Monitoring Pacific marine conservation area effectiveness using aerial and RADARSAT-2 (Synthetic Aperture Radar) vessel detection

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Burke, L., Clyde, G., Proudfoot, B., Rubidge, E.M., and Iacarella, J.C. 2022. Monitoring Pacific marine conservation area effectiveness using aerial and RADARSAT-2 (Synthetic Aperture Radar) vessel detection. Can. Tech. Rep. Fish. Aquat. Sci. 3479: xi + 50 p.

There is a critical need for monitoring and evaluation tools to ensure marine conservation areas are meeting conservation objectives. In particular, monitoring human pressures is fundamental for evaluating management effectiveness and ecological performance. Vessel tracking data shed light on a variety of human pressures within conservation areas and are highly valuable for evaluating vessel- and fishing-related regulations. We analyzed vessel tracking data collected by the Government of Canada in 2020, including aerial surveillance from Transport Canada and Fisheries and Oceans Canada, and RADARSAT-2, to demonstrate how these data can be used for human pressure monitoring and evaluating effectiveness of Canada's marine conservation areas. We found that surveillance effort was highest in glass sponge reef marine refuges and Switftsure Bank Interim Sanctuary Zone. The highest vessel densities were detected in Rockfish Conservation Areas, glass sponge reef marine refuges, and Swiftsure Bank. Commercial vessels (not including fishing vessels) observed by flyovers and large vessels found in RADARSAT-2 images were generally detected more often in conservation areas than other vessel types. Non-compliance with vessel- and fishing-related regulations or guidelines was detected in six of the nine conservation area types. We provide recommendations on which data source to use based on the monitoring focus and conservation area location, as well as for optimizing surveillance data collection and usability moving forward.

RÉSUMÉ

Burke, L., Clyde, G., Proudfoot, B., Rubidge, E.M., and Iacarella, J.C. 2022. Monitoring Pacific marine conservation area effectiveness using aerial and RADARSAT-2 (Synthetic Aperture Radar) vessel detection. Can. Tech. Rep. Fish. Aquat. Sci. 3479: xi + 50 p.

Il existe un besoin criant en matière d'outils de surveillance et d'évaluation pour s'assurer que les aires de conservation marines atteignent les objectifs de conservation établis. Plus précisément, la surveillance des pressions d'origine anthropique est un élément fondamental pour évaluer l'efficacité et le rendement écologique des pratiques de gestion. Les données issues du suivi des navires ont mis en lumière diverses pressions d'origine anthropique dans les aires de conservation et sont grandement utiles pour évaluer l'efficacité de la réglementation visant les navires et les pêches. Nous avons compilé et analysé les données de suivi des navires recueillies par le gouvernement du Canada en 2020, y compris les données issues de la surveillance aérienne faite par Transports Canada, Pêches et Océans Canada et RADARSAT-2, afin de montrer comment celles-ci peuvent servir à surveiller les pressions d'origine anthropique et à évaluer l'efficacité de la gestion des aires de conservation marine du Canada. Nous avons constaté que les activités de surveillance étaient les plus soutenues dans les refuges marins des récifs d'éponges siliceuses et dans le sanctuaire provisoire du banc Swiftsure. Les plus grandes concentrations de navires ont été détectées dans les aires de conservation du sébaste, dans les refuges marins des récifs d'éponges siliceuses et dans le banc Swiftsure. Les navires commerciaux, à l'exclusion des navires de pêche, observés lors de survols ainsi que les grands navires aperçus sur les images de RADARSAT-2 étaient plus souvent repérés dans des aires de conservation que les autres types de navires. Des cas de non-conformité à la réglementation ou aux lignes directrices concernant les navires et la pêche ont été documentés dans six des neuf types d'aires de conservation. Nous formulons des recommandations sur les sources de données à utiliser en fonction de l'axe de la surveillance et de l'emplacement de l'aire de conservation ainsi que pour optimiser la collecte de données de surveillance et leur utilisabilité dans l'avenir.

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1.0. INTRODUCTION

The expansion of marine conservation areas in response to growing national and global conservation targets is creating a critical need for monitoring and evaluation tools to ensure these areas meet the conservation objectives they were intended to achieve. Canada adopted a suite of national conservation targets to meet international commitments to protect 25% of the ocean by 2025 and 30% by 2030 through networks of Marine Protected Areas (MPAs) and other effective area-based conservation measures (OECMs) (Canada Prime Minister's Office 2019; UNEP 2020). Currently, 13.8% of Canada's coastal and marine areas were protected through the establishment of MPAs and OECMs. Fisheries and Oceans Canada (DFO) is responsible for managing MPAs and OECMs, as well as for tracking their effectiveness through monitoring and evaluation.

Human pressure monitoring of MPAs and OECMs (hereafter referred to as 'conservation areas') is integral to evaluating the effectiveness of these areas, but is an often overlooked component of monitoring (Bergseth et al. 2015; Dunham et al. 2020). Tracking and evaluating illegal and legal human pressures in conservation areas is necessary to determine if regulations are effective (i.e., management effectiveness) and for understanding results from ecological performance monitoring (i.e., ecological effectiveness). For the latter, if non-compliance with regulations is high, poor MPA performance would be expected as the closure is not being effectively protected and thus would function similarly to an open area without any regulations (Dunham et al. 2020). Evaluating non-compliance levels can also inform improved management practices and public outreach by understanding where and why non-compliance may be high (Iacarella et al. 2021).

Many human pressures that occur and are regulated within marine conservation areas are associated with vessel activity and can be monitored using vessel tracking data (Iacarella et al., 2020b; Iacarella et al., 2021). Vessel tracking data can be used to estimate numerous vessel-related pressures that are relevant to protecting conservation areas including commercial and recreational fishing activity (McCauley et al. 2016; Kroodsma et al. 2018), boat anchoring (Deter et al., 2017), underwater noise (Erbe et al. 2012), pollution (Bertazzon et al. 2014), and aquatic invasive species (Iacarella et al., 2020a, 2020c).

The Government of Canada (GoC) collects a variety of datasets that can be applied to long term monitoring of vessel activities in conservation areas. However, these data have largely only been used to-date for real-time applications and responses including for marine pollution, maritime security, navigational safety, search and rescue, and enforcement. Vessel tracking surveillance sources include Automatic Identification System (AIS), Vessel Monitoring System, Electronic Monitoring System, aerial surveillance (hereafter 'flyovers'), RADARSAT-2 (RADARSAT) Synthetic Aperture Radar, and violation records. A national-level description of GoC vessel tracking data and applications, along with spatial and temporal resolutions, is provided in the DFO Technical Report on Vessel Tracking Datasets for Monitoring Canada's Conservation Effectiveness (Iacarella et al., 2020b). In addition, national AIS and DFO-Pacific flyover data from 2012-2019 were analyzed in collaboration with Global Fishing Watch to estimate trends in illegal and legal fishing activity in Canada's marine conservation areas (Iacarella et al., in review). Here, we present a complimentary evaluation of vessel tracking data highlighting different surveillance sources (Transport Canada and DFO flyovers, and RADARSAT) and uses for overall monitoring of vessel activity in Pacific Region conservation areas.

The Pacific Region has many conservation areas with vessel-related management measures that are federally designated and were established by DFO, Environment and Climate Change Canada, and Parks Canada. These include three *Oceans Act* MPAs, 17 glass sponge reef marine refuges, 162 Rockfish Conservation Area Fisheries Closures, one marine National Wildlife Area, one Marine National Conservation Area Reserve, and three Interim Sanctuary Zones. In addition, the Offshore Pacific Seamounts and Vents marine refuge located within the Offshore Pacific Area of Interest, an interim area currently set aside for consideration as an *Oceans Act* MPA. Most of the vessel-related management measures for these areas include gear and user-group specific fishing prohibitions or restrictions put in place to protect and promote fish abundances and important benthic habitats. Vessel entry is also prohibited in the Scott Islands marine National Wildlife Area for the protection of seabirds and in the Interim Sanctuary Zones for the protection of Southern Resident Killer Whales. Other vessel-related management measures include restrictions on the exchange of ballast water to avoid aquatic invasive species introductions in SG̱aan Ḵinghlas-Bowie Seamount MPA and vessel anchoring restrictions to protect sensitive benthic habitats, such as the glass sponge reefs in the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA. Monitoring human pressures across these conservation areas is a non-trivial undertaking owing to the complexity of vessel regulations and/or guidelines, variable usability of vessel tracking data in raw form (i.e., often distributed as text and attachments in emails), and characteristics of the conservation areas that make some vessel tracking data more useful than others (e.g., distance from shore, closure size).

1.1. GOALS

We compiled and analyzed data from 2020 for two vessel tracking surveillance types, flyovers and RADARSAT, available from three sources to:

- Develop and apply vessel-related metrics from MPA management plans and risk-based indicators from MPA ecological risk assessments to demonstrate how these data can be used by DFO for human pressure monitoring and management effectiveness evaluation of Canada's marine conservation areas.
- Examine and compare the usefulness of the vessel tracking data types for monitoring using three case-studies: an offshore MPA (SG̱aan Ḵinghlas-Bowie Seamount), an inshore MPA (Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs), and an Interim Order to protect Southern Resident Killer Whales (Swiftsure Bank Interim Sanctuary Zone).
- Provide results on detected non-compliance for vessels with and without AIS, and identify conservation areas with relatively high vessel activity and low surveillance to help inform where there may be high human pressures and a need for increased surveillance.

By developing these methods and making them accessible, we hope to improve vessel tracking data usability and to increase capacity in applying these data for monitoring the effectiveness of Canada's conservation areas. We provide three key summary outputs in this report (1) a ranking of the three surveillance sources based on several data-driven criteria for use in long-term closure monitoring and on their ability to detect non-compliance, (2) an initial 'score card' noting whether non-compliance was observed for each closure in the Pacific region by surveillance source, and (3) a decision tree framework to help guide selection of data appropriate for a given closure. Finally, we provide protocols and R code to compile and process the vessel tracking data types for future use.

1.2. SCOPE

We evaluated vessel tracking data within Pacific conservation areas using three sources: (1) coastwide flyovers conducted by DFO's Conservation & Protection Aerial Surveillance Program (hereafter 'C&P'), the program responsible for fisheries enforcement, (2) targeted flyovers conducted by Transport Canada National Aerial Surveillance Program (hereafter 'TC') at the request of DFO's Oceans Program, and (3) image analysis of RADARSAT provided by the space technology company MDA Ltd[1]. These surveillance sources are capable of detecting vessels with or without AIS transponder units on board. AIS are used to broadcast information about a vessel's identity, position, and activity and are a powerful tool for monitoring vessel activity due to their high spatial and temporal resolution (Iacarella et al., 2020). In Canada, AIS is required for large vessels (≥ 300 tons on an international voyage or ≥ 500 tons not on an international voyage), vessels ≥ 150 tons carrying more than 12 passengers on an international voyage, vessels voyaging outside of sheltered waters certified to carry more than 12 passengers, or vessels that are ≥ 8 m in length and carrying passengers (Navigational Safety Regulations (Automatic Identification Systems): SOR/2019-100). However, there can be significant vessel omissions in Canada's AIS data because smaller commercial fishing and recreational vessels are not required to carry AIS. For instance, 70% of vessel traffic detected on flyovers over the Salish Sea in British Columbia were not transmitting AIS (Serra-Sogas et al., 2021). Vessel Monitoring Systems are required for some fishing vessels, but use is limited in the Pacific Region and data availability and permissions are restricted nationally (Iacarella et al., 2020). AIS and Vessel Monitoring Systems are essential vessel tracking surveillance sources for monitoring conservation areas and can be improved with increased carriage requirements by TC and DFO, respectively. Here, we focus on flyovers and RADARSAT to fill in gaps from the current limitations of AIS and Vessel Monitoring Systems, and to highlight benefits of these other surveillance data. All DFO Regions have access to flyover data, whereas RADARSAT imagery is more commonly used in the Pacific (Iacarella et al., 2020); metrics and code provided here can be applied to conservation areas nationally.

2.0. METHODS

2.1. VESSEL TRACKING SURVEILLANCE TYPES

Detailed descriptions of the flyovers and RADARSAT vessel tracking surveillance types used in this report are provided by Iacarella et al. (2020), including for other DFO Regions. The vessel detection and surveillance effort information extracted from C&P, TC, and RADARSAT vessel tracking surveillance sources is provided in Table 1. Spatial analyses were done using ArcGIS (V.10.8) and Python (V3), and data compilation and plotting, were done using R (R Development Core Team, 2021). R code and instructions on how to access, compile and process the surveillance sources can be found on GitLab at: https://gitlab.com/dfo-msea.

2.1.1. DFO Conservation & Protection (C&P) Aerial Surveillance Program (ASP)

Aerial surveillance has been conducted by C&P since 2002 as part of the ASP to enforce DFO regulated spatial fishing closures. Vessels with AIS transponders are detected during flyovers by

[1] MDA Ltd. is an international space mission partner that provides robotics and space operations, supplies satellite systems, and geointelligence. MDA supports Canada's role in space by designing, manufacturing, testing and integrating satellite payloads and full mission plans. This includes the RADARSAT-2 and RADARSAT Constellation Missions for the Government of Canada, which provides the imagery for vessel detections.

an AIS receiver attached to the plane while vessels without AIS are detected by Inverse Synthetic Aperture Radar (ISAR) or by visual observation by aircraft observer. Historical data from flyovers were stored in the online Surveillance Information Server 3 (SIS 3) database in the form of multiple reports for each mission and provide mission event details, vessel detections, aircraft tracks, and observation summaries with pictures. Since 2021, data from flyovers are stored in a new system called AIMS-C4. We downloaded six reports (.csv and .xls files) for each flyover mission from the SIS 3 database from 2018-2020. The flyover reports are labeled as: Mission Targets List, Fishing - ManualOnTop, Fishing - AIS, Commercial - ManualOnTop, Commercial - AIS, Target, and Aircraft reports. Reports include information on the activities vessels were engaged in, vessel identification (name and unique Maritime Mobile Service Identity number [MMSI], if available), vessel location (latitude/longitude), the speed and course of vessel travel, and the location and timing of the flyovers. We used 2020 C&P flyover data to evaluate vessel activity in Pacific conservation areas, and data from 2018-2020 to better evaluate the change in vessel activity after Swiftsure Bank Interim Sanctuary Zone prohibitions were put in place. Potential non-compliance with conservation area regulations was identified using information provided in flyover reports and included vessel activity and fishing gear type, as well as species targeted. Note, we report non-compliance as ‘potential’ throughout as violation records are classified.

2.1.2. Transport Canada (TC) National Aerial Surveillance Program (NASP)

TC have conducted flyovers as part of the NASP since 1991 to monitor shipping activity, ice conditions, marine security, and marine pollution. The aircraft is equipped with remote sensing equipment that detects and documents oil spills and other marine pollutants along with MPA boundary markers to highlight areas of interest for monitoring. Vessel detection during flyovers primarily relies on visual observation by aircraft observers; weather conditions affect flyover success with cloud cover impairing visibility. There is also an AIS receiver attached to the plane that can be used to detect vessels with AIS transponders and vessels can also be detected with radar. Since 2019, TC flies over and reports on three MPAs during pollution patrols: Endeavour Hydrothermal Vents, Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs, and SG̱aan Ḵinghlas-Bowie Seamount. Reports are provided as text and picture attachments in emails and note the number of vessels observed within the MPAs, vessel identification and activity, and whether the vessels are identified with AIS. The type of vessel information collected by TC and how the information is reported were developed with guidance from DFO’s Oceans Program and Science Branch. We saved and transcribed the email reports from 2020 for analysis; we note that because there is no repository for these data, *historical and future data from TC flyovers will be lost if not compiled and saved by single users*.

2.1.3. Synthetic Aperture Radar (SAR) RADARSAT-2 Satellite Imagery

The SAR imaging satellite program, RADARSAT-2 (RADARSAT), was launched in 2007 and is used for maritime surveillance, vessel traffic and environmental monitoring, and resource and disaster management (CSA 2017). RADARSAT has several imaging modes with different resolutions that detect a wide range of vessels and have varying swath widths (i.e., the area imaged on the Earth’s surface) over the Pacific Exclusive Economic Zone (EEZ). *Fine* mode was used to detect vessels as small as 8 m in length with a swath width of 50 km in the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA, though this mode was no longer supported as of July 2020. The remaining areas are imaged using the *Detection of Vessels Wide*

Far beam mode, which detects vessels down to 25 m in length with higher confidence (i.e., smaller vessels can be detected, but detection confidence decreases) with a swath width of 450 m (Iacarella et al., 2020). RADARSAT data were obtained by C&P using the GoCs credit with the satellite program from 2017 until July 15, 2020 at a cost of $0.024/km for *Detection of Vessels Wide Far* mode (Iacarella et al., 2020). These data were used by C&P to monitor vessel presence within the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA, SG̱aan K̲inghlas-Bowie Seamount MPA, and the Offshore Pacific Area of Interest. Since July 2020, the Department of National Defence has provided RADARSAT ship detection data captured using *Detection of Vessels Wide Far* mode at no cost to support the DFO-Pacific MPA program on a non-interference basis (P. Hagell, MDA, Esquimalt, B.C., personal communication, 2020). These data are provided to DFO Oceans for MPA management purposes.

Images from RADARSAT are analyzed by MDA Ltd. and data are provided in Marine Security Operations Centre DFO MPA emails. Emails include Google Earth files (.kmz), Over-The-Horizon (OTH) gold text files (.txt), and spreadsheets (.csv). These files detail vessel observations, including the time and location, MMSI number if the vessel was transmitting AIS, vessel length, and confidence of vessel detection as image analysis may have false positives from waves or rocks. We compiled and processed RADARSAT data from 2020 for analysis; we note that *historical and future data from RADARSAT will be lost if not compiled and saved by single users*.

Table 1. Vessel detection and surveillance effort information extracted from Conservation & Protection, Transport Canada, and RADARSAT vessel tracking surveillance sources.

Surveillance Data Source	Vessel detection information	Surveillance effort information
Conservation & Protection Aerial Surveillance Program	Mission #, Date, Time, Vessel name, Vessel #, Nationality, Vessel ID, Maritime Mobile Service Identity #, Vessel Registration #, International Maritime Organization #, Call Signal, Radius, Latitude/Longitude, Area, Activity, Course, Speed, Vessel type, Vessel subtype, Work element, Species, Fish, Observation, Photo, Video	Mission #, Date, Time, Latitude/Longitude, Altitude
Transport Canada National Aerial Surveillance Program	Mission #, Date, Time, MPA name, Vessel name, Vessel # in MPA, Nationality, MMSI, Activity, Navigation status, Ship/Cargo type, Destination, Origin, Vessel length, Latitude/Longitude	Mission #, Date, Time, Flyover time in MPA, Total flyover time
RADARSAT	CTC #, Date, Time, Vessel name, MMSI, IMO, Timedelta, Sensor, Bearing, Source/Beam setting, Latitude/Longitude, Vessel length, Vessel width, Detection confidence	Swath name, Description, Sensor, Duration, Sensor mode, Direction, Beam, Start date time, End date time, Swath ID

2.2. MARINE CONSERVATION AREAS

The Pacific conservation areas spatially represented in this study are Endeavour Hydrothermal Vents MPA (Endeavour MPA), Gwaii Haanas National Marine Conservation Area Reserve (NMCA) & Haida Heritage Site (Gwaii Haanas), Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA (Hecate MPA), Offshore Pacific Seamounts and Vents Closure marine refuge (Offshore Pacific), Strait of Georgia and Howe Sound Glass Sponge Reefs marine refuges (sponge reef marine refuges), Rockfish Conservation Areas (RCAs), Scott Islands marine National Wildlife Area (Scott Islands mNWA), SG̱aan K̲inghlas-Bowie Seamount MPA (SK-B MPA), and Swiftsure Bank Interim Sanctuary Zone (Swiftsure ISZ) (Figure 2). Shapefiles of conservation areas were obtained from the Canadian Protected and Conserved Areas Database (CPCAD) and Fisheries and Oceans Canada. All of these conservation areas have vessel-related restrictions or prohibitions. We further focused on three case-studies (SK-B MPA, Hecate MPA, and Swiftsure ISZ) to evaluate the utility of the three vessel tracking surveillance sources for monitoring across a range of vessel restrictions and marine areas.

2.2.1. Case-study 1: Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs Marine Protected Area (Hecate MPA)

The Hecate MPA was designated under the *Oceans Act* in 2017 to conserve the biological diversity, structural habitat, and ecosystem function of the glass sponge reefs (Hannah et al. 2019). The MPA (2,410 km^2) is located between Haida Gwaii and the mainland of B.C. in the Hecate Strait and Queen Charlotte Sound and is comprised of three distinct components: the Northern reef, two Central reefs, and the Southern reef (Figure 2). Each reef has three zones; 1) a Core Protection Zone, which contains the sponge reefs and provides the highest degree of protection prohibiting all fishing, anchoring, and cable installation, maintenance and repair, 2) a Vertical Adaptive Management Zone above the Core Protection Zone, and 3) an Adaptive

Management Zone surrounding the Core Protection and the Vertical Adaptive Management Zone. The Vertical Adaptive Management and the Adaptive Management Zones are designed to mitigate the risk of indirect impacts to the reefs and prohibit activities that result in the damage, destruction or removal of the glass sponge reef, e.g., commercial bottom contact fishing activities and midwater trawl for hake.

Risk-based indicators were identified for the Hecate MPA for vessel activities and associated stressors known to impact the MPA (Thornborough and Dunham 2019). Indicators with a measurable component that can be evaluated using vessel tracking surveillance types are i) the frequency of potential exposure and ii) vessel density in the vicinity of the MPA. The measurable component for each of these indicators are the number of vessel movements per traffic reporting zone or per 5 x 5 km grid cell.

2.2.2. Case-study 2: SGaan Kinghlas-Bowe Seamount Marine Protected Area (SK-B MPA)

The SK-B MPA is located in the North Pacific Ocean approximately 180 km west of Haida Gwaii (Figure 2). The MPA was designated as a protected area by the Haida Nation and the GoC, with designation under the *Oceans Act* taking place in 2008. The MPA (6,131 km^2) includes three seamounts within its boundaries – SG̱aan K̲inghlas-Bowie, Hodgkins, and Davidson. The seamounts are sub-marine volcano ranges with SG̱aan K̲inghlas-Bowie being the largest of the three.

SK-B Regulations prohibit activities that disturb, damage, destroy or remove from the MPA, living marine organisms or any part of their habitat, or the seabed. Additionally, any activity that deposits, discharges or dumps substances likely to result in the disturbance, damage, destruction, or removal of living marine organisms or any part of their habitat is prohibited. SK-B is closed to all commercial fisheries, but other vessel activities may be carried out within the MPA including some non-bottom contact Aboriginal and recreational fishing, vessel travel, tourism, scientific research, and activities for the purpose of public safety, law enforcement, national security, national defense or emergency response. Due to the remote location of SK-B MPA, the primary activity that takes place are vessel transits and infrequently, scientific research and monitoring; however, sablefish trapping used to occur regularly and illegal fishing activity has been reported since designation. Vessel traffic in and around SK-B mainly consists of commercial vessels such as tankers transporting crude oil between Alaska and ports along the United States west coast and cargo vessels carrying products across the North Pacific.

The SK-B Management Plan includes Operational Objectives specific to vessel travel: large vessels are encouraged to transit a minimum of 50 nm from the SG̱aan K̲inghlas-Bowie pinnacle; underwater noise from vessel traffic is monitored to establish a baseline; and ballast water must be exchanged at least 50 nm from the SG̱aan K̲inghlas-Bowie pinnacle to avoid the introduction of invasive species from vessels (Council of the Haida Nation and Government of Canada 2019). Additionally, under the SK-B monitoring objectives, trends in vessel activity in and around the MPA are to be monitored by working with relevant agencies to better understand impacts related to human activities.

Risk-based indicators were identified for SK-B for vessel activities and associated stressors known to impact the MPA (DFO 2015). Indicators, similar to those identified for Hecate MPA, with a measurable component that could be evaluated using vessel tracking surveillance types are i) the frequency of potential exposure and ii) vessel density in the vicinity of the MPA. The measurable component for these indicators is the number of vessel movements per traffic reporting zone or per 5 x 5 km grid cell.

2.2.3. Case-study 3: Swiftsure Bank Interim Sanctuary Zone (Swiftsure ISZ)

Swiftsure Bank is located approximately 24 km off the southwest coast of Vancouver Island at the entrance to the Strait of Juan de Fuca (Figure 2). Swiftsure Bank is a key salmon foraging area for Southern Resident Killer Whales, as well as a hotspot for commercial and recreational salmon troll fisheries. Swiftsure Bank is a highly transited area with daily AIS reports suggesting that vessels are present up to 25% of the time (Vagle 2020); note these reports underestimate vessel traffic in this area as a number of vessels, particularly recreational fishers, are not equipped with AIS transmitters (Serra-Sogas et al. 2021). In 2019, Swiftsure ISZ was implemented as a mitigation measure to reduce noise and physical disturbance from vessels to killer whales in this critical foraging area. Vessel traffic was prohibited in Swiftsure ISZ from June 1 to October 31, 2019 and from June 1 to November 30, 2020 as per the Interim Order enacted under the *Canada Shipping Act*. There are some exceptions to the closure including vessels that are involved in Indigenous fishing for food, social or ceremonial purposes and vessels that are involved in emergency response.

There is an outbound shipping lane located adjacent and south of Swiftsure ISZ where vessel traffic consists mostly of bulk carriers, container ships, passenger vessels, tankers, and vehicle carriers transiting North to Alaska or across the North Pacific (Vagle 2020). A voluntary vessel slowdown trial was initiated in the shipping lane from August 1 – October 31, 2020 as part of the Vancouver Fraser Port Authority led Enhancing Cetacean Habitat and Observation (ECHO) Program to reduce underwater noise and to support the recovery of the Southern Resident Killer Whales. The Swiftsure vessel closure and the voluntary slowdown in the nearby shipping lane were continued in 2021.

2.2.4. Metrics

We used a count of the number of unique vessels and surveillance effort as well as the number of vessels per unit effort (VPUE) (1) coastwide, (2) in conservation areas, and (3) for the three case-studies to evaluate the three surveillance sources (Table 2). Surveillance effort ‘passes’ refer to the number of flyovers (C&P, TC) and satellite swaths (RADARSAT). C&P flyovers use multiple technologies (i.e., AIS, ISAR, and visual) to search the ocean simultaneously and detect vessels. This makes it difficult to determine total C&P flyover surveillance effort, i.e., total number of passes at the location of the aircraft track only shows a small section of the search area, and does not account for the area surveilled with AIS and ISAR. To improve the estimation of total number of C&P passes, the number of unique flyover missions (i.e., using the unique Mission # per flyover) from the C&P aircraft tracks report was added to the total number of unique flyover missions from the C&P vessel detections dataset (i.e., each vessel detection includes the Mission #) per grid cell or conservation area. Duplicate Mission numbers were identified and only counted once. We calculated the average length of a C&P flyover as well as the average distance (in km) each vessel was detected from the C&P aircraft track per detection observation type (i.e., AIS, ISAR, and visual) to identify the range in distance for type of detection. Vessels more than 300 km outside of the Pacific EEZ were removed from this calculation. The total area searched (i.e., distance plane overflew multiplied by detection type search area) was not calculated because the search area for each detection type can vary during the flight as a result of altitude and weather conditions. The RADARSAT swath coverage of conservation areas varied, and entire conservation areas were not always imaged in one swath. We used a weighted mean surveillance effort calculation to account for the variation in closure area swath coverage (Figure 1). We also examined coastwide vessel and surveillance effort density metrics within 100 km^2 hexagons, and vessel density in and around SK-B and Hecate MPAs in 5 x 5 km grid cells using C&P and RADARSAT data. We used monthly and annual means to explore changes in vessel counts, surveillance effort, and VPUE for the three surveillance sources in conservation areas over time. For the case-studies, the number of vessel counts for vessel type, activity, and nationality metrics were applied to the C&P data, and a vessel size metric (i.e., number of vessels within a size category) were developed with RADARSAT data.

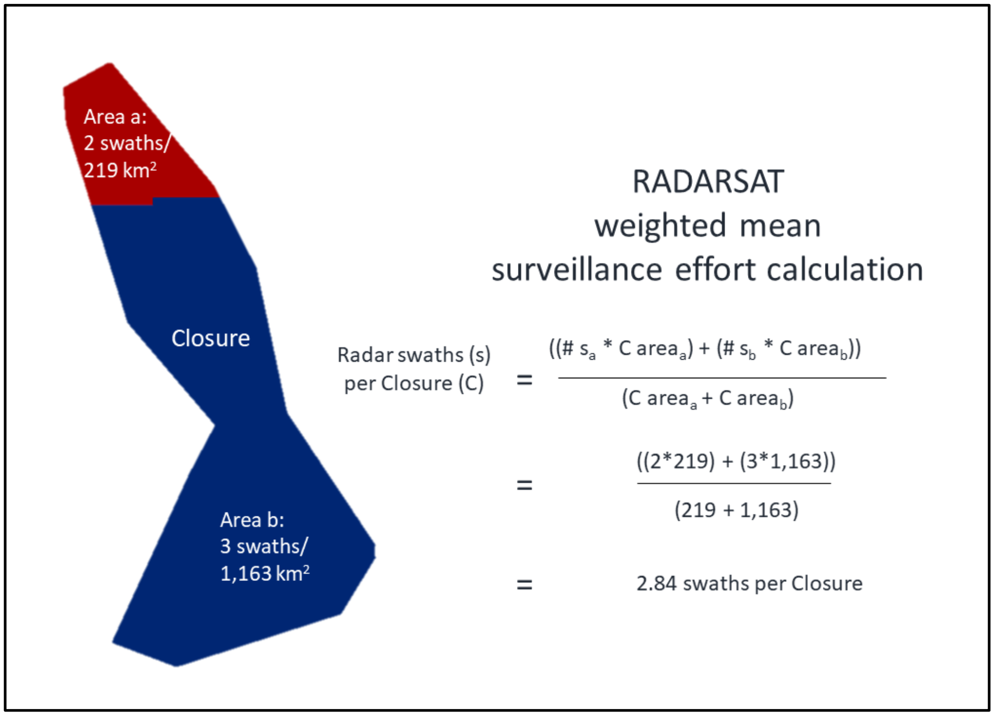

Figure 1. RADARSAT weighted mean surveillance effort calculation.

Table 2. Metrics applied to the Conservation & Protection Aerial Surveillance Program (C&P), Transport Canada National Aerial Surveillance Program (TC), and RADARSAT surveillance sources along with the spatial extent and the years analyzed for this report. Surveillance effort ‘passes’ refer to flyovers (C&P, TC) and satellite swaths (RADARSAT). Three case-studies were also evaluated: Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA (Hecate), SG̱aan Ḵinghlas-Bowie Seamount MPA (SK-B), and Swiftsure Bank Interim Sanctuary Zone (Swiftsure).

Spatial extent	**Metric**	**Surveillance source**	**Measurement**	**Years analyzed**
Coastwide	Vessel count	C&P, RADARSAT	Number of vessels per 100 km^2	2020
	Surveillance effort	C&P	Number of passes per 100 km^2	2020
		RADARSAT	Number of passes within 5 km grid cell	2020
	Vessels per unit effort	C&P, RADARSAT	Vessel count/surveillance effort per 100 km^2	2020
In/adjacent to conservation areas	Vessel count	C&P, TC, RADARSAT	Number of vessels	2020
		C&P, RADARSAT	Number of vessels in 5x5 km grid cell	2020
	Surveillance effort	TC	Number of passes	2020
	Vessel per unit effort		Vessel count/surveillance effort	2020
	Vessel type density	C&P	Mean number of vessels/km^2 of conservation area by type	2020
	Vessel size density	RADARSAT	Mean number of vessels/km^2 of conservation area by size	2020
In conservation areas: **monthly and annual means**	Vessel count mean	C&P, TC, RADARSAT	Monthly mean number of vessels	2020
	Surveillance effort mean		Monthly mean number of passes	2020
	Vessels per unit effort mean		Monthly mean vessel count/ surveillance effort	2020
	Vessel density mean		Annual mean number of vessels/km^2 of conservation area	2020
	Surveillance effort density mean		Annual mean number of passes/km^2 of conservation area	2020
	Vessels density per unit effort density		Annual mean vessel count/surveillance effort/km^2 of conservation area	2020
Hecate, Bowie	Vessel type count	C&P	Number of vessels by type	2020
	Vessel activity count		Number of vessels by activity	2020
Hecate	Vessel size count	RADARSAT	Number of vessels by size	2020
Bowie	Vessel nationality count	C&P	Number of vessels by nationality	2020
Swiftsure	Vessel count per surveillance effort		Number of vessels/number of passes	2018 - 2020
	Vessel type count		Number of vessels by type	

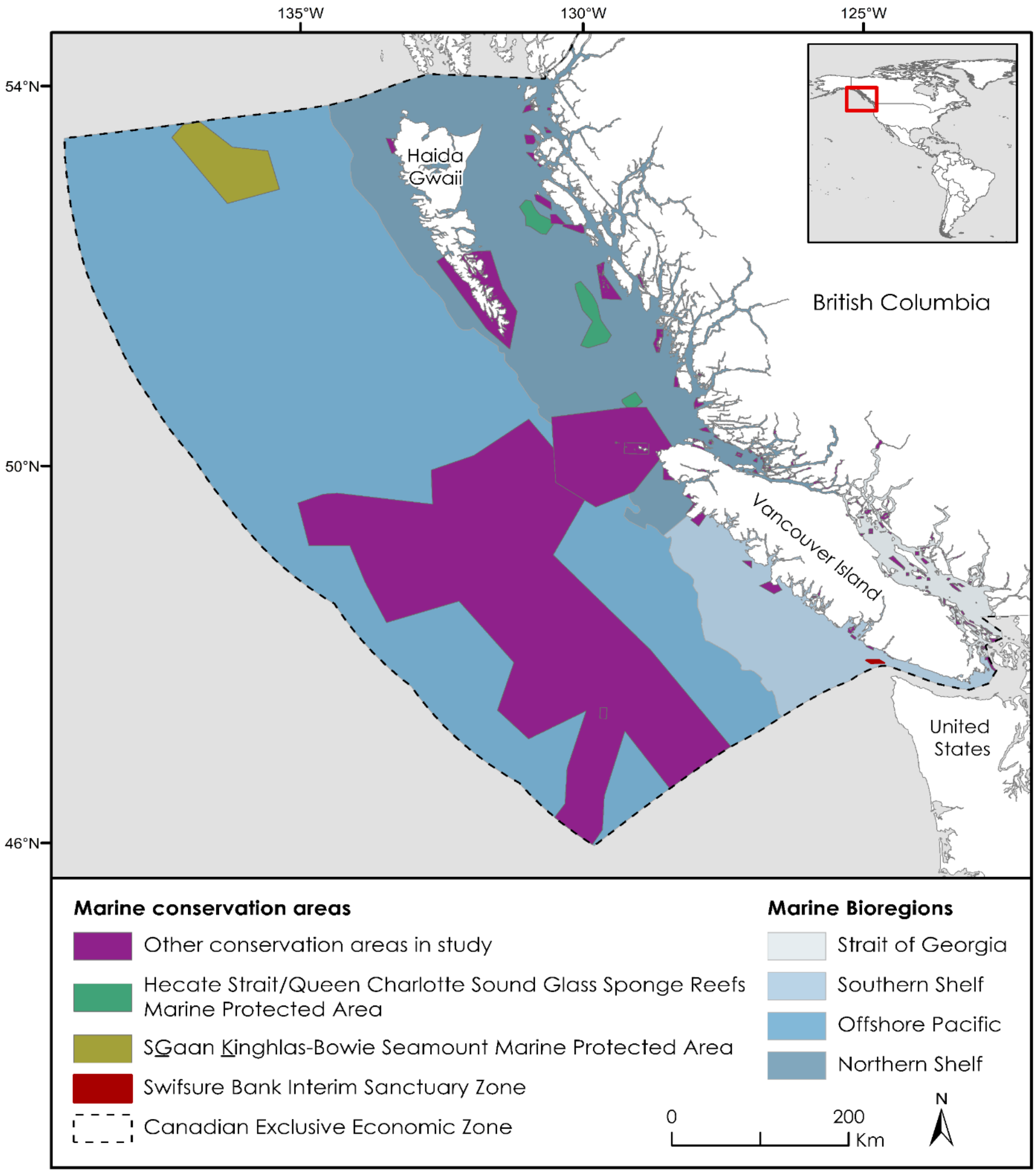

Figure 2. Pacific marine conservation areas with vessel-related restrictions. Focal case-study areas for evaluating vessel tracking datasets are indicated separately.

3.0. RESULTS

3.1. COASTWIDE METRICS

3.1.1. Vessel detections

TC detected few vessels in comparison to the numbers of vessels detected by C&P and RADARSAT, and most of these vessels were detected with AIS (Table 3, Figure 3a). However, TC observed vessels within SK-B and Endeavour MPAs that were not detected by the other surveillance sources. C&P detected more vessels overall and more vessels in conservation areas than TC or RADARSAT, and the majority of these vessels were detected with AIS (Table 3, Figure 4). More AIS and non-AIS vessel density was observed on C&P flyovers in populated coastal areas (e.g., Strait of Georgia) and near port towns, such as Prince Rupert (Figure 4). The number of vessels detected by C&P in the offshore area is low except for the lane of shipping traffic that travels into the offshore area from the Juan de Fuca, and most of these are AIS vessel detections. More non-AIS vessels were observed on C&P flyovers in Hecate Strait, northern Haida Gwaii and in Barkley Sound. RADARSAT detected more vessels across the Offshore Pacific Bioregion than C&P, but the number of vessels per 100 km^2 was low (Figure 5). Higher vessel numbers were detected by RADARSAT in areas similar to high C&P detections, i.e., populated coastal areas. RADARSAT detected slightly more vessels with AIS than without, with more AIS detections in the Offshore Pacific Bioregion. RADARSAT is limited in that it detected vessels > 25 m in length with higher confidence than smaller vessels for most of British Columbia coast (i.e., using *Detection of Vessels Wide Far* beam mode).

Table 3. Total number of vessels detected with and without AIS and in conservation areas (CA) by Conservation & Protection Aerial Surveillance Program (ASP), Transport Canada National Aerial Surveillance Program (NASP), and RADARSAT in 2020. Conservation & Protection and RADARSAT surveillance covers the Pacific EEZ while TC surveillance targets a few MPAs.

Surveillance Source	**AIS vessels**	**Non-AIS vessels**	**Total vessels**	**AIS vessels in CA**	**Non-AIS vessels in CA**	**Total vessels in CA**
Conservation & Protection ASP	85% (64,272)	15% (11,509)	75,781	81% (3,397)	19% (819)	4,216
Transport Canada NASP	90% (44)	10% (5)	49	100% (28)	0% (0)	28
RADARSAT	59% (8,781)	41% (6,157)	14,938	54% (676)	46% (585)	1,261

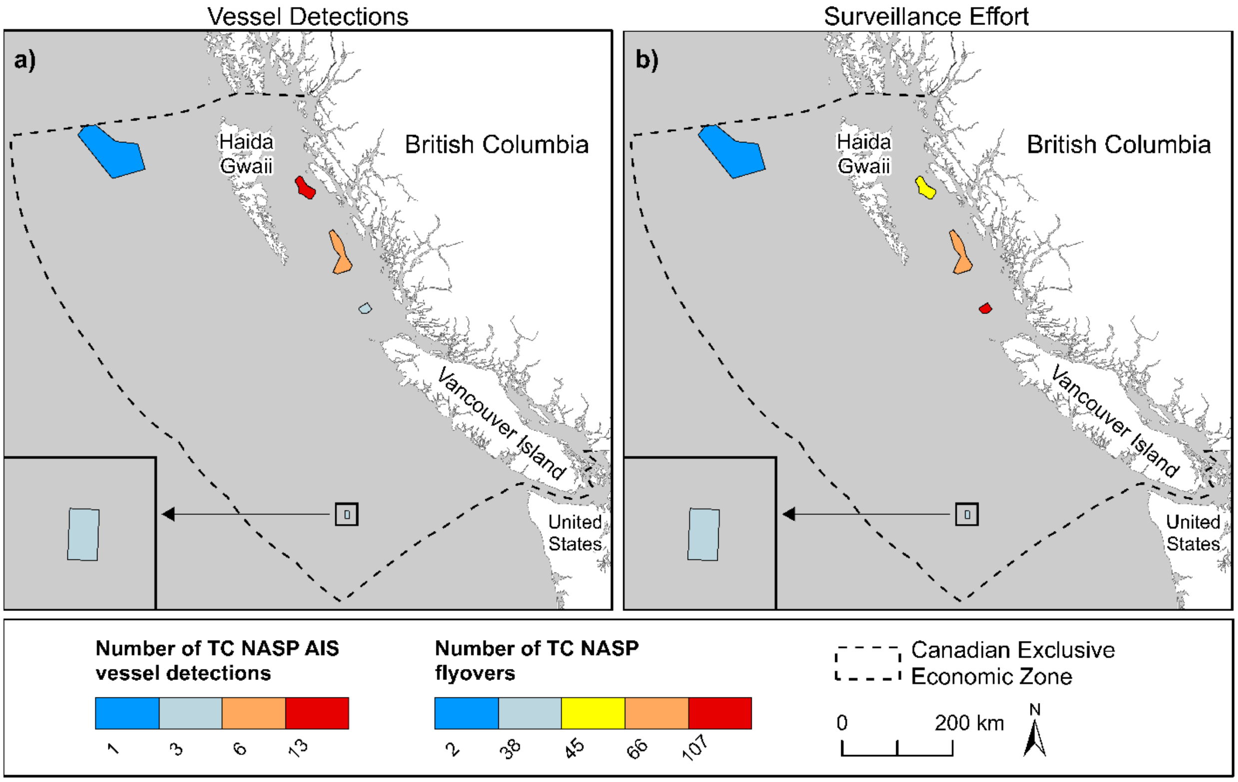

Figure 3. Transport Canada National Aerial Surveillance Program flyovers in 2020. (a) Number of vessels detected in the Endeavour Hydrothermal Vents MPA, Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA, and SG̱aan K̲inghlas-Bowie Seamount MPA and (b) the number of flyovers that took place in each MPA.

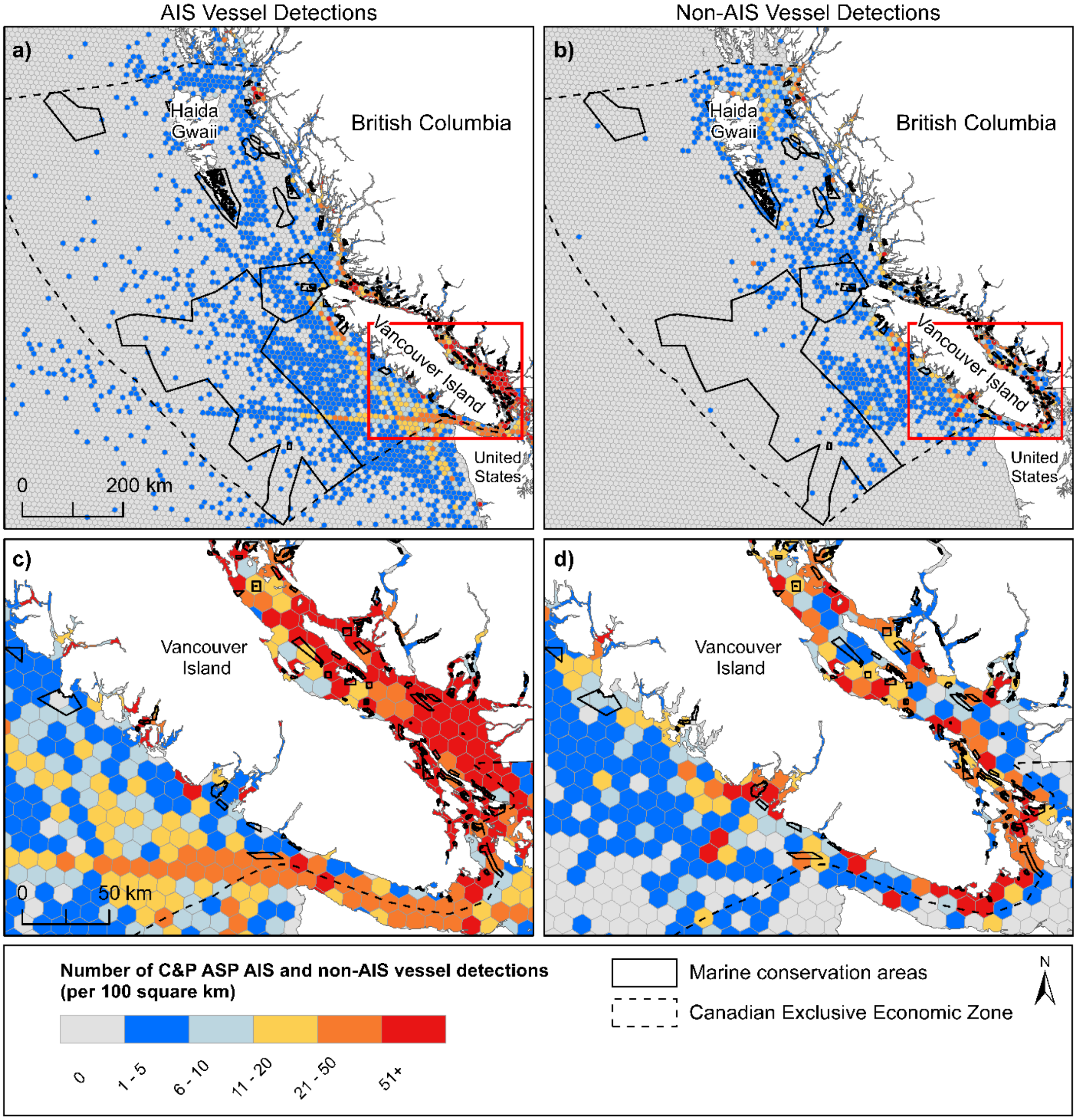

Figure 4. Conservation & Protection Aerial Surveillance Program (C&P ASP) flyovers in 2020. (a) Number of AIS vessel detections on flyovers over the Pacific coast and (b) the number of non-AIS vessel detections on flyovers. Focus figures show (c) the number of AIS vessel detections and (d) the number of non-AIS vessel detections in the southern Strait of Georgia where high vessels per square kilometre were observed. Vessel counts are summed within 100 km^2 hexagon cells.

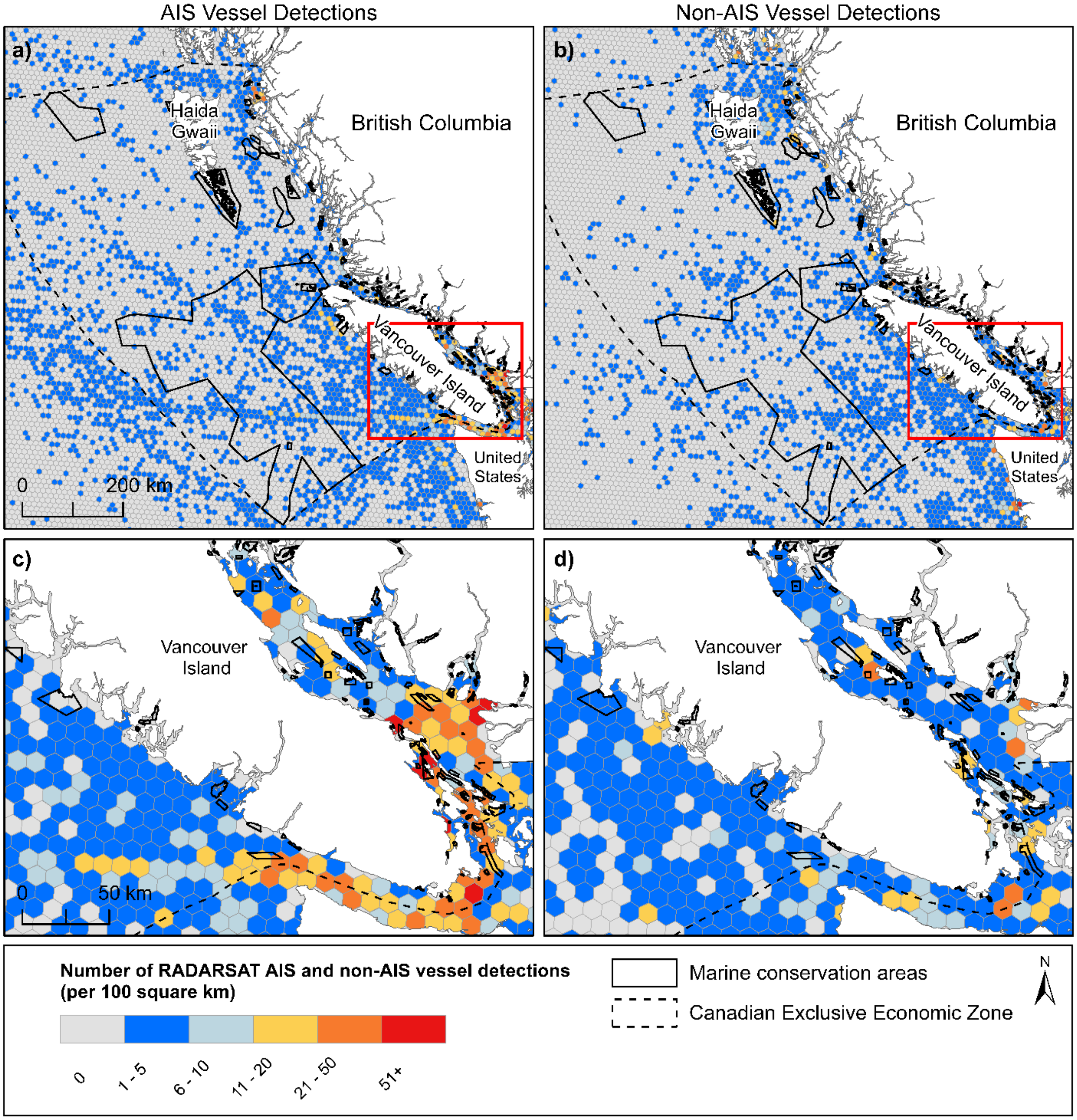

Figure 5. RADARSAT imaging satellite program surveillance over the Pacific coast in 2020. (a) Number of AIS vessel detections in satellite images and (b) Number of non-AIS vessel detections. Focus figures show (c) the number of AIS vessel detections and (d) the number of non-AIS vessel detections in the southern Strait of Georgia where high vessels per square kilometre were observed. Vessel counts are summed within 100 km^2 hexagon cells.

3.1.2. Surveillance effort

C&P flyovers were concentrated in coastal areas around Vancouver Island, the mainland of British Columbia, and Haida Gwaii (Figure 6a). There were also pockets of high C&P flyover numbers in populated coastal areas in the Strait of Georgia, and Southern Shelf and Northern Shelf Bioregions. C&P flyover density was low in the Offshore Pacific Bioregion and the offshore conservation areas were patrolled less often than inshore ones. RADARSAT surveillance effort targeted the Offshore Pacific Bioregion with the highest number of satellite swaths taking place over the Offshore Pacific Bioregion and Offshore Pacific closure (Figure 6b). There were fewer satellite swaths in coastal areas, between Vancouver Island and the mainland of British Columbia, and over the waters around Haida Gwaii. Transport Canada NASP flyovers focused surveillance effort on three MPAs: Endeavour, Hecate, and SK-B (Figure 3b). The greatest number of flyovers took place in Hecate's Southern Glass Sponge Reef MPA while SK-B MPA had the least number of flyovers.

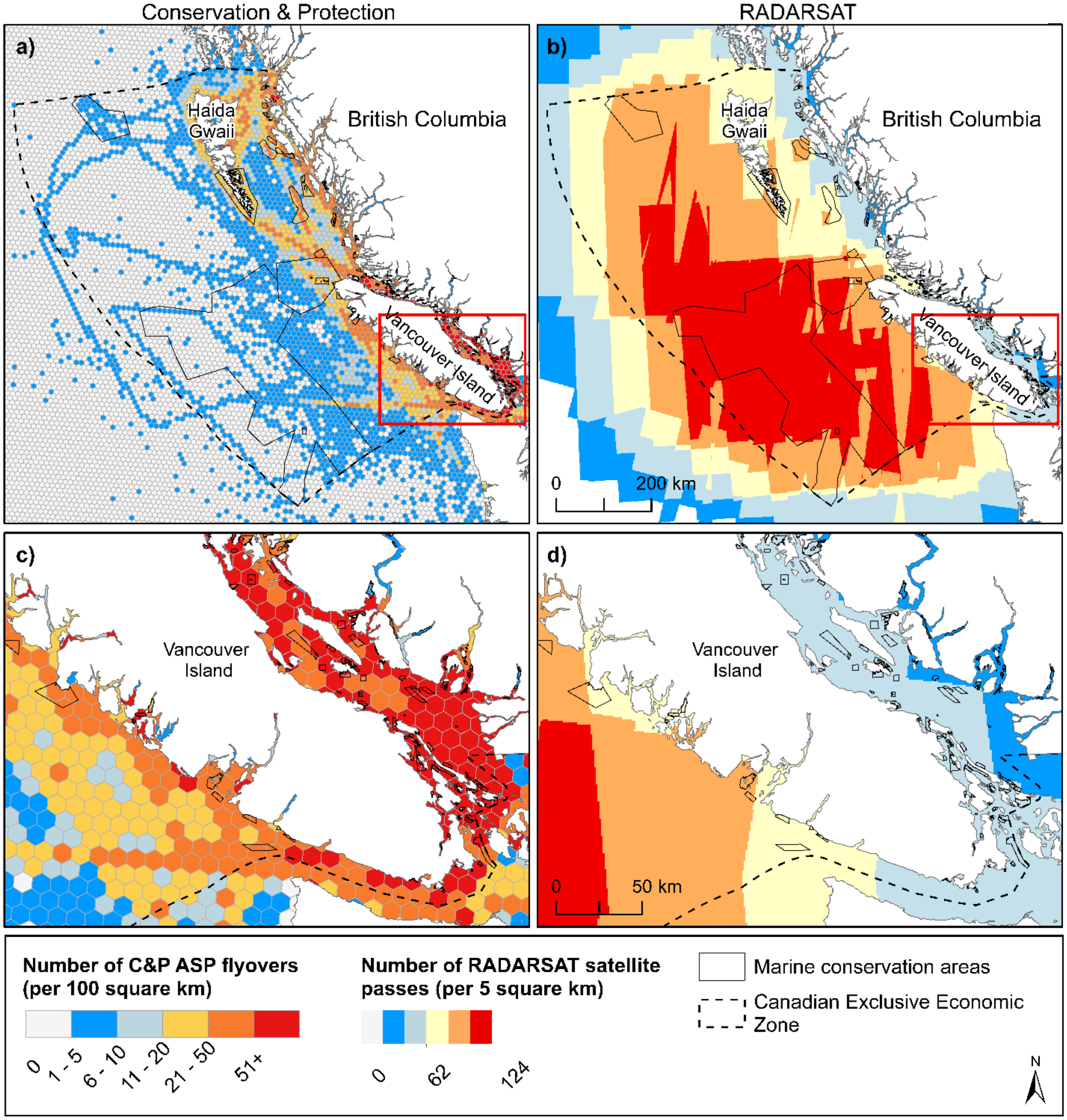

Figure 6. Conservation & Protection Aerial Surveillance Program (C&P ASP) and RADARSAT imaging satellite program surveillance effort in 2020. (a) Number C&P ASP flyovers and (b) the number of satellite swaths per 5 km grid cell. Focus figures show the (c) number of C&P ASP flyovers and the (d) number of satellite swaths in the southern Strait of Georgia, where high vessels per 100 km^2 was observed. C&P surveillance effort is the combined number of unique flyovers per cell from the aircraft track and vessel detection files and RADARSAT surveillance effort is the number of swaths per 5 km^2 grid cell. C&P surveillance effort does not account for total area surveilled by AIS and ISAR.

The average aircraft track length of C&P flyovers in 2020 was 1,772 ± 569 km (mean ± 1 SD), and the distance vessels were detected from the aircraft track varied by detection type with AIS vessel detections occurring furthest from the aircraft than ISAR or visual detections (vessel detection distance from aircraft track line: AIS 61.3 ± 67.4 km, ISAR 5.1 ± 22.5 km, and visual 0.8 ± 3.9 km). More than 95% of C&P AIS vessel detections were within 200 km of the aircraft track line, indicating the search range for vessels on a C&P flyover can be up to 400 km wide (Figure 7). Conversely, more than 95% of ISAR and visual vessel detections were within 40 km and 2 km of the aircraft, respectively. The average area of RADARSAT swaths (i.e., survey area of satellite imagery) collected using the *Detection of Vessels Wide Far* beam mode is 32,2752 ± 13,3857 km^2 (swath length 766 ± 288 km and width 421 ± 51 km) while the average area of *Fine* mode imagery, collected in the Hecate MPA until July 2020, was 707 ± 1,015 km^2 (swath length 61 ± 18 km and width 44 ± 6 km). Vessel detection distance was not calculated for TC flyovers because these flyovers target specific MPAs visually and aircraft location information is not provided in TC email reports. However, TC flyovers detect vessels using the same methods as C&P flyovers (i.e., AIS, radar, and visual) so the average distance of detection is likely similar.

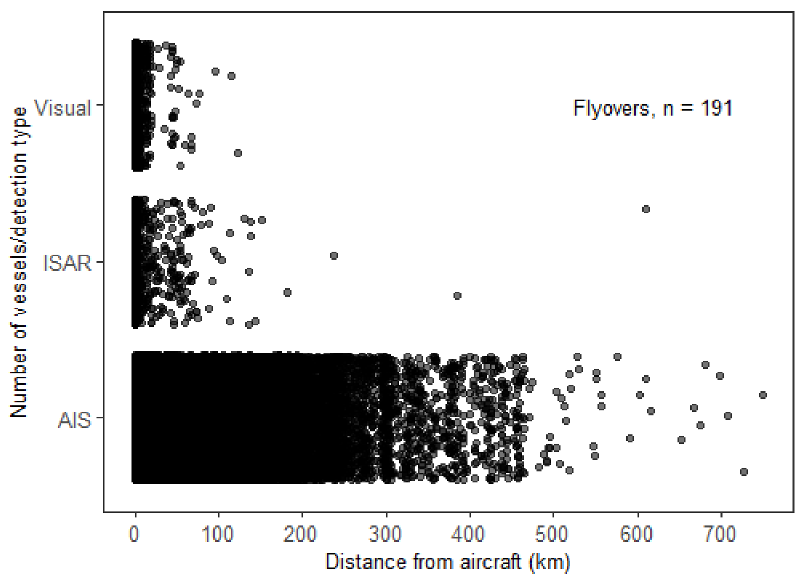

Figure 7. Number of vessels detected on Conservation & Protection Aerial Surveillance Program flyovers in 2020 by AIS, ISAR (radar), and visually, by observer.

3.1.3. Vessels per unit surveillance effort (VPUE)

C&P VPUE was low in the Northern Shelf Bioregion, around Haida Gwaii, and in the northern area of the Offshore Pacific Bioregion, but increased in the Strait of Georgia, Southern Shelf, and southeastern area of the Offshore Pacific Bioregions. (Figure 8a and d). The highest C&P VPUE occurred in populated coastal areas – similar to where C&P detected the most vessels. There are large portions of the Offshore Pacific Bioregion where no vessels were detected and C&P surveillance effort is unknown because the aircraft track only shows a small section of the search area, and does not account for the total area surveilled with AIS and ISAR. The number of VPUE was low for TC, and there were more flyovers than vessels detected for all three MPAs (Figure 8b and e). The greatest number of TC flyovers (107) took place in Hecate's Southern Glass Sponge Reef where only three vessels were detected, meaning one vessel was detected every 35 flyovers. The most vessels detected on TC flyovers were in the Northern Glass Sponge Reef of Hecate, where only a moderate number of flyovers took place. RADARSAT VPUE was low for the majority of the survey area (Figure 8c and f). There were a few areas in the southern Strait of Georgia Bioregion around Vancouver and the Gulf Islands where RADARSAT VPUE increased and more vessel detections than surveillance effort took place.

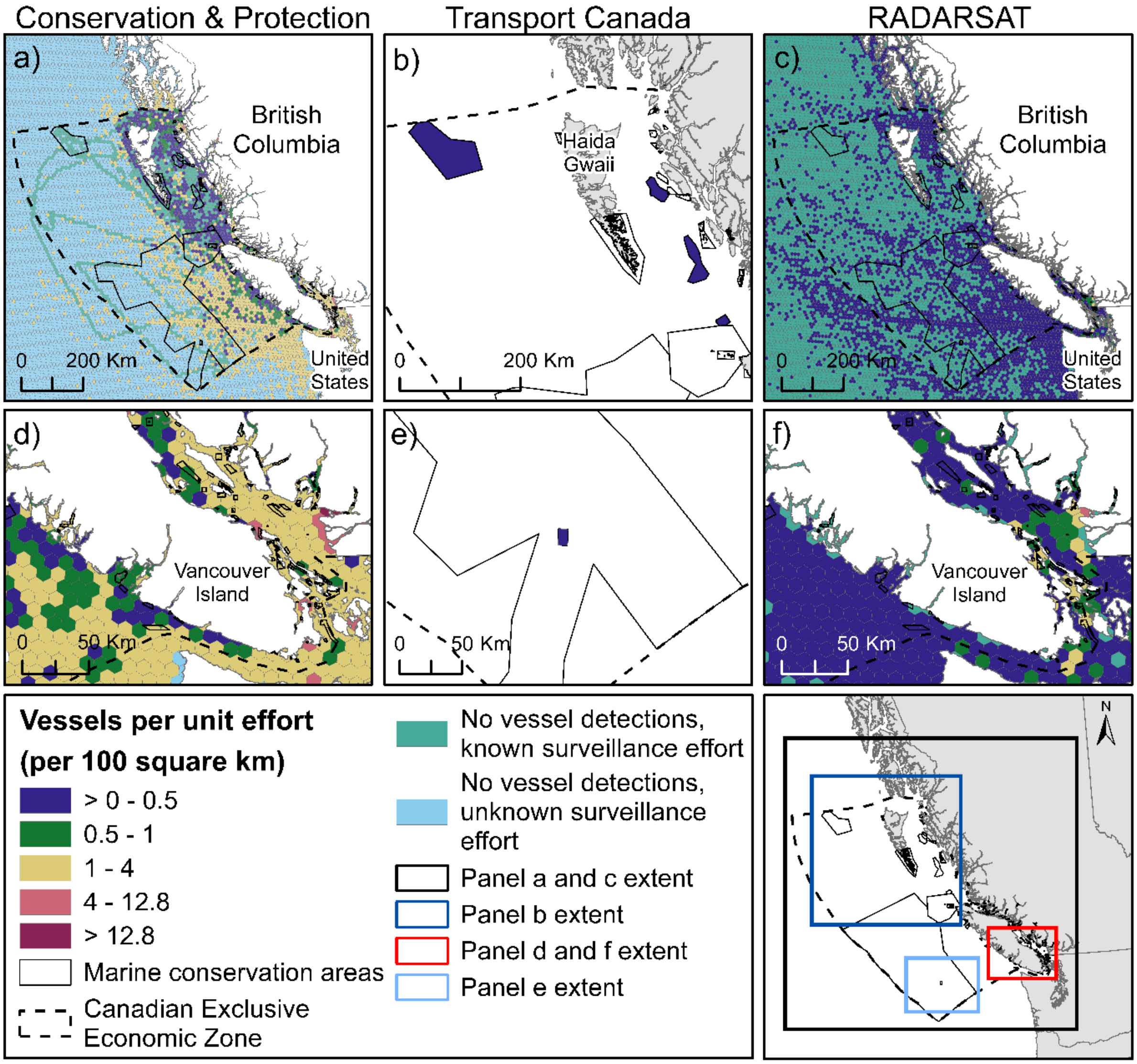

Figure 8. Vessels per unit effort detected by (a) Conservation & Protection Aerial Surveillance Program, (b) Transport Canada National Aerial Surveillance Program, and (c) RADARSAT. Focus figures show vessels per unit effort in the Southern Strait of Georgia (d, f) and in Endeavour Hydrothermal Vents MPA (e). C&P ASP and RADARSAT vessels per unit effort are summed within 100 km^2 hexagon cells. TC vessels per unit effort are calculated per MPA. C&P surveillance effort is the combined number of unique flyovers per cell from the aircraft track and vessel detection files and RADARSAT surveillance effort is the number of swaths per cell. C&P surveillance effort does not account for total area surveilled by AIS and ISAR.

3.2. COASTWIDE CONSERVATION AREA METRICS

The number of vessels detected in conservation areas by C&P and RADARSAT increased in the summer months and decreased in the winter months (Figure 9, panel 1), while TC vessel numbers stayed constant. C&P detected 3 times more vessels in conservation areas than RADARSAT (4,216 vessels to RADARSAT's 1,261 vessels) and 150 times more vessels than the 28 detected by TC in conservation areas (Table 3). C&P detected more vessels with AIS in conservation areas than without (3,397 AIS vessel detections to 819 non-AIS detections), whereas RADARSAT AIS and non-AIS vessel detections in conservation areas were similar each month and ranged from 2-136 vessels detections. No non-AIS vessels were detected in conservation areas overflown by TC flyovers, but non-AIS vessels were detected by visual means near these areas. RADARSAT had higher monthly surveillance effort in conservation areas compared to C&P and TC (Figure 9, panel 2). Every C&P flyover and RADARSAT satellite swath included coverage of a conservation area, with a total of 199 C&P flyovers and 310 RADARSAT satellite swaths in 2020. There were 122 TC flyovers in targeted conservation areas. C&P and TC surveillance effort in conservation areas fluctuated between 6-22 flyovers per month throughout the year while the number of RADARSAT satellite swaths increased from 19 in January to over 40 in December 2020. The VPUE detected in conservation areas by C&P and TC changed little from month to month, indicating surveillance effort matched fluctuations in vessel activity (Figure 9, panel 3). The VPUE detected by RADARSAT in conservation areas increased in summer months (June – September) and decreased after September; both vessel counts and satellite swaths increased during the summer. C&P VPUE was higher than TC and RADARSAT indicating C&P is more efficient at capturing vessel activity on the water than the other two surveillance types.

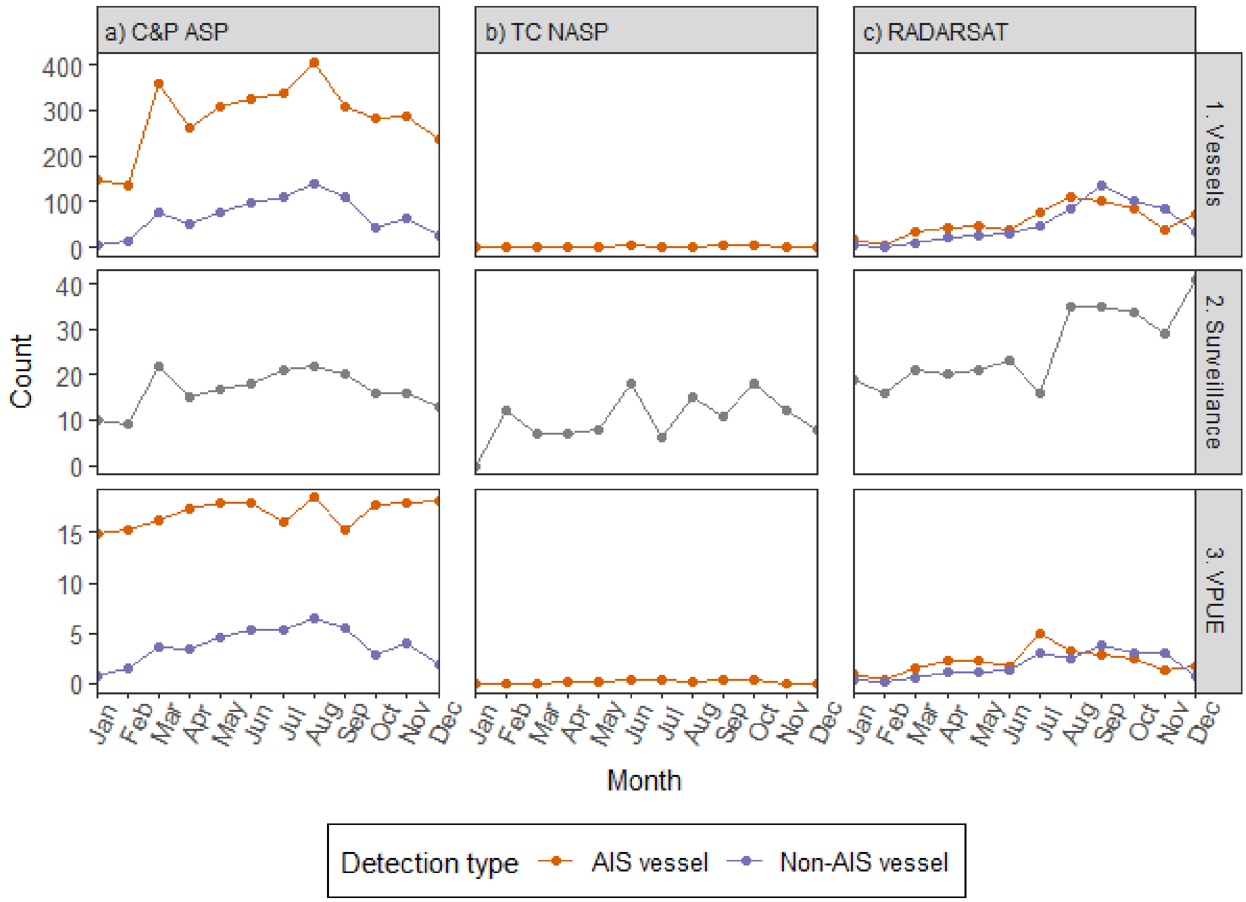

Figure 9. Monthly number of vessels detected with and without AIS in 2020 in conservation areas by a) Conservation & Protection Aerial Surveillance Program (C&P ASP), b) Transport Canada National Aerial Survellance Program (TC NASP), and c) RADARSAT as well as monthly surveillance effort and number of vessels detected per unit effort (VPUE). Note: y-axis varies between figures.

More vessels per conservation area size were detected by C&P and RADARSAT in RCAs, sponge reef marine refuges, and Swiftsure ISZ than in any of the other conservation areas (Figure 10, panel 1a). The VPUE was also highest in these conservation areas (Figure 10, panel 1c). C&P detected the most vessels in RCAs, whereas RADARSAT detected similar numbers of vessels in RCAs and sponge reef marine refuges. More surveillance effort per conservation area size took place in sponge reef marine refuges and Swiftsure ISZ by C&P and RADARSAT than in any other conservation area (Figure 10, panel 2a). Of the three MPAS targeted by all three surveillance types, more vessels, surveillance effort and VPUE per conservation area size were detected in Endeavour MPA by C&P, TC, and RADARSAT (Figure 10, panels 1-3b). RADARSAT detected more vessels and had higher surveillance effort in Endeavour than C&P and TC, whereas C&P detected more VPUE than TC and RADARSAT. Very low numbers of vessels, along with surveillance effort, and VPUE were detected in the remaining conservation areas.

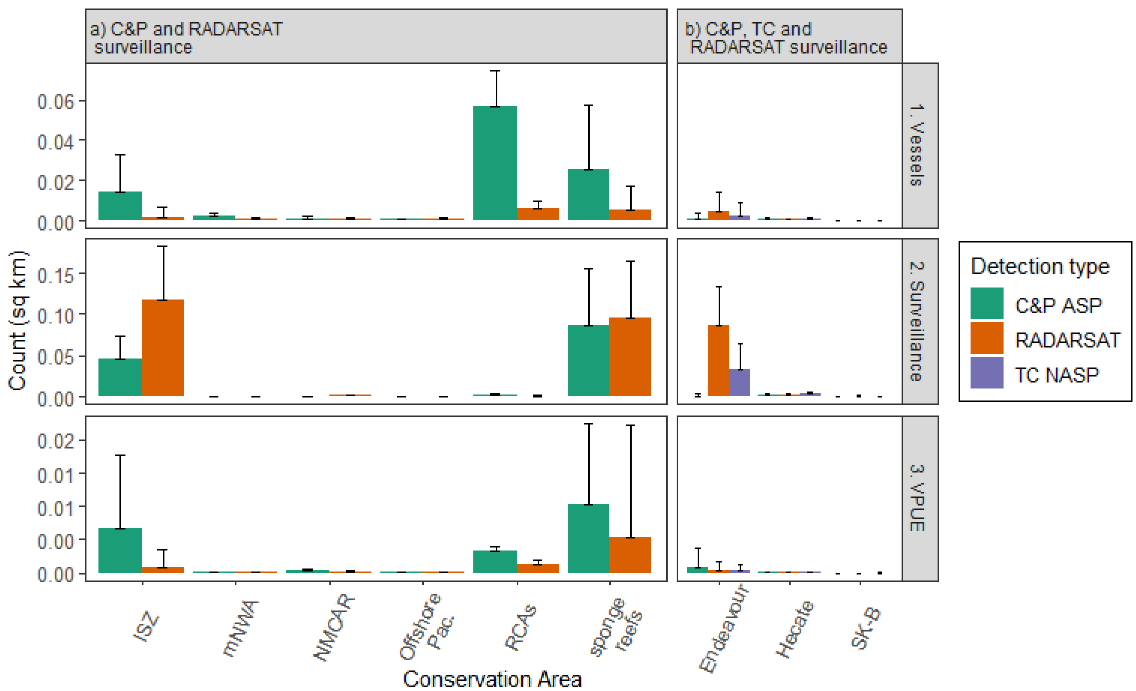

Figure 10. Mean (+ 1 SD) number of 1. vessels, 2. surveillance effort and 3. vessels per surveillance effort (VPUE) in conservation areas (standardized by conservation area size, km^2) detected in 2020 by Conservation & Protection Aerial Surveillance Program (C&P ASP), RADARSAT, and Transport Canada National Aerial Surveillance Program (TC NASP). Shown in Panel a) are the conservation areas surveilled by C&P and RADARSAT and shown in Panel b), are the conservation areas surveilled by all surveillance sources. ISZ=Swiftsure Bank Interim Sanctuary Zone; mNWA= Scott Islands marine National Wildlife Area; NMCAR=Gwaii Haanas National Marine Conservation Area Reserve; Offshore Pac.=Offshore Pacific Seamounts and Vents Closure marine refuge; RCAs=Rockfish Conservation Areas; sponge reefs=Strait of Georgia and Howe Sound Glass Sponge Reefs marine refuges; Endeavour=Endeavour Hydrothermal Vents MPA; Hecate=Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA; SK-B=SG̱aan K̲inghlas-Bowie Seamount MPA.

Commercial vessels (i.e., not including fishing vessels) were detected more than any other vessel type in conservation areas by C&P in 2020 (Figure 11). C&P detected similar numbers of Other/Unknown and Fishing vessels in conservation areas, but low numbers of all other vessel types were detected; 78% of vessels were detected in RCAs. Most Commercial, Other/Uknown, and Government/Research vessels were AIS detections, whereas Fishing and Pleasure Craft vessels consisted of more non-AIS detections (Commercial and Other/Unknown: 2% non-AIS detections, Government/Research: 14% non-AIS detections, Fishing: 64% non-AIS detections, and Pleasure Craft: 60% non-AIS detections).

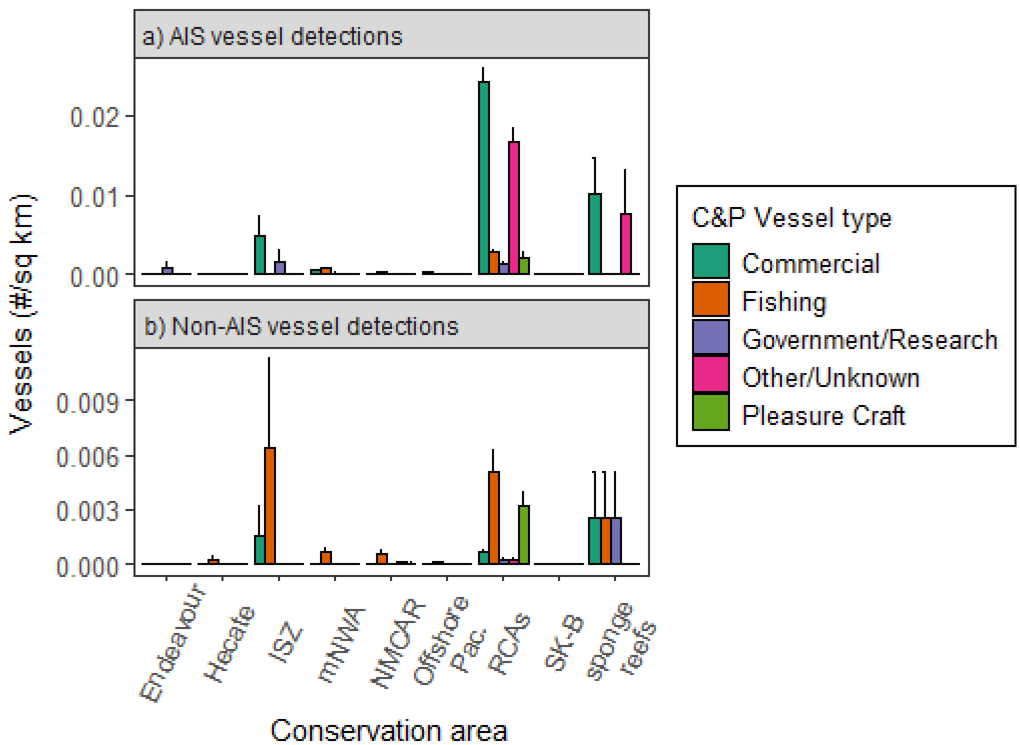

Figure 11. Mean (+ 1 SD) number of (a) AIS vessel types and (b) non-AIS vessel types detected per area of marine conservation area type in 2020 by Conservation & Protection Aerial Surveillance Program. ISZ=Swiftsure Bank Interim Sanctuary Zone; mNWA= Scott Islands marine National Wildlife Area; NMCAR=Gwaii Haanas National Marine Conservation Area Reserve; Offshore Pac.=Offshore Pacific Seamounts and Vents Closure marine refuge; RCAs=Rockfish Conservation Areas; sponge reefs=Strait of Georgia and Howe Sound Glass Sponge Reefs marine refuges; Endeavour=Endeavour Hydrothermal Vents MPA; Hecate=Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA; SK-B=SG̱aan Ḵinghlas-Bowie Seamount MPA.

RADARSAT detected more large vessels (>50 m in length) in conservation areas than small vessels (≤ 50 m), and most of these were AIS vessel detections (Figure 12). Similar averages of the vessel size categories were detected in RCAs, Scott Islands mNWA, Gwaii Haanas NMCAR, and the Offshore Pacific marine refuge. For the other conservation areas, mostly larger vessels were detected. Most RADARSAT imagery collected on the British Columbia coast in 2020 detected vessels down to 25 m in length with higher confidence (using *Detection of Vessels Wide Far* beam mode). Vessels were detected down to 8 m in length over the Hecate MPA from January – July 2020 using *Fine* beam mode.

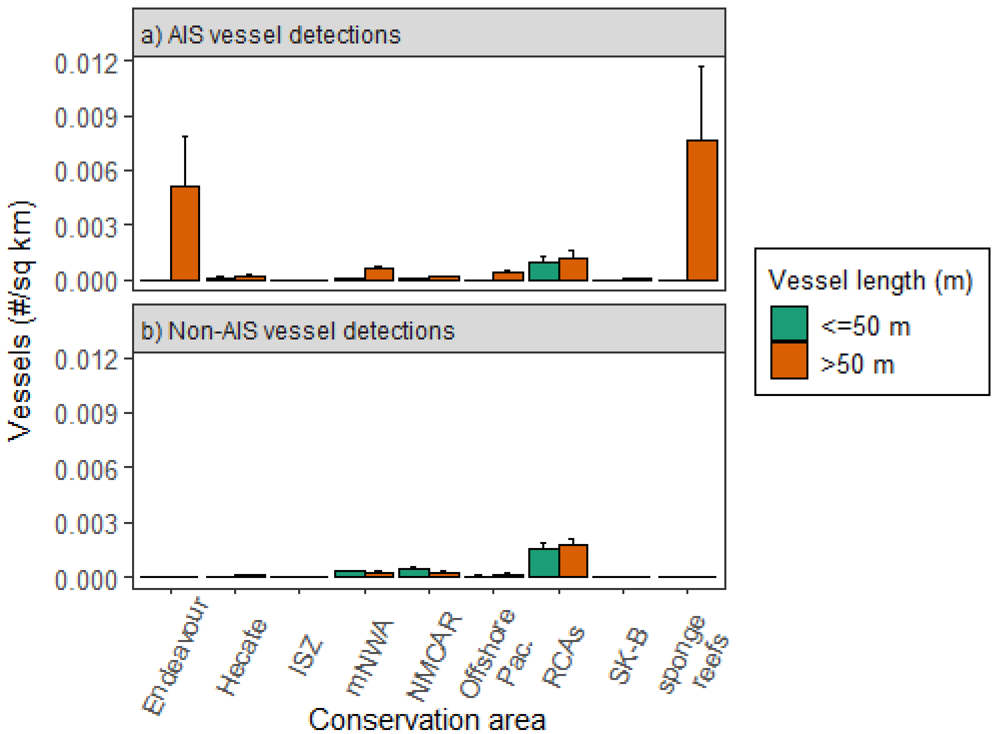

Figure 12. Mean (+ 1 SD) number of (a) AIS vessels and (b) non-AIS vessels detected per area of marine conservation area type by RADARSAT that are less than or equal to 50 m in length or greater than 50 m in length. RADARSAT has a minimum vessel size of 25 m in length for detections. ISZ=Swiftsure Bank Interim Sanctuary Zone; mNWA= Scott Islands marine National Wildlife Area; NMCAR=Gwaii Haanas National Marine Conservation Area Reserve; Offshore Pac.=Offshore Pacific Seamounts and Vents Closure marine refuge; RCAs=Rockfish Conservation Areas; sponge reefs=Strait of Georgia and Howe Sound Glass Sponge Reefs marine refuges; Endeavour=Endeavour Hydrothermal Vents MPA; Hecate=Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA; SK-B=SG̲aan K̲inghlas-Bowie Seamount MPA.

3.3. CONSERVATION AREA CASE-STUDIES

We focus results of the three case studies on different vessel tracking metrics as each conservation area had different regulations and/or guidelines, zones, or other spatial characteristics that were important for understanding ongoing human pressures and the management effectiveness of these conservation areas.

3.3.1. Case-study 1: Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA

Flyovers and RADARSAT were used to examine trends in vessel activity in and around Hecate MPA as well as to evaluate fishing vessel activity in the MPA. Though few vessels were detected in Hecate MPA, some were fishing vessels and one of these (an AIS vessel detection) was potentially fishing illegally in the South reef (Figures 18 and 19). The three surveillance sources detected a similar number of vessels within the Vertical Adaptive Management Zone and the Adaptive Management Zone of the MPA (Figure 13). Inside the MPA, C&P detected more non-AIS vessels, whereas RADARSAT detected more AIS vessels than non-AIS vessels and TC detected only AIS vessels. C&P detected more vessels in the 5 km buffers surrounding the management zones than TC and RADARSAT. RADARSAT detected more vessels in the 10 km buffers than C&P and TC, and most of these were non-AIS vessel detections. As distance from the Vertical Adaptive Management Zone increased, so did the number of vessels detected by C&P and RADARSAT with the most vessels observed by these surveillance sources in the 10 km buffers. Conversely, TC detected fewer vessels in the 10 km buffers than in the management zones and in the 5 km buffers. The Core Protection Zone is not depicted in the case-study assessment figures as it is directly below the Vertical Adaptive Management Zone and we were unable to assess vessel detections vertically in the water column.

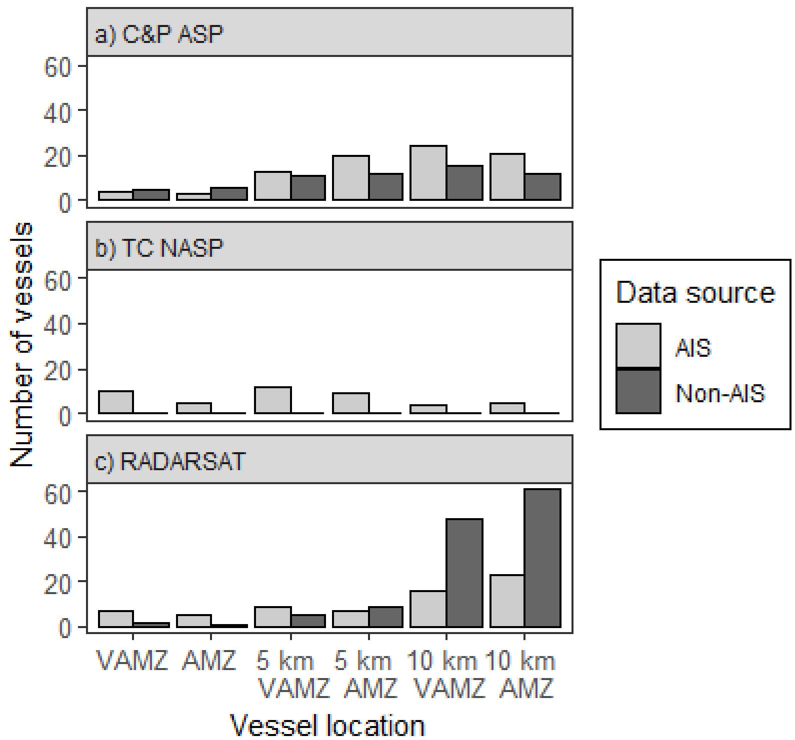

Figure 13. Number of vessels detected within the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA Vertical Adaptive Management Zone (VAMZ), Adaptive Management Zone (AMZ) and respective buffers IN 2020 by Conservation & Protection Aerial Surveillance Program (C&P ASP), Transport Canada National Aerial Surveillance Program (TC NASP), and RADARSAT. Note, vessel counts are not exclusive spatially where overlap occurs in different buffer zones, e.g., VAMZ versus AMZ buffers.

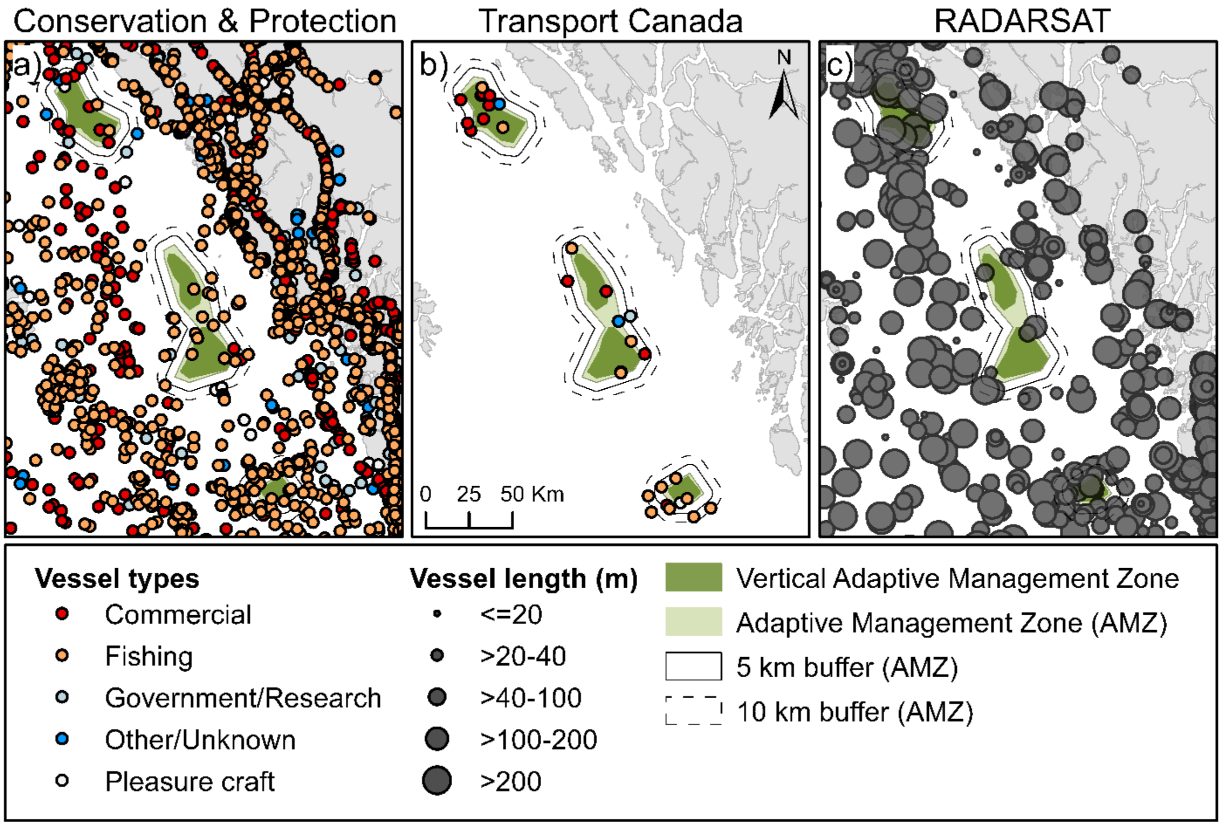

Figure 14. Trends in vessel activity detected in the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA in 2020 by (a) Conservation & Protection Aerial Surveillance Program, (b) Transport Canada National Aerial Surveillance Program, and (c) RADARSAT.

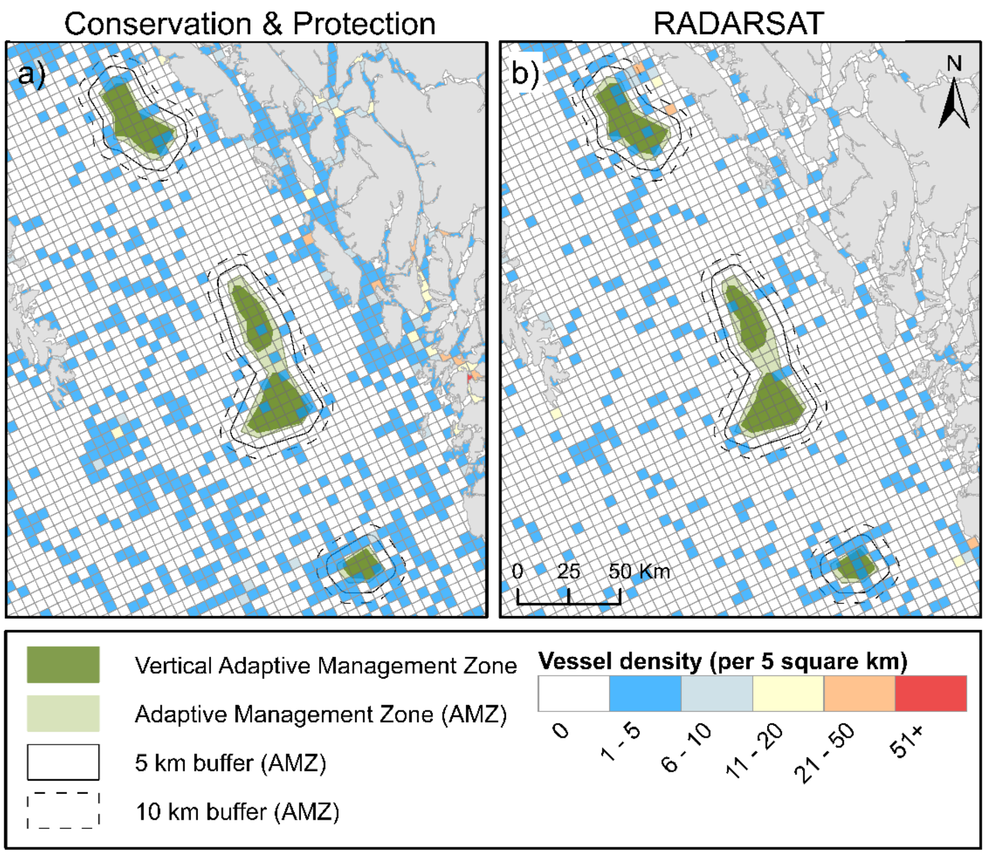

Figure 15. Vessel densities per 5 x 5 km grid cell in the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA detected by (a) Conservation & Protection Aerial Surveillance Program and (b) RADARSAT in 2020.

C&P and RADARSAT VPUE is low in and around Hecate MPA (Figure 16). More VPUE was detected in the South Reef than the Central and North Reef of the MPA. Both C&P and RADARSAT surveillance covered the entire Hecate MPA, though total area surveilled by C&P AIS and ISAR is unknown (i.e., no vessel detections and surveillance effort unknown).

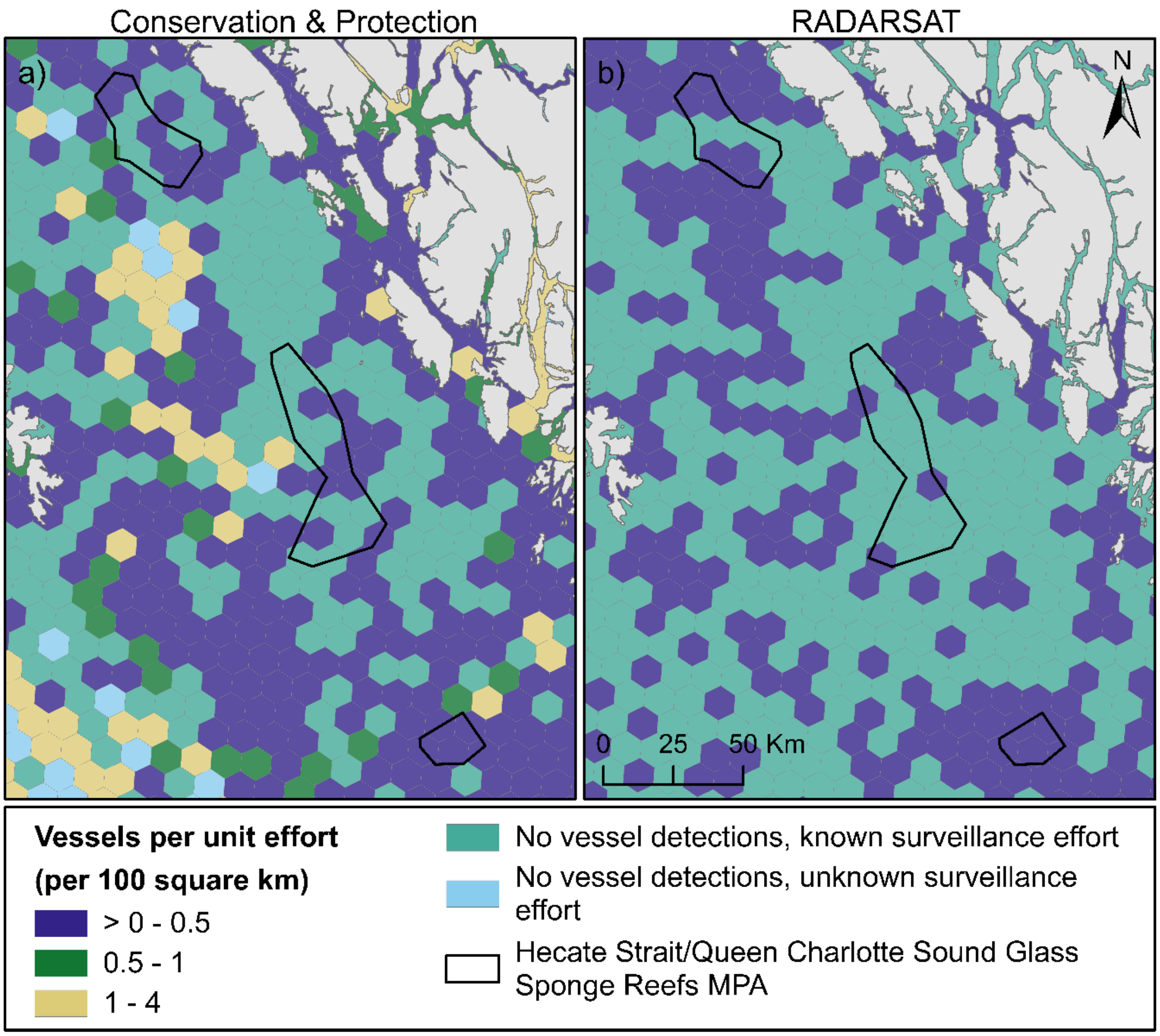

Figure 16. Vessels per unit effort detected by (a) Conservation & Protection (C&P) Aerial Surveillance Program and (c) RADARSAT in the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA. Vessels are summed within 100 square km hexagon cells. C&P surveillance effort is the combined number of unique flyovers per cell from the aircraft track and vessel detection files and RADARSAT surveillance effort is the number of swaths per cell. C&P surveillance effort does not account for total area surveilled by AIS and ISAR.

RADARSAT detected more large vessels than small vessels in and adjacent to the Hecate MPA and of these vessels, more non-AIS vessels (79% of vessels ≤50 m were non-AIS detections and 57% of vessels >50 m were non-AIS detections). The number of small and large vessels as well as AIS and non-AIS vessel detections, increased as distance from the MPA increased, with the most vessels of both sizes detected in the 10 km buffers surrounding the Management Zones.

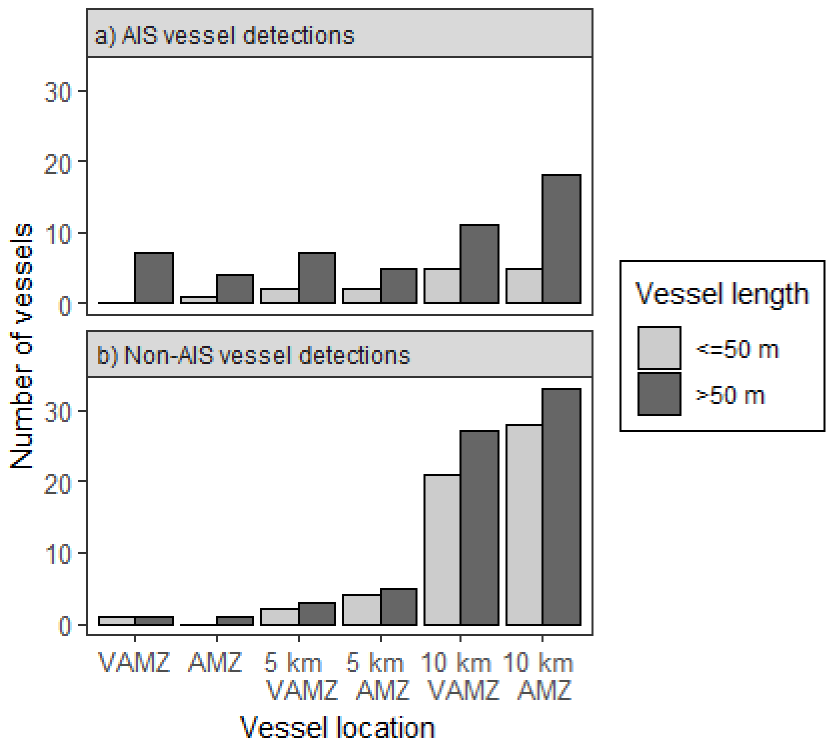

Figure 17. Sizes of a) AIS vessels and b) non-AIS vessels detected by RADARSAT in the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA Vertical Adaptive Management Zone (VAMZ), Adaptive Management Zone (AMZ), and respective buffers. Note, vessel counts are not exclusive spatially where overlap occurs in different buffer zones, e.g. VAMZ versus AMZ buffers.

C&P detected more fishing vessels within the Hecate MPA than any other vessel type (Figure 18). Most fishing vessels were detected in and adjacent to the South Reef of Hecate. There were few other vessel types detected in the South Reef while commercial (not including fishing vessels), government/research, pleasure craft, and unknown vessel types were all observed in the Central and North Reefs. More commercial vessels were detected in the North Reef than any other vessel type. Similar numbers of AIS and non-AIS vessels were detected for all vessel types except for commercial vessels (% of AIS vessel detections per vessel type: Commercial 93%, Fishing 50%, Government/Research (50%), Pleasure Craft (57%), and Unknown (33%).

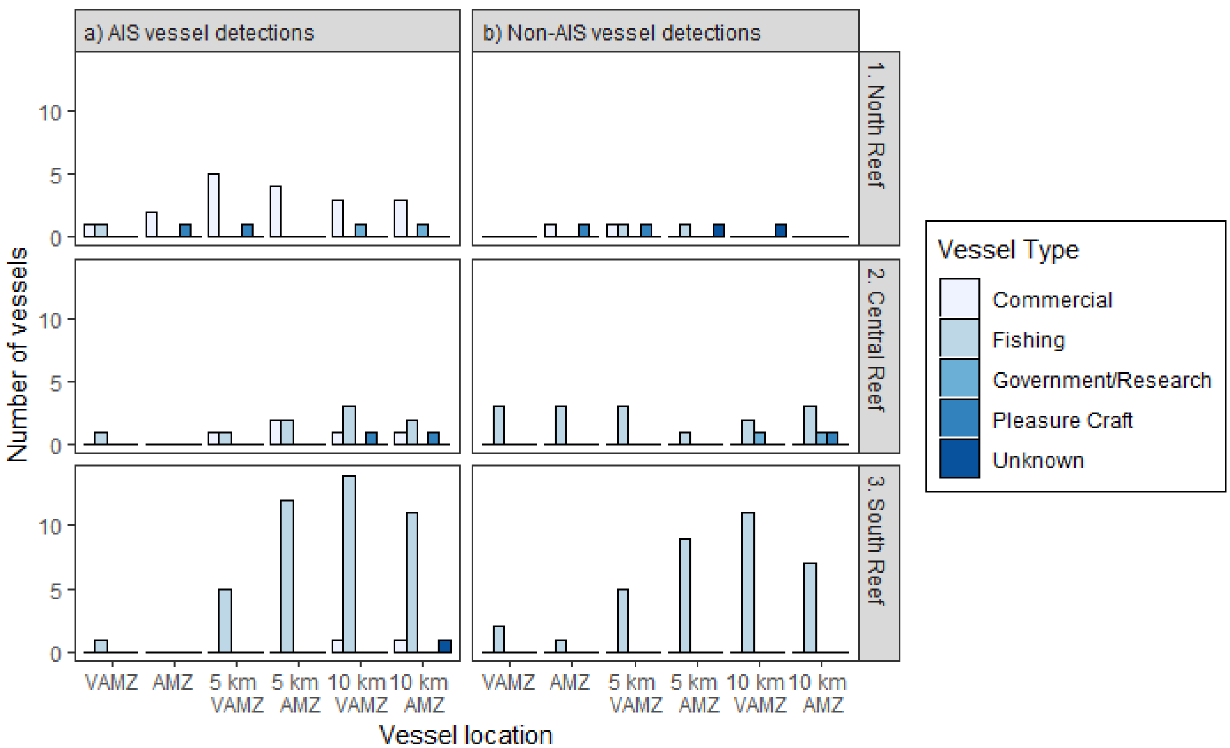

Figure 18. Number of a) AIS and b) non-AIS vessel detections by vessel type detected by Conservation & Protection Aerial Surveillance Program in the 1. North, 2. Central, and 3. South Reefs of the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA and in the Vertical Adaptive Management Zone (VAMZ) and the Adaptive Management Zone (AMZ) and respective buffers. Note, vessel counts are not exclusive spatially where overlap occurs in different buffer zones, e.g. VAMZ versus AMZ buffers.

Four activity types of fishing vessels were detected in Hecate MPA: drifting, fishing, steaming, or vessel activity was unknown (Figure 19). More fishing and steaming vessels were detected with AIS while more vessels with unknown activity were detected with ISAR (% of AIS vessel detections per fishing vessel activity type: Drifting 50%, Fishing 58%, Steaming 65%, and Unknown 31%). More vessels were detected as actively fishing in the South Reef and surrounding buffers than in either the Central or North Reefs of the MPA. Of the three fishing vessels detected within the Vertical Adaptive Management Zone of the South Reef, one was identified as potential illegal fishing (not verified by C&P) from the activity and vessel type information provided in the flyover reports (an active groundfish dragger/trawler operating under a T-License) while the other two fishing vessels in the Management Zone were steaming.

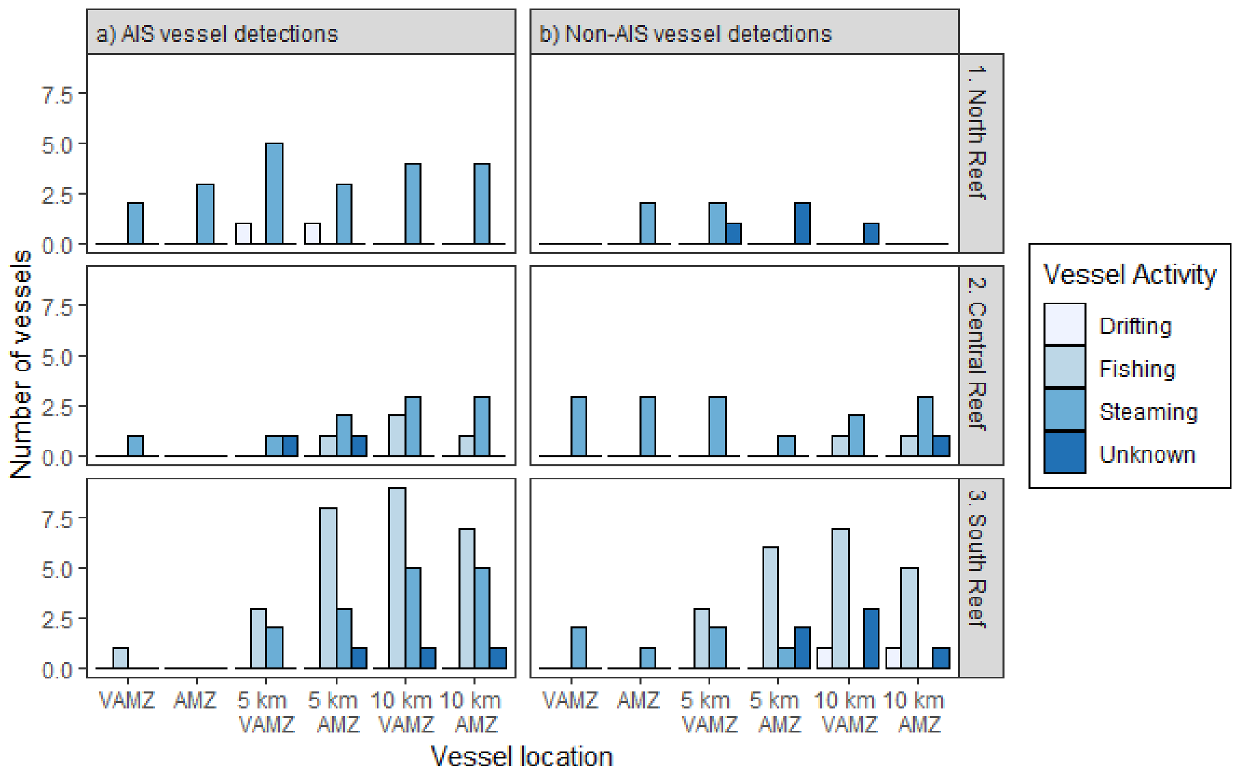

Figure 19. Number of a) AIS and b) non-AIS fishing vessel detections by vessel activity detected by Conservation & Protection Aerial Surveillance Program in the 1. North, 2. Central, and 3. South Reefs of the Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA Note, vessel counts are not exclusive spatially where overlap occurs in different buffer zones, e.g. VAMZ versus AMZ buffers.

3.3.2. Case-study 2: SG̱aan K̲inghlas-Bowie Seamount MPA

We used the three surveillance sources to examine vessel trends in and around SK-B MPA and to evaluate management measures (e.g., bottom contact fishing prohibited) and guidelines (i.e., voluntary avoidance zone) described in the SG̱aan K̲inghlas-Bowie Management Plan (Council of the Haida Nation and Government of Canada 2019). Few vessels were detected in the SK-B MPA and vessel density in and around the MPA was low (Figures 20 -22). RADARSAT detected more vessels in and adjacent to the MPA than C&P and TC, and 63% of these were AIS detections (Figure 20). Vessels were detected by C&P and RADARSAT legally transiting within 50 nm of the SG̱aan K̲inghlas-Bowie pinnacle even though large vessels are encouraged to transit outside of this area (i.e., voluntary avoidance zone). C&P detected eight vessels within 50 nm of the pinnacle while TC detected one 35 m long pusher tug in the MPA, directly over the shallow pinnacle (Figure 21). RADARSAT detected 30 vessels within this 50 nm area and these vessels ranged in size from < 25 m to > 200 m. However, large vessels were more frequently detected by RADARSAT in this area (67% of vessels were >100 m long) (Figure 21).

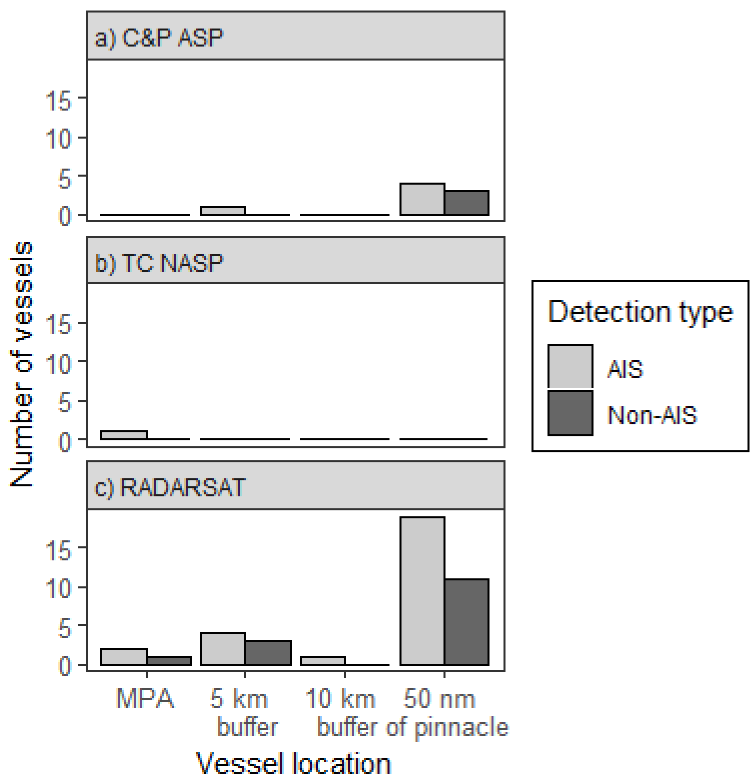

Figure 20. Vessels detected by (a) Conservation & Protection Aerial Surveillance Program (C&P ASP), (b) Transport Canada National Aerial Surveillance Program (TC NASP), and (c) RADARSAT in 2020 in the SG̱aan K̲inghlas-Bowie Seamount MPA, a 5 km buffer of the MPA, a 10 km buffer of the MPA, and a 50 nm buffer of the pinnacle. Note, vessels detected in the 5 km buffer are not included in the 10 km buffer.

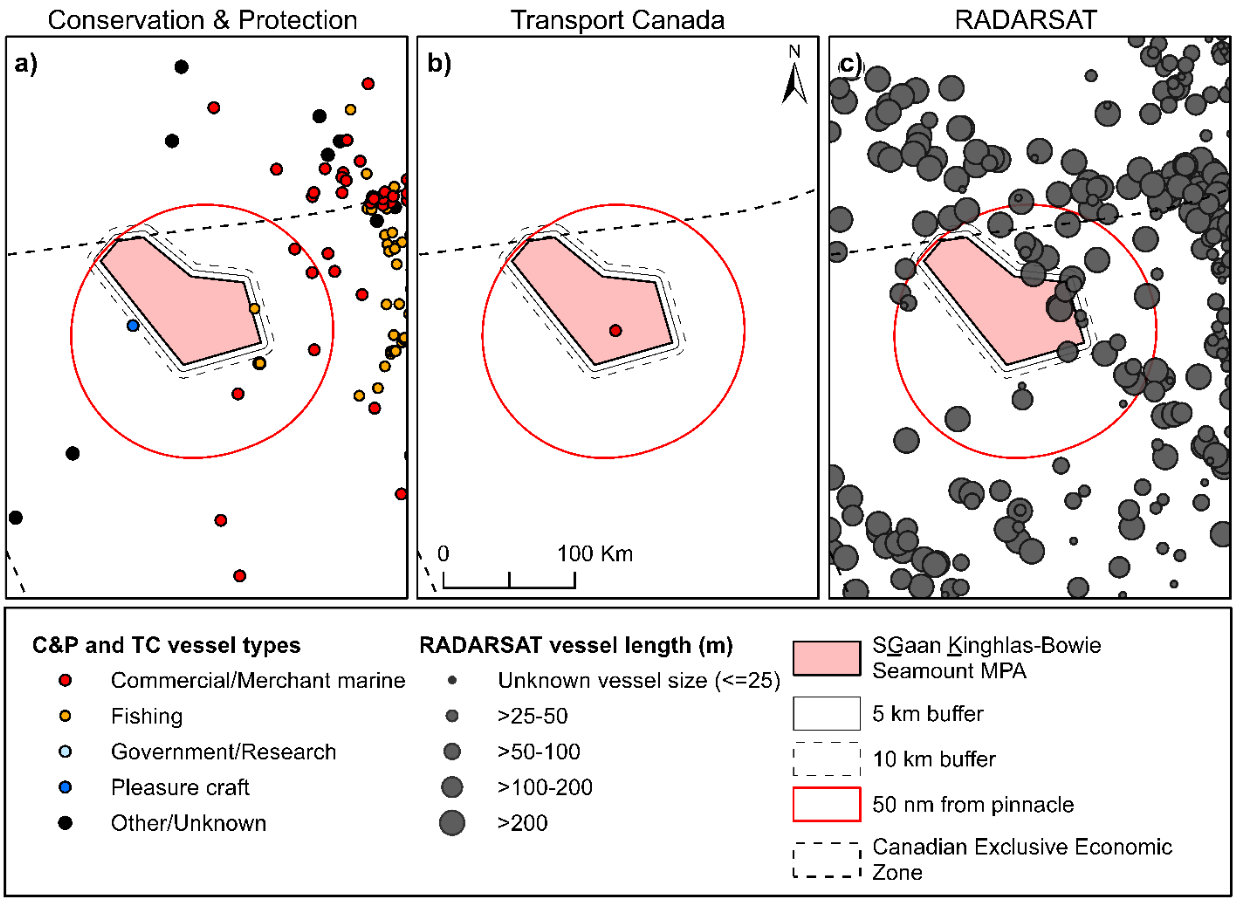

Figure 21. Trends in vessel type and length detected at the SG̱aan K̲inghlas-Bowie Seamount MPA in 2020 by (a) Conservation & Protection (C&P) Aerial Surveillance Program, (b) Transport Canada (TC) National Aerial Surveillance Program, and (c) RADARSAT. Under the MPA Management Plan large vessels are encouraged to transit a minimum of 50 nm from the SK-B pinnacle and the MPA is closed to all bottom contact fishing.

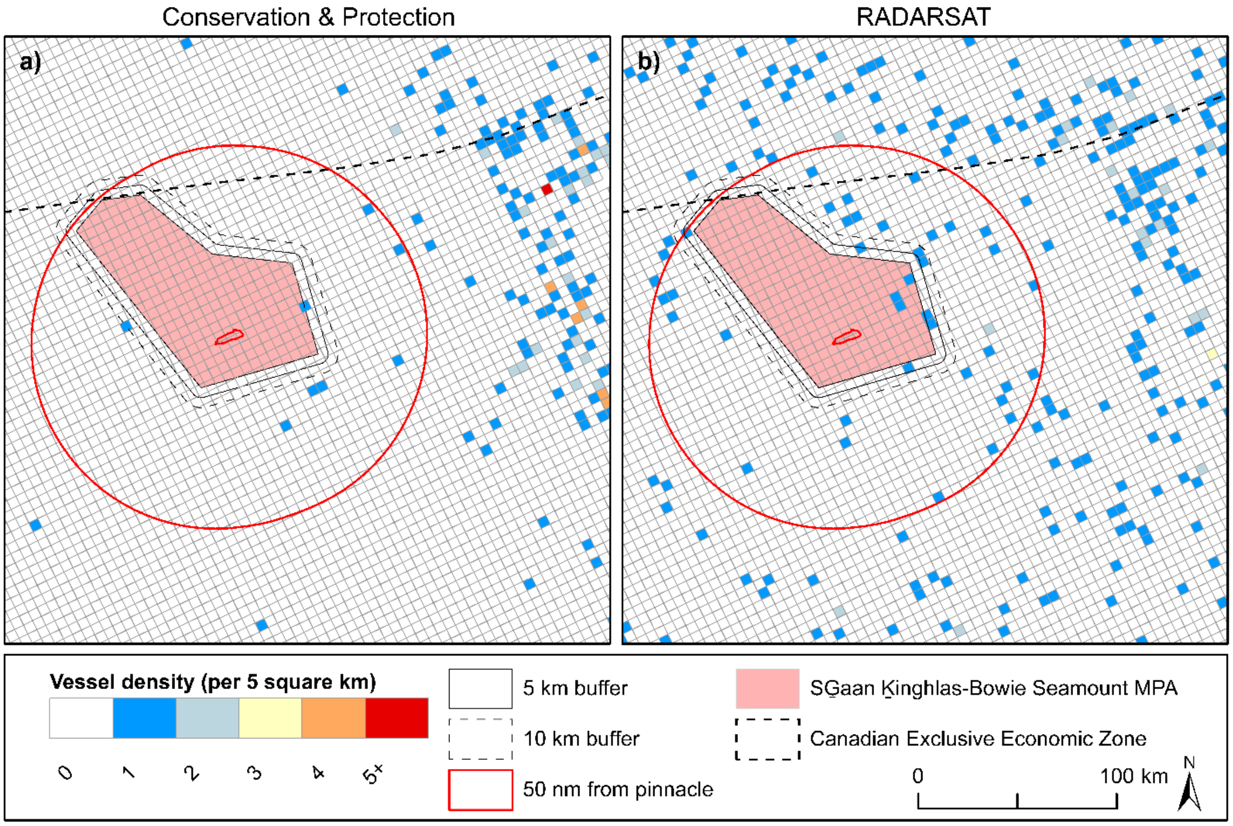

Figure 22. Number of vessel movements per 5 x 5 km grid cell in the SG̲aan K̲inghlas-Bowie Seamount MPA detected by (a) Conservation & Protection Aerial Surveillance Program and (b) RADARSAT in 2020.

C&P and RADARSAT VPUE is low in and around SK-B MPA (Figure 23). C&P detected higher VPUE in single hexagon cells around the MPA than RADARSAT, but RADARSAT detected more vessels across a greater spatial extent. Both C&P and RADARSAT surveillance covered the entire SK-B MPA, even though total area surveilled by C&P AIS and ISAR is unknown (i.e., no vessel detections and surveillance effort unknown).

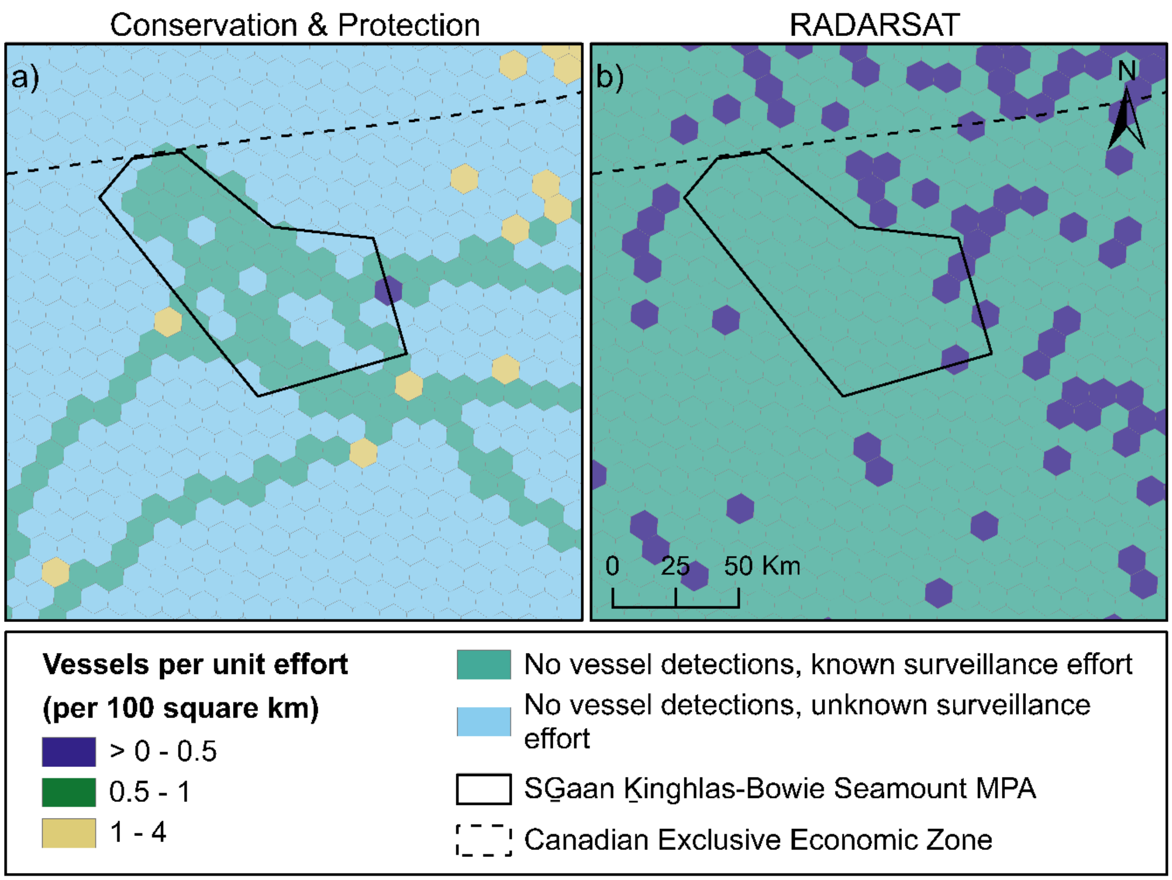

Figure 23. Vessels per unit effort detected by (a) Conservation & Protection (C&P) Aerial Surveillance Program and (c) RADARSAT in the SG̲aan K̲inghlas-Bowie Seamount MPA. Vessels are summed within 100 km^2 hexagon cells. C&P surveillance effort is the combined number of unique flyovers per cell from the aircraft track and vessel detection files and RADARSAT surveillance effort is the number of swaths per cell. C&P surveillance effort does not account for total area surveilled by AIS and ISAR.

Commercial cargo/merchant marine vessels were more frequently observed in and around SK-B by C&P than fishing, pleasure craft, or unknown vessels (Figure 24). All the larger vessels detected by C&P (commercial/merchant marine and the fishing vessel) were steaming or in transit while one fishing vessel, a longliner, was actively legally fishing within 50 nm of the pinnacle but outside the MPA. The activity of the pleasure craft and unknown vessel type was unknown. Three of the commercial/merchant marine vessels, the fishing factory vessel, and the pleasure craft were sailing under the flag of the USA. The longliner was sailing under the flag of Canada, one of the commercial/merchant marine vessels was sailing under the Norwegian flag, and the unknown vessel was of unknown origin. One of the RADARSAT vessels was the factory fishing vessel detected by C&P; this vessel was observed by RADARSAT three months after (June 2020) it was detected by C&P.

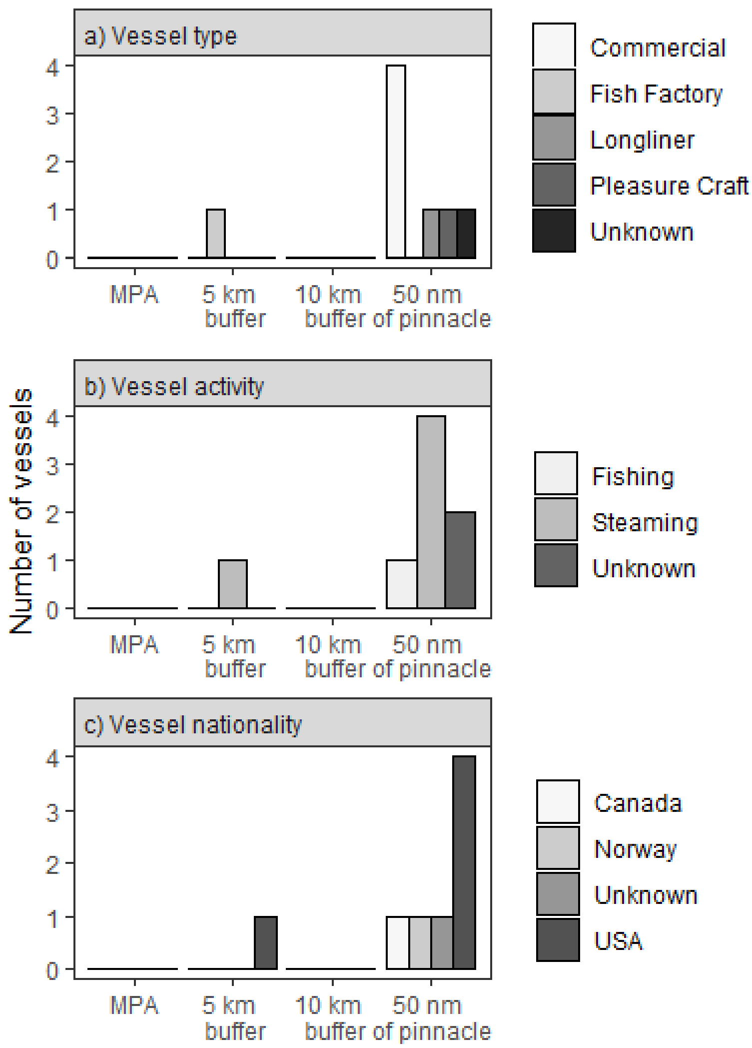

Figure 24. Number of vessels by (a) type, (b) activity, and (c) nationality detected by Conservation & Protection Aerial Surveillance Program in and around the SG̱aan K̲inghlas-Bowie Seamount MPA. Note, vessels detected in the 5 km buffer are not included in the 10 km buffer.

3.3.3. Case-study 3: Swiftsure Bank Interim Sanctuary Zone

We used C&P and RADARSAT surveillance sources to identify the number of vessels and types of vessels in Swiftsure during the vessel prohibition periods in 2019 and 2020. C&P detected vessels in Swiftsure during the 2020 prohibition period from June 1 – November 31 (Figure 25). No vessels were detected by RADARSAT in this zone during that time. Both C&P and RADARSAT show vessels adjacent to Swiftsure during the prohibition period and similar vessel patterns were detected by both surveillance sources in the shipping lane south of the Interim Sanctuary Zone. More vessel activity was observed in Swiftsure by C&P during the 2019 and 2020 prohibition periods than in 2018, when the zone was open to vessel traffic (Figures 25 and 26). However, there was no corresponding increase in vessel activity during the prohibition periods in the Swiftsure Bank shipping lane, located adjacent and south to Swiftsure (Figure 26).

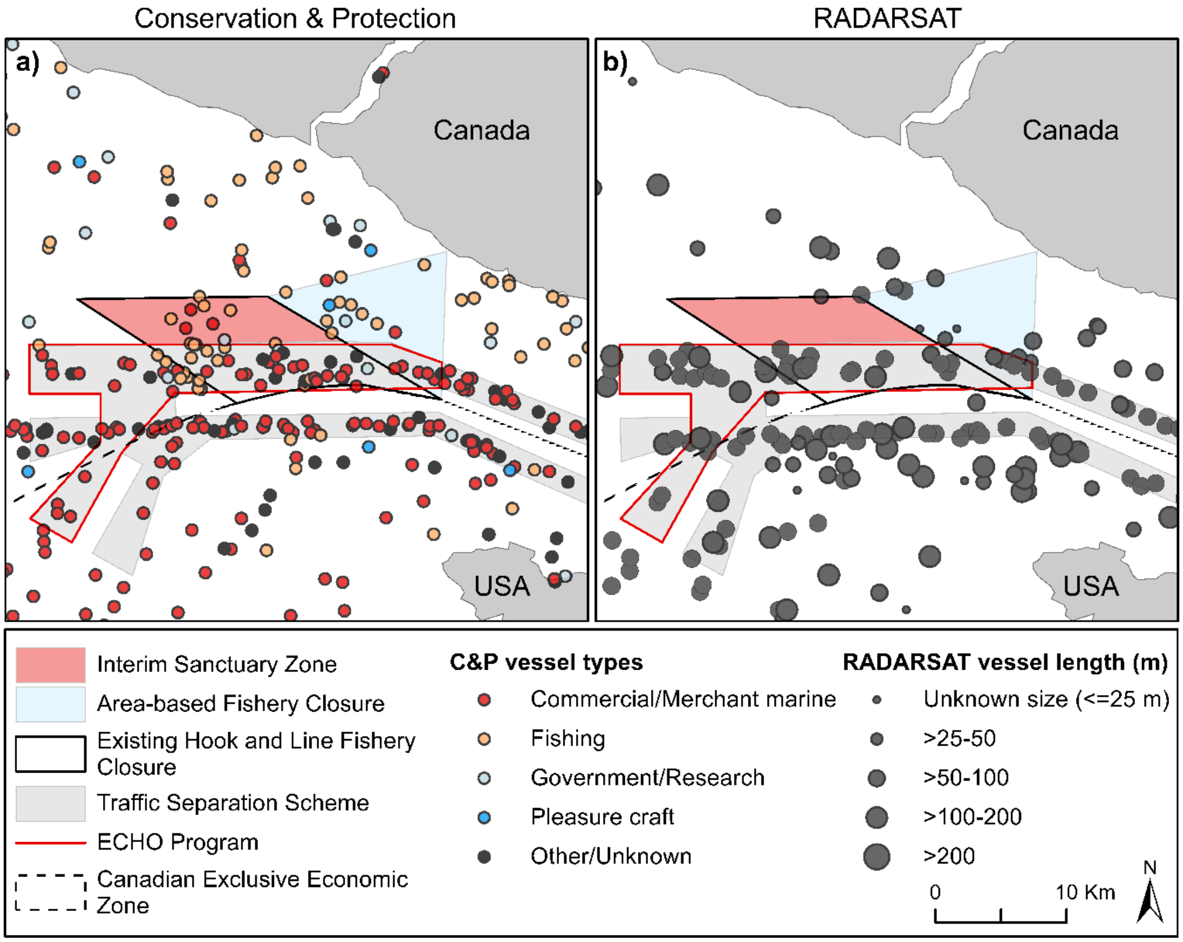

Figure 25. Vessels detected in and adjacent to Swiftsure Bank Interim Sanctuary Zone by a) Conservation & Protection (C&P) Aerial Surveillance Program and b) RADARSAT during the vessel prohibition (fishing and boating) period from June 1 – November 31, 2020. The Area-based Fishery Closure also prohibited recreational and commercial salmon fishing from August 1 – October 31, 2020. No finfish fishing is allowed in the Existing Hook and Line Fishery Closure at any time. The ECHO Program is a voluntary slowdown for outbound large commercial vessels in Swiftsure Bank from June 1 – October 31, 2020.

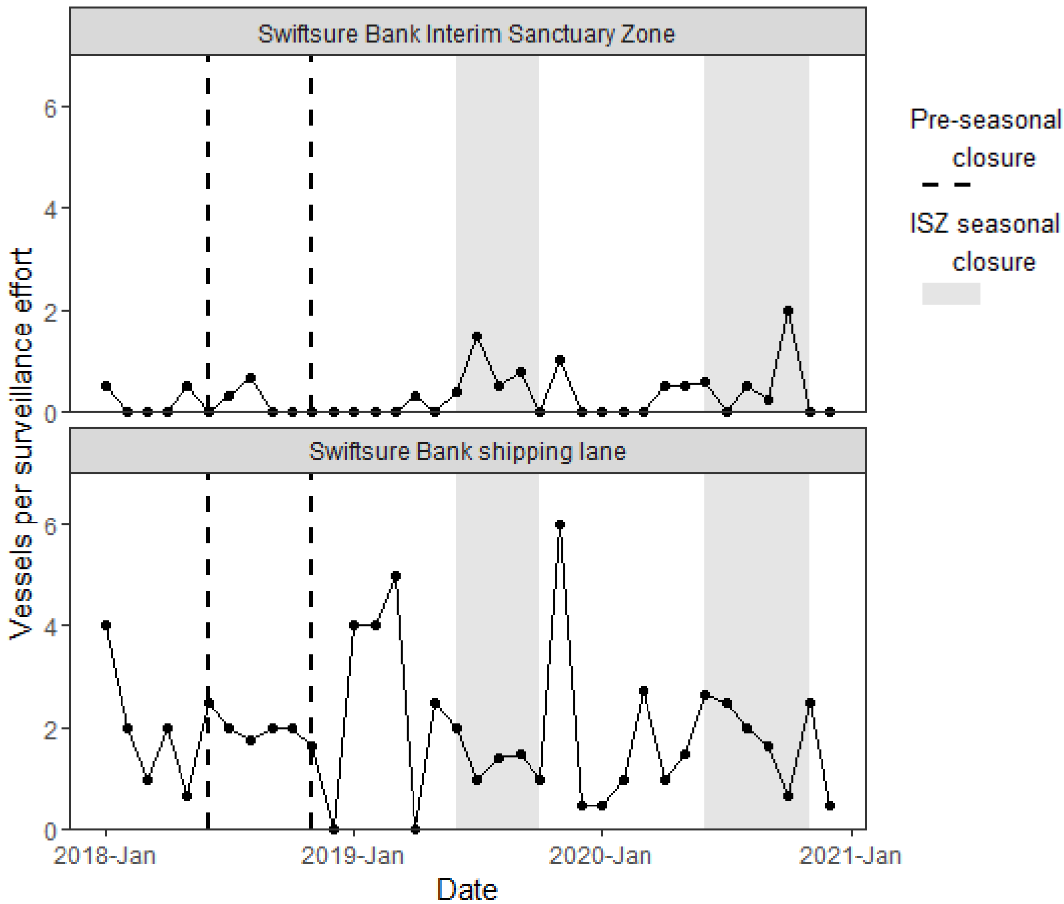

Figure 26. The number of vessels detected on each mission by Conservation & Protection Aerial Surveillance Program from January 2018 – December 2020 in the (a) Swiftsure Bank Interim Sanctuary Zone (ISZ) and (b) the adjacent Swiftsure Bank shipping lane located south of the Interim Sanctuary Zone.

Fishing, pleasure craft, commercial (not including fishing vessels), and government vessels were observed in the Swiftsure Bank Interim Sanctuary Zone. Recreational fishing vessels were the most common type of vessels detected by C&P within Swiftsure Bank during the prohibition period (Figure 27). There were two fishing vessels of unknown subtype and activity that were detected in Swiftsure Bank in 2019. These vessels did not have AIS and were detected using ISAR (i.e., radar).

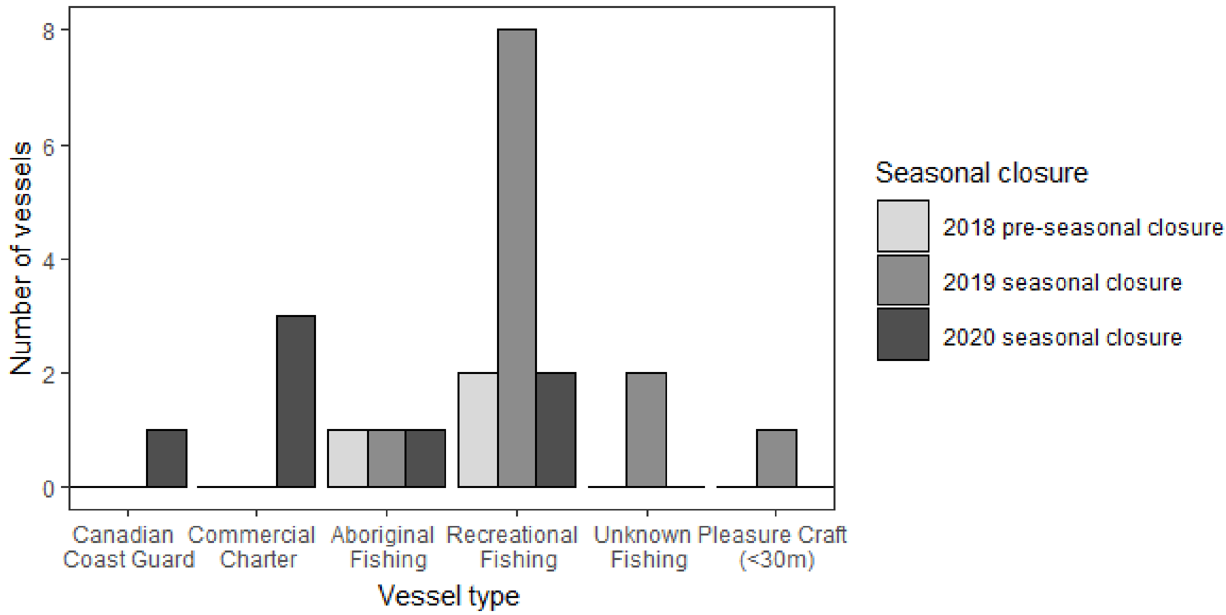

Figure 27. Number of vessels by vessel type detected by Conservation & Protection Aerial Surveillance Program in the Swiftsure Bank Interim Sanctuary Zone prior to zone designation in 2018 (June 1 – November 30), after zone designation when the seasonal vessel closure was implemented from June 1 – October 31, 2019, and from June 1 – November 30, 2020.

4.0. SUMMARY RESULTS

We provide summary rankings of surveillance sources, initial score-cards and ratings for management effectiveness of Pacific marine conservation areas, and a decision tree framework for managers to select appropriate surveillance sources for further human pressure monitoring and management effectiveness evaluation.

We ranked each surveillance source from one to three by their ability to evaluate management effectiveness using categories of: spatial and temporal coverage, surveillance effort aligned with high vessel density locations, the number of vessels detections per surveillance effort in conservation areas (detection efficiency), and the level of detail of information provided on vessel detections (Table 4). Overall, C&P scored higher (13) than TC (6) and RADARSAT (11) for evaluating conservation area management effectiveness. C&P and RADARSAT had the greatest spatial coverage, spanning the entire Pacific EEZ and all of the conservation areas. However, C&P surveillance efforts were more focused on coastal areas and was particularly higher for conservation areas closer to the mainland of BC and Vancouver Island. Conversely, RADARSAT targeted the conservation areas in Offshore Pacific Bioregion. The spatial coverage of TC surveillance efforts was small as only a few MPAs were targeted during TC flights. TC also collects and stores information on AIS vessel detections during the flight and this could be used to increase the spatial coverage of TC surveillance data. This information is not typically provided to DFO in the email reports, but it is available. C&P had the greatest temporal coverage since they have been conducting flyovers since 2002 while TC and RADARSAT have low (since 2019) and moderate (since 2017) temporal coverage, respectively. C&P also stores historical data from flyovers in an online database whereas TC and RADARSAT data are provided in email reports and historical data are lost unless compiled and saved by single users.

Table 4. Ranked scores of Conservation & Protection Aerial Surveillance Program (C&P ASP), Transport Canada National Aerial Surveillance Program (TC NASP), and RADARSAT surveillance sources in terms of spatial and temporal coverage, optimal surveillance effort, detection efficiency and the information provided on vessel detections. A score of 3 indicates a high rating for that attribute, 2 indicates a moderate rating, and 1 indicates a low rating.

Data source	Spatial coverage	Temporal coverage	Aligned surveillance effort	Detection efficiency	Vessel information	Overall Score
C&P ASP	3	3	2	2	3	13
TC NASP	1	1	1	1	2	6
RADARSAT	3	2	2	3	1	11

C&P and RADARSAT surveillance effort was moderately aligned with areas of high vessel densities. C&P surveillance efforts focused in areas of high vessel activity but few flyovers took place in the Offshore Pacific marine refuge and SK-B MPA. RADARSAT surveillance covered the Offshore Pacific Bioregion, but the number of satellite swaths was lower in areas of high vessel density. Since TC surveillance effort only focused on a few MPAs, aligned surveillance effort was rated as low. The lower number of vessel detections by RADARSAT in the coastal areas compared to C&P may be due to the higher number of smaller vessels operating in this area. Vessels smaller than 25 m in length are typically not picked up on the RADARSAT *Detection of Vessels Wide Far* imaging mode used for the Pacific EEZ.

Detection efficiency, the number of vessel detections per surveillance effort in conservation areas, was highest for C&P with more vessels detected by C&P than RADARSAT in eight of the nine conservation area types. This was especially apparent in conservation areas located closer to population centres and land, including Haida Gwaii, Vancouver Island, and the mainland of British Columbia (e.g., glass sponge reef marine refuges, RCAs, and Swiftsure), but RADARSAT detected more vessels in and adjacent to the conservation areas in the Offshore Pacific Bioregion (i.e., SK-B, Offshore Pacific, and Endeavour MPA). In the three MPAs overflown by TC, few vessels were detected by all three surveillance sources, and detection efficiency was low with more surveillance effort than vessels detected, which may indicate vessels are avoiding these MPAs.

All three datasets collected information on the vessels detected, however C&P provided additional details on vessel activity and type, and species harvested and/or fishing licence the vessel was operating under. This information is especially useful for evaluating conservation area compliance because most conservation area management measures include gear and user-group specific fishing prohibitions or restrictions. As a result, C&P evaluated conservation area management measures better than TC or RADARSAT (Table 5) and detected potential non-compliance in six of the nine conservation area types while TC and RADARSAT detected non-compliance in one conservation area. RADARSAT only detected non-compliance in terms of vessel presence while C&P conducted a finer resolution assessment, and potential non-compliance was detected using vessel presence as well as activity. Like C&P flyovers, TC flyovers collected information on vessel type and nationality along with vessel speed and course, but only for AIS vessel detections. TC also provided information on the vessel destination and origin and vessel size (length and width). RADARSAT provided little vessel information but included vessel size and provided the unique vessel identification number (i.e., MMSI) for AIS detections, and additional vessel information can be found using this number. Additionally, all three surveillance sources detected vessels with and without AIS, and these datasets can be used to address the gap in AIS datasets by detecting smaller vessels, such as fishing vessels, without AIS. C&P and RADARSAT also provided information on how a vessel was detected. C&P distinguishes between vessels detected by AIS, manual observation, or by radar, while RADARSAT provided information on the imaging mode used for vessel detection as well as a confidence measure of detection. C&P and RADARSAT both evaluated management measures where vessel entry was prohibited (e.g., Scott Islands and Swiftsure).

There were areas of low surveillance in the Offshore Pacific Bioregion, particularly west of Haida Gwaii. Even though all three sources we evaluated have surveillance over SK-B in this area, few flyovers or satellite swaths took place. Increasing C&P and RADARSAT surveillance in SK-B and Offshore Pacific would improve C&P and RADARSAT optimal surveillance effort over these conservation areas. High vessel activity was detected by C&P in the Southern Strait of Georgia and in the Southern Shelf Bioregion, and more vessels were detected in these areas by C&P than RADARSAT. Increasing C&P and RADARSAT surveillance in areas where high vessel activity was detected in RCAs and glass sponge reef marine refuges would improve both the optimal surveillance effort and the detection efficiency for these surveillance sources.

Table 5. Evaluating non-compliance with marine conservation area management measures by Conservation & Protection Aerial Surveillance Program (C&P), Transport Canada National Aerial Surveillance Program (TC), and RADARSAT (RS). "Y" indicates non-compliance was observed within the timeframe of this analysis, "N" indicates no non-compliance was observed, and "NA" indicates the surveillance source was unable to evaluate compliance for the focal conservation area or management measure.

Conservation area	**Management measures**	**Potential non-Compliance observed**		
		C&P	**TC**	**RS**
Endeavour Hydrothermal Vents MPA	No bottom contact fishing	N	N	NA
Gwaii Haanas National Marine Conservation Area Reserve & Haida Heritage Site Restricted Access Zone	No commercial, recreational fishing	N	NA	NA
Gwaii Haanas National Marine Conservation Area Reserve & Haida Heritage Site Strict Protection Zone	No commercial, recreational fishing	Y	NA	NA
Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA Core Protection Zone	No fishing	Y	N	NA
Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA Vertical Adaptive Management Zone	No bottom contact fishing, no midwater trawl fishing for hake	Y	N	NA
Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs Adaptive Management Zone	No commercial bottom contact fishing, no midwater trawl fishing for hake	N	N	NA
Other Effective Area-Based Conservation Measures (Strait of Georgia, Howe Sound Glass Sponge Reefs)	No bottom contact fishing	Y	NA	NA
Offshore Pacific Seamounts and Vents Closure	No bottom contact fishing	N	N	NA
Rockfish Conservation Areas	No groundfish bottom trawl; no hook-and-line for halibut, rockfish, lingcod, dogfish; no sablefish by trap; no salmon trolling, jigging, mooching; no spearfishing	Y	NA	NA
Scott Islands marine National Wildlife Area	Be within 300 m of the low water mark of Triangle, Sartine or Beresford Islands	N	NA	N
	Anchor vessel > 400 GT within 1 nm of the low water mark of Triangle, Sartine or Beresford Islands	N	NA	NA
SG̱aan K̲inghlas-Bowie Seamount MPA	No bottom contact fishing	N	N	NA
	Large vessels encouraged to transit > 50 nm from SG̱aan K̲inghlas-Bowie pinnacle	Y	Y	Y
Swiftsure Bank Interim Sanctuary Zone	No vessel entry June 1 – Nov. 31, 2020	Y	NA	N

C&P better evaluated compliance with management measures for the conservation areas case-studies than TC or RADARSAT and detected non-compliance with management measures in 58% (seven of the 12) of the conservation areas types and zones we evaluated (Tables 5 and 6). TC surveillance only covered Hecate and SK-B MPAs and although C&P detected illegal fishing (i.e., one vessel potentially fishing illegally) in Hecate MPA and legal fishing adjacent to SK-B MPA, no vessels were detected actively fishing by TC in or adjacent to either of these MPAs. All three surveillance sources detected vessels transiting within 50 nm from the SG̲aan K̲inghlas-Bowie pinnacle and RADARSAT detected more vessels in and around Bowie than either C&P or TC. However, vessels are permitted to transit in this area even though they are encouraged not too. Both C&P and RADARSAT provided surveillance coverage over the Swiftsure but C&P detected vessels within the Zone while RADARSAT did not.

Table 6. Initial rating of management effectiveness for the conservation areas case-studies and the surveillance source (Conservation & Protection Aerial Surveillance Program [C&P], Transport Canada National Aerial Surveillance Program [TC NASP], and RADARSAT) best used to evaluate non-compliance. "Low" management effectiveness indicates non-compliance was observed within the timeframe of this analysis for greater than 5 vessels, "Moderate" management effectiveness indicates non-compliance was observed for less than or equal to 5 vessels, and "High" management effectiveness indicates that all vessels detected within the timeframe were compliant with management measures.

Conservation Area	**Management measures**	**Management effectiveness rating**	**Hierarchy of surveillance source best used to evaluate compliance**
Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA - Core Protection Zone	No fishing	Moderate	C&P ASP > TC NASP
Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs MPA - Vertical Adaptive Management Zone	No bottom contact fishing, no midwater trawl fishing for hake	Moderate	C&P ASP > TC NASP
Hecate Strait/Queen Charlotte Sound Glass Sponge Reefs - Adaptive Management Zone	No commercial bottom contact fishing, no midwater trawl fishing for hake	High	C&P ASP > TC NASP
SG̲aan K̲inghlas-Bowie Seamount MPA	No bottom contact fishing	High	C&P ASP > TC NASP
SG̲aan K̲inghlas-Bowie Seamount MPA	Large vessels encouraged to transit a minimum of 50 nm from the SG̲aan K̲inghlas-Bowie pinnacle	Low	RADARSAT > C&P ASP > TC NASP
Swiftsure Bank Interim Sanctuary Zone	No vessel entry during June 1 – November 31, 2020	Low	C&P ASP > RADARSAT

We created a decision tree framework to help managers select the vessel tracking surveillance source best suited to evaluate a marine conservation area management measure (Figure 28), as the best surveillance source will vary depending upon the geographic location and size of the conservation area and the vessel-related monitoring objective. The decision tree currently only considers the vessel tracking surveillance sources discussed in this report, but can be developed further with the incorporation of ongoing and future analyses using other sources such AIS and Vessel Monitoring Systems.

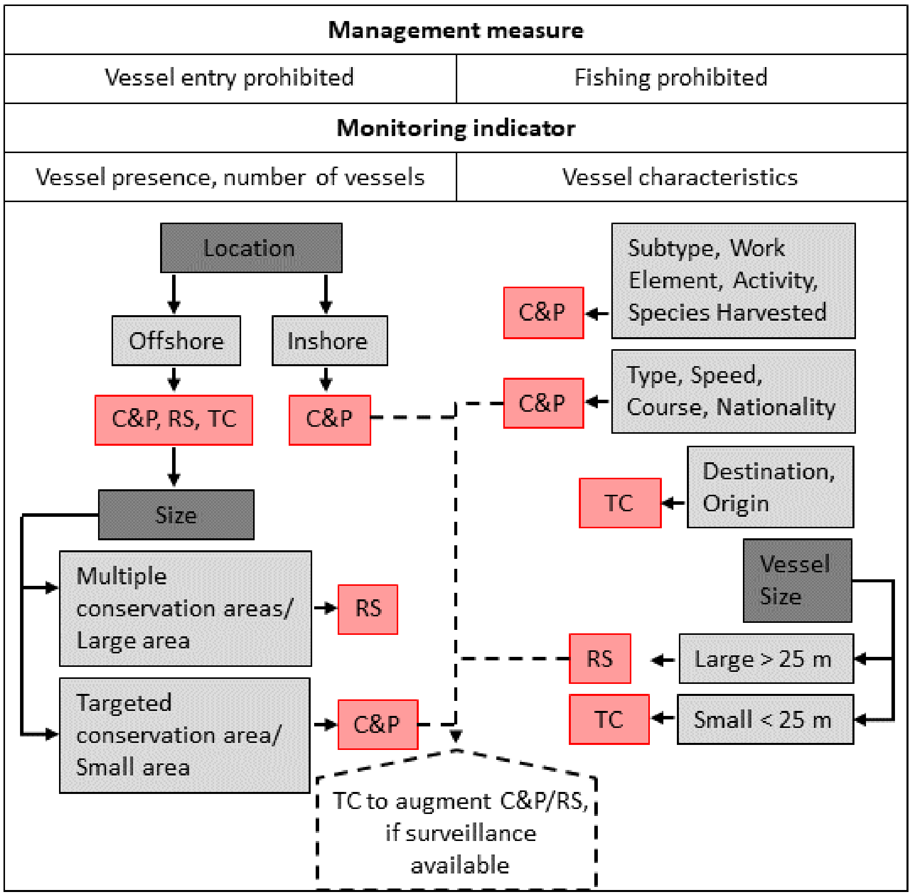

Figure 28. Decision tree framework to aid in the selection of the vessel tracking surveillance source best suited to evaluate a management measure or a monitoring requirement. The dashed line identifies the monitoring indicators that Transport Canada (TC) National Aerial Surveillance Program data can augment, if available for the conservation area. C&P = Conservation & Protection Aerial Surveillance Program and RS = RADARSAT. Most RS imagery collected on the B.C. coast in 2020 detected vessels down to 25 m in length and C&P, TC and RS all detect AIS and non-AIS vessels.

5.0. CONCLUSIONS

As the number of marine and coastal conservation areas increases there is a critical need for monitoring and evaluation tools to ensure these areas are meeting their intended conservation objectives. Vessel tracking data can be a highly effective monitoring and evaluation tool for assessing ongoing human pressures within conservation areas and for evaluating the effectiveness of regulating these areas. Though the GoC has several ongoing vessel tracking programs, most are used for real-time enforcement responses rather than for long-term evaluation of management effectiveness. We demonstrated how vessel data collected from three of these programs have great potential for monitoring vessel activity in and adjacent to conservation areas, and for evaluating compliance with regulations and/or guidelines. The datasets we used are complimentary and fill in gaps from more accessible and commonly used AIS data as both AIS and non-AIS vessels were detected. Furthermore, these data capture all types of vessel traffic that may impact conservation areas in ways other than fishing.

We detected non-compliance in six of the nine conservation area types and for most of the management measures related to gear or user-group specific fishing prohibitions. Only two conservation area types prohibited vessel entry (i.e., Swiftsure and Scott Islands) and one other encouraged vessel avoidance within an area (i.e., SK-B). C&P collected valuable vessel information on vessel activity, vessel type, and species targeted, and this information best determined vessel compliance with conservation area regulations. TC also collected valuable vessel information, but only for three MPAs (as currently requested by DFO Oceans managers). Vessel information provided for AIS vessel detections by TC is the same as information provided with AIS. RADARSAT provided little vessel information apart from vessel name, MMSI, and length, but had greater spatial coverage over the Offshore Pacific Bioregion than either C&P or TC. Historically, these datasets have been difficult to access and process, and until now, rarely used by DFO for conservation area monitoring or effectiveness evaluation. Management and monitoring plans are currently being created for marine and coastal conservation areas and are likely to include human pressure monitoring objectives related to vessel activity. We encourage the use and further development of the methods and results presented here for monitoring Canada’s conservation area effectiveness moving forward.

6.0. RECOMMENDATIONS

The three surveillance sources we used to evaluate management measures in conservation areas are complimentary. Each source provides either temporally or spatially intermittent surveillance, however they can be used together to address data gaps. Based on how vessel data are currently collected and accessed for the three surveillance sources reviewed here, we make the following recommendations to managers for data selection and collection.

Data selection:

- Use C&P data to evaluate management measures related to fishing prohibitions.
- Use C&P and RADARSAT data to evaluate management measures regarding vessel prohibition. RADARSAT provides better surveillance coverage of the Offshore Pacific Bioregion while C&P provides better coverage in the Strait of Georgia, Southern Shelf, and Northern Shelf Bioregions.
- Use TC data to augment C&P and RADARSAT data if assessing SK-B, Hecate, and Endeavour MPAs.

- Use C&P data to examine changes in vessel activity over time as data from C&P flyovers have been collected since 2002 and are available in online databases.
- Use TC and RADARSAT to examine trends in vessel sizes. Note, TC only provides information on three MPAs.
- Additional data sources could be used in conjunction with the three surveillance sources evaluated here, e.g., satellite and terrestrial AIS data and fisheries log books. A national-level description of GoC vessel tracking data and applications, along with spatial and temporal resolutions, is provided in the DFO Technical Report on Vessel Tracking Datasets for Monitoring Canada's Conservation Effectiveness (Iacarella et al., 2020b).

Data collection:

- The vessel information and reporting template provided by TC was developed with guidance from DFO Oceans. There is an opportunity to work with TC to update their methods with regard to the type of vessel information collected, the focal conservation areas surveilled, and the information reporting template. Specifically, we recommend that fishing vessel activity as well as species targeted or gear information be collected in addition, that more conservation areas be surveilled as feasible, and that information be provided to DFO as raw data in Excel spreadsheets.
- Develop a repository for TC and RADARSAT data as currently historical and future data from these two surveillance sources will be lost if not compiled and saved by single users.
- Coordinate surveillance efforts across federal agencies to optimize data collection as well as data access and usability for monitoring vessel-related human pressures.
- Conduct additional research on the spatial variability of non-compliance across conservation areas to elucidate where to focus surveillance efforts.

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