# Detecting and Monitoring Megafauna from Space: Exploring Opportunities for the Northeast Pacific

Photo: Crowe *et al.* 2018

## Webinar and Workshop, November 2nd and 3rd, 2022

Megafauna such as baleen whales can now be detected using very high resolution (VHR) satellite imagery. To co-explore the potential applications of this exciting technology in the Pacific, the Canadian Department of Fisheries and Oceans (DFO) and the UN Ocean Decade Regional Collaborative Center for the Northeast Pacific are holding a webinar and workshop that will set the stage for future collaborations to detect, monitor, and forecast megafauna using space-based data and advanced analysis methods.

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## SUMMARY

Emerging technologies for detecting and monitoring large-bodied animals – or 'megafauna' – are becoming increasingly important for assessing presence, abundance, density, distribution, and health status, and for mitigating threats to at-risk species. Recent work globally has shown that marine megafauna such as baleen whales can be successfully detected using very high resolution (VHR) satellite imagery, allowing for scientific studies, monitoring, and forecasting in remote and inaccessible areas. In Canada, the Canadian Space Agency in collaboration with Fisheries and Oceans Canada and Transport Canada recently launched a smartWhales initiative funding numerous research and development projects leveraging satellite detection data to protect the North Atlantic right whale (*Eubalaena glacialis*). In the Northeast Pacific, numerous megafauna species, such as the blue whale (*Balaenoptera musculus*), the fin whale (*Balaenoptera physalus*), and the basking shark (*Cetorhinus maximus*), are listed under Canada's *Species at Risk Act* (SARA) as either endangered or threatened. The application of VHR satellite imagery in the Pacific region is recommended to supplement traditional surveys using boat, land, and/or aerial platforms, to support a greater understanding of species at risk and their habitats and to work towards their survival and recovery. In particular, automated detection using machine learning and VHR has the potential to increase the capability and efficiency with which megafauna are detected and monitored, and forecasting using these technologies can be used towards threat mitigation and marine planning.

**This webinar/ workshop has been officially endorsed by UNESCO's Intergovernmental Oceanographic Commission (IOC) as a United Nations (UN) Ocean Decade activity.**

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## BACKGROUND

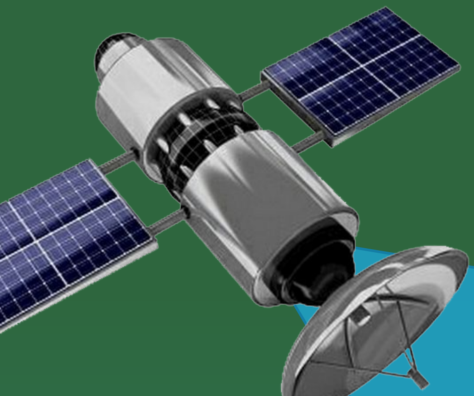
Large-bodied marine animals such as whales and sharks are charismatic creatures that play integral roles in marine ecosystems worldwide. However, many are threatened – some perilously so – due to past and current anthropogenic impacts such as overharvesting, ship strikes, entanglement, and pollution[3,20]. Surveys are crucial for assessing key characteristics of marine megafauna and are particularly important for data deficient species and species at risk where information on abundance and distribution is used for assessment and ongoing recovery efforts. Traditionally, marine megafauna are monitored using boats, planes, ground stations, hydrophones, live-capture, and tagging surveys[17]. These traditional surveys are logistically complicated and very expensive in cases where species inhabit remote areas, have large ranges, and/or are seasonally migratory[17,18]. With the emergence of new remote sensing technologies, innovative methods have been developed to monitor megafauna using very high resolution (VHR) satellite imagery[1-2,4-5,7-11,13-15,17].

| Satellite | Resolution (cm) | Launch Date |
|---|---|---|
| Worldview 3 | 31 (15*) | 2014 |
| Pleaides Neo | 30 | 2021 |
| Worldview 4 | 31 | 2016- 2019 |
| Geoeye 1 | 40 | 2008 |
| Worldview 2 | 40 | 2009 |
| Kompsat 3A | 40 | 2015 |
| SkySat | 50 | 2013 |
| Superview-1 | 50 | 2016 |
| Pleaides 1A/1B | 50 | 2011 |
| Worldview 1 | 50 | 2007 |
| Quickbird 2 | 60 | 2001- 2014 |

Summary of VHR satellites (<0.60 m panchromatic resolution) available in Canada (* refers to MAXAR's new HD proprietary sharpening software)

Abileah (2002) was the first to propose the use of VHR satellite imagery to detect whales; however, the resolution of imagery was not yet high enough to detect whales with complete certainty. After a change in legislation in the United States in 2014 allowed commercial satellite imagery companies to start producing imagery at very high resolutions (i.e., less than 50 cm[19]), Fretwell *et al.* (2014) successfully identified southern right whales (*Eubalaena australis*) in VHR satellite imagery. Since the launch of the world's highest resolution satellite to date – Worldview 3 with a spatial resolution of 31 cm – many studies have successfully identified whales using satellite imagery [4-5,7-11,13,15,17]

Per unit area, and as the technology develops further, VHR satellites have the potential to provide cheaper and safer means of studying marine megafauna in remote places compared to traditional surveys. Some studies have even proposed and successfully used this technology to monitor whale stranding events[8,14]. While VHR satellite detection and monitoring cannot fully replace traditional survey methods, when used in tandem with traditional methods, they can allow researchers and governments to deepen their understanding of species, including species at risk.





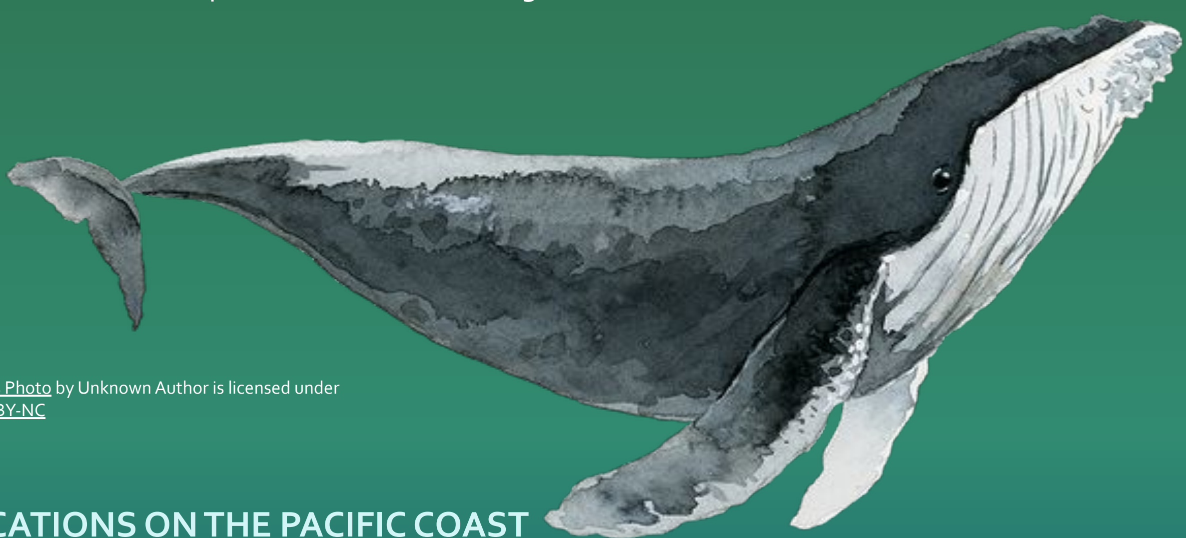
For implementation at a large scale, some automated detection methods have been developed that use machine learning algorithms which increase the capability and efficiency of megafauna detection from satellite imagery. These algorithms are the first step in developing real time detection and forecasting models that can be used for threat mitigation and marine planning[5,15].

Although the potential for this work is high, several challenges exist. While VHR satellite imagery can offer a cheaper alternative to traditional surveys, imagery can still be **cost** prohibitive given that most VHR satellites are commercially owned. Many marine **environmental conditions** like clouds, haze, sun glint, waves, swell, and water turbidity can impact the detectability of megafauna in satellite imagery. The **resolution** of VHR satellite imagery still limits the size of megafauna that can be detected confidently in imagery (>3 m) and **species differentiation** of morphologically similar species, such as baleen whales where they co-occur, is difficult at the current resolutions available. Manual analysis of imagery is **time consuming**; however, automated detection algorithms can help combat this challenge. Lastly, more data needs to be collected to account for **availability bias** to accurately determine the abundance/ density of marine megafauna from space. With growing advancements in satellite imagery technology, solutions to many of these challenges are likely in the future.

## ONGOING RESEARCH IN CANADA

Two large-scale initiatives related to detection of marine megafauna using VHR satellite imagery exist in Canada to date: (1) the **Space Whales and Arctic Marine Mammals (SWAMM) program** established in 2021 and led by DFO in collaboration with MacDonald, Dettwiler and Associates Systems Ltd. (MDA), Whale Seekers Inc., and MAXAR; and (2) the **smartWhales initiative** established in 2021 and led by the Canadian Space Agency (CSA) in collaboration with DFO and Transport Canada (TC).

- The **SWAMM program** is currently funded through a SARA Nature Legacy grant (2021 – 2023) and focuses on using VHR satellite imagery of the Canadian Arctic to detect and estimate the density/ population size of belugas, narwhals, and possibly walruses.
- The goal of **smartWhales** (2021-2023) is to advance solutions using satellite data to help detect, monitor, and protect the endangered North Atlantic right whale (NARW). Five companies and their collaborators were funded with a 5.3-million-dollar grant. Out of these five consortiums, three are focused on the detection and monitoring of NARWs using VHR satellite imagery (Stream 1), and two are focused on the prediction and modelling of NARW habitat (Stream 2).

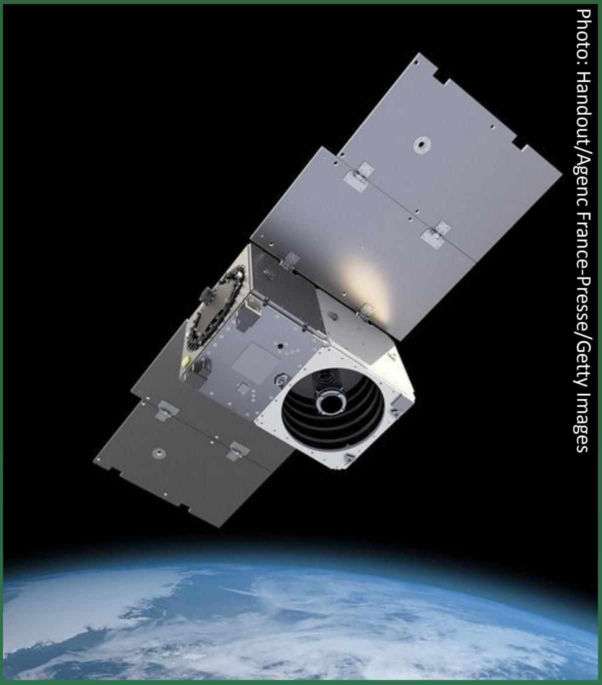




## APPLICATIONS ON THE PACIFIC COAST

On the Canadian Pacific coast, no VHR satellite imagery detection programs exist. However, several large cetacean species at risk that occur in the Northeast Pacific, including multiple ecotypes of killer whale (*Orcinus orca*), along with many medium- to small- sized cetaceans[12] that may or may not be detectable in VHR satellite imagery, could benefit from the adoption of a satellite imagery monitoring program. While traditional survey methods have increased our understanding of megafauna on this coast, many questions remain on population abundance, density, distribution, and habitat usage, especially in remote areas. VHR satellite imagery could aid in answering these questions and help managers implement species planning and policy to advance recovery efforts.

Three major satellite imagery providers: MDA, Planet, and Airbus, that are each covered by National Masters Standing Offers, and one major secondary satellite imagery distributor, Apollo Mapping, offer imagery in Canada. Within the Canadian government, the Canadian Hydrographic Service (CHS) has already purchased satellite imagery for most of the coast made up of Worldview 2, 3 and 4, Geoeye, Quickbird, and aerial images. These data are available for internal access through a DFO Internal End User Restriction Agreement or to academics or outside collaborators under a Direct User License Agreement.

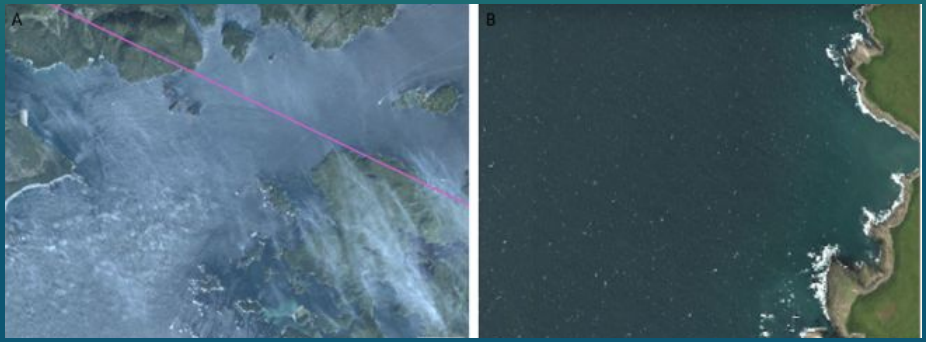



## CHALLENGES ON THE PACIFIC COAST

There are specific challenges associated with using VHR satellite imagery to monitor marine megafauna on the Pacific Coast of Canada. This coast is characterized by high amplitude tides, complex topography, steep bathymetry, turbidity, complex currents, high cloud cover, and low sun angles[6]. Knowing how these and other environmental factors occur across space and time is important in understanding how well VHR satellite imagery will work for detecting marine megafauna in certain areas. Additional limiting factors are the distributions and morphologies of Pacific species. The marine megafauna species found on the Pacific Coast often occur in low densities spread across large areas, making imagery tasking difficult. Similar species of large cetacean also co-occur making species differentiation difficult. Some morphological characteristics like the general size or shape of species, or specific characteristics like the callosities on the heads of North Pacific right whales (*Eubalaena japonica*) or the long pectoral fins on the humpback whale (*Megaptera novaeangliae*), can be used to differentiate species but not with one hundred percent accuracy at the current resolutions offered[10,17].

Clips of imagery from Apollo Image Hunter showing:

A) a Quickbird image that has a combination of fog, glint, haze and low-lying clouds; and,
B) a Worldview 2 image showing rough sea conditions including white caps and shore waves




## METHODOLOGICAL CONSIDERATIONS ON THE PACIFIC COAST

With these considerations in mind, the most efficient and effective way to monitor species in the Northeast Pacific using VHR satellite imagery is by developing **automated (or semi-automated) detection algorithms**, potentially in combination with crowdsourcing. **Crowdsourcing** is a method that has been used to sift through substantial amounts of images by leveraging large numbers of decentralized volunteers to generate data[16,21]. While there are limitations, crowdsourcing does hold some promise for binary detection (e.g., whale versus non-whale object), especially if combined with automated or semi-automated detection methods to minimize the amount of imagery to be inspected by users.

Multiple different approaches can be used when developing automated or semi-automated detection algorithms for marine megafauna. One semi-automated approach is to develop a basic algorithm that flags images within possible megafauna sightings for manual inspection, removing a large percentage of the imagery and reducing time associated with manual detection. Another option is to develop an algorithm which selects images with possible megafauna sightings and then identifies the location of each possible sighting within each image. No algorithm (globally) has been trained to differentiate species yet; thus, manual inspection of each possible megafauna observation would still be needed to differentiate species on the Pacific Coast. Efforts on the Pacific Coast could be focused on developing a fully automated detection algorithm that is able to differentiate species, but this may take longer than the already established methods described above. Building off the smartWhales algorithms, once they can differentiate NARW from co-occurring species, could be an efficient way of advancing megafauna detection on the Pacific Coast, if these algorithms are trained to recognize and differentiate Pacific Coast species.

## LOOKING AHEAD: REAL-TIME AND FORECASTING SYSTEMS

There is great potential for developments in space-based data and advanced analysis methods to lead to combined or integrated systems that generate a greater understanding of species and result in real-time threat mitigation. The BC Cetacean Sighting Network (BCCSN) has already implemented an alert system where real-time observations of cetaceans and sea turtles submitted by members of the public are used to alert ships to reduce the risk of disturbance and/or collisions. In the future, a real-time 'tip and cue' system could be developed where sightings from the BCCSN and/or other sightings networks are used to initiate the collection of satellite imagery in a certain area(s) where species of interest are observed. Alternately, a more costly type of real-time alert system could be developed consisting of VHR satellites continually collecting imagery over a specific are(s) (e.g., of high threat/risk) in combination with an automated detection algorithm to alert boats when a species of interest is detected in an area. Lastly, a system to aim for might be one in which all the above elements, plus forecasting (predicting animal movements following sightings) using other types of data - like environmental, historic, Indigenous Knowledge , and satellite imagery of ocean conditions and/or food sources such as plankton - are combined in a cyclical way to increase detection and threat-mitigation for marine megafauna.

### A SYSTEM TO AIM FOR

This system might consist of, for example: citizen science reporting of sightings; continual (or cued) VHR satellite imagery collection and analysis via automated detection; and other types of continual (or cued) data collection (such as acoustic data from hydrophones). This species-specific detection data could be integrated with other types of data (e.g., environmental, historical) in a stochastic movement model to predict animal movements that inform real-time and future trajectories and locations of vulnerable whales.

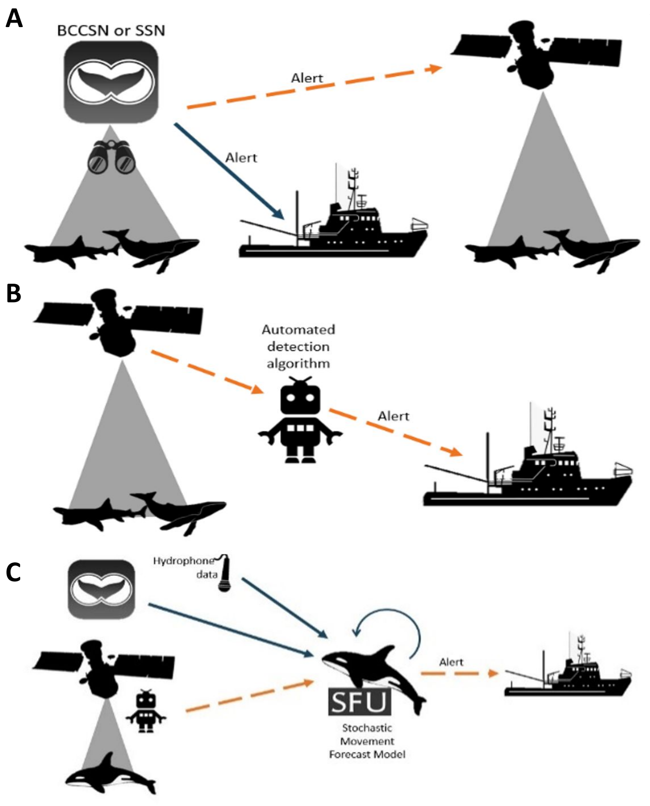



Diagram of possible real-time and/or forecasting systems showing: A) a tip and cue system; B) an automated detection alert system; and, C) an automated detection system integrated into a forecast model (e.g., work on southern resident killer whales being developed at Simon Fraser University (SFU) by Dr. Ruth Joy and Dr. Marine Randon).

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## ADDITIONAL APPLICATIONS

Beyond species' population monitoring for the purposes of assessment or recovery, there are numerous large-scale initiatives on the Pacific Coast of Canada that could benefit from the procurement of VHR satellite imagery and the advancement of automated detection algorithms for megafauna (and/or other targets of interest, such as boats). For **oil spill response planning**, for example, the Pacific Coast offers a unique challenge, with more than 25,000 km of coastline, much of it in extremely remote locations. For this reason, it is crucial that spill response planners have access to the best available satellite data during planning, preparedness, and response. Real-time, automated detection of megafauna with forecasting could be used to inform adaptive response plan development and actual responses in the event of a spill. Additionally, the Northern Shelf Bioregion (NSB) Marine Protected Area Network (MPAn), once designated, the Parks Canada Agency's National Marine Conservation Areas (NMCAs), and Indigenous Protected and Conserved Areas (IPCAs), among other **spatial planning initiatives**, face similar challenges with respect to **large-scale monitoring and enforcement** that could be aided by using VHR satellite imagery-based projects and programs. Monitoring frameworks for spatial management initiatives that consider all the applications of VHR satellite imagery – from mapping and monitoring ecologically important areas to megafauna detection – will be more beneficial than ones that consider one-off applications. Local to global partnerships and collaborations will be key for cost-sharing, fund-leveraging, and ongoing knowledge-building.

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