of the presence of SRKW. The operations of the network; however, would need a dedicated team of technicians to maintain its monitoring capacity throughout the year while acoustic analysts need to verify the species and ecotype of any detection transmitted by the network in near real-time to make the WTN an effective ship alert tool.

Moored oceanographic buoys (e.g., SPAR buoys, etc.) may provide platforms for PAM systems in waters of Juan de Fuca Strait and off the west coast, but their application will always be limited due to the sea state conditions at particular locations. Heavy wave action in many of the coastal areas of monitoring interest for SRKWs will create noise and acoustic interference limiting the ability to detect SRKW calls. A test of an alternative surface buoy tethered system for detecting SRKWs consisting of underwater acoustic nodes communicating via modems is planned for the west coast. This system was developed by the Department of National Defense iniitially for monitoring and tracking sub-marines. Drifting buoy systems are currently being tested as potential PAM systems for SRKW detection in inshore areas off the west coast and have showed good initial results. Offshore testing of these systems is not currently planned but the results of the tests will provide information on the usefulness of these devices in offshore locations.

Because of the high mobility of SRKW the acoustic detection range variation will be assessed for each system and location of deployment to determine their effectivenss as a ship alert tool. Furthermore, the effectiveness of DCLT algorithms in detecting killer whale calls automatically will be improved and tested on acoustic data recorded at locations of potential deployment.

Acoustic gliders equipped with automated SRKW detector-classifiers will be tested in areas off the west coast of Vancouver Island near Swiftsure Bank and on La Perouse Bank.

IR Camera Testing

Automated TID systems using high Definition (HD) and Forward Looking Infrared (FLIR) cameras should be tested in inshore BC waterway locations at different times of the year to investigate their effectiveness for detecting SRKWs in different settings and under varying environmental conditions. Although wind dispersion of whale blows could be a limitation of this technology, waterways in the Southern Gulf Islands are sufficiently sheltered to provide a good test site for this technology. Additionally, SRKWs are a good test species as they have tall dorsal fins and expose parts of their bodies when surfacing which may be detected by IR cameras in addition to their blows. IR (FLIR) cameras with automated detection systems are being tested overlooking the eastern entrance to Active Pass (a narrow waterway that serves as the main traffic route for ferries and smaller commercial vessels travelling between Metro Vancouver on BCs mainland and Victoria on Vancouver Island.). The test will provide information on the benefit of using TID technology to accompany the PAM already being implemented in the narrower waterways of that area. The system being tested consists of four cameras (two FLIR and two RGB cameras), a computer with installed detection software, a modem that transmits detection via the internet, and hard drives to record RGB camera data to determine false positive and negative detections manually. The system is equipped with a compressed air blower that dries the lenses and attempts to remove dust and obstacles on the lenses at regular intervals. As well, as IR cameras are based on line of sight and localization is based on the inclination angle, localization accuracy can be improved with increased altitude and this will also be examined. Testing of this system will provide a better indication of its effectiveness for detecting SRKWs, though on a limited spatial scale (as the width of waterway is less than 1.5 km). If tests are successful in Active Pass, this technology could also potentially be implemented in other areas, for example, it could be mounted on lighthouse stations in areas known to be used by SRKW. In those areas, a 360 degree panoramic view could be beneficial.

Testing the effectiveness of IR camera systems mounted on the bow of a vessel for detecting SRKWs is also planned.

SUMMARY

This paper reviews technologies that could be used to potentially provide near real-time information on the presence of NARWs and SRKWs within an area, with the intent to help reduce the risk of vessel strikes. Each of the technologies reviewed showed some promise for being an effective whale detection system, but each also has limitations that must be considered. Of the reviewed technologies, PAM and IR camera systems were identified as the most suitable and likely most effective technologies for detection, classification, localization, and tracking of NARWs and SRKWs in Canadian waters, and testing these technologies in near shore areas off eastern and western Canada will be the focus of the OPP WDCA initiative. Results of testing will provide insights into future applications of PAM and IR camera technologies for NARW and SRKW DCLT, and will inform development of a near real-time alert system for reducing the risk of NARW and SRKW vessel strikes.

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APPENDIX A

Workshop Terms of Reference

Review of whale detection technologies and their applicability in Canadian waters

February 20-21, 2018

Montreal, Quebec

Context

Vessel traffic is increasing in many Canadian ports where endangered and threatened whale species occur, including the iconic North Atlantic Right Whale (NARW) and the Southern Resident Killer Whale (SRKW). Vessel collisions causing whale injuries and mortalities have occurred and will likely continue to occur in these high vessel traffic areas. To help reduce the magnitude of this threat, as well as entanglements and acoustic disturbance, Fisheries and Oceans Canada (DFO) will be evaluating and testing whale detection technologies in areas of high concentration of whales in Canadian waters on the Pacific and Atlantic coasts. Ultimately, these whale detection technologies will help inform the development of a system able to provide up-to-date warnings to mariners of the presence of whales in order to help reduce the risk of ship collisions with whales.

Objectives

The objectives of this meeting will be to:

1. Identify existing and emerging technologies or systems that might be useful in detecting whale presence.
2. Gather information on each of the technologies or systems and evaluate their suitability and effectiveness in detecting NARW and/or SRKW in Canadian waters.
3. Identify which technologies or systems could be used in combination to detect NARW and/or SRKW in Canadian waters.

Expected Publication

- Technical Report on whale detection technologies applicable to the Canadian context.

Expected Participation

- Fisheries and Oceans Canada (DFO)
- National Oceanic and Atmospheric Administration (NOAA)
- Other government agencies
- Academia
- Other experts