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# Review of International Protocols and Recommended Mitigation for the Use of Autonomous Unmanned Vehicles (AUVs) in the Study of Marine Mammals

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**Foreword**

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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## TABLE OF CONTENTS

## ABSTRACT

The use of autonomous unmanned vehicles (AUVs) for wildlife research has increased rapidly recently. Using smaller AUVs might be a mitigation for flying a full-size aircraft. Here we provide an overview of studies from both published and grey literature that directly or indirectly assess the impacts of AUVs (mainly aerial types) on marine mammals, focusing mainly on species occurring in Canadian waters. As well, we review demonstrated and prospective impact mitigation approaches and current regulatory reporting requirements to identify information gaps and provide suggested guidelines for Fisheries and Oceans Canada (DFO) permitting and reporting processes regarding the use of all types of AUVs for marine mammal research.

Most studies to date have categorized and reported variables such as received noise levels, distance to animals, height above animals, and behavioural responses to AUVs that were highly variable and/or not reported in a standardized manner. This makes it difficult to compare studies and make general statements. There is a need for a standardized protocol for reporting behavioural responses to AUVs. As a primary goal, the AUV user should be able to justify the type of AUV, the approach profile at which they plan to use it and demonstrate that their plan is the best they can do to minimize potential effects on marine mammals. Providing detailed measures of context and animal responses during their research would help regulators determine this.

In order to improve our understanding of the potential impacts of AUVs on marine mammals (relevant for users of AUVs for marine mammal research and/or for users of AUVs within DFO more generally), we suggest that it would be beneficial if the regulator(s) would clarify/improve the level of reporting detail required of AUV operators, that explicit studies of the responses of marine mammals to AUVs in different contexts be considered, and that DFO considers adopting a precautionary approach (PA) to permitting and training, as informed by available data.

# INTRODUCTION

The use of autonomous unmanned aerial vehicles (AUVs, often termed “drones”) for wildlife research has increased rapidly in recent years as AUV capabilities have increased while costs have decreased (for a review of Canadian AUV applications, see the report by Canadian Council on Geomatics 2016). Two classes of aerial AUVs are particularly common: rotary, which are helicopter-type aircraft with multiple rotors (also called vertical take-off and landing), and fixed-wing, which are plane-like aircraft. Chabot and Bird (2015) suggest that the uses of aerial AUVs fall into two categories:

1. “close-up”, rotary AUVs flown at lower altitudes and in close-proximity to focal animal(s) to collect specific data, such as particulates from cetacean exhalations (Acevedo-Whitehouse et al. 2010), or
2. “overflight”, fixed-wing AUVs flown at higher altitude in a defined pattern collecting photos or video in a similar way to manned aircraft surveys.

Most commonly, AUVs have been used as an alternative to manned aircraft for aerial wildlife surveys and are often reported as a more effective (Hodgson et al. 2013; Hodgson et al. 2016), cheaper, safer, and less disturbing option (see reviews by Chabot and Bird 2015; Smith et al. 2016). Particularly, AUVs can reduce data collection errors caused by observer fatigue (Hodgson et al. 2013) and variation in platform flight path (Koski et al. 2015). As well, they eliminate the need for researchers to assume the considerable risk of being on an aerial platform (Wiegmann and Taneja 2003), and are smaller and less noisy than manned aircraft or vessels. For example, the silhouette of an AUV between 6–35 m altitude is similar to a Twin Otter manned aircraft at 200 m altitude; the noise level experienced 6 m from a ScanEagle fixed-wing AUV (85–90 dbA) is similar to noise level experienced from a Partenavia P68 twin-engined aircraft overflight at 150 m (82 dbA) (Born et al. 1999; Hodgson et al. 2013). Even though AUVs are flown in closer proximity to study subjects compared to manned aircraft, the noise levels experienced by study subjects is lower (Christie et al. 2016; Figure 1, Table 1). As surveys from aerial platforms are important in the monitoring and management of wildlife, especially marine mammals, AUVs present exciting new possibilities for improving and extending collection of vital data. Hence, it is predicted that AUVs will increasingly be integrated into data collection protocols and possibly transform the way wildlife data are collected (Christie et al. 2016).

While we briefly consider terrestrial and vessel AUV types (remote-control boats, undersea gliders) later in this document, most of the discussion applies to aerial AUV applications.

As AUVs have become increasingly available and affordable, Fisheries and Oceans Canada (DFO) Species At Risk (SAR) Management Division and Integrated Resource Management have had to review permit applications for projects that use AUVs to study marine mammals. Prior to issuing a permit (Species At Risk Act S. 73.3[b] or Fishery General Regulations S.52), DFO must ensure that all feasible measures will be taken to minimize the impact of the activity on these species. However, as stated in a recent review by Smith et al. (2016), there is a lack of information available to scientific permitting bodies regarding both the impacts of AUVs on marine mammals and recommended mitigation measures that can be used to minimize these impacts. The anticipated increase in applications for research involving AUVs has led to a call for a comprehensive summary of existing information regarding the impacts of AUVs on marine mammals. The information compiled in this review is intended to be used to ensure national consistency in permit review and in the development of permit conditions, and to reduce the need for repeated requests to Science for stand-alone advice on the same activities. If no action is taken, negative impacts to marine mammals may result from the inconsistent requirement for and application of mitigation measures to reduce impacts of AUVs (if any). In addition to these biological impacts, it reflects poorly on DFO if national advice is inconsistent, and if there are inconsistencies in permit condition requirements.

Despite increased use of AUVs for research purposes, Smith et al. (2016) found that few studies have systematically assessed impacts of AUVs on marine mammals (see Table 1 in Smith et al. [2016]). From existing studies, noise and visual cues from the AUV (or its shadow) were identified as the most common sources of disturbance, regardless of species or AUV type. Marine mammals that breed and rest on shore, such as pinnipeds, may be the most sensitive to AUV noise and visual cues, but marine mammal responses to AUVs appear to vary greatly depending on species, type of survey, alternative methods, environmental conditions, previous disturbance, and AUV type (Smith et al. 2016). The authors also cautioned that much of the existing data on the response of marine mammals to AUVs has been collected opportunistically as a by-product of studies testing AUV protocols rather than dedicated, empirical studies of animal responses. Hence, there may be an under-reporting in the current literature of cases in which animals did not respond to AUVs. Furthermore, they suggest that existing data must be interpreted carefully, and note the limited value of the plentiful anecdotal information on marine mammal responses to AUVs that is available via the internet (blogs, YouTube videos, etc.).

Just as the methods for assessing and mitigating impacts of AUVs on wildlife are still in development and may vary depending on numerous factors, the framework for the regulation of AUVs in Canada is evolving and current regulations vary depending on factors such as the user (private versus commercial), AUV weight class, and AUV use. Specifically, within the current regulatory framework developed by Transport Canada, the use of AUVs for research purposes qualifies as commercial use. A researcher must obtain a Special Flight Operations Certificate (SFOC) from Transport Canada to fly an AUV. As per Canadian Aviation Regulations (Transport Canada), there are two types of exemptions (based on AUV weight) from requiring a SFOC: one for less than 1 kg, the other for above 1 kg up to and including 25 kg. Up to 61 conditions must be met to qualify for an exemption, including: $100,000 liability insurance (not applicable for Government of Canada employees as the government is self-insured), flying at or below 100 m above ground level, staying at least 30 m (less than 1 kg) to 152 m (1 to 25 kg) away from people or animals, and operating the AUV within unaided visual contact of the pilot (see Transport Canada Infographic, Appendix A). However, if researchers are unable to meet the exemption conditions, they must apply for a SFOC for every mission that they fly. Application for a SFOC requires the researcher to give a detailed description of planned AUV mission, including the AUV details, description of safety equipment, details about the crew involved in the flight, the date and time of the flight, and plans in place to deal with an emergency (see Transport Canada SFOC Application). The AUV pilot must also successfully complete a course of training providing required knowledge, regardless of qualifying for an exemption (Transport Canada 2019). The processing time for SFOC applications can take weeks, meaning that researchers must apply well in advance of their scheduled mission date and cannot take advantage of AUV flight opportunities that arise on short notice. Flying without a SFOC when one is required can result in fines of $5,000 for individuals and $25,000 for corporations (Transport Canada 2019).

Although Transport Canada does make SFOCs easier to obtain with each successful AUV mission a researcher flies, SFOC applications require a high degree of detail and are evaluated on a case-by-case basis, making it a time-consuming process for both researchers and regulators. In a Notice of Proposed Changes issued in May 2015, the Canadian Aviation Regulations Advisory Council (CARAC, Transport Canada) noted that the current SFOC process had caused frustration for AUV users, particularly since the number of SFOC applications submitted increased 435% from 2013 to 2015. The CARAC Notice of Proposed

Changes attempts to make the current regulatory framework more user-friendly and more consistent with international partners, while also managing risk effectively. With the rule changes, Transport Canada aims to establish classifications, clarify terminology, establish aircraft marking and registration requirements, address personnel licensing and training, and create flight rules. Online tools such as those available from Civilian Unmanned Aircraft Systems (CivUAS), assist AUV operators in choosing a legal operations area (Appendix B).

In this review, we provide an overview of studies from both published and grey literature that directly or indirectly assess the impacts of AUVs (mainly aerial types) on marine mammals, focusing mainly on species occurring in Canadian waters. As well, we review demonstrated and prospective impact mitigation approaches and current regulatory reporting requirements to identify information gaps and provide suggested guidelines for DFO permitting and reporting processes regarding the use of all types of AUVs for marine mammal research.

# REVIEW OF PRIMARY OR GREY LITERATURE ON MEASURED, OR POTENTIAL, IMPACTS OF AUVS ON MARINE MAMMALS

## PINNIPEDS

When pinnipeds are hauled out on shore (e.g., in rookeries), they may flush suddenly into the ocean if disturbed. Especially if a large number of individuals are involved, a flushing event or stampede can lead to individuals sustaining serious injuries or being killed (Wilson et al. 2012). As low-flying aerial AUVs have been found to cause several pinniped species to flush (Fritz 2012), this form of disturbance must be considered in the regulation of AUV use for marine mammal research. However, as different individuals, populations, and species of pinnipeds appear to vary in their responses to AUVs, potential impacts may need to be assessed on a case-by-case basis, considering factors such as species, type of survey, alternative methods, environmental conditions, previous disturbance, and AUV type (Smith et al. 2016).

### Rotary

In one of the only studies that directly quantified the effects of AUVs on pinnipeds, Pomeroy et al. (2015) found that responses of pinnipeds to rotary AUVs were variable. These authors conducted trials quantifying Grey Seal (*Halichoerus grypus*) behaviour in response to increasingly nearer (in terms of distance to the seals) flights of two types of rotary aerial AUVs (Vulcan 8 and Cinestar 6) to haulout sites. Specifically, they quantified the number of trials in which particular behavioural responses were shown and the height and proximity to animals at which these behaviour types were elicited. They found substantial variation in Grey Seal responses depending on breeding status, moult status, and AUV model. For example, they found that 60 yearlings and juveniles flushed into the water in response to a Vulcan 8 AUV at a range of 200 m, but a Cinestar 6 AUV elicited only head-up and movement responses at 30 m altitude above haulouts of moulting and breeding individuals (Pomeroy et al. 2015).

In addition to Grey Seals, Pomeroy et al. (2015) systematically measured effects of AUVs on Harbour Seals (*Phoca vitulina*). They found that harbour seals at a site frequently disturbed by other human activities showed little response to a Cinestar 6 AUV flying 30 m above the haulout and showed the same lack of response when a noisier Skyjib AUV was flown over the haulout a month later. In contrast, on the same day as the Skyjib flight over the other haulout, Pomeroy et al. (2015) flew the same Skyjib AUV over Harbour Seals at an isolated, less-disturbed haulout and the seals responded when the AUV was at an altitude of more than 50 m, with some flushing into the water. From their trials, Pomeroy et al. (2015) concluded that the ideal AUV system for pinniped research was dependent on many factors, including site, AUV model, field situation, and data required. Hence, they suggested that the potential impacts of AUVs on pinnipeds likely needed to be assessed on a case-by-case basis.

Opportunistic observations of pinniped responses to AUVs have also been reported as a result of trials testing new aerial AUV data collection methods. Goebel et al. (2015) found two species of seals (Antarctic Fur Seals [*Arctocephalus gazelle*] and Leopard Seals [*Hydrurga leptonyx*]) showed no signs of disturbance when a rotary AUV (APH-22) was flown 23 m above them. They used the AUV to census Antarctic Fur Seals and identify and measure Leopard Seals, describing it as a “disturbance-free alternative” to existing methods. In contrast, conservation groups have complained that Harbour Seal colonies show evidence of disturbance (changed resting behaviour, colony flushes to the sea) when rotary AUVs pass over them. As disturbance of seals at haulouts can depend on many factors, and can be with or without obvious cause, non-systematic assessments of disturbance by AUVs should be interpreted carefully.

In a case study using data collected by the National Oceanic and Atmospheric Administration (NOAA), Christie et al. (2016) identified the costs and benefits of using an AUV (APH-22 hexacopter) to survey Steller's Sea Lions (*Eumetopias jubatus*) and compared this with the costs and benefits of using a manned aircraft for the same purpose. They reported that manned aircraft caused “slight and variable” effects on Sea Lions, with 5% of adults moving toward the water. In contrast, the observed effects from the aerial AUV were “very low to none”, with only 0.3% of adults moving toward the water when overflown at 45 m.

### Fixed-wing

Fixed-wing AUVs have been used to survey marine mammals in place of manned aircraft, but there are few studies of the impacts of fixed-wing AUVs on pinnipeds. In the Bering Sea, Moreland et al. (2015) evaluated the disturbance caused to seals by a fixed-wing ScanEagle AUV compared to a manned, low-flying helicopter. Seal response was quantified by analysing images collected using both types of platforms during breeding season surveys. The results of the image analysis suggest that seals showed significantly less response to the ScanEagle AUV compared to the helicopter. When the ScanEagle AUV was flown at an altitude as low as 91 m over seals hauled out on ice floes, the seals showed no sign of disturbance and observers on a nearby vessel saw no seals entering the water or moving away from the AUV flight line (NOAA MC2-09-02 UAS Report; Moreland et al. 2015). In a different study using a fixed-wing AUV (TD100E), researchers reported that seals entered the water off ice floes as the boat accompanying the AUV approached slowly (Koski et al. 2014). It was not clear if the seals responded to the AUV itself, but this example illustrates that in some cases it may be necessary to consider disturbances caused by boats carrying AUV pilots who are required to keep the AUV within their line of sight and within 1.5 km (as required by regulations).

### Vessel (e.g., remote-control boats, undersea gliders)

No published or grey literature research was found for pinniped responses to these remotely-operated vehicle types.

### Terrestrial

Twiss et al. (2011) employed a remote-controlled land vehicle, equipped with a small sound speaker, to drive within approximately 3 m of Grey Seals and deliver a standardized acoustic test stimulus to individual seals on a terrestrial breeding colony in western Scotland. The approximate dimensions of the four-wheeled vehicle were: height = 225 mm, length = 645 mm, width = 375 mm, wheelbase = 460 mm, and weight = 5,300 g. Analysis of behavioural responses from both males and females revealed consistent individual differences across sound playback exposure tests but did not reveal significant negative responses to the approach of the test vehicle itself, and the seals habituated quickly to its presence.

## CETACEANS

Due to loss of acoustic energy at the air–water interface, behavioural responses of cetaceans to AUVs are more likely to be driven by visual than by acoustic modalities (Smith et al. 2016), unless the AUV is operated at very low altitude over the water's surface, such as to collect whale blow samples (e.g., Pirotta et al. 2017). For example, Hodgson et al. (2013) suggest that marine fauna are unlikely to detect noise from a fixed-wing AUV (ScanEagle) flying at an altitude of 300 m. Hence, the potential for disturbance likely increases as AUVs enter the visual range of cetaceans (i.e., lower altitude). Few studies have attempted to identify and/or quantify disturbance to cetaceans caused by AUVs, and none to date have measured noise that penetrates into the water column via underwater received sound levels from an AUV under varying conditions.

There is a blind spot directly above the cetacean, based on eye position, so they would probably have to turn on their sides to see an AUV above them. Unless AUV lights or shadows were cast on the water to provide a visual cue, it seems probable that they would have to hear it first in order to have a stimulus for changing their swimming orientation.

### Rotary

Rotary aerial AUVs have been used in several ways to collect data on cetaceans, including the collection of exhaled breath condensate ("blow"; Acevedo-Whitehouse et al. 2010) and photographs for photogrammetry (Durban et al. 2015). Acevedo-Whitehouse et al. (2010) reported that Blue (*Balaenoptera musculus*), Gray (*Eschrichtius robustus*), Humpback (*Megaptera novaeangliae*), Sperm (*Physeter macrocephalus*), and Fin (*Balaenoptera physalus*) whales did not show any more avoidance responses (such as rapid diving) toward a rotary AUV (Raptor 30 V2 Thunder Tiger) flown directly over them at 13 m altitude than they did to more standard photo identification approaches using vessels. Durban et al. (2015) reported that a rotary AUV (model APH-22) flown over groups of Killer Whales (*Orcinus orca*) at an altitude of 35–40 m did not elicit any responses from the whales, and the researchers concluded that these whales were not aware of the presence of the AUV. However, neither of the above studies directly quantified cetacean responses to the AUVs, so it is possible that the whales responded in subtle ways that were not detectable though simple observation. Amateur video taken using a DJI Phantom quadcopter flown over Killer Whales in shallow coastal waters showed that these whales could detect the AUV flying overhead and may have oriented in the water to view the aircraft – perhaps responding to the lights on this model of AUV.

Studies of the effects of AUVs on dolphins are more limited than for whales. There is anecdotal evidence that Bottlenose Dolphins (*Tursiops truncatus*) sometimes chase shadows of rotary AUVs (Smith et al. 2016). However, there is also evidence that dolphins from the same population sporadically avoided larger shadows cast by an blimp airship that hovered above them (Nowacek et al. 2001).

### Fixed-wing

In one of the first studies using a fixed-wing aerial AUV to study cetaceans, Sleno and Mansfield (1978) found that a radio-controlled model aircraft (Senior Telemaster), with a 1 m wingspan, flying at an altitude of ~150 m caused no obvious disturbance to a herd of Beluga Whales (*Delphinapterus leucas*). This was in contrast to a multi-tonne manned aircraft flying at 300 m over the same herd, which caused the animals to disperse and the herd took up to two days to re-form (Sleno and Mansfield 1978). More recently, Koski et al. (2015) found that Bowhead Whales (*Balaena mysticetus*) showed no obvious responses when overflown by a fixed-wing AUV (TD100E) at approximately 83 km/h (23 m/s) and at altitudes from 120 to 210 m. Behaviour patterns considered to be signs of disturbance were based on previous studies (Patenaude et al. 2002; Richardson et al. 1995) and included abrupt or hasty dives, a rapid turn, breaching, and/or tail slaps (Koski et al. 2015). A report using the same data also noted that Bowheads did not appear to respond to the slow moving boat that accompanied the AUV to keep the pilot within the mandated minimum proximity to the AUV (1.5 km; Koski et al. 2014). As well, they noted that lack of disturbance caused by the aerial AUV was not surprising considering that bowhead whales do not respond to the much noisier manned aircraft that is traditionally used to take aerial photographs of this species (Koski et al. 2014). Similarly, a study of migrating Australian Humpback Whales (*Megaptera novaeangliae*; Hodgson et al. 2017) demonstrated that these whales did not appear to react to the overflight of a ScanEagle AUV at 732 m, the maximum altitude at which humpback whales were detectable with their camera system, and much higher than many manned aerial surveys.

### Vessel (e.g., remote-control boats, undersea gliders)

There are very few studies of the effects of undersea gliders on marine mammals. Baumgartner and Fratanoni (2008) studied Sei Whale (*Balaenoptera borealis*) vocalizations using four underwater gliders (Teledyne Webb Research) and, since vocalizations were detected throughout the study period, concluded that whales did not move away from the gliders. Although, whales could be detected at far greater distances, so it seems likely that they could detect the glider operation sounds. Baumgartner et al. (2013) also used two of the same gliders to collect vocalizations of Fin, Humpback, and North Atlantic Right *(Eubalaena glacialis*) whales, but did not comment on responses of these cetaceans to the operating sounds of gliders, which are not yet available in the literature.

Another wave glider system, with a surface hull and a subsea tow body, was used to measure abiotic and biological sounds off the Northeast United States (Luczkovich et al. 2019). This AUV, a Liquid Robotics SV2 Wave Glider (Liquid Robotics, Sunnyvale, California) is equipped with hydrophones and acoustic tag detectors. This low self-noise system recorded sounds of dolphins and humpback whales at close range, so the cetaceans were not displaced by the slowly moving vehicle, but behavioural reactions were not observed or quantified.

### Terrestrial

No published or grey literature research was found.

## OTHER (E.G., SEA OTTERS, POLAR BEARS)

### Rotary

Researchers at the University of Alaska Fairbanks found that most Sea Otters (*Enhydra lutris*) showed no behavioural responses, however a few swam slowly away when overflown by a small rotary AUV at less than 100 m altitude (Aeryon Scout quadcopter; UAF 2015). The researchers identified AUVs as a promising tool for studying of Sea Otters without disturbing them.

No studies were found that directly assessed the effect of rotary AUVs on Polar Bears (*Ursus maritimus*), but there is one study of the effects of rotary aerial AUVs (3D Robotics) being flown ~20 m above Black Bears (*Ursus americanus*). Ditmer et al. (2015) found that Black Bears did not respond behaviourally, but did show elevated heart rates (as measured by heart monitors attached to the bears previously) in response to the AUV overflights. Further study is required to determine if this result would be the same for polar bears (or any other marine mammal), but the study suggests that non-behavioural responses should be considered when assessing the effects of AUVs on animals.

Although sea turtles are not marine mammals, they are often counted in marine mammals surveys, and thus, are included here. Bevan et al. (2015) found no behavioural responses by sea turtle hatchlings or adults when they were monitored with an aerial quadcopter equipped with a GoPro camera, flying overhead at altitudes of 30–50 m.

### Fixed-wing

No published or grey literature research was found.

### Vessel (e.g., remote-control boats, undersea gliders)

Smolowitz et al. (2015) used underwater remotely operated vehicles (ROV; Teledyne Benthos Stingray and Teledyne Benthos MiniROVER) to follow and film Loggerhead Sea Turtles (*Caretta caretta*) in the mid-Atlantic. The researchers found that turtles responded to both types of ROVs and the tethers that attached them to the research boat. Turtles were startled by the ROV and moved away by diving if the ROV was not in the turtle's direct line of sight when it approached or if it approached closer than 3–5 m. Also, turtles sometimes swam over to investigate and interact with the ROV and/or its tether or swam wide circles around the ROV.

### Terrestrial

No published or grey literature research was found.

## A REVIEW OF PROVEN AND POTENTIAL IMPACT MITIGATION APPROACHES WHEN USING AUVS IN THE STUDY OF MARINE MAMMALS

Most of the studies described in this paper have categorized and reported variables (such as received noise levels, distance to animals, height above animals) and behavioural responses that were highly variable, inconsistently reported, and/or not reported in a standardized manner. This makes it difficult to compare studies and make general statements. There is a need for a standardized protocol for reporting behavioural responses of marine mammals to AUVs (see “Suggested Guidelines for AUV Operations”, below).

Most studies of the effects of AUVs on wildlife report minimal or no behavioural responses from animals exposed to aerial AUVs (Christie et al. 2016). However, there are few studies that directly and quantitatively assess responses of marine mammals to AUVs, and responses that were recorded appear to vary greatly depending on breeding state, previous disturbance, environmental conditions, and many other factors. Hence, proven impact mitigation approaches are scarce, and their development may need to occur on a population- and/or species-specific basis. As many researchers report that aerial AUVs cause significantly less disturbance to marine mammals than traditional manned aircraft (Acevedo-Whitehouse et al. 2010; Hodgson et al. 2013; Moreland et al. 2015; Sleno and Mansfield 1978), AUV use itself could be considered a proven impact mitigation approach. In a recent review of aerial AUV impacts on wildlife, Christie et al. (2016) suggest that AUVs are better suited for shorter surveys, while manned aircraft are more appropriate for longer surveys. As such, when evaluating impacts of AUVs on marine mammals, it is important to consider the degree of disturbance caused by the method traditionally used to collect the same data (i.e., manned aircraft) and how the use of an aerial AUV may result in a net reduction of disturbance.

Existing research suggests that marine mammal responses to aerial AUVs increase with decreasing flight altitude (Smith et al. 2016), prompting the conclusion that setting altitude limitations may help mitigate impacts of AUVs. Particularly for studies and methods that are novel and for which little research on the impacts exists, maximizing the distance between the AUV to the study subjects may be a simple, yet effective, way to reduce impacts. It is not clear whether increased noise or visual cues (or a combination of both) are the impetus for responses by marine mammals to lower-altitude flights (Smith et al. 2016). As such, impacts may be mitigated by using the quietest, smallest AUVs possible for a given study, and operating the AUV in environmental conditions that mask AUV flight noise and make it difficult for the animals to see it (e.g., noisy wind, bright sun) when feasible.

One example of a formal impact mitigation guide is a document by the Cornwall Seal Group (Cornwall, UK) that outlines the best practices for flying AUVs over the Cornwall grey seal population for research purposes (Cornwall Seal Group Research Trust 2016). This document provides advice that could be adapted for other populations and species. It provides guiding principles and suggestions based on the previous experiences of researchers flying AUVs over Grey Seals, such as using the smallest, quietest AUVs available that can complete the work and employing a licensed AUV pilot with wildlife safety accreditation. It also defines several behaviours, such as flushing and moving away, that should be considered as disturbance, and lists circumstances in which seals are at greater risk of being impacted (pregnant females, larger groups, juveniles). As well, the document provides advice for impact mitigation during the flight. These include considering ambient sound and light levels that may help mask the AUV sounds and hide it from seal sight lines, setting observers to watch for changes in seal behaviour, approaching slowly from a distance of more than 100 m, and making a slow and quiet retreat if seals look up at the AUV and do not look away after a minute of the AUV hovering nearby. Another effective feature of the Cornwall Seal Group AUV document is that it is reviewed regularly to improve the guidelines based on new research and experiences of researchers flying AUV missions. Considering the lack of information that is currently available about the impacts of AUVs on marine mammals, it is necessary for all documents providing guidelines for impact mitigation to be constantly revised as new information becomes available.

Despite (and due to) the lack of information available, Hodgson and Koh (2016) recommended a number of best practices for minimizing impacts of AUVs on wildlife. Specifically, they suggested a PA to the use and permitting of AUVs for wildlife research. They also recommend a permitting process modelled on current animal care/ethics processes, the use of appropriate AUV and sensor equipment, maintaining flight distances and practices that minimize disturbance, and the measurement and detailed reporting of animal responses/non-responses before, during, and after AUV operations (Hodgson and Koh 2016).

## A REVIEW OF AUV OPERATIONAL REPORTING REQUIREMENTS DURING THE STUDY OF MARINE MAMMALS

Although rules and operational reporting requirements for AUV use have been established by Transport Canada, these regulations are in a state of evolution due to rapid, on-going advances in the accessibility and capabilities of AUVs. At the time of this review, the Canadian Aviation Regulations, provided an exemption that allowed an AUV to be flown for commercial use (which includes research) without a special permit. To qualify for this exemption, the AUV must be between 2 kg and 25 kg and the flight operation must meet a number of criteria, including the operator having $100,000 liability insurance, the AUV staying at least 30 m away from people or animals, and the AUV operating within the unaided visual contact of the pilot. If the operator and flight plan meet the criteria necessary for exemption, they operator is required to provide the following information via the Transport Canada website prior to the flight: name, address, phone number, email address, AUV model and serial number, description of the operation, and geographical boundaries of the operation.

If an operator and/or flight plan does not meet the criteria necessary for a Transport Canada AUV rule exemption, the operator must apply for a SFOC to legally conduct the AUV mission. Application for a SFOC requires the researcher to give a detailed description of planned AUV mission, including the AUV details, operator contact information, details about the crew involved in the flight, the date and time of the flight, and plans in place to deal with safety risks. The process for obtaining and SFOC is time-consuming, requiring detailed information about the planned mission prior to submission, and up to 20 days of waiting for the application to be assessed and approved/rejected (Transport Canada). For each mission, a researcher must apply for a new SFOC; however, applications may be approved more quickly, or issued over a longer period of time (Standing SFOC) after a researcher has flown several missions safely and without incident. If a certificate is granted over a longer period, Transport Canada requires notice (via email or otherwise) at least two days prior to each operation.

Due to the huge increase in applications for SFOCs in recent years, the CARAC issued a Notice of Proposed Changes to the AUV regulatory framework on May 28, 2015. The suggested changes aimed to make the current regulatory process more user-friendly and more consistent with international partners, while also managing risk effectively. More specifically, Transport Canada aims to establish classifications (including the possibility of placing very small AUVs in their own category), clarify terminology, establish aircraft marking and registration requirements, address personnel licensing and training, and create flight rules. However, even with these changes, the SFOC process will still be required for some AUV operations, such as those that are deemed high risk, include AUVs heavier than 25 kg, and/or are operated out-of-sight of the pilot.

Similar to Canada, the United States is also in the process of making changes to its AUV use regulations. On June 21, 2016, a new set of regulations for non-hobbyist AUV operators was issued by the Federal Aviation Administration (FAA) in the United States. Notable differences from the current Canadian regulations include:

1. an online portal through which operators can apply for waivers that will allow them to bypass certain restrictions, given they can demonstrate that the operation can be carried out safely under a waiver, and
2. the requirement that AUV pilots are at least 16 years old and hold a remote pilot airman certificate with a small AUV rating (obtained by passing a FAA-approved aeronautical knowledge test) or are under the supervision of someone who has this certificate.

The European Union also made changes to its previous AUV regulations, with the European Commission releasing a formal Technical Opinion on the operation of AUVs on December 9, 2015. The new European rules focus on safety, security, privacy, data protection, insurance, and liability, and came into effect in 2016–17 (European Aviation Safety Agency 2022). Similar to current AUV rules in Australia, South Africa, and the United States, the new European Union rules will require AUV operators to be licensed. In a recent review, Linchant et al. (2015) suggest that many countries are taking a similar, cautious approach to regulating AUVs, and that wildlife research has been hindered by the slow pace at which legislation is being changed to better accommodate AUVs. However, they state that they are optimistic about recent progress and predict that countries will adapt their regulations as they see the examples of others (Linchant et al. 2015).

Although detailed descriptions of proposed AUV missions are needed for permit or exemption applications, neither Transport Canada nor the FAA currently require much post-mission reporting. Transport Canada does not explicitly require a report on permit-exempt or SFOC missions, and the only thing FAA regulations require is that AUV operators must report within 10 days of occurrence any incidents that “result in serious injury, loss of consciousness, or property damage (to property other than the AUV) of at least $500.” Neither regulator explicitly require reporting of animal disturbance.

In terms of permits and reporting required by other government agencies, in both the United States and Canada, it is illegal to operate an AUV within a National Wildlife Refuge/Area or National Park without a permit (National Parks of Canada 2017). In Canada, if the AUV operator provides a written proposal describing how the AUV flight will support natural or cultural resource management and protection that is directly related to the administration of the park, they may be able to obtain a Restricted Activity Permit. In the United States, the National Marine Fisheries Service (NMFS) is in the process of evaluating the use of AUVs for marine mammal research and provides a webpage with best practices guidelines. These guidelines recommend that marine mammals be observed at an aerial distance of at least 305 m, a guideline similar to that suggested by DFO in Canada (Canada Gazette 2012). Both the United States and Canada have laws that prohibit the disturbance of marine mammals (Marine Mammal Protection Act 1972; Marine Mammal Regulations SOR/93-56), but this legislation sometimes lacks the details necessary to effectively protect marine mammals during specific activities, such as whale watching, leading to efforts to develop amendments (DFO-Watching Marine Wildlife). As research on the effects of AUVs on marine mammals progresses, amendments to legislation may become necessary.

Outside of government, individual universities in Canada also have their own regulations to allow AUV research to fit within their risk management frameworks. For example, in addition to adhering to Transport Canada regulations, the University of Calgary requires researchers to register the AUV and pilot with the university's department of Risk Management and Insurance, obtain a certificate of insurance from the same department, and complete a Field Level Hazard Assessment before conducting AUV operations (University of Calgary 2023). Additionally, other non-governmental groups, such as those associated with a particular research site, have processes through which researchers can report, on a voluntary basis, incidents of disturbance and lessons learned. For example, the Cornwall Seal Group requests that researchers using AUVs to study Grey Seals in Cornwall report their experiences via email so that best practices guidelines and disturbance mitigation efforts can be continually improved (Cornwall Seal Group Research Trust 2016).

## SUGGESTED GUIDELINES FOR AUV OPERATIONS

Upon reviewing the existing information on the measured and potential impacts of AUVs on marine mammals, proven and potential mitigation approaches, and current operational reporting requirements, it is clear that there is a lack of empirical research on the identification and prevention of impacts, and that international regulatory frameworks are still evolving. Based on this conclusion and the information that does exist, we suggest the following guidelines that would be relevant for users of AUVs for marine mammal research and/or for users of AUVs within DFO.

### Guideline 1: Regulator(s) could clarify the level of reporting detail required of AUV operators

The regulator would benefit from clarifying the level of reporting detail they require of AUV operators before and following flight operations. Given that Transport Canada often requires a SFOC application to include a full, detailed description of the planned operations, we recommend that the operator be required to produce a follow-up report. This report would describe not just the actual flight, but if marine mammals were encountered, the context of the encounter (such as distance between AUV and the mammal, the location and apparent activity of the mammal during the encounter), and any apparent mammal responses (including whether the response(s) were recorded by the AUV imagery system).

**Guideline 2: Conduct explicit studies of the responses of marine mammals to AUVs in different contexts**

It is clear that AUV regulations are continually evolving in order to keep up with the rapid advancement of AUV technology and accessibility. However, it is also clear that regulators require more studies that explicitly measure the physiological (e.g., Ditmer et al. 2015) and behavioural effects of AUVs on different taxa in different contexts in order to develop effective frameworks and guidelines for mitigating disturbances to wildlife (Hodgson and Koh 2016). As existing information suggests that marine mammal responses to AUVs vary significantly with context, we concur with the recommendation by Smith et al. (2016) that researchers need to consider and quantify numerous factors to effectively evaluate animals' responses to AUVs. For example, Smith et al. (2016) suggest that marine mammal responses to AUVs may be affected by: acoustic features of the study area (e.g., if ambient sounds mask the sound of the AUV); species and age class of study animals (e.g., young animals that may be more responsive); behavioural and physiological state of study animals (e.g., pregnant or nursing females, moulting animals); presence, degree, and type of other nearby anthropogenic activities; AUV acoustic and visual properties (i.e., noise produced by rotary versus fixed-wing); AUV approach angle, altitude, and speed which would affect at what point are animals able to see the AUV); and frequency of exposure to AUVs. Although it is challenging to account for the numerous factors within a given situation that may affect marine mammal responses to AUVs, the existing data on this subject strongly suggest this level of detail is necessary to rigorously evaluate AUV effects and develop effective mitigation strategies in the long term. Hence, the core recommendation stemming from the current review is that more studies of this nature are needed. Ideally, the results of these studies would allow DFO researchers and those elsewhere to better pair appropriate mitigation techniques with specific contexts of AUV exposure.

**Guideline 3: Precautionary approach (PA) to permitting and training informed by available data**

Although more data are needed to properly evaluate the effects of AUVs on marine mammals, the need for policies regarding AUV use is immediate. Due to the fact that,

1. policies must be based on the limited data that is presently available,
2. there are many unknowns regarding how AUVs may be used in the future (e.g., multiple AUVs around one individual, AUVs with projectiles used to obtain samples, etc.), and
3. there is potential for injury to marine mammals if AUVs malfunction (e.g., gas-powered AUV crash at manatee wintering site; Jones 2003) or are improperly used.

We recommend that DFO regulators take a precautionary approach to permitting the use of AUVs for marine mammal research. This recommendation is consistent with Hodgson and Koh's (2016) call for caution in the use and permitting of AUVs for wildlife research in general. Specifically, we suggest a standardized, national approach that, at least initially, requires DFO and other researchers to apply for a permit similar to a SFOC. The permit application form should include sections in which researchers briefly outline their proposed AUV operation, describe plans to avoid/minimize disturbances to wildlife, and describe if/how the use of an AUV avoids the use of an alternative method that is demonstrated to be (or can reasonably be assumed to be) more disturbing to wildlife. Previous research demonstrating less disturbance caused by an AUV as compared to alternative methods (e.g., helicopter) should weigh very heavily in favour of the permit application being accepted. In addition to a permit, the person who will be piloting the AUV should be required to take a one-time, online training course developed by DFO that outlines, based on available information, best practices for flying AUVs near marine mammals. The extent and content of this pilot training may depend on training required/not required by Transport Canada as regulations develop over the next few years. Once a permit is granted and the operation has been completed, permit holders should be required to fill out a simple, online, post-operation reporting form with set fields that are automatically entered into a database. The main function of this form would be for permit holders to report whether or not they observed responses by marine mammals during their AUV operation, and to indicate the species, population (if applicable), other context details, and the type of response (if any).

Although requiring operation-specific permits, pilot training, and follow-up reporting is more time consuming and logistically-demanding for researchers and those issuing permits, the pace at which AUV technology is evolving paired with the slow pace of research creates too many unknowns to allow for general guidelines and broad policies. That said, similar to the SFOC process for Transport Canada, if a researcher is issued successive permits for similar operations and is able to report successful data collection with no disturbance or less disturbance than alternative methods, there should be a consistent policy in place to issue a longer term or blanket permit. Also, permit requirements and evaluation should be revised, and potentially relaxed, as more empirical data on the effects of AUVs on different marine mammals in different contexts become available.

**Guideline 4: Develop best practice guidelines based on existing research and the results of required reporting**

In order to best pair mitigation techniques with specific contexts of exposure, a brief "best practices" document should be developed for DFO researchers, perhaps under the auspices of the expert members of the Centre of Expertise in Marine Mammalogy (CEMAM). This document would include current information about known forms of disturbance by AUVs to marine mammals, the factors on which this disturbance appears to depend, and the known strategies for preventing or mitigating disturbance. This document could then be updated and revised regularly based on new data from studies and post-mission reporting. As more information on disturbance (or lack thereof) becomes available, individual best practices documents could be developed for different species, taxa, and/or populations that are regularly monitored by AUVs. In addition to describing responses by animals to AUVs, researchers would benefit from a requirement to document the sound frequency range and source level of the AUV, as well as the operational (altitude if flying, distance from animal target if on water or land, AUV speed, planned duration near the animal target) and environmental conditions associated with craft's usage. This would permit estimation of received sound levels in cases where this can't be measured directly using acoustic recorders affixed to the animals.

As an overarching goal, the AUV user should be able to justify the type of AUV and approach profile (including altitude and airspeed) at which they plan to use it. They should be able to demonstrate that their plan is the best they can do to minimize potential effects on marine mammals and providing detailed measures of context and animal responses during their research would help regulators determine this.

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## TABLES AND FIGURES

*Table 1. In-air sound levels for DJI-brand multirotor AUVs, with a professional decibel meter and the AUV hovering at various altitudes (Source: kperkins1982, upubl. data). Also included are some other in-air sound levels.*

| Sound Source | In-air Received Sound Level |
|---|---|
| Quiet library | 30 dB |
| DJI Phantom 3 running on ground | 38 dB |
| DJI Phantom 3 at 10 feet | 73 dB |
| DJI Phantom 3 at 150 feet | 58.5 dB |
| DJI Phantom 3 at 1,100 feet | 54.5 dB |
| DJI Phantom 3 at 1,200 feet | 49.5 dB |
| DJI Phantom 3 at 1,300 feet | 45 dB |
| DJI Phantom 3 at 1,400 feet | 43 dB |
| DJI Phantom 2 | ~75.8 dB |
| DJI Phantom 4 Pro | ~76.9 dB |
| DJI Inspire 2 | ~79.8 dB |
| Normal conversation at 1 m | 60-65 dB |
| Telephone dial tone | 80 dB |
| City traffic (from inside car) | 85 dB |
| Truck traffic | 90 dB |
| Jackhammer at 15 m distance | 95 dB |

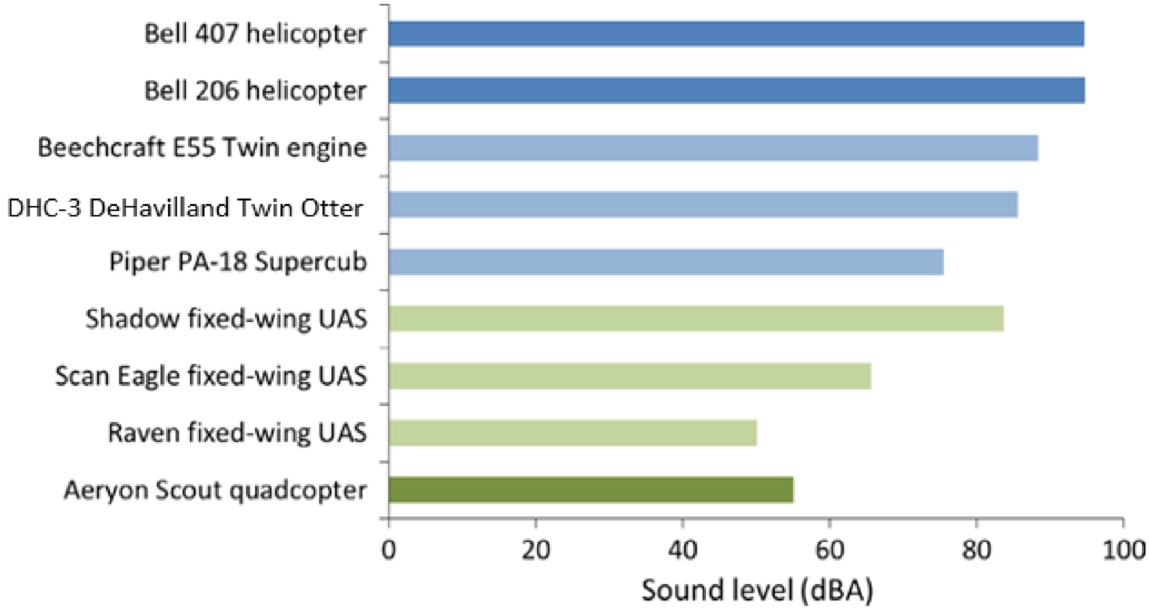


*Figure 1. Sound levels of different models of AUV (green bars), fixed-wing aircraft (light blue bars), and helicopters (dark blue bars), expressed in dB (A-weighted) adjusted to a common altitude of 100 m using the equation: 20°- log (altitude of measurement ÷ desired altitude) + measured sound level (from Figure 2 in Christie et al. 2016).*

## APPENDIX A: TRANSPORT CANADA'S "NEW RULES" INFOGRAPHIC, 2017

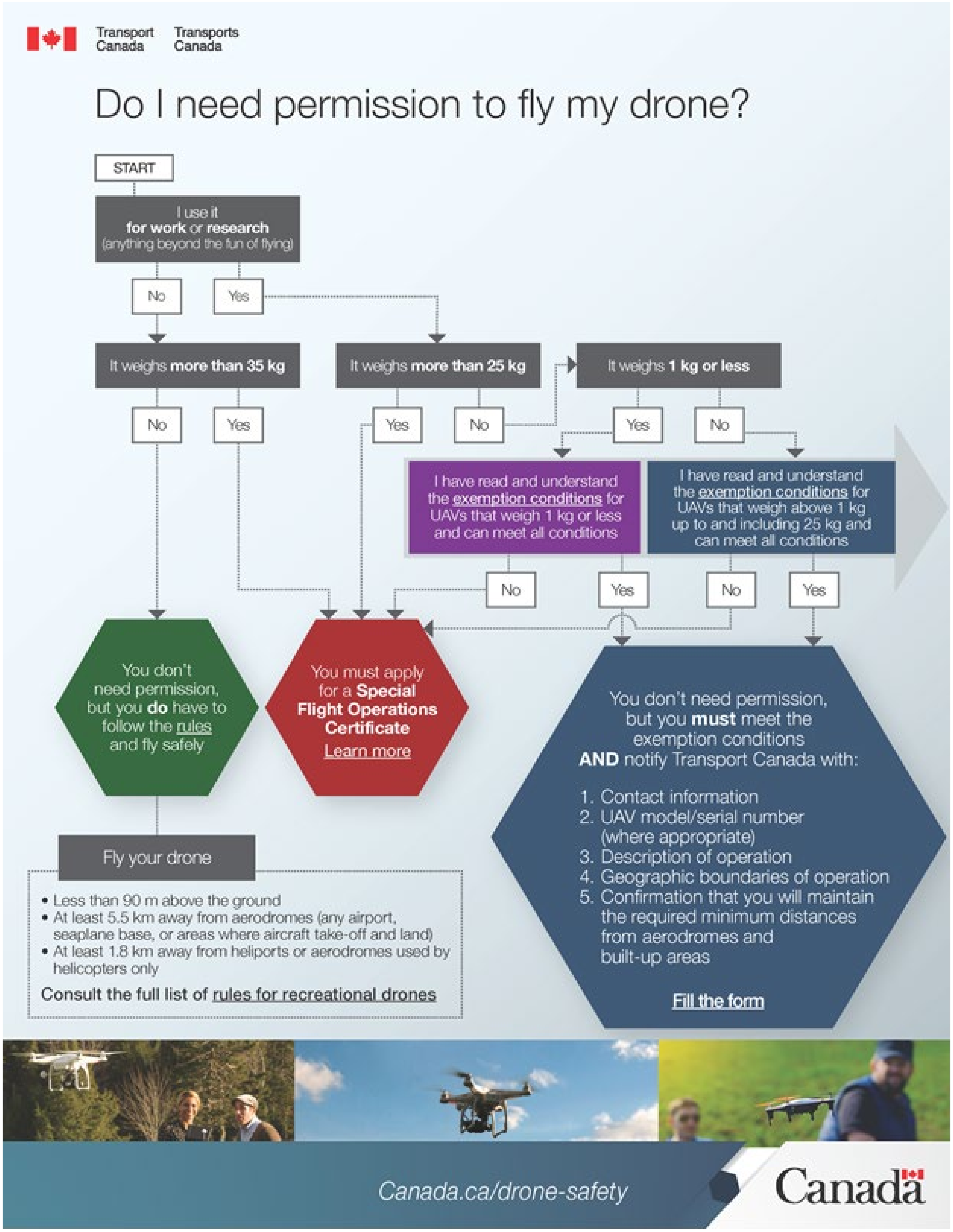


*Figure A1. Do I need permission to fly my drone poster from Transport Canada.*

## APPENDIX B: MAPPING WEBSITE FOR AUV OPERATORS IN CANADA

The Civilian Unmanned Aircraft Systems (CivUAS) program is offering an online tool to help AUV operators determine their compliance with safety guidelines and Transport Canada regulations. Using Google Maps and on-screen visual aids, the tool gives operators the ability to select a geographical area and easily verify if it is close to known aerodromes or airspace below 300 feet that is not class-G.