OILING THREATS TO MARINE BIRDS ON SOUTHERN VANCOUVER ISLAND, BRITISH COLUMBIA, CANADA

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ABSTRACT

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Information on the distribution and abundance of marine birds is needed to evaluate current status in relation to threats from potential increases in vessel traffic off southern Vancouver Island, British Columbia (BC), Canada, in the Salish Sea. We conducted year-round boat-based surveys in waters between Sidney, BC and Victoria, BC from November 2015 to August 2019 and examined seasonal variation in bird distribution and abundance. Our study area included parts of the Sidney Channel Important Bird Area, the Shoal Harbour and Victoria Harbour Migratory Bird Sanctuaries, and the Chain Islets Ecological Reserve, adjacent to major shipping lanes, as well as ports and marinas. With the approval for the proposed expansion of the Trans Mountain pipeline to Burnaby, BC, tanker traffic is expected to increase in our study area. Increases in several categories of marine vessel traffic have occurred recently in the Salish Sea and are expected to increase further with the development of Liquefied Natural Gas projects and the Delta Port expansion on Roberts Bank. Within that context, we counted all marine birds but focused primarily on alcids: Rhinoceros Auklet *Cerorhinca monocerata*, Common Murre *Uria aalge*, Pigeon Guillemot *Cepphus columba*, Marbled Murrelet *Brachyramphus marmoratus*, and Ancient Murrelet *Synthliboramphus antiquus*. Alcids were present year-round but showed species-specific seasonal spatial patterns. These patterns are likely related to seabird annual cycles as well as fluctuations in forage fish prey populations, their habitats, and variation in seasonal availability to birds. Increasingly busy shipping lanes for tanker, cargo, and passenger vessels pass nearby and through our study area. These shipping lanes, together with traffic from tugs, fishing vessels, and recreational motor and sailing vessels, plus the many marinas and terminals in the area, pose significant risks to marine birds.

Key words: Salish Sea, marine birds, marine vessel traffic, oiling risks, bitumen, Trans Mountain pipeline

INTRODUCTION

The Salish Sea is an important transboundary ecosystem that provides critical habitats for many migratory marine bird species (ECCC & US EPA 2021) including birds of the family Alcidae, which use their short wings to pursuit dive for fish and larger zooplankton prey (Gaydos & Pearson 2011, Bertram 2014). Here, we seek to quantify temporal and spatial patterns of alcid marine habitat use in relation to vessel traffic patterns in the bird-rich coastal region on southern Vancouver Island, British Columbia (BC) between the cities of Sidney, BC and Victoria, BC. The region is highly urbanized with many marinas, ports, fuel docks, and wastewater outfalls, which can be significant sources for hydrocarbon spills into the marine environment (NRC 2003, GESAMP 2007). Alcids frequent nearshore waters year-round and are considered highly vulnerable to oiling due to their tendency to form large flocks in small areas that overlap with shipping lanes (e.g., Thompson *et al*. 2003, Thomas & Lyons 2017). Alcids are also vulnerable to oiling because they spend most of their lives on the surface of the ocean, only coming to land to breed (King & Sanger 1979, Camphuysen 1989, Fox *et al*. 2016). In addition, only a small amount of oil can kill a bird by causing feather damage, which can lead to hypothermia (Stephenson 1997, Morandin & O'Hara 2015) and other chronic or acute impacts (King *et al*. 2021).

Marine birds are vulnerable to risks from oiling worldwide. Vessels are linked with both acute and chronic oil spills (NRC 2003, GESAMP 2007), and vessel traffic rates are widely used as an index of oiling risk for birds (e.g., Wong *et al*. 2018, Lieske *et al*. 2020, O'Hanlon *et al*. 2020). In British Columbia coastal waters, oil pollution has been modelled based on marine vessel traffic (Bertazzon *et al*. 2014, Serra-Sogas *et al*. 2014), and model output has been used to assess risk of oil exposure to marine birds in the Hecate Strait region of the north (Fox *et al*. 2016). In southern BC, the highest intensity of discharges was observed in the Salish Sea region (Bertazzon *et al*. 2014), with a high probability of discharges in Important Bird Areas and Migratory Bird Sanctuaries on southern Vancouver Island (Serra-Sogas *et al*. 2012). We note that marine oil pollution can come in many forms, including from discharges of unburned oil (such as the intentional or unintentional discharges of waste oil, leaks, oil/fuel transfer, or lubricating oils in exhausts) or emissions from the burning of fossil fuels (NRC 2003). Winds and currents can move oil quickly over large distances (e.g., Rodway *et al*. 1989), but in general, the closer the proximity of marine birds to sources of oil, the greater their risks of exposure.

On the southwest coast of Canada in the Salish Sea, tanker traffic rates are expected to increase with the approval of the Trans Mountain pipeline expansion (Trans Mountain Expansion [TMX] Project) from Edmonton, Alberta (AB), to Westridge Marine Terminal, Burnaby, BC (see GoC 2019). Increases in several categories of marine vessel traffic have occurred recently in the Salish Sea (McWhinnie *et al*. 2021) and are expected to increase further with the development of Liquefied Natural Gas projects and the Delta Port expansion on Roberts Bank. It is recognized that the TMX Project and its related marine shipping could have adverse effects on Species at Risk and their critical habitats (GoC 2019). Indeed, for the threatened Marbled Murrelet *Brachyramphus marmoratus*, the species Recovery Strategy (ECCC 2023) identifies increased shipping activity as an emerging threat. The TMX Recommendations also require a program to monitor marine bird populations in the Salish Sea in relation to all vessel traffic (GoC 2021).

Here we report the results of an investigation to quantify the year-round use of Salish Sea alcids over the course of four years (2015–2019): Rhinoceros Auklet *Cerorhinca monocerata*, Common Murre *Uria aalge*, Marbled Murrelet, Pigeon Guillemot *Cepphus columba*, and Ancient Murrelet *Synthliboramphus antiquus*. Breeding populations of four of our study species are in decline in BC. Under the Species at Risk Act, Marbled Murrelet is listed as Threatened (EC 2014, ECCC 2023, Drever *et al*. 2021) and the Ancient Murrelet is listed as Special Concern (COSEWIC 2004, ECCC 2018). The Common Murre also is in decline in BC (Hipfner 2005), as is the Rhinoceros Auklet at the largest colony on Pine Island (Laurie Wilson and Adam Smith, unpubl. analysis; see also Rodway & Lemon 2011). Winter populations of these birds have also shown long-term declines in the Salish Sea (Bower 2009, Crewe *et al*. 2012, Vilchis *et al*. 2014, Devitt & Bradley 2018, Pearson *et al*. 2022, but see Ethier *et al*. 2020). Our results should support oil-spill response and marine spatial planning needs for waters off Southern Vancouver Island, and should contribute to conservation efforts aimed at mitigating marine vessel-associated threats that may be contributing to these long-term declines. While our analysis is principally geared toward oil pollution, we are aware of other potential impacts of increased vessel traffic, such as sub-sea noise, with diving seabirds being especially vulnerable (e.g., Pichegru *et al*. 2022).

STUDY AREA AND METHODS

Study area

Our study area in Juan de Fuca and Haro Strait contains several portions with special conservation status: (1) two long-standing Migratory Bird Sanctuaries in Victoria (Victoria Harbour Migratory Bird Sanctuary, established 1923) and Sidney (Shoal Harbour Migratory Bird Sanctuary, established 1931; Fig. 1); (2) Sidney Channel, Chain Islets, and Great Chain Island, which are recognized internationally as Important Bird Areas (IBA, Birds Canada 2022); (3) British Columbia Ecological Reserves (Ten Mile Point, Trial Island, and Oak Bay Islands) and Marine Parks (Discovery Island); (4) the Gulf Islands National Park Reserve managed by Parks Canada (Parks Canada Agency 2017); and (5) several rockfish conservation areas identified by Fisheries and Oceans Canada (DFO; FOC 2016), which bridge two DFO Pacific Bioregions—the Strait of Georgia and the Southern Shelf.

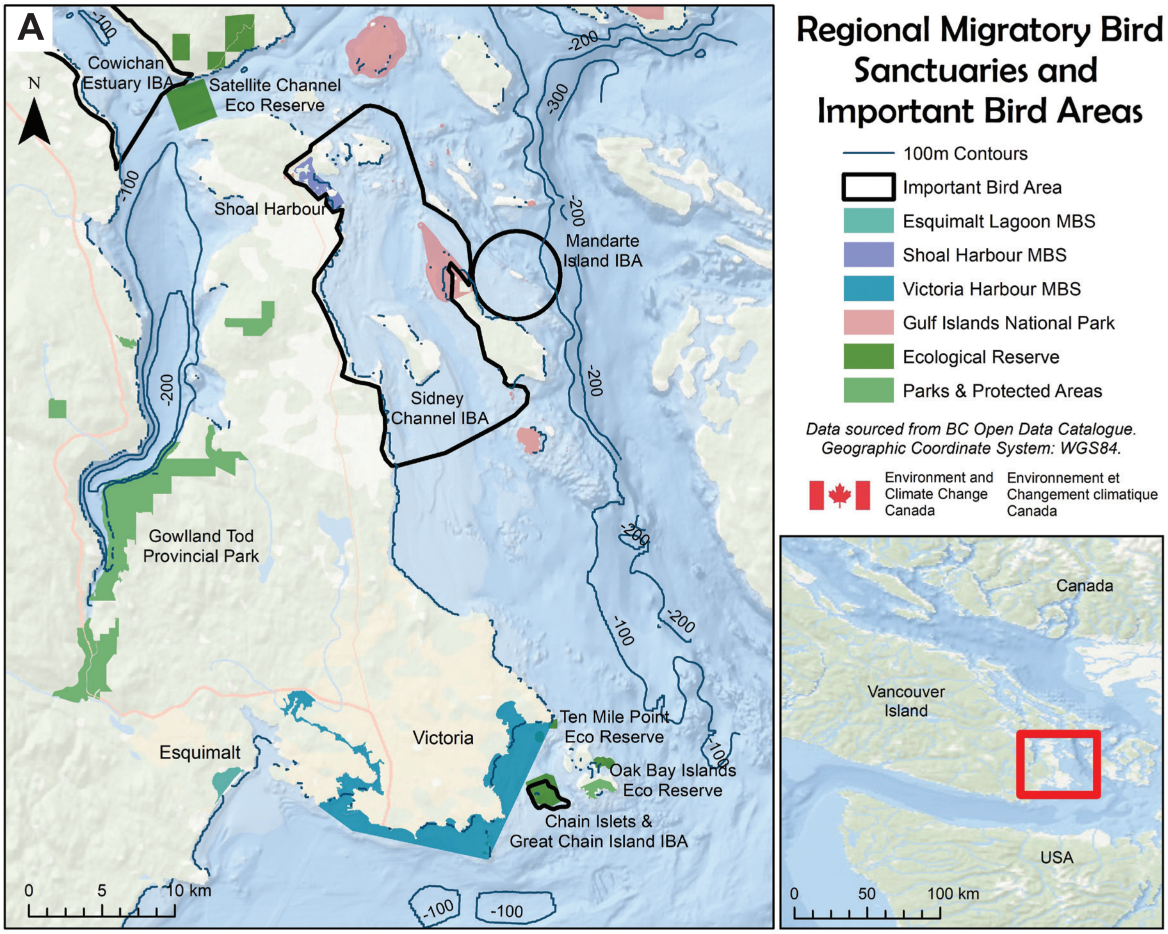
There are a number of oceanographic features in the region that likely enhance prey availability and quality, including a large counter-clockwise eddy off the south and southeastern sides of Discovery Island on both the flood and ebb tides. Juan de Fuca Strait extends as a submarine canyon from the Pacific Ocean and 50% of the water that enters Juan de Fuca Strait passes the shores of Discovery Island, dispersing upwelled nutrients and plankton (Thomson 1981). Pacific Sand Lance *Ammodytes personatus* subtidal burying habitat has been identified in our study area, particularly in Cordova Channel and Sidney Channel (Robinson *et al*. 2013, 2021). The shallow subtidal sand wave habitat supports populations of sand lance, a vital species of forage fish for the Salish Sea ecosystem (Selleck *et al*. 2015).

The Sidney Channel IBA has been identified as particularly vulnerable to chronic oil pollution based upon spatial overlap between spill intensity and marine bird densities (Serra-Sogas *et al*. 2012). Place names used in the text are mapped in Appendix 1 (available online).

Bird surveys and data processing

Surveys between Sidney and Victoria (Fig. 1B) were conducted sporadically depending on weather from November 2015 to August 2019 on the F/V *Misty Lady*, a 12.8-m Deltaga motor vessel with a viewing platform inside the cabin about 3 m above the waterline. The vessel generally travelled at 7–9 knots (13.0–16.7 km/h), depending on the strength of the current, and the full survey took approximately 8 hrs. The survey route had an inside track heading south from Tsehum Harbour in Sidney passing along the western sides of James Island and Discovery Island to Victoria Harbour, and an outside track heading north along the eastern sides of the above-mentioned islands. We conducted 46 surveys, most of which were complete, but we also included partial coverage along the route when surveyed opportunistically. Strip transect methodology was used to estimate relative abundance and distribution, in accord with surveys conducted in the past by Environment and Climate Change Canada (Kenyon *et al*. 2009, Fox *et al*. 2023). The method is widely employed to determine relative abundance of seabirds (Hyrenbach *et al*. 2007). The surveys did not measure detectability (e.g., Raphael *et al*. 2007, Ronconi & Burger 2009, Pearson *et al*. 2022), so the estimates represent minimum counts. We assumed that double counting did not occur. Surveys were conducted only under calm conditions (Beaufort 2 or less). We assumed that periodic reduced detectability from glare and choppy waters were minimal. We attempted to minimize variation in detectability by using a single survey platform. Moreover, although just one person conducted the counting, they were one of only two persons who participated throughout the study. On each cruise, the single observer counted all birds within 150 m of the starboard side of the vessel (flying, perching, or on the water). Location was recorded every 10 min. Observers gauged the strip width distance by periodically using a rangefinder. The full survey covered an area of approximately 14 km^2 given the 90-km average route length and 150-m strip width. The bird count dataset is published on DRYAD (Bertram 2023).

To show seasonal patterns of species abundance, we report numbers per unit area (counts corrected for effort) for each survey throughout



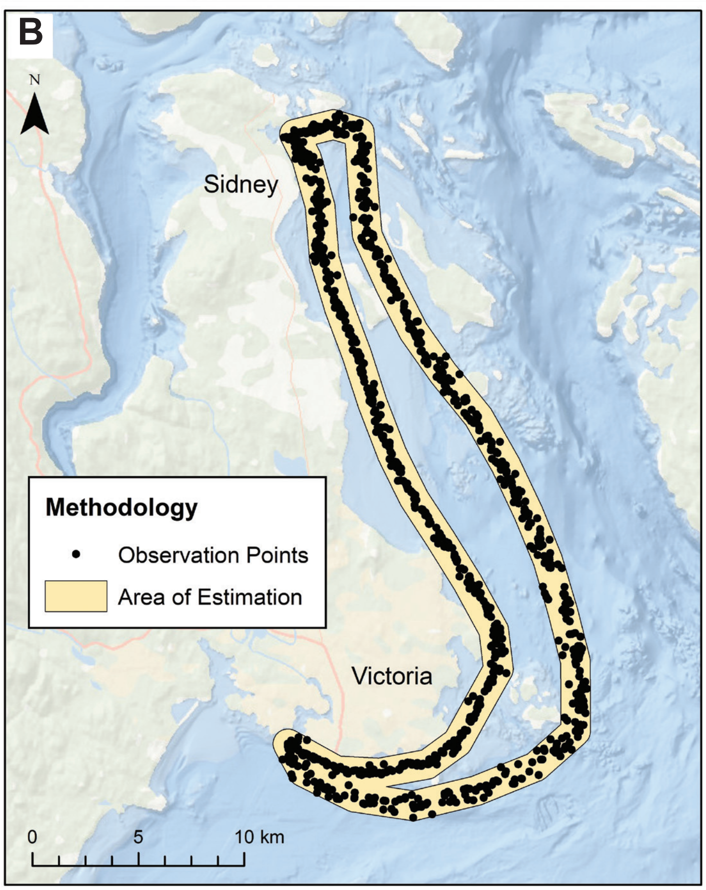


Fig. 1. Map of the study region in Juan de Fuca and Haro Strait, British Columbia, Canada, including areas recognized for conservation (A). Survey route and zone of observations (B).

the year by month. All counts were assigned to a centroid, or the mid points of each 10-min segment along the survey transect. The coordinates from the centroids were used to convert CSV files to point layer shapefiles in ArcMap using WGS84 as the geographic coordinate system. The shapefile was then projected to NAD83 UTM Zone 10 to allow for distance–based spatial analysis.

Due to the natural variations caused by ocean conditions, currents, weather, and human error, the survey route was not exactly aligned every time, which created an 'area of estimation' (see below for the kernel density estimation) approximately 1.4 km in width and 123 km^2 in area (see Fig. 1B). The attribute tables in the shapefiles were queried by both species and unique survey ID to isolate single species observation numbers by individual surveys. Results of these queries were output as point layers.

Kernel Density Estimation (KDE) corrected for effort was used to facilitate visualization of the areas used by the alcids in summer (April–September) and winter (October–March) for all years pooled. KDE was performed on each queried point layer using a 5 km bandwidth with the total number of birds counted (abundance) as the population variable (ESRI 2017, ArcGIS v. 10.5.1 with Spatial Analyst extension), projecting results onto 400 m grid raster. This created a single raster layer per species per survey, displayed as kernel densities. KDE was also performed on each individual survey track using the same 5 km bandwidth projected onto the same 400 m grid raster as the KDE layers based on abundances, with the total area surveyed (in m^2) as the population variable. This created a single raster layer for each survey that represented survey effort. Using raster math (ESRI 2017, ArcGIS v. 10.5.1 with Spatial Analyst), KDE raster layers were stacked (i.e., raster pixels added to each other among layers) among surveys to produce total abundance KDEs for each species per season and total effort per season (pooled among years). Total abundance rasters were divided by total effort rasters to produce single raster layers of average densities for each species per season (i.e., corrected KDE abundance using effort). Finally, these density rasters were clipped to our original area of observation (Fig. 1B) to avoid extrapolation of estimations. We refer to "hotspots" as areas with elevated densities, defined as the upper 20% quantile of densities. Note that the KDE colours are relative *within* a figure, and not *between* figures, so a detection of one bird in the winter will appear to be an area of high concentration. All spatial analysis was performed in ESRI ArcMap version 10.5.1 (ESRI 2017).

Oiling threats from vessel traffic

Automated Identification Services (AIS) data were collected by the Canadian Coast Guard and were archived by Ocean Networks Canada who provided access to the stored AIS data. These AIS data were processed by O'Hara and colleagues from the Coastal and Ocean Resources and Analysis Lab (CORAL) at the University of Victoria. The AIS data contained vessel positions with time stamps and descriptions of vessel types and lengths. We pooled the data into three vessel categories based on vessel size and purpose: (1) Tanker, Cargo, and Passenger, (2) Tugboats and Fishing, and (3) Recreational Motor and Sailing vessels. These categories reflect varying oil exposure risk levels to alcids associated with vessel traffic. Further qualitative analysis was performed to visually assess overlapping high bird densities with high intensity vessel traffic areas to identify those regions at the highest risk for vessel-wildlife interactions, focusing on exposure risk to oil pollution. The AIS data consisted of point positions that were converted to individual vessel tracks based on Maritime Mobile Service Identity (MMSI), which are uniquely assigned to each AIS transducer on each vessel (please refer to McWhinnie *et al*. 2021, O'Hara *et al*. 2021, and O'Hara *et al*. 2023 for processing details and examples of products).

Because we detected an increasing trend in traffic intensity for some vessel categories in recent years (McWhinnie *et al*. 2021, O'Hara *et al*. 2022), we chose traffic data from 2018 as most representative of current conditions prior to the onset of the COVID-19 pandemic and associated effects on vessel patterns. Data from February and August were further extracted to represent winter and summer, respectively. Total vessel track length within each grid cell (400 m grid raster) was used as an indication of traffic intensity for each vessel category per season, and intensity was visualized using Jenks Natural Breaks (12 classes) on a similar colour ramp to the alcid KDE figures.

We emphasize here that vessels are not equally represented by AIS among our three categories (O'Hara *et al*. 2023), and for this reason we discuss exposure risk within each category (i.e., relative exposure intensity) and refrain from making comparisons between vessel categories. We highlight the close proximity of vessels with seasonal bird densities in this paper. We did not model the interaction between oiling risk and alcid distribution because these data contribute to a larger-scale companion paper to develop spatially explicit seasonal risk models for alcids in the Salish Sea. The upcoming models will facilitate direct assessment of the risks of oil and vessel traffic to alcids and other marine birds.

RESULTS

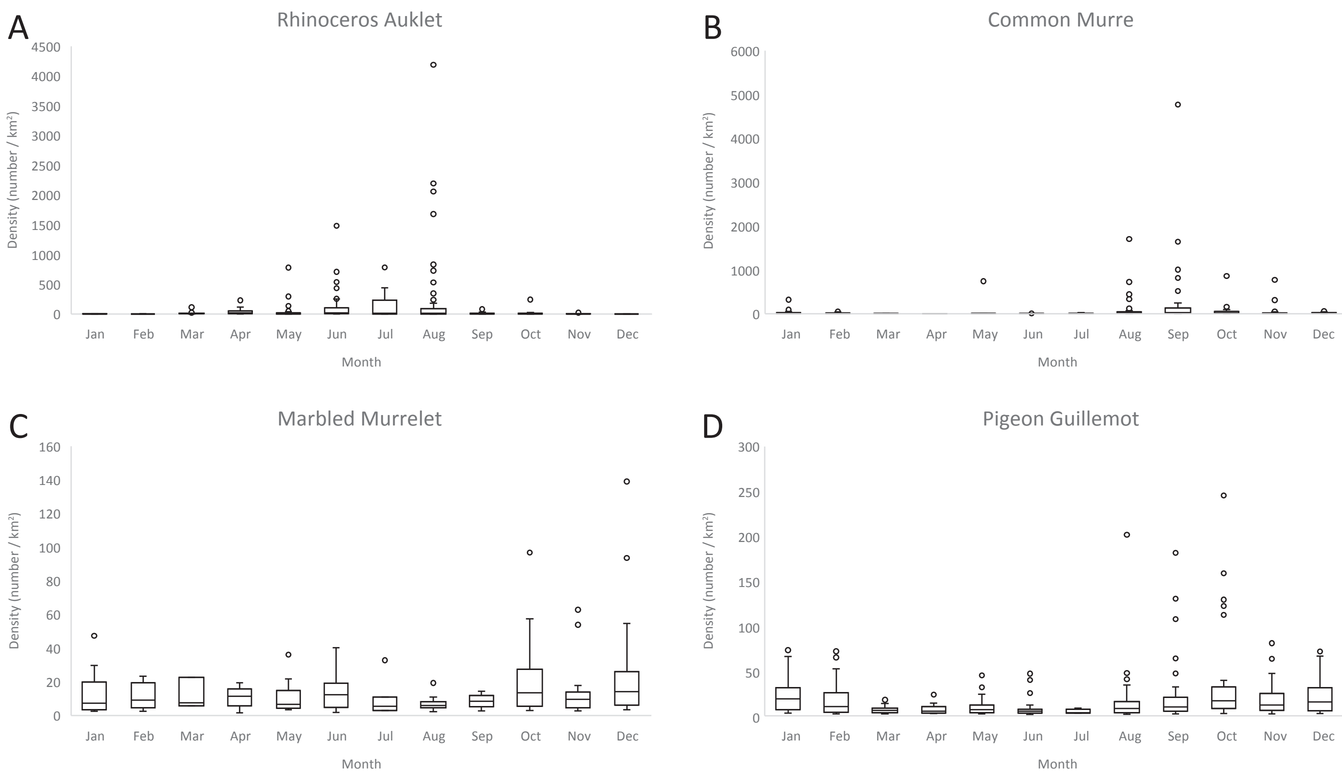
Annual and spatial patterns

Rhinoceros Auklets demonstrated an influx in March and were most abundant in July and August (Fig. 2A). Large flocks were often observed in the Sidney Channel IBA (Fig. 3A), and other groups were seen regularly south of Victoria in the Migratory Bird Sanctuary and Oak Bay Ecological Reserve. Juvenile birds began to appear in our survey area in August. Numbers of birds diminished quickly in September and were almost absent in December and January. In winter, Rhinoceros Auklets tended to be most abundant along the outside track in the southeast of the study region, around Discovery Island.

Common Murres exhibited an influx to the study area in August, September, and October. The largest numbers were observed in August and September (Fig. 2B). In late summer and winter, Common Murres tended to be most abundant along the outside track in the southeast of the study region, around Discovery Island and Trial Island (Fig. 3B).

Marbled Murrelets were present year-round in the study region (Fig. 2C). There were fewer birds in summer than winter, with the highest counts in October to December. Notable peaks were near Coal Island (Sidney Channel IBA) in December and November. In both winter and summer, Marbled Murrelets occupied similar locations, with a hotspot in the north of the study region near Coal Island, and a secondary hotspot south off Ten Mile Point (Fig. 3C).

Pigeon Guillemots were present year-round (Fig. 2D) but showed an influx into the study region in September and October. The



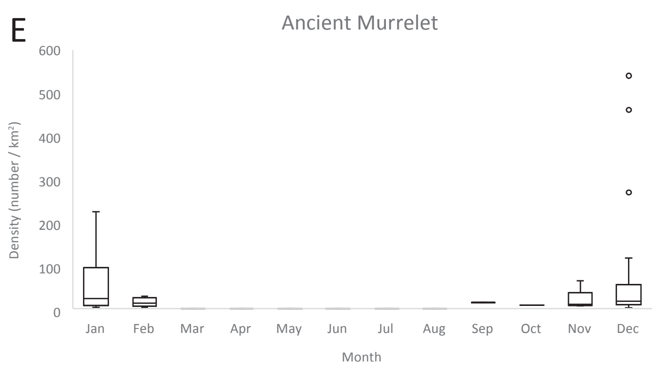


Fig. 2. Monthly relative densities (2015–2019) of (A) Rhinoceros Auklets *Cerorhinca monocerata*, (B) Common Murre *Uria aalge*, (C) Marbled Murrelet *Brachyramphus marmoratus*, (D) Pigeon Guillemot *Cepphus columba*, and (E) Ancient Murrelet *Synthliboramphus antiquus* in the study area in Juan de Fuca and Haro Strait, British Columbia, Canada. The box and whisker plots show the minimum value (the lowest whisker), the first and third quartile (the box values), the maximum value (the upper whisker), the median (the line within the box), and the outliers (the small open circles).

highest counts occurred in October. In winter, Pigeon Guillemots were most abundant along the survey track closest to shore, with the highest concentrations southwest of James Island in the Sidney Channel IBA (Fig. 3D). Lower but consistent counts were observed from Ten Mile Point to the Victoria Harbour entrance in the Migratory Bird Sanctuary. In the summer, Pigeon Guillemots were most abundant off Bazan Bay in the northern section of our study area to Coal Island.

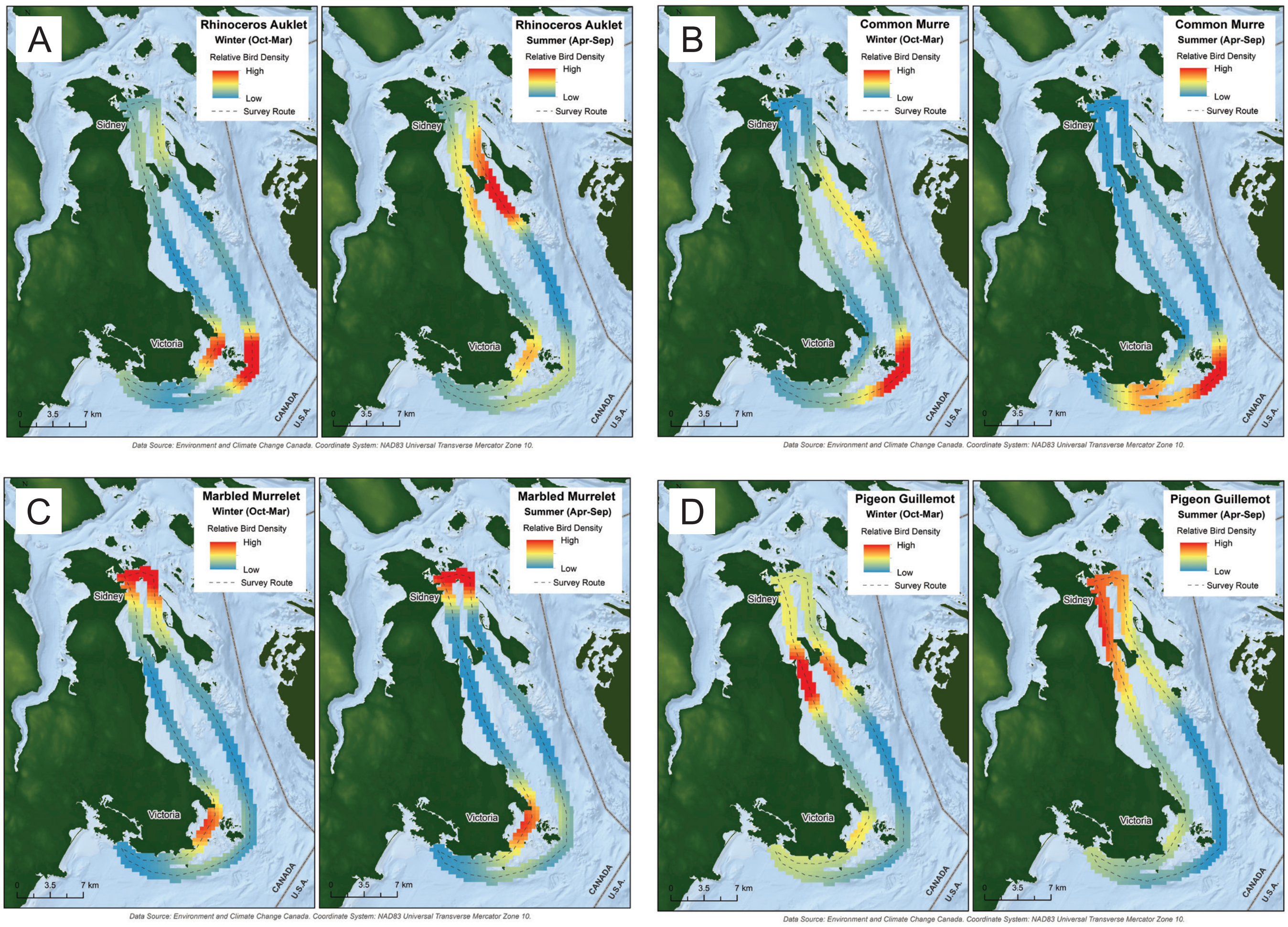
Ancient Murrelets were observed almost exclusively during winter, and they were often observed in numerous small groups with the highest tallies in December and January (Fig. 2E). In winter, Ancient Murrelets tended to be most abundant in the region between Coal and James islands. A secondary dominant area stretched along the entire inside curve of the survey track from the northern approach to Ten Mile Point and around to Discovery Island/Oak Bay Ecological Reserve. Almost no Ancient Murrelets were observed during summer. The red region of Fig. 3E represents a lone bird observed in July in one year and should not be considered a "hotspot."

Oiling threats from vessels

Intense tanker, cargo vessel, and passenger activity was observed close to or within our study region, primarily in the southern section (Fig. 4A), and this activity did not vary across seasons. Tugs and fishing vessel activity also showed high year-round intensity, with routes passing directly through our study area in the north and south (Fig. 4B). In contrast to other categories, there was large seasonal variation in motor and sailing vessel activity, with a large influx in summer months (Fig. 4C). The increase in summer traffic was particularly noticeable in the Sidney Channel IBA, which is close to many marinas as well as a terminal for the Washington State Ferry in Sidney (Appendix 2, available online).

DISCUSSION

The Haro Strait region around southern Vancouver Island has long been recognized for its importance to marine birds. The present study confirms this knowledge and provides a recent time series of year-round observations of alcids. For each alcid, we discuss



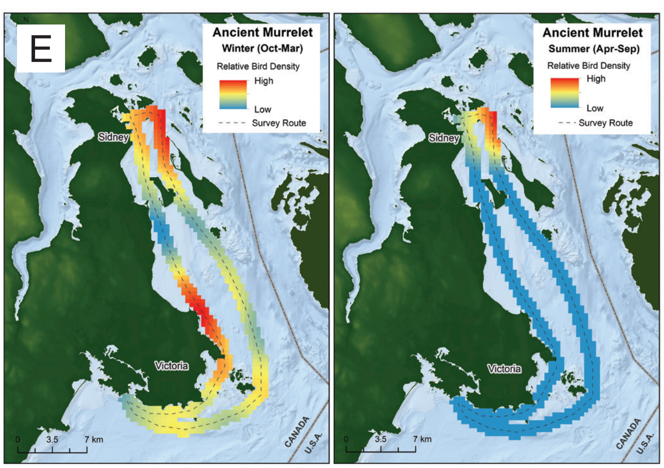


Fig. 3. Spatial patterns during winter (October–March, left panels) and summer (April–September, right panels) for (A) Rhinoceros Auklets *Cerorhinca monocerata*, (B) Common Murre *Uria aalge*, (C) Marbled Murrelet *Brachyramphus marmoratus*, (D) Pigeon Guillemot *Cepphus columba*, and (E) Ancient Murrelet *Synthliboramphus antiquus* in the study area of Juan de Fuca and Haro Strait, British Columbia, Canada. Surveys from all years are pooled and the KDEs (Kernel Density Estimation) are corrected for pooled survey effort. Note that the KDE colours are relative within a figure, but not between, so a detection of a few birds can appear to be an area of high concentration (e.g., Ancient Murrelets in summer).

the distinct seasonal and spatial patterns and link them to key prey species, their habitats, and physical processes that could contribute to bird hot spots.

Specifics about seabird species

Rhinoceros Auklet

This species showed a strong seasonal component with high numbers during spring/summer and low numbers in fall/winter. There are no major colonies in southern BC, but in neighboring Washington there is a large colony at Protection Island (36 145 pairs in 2008) and a small colony (1 548 breeding pairs) on Smith Island (Pearson *et al*. 2013). Breeding Rhinoceros Auklets fly up to 164 km from their colony in this region, although most foraging trips are less than 100 km in distance (Domalik 2018, Cunningham *et al*. 2018). It is presumed that the large numbers of Rhinoceros Auklets seen in spring and summer around southern Vancouver Island (Kenyon *et al*. 2009) are from the colonies in Washington, as Canadian waters are easily within their foraging range during

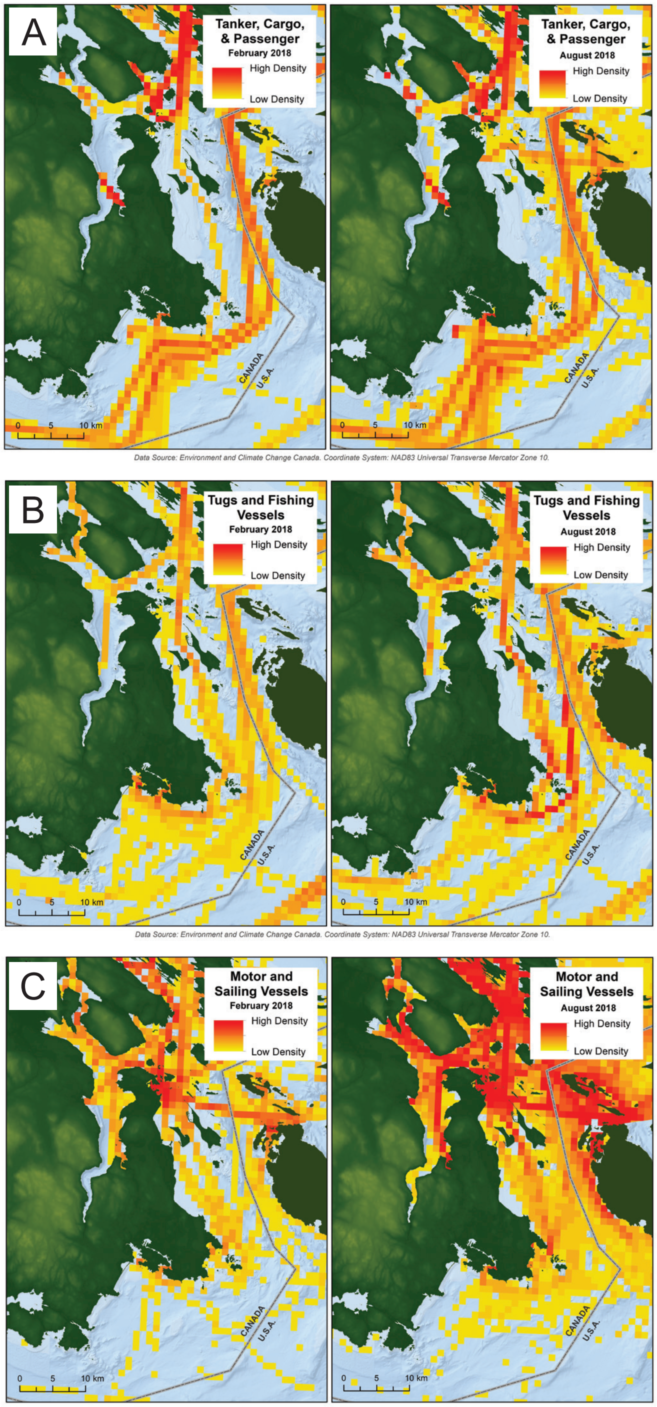


Fig. 4. Marine traffic rates in winter (February, left panel) and summer (August, right panel) for tanker, cargo, and passenger vessels (A), tugs and fishing vessels (B), and recreational motor and sailing vessels (C) in the study area of Juan de Fuca and Haro Strait, British Columbia, Canada.

breeding. Indeed, recent GPS tracking of chick rearing birds on Protection Island confirmed that breeding birds ventured into our study area (MOVEBANK 2023).

Rafts of hundreds to thousands of birds can form on the water during breeding (Kenyon *et al*. 2009); for instance, in summer 2019, an independent survey estimated 12 000 Rhinoceros Auklets in the Sidney Channel IBA (31 July 2019, Peter McCallister pers. obs). In stark contrast to summer, most Rhinoceros Auklets had left the study area by November 2019. The departure overlaps with an extended burying period of Pacific Sand Lance, during which time this species is buried in the sand both day and night whilst developing gonads and is therefore unavailable to birds as prey.

Common Murre

Murres showed a strong post-breeding influx into the Salish Sea in fall, likely from breeding colonies in Oregon and Washington (Hamel *et al*. 2008). In addition, during poor breeding years, failed breeders may enter the Salish Sea earlier (Hamel *et al*. 2008, Hamel *et al*. 2009). Common Murre wintered in the study region but were largely gone by March. In our study, Common Murre showed elevated densities in the southern region near Discovery Island where the waters from Juan de Fuca meet with those of Haro Strait and vertical and horizontal mixing is intense (Thomson 1981). Like Rhinoceros Auklet during summer, Common Murre are highly vulnerable to oil-spill contamination because they raft on the water in large groups and have relatively small wintering areas. These often overlap with regions of high vessel traffic densities, particularly within the Salish Sea (Thompson *et al*. 2003).

Marbled Murrelet

Marbled Murrelets were present year-round with low relative densities in every month (despite a few outliers between October and December). No evidence indicates that birds move into the relatively protected inner marine waters of the Salish Sea from more outer coastal environments during the non-breeding season. In nearby Puget Sound, a concurrent study (2012–2020) reported that non-breeding season densities were nearly the same or higher in some years than breeding season densities (Pearson *et al*. 2022).

During the breeding season, birds observed locally could be breeders from southern BC or the Olympic Peninsula, where tracking studies revealed use of waters in our study area (Lorenz *et al*. 2016). Observations of daily foraging behavior have shown that breeding Marbled Murrelet will return to the same place each day (Carter & Sealy 1990).

We found a hotspot in the northern section of the Sidney Channel IBA and another off Victoria. An additional hotspot for Marbled Murrelet just outside of our transect existed at the south end of Sidney Island (Peter McCallister pers. obs.). Marbled Murrelet tended to be found closer to shore than other alcids and also showed some segregation from Common Murres and Rhinoceros Auklets, as reported elsewhere (Ronconi & Burger 2011).

Pigeon Guillemot

Guillemots were present year-round, but the frequency of the highest counts swelled (two to five-fold) in late summer through to February. It is plausible that some of the non-breeding visitors could be seasonal migrants from breeding colonies in central California, as indicated by tracking studies of birds from the Farallon Islands (Johns & Warzybok 2022). Birds tended to be most abundant in the Sidney Channel IBA but also off Victoria (Oak Bay & Cadboro Bay). Previous counts of Pigeon Guillemot off Victoria showed higher abundance at tide phases with maximum current. In a channel with strong tidal flow the birds repeated upstream flights interspersed with downstream diving bouts (Holm & Burger 2002).

Ancient Murrelets

These murrelets were abundant winter visitors to the well-mixed waters of our study region off Victoria, similar to a historic study from 1979–1980 (Gaston *et al*. 1993).

It is interesting to note that in a tracking study of Ancient Murrelets from colonies on George and Hippa islands in Haida Gwaii, BC, none of the birds from those colonies were observed near Victoria, despite extensive dispersion (Gaston *et al*. 2015, 2017). It is plausible that the birds, which winter off Victoria, are from other colonies, and that wintering areas may be colony-specific with potentially limited overlap (e.g., Hipfner *et al*. 2020). Investigations of winter habitat use of seabirds can inform changes in population structure and reproductive success, aiding managers in determining potential causes and mechanisms of breeding failures (Johns *et al*. 2019). Below we examine the importance of prey species in our study region, and in particular, the importance of a key forage fish, the Pacific Sand Lance, within Haro Strait.

Key prey species

In this study, we observed that the Haro Strait region supports an important hotspot for seabirds, particularly in spring/summer. One reason for the seasonal increase in abundance of various seabirds in Haro Strait is likely the higher abundance and availability of major forage fish species such as Pacific Sand Lance. In fact, the importance of Haro Strait as a Pacific Sand Lance production area for predators is emphasized by the very high occurrence of Chinook *Oncorhynchus tshawytscha* and Coho *O. kisutch* salmon diets compared to other regions in the Strait of Georgia (Wesley Greentree unpubl. data; Robinson *et al*. 2023). The factors responsible for high production and occurrence of sand lance in Haro Strait are most likely related to the predominance of low silt, seabed burying habitat (Robinson *et al*. 2013, 2021), and the prevalence of highly suitable intertidal spawning habitats (Huard *et al*. 2021). Furthermore, Robinson *et al*. (2023) indicated that the relative body condition of sand lance remains high in the Haro Strait region during summer due to high local plankton production, supporting the attraction of this key forage fish to piscivorous seabirds and other marine predators.

Hotspots for Rhinoceros Auklet, Marbled Murrelet, and Pigeon Guilllemot in our survey area overlapped the subtidal burying habitat for sand lance identified in the Sidney Channel IBA (Robinson *et al*. 2021). During the day in the spring and summer, sand lance form schools in the water column while feeding on small zooplankton and, hence, are readily available to diving alcids, which often force fish to ball at the surface causing multispecies “feeding frenzies” (Grover & Olla 1983). In summer, juvenile Pacific Herring *Clupea pallassii* will also school in the study region, forming mixed species schools with sand lance in Sidney Channel (DFB unpubl. data; see also Hobson 1986). On nearby Protection Island, the nestling diet of Rhinoceros Auklet is predominantly sand lance with juvenile herring the second most important prey species (Wagner *et al*. 2023). In late summer and fall, Common Murre consume primarily herring, sand lance, and salmonids (Lance & Thompson 2005). Our study area also contains rockfish *Sebastes* spp. conservation areas (FOC 2016), which could benefit marine birds. Juvenile rockfish exhibit pelagic schooling behavior and high densities in kelp forests in summer (Hay *et al*. 1989).

A historic study of winter ecology and diet off Victoria (1978–1979) revealed that Ancient Murrelets preyed almost entirely on North Pacific Krill *Euphausia pacifica*, although juvenile herring was also taken in one year (Gaston *et al*. 1993). The authors observed that aggregations of Ancient Murrelets were frequently found in association with visible tidal rips and fronts, where prey can be concentrated and transported towards the surface by tidal upwelling. Feeding bouts were observed to be of short duration, suggesting that dives were shallow in comparison with the breeding season in Hecate Strait, BC. Birds’ mass increased during winter and reached a peak in January when guts contained the maximum number of prey organisms. These observations suggest that feeding intensity, or food availability, reaches a maximum in midwinter (Gaston *et al*. 1993) and, coupled with our study, highlight the major importance of the wintering region off Victoria for Ancient Murrelets.

Increases in shipping and likelihood of oiling interactions

Our study region is a focal point of marine vessel activity year-round on the approach to major urban areas on both sides of the Canada-USA international border. Virtually all cargo and tanker vessel traffic entering the Salish Sea enter through the Strait of Juan de Fuca. For tankers in 2017, 37% passed through our study area en route to oil transfer sites in Burnaby, while 63% went through US waters to refineries in Puget Sound, including the largest facility at Cherry Point (Department of Ecology State of Washington 2019). The Canadian route is expected to exhibit a significant increase in tanker traffic upon completion of the current expansion (twinning) of the Trans Mountain pipeline to Burnaby and Westridge Marine Terminal Expansion (https://www.transmountain.com/marine-safety). With these developments, tanker traffic is set to increase from approximately 30 to 50 tankers per year to over 400 (https://www.portvancouver.com/about-us/faq/petroleum-products-and-tanker-safety/). Currently, the Port of Vancouver is experiencing a throughput bottleneck and is ranked as one of the least efficient ports in the world for container ships, with a recent ranking of 368 out of 370 ports by the World Bank (2021). In addition to recent expansion of Port Vancouver Deltaport, cargo ship traffic will continue to increase with the expansion of the Delta Port Terminal 4, which is currently under review for impact assessment (Global Container Terminals Deltaport Expansion - Berth Four: https://www.iaac-aeic.gc.ca/050/evaluations/proj/81010?&culture=en-CA).

Large ferries and tugs operate year-round in the study region. Tugs may pull fuel barges to 27 potential oil transfer sites in the Salish Sea (10 in Canada, 17 in the USA; Susan Allen pers. comm.). Note that the largest acute oiling incident in BC history occurred after a bunker fuel oil spill in Washington moved northward from a punctured oil barge “Nestucca” in 1988, killing an estimated 56 000 birds on the outer coast (Ford *et al*. 1991, Bertram 2019).

In addition to the risks of acute and chronic oiling (e.g., O’Hara *et al*. 2006, 2009, Henkel *et al*. 2014, Fox *et al*. 2016) from vessels, our study area is adjacent to many marinas, ports, and terminals (see Appendix 2) that are also important sources of spills (Serra-Sogas 2012, 2014). Recreational vessel traffic from these locations shows a strong seasonal pattern with most activity in summer, particularly within the Sidney Channel IBA. Within our study site, numerous waste-water outfalls can also be sources of oils and other hydrocarbons as run off from roads and runways (e.g., Victoria International Airport). It is estimated that land-based sources (river and runoff) contribute approximately 60% of total oil pollution input into the seas globally (NRC 2003).

Although we focus specifically on oil pollution and alcid species that are particularly vulnerable to this form of pollution, vessel traffic can be used to indicate intensity levels for many threats including noise pollution (Pichegru *et al*. 2022), light attraction (vessel strikes, Montevecchi 2006), and disturbance/displacement (Fliessbach *et al*. 2019). We currently have ongoing projects investigating these threats and how they might impact marine birds.

CONCLUSIONS

Alcids are attracted in large numbers to our study area and are at risk from interactions with vessels, especially oiling year-round (see Infographic, Appendix 3, available online). Oiling risks to alcids and other seabirds will increase in step with the projected regional increases in vessel traffic. The alcids are particularly vulnerable to oiling because of their tendency to form large on-sea flocks and their foraging mode of pursuit diving, propelling themselves underwater with their wings. They need their plumage for insulation from the heat-sapping ocean (always much colder than alcid body temperature). Even small amounts of oil can be lethal because it reduces the insulative qualities of feathers (Stephenson 1997, Morandin & O'Hara 2010, King *et al*. 2021). Oiling is a long-standing threat to the biota of the Strait of Georgia, Puget Sound, and Juan de Fuca Strait (Speich & Thompson 1987, Mahaffy *et al*. 1994). This study provides a current baseline account of year-round oiling threats to alcids which can be used to gauge the expected impacts of future increases in vessel traffic.

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