Assessing the likelihood of non-indigenous species biofouling on vessel arrivals within the Exxon Valdez oil spill region

Final report

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Acronyms

CCR	California Code of Regulations
EVOS	Exxon Valdez oil spill
GT	gross tonnage
IMO	International Maritime Organization
km	kilometer
NBIC	National Ballast Information Clearinghouse
NIS	non-indigenous species
N_p	niche proportion
NVMC	National Vessel Movement Center
PWSRCAC	Prince William Sound Regional Citizens' Advisory Council
r^2	coefficient of determination
RoRo	roll-on roll-off
SD	standard deviation
SERC	Smithsonian Environmental Research Center

SOLAS	International Convention for the Safety of Life at Sea
USCG	United States Coast Guard
VIDA	Vessel Incidental Discharge Act
WSA	wetted surface area

Executive Summary

Biofouling on commercial shipping vessels constitutes a major vector by which marine non-indigenous species (NIS) are transported between coastal environments. Certain vessel characteristics and behaviors contribute to the likelihood of introducing biofouling NIS from vessel arrivals. This project (1) assesses the spatial and temporal patterns of vessel arrivals in the Exxon Valdez oil spill (EVOS) region between 2012 and 2022, and (2) quantifies the likelihood of NIS introduction and survival in for six commercial vessel groups (bulk carrier, container, passenger, tanker, roll-on roll-off (RoRo), and general cargo) based on four established and quantifiable biofouling risk factors.

Since 2012, nearly 700 commercial vessels arrived annually to ports in the EVOS region, driven predominantly by nearly 300 annual tanker arrivals to the Alyeska Pipeline Service Company's Valdez Marine Terminal. While tanker arrivals declined slightly over the study period, tanker traffic to Cook Inlet is expected to increase in the next few years from liquified natural gas imports. Outside of the anomalous COVID-19 pandemic from 2020-2021 when cruise ships were out of operation, passenger vessel traffic increased in the study period and is expected to continue this trend. Container ships arrived in comparable numbers as passenger vessels while few bulkers, general cargo vessels, and RoRos arrived to the region during the study period.

Arrivals were analyzed using four biofouling risk factors: wetted surface area (WSA) - vessel's quantifiable submerged fouling habitat, years since last dry dock, environmental distance between ports of call, and residency time in arrival port. An average of 10 kilometers^2 (km^2) of WSA arrived to the EVOS region each year of the study period – roughly three times the size of Central Park in New York City. Residency time in arrival port was less than 24 hours for most vessel arrivals in the study area. The top port connections for tankers were between Nikiski and Valdez and Port Angeles, Washington, and Valdez and Long Beach, California. Most arrivals to the EVOS region originated from ports in the Gulf of Alaska, followed closely by arrivals from the North American Pacific coastline. Some arrivals also came from ports in eastern Asia. Environmental distance, measured as the similarity of mean annual temperature and salinity between ports, was minimal for arrivals from the Gulf of Alaska and generally increased with geographic distance to a maximum for ports in eastern Asia. Most vessel arrivals for which data are available reported having been in dry dock within the last 5 years, in compliance with international regulations.

An assessment of these risk factors is combined with a review of best practices for hull maintenance, biofouling regulation, and recommendations to refine regional and local assessments of vessel biofouling, providing critical context for proactive management and

regional biosecurity at high latitudes. Additional recommendations for research, regulatory oversight, and industry engagement are also provided.

Introduction

Marine Non-indigenous Species

Changes in transportation networks, maritime shipping, and globalization over the past two centuries have increased the pace with which the anthropogenically-mediated spread of NIS occurs (Seebens et al., 2017). NIS can disrupt marine ecosystems by out-competing native species, changing species composition, and altering resource availability (Bax et al., 2003). These invasions can dominate habitats and threaten the survival of native populations, economies, and human well-being (Catford et al., 2018).

Sessile (fixed and immobile) organisms found on hard substrates, including tunicates, bivalves, sponges, bryozoans, and algae, are among the most prevalent documented marine invaders (G. Ruiz et al., 2009). Among sessile marine NIS, tunicates are the most common group (Lambert, 2007). These NIS filter feeders have been observed to replace native species and eventually dominate benthic communities; as seen in Sitka, Alaska, where colonies of the tunicate *Didemnum vexillum* in Whiting Harbor has been observed coating fishing gear and other marine infrastructure (Cohen *et al.* 2011).

Sessile NIS can be transported vast distances numerous ways, including as juvenile zooplankton discharged in ballast water of ships or as adult forms attached to vessel hulls and niche areas such as rudders, propellers, and sea chests or to aquaculture equipment. Vessels take on coastal seawater as ballast water to offset the weight of delivered cargo, often unintentionally transporting large volumes of coastal organisms between ports. In contrast, biofouling refers to the process by which organisms attach to or occupy submerged parts of a vessel and can include both sessile and mobile fauna of various sizes. Biofouling has long been considered a major vector for NIS introduction and is deemed responsible for the largest share of historical introductions of marine NIS in San Francisco Bay (Bax et al., 2003).

Biofouling Management & Policy

Recently, rigorous management requirements have been implemented for ballast water by the International Maritime Organization (IMO), United States, and other regulatory entities, yet similar requirements for biofouling are lacking in most places. Notable exceptions include New Zealand and Australia where biosecurity is a top concern and stringent regulations, such as proof of hull cleaning within 30-days of arrival, have been implemented since 2018 (New Zealand Ministry for Primary Industries, n.d.).

Through the International Convention for the Safety of Life at Sea (SOLAS), the IMO requires active commercial vessels to drydock for hull cleaning and other maintenance every five years with an intermittent underway survey in lieu of drydocking. However, some vessels take additional biofouling precautions at more frequent intervals. More proactive management for biofouling can include in-water cleaning by divers or robots between dry-dock cleanings. Biofouling is also managed by antifouling paints and coatings applied to ship hulls. There are various types of antifouling treatments and these coatings must balance effectiveness with environmental impacts.

Regional Context

The distribution of marine NIS varies latitudinally. Outside of the tropics where low rates of NIS are attributed to high biotic resistance, the distribution of NIS align with latitudinal trends in species richness and geographic range sizes (Sax, 2001). Rates of marine NIS are high in the temperate zones and decrease at higher latitudes towards the polar regions (de Rivera *et al.*, 2011). While a relatively low number of established marine NIS have been documented at high latitudes, some high latitude locations receive large volumes of vessel traffic and associated propagule pressure (the number of individuals released and the frequency of release), thereby increasing the risk of marine NIS establishment (Lo et al., 2012). Despite this increased risk, a combination of limitations in dispersal mechanisms, abiotic resistance (e.g., salinity, temperature), or biotic resistance (e.g., predators) currently limit NIS from establishing and spreading in these areas. However, the compounding impacts of climate change altering the marine environment and vessel traffic patterns, such as increased shipping in the Arctic, pose a potential increase in the risk of marine NIS establishment at high latitudes (Mahanes & Sorte, 2019) (Chan et al., 2013).

Given its high latitude and relatively low anthropogenic disturbances, Alaska has relatively few established marine NIS (<15 species, Fofonoff et al., 2018). Despite this low number, much of the commercial vessel traffic to Alaska comes from more heavily invaded ports, such as San Francisco Bay with over 300 established NIS (G. M. Ruiz et al., 2015). Many established NIS on the west coast of North America have potential ranges that are much larger than their current extent, encompassing significant reaches of Alaska's coastline (de Rivera et al. 2011, Ruiz, unpublished data). For example, the barnacle *Amphibalanus improvisus*, the crab *Carcinus maenas*, the snail *Littorina saxatilis*, and the tunicate *Styela clava* have a projected suitable habitat range that encompasses considerable sections of Alaska's coastline (de Rivera *et al.*, 2011). This habitat compatibility suggests that limitations in dispersal mechanisms, rather than biotic or abiotic factors, could currently be preventing the establishment of many NIS species in Alaska. Consequently, focal points for early detection of marine NIS in Alaska are regions with relatively high abundance of vessel traffic engaged in coastwise and overseas travel. In addition, warming water and air temperatures also have the potential to make coastal Alaska increasingly hospitable to NIS that are currently thermally restricted from establishing in higher latitudes (Mahanes & Sorte, 2019), further increasing the importance of early detection protocols in areas of high ship traffic.

Coupled with increasing vessel traffic from more heavily-invaded regions of the North American Pacific coast and climate-induced changes in ocean conditions (de Rivera et al. 2011, Mahanes & Sorte 2019), Alaska faces an increasing risk of novel marine invasions. European green crab (*Carcinus maenas*), a recent NIS arrival to Alaska, was first detected on Annette Islands Reserve in southern southeast Alaska in 2022, and has since been observed in multiple places in southeast Alaska (NOAA, 2022). In southcentral Alaska, the EVOS region faces particular risks from marine NIS. Not only does the EVOS region receive considerable commercial vessel traffic, but also, environmental disturbances, such as oil spills, have been shown to affect invasion resistance from native species (G. M. Ruiz et al., 2000).

EVOS Region Analysis

Since the Prince William Sound Regional Citizens’ Advisory Council (PWSRCAC) last funded a research effort to characterize risk associated with vessel fouling and NIS in Prince William Sound (Cordell and Sosik 2009), novel and data-driven methodologies to characterize risk from NIS biofouling on vessel arrivals have been developed. Quantifying total WSA of a vessel, the submerged surface area of the hull and niche spaces, functions as a quantitative representation of habitat availability to biofouling NIS (Ceballos-Osuna et al., 2021). Niche areas, such as sea chests, propellers, and thruster tunnels, are features of the hull with increased surface area and reduced drag during transit, resulting in greater accumulation of biofouling (Moser, 2017). In a pioneering work, Moser (2015) quantified total WSA for the global commercial shipping fleet by calculating the relationship between WSA and vessel tonnage using naval architecture to account for the proclivity of biofouling on the submerged surfaces of commercial vessels.

Calculating WSA provides a proxy for potential propagule pressure – a measure of how many organisms are introduced to a specific place and time - to facilitate NIS invasion. Consequently, quantifying the WSA of vessel traffic is a foundational step to understanding the potential introduction of biofouling-based NIS to areas of interest (Ceballos-Osuna et al., 2021). Miller *et al*. (2018) combined WSA calculations and information on vessel arrivals and previous ports of call to profile potential sources of biofouling for the contiguous United States.

In addition to analyzing WSA, other arrival characteristics affect the likelihood of introducing marine NIS from biofouling. Since the likelihood of hull fouling organisms having the opportunity to spawn or reproduce within an arrival port increases with the time spent in port, analyzing residency time of arrivals furthers understanding of introduction potential. Assessing the environmental distance between the arrival port and last port of call as a measure of abiotic similarity and physiological suitability for biofouling organisms provides an indication of the survival potential for any NIS introduced into a new environment. A smaller environmental distance between port calls indicates higher environmental similarity and a potentially greater opportunity for NIS survival. Date of last dry dock can also be a useful data point, providing an indication of opportunity for hull fouling growth on a vessel over time, which may also affect the likelihood of introducing marine NIS. The more recently a vessel was cleaned the less opportunity for hull fouling growth on the vessel and the fewer potential NIS that could be introduced to a new environment.

Building on existing research and using publicly available vessel arrival databases, this project quantifies the likelihood of NIS introduction and survival in the EVOS region for six commercial vessel groups (bulk carrier, container, passenger, tanker, RoRo, and general cargo) between 2012 and 2022. Likelihood of biofouling on commercial vessels is assessed using the variability among the following risk factors: total WSA including niche areas, environmental similarity between ports of call, residency time in arrival port, and years since last dry dock. An assessment of these risk factors is combined with a review of best practices for hull maintenance, biofouling regulation, and recommendations to refine regional and local assessments of vessel biofouling.

Given the region’s large coastline, numerous coastal communities dependent on marine economies, expanding commercial shipping activity, and warming climate, analyzing these risk factors is a foundational step towards risk assessment of biofouling NIS arrivals. Profiling risk from a regional perspective with a focus on port and vessel type rather than by individual vessel arrival is prudent in places with limited resources to prioritize locations for piloting additional management practices and implementing early detection efforts. These findings provide important and timely information on port-specific NIS arrival potential to inform proactive management priorities and provide critical context for regional biosecurity assessments.

Methods

Data Sources

Data on vessel arrivals to the EVOS region, from 2012 through 2022, were obtained from National Ballast Information Clearinghouse (NBIC) and National Vessel Movement Center (NVMC) as part of a larger statewide analysis. NBIC is jointly managed by Smithsonian Environmental Research Center (SERC) and the United States Coast Guard (USCG), and NVMC is managed by the USCG. Nearly all commercial vessels that operate in U.S. waters must submit a Ballast Water Management Reporting Form to NBIC, which documents their arrival to a U.S. port. Reporting compliance is estimated to be 94% (M. Minton, personal communication). Applicable data include vessel name, IMO number, owner, vessel type, gross tonnage (GT), arrival date, arrival port, last port of call, next port of call, transit type (i.e., coastwise or overseas), and date of last dry dock. The exclusive economic zone (200 nautical miles) marks the boundary between “coastwise” and “overseas” vessel transit types. Similarly, NVMC records all notices of arrival and departure information for vessels entering U.S. ports and facilities except for vessels under 300 GT and certain tugs operating without hazardous materials on board, which are exempt from NVMC reporting. For this project, relevant information from the two data sources has been integrated to ensure the most comprehensive dataset of vessel arrivals available for analysis.

The integrated NBIC and NVMC dataset is informative to analyze trends in vessel behavior in the EVOS region. This information was analyzed to consider changes in vessel arrivals over time for certain vessel types and arrival ports, along with the relative makeup of vessel arrivals by factors that include last port of call, seasonality, and relative size classes.

Although the EVOS region has arrivals for other vessel types – namely fishing vessels, ferries, tugs, barges, and recreational vessels – this analysis is limited to the six commercial vessel types identified due to the availability of information for arrival validation and calculating risk factors.

Risk Factors

Wetted Surface Area

WSA, which includes exposed hull and niche areas, was calculated for documented commercial vessels arrivals in the dataset following Ceballos-Osuna et al. (2021), Miller et al. (2018), and Moser et al. (2015). WSA is estimated using a vessel’s GT, a widely available metric of vessel’s internal volume. The relationship between WSA and GT is calculated for each vessel type using established linear regressions with coefficients of determination (r^2) greater than 0.9 (Ceballos-Osuna et al., 2021). An individual vessel’s WSA is then multiplied by a type-specific niche proportion (N_p), typically ranging from 0.07 to 0.09 except for passenger vessels which have a higher N_p (0.27). The sum of these values yields the total WSA per vessel and represents area for biofouling relative to their GT and type (Moser, 2017). WSA equations were readily available for the six commercial vessel types identified for this study (Ceballos-Osuna et al., 2021).

Environmental Distance

Environmental distance is assessed for each arrival using a method of calculating environmental similarity between the ecoregion of the last port of call and the ecoregion of the arrival port. Ecoregions were identified based on a global system for classifying coastal environments into areas of general similarity based on oceanographic and biological characteristics (Spalding, 2007). For this analysis, environmental distances are based on Euclidian distances calculated between ecoregions using monthly minimum, maximum, and average salinity and temperature measurements at three depths based on data in the World Ocean Atlas (Tzeng, 2022). Smaller environmental distance values suggest greater environmental similarity between ports and consequently increased likelihood of NIS survival. Environmental distances between ecoregions ranges from 0-110 globally.

Residency Time

Residency time is the reported amount of time a vessel spends in arrival port, ranging from less than one day to multiple days, or on rare occasions weeks. Residency time is available for NVMC arrivals (about two-thirds of the dataset).

Years Since Dry Dock

Years since last dry dock for individual vessels is available for a subset of the data – arrivals from 2020 to 2022 in the NBIC database. In 2020, NBIC added date of last dry dock to its reporting requirements. Since the IMO requires commercial vessels go into dry dock every five years in SOLAS, the expected range of years since last dry dock in this data set is from less than one year to five years.

Risk Assessment

For this analysis, these risk factors are considered as comparative metrics between vessel types and ports to assess how tankers compare to other vessel arrivals. These risk factors are also assessed to identify priority areas for further research and management recommendations.

Results

Descriptive Analysis

Arrivals per Year

A total of 7,547 vessels arrived to ports in the EVOS region between 2012 to 2022, to 33 different ports, averaging nearly 700 arrivals each year. Vessel traffic to the region was dominated by tanker arrivals (461 mean annual arrivals), followed by passenger vessels (111 mean annual arrivals) and container vessels (81 mean annual arrivals, Figure 1). There were less than 20 mean annual arrivals for bulkers and general cargo vessels and only three RoRo arrivals throughout the study period. Most vessel types had modest variation in vessel arrivals year over year, but passenger vessels dramatically declined during the COVID-19 pandemic in 2020 and 2021. Outside of those years, passenger vessel arrivals gradually increased over the study period.

Arrival Histories

Last port of call was available for all vessel arrivals. Most vessel traffic to the EVOS region arrived from ports in the North Pacific – coming from ports within Alaska, along the North American Pacific coastline, and from East Asia (Figure 2). Tankers traveled within the EVOS region between Valdez and Nikiski, and also arrived from ports with oil and gas refineries along the North American Pacific coastline (Table 1). Key port connections within the EVOS region for tanker arrivals were Nikiski, Valdez, and Homer, with the most arrivals attributed to tankers arriving in Nikiski from Valdez (488 arrivals during the study period). Tankers arriving to the EVOS region outside of Alaska came from refineries in Washington (Port Angeles and Anacortes) and California (Long Beach and San Francisco). Far fewer tanker arrivals to the EVOS region came from ports outside of the North American Pacific coastline. The top overseas tanker port connections were attributed to Valdez-bound arrivals from Singapore (28 arrivals) and Onsan, South Korea (25 total arrivals).

The most common last port call connection for non-tanker arrivals were container ships that arrived in Kodiak from Anchorage (744 total arrivals, Table 2). Most passenger vessels arriving to the EVOS region traveled between ports in Alaska with cruise ship terminals, namely arrivals to Whittier and Seward from Skagway, and Sitka in Southeast Alaska. Few vessels arrived to the EVOS region from overseas with some bulker arrivals to the timber export port in Afognak from Taiwan and South Korea, and a few passenger vessels that arrived to Japan from Kodiak (9 total arrivals).

Tanker Arrivals

As the most common vessel arrival, variation and trends in tanker arrivals are of particular importance. With an average of 461 tanker arrivals each year, tanker traffic declined 3.1% annually over the study period from 530 arrivals in 2012, to 366 arrivals in 2022 (Figure 3). While daily tanker arrivals were relatively consistent throughout each year of the study period, average daily arrivals declined from 1.9 tankers per day in 2012, to 1.5 tankers per day in 2022 (Figure 4).

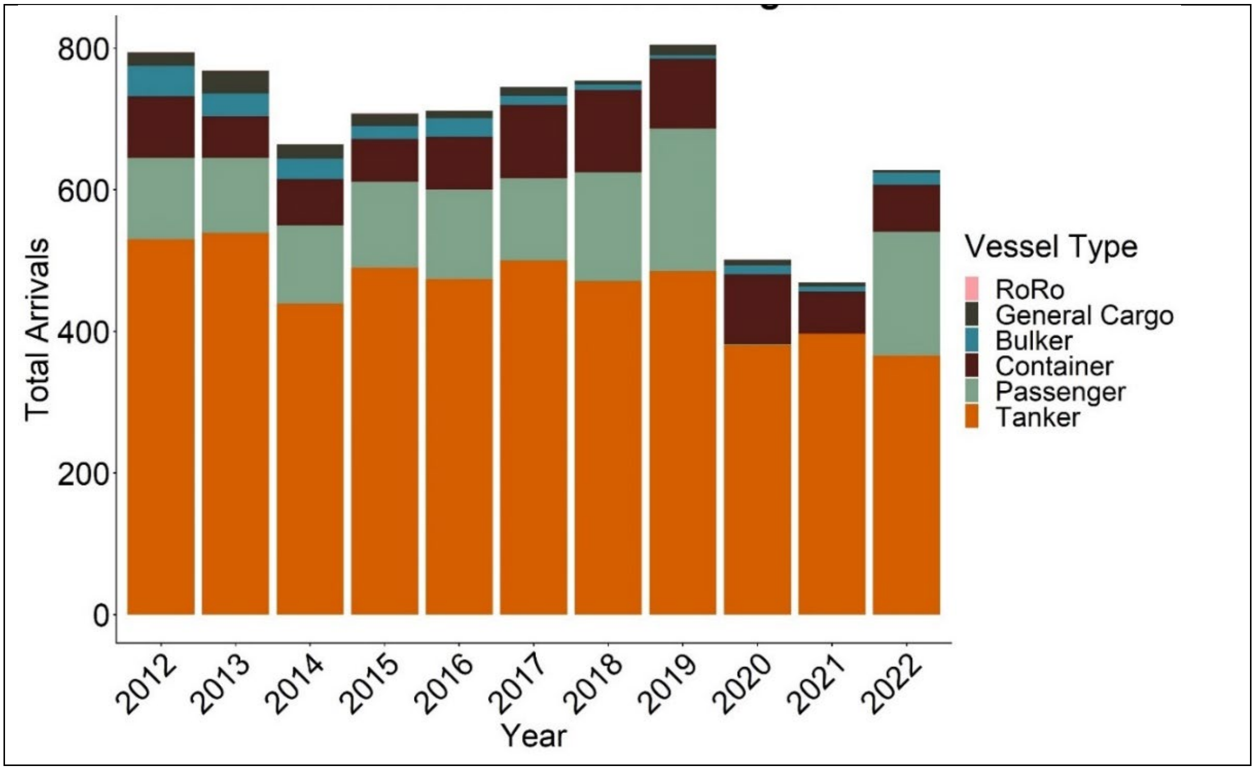

Figure 1. Total commercial vessel arrivals to the EVOS region 2012-2022.

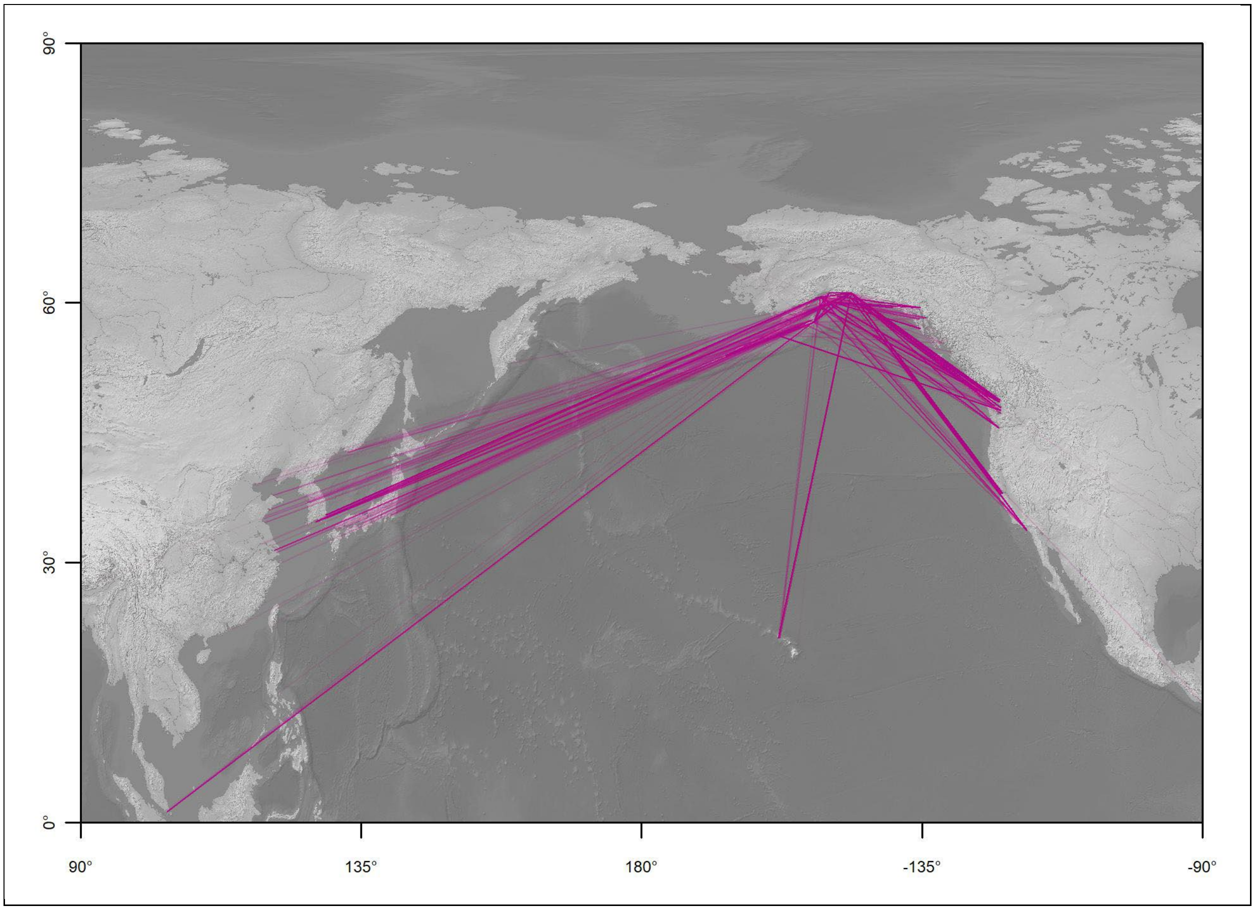

Figure 2. Port connections for commercial vessel arrivals the EVOS region 2012-2022.

Table 1. Top port connections for tanker arrivals to the EVOS region 2012-2022.

Arrival Port	Last Port of Call	Vessel Type	Transit Type*	Arrivals
Nikiski	Valdez, AK	Tanker	Coastwise	488
Valdez	Port Angeles, WA	Tanker	Coastwise	443
Valdez	Nikiski, AK	Tanker	Coastwise	412
Valdez	Long Beach, CA	Tanker	Coastwise	359
Homer	Valdez, AK	Tanker	Coastwise	279
Valdez	Anacortes, WA	Tanker	Coastwise	278
Valdez	San Francisco, CA	Tanker	Coastwise	278
Valdez	Bellingham, WA	Tanker	Coastwise	219
Valdez	Puget Sound, WA	Tanker	Coastwise	190
Valdez	Benicia, CA	Tanker	Coastwise	182
Valdez	Singapore	Tanker	Overseas	28
Nikiski	Onsan, South Korea	Tanker	Overseas	25

*Transit Type: coastwise transit includes all vessel arrivals from the North American Pacific coastline and overseas transit includes all vessel arrivals from outside the North American Pacific coastline.

Table 2. Top port connections for non-tanker arrivals to the EVOS region 2012-2022.

Arrival Port	Last Port of Call	Vessel Type	Transit Type	Arrivals
Kodiak	Anchorage, AK	Container	Coastwise	744
Whittier	Skagway, AK	Passenger	Coastwise	369
Seward	Skagway, AK	Passenger	Coastwise	309
Seward	Sitka, AK	Passenger	Coastwise	121
Chignik	Seattle, AK	Container	Coastwise	76
Chignik	Seattle, AK	General Cargo	Coastwise	66
Kodiak	Homer, AK	Passenger	Coastwise	47
Homer	Anchorage, AK	Passenger	Coastwise	43
Seward	Yakutat, AK	Passenger	Coastwise	30
Afognak	Taicang, Taiwan	Bulker	Overseas	20
Afognak	Busan, South Korea	Bulker	Overseas	17
Kodiak	Kushiro, Japan	Passenger	Overseas	9

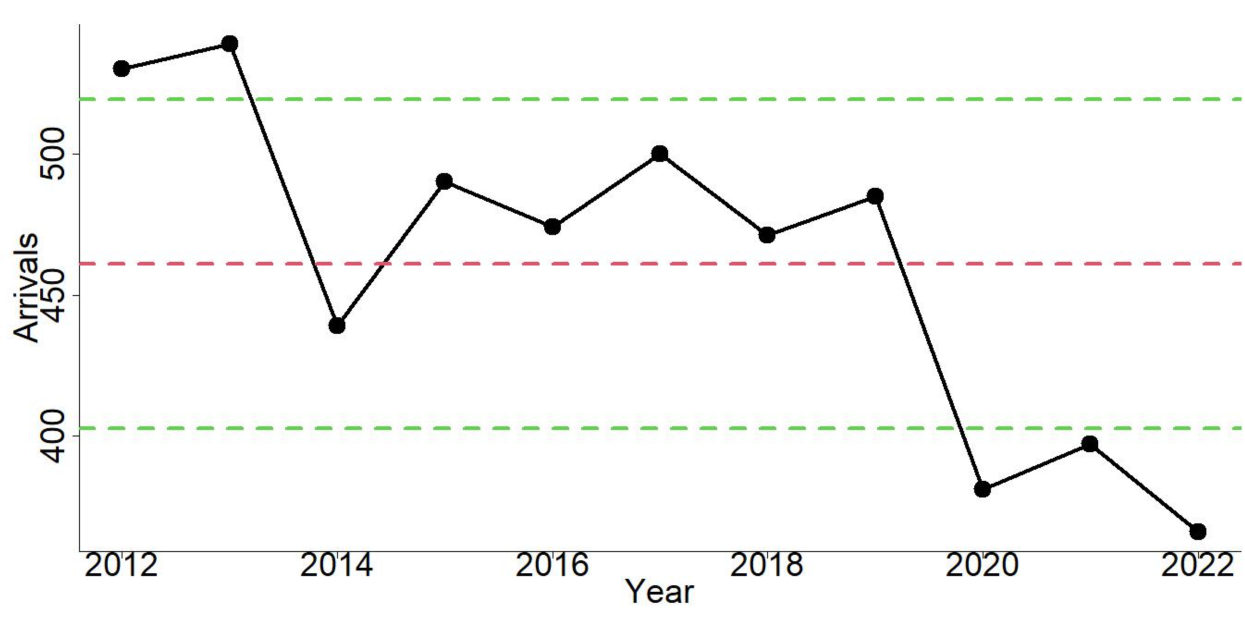

Figure 3. Average tanker arrivals to the EVOS region 2012-2022.

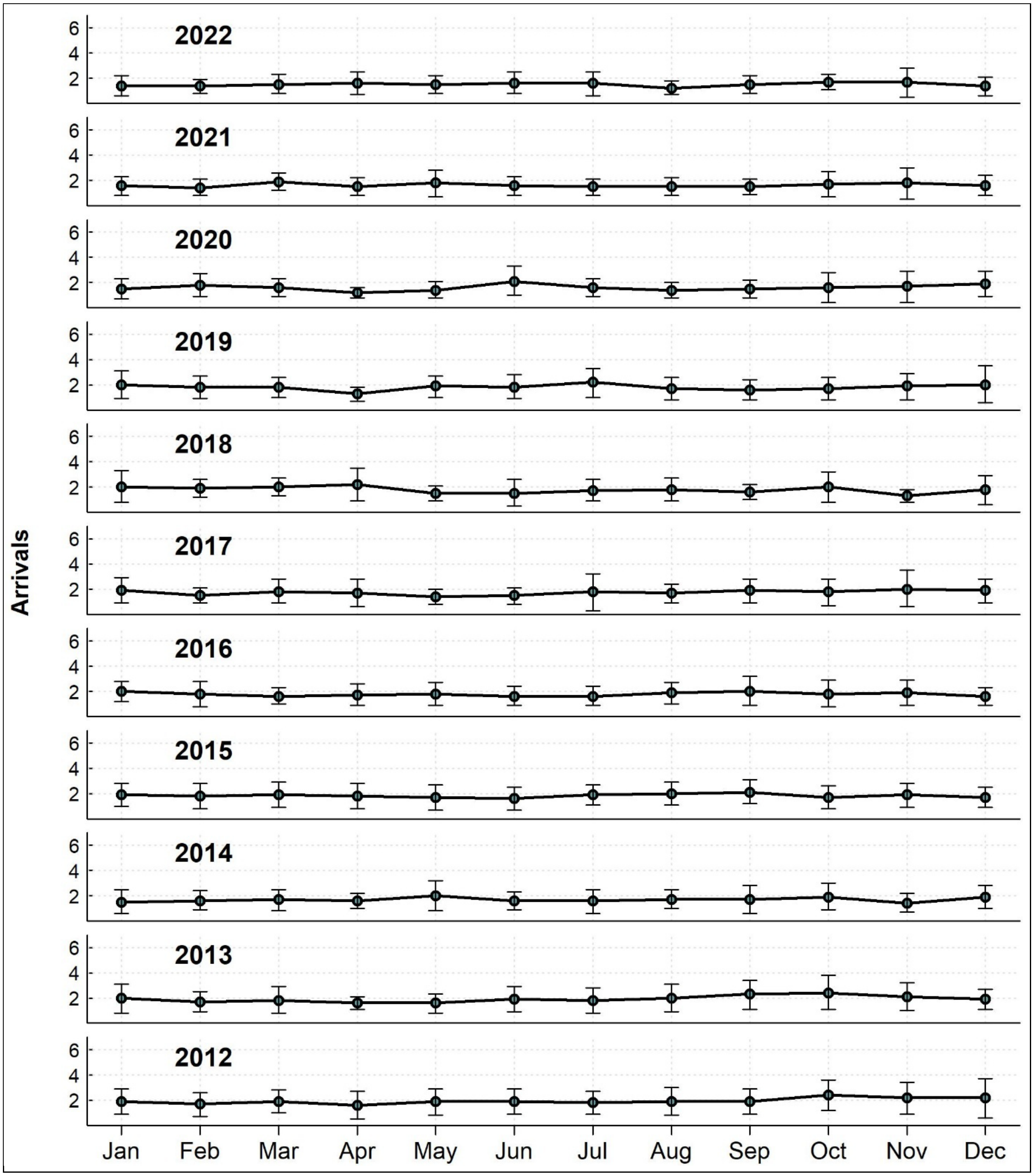

Figure 4. Monthly mean daily tanker arrivals to the EVOS region 2012-2022.

Wetted Surface Area

An average of 9.4 km^2 of WSA arrived to the EVOS region during the study period – roughly three times the size of Central Park in New York City (Figure 5). A majority of WSA is attributed to tanker vessel arrivals, followed by passenger vessels and container ships. There was little WSA attributed to passenger vessel arrivals in 2020 and 2021. Similar to their overall arrival numbers, the volume of WSA arriving from tanker vessels declined over the study period.

Valdez received more than half of all WSA in the EVOS region, averaging 5.6 km^2 each year (Figure 6). Prominent cruise ship terminal ports of Seward, Whittier, and Homer received considerable WSA outside of notable declines during the COVID-19 pandemic in 2020 and 2021. Other ports with comparable WSA and arrivals to cruise ship ports were Nikiski, Kodiak, and Knowles Head. Afognak, Drift River, and Cape Hinchinbrook[1] had small but measurable WSA arrivals each year.

The distribution of WSA per arrival varies by vessel type, reflecting different sizes of vessels as vessels with a higher GT have a larger WSA (Figure 7). The largest vessels were tanker and passenger vessels that had the largest WSA arrivals, indicating more available biofouling habitat than other vessel types (WSA >20,000 m^2). However, there were more midsize tankers than passenger vessels (20,000 m^2 > WSA > 10,000 m^2). Most container ships and bulkers are also midsize vessels with a moderate amount of WSA. General cargo and RoRo arrivals tended be smaller in size with less WSA and a smaller amount of available biofouling habitat than other vessel types (WSA <5,000 m^2).

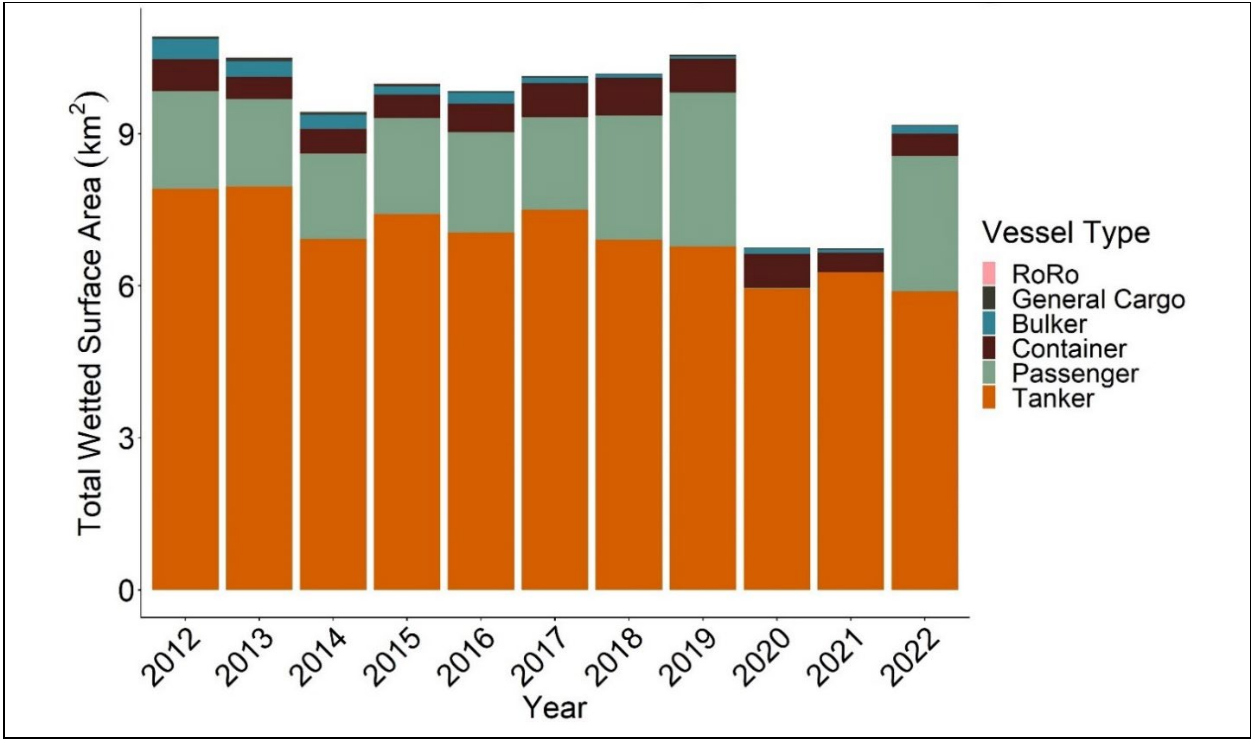

Figure 5. WSA from commercial vessels arrivals to the EVOS region 2012-2022.

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[1] Some arrival records identify anchorage locations and marine landmarks as their arrival port, such as Cape Hinchinbrook.

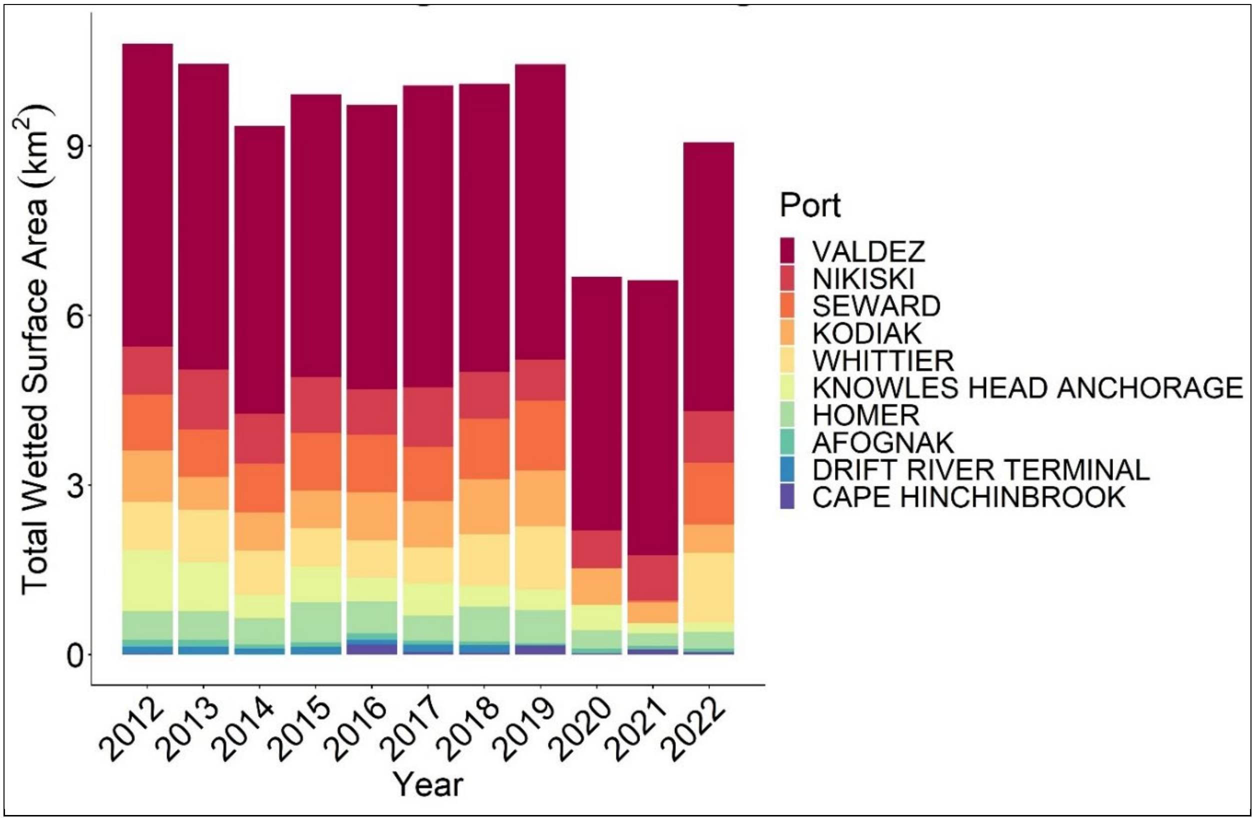

Figure 6. WSA from commercial vessel arrivals received at top 10 ports in the EVOS region 2012-2022

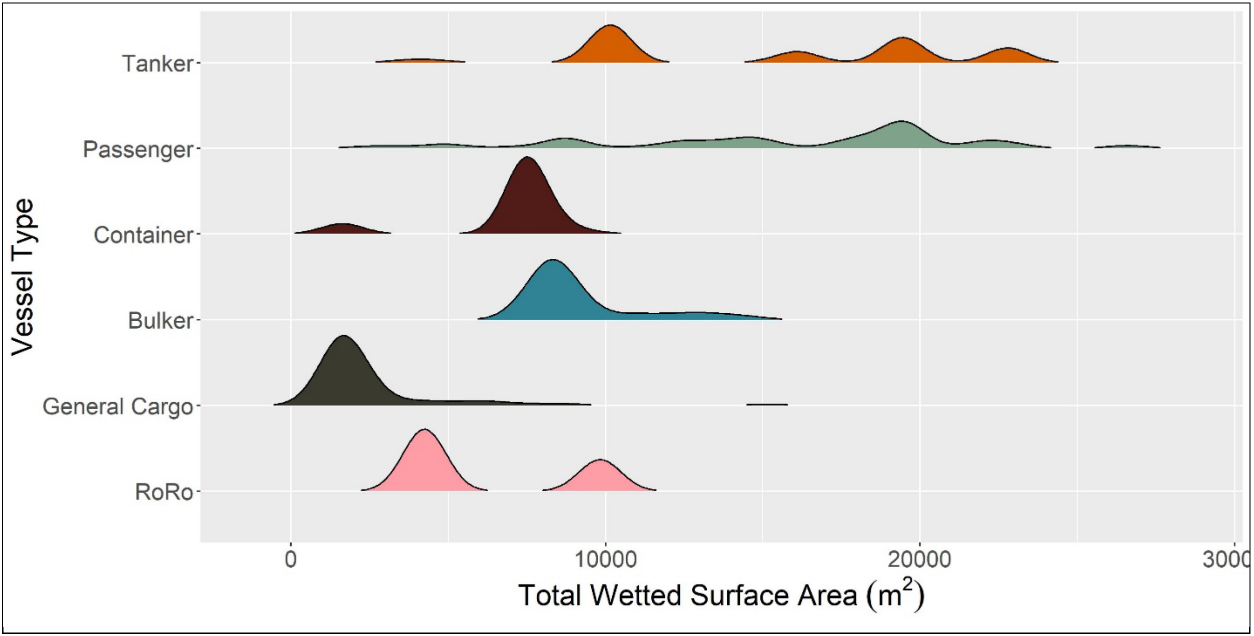

Figure 7. Distributions of WSA by vessel type for the EVOS region 2012-2022.

Residency Time

With the exception of bulkers, arrivals to the EVOS region had an average residency time of less than two days for most vessel types (Figure 8). Container and general cargo ships spent the least time in arrival ports. While passenger vessels and container ships kept port visits to less than two days, some tankers stayed for more than two days and even longer than a week. Bulkers spent multiple days in port with most staying 5-10 days.

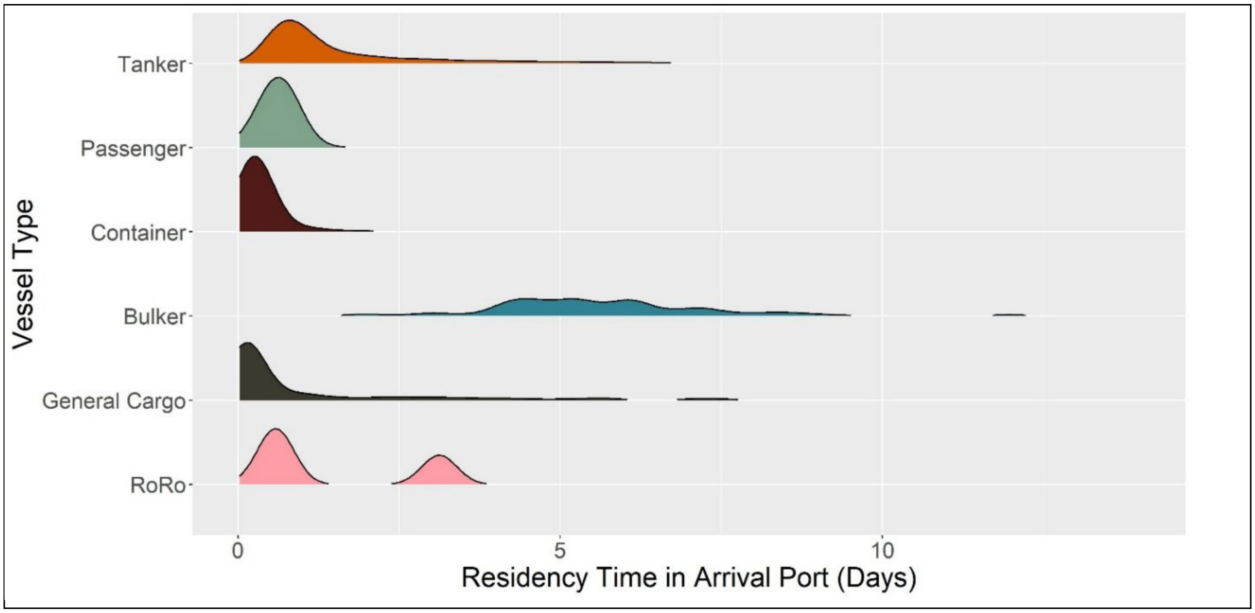

Figure 8. Distributions of residency time by vessel type for the EVOS region 2012-2022.

Environmental Distance

There are six marine ecoregions in Alaska – southeast Alaska (known as the North American Pacific Fjordland), Gulf of Alaska, Aleutian Islands, Eastern Bering Sea, Bering Sea, and Chukchi Sea. Vessel arrivals to the EVOS region came from last ports of call from 23 different marine ecoregions. All of the arrival ports within the EVOS region and many of the last ports of call were located within the Gulf of Alaska ecoregion (Figure 9).

Tanker, passenger vessel, and container ship voyages departing from and arriving to ports within Gulf of Alaska had an environmental distance score of zero (Figure 10). The mode centered over zero for tankers reflects travel between Valdez and Nikiski, and the mode centered over zero for container ships reflects vessels arriving in Kodiak from Anchorage. Most passenger vessels had a small environmental distance, arriving from Skagway and Sitka in the adjacent southeast Alaska ecoregion. Tankers, container ships, bulkers, and general cargo ships arrivals with an environmental distance of 10-20 indicate vessel arrivals from Washington, California, or other places on the North American Pacific Coastline.

Tankers, bulkers, and general cargo ships arrivals with an environmental distance of 35-45 reflect overseas arrivals from East Asia.

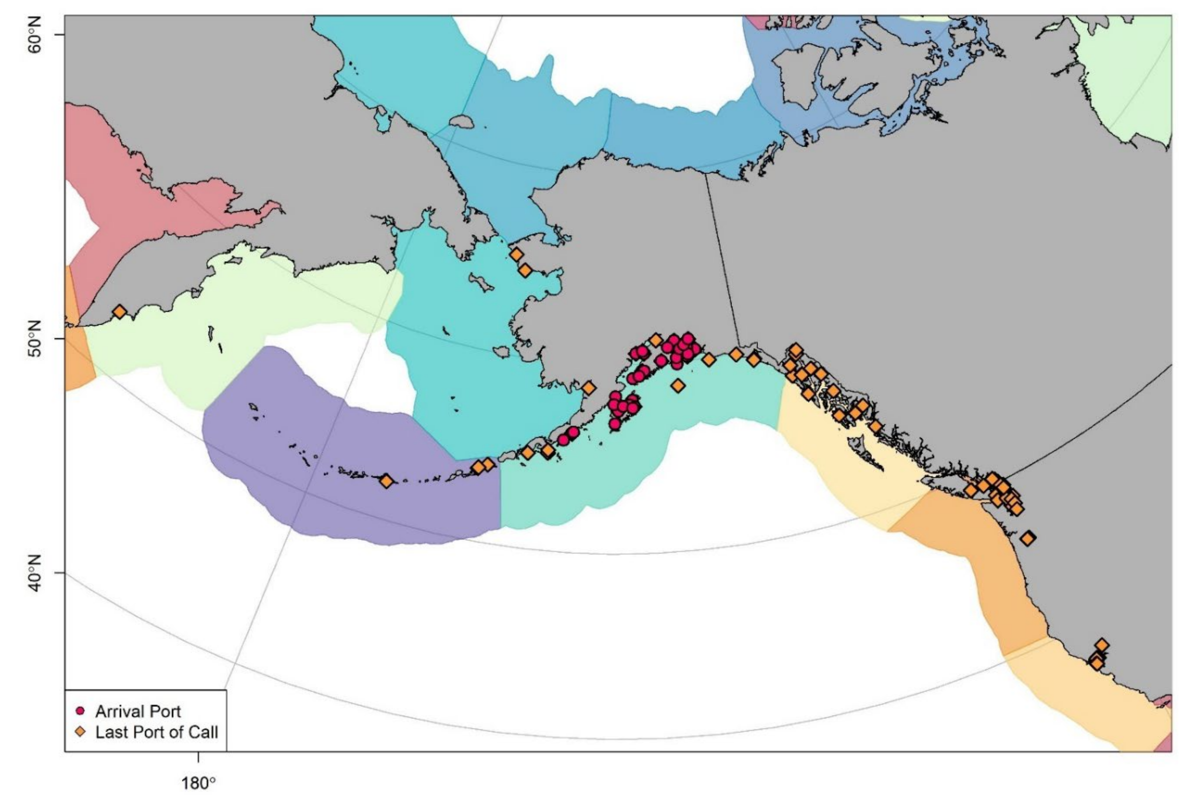

Figure 9. Arrival ports, last ports of call, and marine ecoregion boundaries for commercial vessel arrivals the EVOS region 2012-2022.

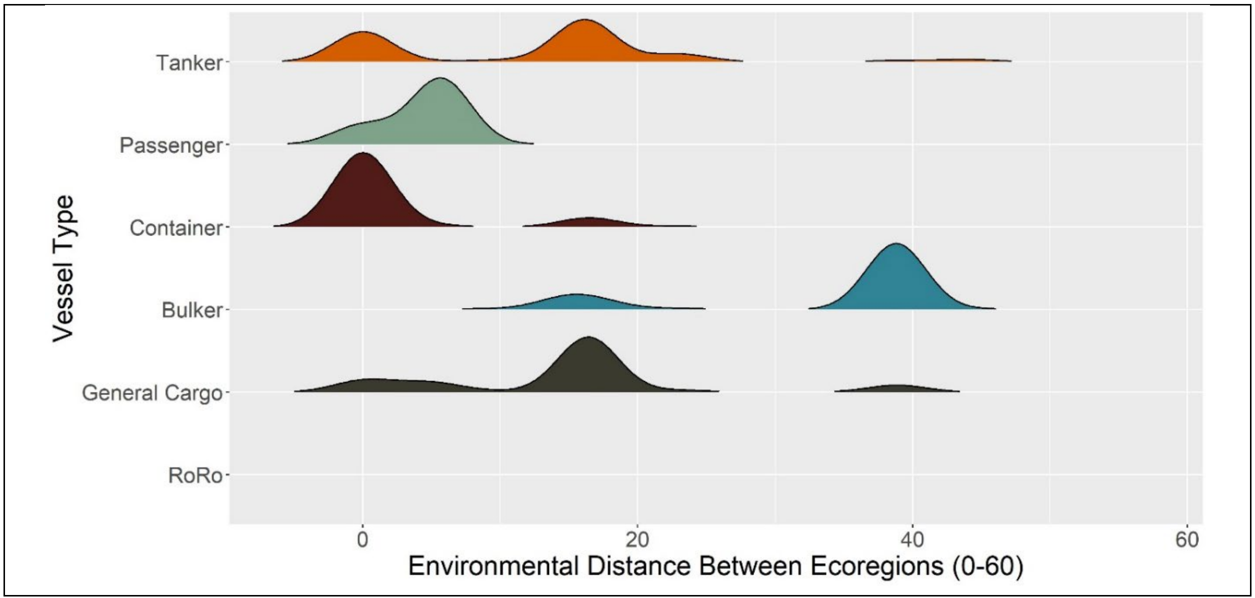

Figure 10. Distributions of environmental distance between ecoregions by vessel type for the EVOS region 2012-2022.

Years Since Dry Dock

For the subset of data that date of last dry dock is available (2020-2022 NBIC arrivals), most vessel arrivals to the EVOS region were cleaned in dry dock within three years of each arrival (Figure 11). Tankers had a wider distribution of years since last dry dock than other vessel types with some arrivals from vessels having gone four or five years since their last dry dock. Passenger vessel arrivals were mostly last in dry dock within two years of their arrivals.

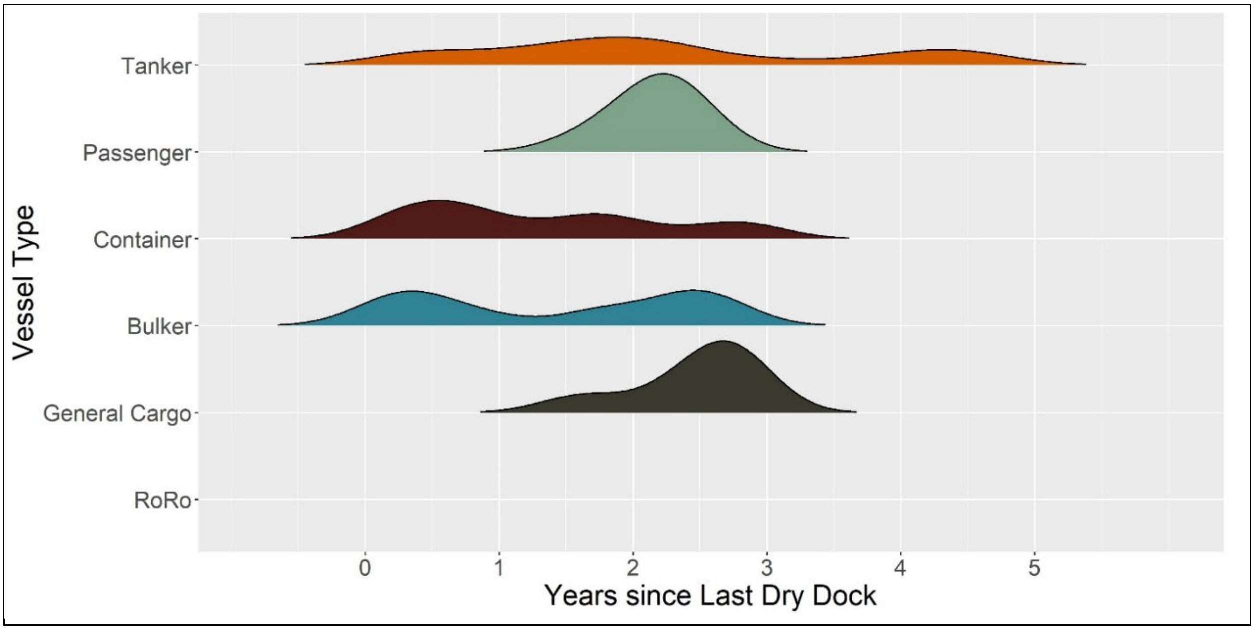

Figure 11. Distributions of years since last dry dock by vessel type for the EVOS region 2012-2022.

Risk assessment

Table 3 provides a summary of biofouling risk factors for vessel arrivals to the EVOS region with total arrivals, mean annual arrivals, and the mean per arrival for each risk factor: WSA, residency time, environmental distance, and years since last dry dock.

Table 3. Vessel biofouling risk factors summary for commercial vessel arrivals to the EVOS region 2012-2022.

Vessel Type	Total Arrivals	Mean Annual Arrivals	Mean WSA per Arrival (m^2 ± SD*)	Mean Residency Time per Arrival (Days ± SD*)	Mean Environmental Distance per Arrival (0-60 ± SD*)	Mean Years since Last Dry Dock per Arrival (Years ± SD*)
Tanker	5,072	461	15,092 (± 5,469)	1.9 (± 2.8)	12.0 (± 10.4)	2.3 (± 1.3)
Passenger	1,226	111	15,677 (± 5,660)	0.6 (± 0.6)	4.7 (± 3.7)	2.2 (± 0.3)
Container	890	81	6,926 (± 1,938)	0.3 (± 0.3)	2.5 (± 6.9)	1.3 (± 0.9)
Bulker	210	19	9,114 (± 1,878)	6.2 (± 8.3)	33.3 (± 10.2)	1.4 (± 1.0)
General Cargo	146	14	2,449 (± 2,150)	3.9 (± 12.3)	14.7 (± 9.5)	2.2 (± 0.5)
RoRo	3	0	6,104 (± 3,226)	1.4 (± 1.5)	27.5 (± 15.7)	NA

*SD: standard deviation

Discussion

Tankers

Tankers likely represent a greater risk of introducing marine NIS via biofouling than other vessel types based on the number and frequency of arrivals, relatively large WSA per arrival, time spent in arrival port, and environmental similarity to their last port of call. Since Valdez receives the majority of tanker arrivals, it is likely that Valdez is at a greater risk of marine NIS being introduced from biofouling than other ports in the EVOS region based on these variables.

Not only do tanker arrivals constitute two-thirds of all vessel arrivals to the EVOS region, tankers also have a large average WSA when compared to other vessel types in this analysis. Tankers had an average WSA comparable only to passenger vessels with both vessel types averaging more than 15,000 m^2. Based on their larger volume of WSA, tanker arrivals have higher potential for increased propagule pressure and higher likelihood of introducing marine NIS when compared to other vessel types. At 1.9 days, tankers also had a longer average residency time in arrival ports than passenger vessels and container ships which both stayed in port less than 1 day. Longer residency time also increases the likelihood of marine NIS introduction as hull fouling organisms have a longer chance to spawn while in the arrival port or relocate into the arrival port.

Tanker arrivals had a bimodal distribution of environmental similarity between last port of call and arrival port with a peak of high environmental similarity for vessels traveling from Washington and California. Tanker arrivals with a moderate environmental distance (10-20) suggest that environmental conditions were relatively similar between the last port of call and arrival port, increasing the likelihood that an introduced NIS survives in the arrival port. Most documented marine NIS introduced in Alaska spread northward from existing invasions on the North American Pacific coastline (G. M. Ruiz et al., 2011). Arrivals from within Alaska and from heavily invaded ports in California and Washington have the potential to introduce NIS through secondary invasion. Although tanker arrivals were comparable to other vessel types based on mean years since last dry dock, tankers had a larger distribution of time since last dry dock with more vessel arrivals having hulls cleaned within the last four or five years than other vessel types.

Although tanker arrivals declined over the study period, tanker traffic to the EVOS region may increase if gas and electric utilities begin importing natural gas to proposed terminals in Nikiski in response to the on-going natural gas shortfall in Cook Inlet. The source of imported natural gas has not been determined. Importing natural gas to Cook Inlet would change the volume, arrival ports, and last ports of call for tanker traffic in the EVOS region.

Passenger Vessels

Based on the number and WSA of arrivals, passenger vessels likely represent a higher risk of introducing marine NIS than other non-tanker vessel arrivals. Passenger vessels have the highest mean WSA per arrival, in part based on their high niche proportion ($N_p = 0.27$). With large niche areas and high mean WSA per arrival, passenger vessels have a higher risk of introducing marine NIS per arrival than other vessel types, comparable only to tankers. Passenger vessels have low mean residency time compared to other vessel types which reduces the opportunity to introduce marine NIS. However, these arrivals came from ports with a lower mean environmental distance than other vessel types, increasing the likelihood marine NIS from the last port of call survive if introduced. On average, passenger vessels were last in dry dock about two years ago which is relatively low risk and on par with other vessel types in the EVOS region. Outside of the COVID-19 pandemic, passenger vessel traffic increased in the EVOS region during the study period and is expected to continue to increase from new cruise ship terminals and expansions in Whittier and Seward.

Container

Container ships constituted the third most EVOS region arrivals, but each arrival is attributed to less WSA on average than tanker and passenger vessels. With less WSA per arrival, container ships have lower potential propagule pressure, decreasing the likelihood of their arrivals introducing marine NIS. These arrivals also had the shortest residency time in arrival port and were most recently dry docked among the vessel types in this analysis, further reducing the potential risk of introducing marine NIS. The highest risk factor for container ships was a lower mean environmental distance among the vessel types in this analysis, increasing the likelihood of a potential NIS surviving in the arrival port.

Other Vessel Types

With few arrivals, bulkers, general cargo ships, and RoRos are likely at a lower overall risk of introducing marine NIS to the EVOS region. These vessels bring less WSA per arrival than tankers and passenger vessels on average, with general cargo vessels bringing the least WSA to arrival ports. However, bulkers and general cargo vessels have the longest mean residency time per arrival which increases the likelihood of any one of these arrivals successfully introducing a marine NIS. These vessel arrivals have the largest average environmental distance per arrival due to more overseas arrivals from East Asia which reduces the likelihood that a potential marine NIS from the last port of call survives in an arrival port in the EVOS region. Most arrivals for these vessel types have been cleaned in dry dock within one to three years of arriving.

Management Review

Maintenance

Vessel owners and operators are incentivized to maintain clean hulls because biofouling on vessel hulls causes drag, which affects fuel efficiency while a vessel is underway, and biofouling on rudders and propellers affects vessel performance (Davidson et al., 2016). However, there is little industry incentive to minimize biofouling in other niche areas because they do not have a direct impact on vessel performance (Davidson et al., 2016).

As discussed, vessels go into dry dock at least every five years where they undergo thorough out of water cleaning. Dry dock cleaning removes most if not all biofouling on the hull and niche areas of vessels, thereby heavily reducing the likelihood that vessels that recently underwent dry dock cleaning introduce marine NIS to arrival ports.

To further control biofouling, vessels hulls are coated in anti-fouling treatments during dry dock. These treatments can include antifouling paints and coatings with biocides like copper and zinc, or other foul release materials based on teflon, silicon, or epoxy. Treatment materials strike a delicate balance between making the hull inhospitable without harming the surrounding waters as many of these compounds are also known to bioaccumulate in the environment. In 2008, the IMO banned a common hull treatment, tributyltin, because of its high toxicity to non-target organisms. Overall, there is a global ban on 49 tributyl and organotins that were previously used in coatings but presented negative impacts to marine ecosystems (Hewitt et al., 2009; IMO, 2001; Nehring, 2001).

Some places are also evaluating the impacts of copper based antifouling paints and regulating their use. In Title 3 California Code of Regulations (CCR) § 6190 effective July 1, 2018, California established regulations for the leach rate of copper-based antifouling paints and coatings on recreational vessels after marinas were found to be exceeding the water quality criteria for dissolved copper (Burant, n.d.). Fouling paints reduce and slow marine growth but do not fully prevent it, and their effectiveness reduces over time. However, there is also an emerging world of ultrasonic antifouling systems that provide resilient biocide-free antifouling (Sonihull, n.d.).

Another key area of innovation and regulation is the expanding world of in-water cleaning. Initially in-water cleaning was done by divers, but technological advancements led to the use of cost-saving unmanned cleaning robots. Increasingly in-water cleaning technology operates with capture mechanisms to collect fouling organisms and toxic paints as they are removed in an effort to prevent spreading NIS and toxic coatings in the immediate surroundings during cleaning. California requires capture for in-water cleaning in harbors, ports, and marinas, and other places ban in-water cleaning such as New Zealand, meaning in-water cleaning occurs 12 miles off-shore in international waters (California State Water Resources Control Board, n.d.; New Zealand Ministry for Primary Industries, n.d.).

Management

Management of hull fouling is determined by various geographic jurisdictions – international, national, and regional. The IMO manages requirements for treatments, dry docking, and survey at an international level. All commercial vessels are required to be inspected in dry dock every five years with an intermediate survey every 36 months, except for passenger vessels which are required to get a hull inspection annually. The IMO also requires that ships participating in international voyages and larger than 400 GT are required to hold an International Anti-fouling System Certificate.

Some countries have stricter requirements, notably New Zealand and Australia. New Zealand and Australia require cleaning vessel hulls less than 30 days before arrival or within 24 hours of arrival, documentation of continual maintenance using best practices, and application of approved treatment types (New Zealand Ministry for Primary Industries, n.d.). In 2023, New Zealand turned multiple cruise ships away for being in violation of these regulations (Boerne Marcus, 2024).

The United States is updating hull biofouling management through the Vessel Incidental Discharge Act (VIDA; 2018) which identifies hulls and associated niche areas as incidental discharges. While these regulations have yet to be implemented, they are intended to replace regulations currently in place through the USCG and Environmental Protection Agency's Vessel General Permit (2013). Some states also have stricter requirements. California requires robust documentation of hull fouling maintenance through the Biofouling Management Regulations to Minimize the Transfer of Nonindigenous Species from Vessels Arriving at California Ports (2 CCR § 2298.1). Vessels are required to document consistency with the IMO Biofouling Guidelines, details about the antifouling systems in use, and planned actions to manage biofouling associated with specific niche areas, among other information through their Biofouling Management Plan and Biofouling Record Book (Scianni et al., 2021). Compliance inspections are prioritized for high risk vessels – risk determined by potential propagule pressure of a vessel's WSA and ballast water volume

(Ceballos-Osuna et al., 2021). Vessel operators have a 60-day grace period for compliance after their first violation. There are no additional biofouling regulations in place in Alaska.

Management Recommendations

This analysis provides the basis for developing a targeted program to sample vessel hulls based on higher risk profiles arriving to the EVOS region. Hull sampling efforts would be best focused on comparing low and high-risk arrivals for key vessel types at their respective ports (i.e., tanker arrivals in Valdez, cruise ships in Seward and Whittier, container ships in Kodiak, and bulkers in Afognak). A comprehensive management program would take into consideration relative risk of biofouling factors, such as larger versus smaller WSA, longer versus shorter residency time, smaller versus larger environmental distances, and longer versus shorter time elapsed since last dry dock. Effective analysis of samples collected from vessels could be based on established methodologies of morphological and metagenetic analysis through the Smithsonian Environmental Research Center’s Plate Watch program (G. Ruiz et al., 2024).

Other research opportunities include collecting and analyzing data about vessel hull treatments and maintenance directly from shippers, continuing upkeep of merged NBIC and NVMC datasets (especially since the inclusion of date of last dry dock data in NBIC), and continuing to seek learnings and best practices from leaders in biosecurity (e.g., California and New Zealand). Further, ferry arrivals were not considered as part of this analysis because the Alaska Marine Highway System arrivals are only available for 2017-2022. PWSRCAC has the opportunity to periodically conduct this type of vessel behaviors and risk potential analysis to stay informed on changes in data availability and regional shipping dynamics.

There are also clear opportunities to advocate for improved biofouling regulations in Alaska. PWSRCAC could encourage the Alaska Department of Environmental Conservation to get more involved in state regulation, and advocate for in-water cleaning regulations to require capture and biofouling documentation and inspection akin to California. On the national level, PWSRCAC could continue to stay involved in implementation of VIDA. There is also an opportunity to engage with industry during vessel design stage to identify ways to reduce WSA and niche areas in particular which is an ongoing area of innovation for drag reduction and fuel conservation.

Conclusion

The combined NVMC and NBIC datasets offer a detailed assessment of vessel arrival characteristics and biofouling risk factors for the EVOS region. Since Alaska lacks robust biosecurity measures for hull biofouling, sampling hull fouling on higher risk vessel arrivals and advocating for more increased hull fouling requirements are the most pertinent recommendations from this analysis. As environmental conditions and commercial vessel traffic change in the EVOS region, proactive measures for biofouling and other key NIS vectors are paramount for regional biosecurity.

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