Abundance of Vessels in San Juan County during Busy Summer 2024 Weekends:

Final Report

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Prepared by:

Thomas A. Jefferson
Clymene Enterprises, Lakeside, CA

Mari A. Smultea
Smultea Environmental Sciences, LLC, Preston, WA

Dave Steckler
Mysticetus LLC, Bellevue, WA

Submitted to:

Department of Environmental Stewardship
San Juan County
P.O. Box 729
Friday Harbor, WA 98250

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1. Project Background and Rationale

The San Juan Islands are one of the premier boating destinations in the United States (U.S.). With this popularity come concerns that boating activities may accelerate declines in eelgrass documented throughout the islands as well as adversely impact other benthic habitats and communities of concern (San Juan County, 2023). Flourishing eelgrass beds and other sensitive marine natural resources (e.g., kelp beds, herring spawning habitat, shellfish beds) are foundational to the Salish Sea ecosystem and the Coast Salish lifeways. These habitats are vital to the recovery of federally Endangered salmonids inhabiting Puget Sound as well as the iconic, federally Endangered southern resident killer whale [SRKW] (*Orcinus orca ater*) population. Over one-third of San Juan County's (SJC) 408 miles of shoreline host eelgrass beds (comprised mostly of *Zostera marina;* Friends of the San Juans, 2004). This habitat provides essential nursery and shelter to many ecologically, economically, and culturally important species and serves as a food source sustaining many nearshore organisms. At least 20 listed stocks of juvenile Puget Sound Chinook salmon (*Onchorhynchus tshawytscha*), as well as the Fraser River runs (Beamer and Fresh, 2012), that are essential to the recovery of the SRKW population rely on the Islands' nearshore habitats for feeding and rearing. Eelgrass beds also provide a diverse array of ecosystem services including improved water quality, sediment stabilization and wave attenuation that in turn increase coastal resilience to storm surge and coastal erosion, and enhance carbon sequestration (Fonseca and Cahalan, 1992; Kelly et al., 2019; Tong, 2019). The need to protect eelgrass habitats for the wellbeing of marine ecosystems and coastal communities is broadly recognized regionally and globally.

These habitats are sensitive to environmental and physical stressors; this is particularly apparent in the San Juan Island archipelago, where the biomass and geographical extent of declining eelgrass sites significantly outnumber increasing sites, both historically and in recent years (Christiaen, 2022; WA DNR, 2024). Documented Pacific herring (*Clupea pallasii*) spawning sites have also experienced large declines in San Juan County (e.g., Westcott Bay (Christiaen, 2022)). While the prevalence of eelgrass wasting disease has increased in the islands (Graham et al., 2021), human disturbance is likely further compromising eelgrass meadow health (e.g., Kelly et al., 2019). Extensive literature has documented impacts of physical disturbance on eelgrass beds from vessel anchoring activity (e.g., Barry et al., 2020; Broad et al., 2020; Kelly et al., 2019; Venturini et al., 2021), including anchor and chain scour and sediment resuspension (Kelly et al., 2019; Broad et al., 2020). These anthropogenic mechanisms can result in eelgrass bed fragmentation, accelerating decline in the health and size of beds. Other impacts may include wake erosion, shading, improper discharge of waste, accidental small oil spills (Venturini et al., 2021), dock construction, and damaging types of mooring buoys (Creed and Amado Filho, 1999). Related cumulative impacts remain unmeasured in SJC waters and elsewhere in Puget Sound despite the high levels of water-based human activities and coastal development.

Anchor scars have been shown to persist in soft-sediment habitats for three months (Backhurst and Cole 2000). Recovery of the sediment-dwelling fauna in anchor scars and deep chain scours may take substantially longer to recover, depending on spatial scale (Backhurst and Cole, 2000; Norkko et al., 2006). The recovery of eelgrass beds depends on species, plant type (annual vs. perennial), and growing conditions, but may require multiple years and, in some cases, anchor scars may never 'heal' (Broad et al., 2020; Meehan and West, 2000, Bart Christiaen *pers. comm.)*. Anchoring damage can be extensive at localized scales. For example, studies in San Francisco found that anchoring vessels damaged up to 41% of an eelgrass bed, with individual vessels causing up to 0.3 ha of damage (Kelly et al., 2019). Mooring buoys installed prior to the permitting era, or without permitting, are often not properly configured and can result in persistent chain scour (Seto et al., 2023). Physical disturbance from these activities increases the susceptibility of eelgrass plants to disease (Broad et al., 2020).

The San Juan islands lie at the heart of the Salish Sea, at the convergence of Puget Sound, the Georgia Basin, and the Strait of Juan de Fuca (San Juan County, 2023). These islands have been a thoroughfare to Coast and Straits Salish tribes and Canadian First Nations since time immemorial, and more recently to Euro-American settlers, providing access to natural resources that have shaped indigenous and islanders' lifeways (San Juan County, 2023). The area has historically provided important trading routes between the islands and the mainland. Today, commercial shipping traffic circumnavigates and passes through the county's waters. The islands have also become increasingly popular with visitors and boaters, especially during and since the Covid pandemic started in the U.S. in 2020.

The San Juan islands have long been a world-class boating destination. The islands' marinas and ports provide slips for ~1,940 vessels, but only a small number of slips are available for the influx of visiting vessels during the spring through fall prime boating season. Additionally, in 2023 there were a total of 2,750 registered boats with moorage in San Juan County, this number does not include any boats without an active registration. Of the 1,863 surveyed mooring buoys in the Islands, only ~120 are for public use, with most scattered through the islands' marine parks (Friends of the San Juans, 2010; MRC, 2023). This results in a high prevalence of anchoring throughout the islands. Unpermitted mooring buoys and/or buoys not conforming to environmental standards are also a growing concern, particularly for Tribes with usual and accustomed fishing, hunting, and gathering areas. A 2019 survey of boaters indicated that anchorages in the San Juan Islands are at capacity (60%) or over capacity (35%) during the peak summer season (Whittaker et al., 2020). In 2023, Washington's active recreational boating fleet comprised 231,387 vessels (Washington Sea Grant, 2023), though only a percentage of these will operate on the saltwater. Of the 3,227 boats registered in San Juan County in 2022, 2,809 were considered part of the recreational fleet (Washington Sea Grant, 2023). In addition, San Juan County is considered a net importer of boaters, receiving more vessels registered in other counties than San-Juan-County registered vessels going elsewhere (Washington Sea Grant, 2023). This is further evidence of the high boating levels and popularity of San Juan County waters, highlighting the need to better understand vessel presence, activities, and density in the islands, especially in areas with eelgrass and other sensitive marine resource habitats.

Previous work on this topic found ground-based counts to be unreliable and used aerial surveys to count vessels (Dismukes et al., 2010). However, the latter study did not properly account for vessels that might have been missed and may underestimate total vessels. For the project described herein we undertook a series of eight, one-day San Juan County-wide aerial surveys to determine vessel density and use. Surveys were flown over the course of the 2024 spring-fall boating season starting Saturday, May 25 and ending Saturday, September 21 in 2024. Surveys occurred on each of the three main holiday weekends (Memorial Day, July 4th, and Labor Day) and on five additional weekend days during the season. The project design allowed us to assess total numbers of vessels on the water, as well as vessel presence, activity, type, and density in relation to eelgrass and other sensitive habitats, a current core data gap in our understanding of what factors are limiting eelgrass growth in the San Juan Islands. Understanding the nexus between vessel presence and eelgrass habitat health is crucial.

The overall goals of this project were to:

1) Identify the highest vessel density areas representing the greatest potential adverse impacts to eelgrass and other selected sensitive habitats,
2) Prioritize sites for protection and restoration efforts, and
3) Evaluate management strategies that will preserve sensitive and critical eelgrass habitats, support a positive boating experience, and provide for unhindered access to usual and accustomed fishing and harvesting areas.

This report specifically addresses the first goal with the following specific objectives:

1) Obtain direct counts of the number of vessels when flying on-effort systematic survey lines,
2) Obtain data/photos to evaluate completeness of counts of the number of moored/anchored vessels in certain bays of interest, requiring circling of the aircraft, and
3) Collect line-transect data on the vessels sighted during on-effort periods, so that we can assess the utility of line transect (LT) methods for assessing total vessel numbers.

2. Study Area and Methods

2.1. Study Area

The study area was San Juan County encompassing the San Juan Islands and surrounding U.S. marine waters of the Salish Sea (**Fig. 1**). The islands lie in the transboundary waters on the border between the U.S. and Canada, at the heart of the Salish Sea and include eight large islands (Waldron, Stuart, Orcas, San Juan, Lopez, Shaw, Blakely, and Decatur islands) and many smaller islands. The nine east-west survey lines were configured to provide even coverage of the study area, so that total counts could be obtained, and data could be analyzed using standard distance sampling methods (Buckland et al., 2001). The study area covered a total of 1,166 km^2 of U.S. marine waters. The main survey lines were 5 km apart, and the total length of all transect lines, including transits and connectors, was 3,065.8 km.

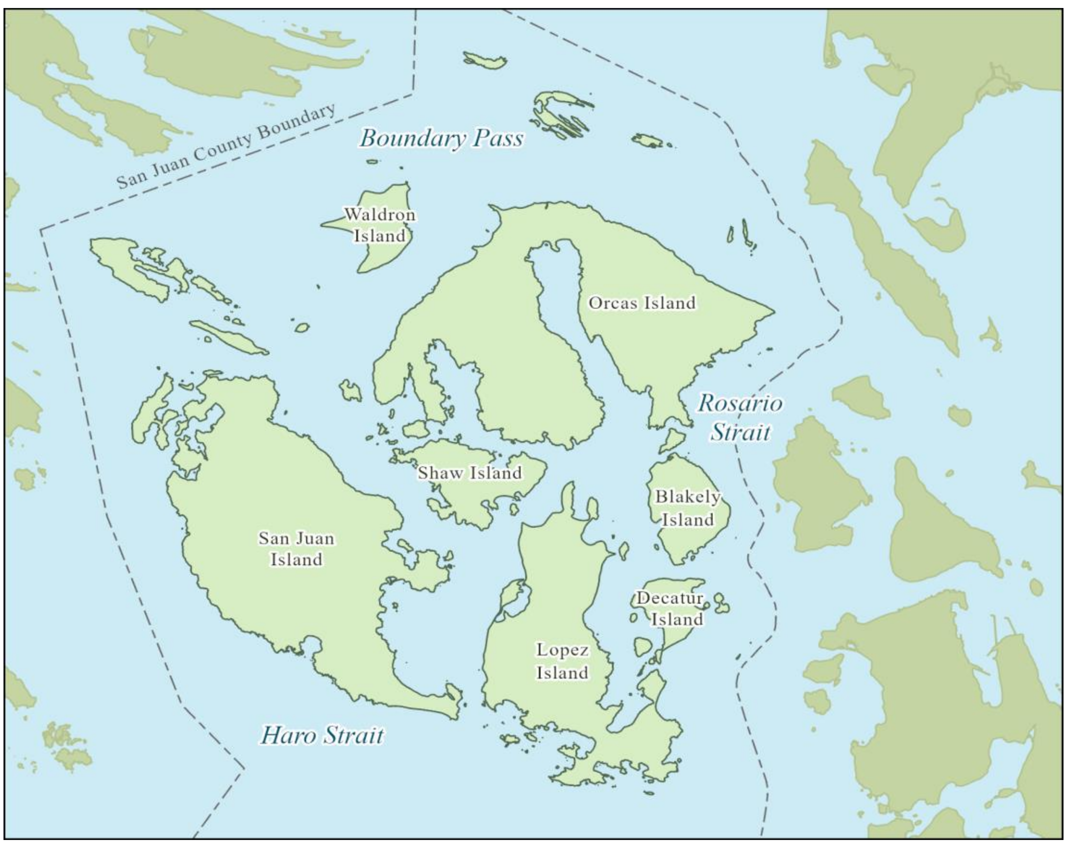

Figure 1. The San Juan County study area (indicated by dashed county line) and its overall setting in the region of the Salish Sea in northwestern Washington.

2.2. Field Survey Methods

Aerial surveys were flown from a *Cessna* 172 fixed-wing aircraft chartered from San Juan Airlines. This aircraft has a high-wing configuration equipped with four seats (two in front and two in back) allowing the observers to view the water below the aircraft and out to the sides. The region directly below the aircraft was not visible to the observers due to the flat windows in the aircraft, representing a ‘blind’ swath of approximately 224 m (110 m on either side of the center of the aircraft) when flying at an altitude of 457 m (1500 feet); this inability for observers to observe directly below the plane was accounted for in the analysis. The surveys followed a standard line-transect protocol (Buckland et al., 2001, 2004, 2015) to systematically count all detected vessels and determine type and activity. Observers counted vessels on each side of the survey plane. Separate surveys were conducted over busy bays not visible from the transect lines to circle for exact counts and take photographs of vessels. Vessel counts and photographs were subsequently compared to facilitate data QA/QC.

The project encompassed eight survey days spread equally through the main boating season of May through September 2024. Survey dates were scheduled to target weekends when the highest levels of boating were expected and included Memorial Day weekend, , July 4th holiday weekend, Labor Day weekend, the first recreational salmon fishing opening weekend, the first weekend of August, and two weekends in early- and mid-September. The nine survey transect lines were designed to ensure equal coverage of the study area encompassing marine waters of San Juan County or WRIA 2 (**Fig. 2**).

Surveys were only conducted if weather conditions were considered acceptable and safe for flying as determined by the pilot and flight team (i.e., windspeed < 30 knots, and no heavy rain or fog). The airplane took off and landed at Bellingham Airport on each survey date. Two flights were conducted on most survey days, weather permitting, with each flight lasting 3-3.5 hours with a stop to refuel between the two surveys. Surveys were conducted at a target altitude of 457 m and a speed of 100 knots. It was considered important to complete all nine survey lines (**Fig. 2**) at least once on each survey day. When weather and other conditions allowed, two sets of survey lines were completed in one day, generally one in the morning and one in the afternoon.

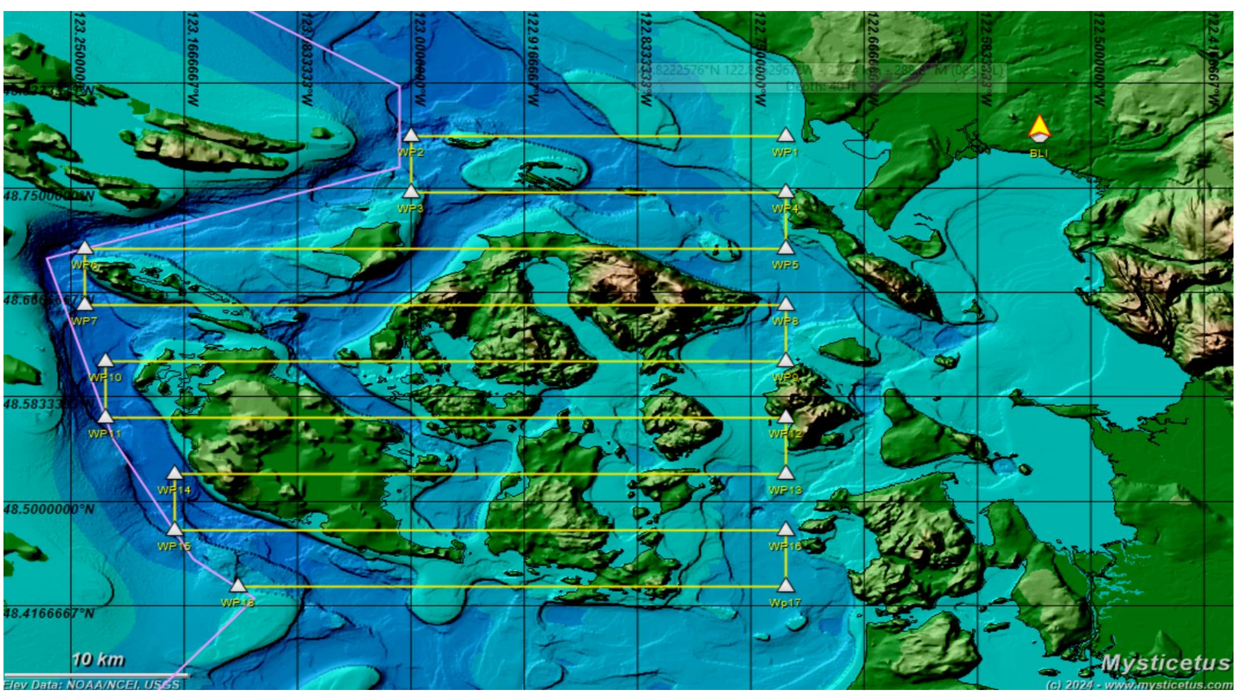

Figure 2. An overhead view of the San Juan County, Washinton study area and locations of the nine systematic line-transect survey lines, with waypoints indicated by triangles.

Equipment used during the survey consisted of a laptop running Mysticetus data collection software (www.Mysticetus.com), Suunto inclinometers to measure the declination angle of each sighting, an SLR Cannon digital camera equipped with a 35-200 mm zoom lens, two handheld Sony digital mini voice recorders each connected to a mini microphone taped into one side of each observer's headset, headsets for communicating with each other and the pilot on the plane, notebooks and pens, and 'cheat sheets' taped to the back of the two front seats for reference by the observers during the flights (e.g., listing vessel types, etc.). A back-up of all equipment was included on the plane.

During each flight, we attempted a complete count/survey of the number of vessels in marine waters of the study area. We started either in the north or south, depending on logistics and weather. Vessel sightings on transits to/from the airport and on connector lines were not used in the analyses. Observers were directed by the recorder to record data in a consistent order matching the entry order into Mysticetus to facilitate expediency of recording.

Four people were on each flight. The pilot was responsible for flying the plane and overall safety. The data recorder sat in the co-pilot's seat and was responsible for entering data into the computer using Mysticetus software and helping the pilot to navigate the lines. The pilot and recorder were not part of the search team. The two observers were seated in rear seats on opposite sides of the aircraft and were responsible for reporting vessel sightings to the data recorder on their side of the plane. Voice recorders were used to provide a backup record, in case data on the Mysticetus computer were lost, or in case the data recorder was unable to record all data in real time on the laptop during periods of high vessel numbers.

When the first survey line was reached, the observers went on effort, and the two observers began searching for and reporting sightings of vessels to the data recorder. Vessel sightings (i.e., events) ranged in size from 1 to more than 1 vessel in each sighting. For example, clumped sightings of vessels were considered one 'sighting' of multiple vessels; this approach conforms with line-transect theory (Buckland et al., 2001). Searching was conducted with the naked eye focusing on the area from perpendicular to the front of the plane, with binoculars only used to confirm sightings and vessel details/activity when necessary. Each observer searched their respective side of the plane from directly below out to at least approximately 2.5 km perpendicular distance (this corresponds to a declination angle of 11° if the plane is flying level at 457-m altitude) and reported all vessel sightings in their search area. The data recorder entered data on the type and number of vessels, as well as the declination angle when the vessel was perpendicular to the transect line for each sighting (**Table 1**; **Appendix A** describes and illustrates the categories we used). Observers were instructed to not record sightings of common marine mammal species so as not to distract from vessel counts (i.e., harbor seals, sea lions, harbor porpoises, killer whales); however, sightings of more rare marine mammal species (e.g., gray whale, Pacific white-sided dolphin) or unusually large groups of the other more common species were noted and recorded, but only if time allowed.

Table 1. Categories used for vessel types and their status.

Vessel Type	Code	Size
Sailboat/sailing catamaran	SAIL	S
Paddle boat (kayak, canoe)	PADDLE	S
Cargo vessel/tanker	CARGO	L
Commercial fishing vessel	COM FISH	S
Wildlife tour boat	TOUR	S
Cabin cruiser - small (<35')	CABIN-S	S
Cabin cruiser - large (36-65')	CABIN-L	S
Yacht (>65')	YACHT	L
Recreational skiff (open) (<~15')	REC SKIFF	S
Recreational fishing boat (<26')	REC FISH	S
Tug boat	TUG	L
Ferry	FERRY	L
Military/Coast Guard vessel	NAVY	L
Unknown/other	OTHER	-

Status
Underway/drifting
Moored (to float)
Anchored
Fishing
Unknown/other

Separately from the line-transect surveys, off-effort counts of vessels in 16 bays that were predicted to have too many vessels to count on transect and were difficult to observe from the transect lines were conducted off-effort while the plane circled (see **Appendix B** for a list and maps of the bays). These bays consisted of Marine state parks, popular marinas, and other anchorages known to be both popular with boaters and/or to be sites where long-term eelgrass monitoring has occurred. The procedures for bay counts were to circle the bay at approximately 610 m (2,000 feet) altitude, with one observer counting vessels, and the other observer taking a series of wide-angle photos from a recognizable perspective, so that post-survey counts could be conducted using the photos.

The photographer attempted to take as many photos as needed (usually 2-6) to obtain good, in-focus shots of the entire bay, or multiple shots that could be "stitched" together so that all vessels in the bay could be seen, counted, and categorized into types. Only vessels underway, moored, or anchored were counted, and not vessels at docks (except vessels at the state park docks). The photographer took a "blank" frame between each set of bay photos. This was something that was clearly not a regular photo (e.g., a 45° angle photo of the back of the pilot's or data recorder's head). These blank photos were meant to assist the person analyzing the photos to separate batches of shots from each bay. Frame numbers for each bay and each blank frame were recorded in Mysticetus.

In addition to vessel data observers noted and the data recorder recorded specific environmental conditions at the beginning of each transect leg on their respective side of the plane and whenever conditions changed. These variables included Beaufort sea state, percent glare extent within the primary viewing area (from 90° left and right of the plane to the nose of the plane), estimated visibility (in kilometers), and estimated percent cloud cover.

2.3. Data Analysis

For the line transect analysis only those sightings of vessels collected during on-effort (i.e., on systematic transects) were used. Line transect analysis for marine mammals often requires that only sightings collected in Beaufort Sea states of 0-2 and in good sighting conditions are used, however this is less important for the subject of this study (vessels) as they do not have the same sighting bias as cetaceans do.

Vessels in general are larger, more conspicuous, and should remain at the surface and therefore available to count.

Line transect data were assembled in Excel spreadsheets and uploaded into Distance V6.2 software (Thomas et al., 2010). During the flight, Mysticetus automatically converted declination angles to perpendicular sighting distances (along the waterline) by applying standard trigonometry incorporating corrections for curvature of the earth. The resulting perpendicular distances were used for line transect analyses. Estimates of density and abundance and their associated coefficients of variation were computed using the following standard formula:

$$D = \frac{n \cdot f(0) \cdot E(s)}{2 \cdot L \cdot g(0)}$$

$$N = \frac{n \cdot f(0) \cdot E(s) \cdot A}{2 \cdot L \cdot g(0)}$$

$$CV = \sqrt{\frac{var(n)}{n^2} + \frac{var[f(0)]}{[f(0)]^2} + \frac{var[E(s)]}{[E(s)]^2} + \frac{var[g(0)]}{[g(0)]^2}}$$

Where *D* is density (of vessels),
n is the number of on-effort sightings on transect lines,
f(0) is the detection function evaluated at zero distance from the plane,
E(s) is the expected group size,
L is the length of the trackline on-effort,
g(0) is the trackline detection probability,
N is the abundance,
A is the size of the study area,
CV is the coefficient of variation, and
var is the variance.

The trackline detection probability [*g(0)*] was assumed to be 1.0. We fit Hazard-Rate and Half-Normal models to the data (with hermit and cosine adjustments), and the final model was chosen automatically by minimizing the value of Akaike's Information Criterion (AIC).

2.4. Vessel Density and Resource Mapping

In addition to the line transect density and abundance analysis, heat maps were created using Mysticetus and ARC GIS software to graphically display calculated numerical vessel density on a continuous numerical scale reflected by color gradations, with densities expressed as the number of vessels per square kilometer. Separate vessel density maps were produced for line transects only (i.e., on-effort data), for circling bay counts only (i.e., off-effort data), and for the pooled line transect and bay circling counts. For maps pooling data from all surveys, average vessel density per square kilometer was displayed.

The pooled heat map of vessel density was then overlaid with shapefiles of eight different sensitive resource polygons or points as well as a 9th GIS layer representing known mooring buoy locations. These overlays allowed a visual display of locations of vessel densities relative to locations of resources of interest. These nine overlays of interest consisted of the following: (1) eelgrass, (2) red sea urchin, (3) Dungeness crab, (4) hardshell intertidal clam, (5) hardshell subtidal clam, (6) kelp, (7) oyster beds, (8) forage fish spawning habitat., and (9) mooring buoys. Maps were zoomed in for some resource displays as needed to better visualize overlaps. Shapefiles of these nine resources were obtained from F. Roberson/San Juan County, as indicated in **Table 2**.

Table 2. Sources of GIS shapefiles for the nine resources mapped for this study. WA DNR = Washington Department of Natural Resources; WDFW = Washington Department of Fish and Wildlife.

Resource	Source	Year
Eelgrass	WA DNR Eelgrass Monitoring Program	2000-2017
Red sea urchin	WDFW	1992
Dungeness crab	WDFW	1992
Hardshell intertidal clam	WDFW	1992
Hardshell subtidal clam	WDFW	1992
Kelp	Samish Indian Nation Department of Natural Resources	2022
Oyster beds	WDFW	1992
Forage fish	Friends of the San Juans	2023
Mooring buoys	San Juan County Marine Program	2022

3. Results

3.1. Survey Summary

Surveys were conducted on eight survey days during the extended summer of 2024. On most survey days two separate flights were conducted, one in the morning, and another in the afternoon. Information on the surveys, including dates, kilometers searched, and other data are presented in **Table 3**. Each survey conducted one or two line-transect flights and one flight on which vessel bay counts were conducted off-effort while the plane circled (the only exception was 14 September, in which a bay count was not obtained due to poor weather). All vessel surveys were conducted during Beaufort sea states ranging from 0- 4.

Table 3. Summary of line-transect surveys results conducted in the San Juan County study area in 2024. Morn = morning, Aft = afternoon, n = sample size (number of vessel sightings), L = survey effort in line kilometers (km) length, ESW = effective strip width, D = vessel density per square kilometer, N = abundance, CV = coefficient of variation in percentage, n/a = not applicable.

Date	Holiday?	Morn/Aft	n	L (km)	ESW (km)	D (/km2)	N	CV (%)
25-May-24	Memorial Day	morn	160	225.4	1.44	0.28	331	15.0
15-Jun-24	n/a	morn	207	257.2	1.49	0.35	407	14.7
15-Jun-24	n/a	aft	252	273.8	2.30	0.26	305	14.1
6-Jul-24	Independence Day	morn	349	247.9	1.80	0.70	819	8.9
6-Jul-24	Independence Day	aft	424	234.7	2.59	0.70	821	11.1
20-Jul-24	Fishing season opens	morn	331	281.4	1.43	0.80	937	19.8
20-Jul-24	Fishing season opens	aft	338	238.4	1.78	0.69	806	20.6
3-Aug-24	n/a	morn	225	225.4	1.48	0.51	599	17.4
3-Aug-24	n/a	aft	278	244.4	1.47	0.55	649	12.9
31-Aug-24	Labor Day	morn	249	235.8	1.18	0.66	774	15.9
31-Aug-24	Labor Day	aft	228	227.8	0.72	1.03	1,196	22.1
14-Sep-24	n/a	aft	194	256.3	1.61	0.30	349	15.3
21-Sep-24	n/a	aft	225	212.6	1.63	0.45	520	18.2

Raw counts of the number of vessels detected on surveys were somewhat correlated with the resulting line-transect estimates, but the correlation was not particularly strong (**Fig. 3**). This suggests that raw count data from these surveys was not a very accurate way of determining the number of vessels in the area; this is likely due to the fact that a significant number of vessels were missed, given the requirement for the airplane to travel at a high rate of speed along the transect lines and the high density of vessels in some areas where vessels may have been missed by the observers.

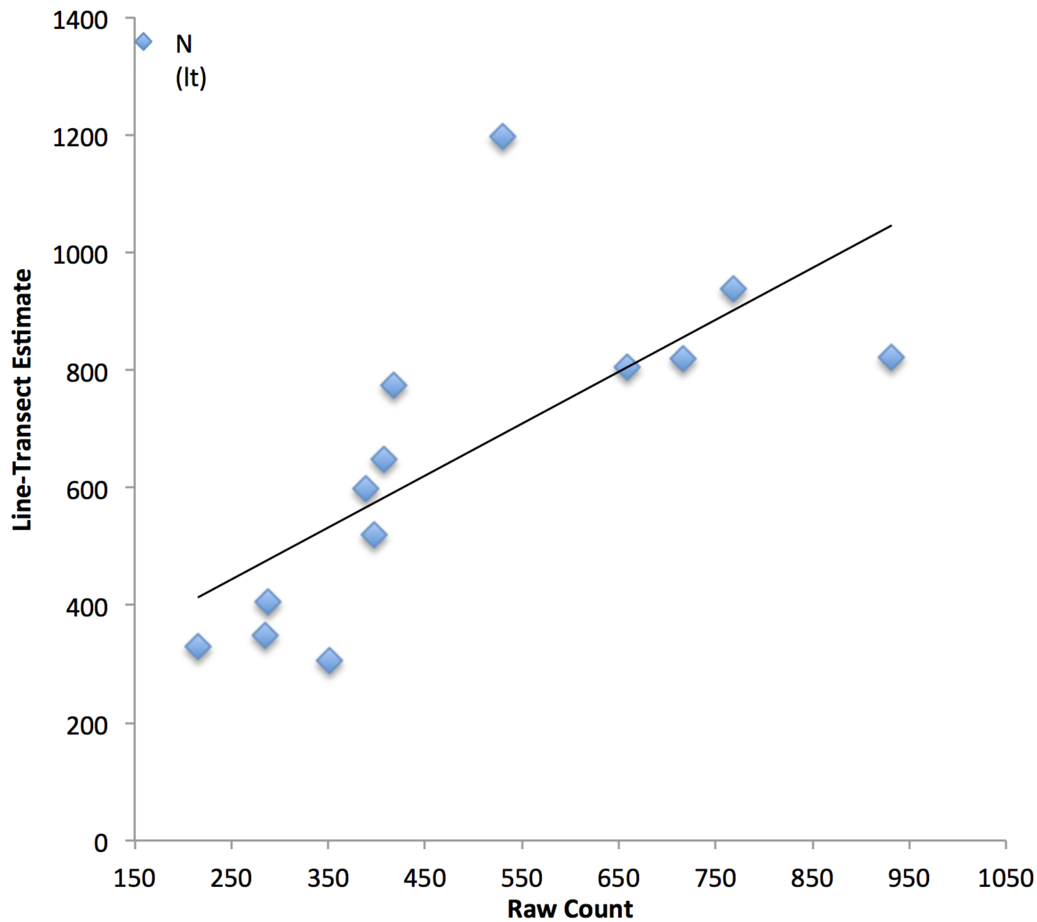

Figure 3. Comparison of raw counts and resulting line-transect estimates of the numbers of vessels.

The numbers of sightings per survey by vessel type are presented in **Table 4**. The most common vessel types were recreational skiffs (10%), sail vessels (24%), small cabin cruisers (24%), and recreational fishing vessels (34%). Together, these vessel types made up 92% of the vessels seen on survey transect lines, and nearly all of the vessels detected in the bay counts. Large ships, like yachts, tug vessels, ferries, and military/Coast Guard vessels were rarely seen in comparison. Bay counts varied over the course of the summer, ranging from 268-795 vessels (mostly sail vessels, small cabin cruisers, and recreational skiffs). They represented a significant fraction of our estimates of the total number of vessels (see below).

Table 4. Summary of number of vessels by type and proportion by each survey date. Note that the totals column in the Numbers table below refers to the number of individual vessels sighted (some sightings had more than one vessel). nd = no data.

Numbers

Date	Total	Sail	Paddle	Cargo	Com Fish	Tour	Cabin-S	Cabin-L	Yacht	Rec Skiff	Rec Fish	Tug	Ferry	Navy	Other
25-May-24	**215**	51	3	2	9	6	78	4	0	25	28	4	2	0	3
15-Jun-24	**286**	56	2	0	2	2	76	7	0	14	121	2	3	0	1
15-Jun-24	**351**	55	4	1	3	5	114	5	0	32	127	2	3	0	0
6-Jul-24	**716**	257	8	0	8	1	198	21	1	39	178	1	1	0	3
6-Jul-24	**931**	269	29	1	8	5	245	28	0	31	308	4	1	0	2
20-Jul-24	**770**	110	26	2	2	4	54	8	1	109	452	0	2	0	0
20-Jul-24	**659**	134	26	3	0	2	72	12	0	61	344	1	1	1	2
3-Aug-24	**389**	126	9	0	1	7	43	11	0	73	114	1	1	0	3
3-Aug-24	**407**	108	22	1	1	10	47	11	0	64	139	1	3	0	0
31-Aug-24	**412**	113	1	1	6	3	125	20	1	27	114	1	0	0	0
31-Aug-24	**530**	145	14	1	9	2	137	25	3	40	150	1	3	0	0
14-Sep-24	**285**	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
21-Sep-24	**397**	49	4	0	14	3	151	16	4	38	109	3	5	0	1

Proportions

Date	Total	Sail	Paddle	Cargo	Com Fish	Tour	Cabin-S	Cabin-L	Yacht	Rec Skiff	Rec Fish	Tug	Ferry	Navy	Other
25-May-24	**1.0**	0.24	0.01	0.01	0.04	0.03	0.36	0.02	0.00	0.12	0.13	0.02	0.01	0.00	0.01
15-Jun-24	**1.0**	0.20	0.01	0.00	0.01	0.01	0.27	0.02	0.00	0.05	0.42	0.01	0.01	0.00	0.00
15-Jun-24	**1.0**	0.16	0.01	0.00	0.01	0.01	0.32	0.01	0.00	0.09	0.36	0.01	0.01	0.00	0.00
6-Jul-24	**1.0**	0.36	0.01	0.00	0.01	0.00	0.28	0.03	0.00	0.05	0.25	0.00	0.00	0.00	0.00
6-Jul-24	**1.0**	0.29	0.03	0.00	0.01	0.01	0.26	0.03	0.00	0.03	0.33	0.00	0.00	0.00	0.00
20-Jul-24	**1.0**	0.14	0.03	0.00	0.00	0.01	0.07	0.01	0.00	0.14	0.59	0.00	0.00	0.00	0.00
20-Jul-24	**1.0**	0.20	0.04	0.00	0.00	0.00	0.11	0.02	0.00	0.09	0.52	0.00	0.00	0.00	0.00
3-Aug-24	**1.0**	0.32	0.02	0.00	0.00	0.02	0.11	0.03	0.00	0.19	0.29	0.00	0.00	0.00	0.01
3-Aug-24	**1.0**	0.27	0.05	0.00	0.00	0.02	0.12	0.03	0.00	0.16	0.34	0.00	0.01	0.00	0.00
31-Aug-24	**1.0**	0.27	0.00	0.00	0.01	0.01	0.30	0.05	0.00	0.07	0.28	0.00	0.00	0.00	0.00
31-Aug-24	**1.0**	0.27	0.03	0.00	0.02	0.00	0.26	0.05	0.01	0.08	0.28	0.00	0.01	0.00	0.00
14-Sep-24	**1.0**	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
21-Sep-24	**1.0**	0.12	0.01	0.00	0.04	0.01	0.38	0.04	0.01	0.10	0.27	0.01	0.01	0.00	0.00
Average	**1.0**	**0.24**	**0.02**	**0.00**	**0.01**	**0.01**	**0.24**	**0.03**	**0.00**	**0.10**	**0.34**	**0.00**	**0.01**	**0.00**	**0.00**
Avg (%)	**100%**	**24%**	**2%**	**0%**	**1%**	**1%**	**24%**	**3%**	**0%**	**10%**	**34%**	**0%**	**1%**	**0%**	**0%**

3.2. Line Transect Analysis

The number of vessel sightings made per line-transect survey are shown in total and by vessel type in **Table 4** (note that this is not the same as the sample size, n, since some sightings had more than one vessel). The total number of vessels ranged from a low of 215 on the first survey in May to a high of 931 on the afternoon survey on July 4th weekend.

Line-transect analysis of the survey data went smoothly, and the resulting PSD plots showed a clear drop-off of sightings with distance (**Fig. 4**). This indicates that some vessels were missed further from the plane, and that distance sampling is an appropriate method to analyze these data. The effective strip widths for the various surveys ranged from 0.72-2.59 km for each survey.

3.3. Combined Line Transect and Bay Count Data

Combining the best bay count data with the estimates of vessel abundance for each survey provides an estimate of the total number of vessels in San Juan County during the survey periods but does not include vessels that were docked or moored (**Fig. 5**). There was a relatively predictable pattern in seasonal vessel numbers, with the first survey (in May) having the lowest estimated number of vessels. The June surveys showed similar numbers. In contrast, the July and August surveys had much larger numbers, with the Memorial Day weekend survey (31 August) showing the highest numbers overall. In September, numbers dropped back down to only slightly higher than they were in May and June (**Fig. 5**). Maps of vessel densities identifying hot spot locations (i.e., highest vessel densities) are displayed in **Figure 6** and **Figure 7** and by survey in **Appendix C**.

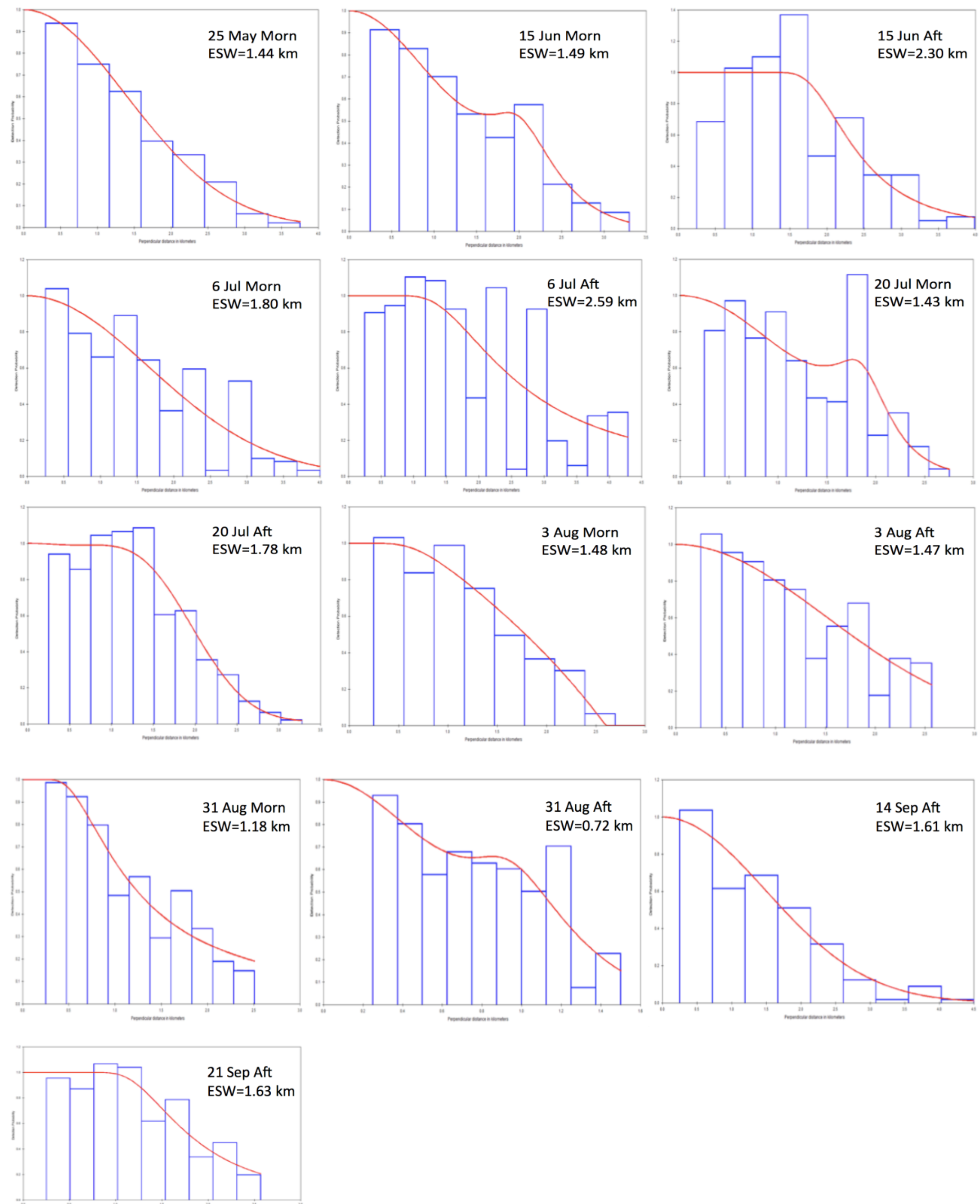

Figure 4. Perpendicular sighting distance plots and fitted models for each line-transect survey by date. Aft = afternoon survey, morn = morning survey, ESW = effective strip width, km = kilometers.

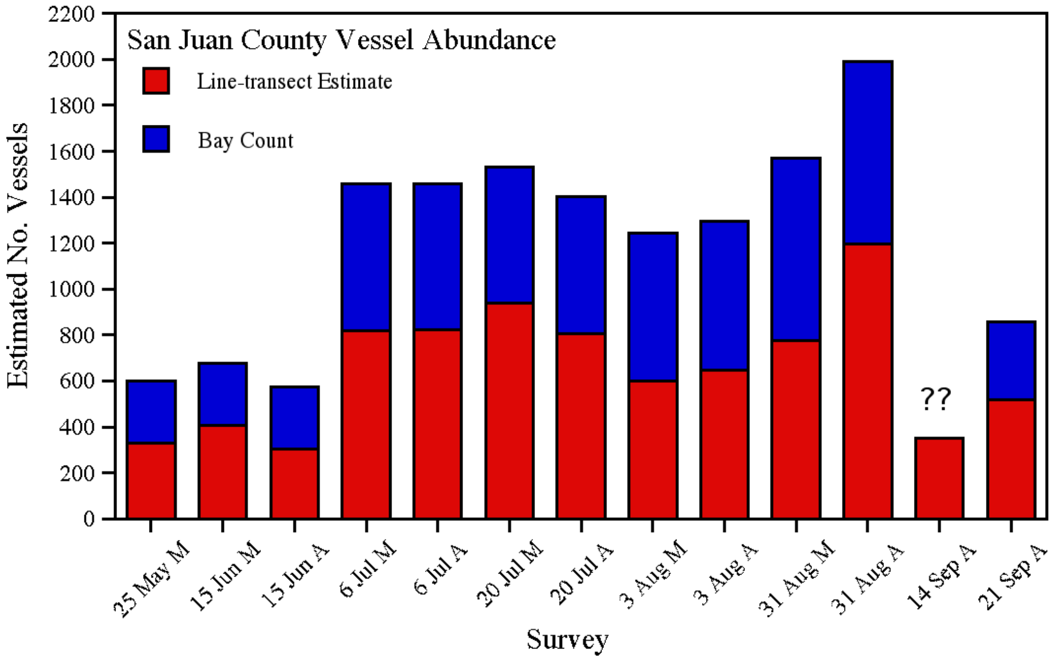

Figure 5. Final estimates of the number of vessels (not including those in marinas, and at docks) in the San Juan County study area by survey date.

Vessel hotspots identified from the transect and bay count data of the different surveys were essentially all in or near harbor/marina and Marine State Park areas, as follows: (1) Echo Bay (Sucia Island); Cowlitz Bay (Waldron Island); Prevost and Reid Harbors (Stuart Island); Roche Harbor, Westcott Bay, and Friday Harbor (San Juan Island); Blind Bay (Shaw Island); and Fisherman Bay, Port Stanley, and Hunter Bay (Lopez Island). Additional hotspots identified from the transect-only data (**Fig. 7**) included: the area around Johns Island, Deer Harbor (Orcas Island), and the southwest coast of San Juan Island, adjacent to the San Juan Islands National Historical Park, and an area known for salmon fishing. When examining the density hotspots from the pooled set of all surveys (**Fig. 6**), the highest-density areas were in tSucia Island, Stuart Island, and Fisherman’s Bay on Lopez Island.

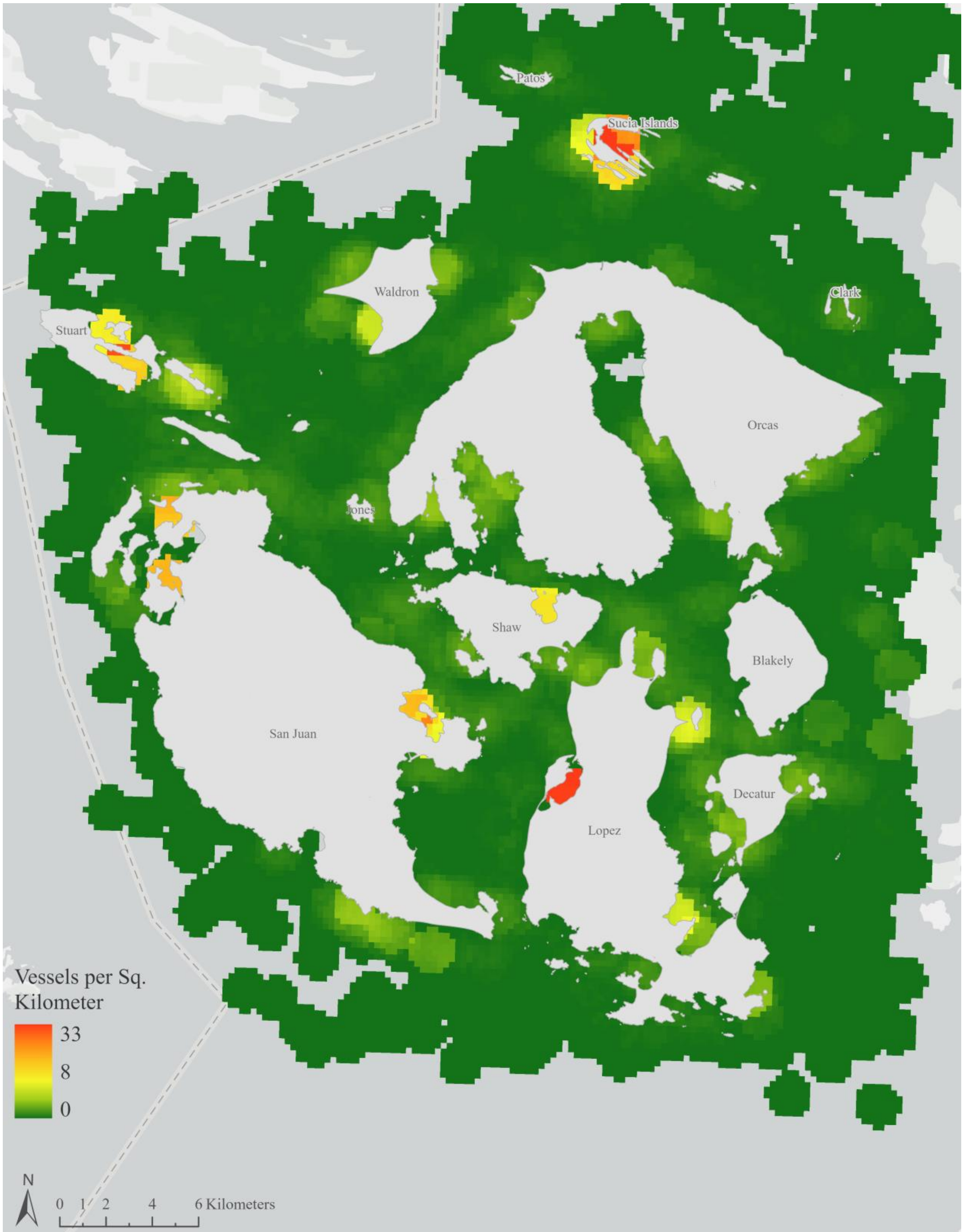

Figure 6. Vessel heat density map showing high-density vessel hotspots (shown in red and yellow) identified from pooled transect and bay count data. Lower vessel densities are represented by green color.

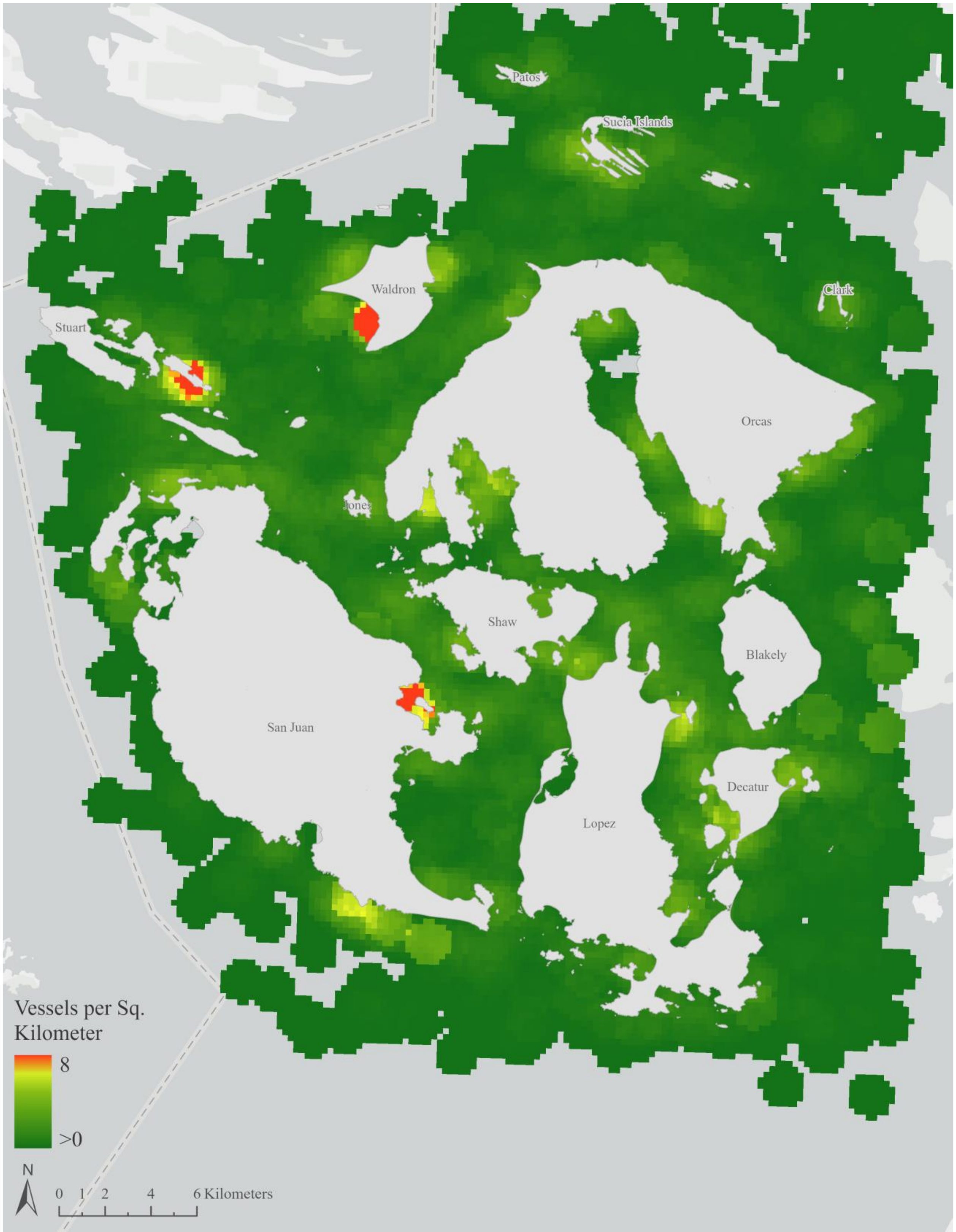

Figure 7. Vessel heat density map showing high-density vessel hotspots (shown in red and yellow) identified from transect-only survey data. Lower vessel densities are represented by green color.

3.4. Vessel Density Overlap with Marine Resources and Mooring Buoys

Heat maps of vessel density overlaid with the eight marine resources and mooring buoy locations are provided in **Figures 8-16. Appendix C** contains heat maps of vessel density by each of the eight survey dates and **Appendix D** contains zoomed-in maps of vessel density heat maps relative to selected marine resources of concern.

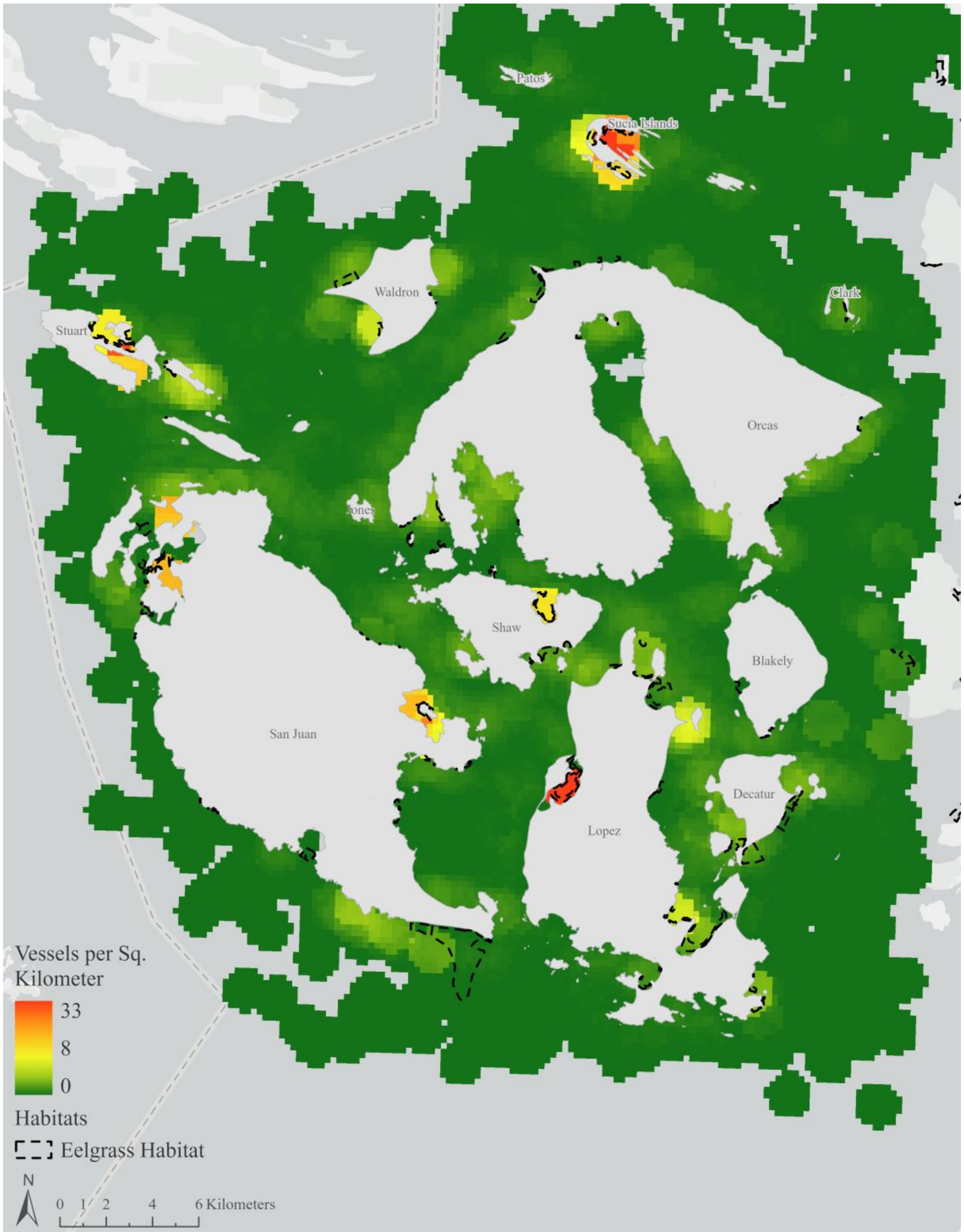

Figure 8. Locations of documented eelgrass beds relative to vessel densities based on results of aerial surveys conducted in the San Juan Islands study area.

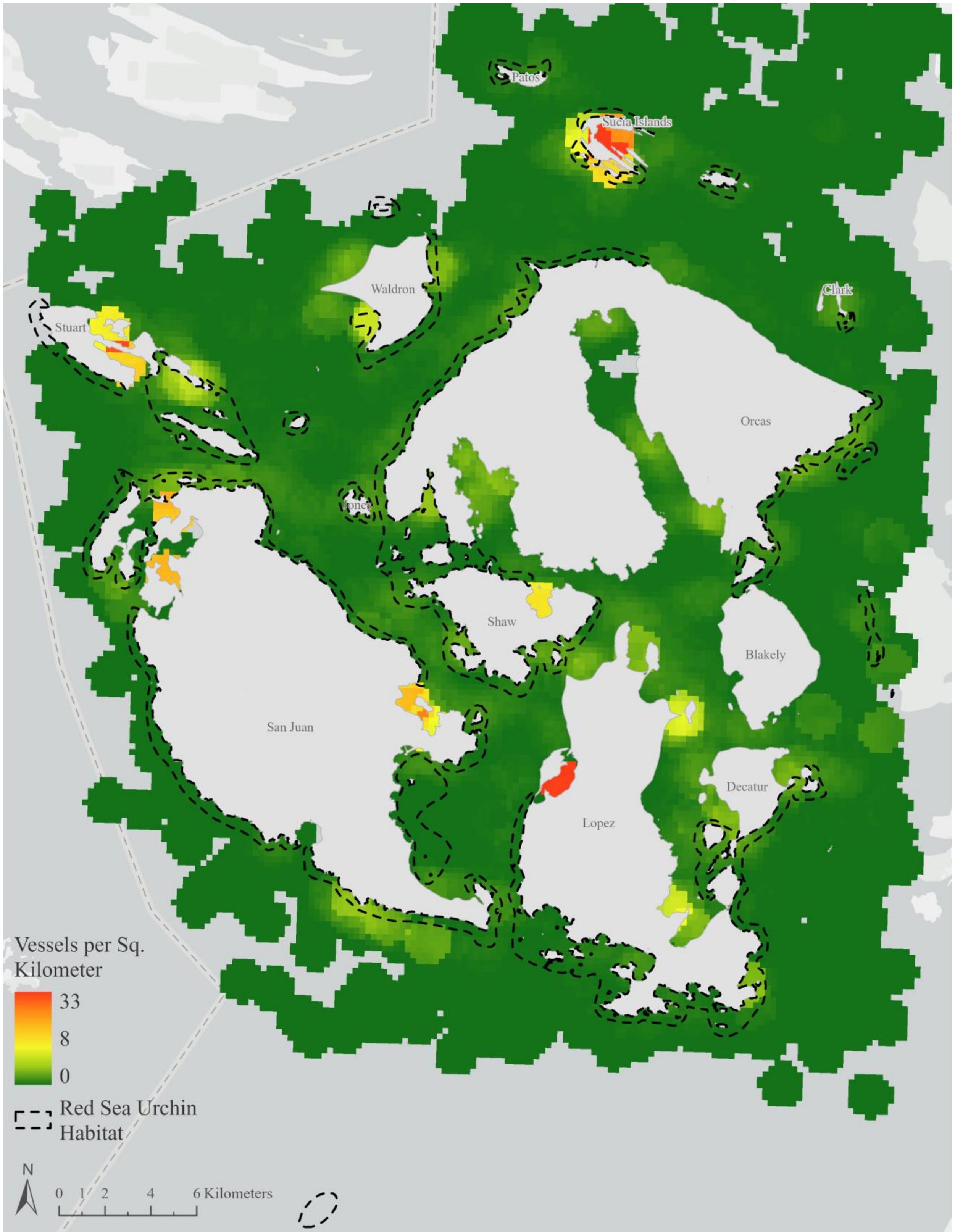

Figure 9. Locations of documented red sea urchin areas relative to vessel densities based on results of aerial surveys conducted in the San Juan Islands study area.

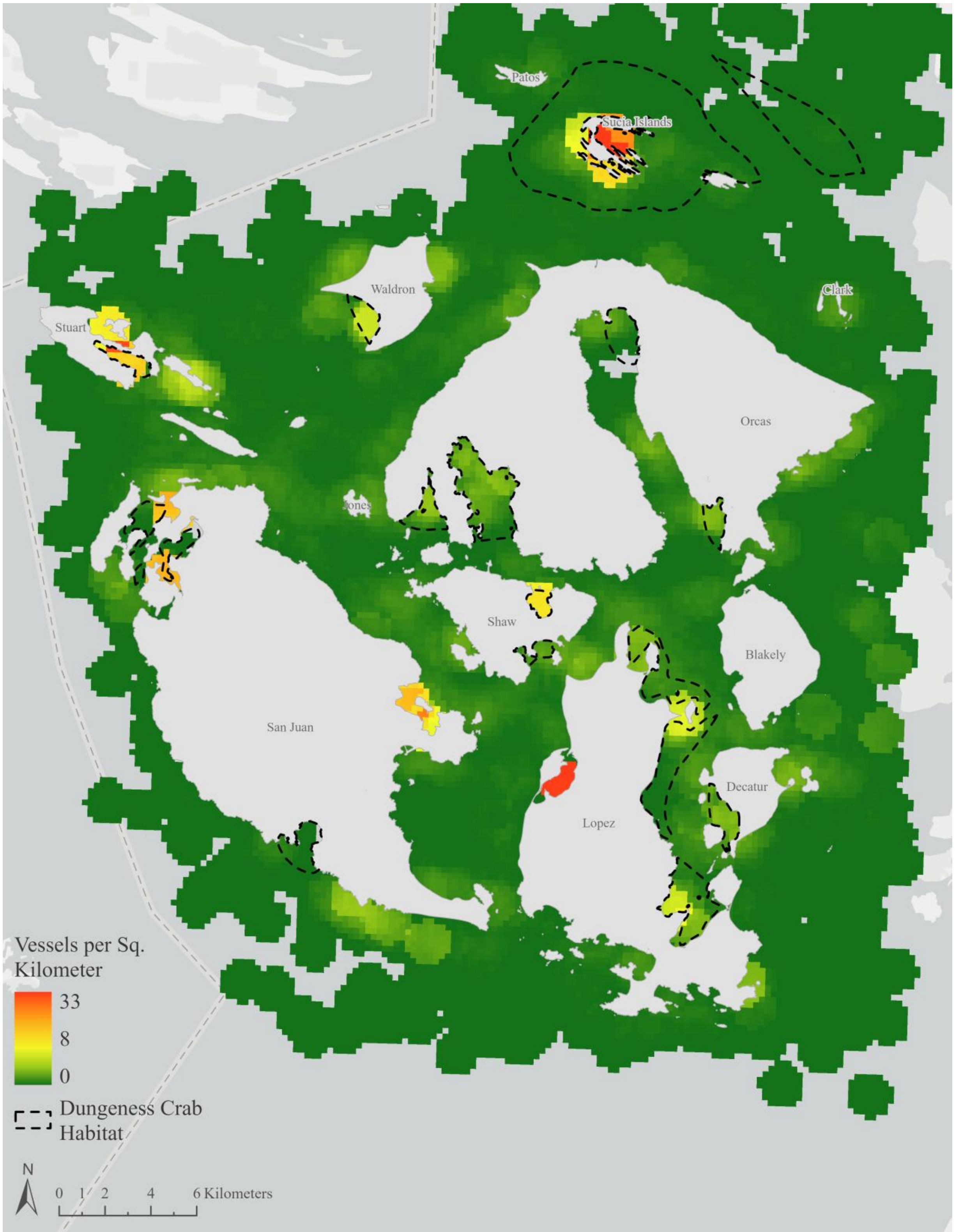

Figure 10. Locations of documented Dungeness crab areas relative to vessel densities based on results of aerial surveys conducted in the San Juan Islands study area.

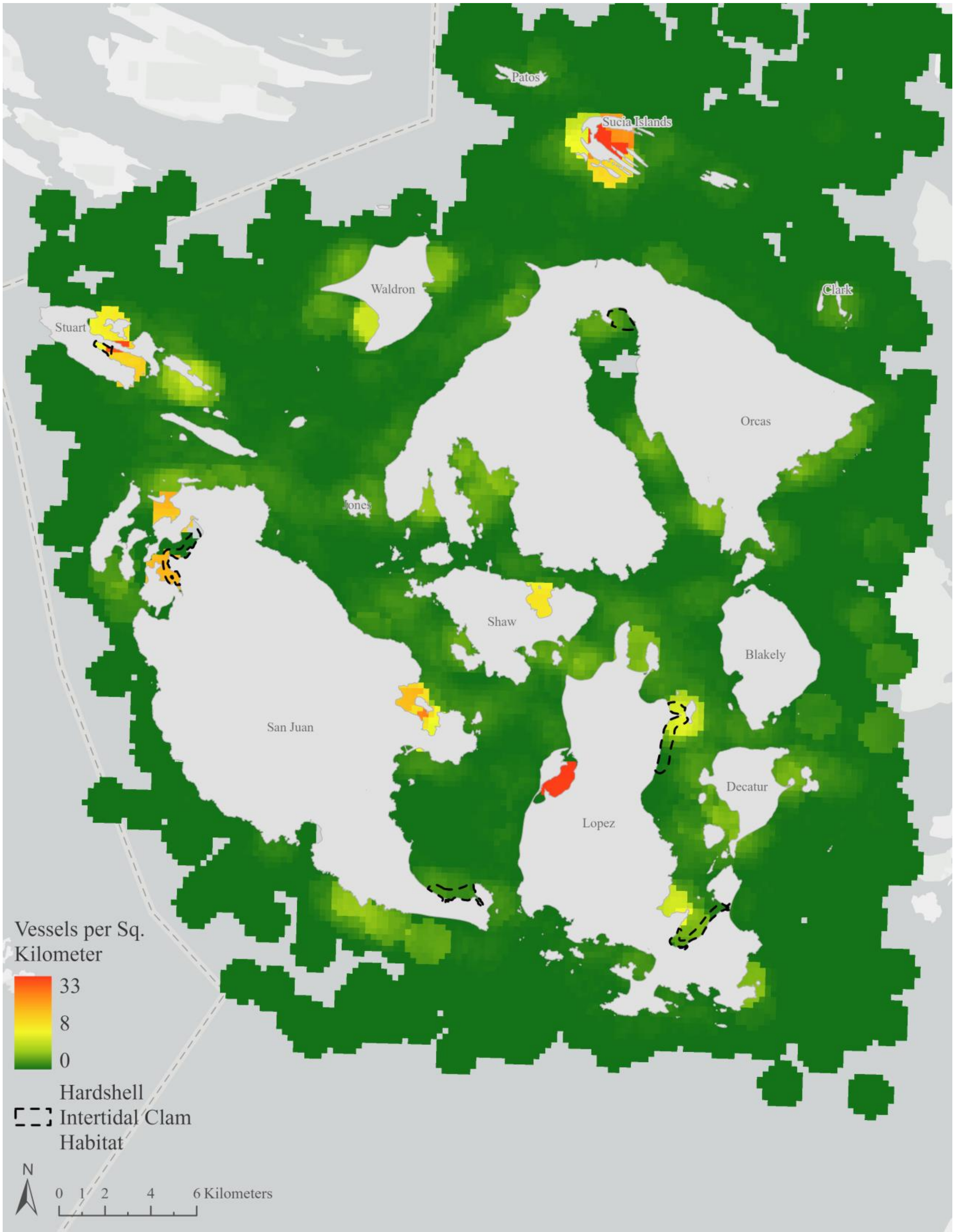

Figure 11. Locations of documented hardshell intertidal clam areas relative to vessel densities based on results of aerial surveys conducted in the San Juan Islands study area.

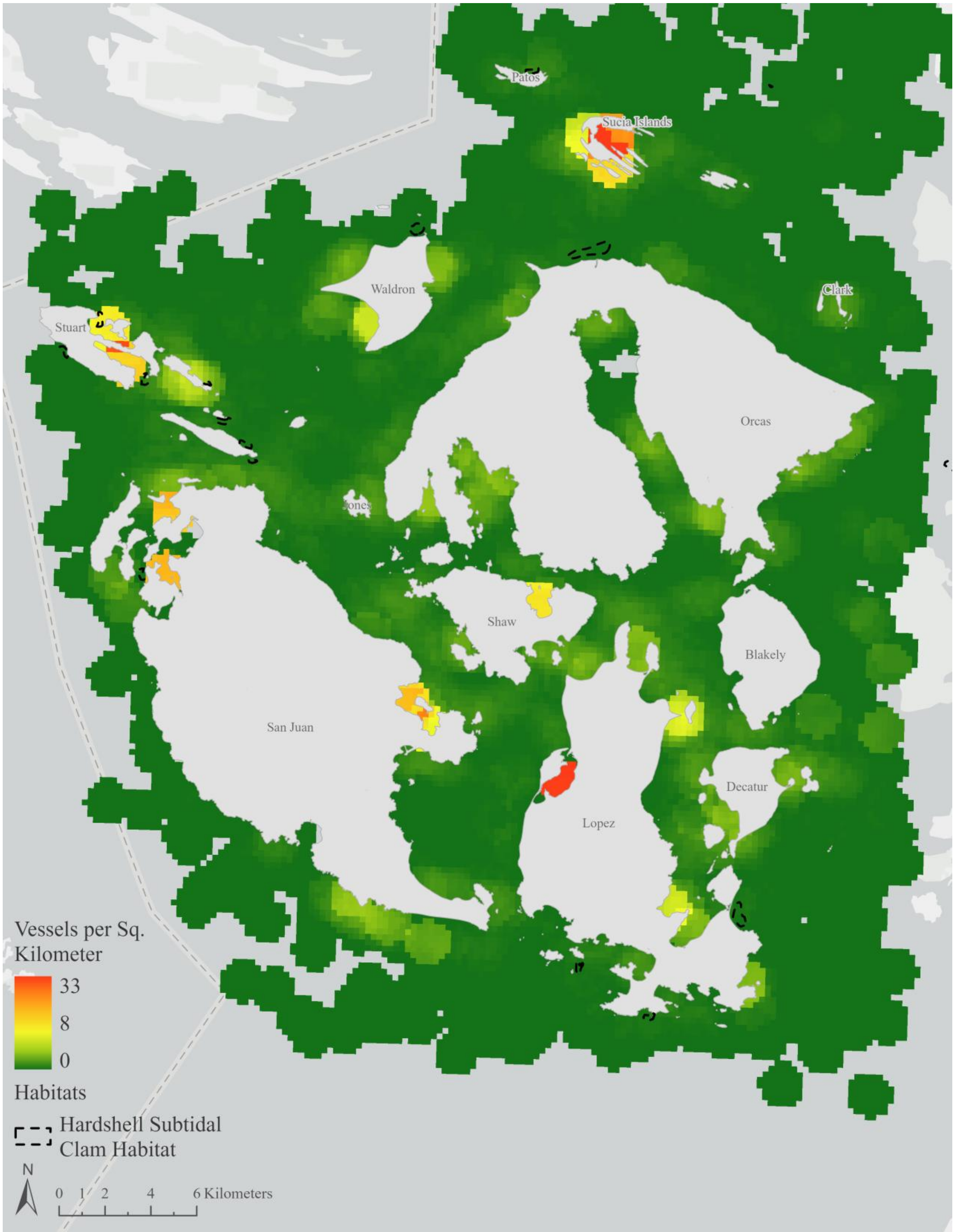

Figure 12. Locations of documented hardshell subtidal clam areas relative to vessel densities based on results of aerial surveys conducted in the San Juan Islands study area.

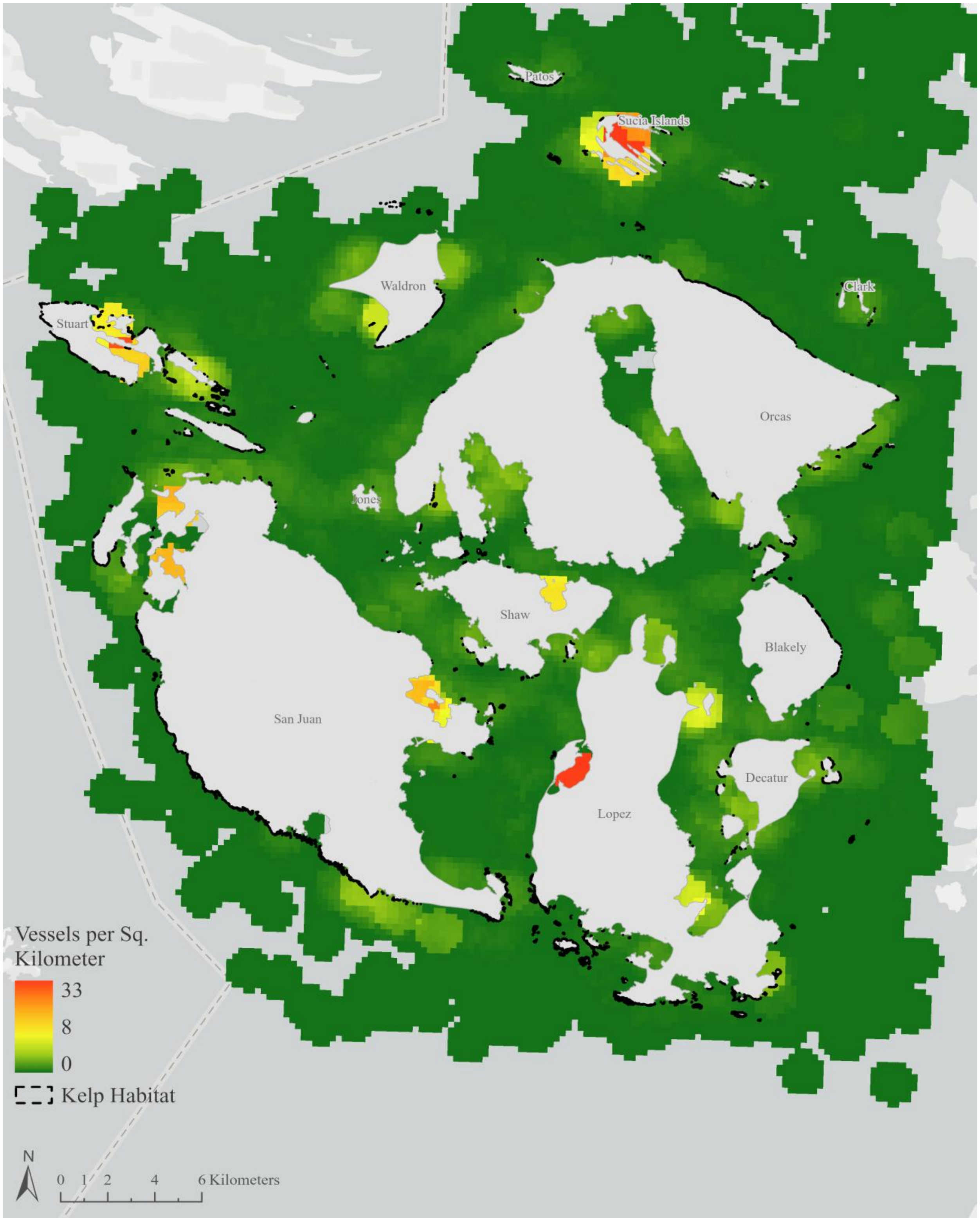

Figure 13. Locations of documented kelp bed areas relative to vessel densities based on results of aerial surveys conducted in the San Juan Islands study area.

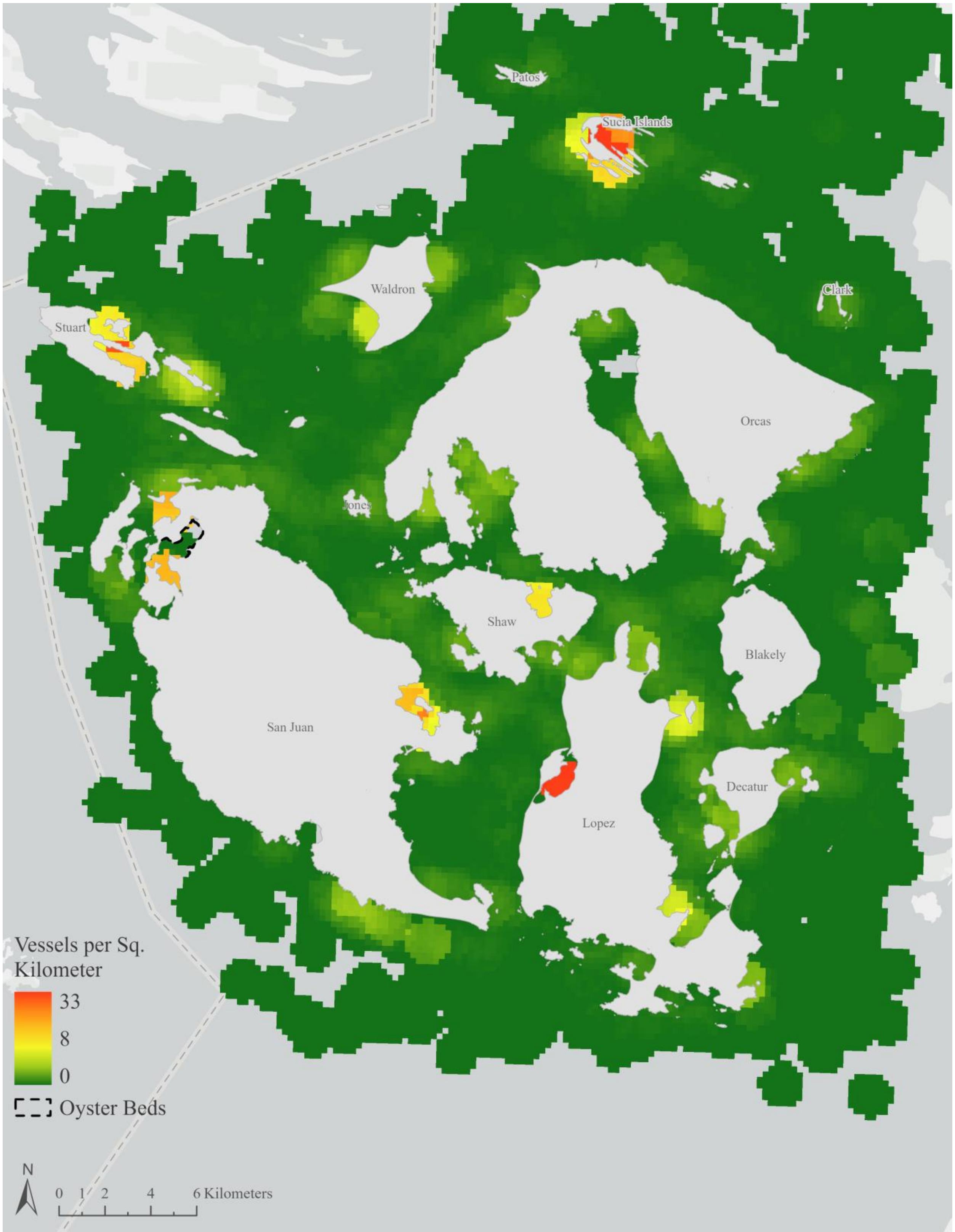

Figure 14. Locations of documented oyster bed areas relative to vessel densities based on results of aerial surveys conducted in the San Juan Islands study area.

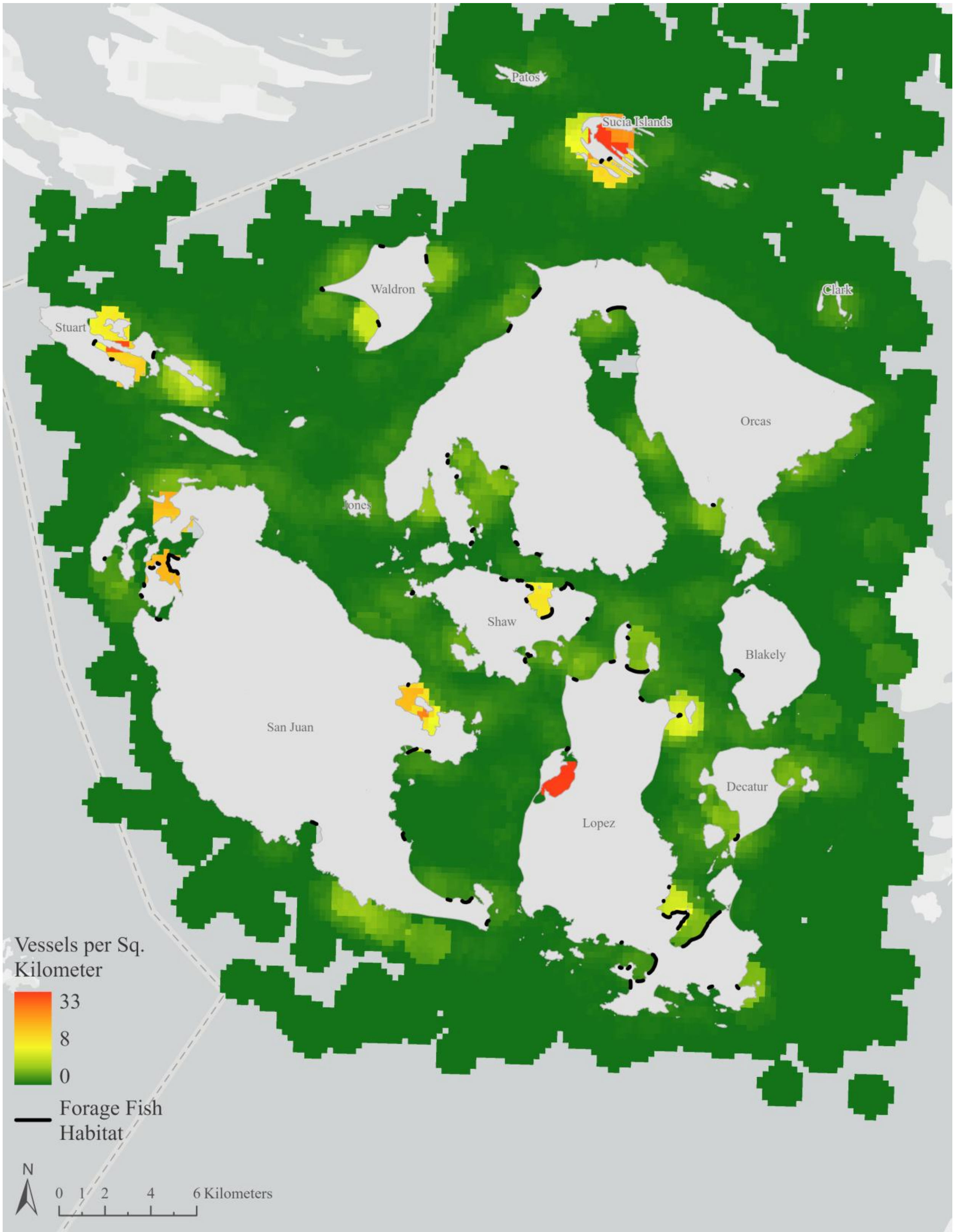

Figure 15. Locations of documented forage fish spawning habitat areas relative to vessel densities based on results of aerial surveys conducted in the San Juan Islands study area.

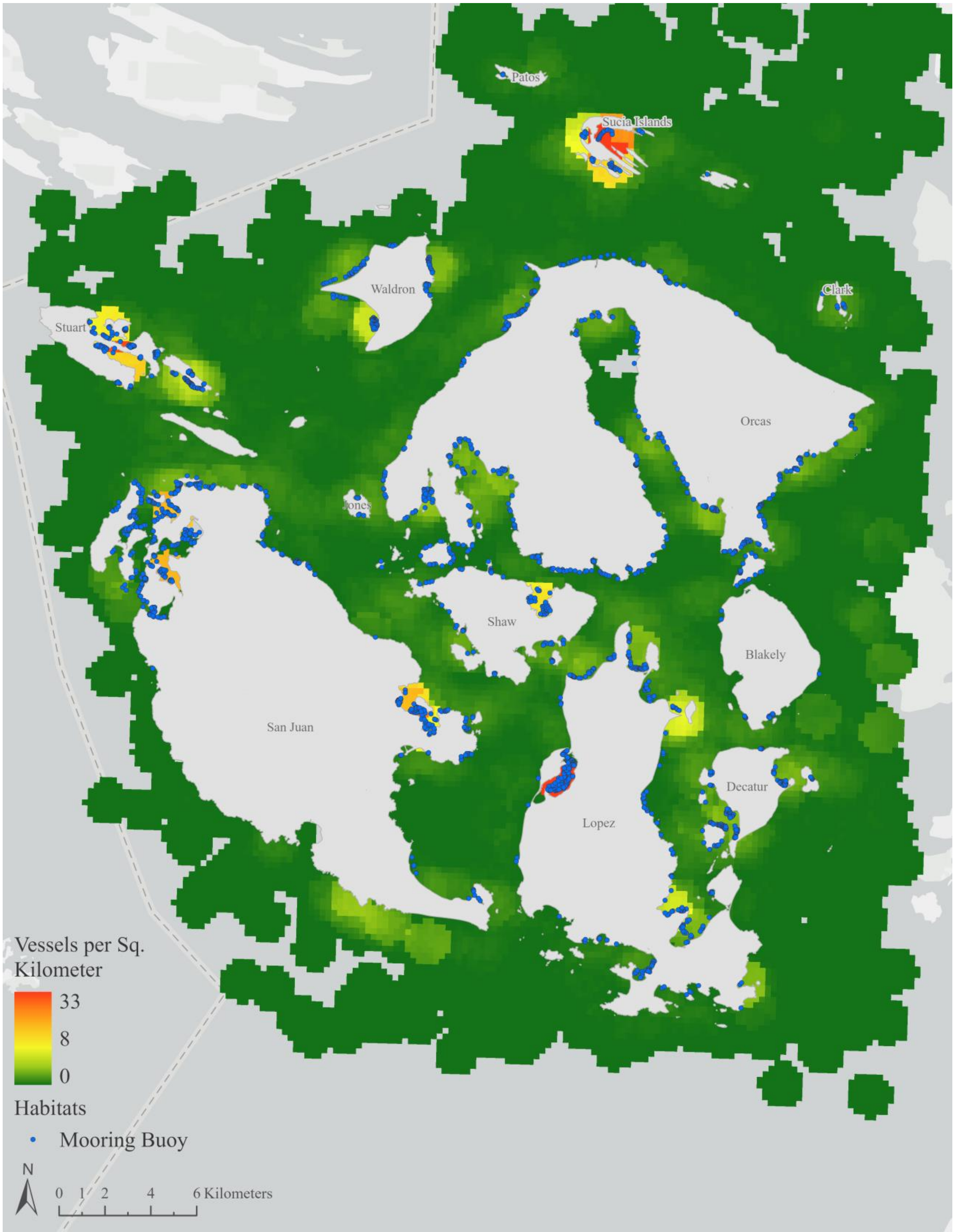

Figure 16. Locations of reported mooring buoys relative to vessel densities based on results of aerial surveys conducted in the San Juan Islands study area.

Eelgrass beds have a restricted range around the islands (**Fig. 8**) but showed a moderate to strong level of overlap with vessel hotspots around several of the islands (e.g. Sucia, Stuart, Waldron, San Juan, Shaw, and Lopez Islands). Considering their importance as spawning/nursery areas for some fish species (such as herring *Clupea pallasii,* and juvenile Chinook salmon *Onchorhynchus tshawytscha*), this overlap with high vessel densities is a particular conservation concern. Kelp beds are moderately extensive in the region but generally occur along outer exposed coastlines (**Fig. 13**). There was little overlap with areas of high vessel densities, but the area along the southwestern coast of San Juan Island showed some overlap with kelp beds.

Red sea urchins have an extensive range in the region and tend to occur on more open exposed coastlines, rather than in harbor and marina areas (**Fig. 9**). However, the ubiquitous occurrence of sea urchins throughout the islands means that some overlap with areas of high vessel densities do occur, primarily on San Juan Island (e.g., in Roche Harbor, Westcott Bay, and along the southwestern coast of San Juan Island).

Dungeness crabs have a moderately extensive distribution in the islands (**Fig. 10**). Dungeness crab areas showed strong overlap with moderate- to high-density vessel hotpots around all the islands characterized by this resource (i.e., Sucia, Stuart, Waldron, San Juan, Shaw, and Lopez Islands).

Hardshell intertidal clams have a limited range in the islands (**Fig. 11**) and showed a weak overlap with vessel density hotspots, essentially only occurring in Roche Harbor, Westcott Bay, and Port Stanley (San Juan and Lopez Islands). On the other hand, hardshell subtidal clams are only found in a few places in the islands (**Fig. 12**), and none of these showed a strong overlap with areas of high vessel density.

Similar to hardshell subtidal clams, oyster beds have a very limited distribution in the islands (apparently only present in Roche Harbor). In general, the available data for this resource showed a weak overlap with high-density vessel locations (mainly due to some overlap in Roche Harbor) (**Fig. 12**).

Forage fish spawning habitat along shorelines are mostly located in enclosed bays where there are suitable pocket beaches but are also scattered in various areas throughout the San Juan Islands (**Fig. 15**). There was a fairly extensive degree of overlap of these areas with the high-density vessel areas.

Mooring buoys overlapped mostly with high-density vessel areas, as might be expected (**Fig. 16**).

4. Discussion

This study demonstrated several important points. First, it showed that distance-sampling methods (and line-transect analysis, in particular) are well-suited to estimating the number of vessels at sea in relatively open areas in which survey platforms have a good view of the water. Secondly, it showed that summer weekends, and in particular, holiday weekends, are characterized by very large numbers of vessels in San Juan County waters. These are on the order of 1,200-1,500 vessels for most summer weekends, with an apparent peak in numbers (at around 2,000) on Labor Day weekend, followed by a dramatic drop thereafter. These patterns are not surprising, but the sheer number of vessels on the water at this time of year is of concern.

Results of this study indicate a need for further study of eelgrass bed declines relative to potential adverse impacts of high numbers of vessels. Results also point to the need for research to evaluate the impacts of vessel density on other aspects of local flora and fauna. While more detailed work on this issue still needs to be done, we have been able to conduct a preliminary analysis by subjective comparison of vessel density hotspots with documented locations for various marine resources of concern to the County and Coast Salish tribes with sovereign treaty fishing areas in the islands (see **Figs. 8-16**). This analysis suggests that there are some marine resources that may be impacted by the high number of vessels using this area on summer weekends and holidays, due to moderate to strong overlap of these resource locations with areas characterized by vessel hotspots that we identified in this study. Among these are Dungeness crab, red sea urchin, and eelgrass, the latter which provides important habitat for fish spawning and rearing, as well providing vital habitat for other environmentally, economically, and culturally important species.

Our study appears to be one of the first to use distance-sampling methods (i.e., line-transect or strip-transect) to estimate density and/or abundance of vessels at sea. An extensive search of the literature (including the primary textbooks, Buckland et al. 2004, 2015), which included searches in the Distance Sampling group's online searchable bibliography: https://distancesampling.org/dbib.html produced only one match (Mayaud et al. 2024). In fact, our searches only found three additional references to previous studies that used distance sampling to estimate any non-biological objects at sea. In all three cases these studies estimated abundance of floating debris (Lecke-Mitchell and Mullin 1992, 1997; Williams et al., 2011). Therefore, it appears that our study may have been the first or second to produce estimates of density or abundance of vessels at sea by distance sampling, and as such represents an important demonstration of the utility of this method for determining at-sea abundance of non-biological objects.

The only comparable previous study used similar aerial surveys to conduct vessel counts for the San Juan Islands in June through September 2010 (Dismukes et al. 2010). However, the latter study attempted to obtain complete counts and did not properly account for vessels that may have been missed/not detected. As we have seen from our work, complete counts of vessel numbers using aerial surveys are difficult to achieve, at least on days when there are many vessels on the water. Dismukes et al. (2010) obtained an average estimate of 1,118 vessels on the water for weekends and holidays in summer months during 2010. While there are some methodological differences between their study and ours, we can broadly compare our results. Our average estimate of total vessels in the islands during their study period (12 June - 5 September) was 1,537 vessels, significantly higher than theirs. This suggests either that their result was an underestimate, or that vessel numbers have increased since 2010, or more likely both.

4.1. Study Limitations / Recommendations

This study only provided information on vessel numbers and density during eight busy summer-season weekends. Data on weekday numbers and outside the busy summer season were not collected. Thus, information from this study should not be considered representative of vessel numbers in the area in general.

As this study was apparently the first to use distance-sampling methods to estimate densities and numbers of vessels at sea, we were in many ways breaking "new ground" and we did not have an extensive body of knowledge to go on. We proceeded with the concept that using these methods for estimating vessels would be very similar to how they are used to estimate marine mammal densities. Our approach, therefore, was based primarily on the very large body of knowledge on distance sampling for marine mammals. The main sources of bias in line-transect surveys include detectability and availability, where detectability is how visible an object is to detect, and availability is whether the object is available to count when in the field of view.

In many ways, surveying for vessels is more straightforward than it is for marine mammals. Vessels do not dive (submarines excepted) and therefore availability bias is not a significant concern. Also, vessels tend to move in relatively predictable patterns and are designed to be visible at the surface, making detection easier and more reliable. For objects such as marine mammals, detectability bias may be introduced by environmental or behavioral factors influencing how well an observer can see the animal on the track line. Factors that may introduce such bias include Beaufort sea state, glare, or fog, while behavioral factors may include group size. Availability bias is introduced if an animal is on the trackline in the field of view but hidden from view (e.g., is diving below the surface). For the subjects of this study (vessels) we do not expect availability bias to be a concern as vessels should always be at the surface and therefore available to count. Likewise, due to the generally larger size and conspicuousness of vessels (often with bright or reflective colors), detectability bias is expected to be much reduced. However, smaller paddle-powered vessels (e.g., kayaks), especially those traveling independently, are likely to be harder to detect compared to large recreational cabin cruisers, ferries, barges, or shipping traffic. The detectability, especially of these smaller vessels, is expected to substantially decrease the further they are from the track line. In line-transect analyses, this bias is addressed through computation of the detection function f(0) (see Buckland et al., 2004; Jefferson et al. 2016, 2022 for examples). Perception bias could still be an issue with vessels, but we tried to minimize this by only surveying when weather and visibility conditions were good.

Probably the main limitation of this study was that there were so many vessels on most of the surveys that it was challenging for the observers to call them all out, and for the data recorder to record all the data. The use of voice recorders in the airplane helped to minimize this issue. However, we suspect there were times when we simply could not get all the visible vessels recorded. Transiting the survey lines at slower speeds would be a way to solve this problem, but fixed-wing aircraft need to maintain a relatively fast minimum flight speed to avoid stalling; this is a major safety concern.

There was some limitation caused by the proximity of Canadian air space to the west side of San Juan Island and the western edges of the County. Our pilots were not allowed to enter Canadian air space when flying at 457 m (1,500 ft) and therefore had to initiate turns prior to the ends of the majority of the transects on the western edges. This meant that observers were unable to observe or collect data for boats observed off the west side as effectively, which likely resulted in an undercounting of vessels there. However, as long as the density of vessels there does not differ much from that in other parts of the survey area, there will be no corresponding underestimation of vessel density and abundance from the line-transect surveys.

Since we have shown that distance-sampling methods work well for estimating vessel density and abundance, we recommend that future work use the methods we have developed to conduct work to estimate overall number of vessels for the area year-round. This would require research with surveys in all four seasons (not just summer) and during weekdays and weekends. Such information could be especially useful not only for further work looking at vessel presence impacts on eelgrass beds and other habitats, but also for determining the impact of vessels on endangered wildlife, such as the federally endangered SRKW population. We also suggest the potential use of drones to count and live-monitor vessels in the study area as a potentially more economic method of study, though current technology for low-cost drones limits the distance from which small drones can be operated as do high wind conditions. Simultaneous shore-based or multiple simultaneous small vessel-based surveys of other vessel numbers and activities is another method that may be of use, though these approaches likely represent a higher risk of re-counting the same vessels, unlike aerial survey which can cover a large survey area in a relatively short period of time.

5. Conclusions

This study is a first of its kind for the San Juan Islands area. Previous work evaluating the number of vessels in the area during the busy summer months, besides being somewhat outdated, suffered from methodological deficiencies that probably resulted in the underestimation of vessel numbers. Our approach, using more sophisticated distance-sampling methods, is considered to provide a better assessment of the number of vessels on the water during our summer 2024 study period.

When examining the identified high-density vessel hotspots by survey date (see **Appendix C**), one can see a general increase in both the number and size of the vessel hotspots from May through June, then an apparent coalescing of hotspots into smaller numbers (but covering larger areas) from July through August, and finally a reduction in both numbers and size of the vessel hotspots in September. This pattern is not unexpected but seeing the data this way provides a good indication of the very high impacts that might be expected from such large numbers of vessels operating in the area, especially during the peak months of July and August.

Follow-up work to evaluate more thoroughly how these large numbers of vessels are affecting marine resources of concern and value, such as Dungeness crab, eelgrass, and SRKW are needed. We hope that this project has provided a good background for such work and provides researchers with the information needed to develop such focused studies, which are essential for protecting the area's precious marine resources.

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WA DNR (Washington State Department of Natural Resources). 2024. "Puget Sound Eelgrass Monitoring Data Viewer". Website accessed 5 December 2024: https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/puget-sound-eelgrass-monitoring-data-viewer.

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APPENDICES

Appendix A – Vessel Identification Guide

Vessel and Boat ID Guide for San Juan County Aerial Surveys 2024

<table>
<tr><td>Cargo / Tanker

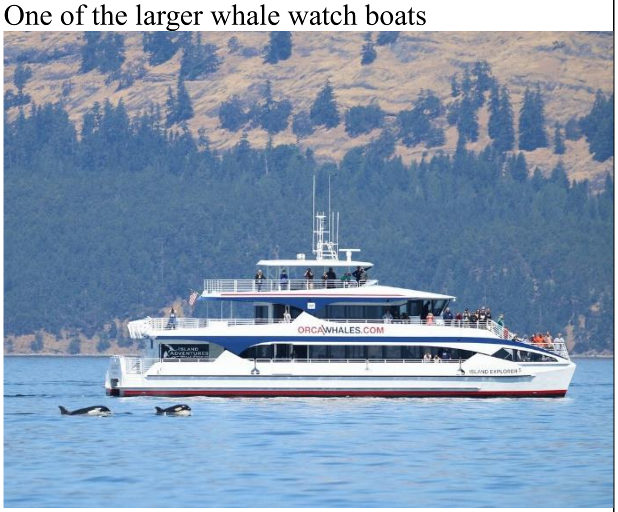
</td><td></td></tr>
<tr><td>Tug with/without barge

</td><td></td></tr>
</table>

<table>
<tr>
<td>Ferry
</td>
<td>(unlikely to see a BC ferry but we did have one off the west side of San Juan June 15).
</td>
</tr>
<tr>
<td>Military/Coast Guard
</td>
<td></td>
</tr>
<tr>
<td>Commercial Fishing
</td>
<td></td>
</tr>
</table>

Tour Boat (Whale watch boat)
This is the only US red Zodiac, other orange and red ones are a little smaller and canadian

One of the larger whale watch boats



Sailboat/Catamaran

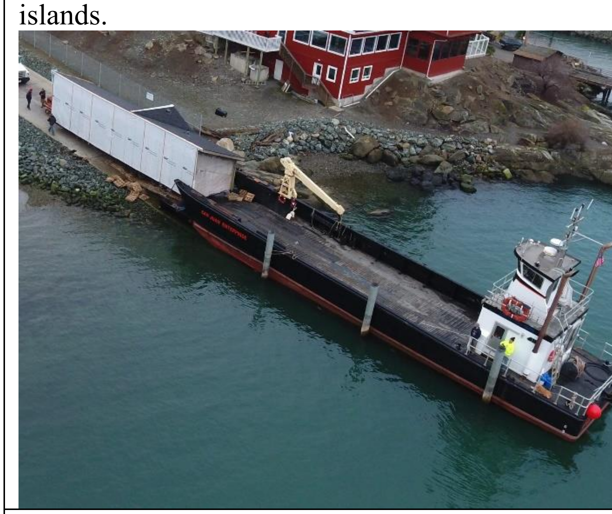
Yacht >65' These large yachts are rare but do occur in the islands. 	
Cabin Cruiser large 36-65' 	

Cabin Cruiser small 20-35’ 	
	
Recreational fishing <26’ This size is probably the most common in the islands. They are not just fishing boats but the regular commuter between islands.  	If the boat is actively fishing, report it’s activity as fishing, if not then as underway/anchored/moored. 

<table>
<tr>
<td>Recreational Fish size continued
</td>
<td>
</td>
</tr>
<tr>
<td>Recreational skiff open

</td>
<td>

</td>
</tr>
</table>

Kayak / Paddle 	
Other These smaller barges are used in the islands to transport fuel, and materials (houses etc) to outer islands. 	This mini cruise ship also turns up in the islands 
These old tugs now turn up, mostly as Charter boats. This one is mostly in Alaska in the summer 	

Appendix B - Embayments for Vessel Bay Counts while Aircraft Circled

San Juan County Key Bays for Total Boat Counts

Sucia Island (Marine State Park):

1. Shallow Bay
2.
    A. Echo Bay
    B. Fossil Bay

Stuart Island (Marine State Park):

3. Prevost Harbor
4. Reid Harbor

Jones Island:

5. Marine Sate park – (bay on northeast end of island)

San Juan Island:

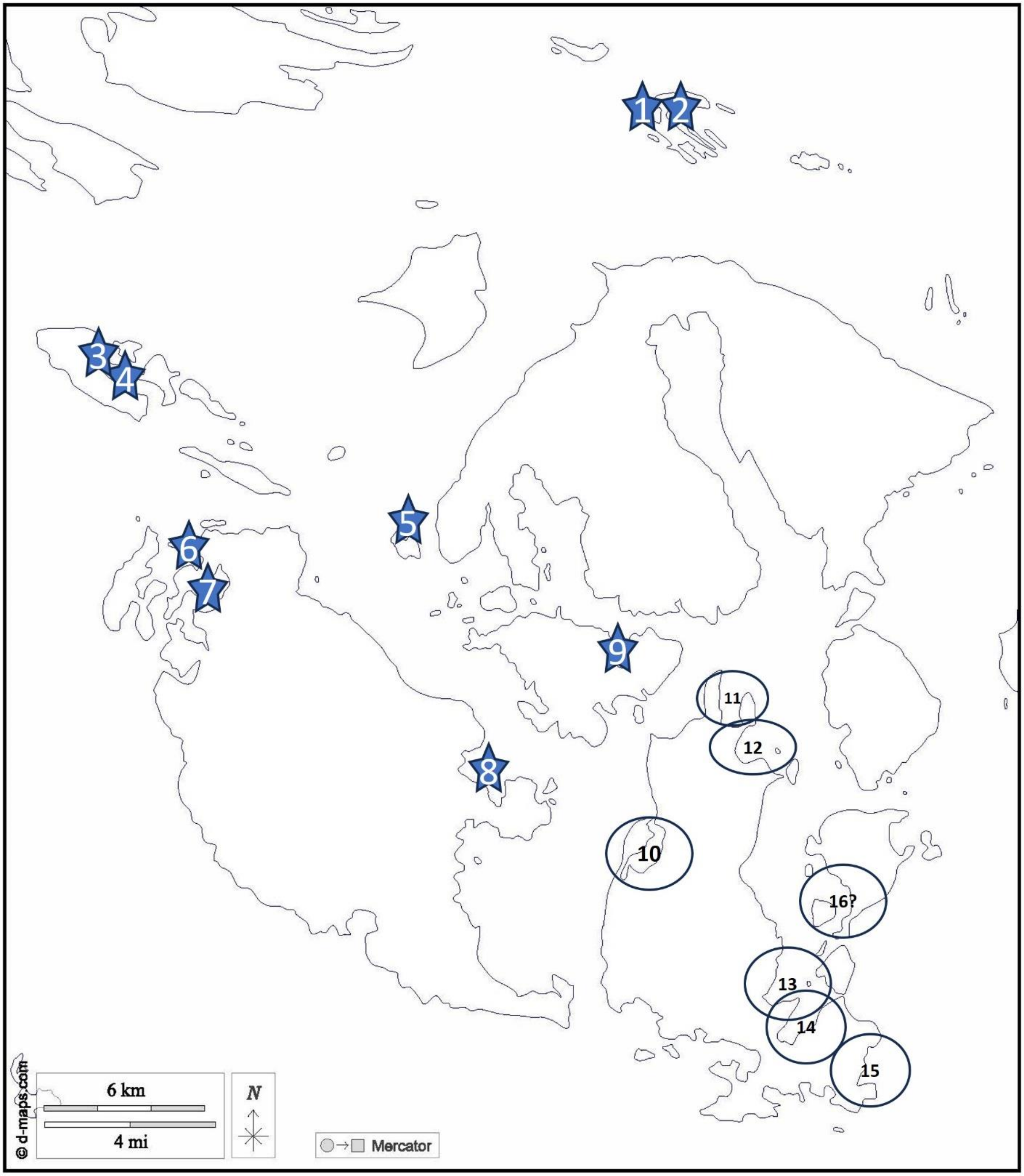
6. Roche Harbor
7.
    A. Westcott
    B. Garrison Bay (National Park)
8. Friday Harbor
    A. Shipyard Cove (south end)
    B. Friday Harbor (central)
    C. Beaverton Cove (north end

Shaw Island:

9. Blind Bay

Lopez Island:

10. Fisherman's Bay
11. Spencer Spit (Marine State Park)
12. Shoal Bay
13. Hunter Bay
14. Mud Bay
15. Watmough Bay (BLM and County Landbank preserves)
16. Decatur Island (this is a possible circle – depends on time and number of boats)


1
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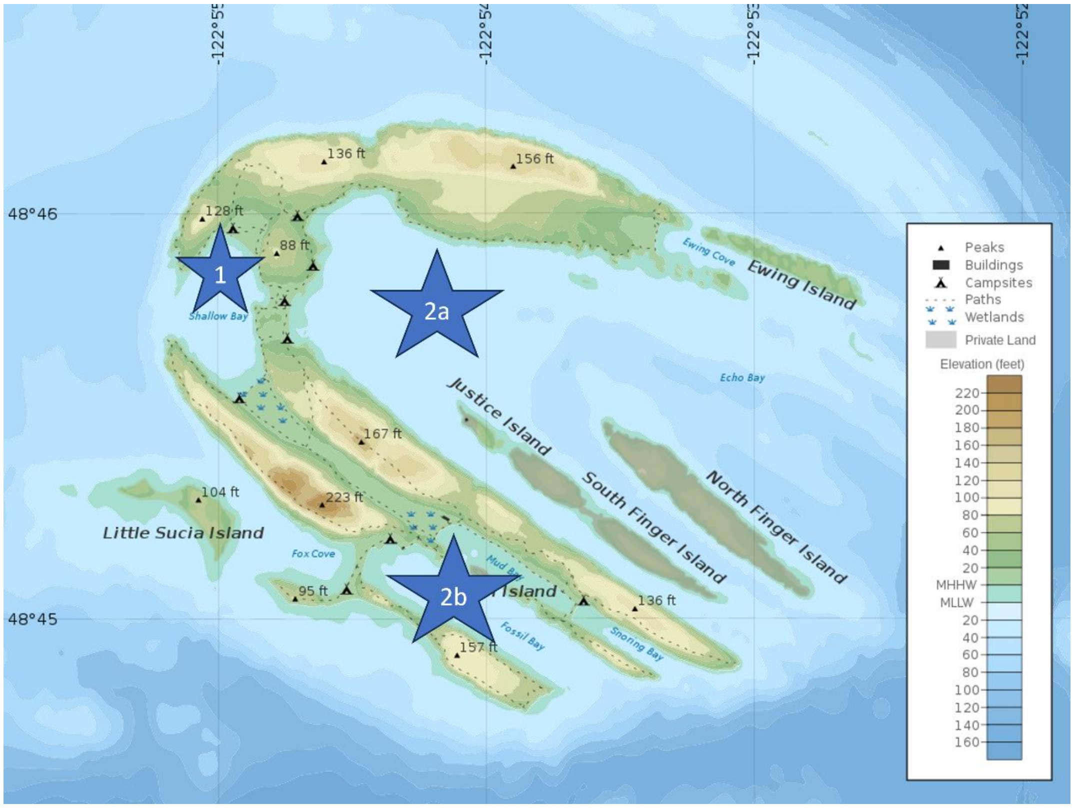
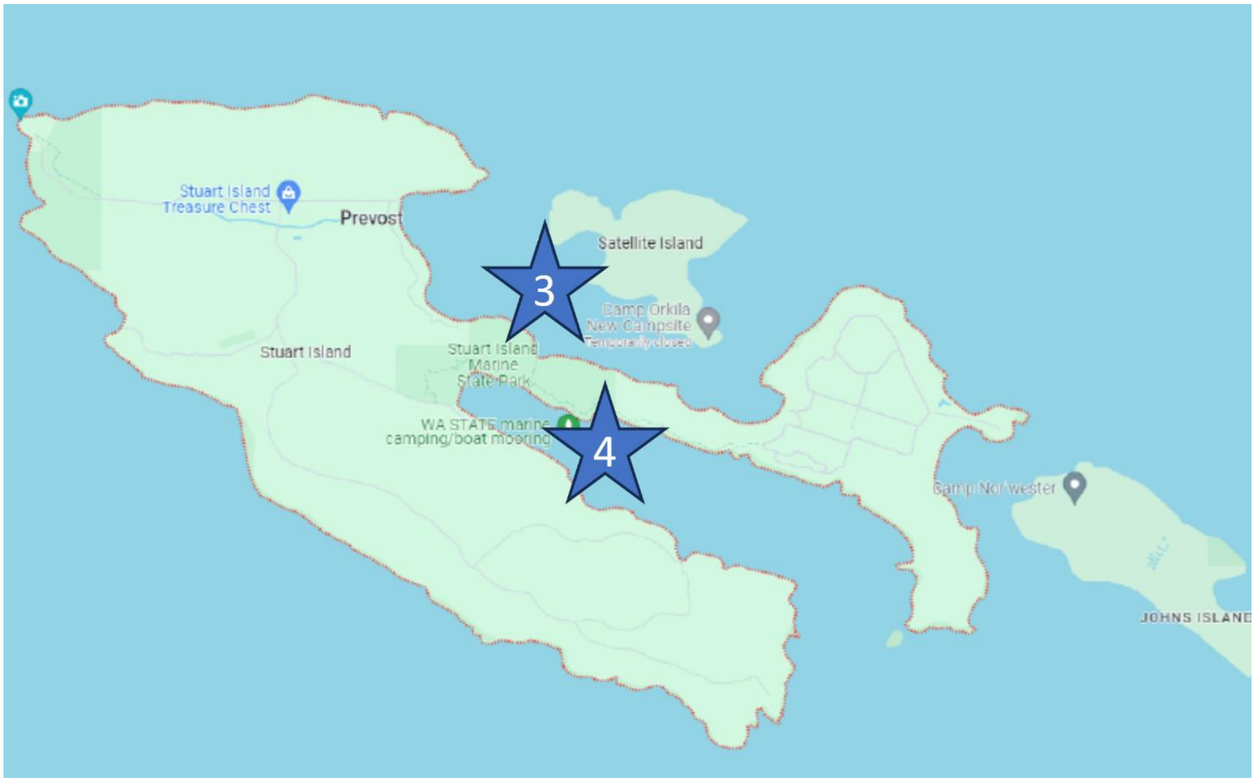
14
15
16?
© d-maps.com
6 km
4 mi
N
Mercator

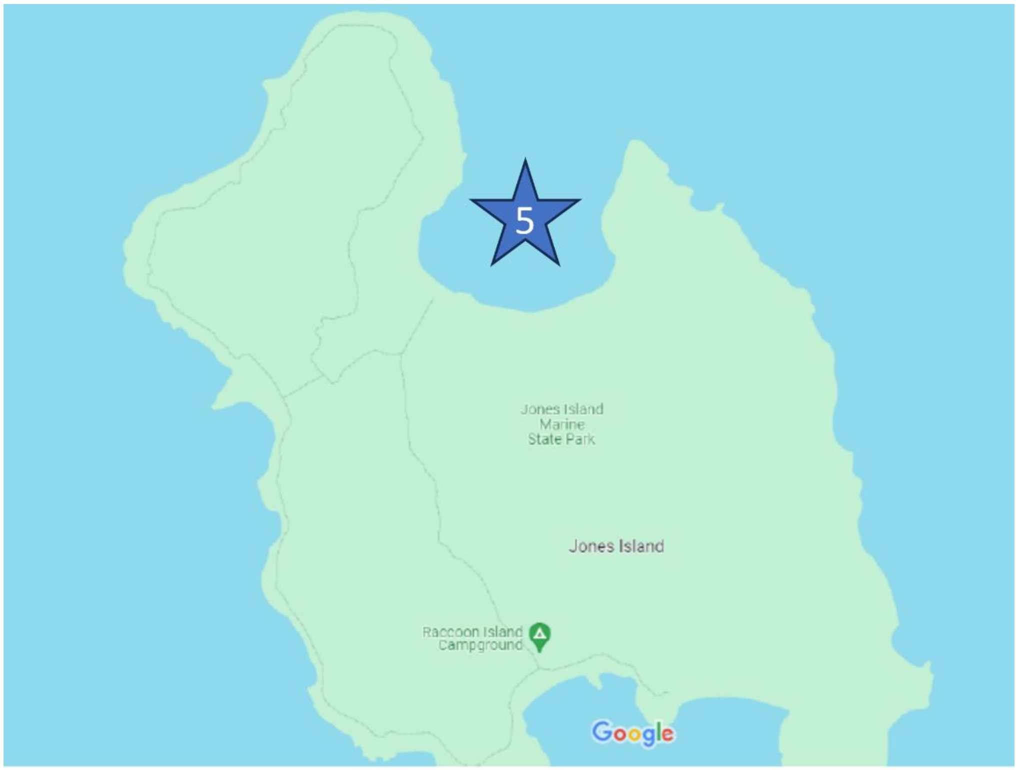
Sucia Island Bays: Shallow Bay (1), Echo Bay (2a), Fossil Bay (2b)



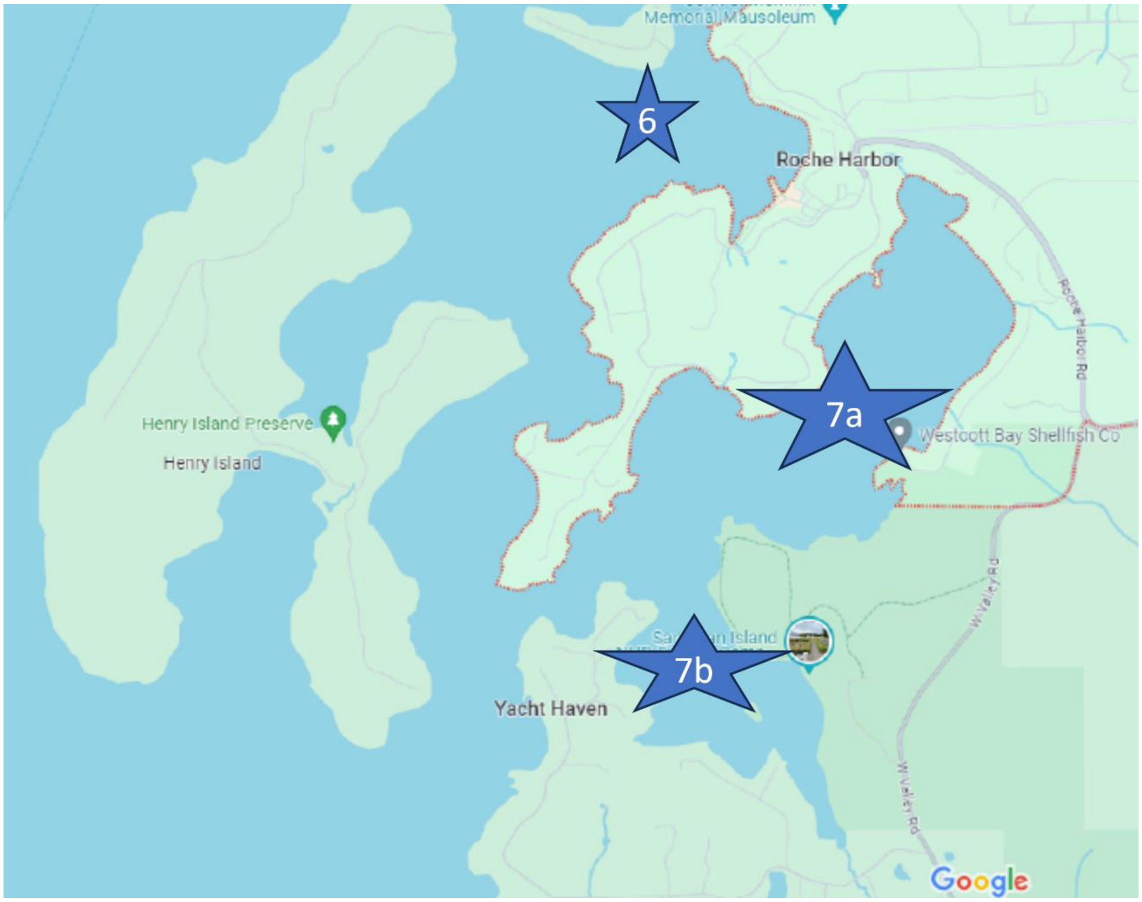
Stuart Island Bays: Prevost Harbor (3) Reid Harbor (4)



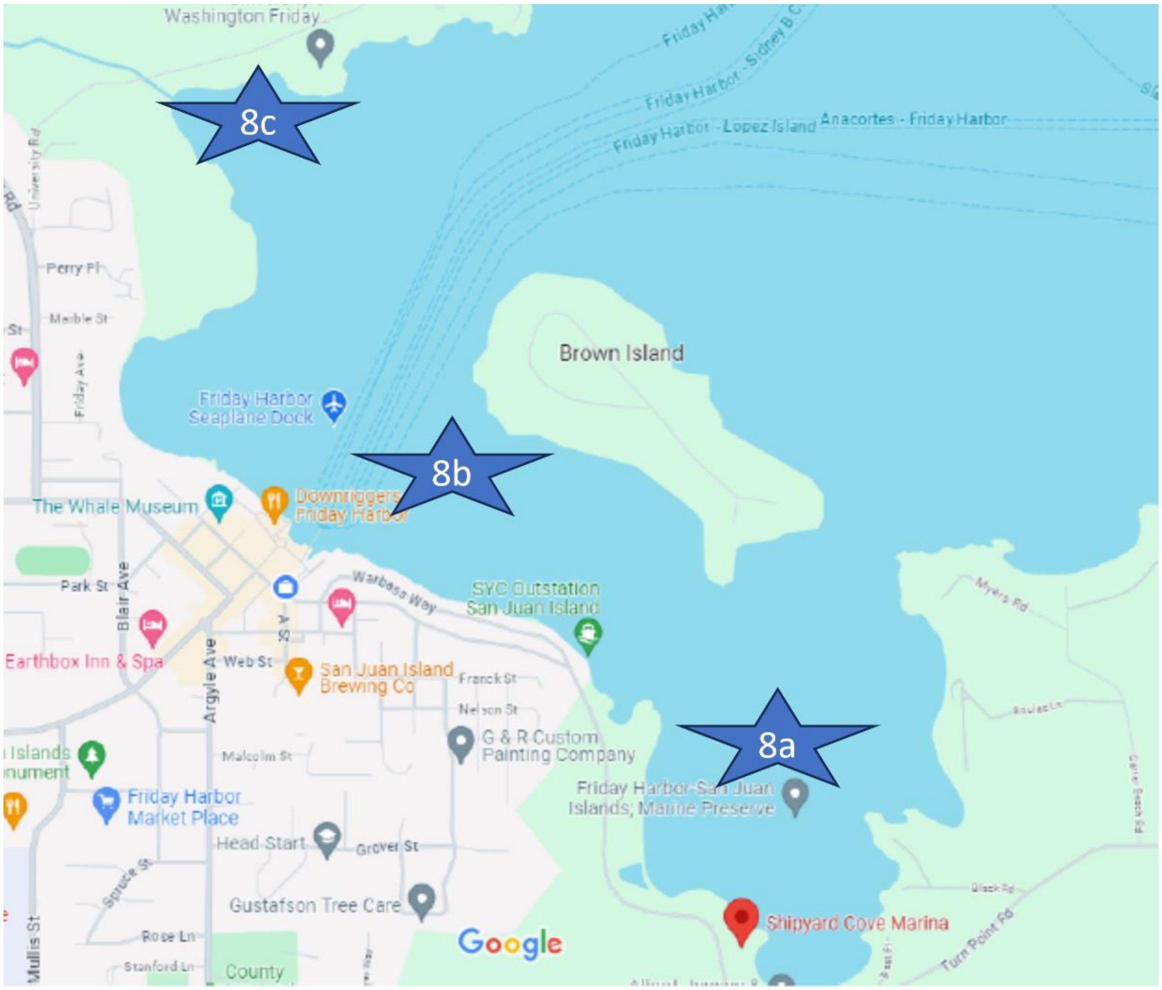
Jones Island (5)



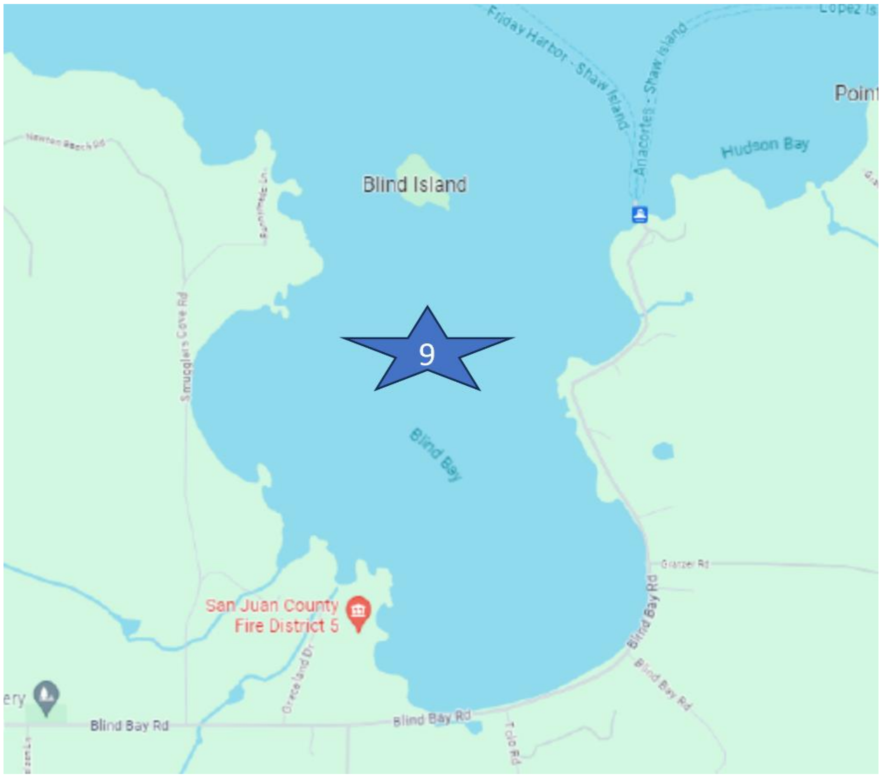
San Juan Island Bays North: Roche Harbor (6) Westcott Bay (7a), Garrison Bay (7b)



San Juan Island Bays South: Shipyard Cove/south (8a), Friday Harbor (8b), Beaverton Cove (8c)

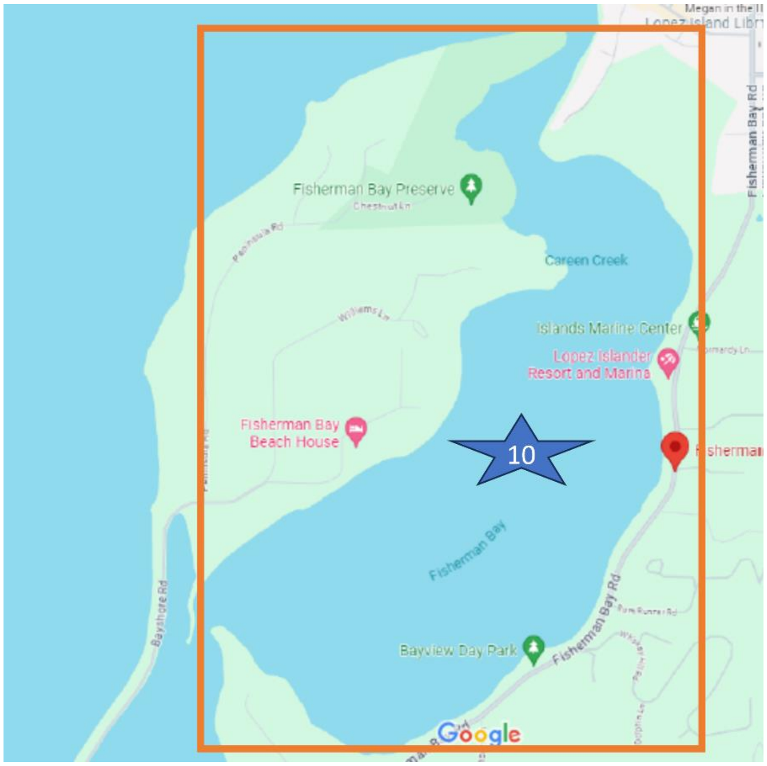


Shaw Island Bays- Blind Bay (9)

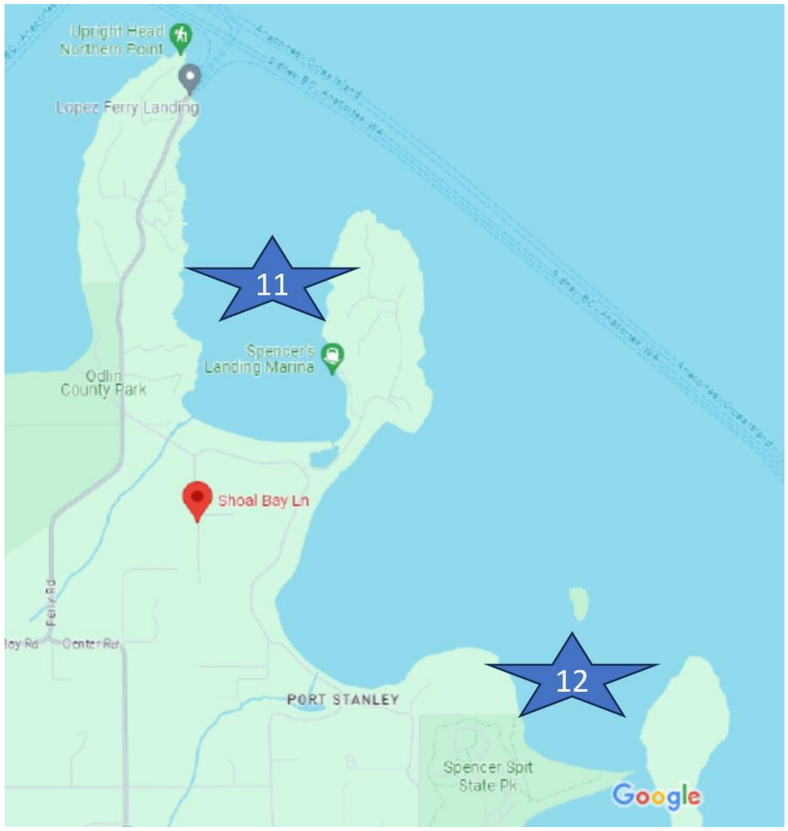


Lopez Island Island Bays – Fisherman's Bay (10)

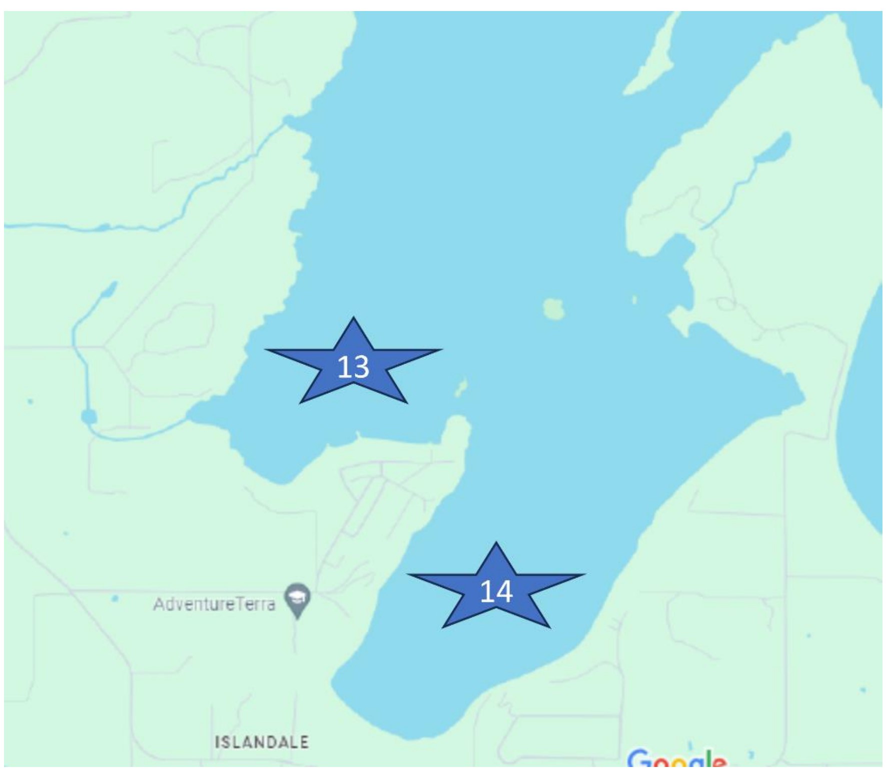
(Note, include vessels anchored/moored from mouth through the whole bay.)



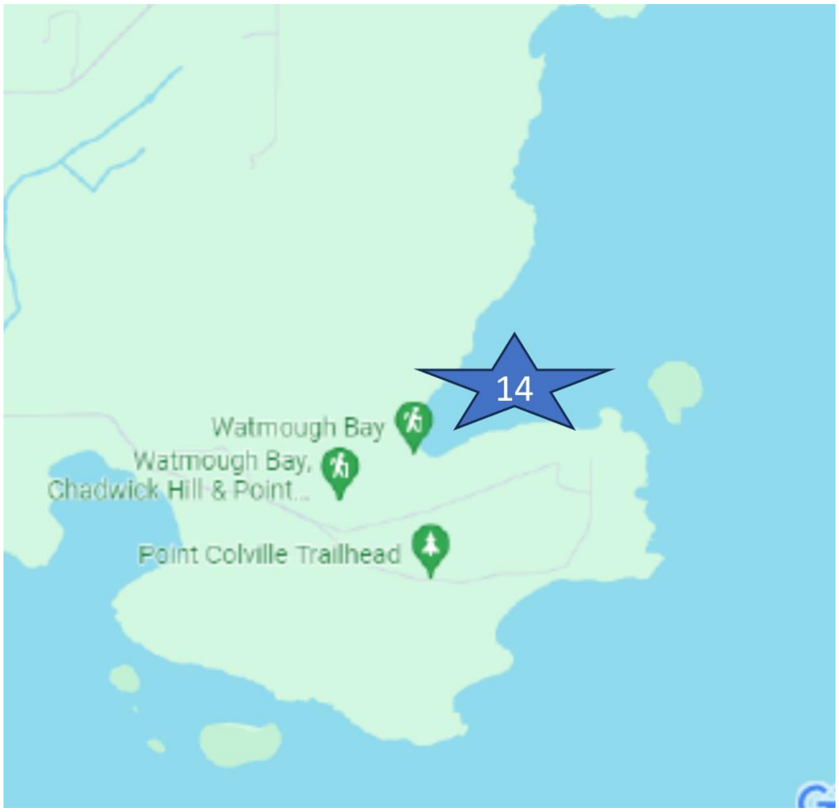
Lopez Island Bays – Shoal Bay (11), Spencer Spit (12)



Lopez Island Bays – Hunter Bay (12), Mud Bay (13)



Lopez Island Bays – Watmough Bay (14)



Appendix C - Vessel Density Heat Maps by Survey Date Identified from Combined Transect and Bay Count Data

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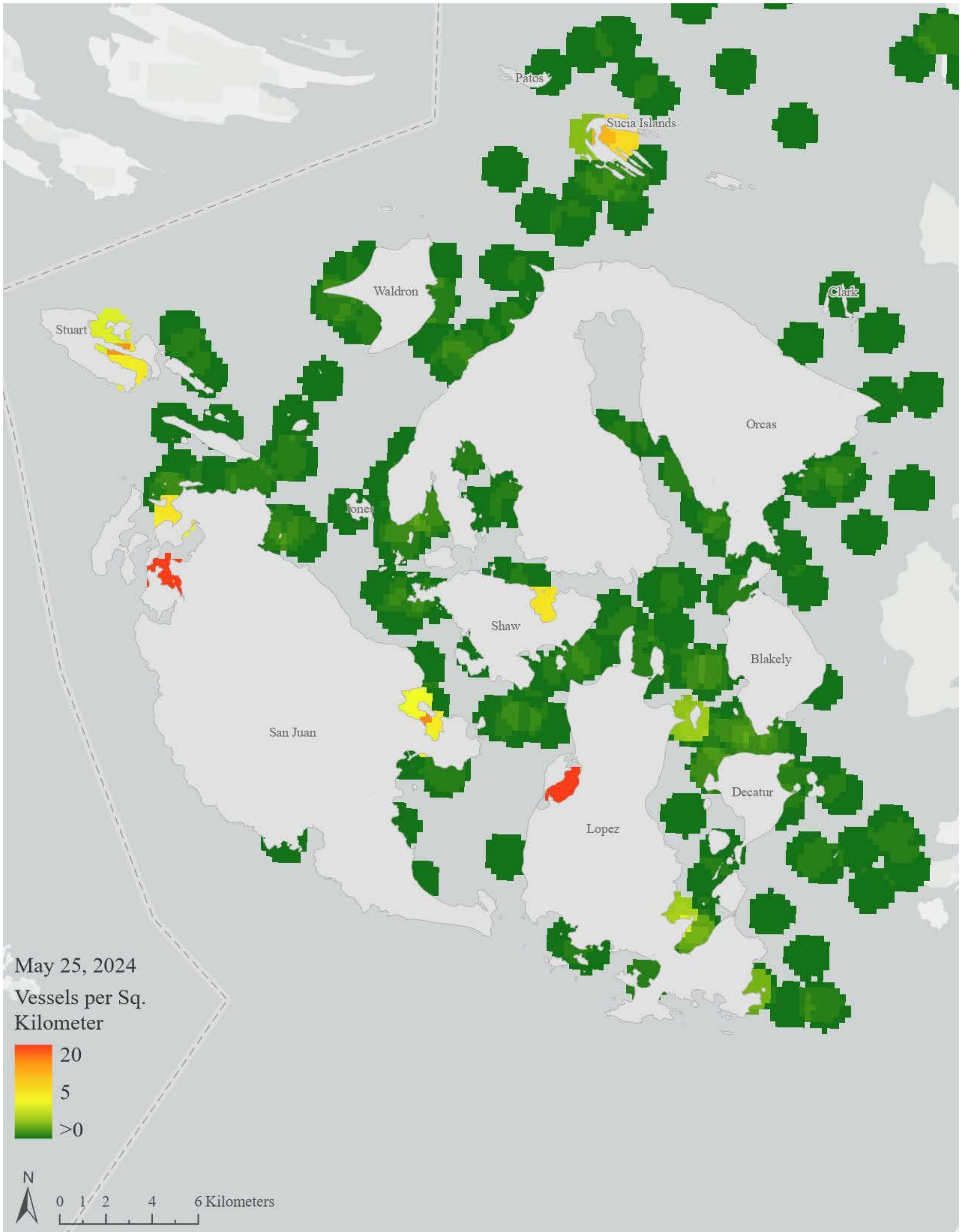

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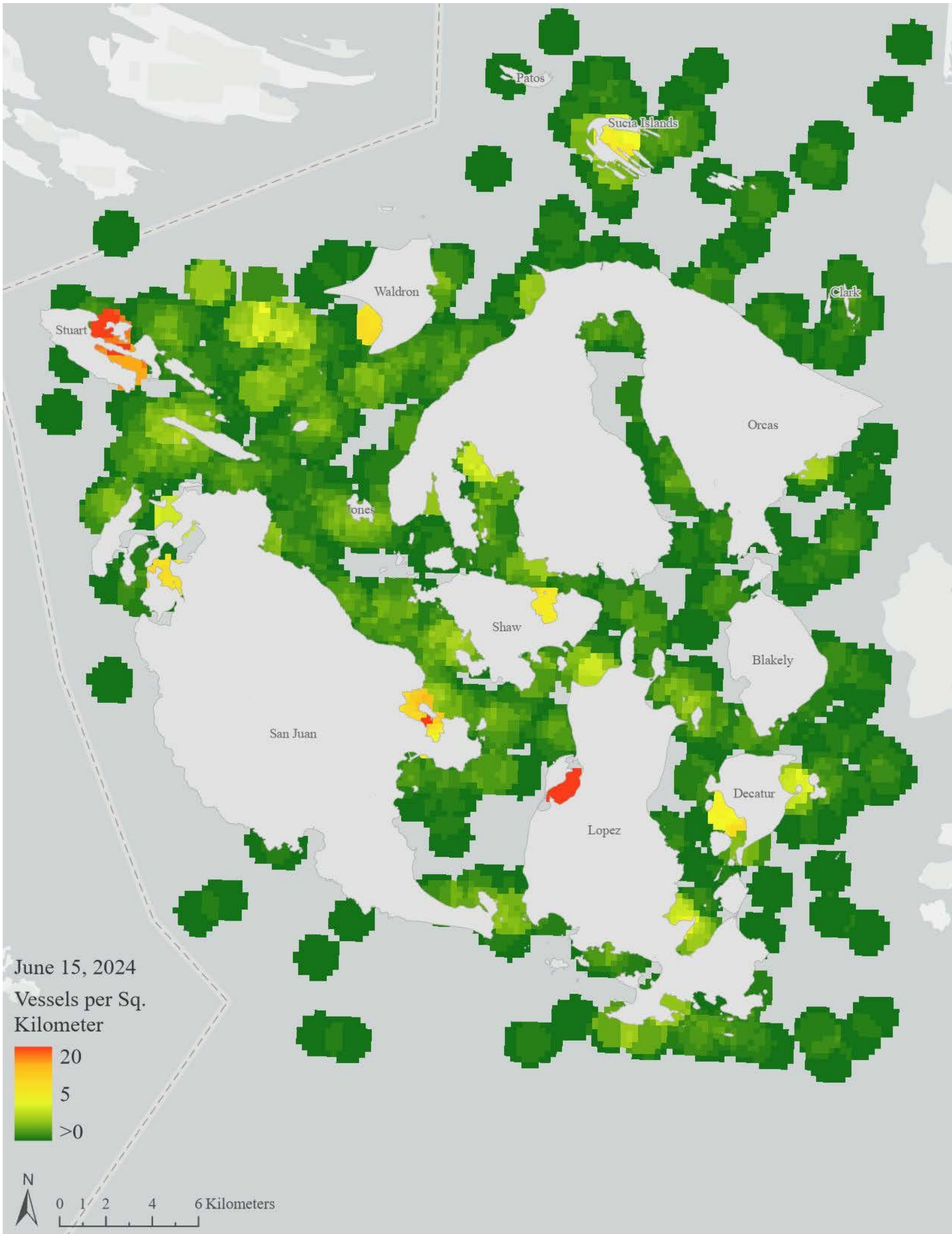
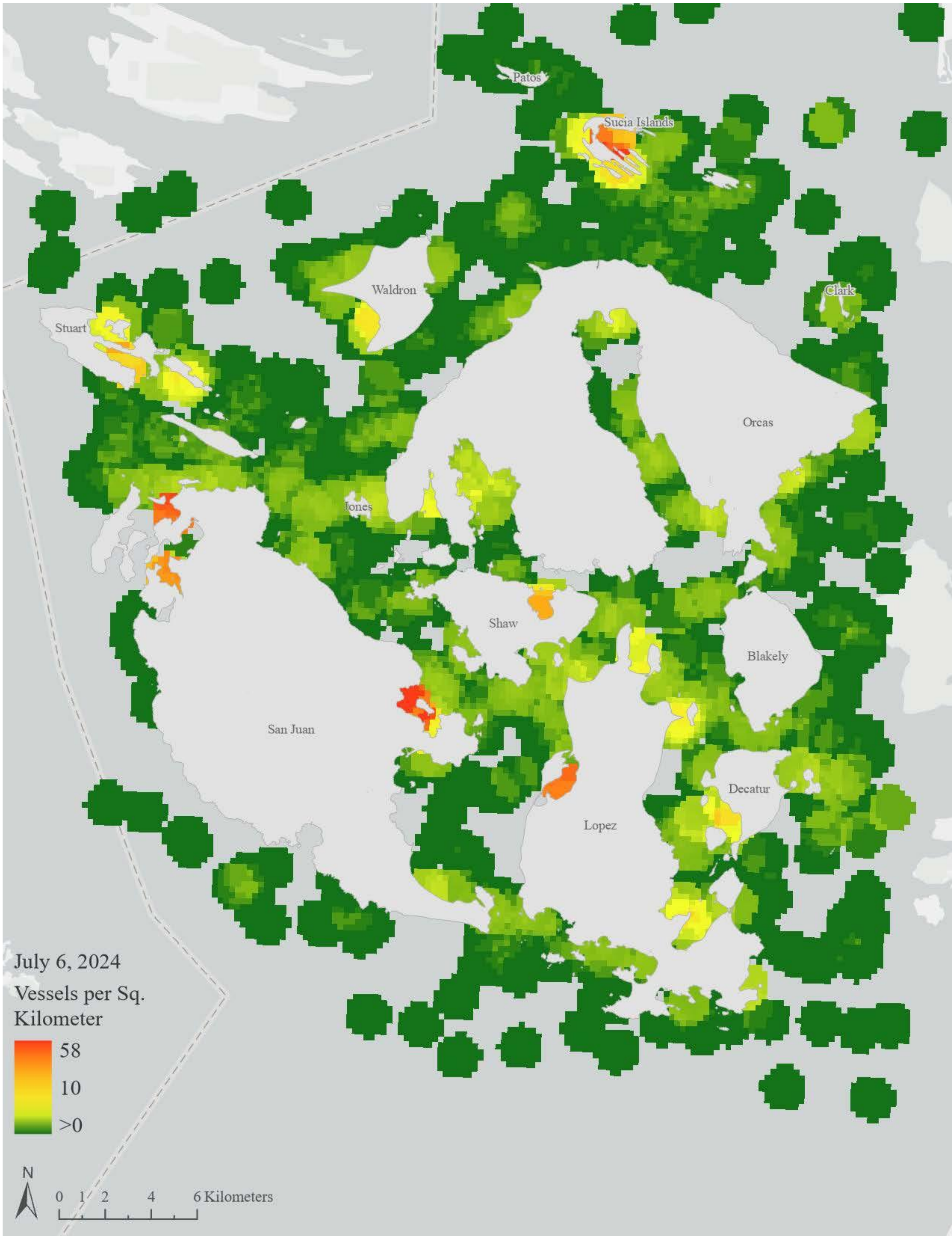
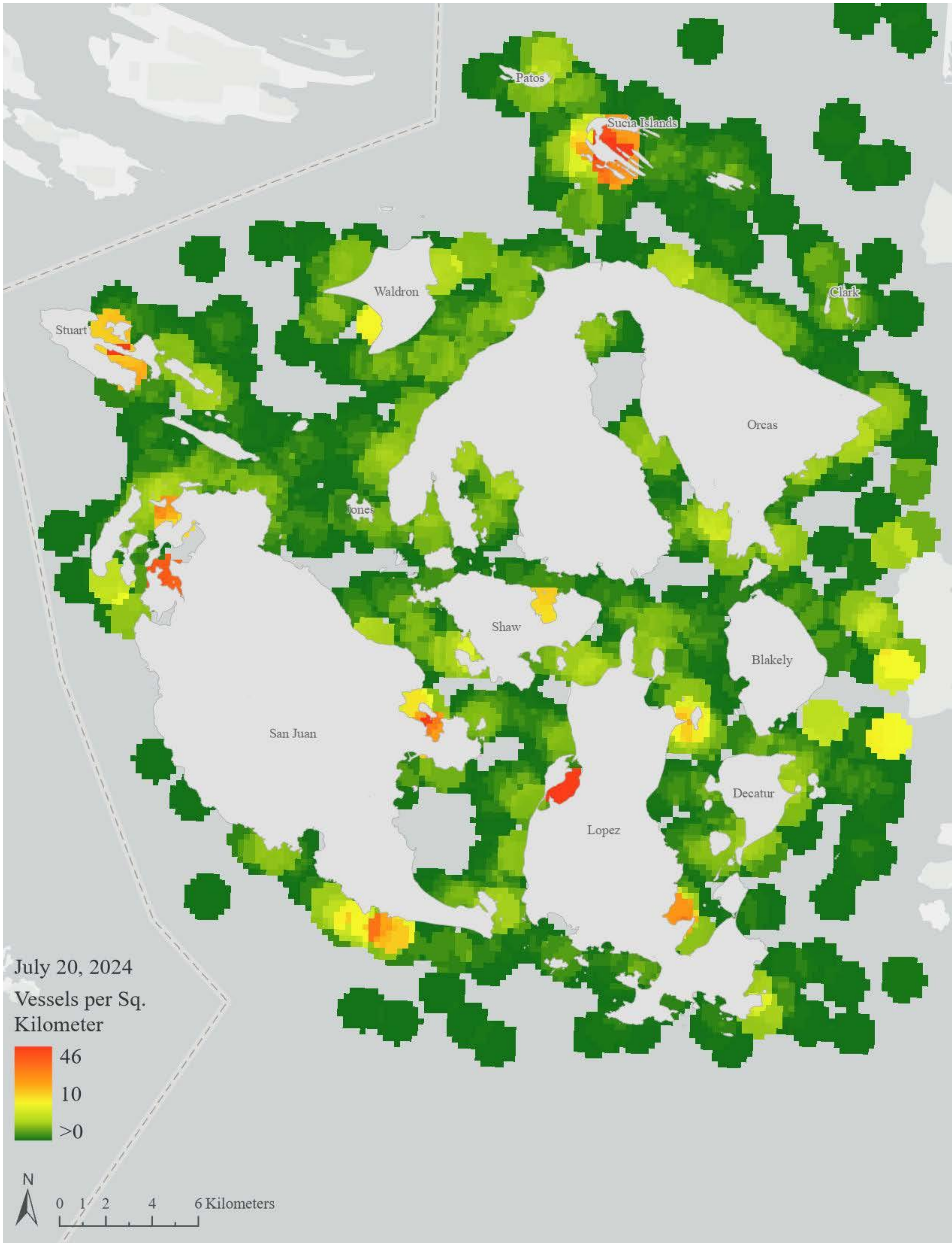


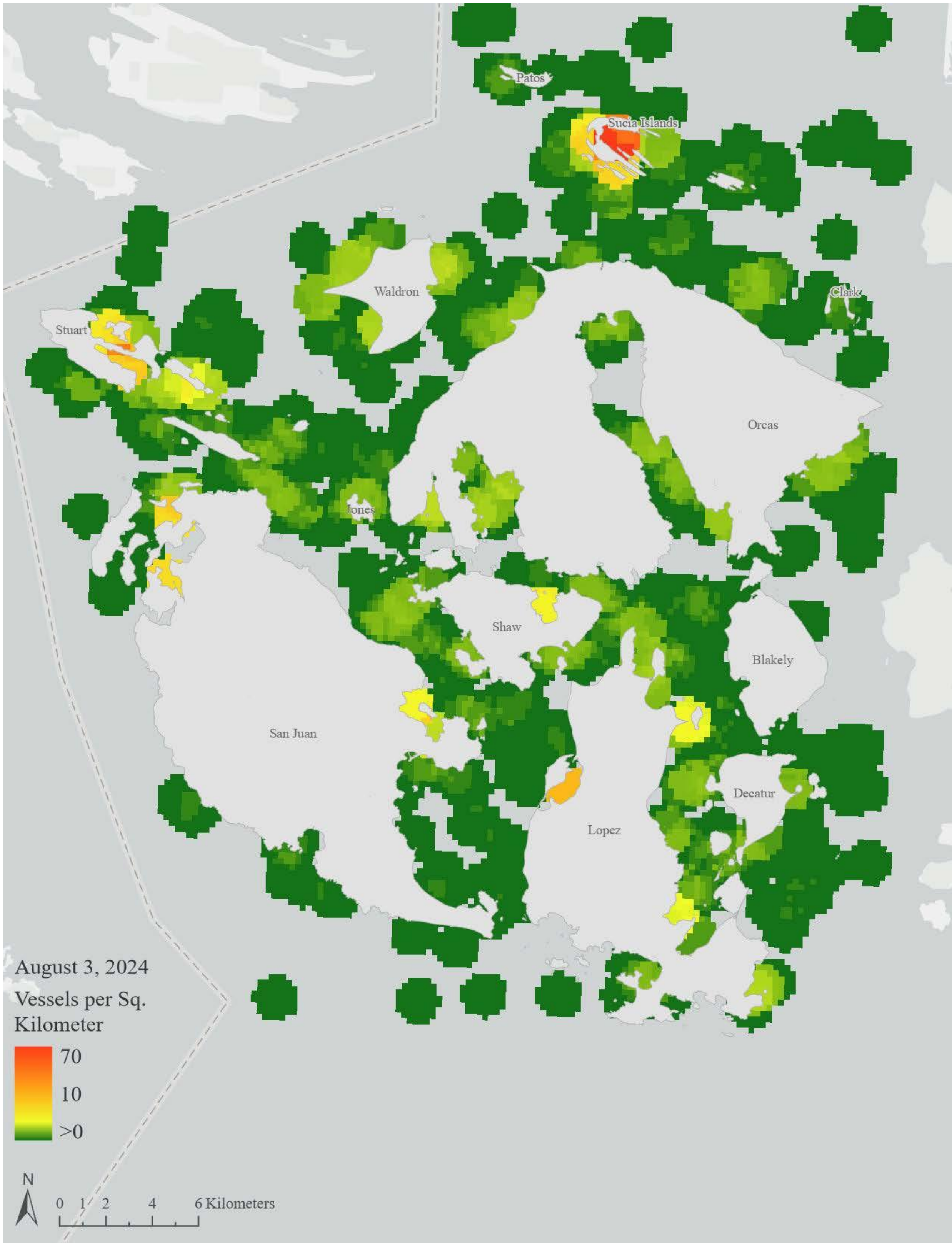
Survey Date: July 06, 2024



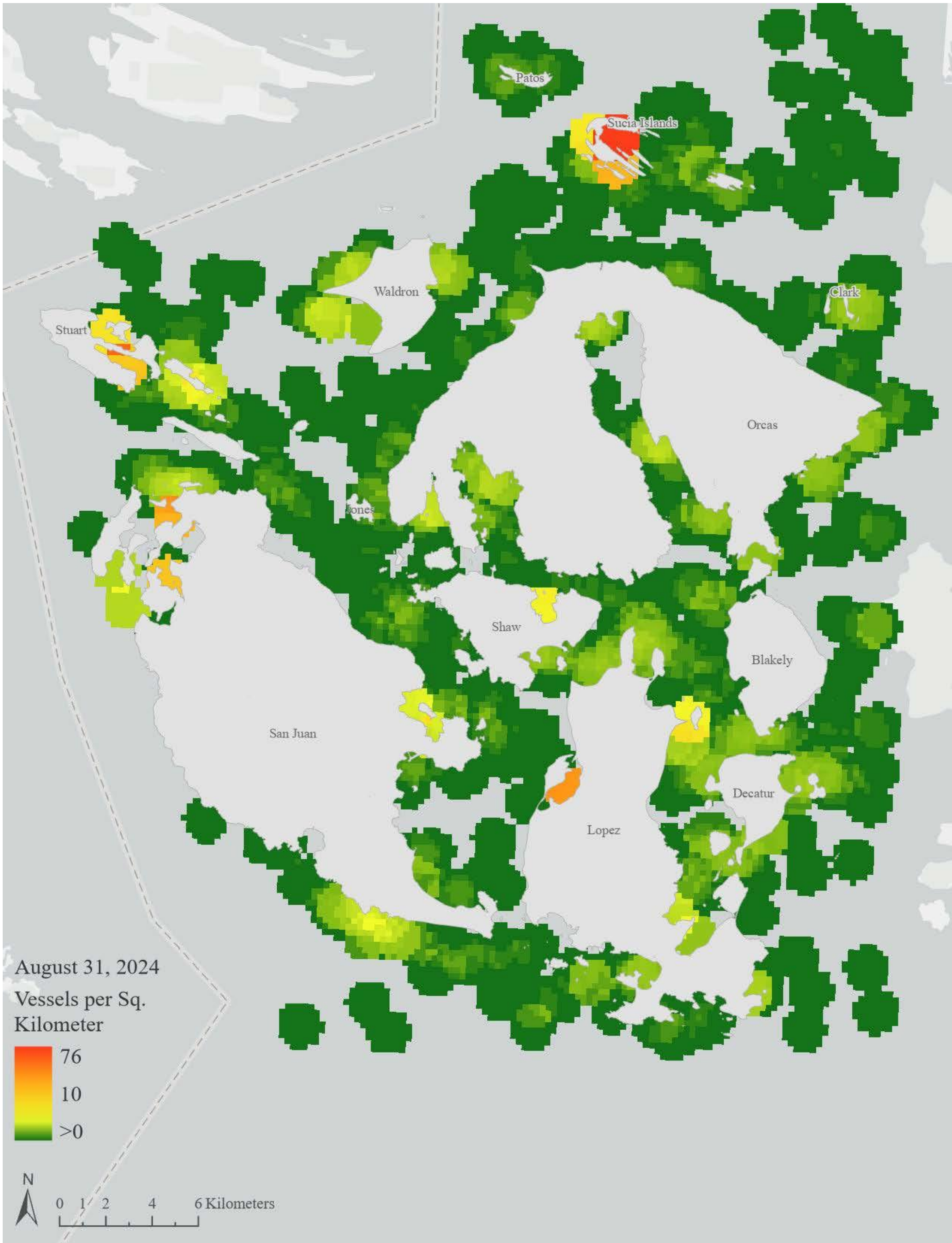
Survey Date: July 20, 2024



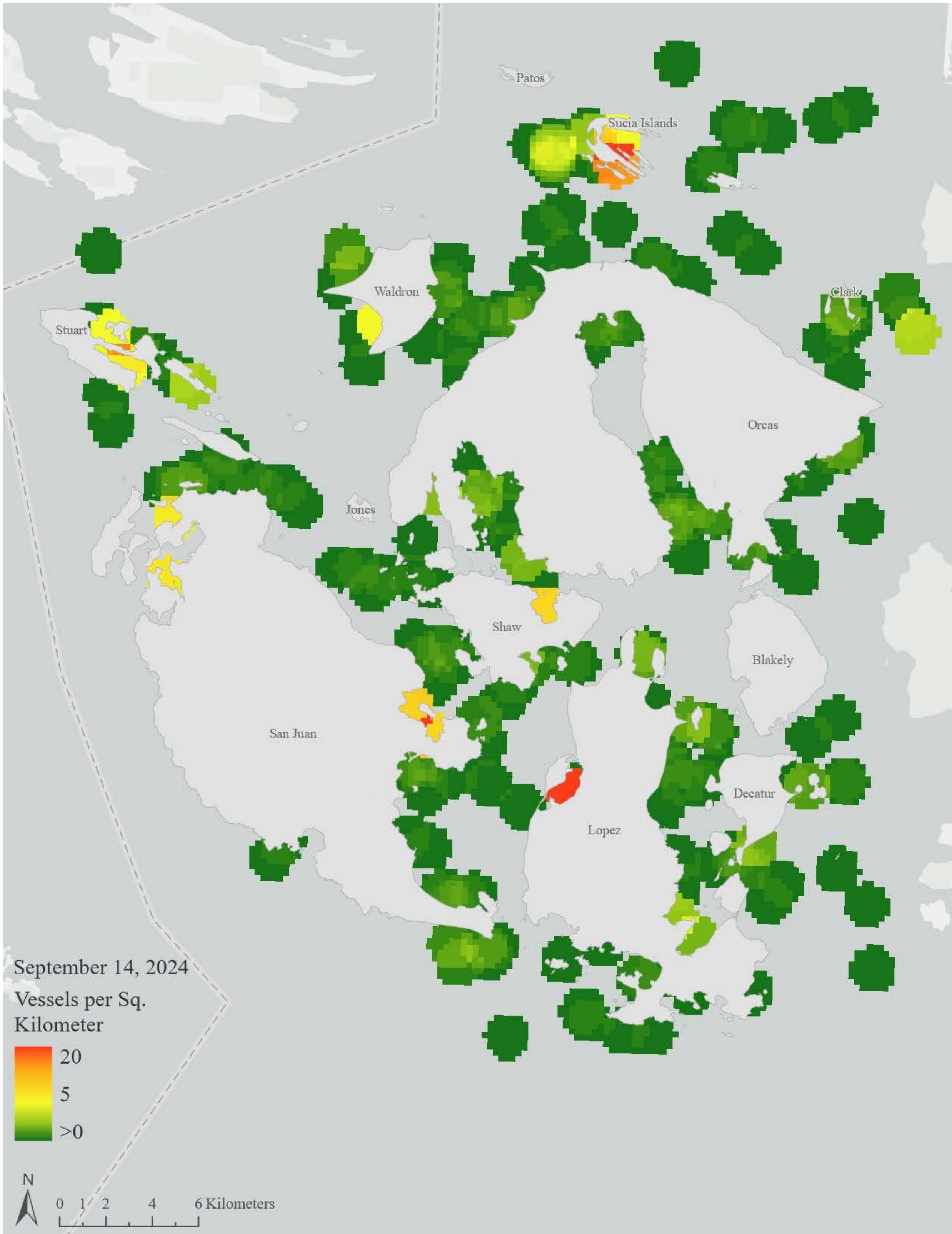
Survey Date: August 03, 2024



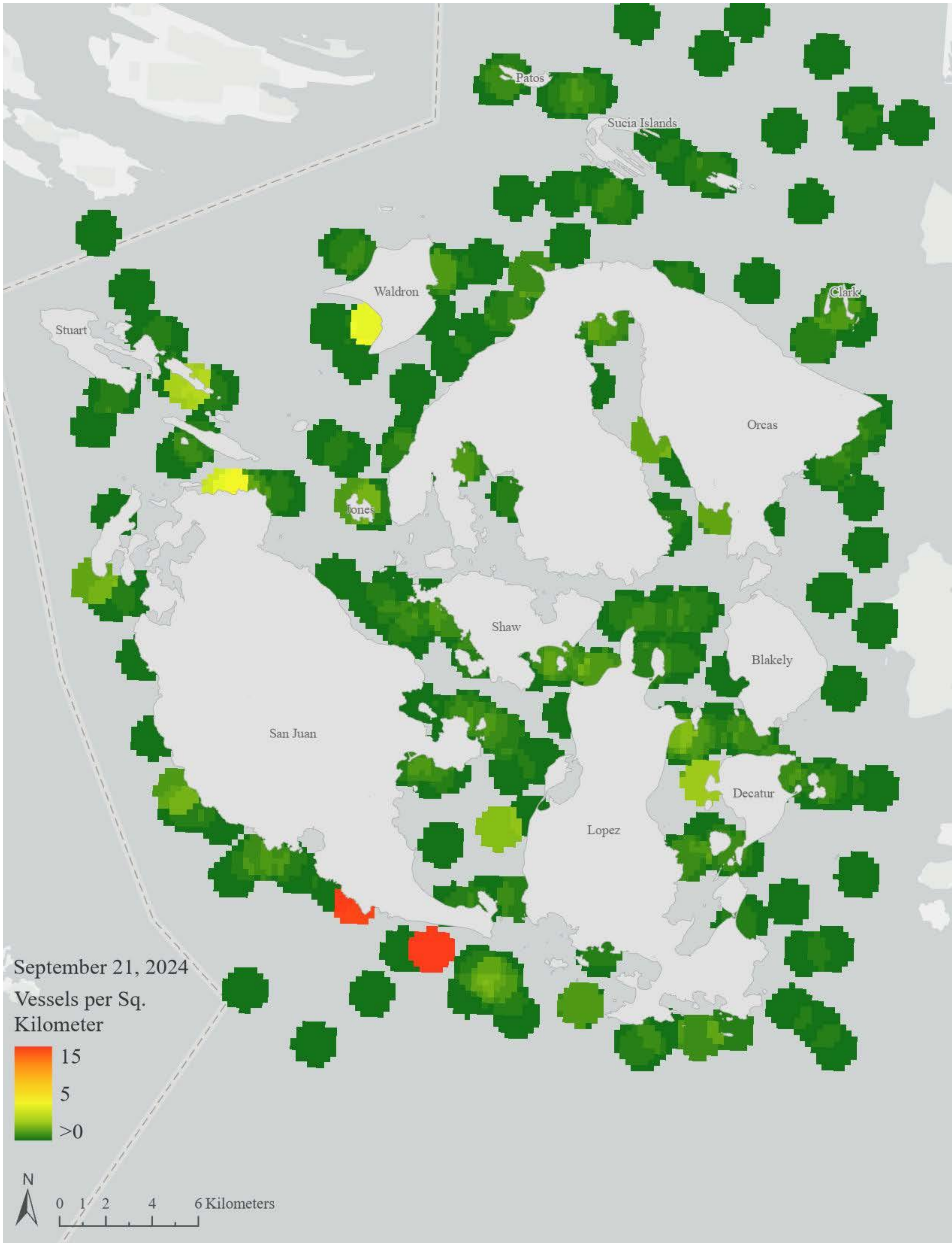
Survey Date: August 31, 2024



Survey Date: September 14, 2024 (no bay counts)

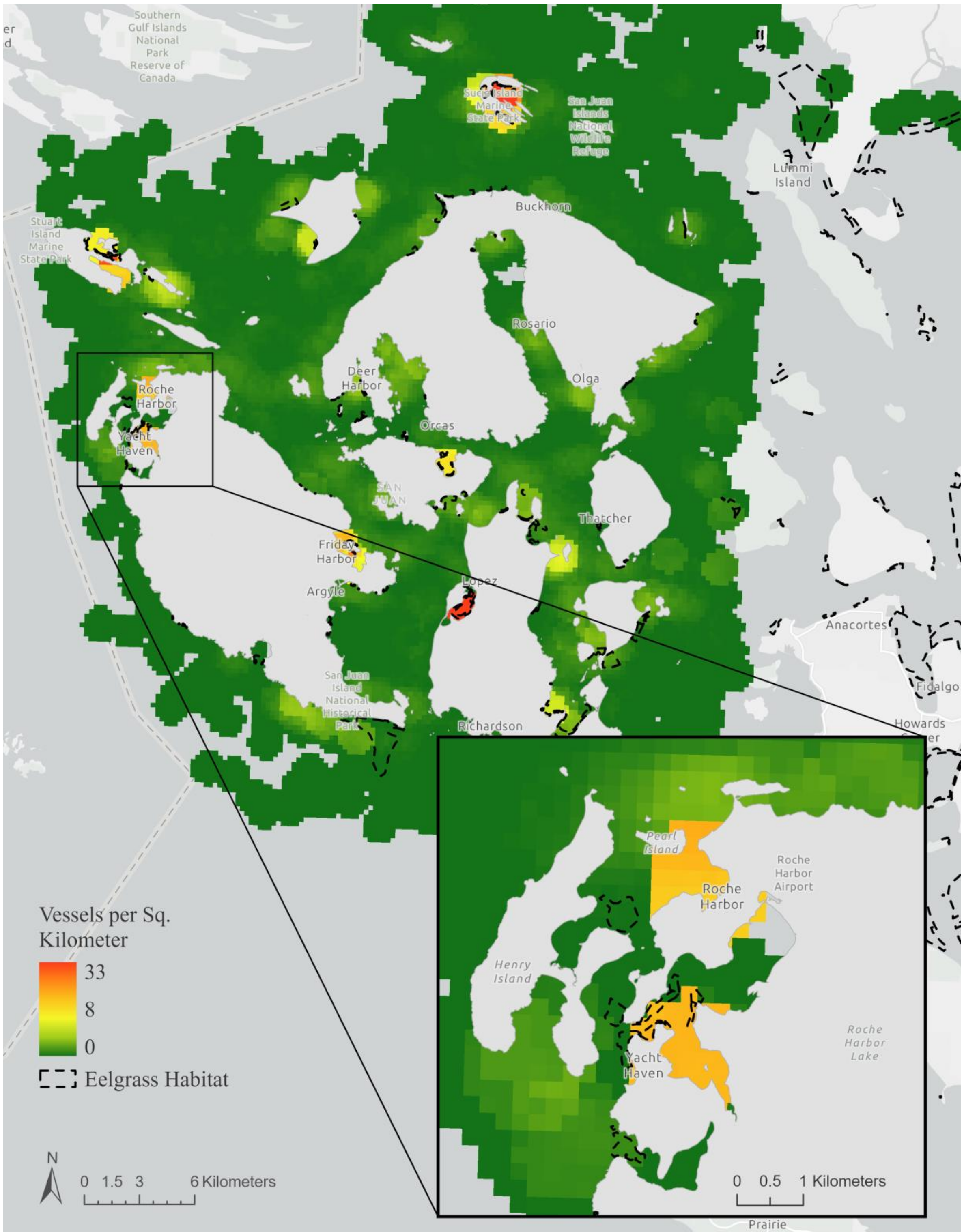


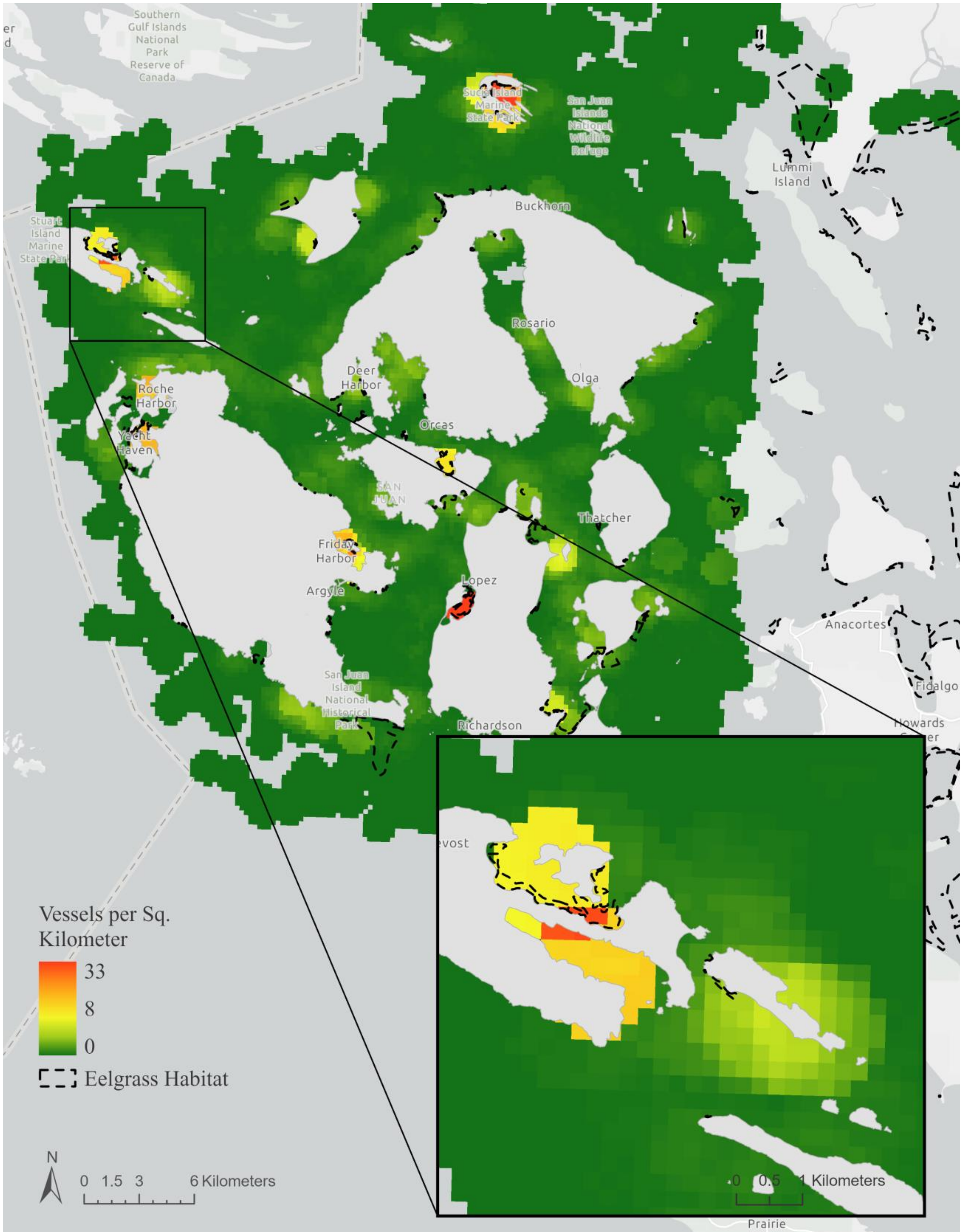
Survey Date: September 21, 2024



Appendix D – Zoomed-in Vessel Density Heat Maps Relative to Selected Marine Resources of Concern

Eelgrass Beds

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Olga
Roche Harbor
Orcas
Yacht Haven
SAN JUAN
Thatcher
Friday Harbor
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Argyle
Anacortes
Fidalgo
San Juan Island National Historical Park
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Prairie Center
Vessels per Sq. Kilometer
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Eelgrass Habitat
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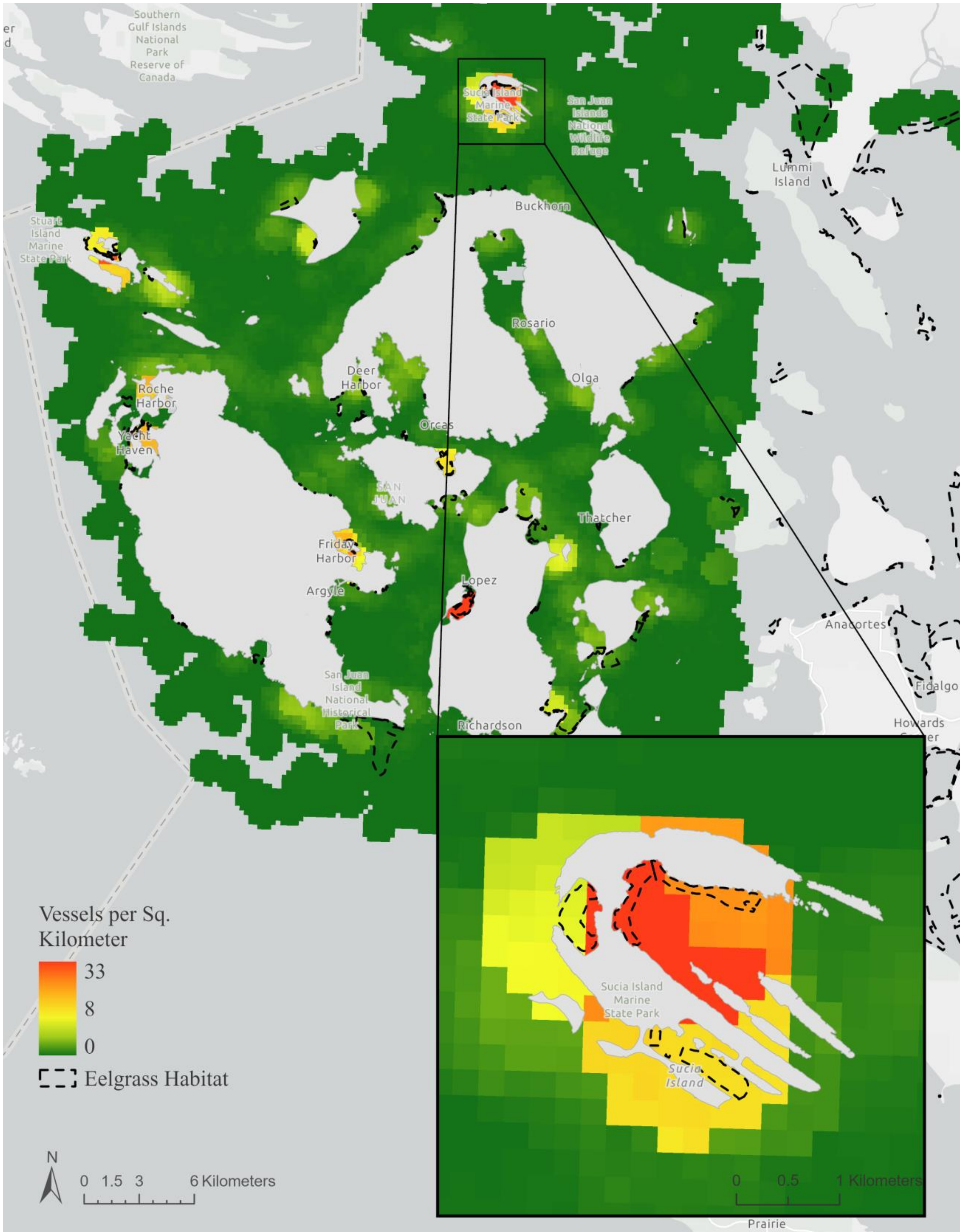

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Thatcher
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San Juan Island National Historical Park
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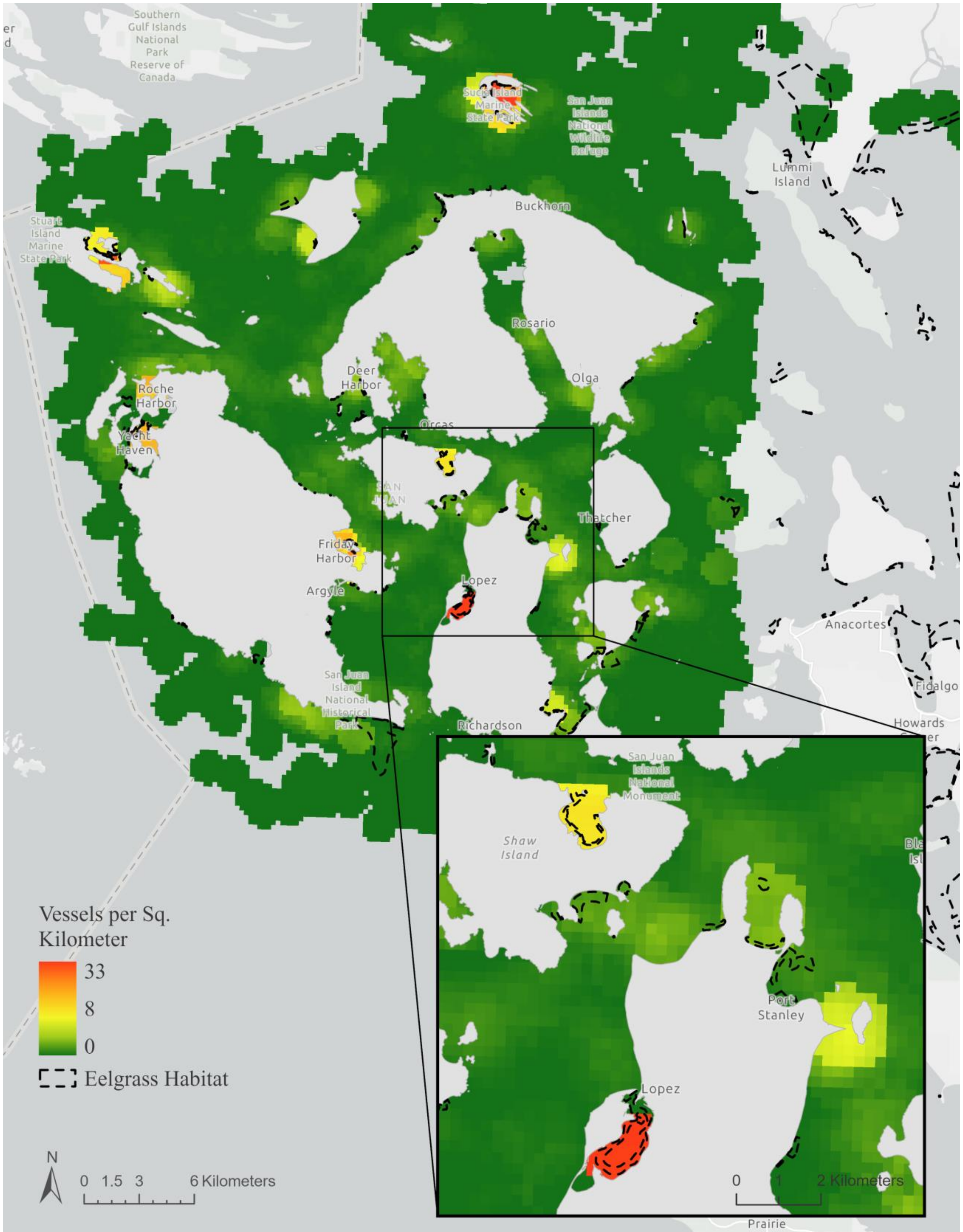
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San Juan
Thatcher
Friday Harbor
Lopez
Argyle
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Fidalgo
Richardson
Howards Corner
San Juan Islands National Monument
Shaw Island
Port Stanley
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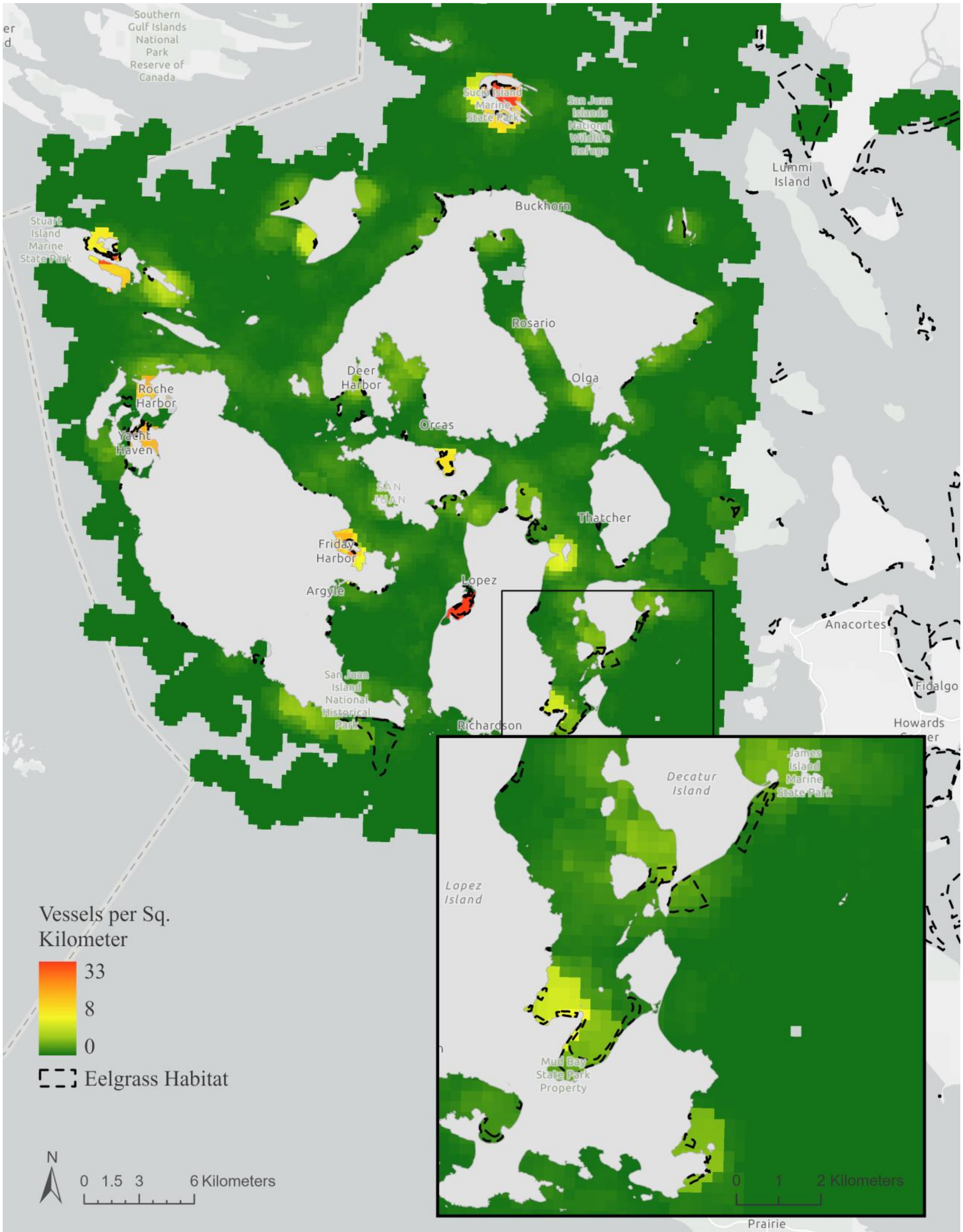
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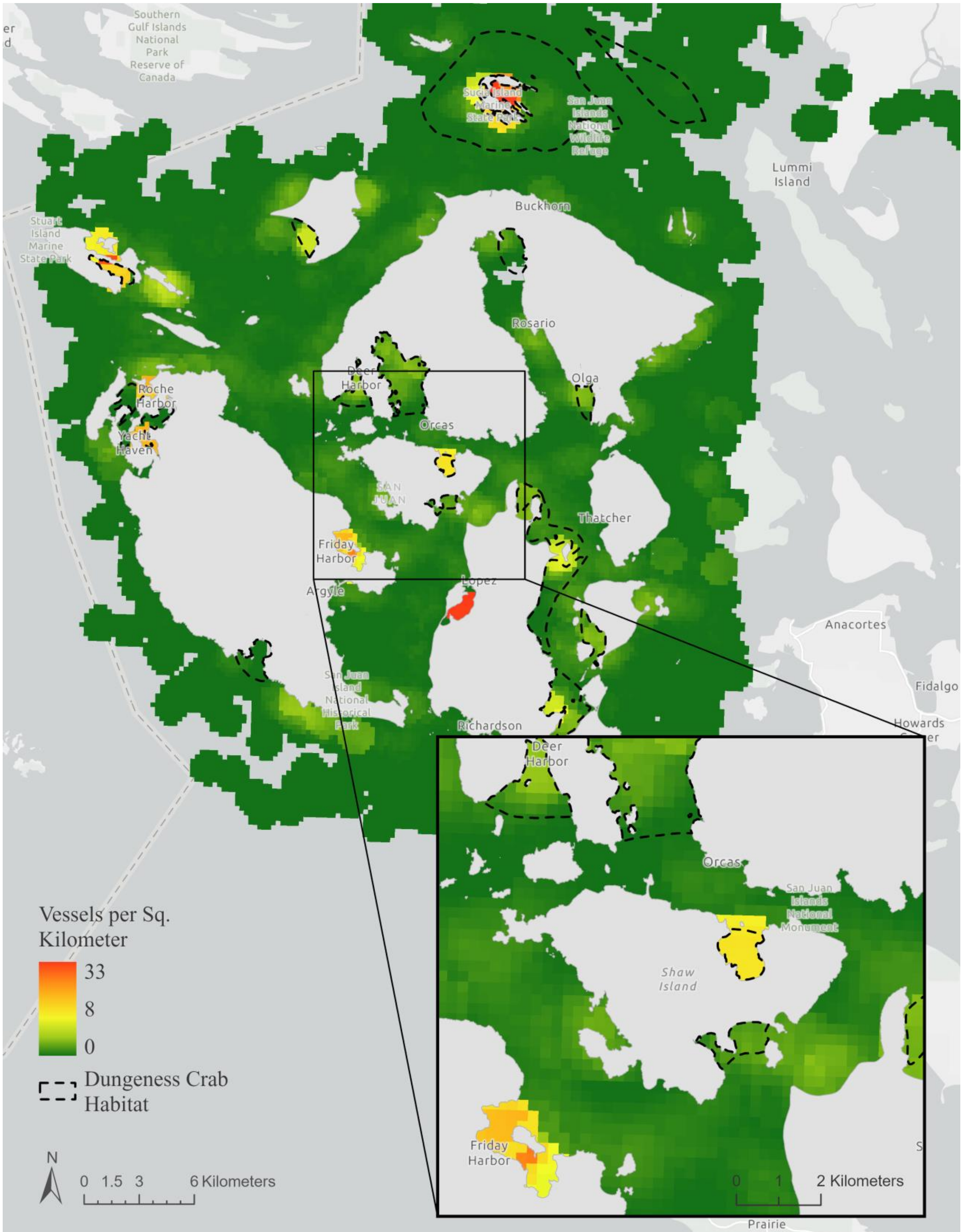
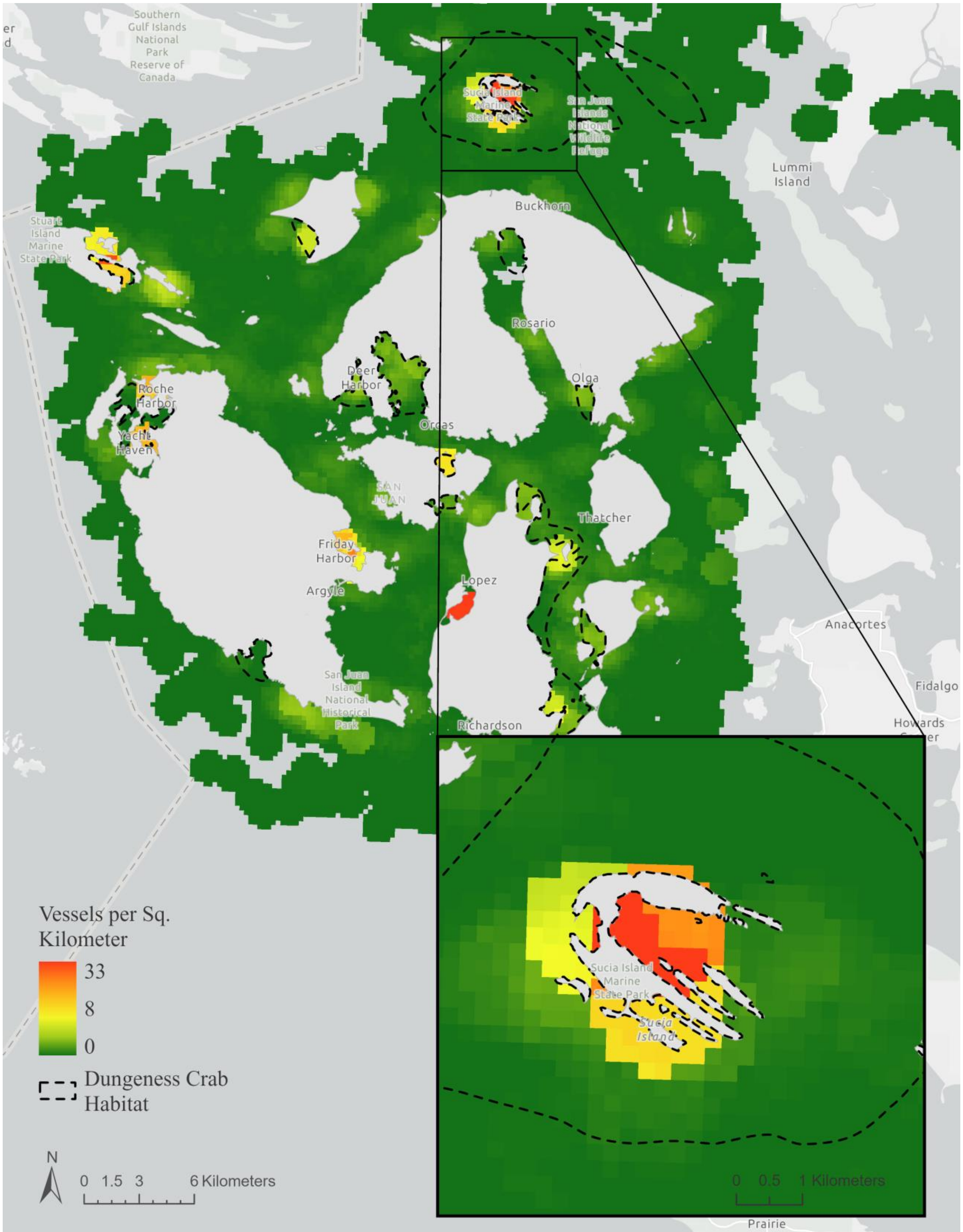
Dungeness Crab Habitat

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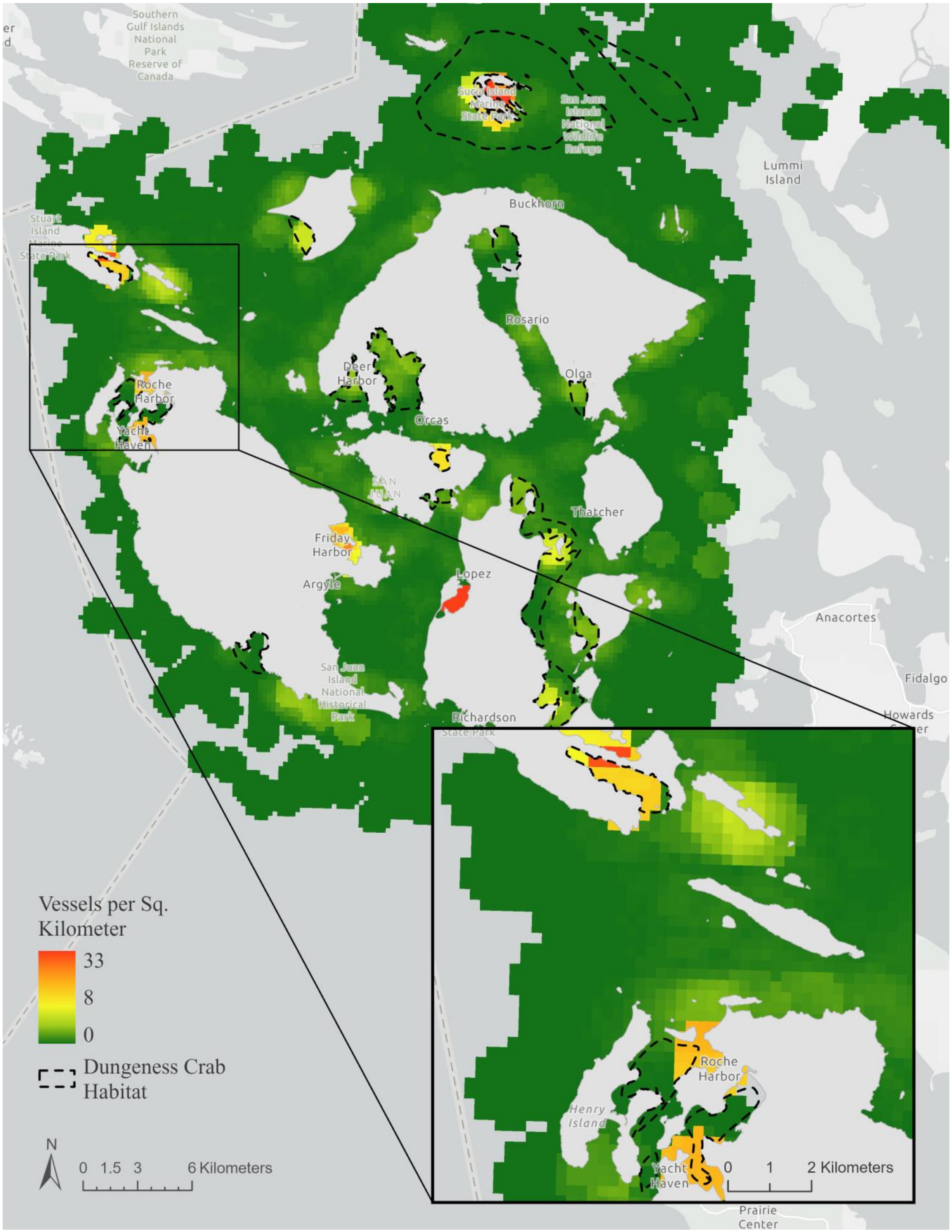

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San Juan Island National Historical Park
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State Park
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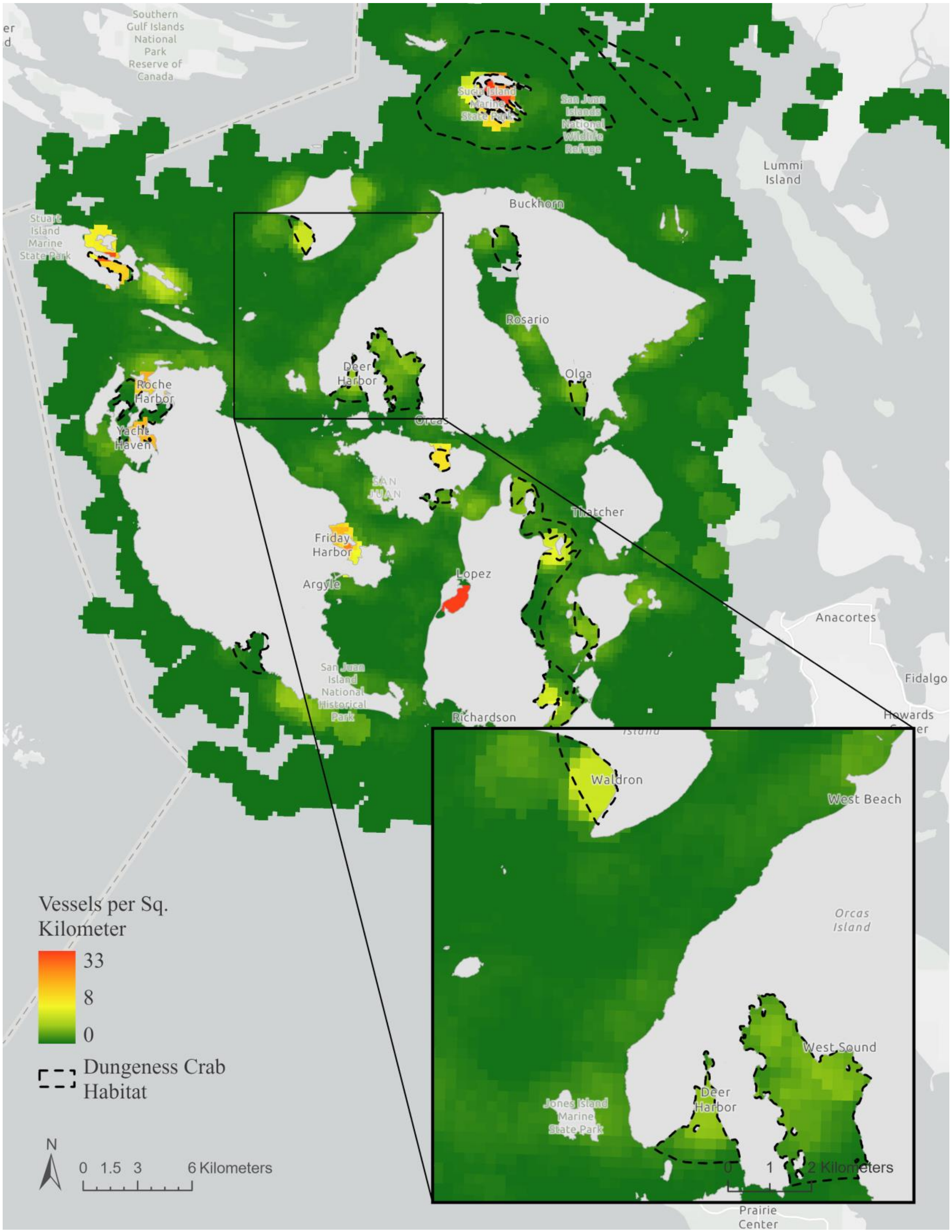
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Lopez
Anacortes
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Orcas Island
West Sound
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Jones Island Marine State Park
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Prairie Center
Vessels per Sq. Kilometer
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Dungeness Crab Habitat
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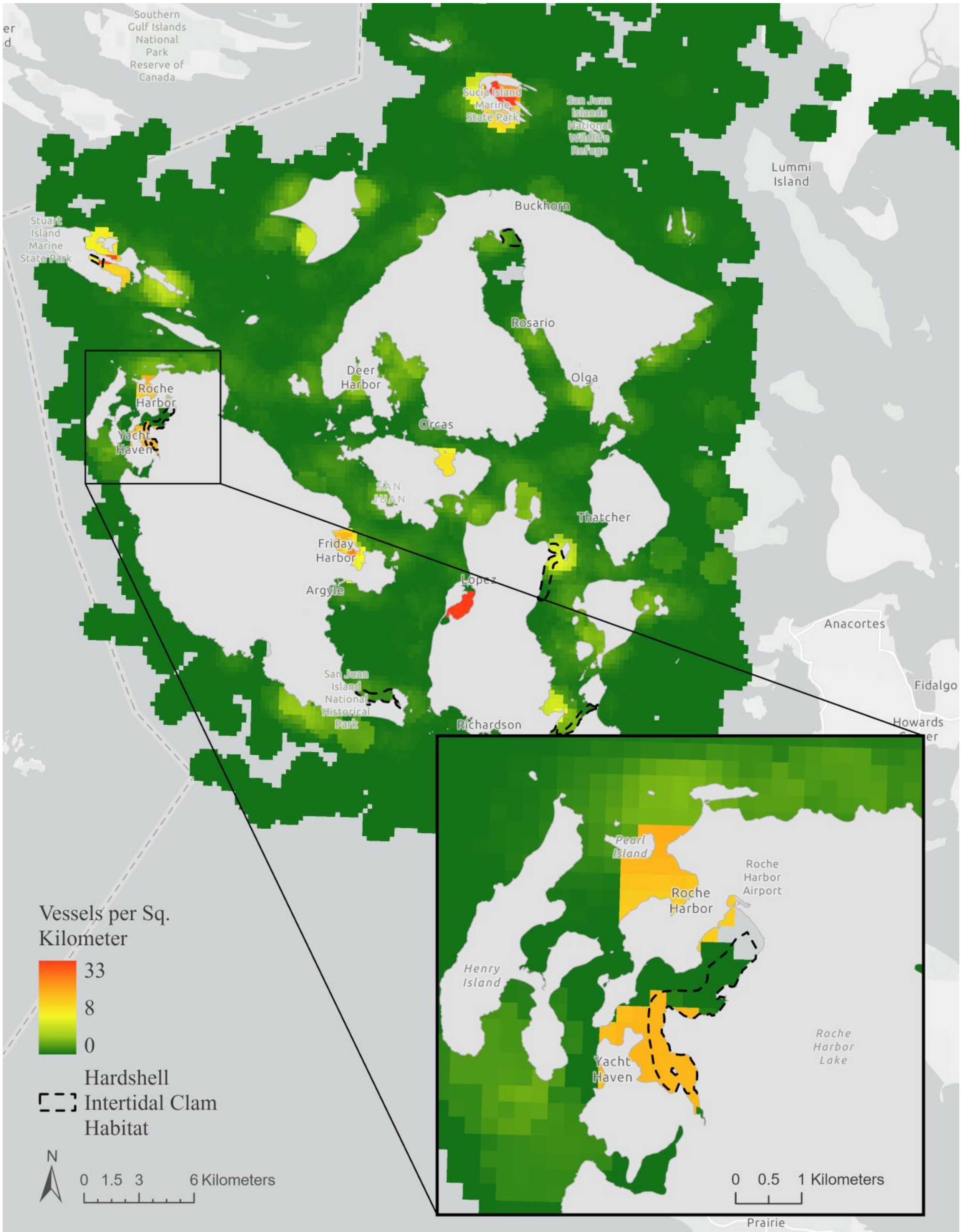
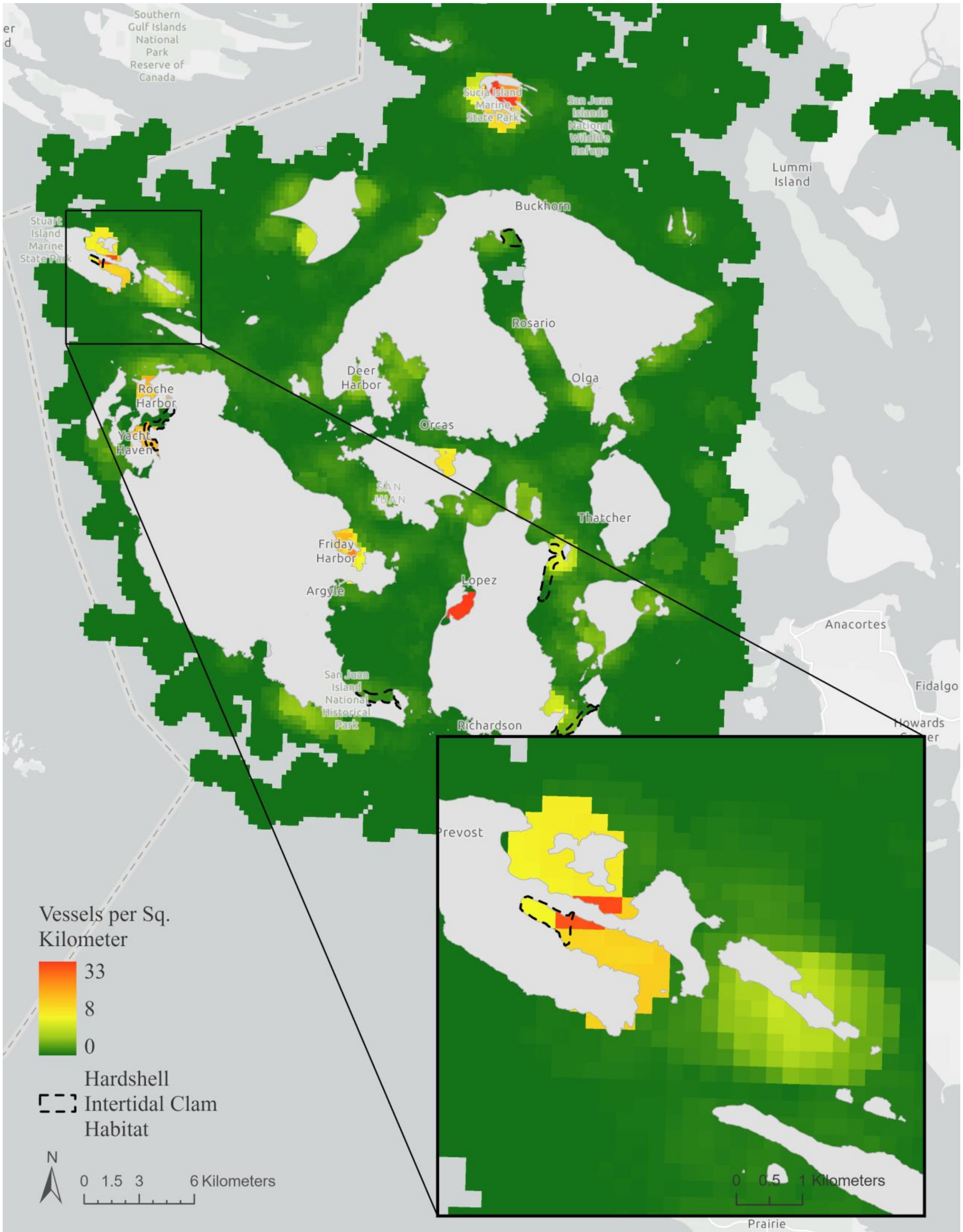
Hardshell Intertidal Clam

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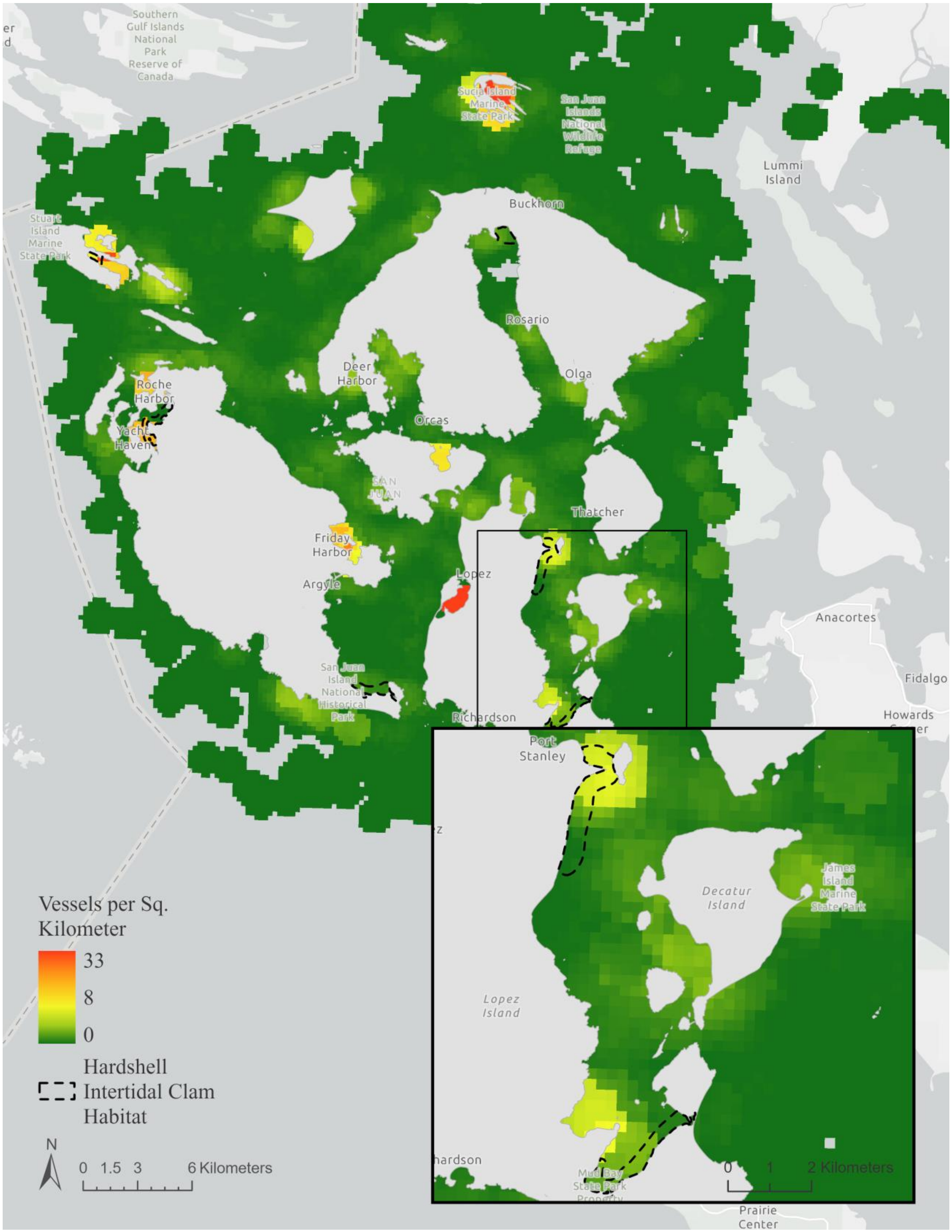

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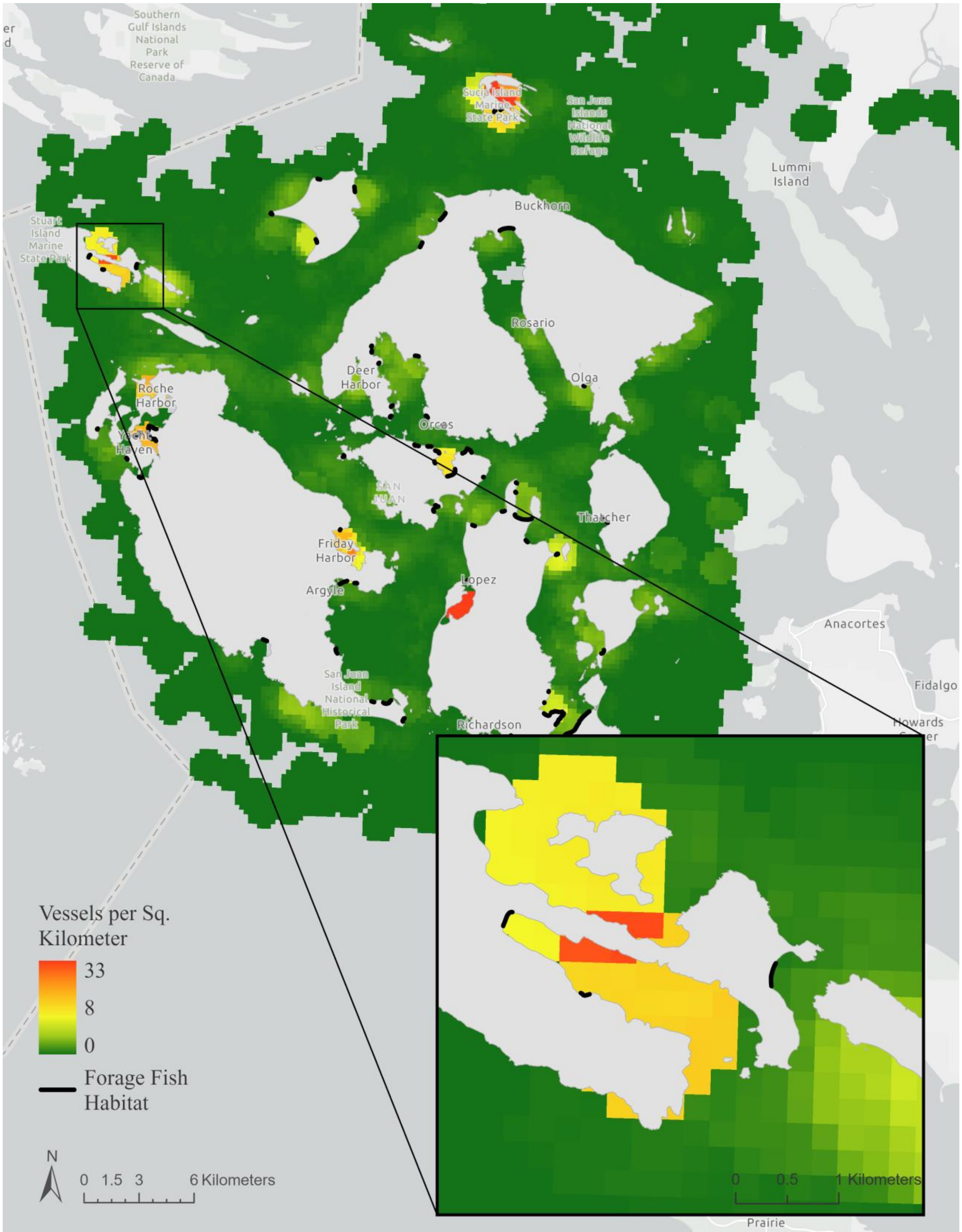
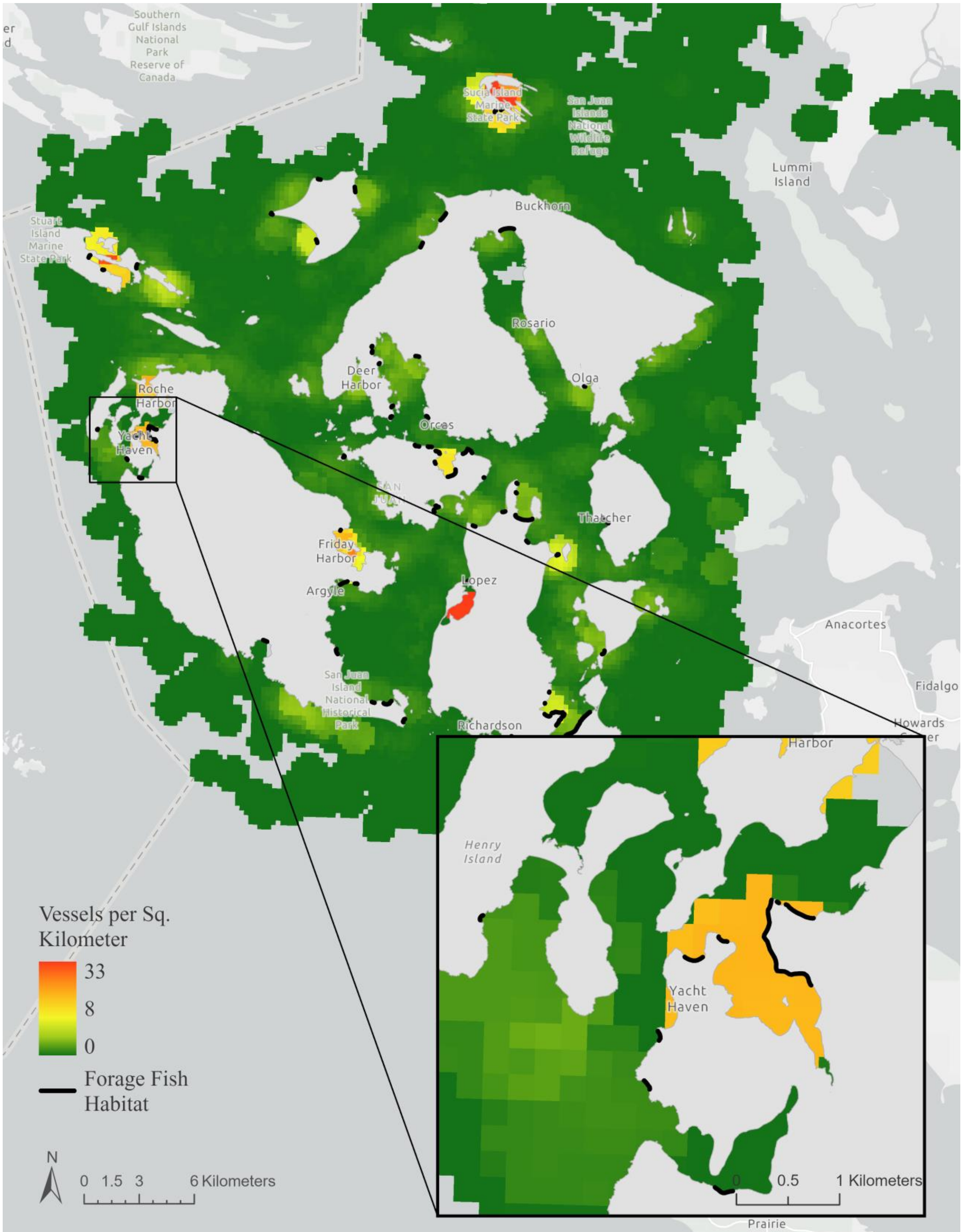
Mud Bay State Park Property
Prairie Center

Forage Fish Spawning Habitat

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Forage Fish Habitat
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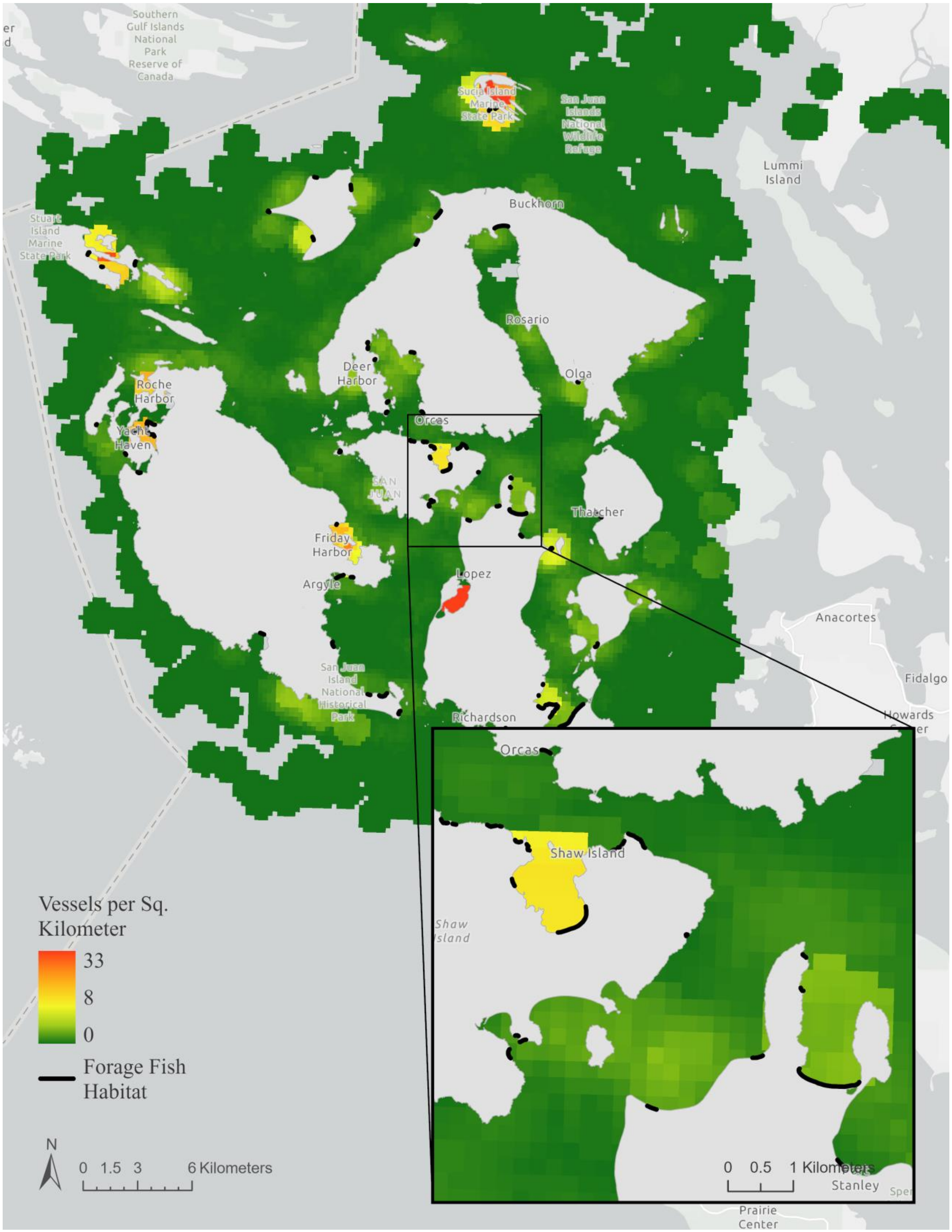
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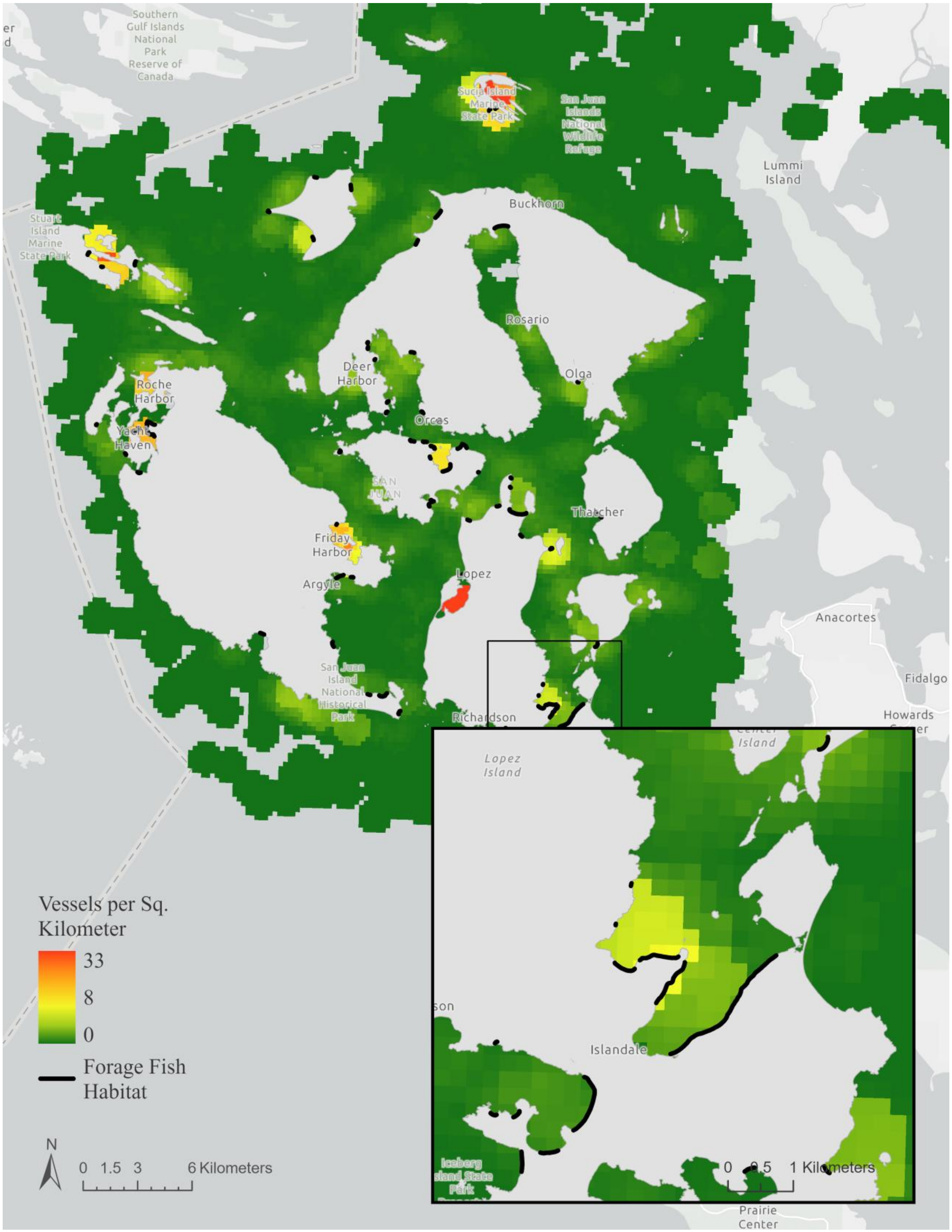
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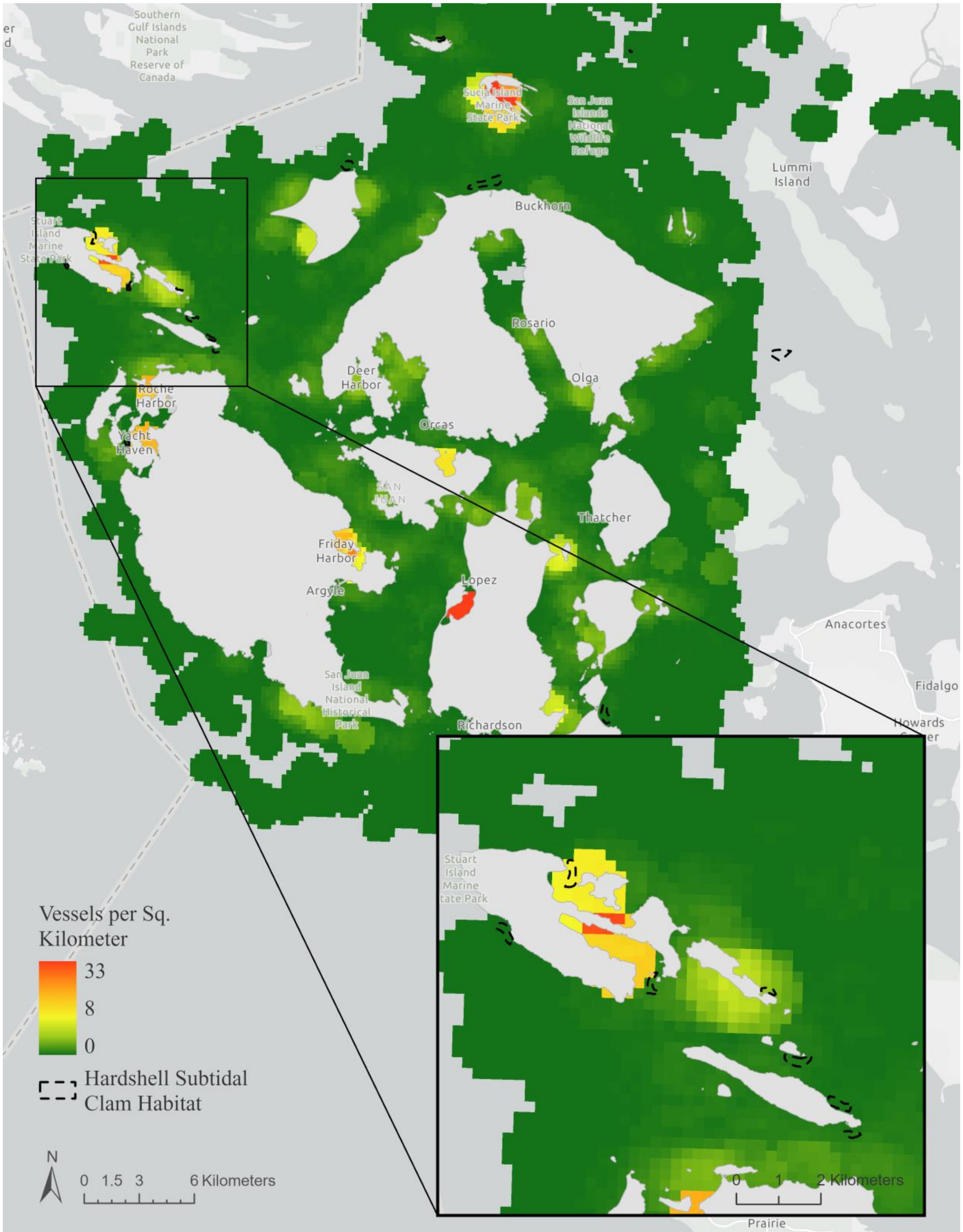
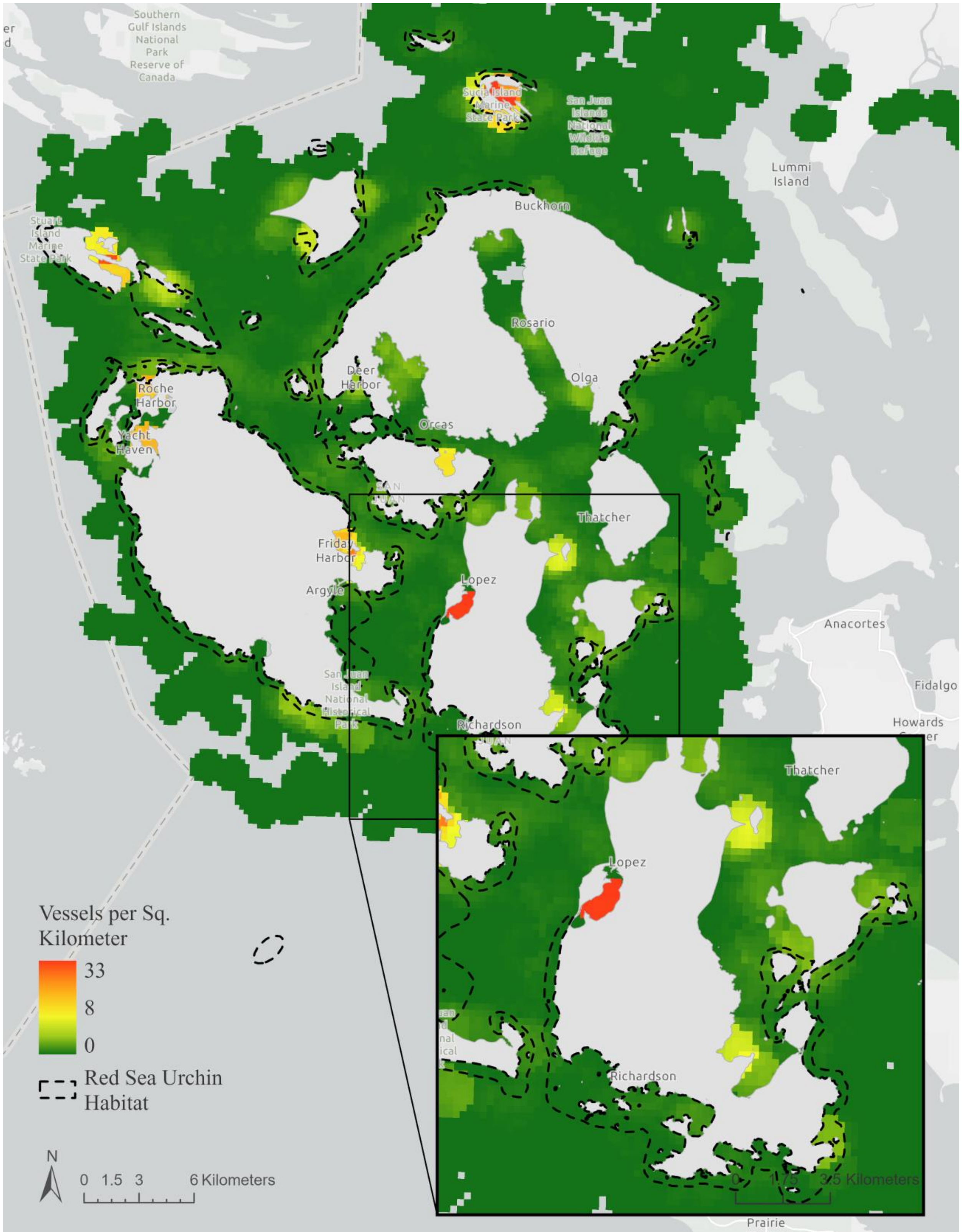
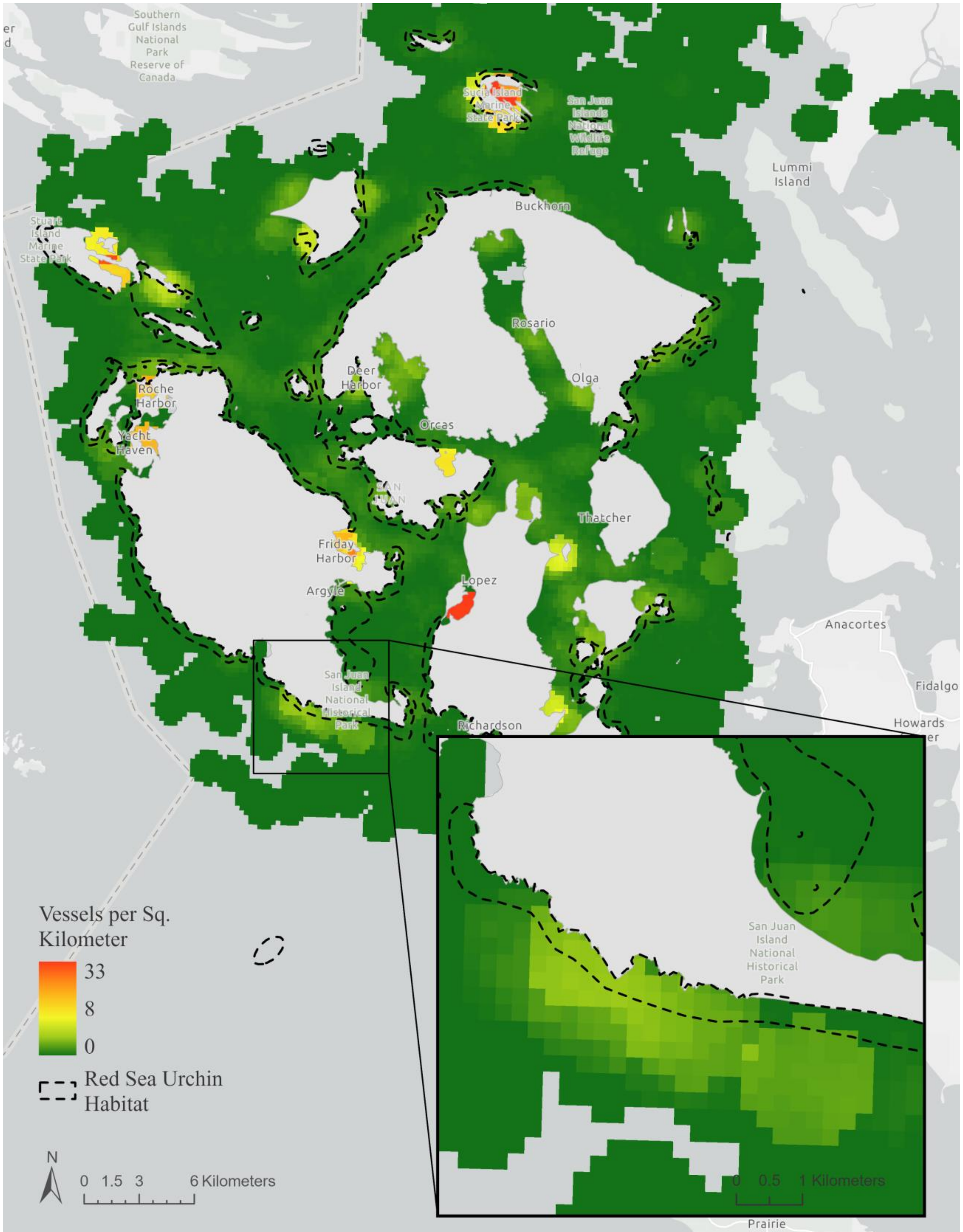
Hardshell Subtidal Clam



Red Sea Urchin

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Lummi Island
Buckhorn
Stuart Island Marine State Park
Rosario
Deer Harbor
Olga
Roche Harbor
Orcas
Yacht Haven
Thatcher
Friday Harbor
Argyle
Lopez
Anacortes
Fidalgo
San Juan Island National Historical Park
Richardson
Howards
Vessels per Sq. Kilometer
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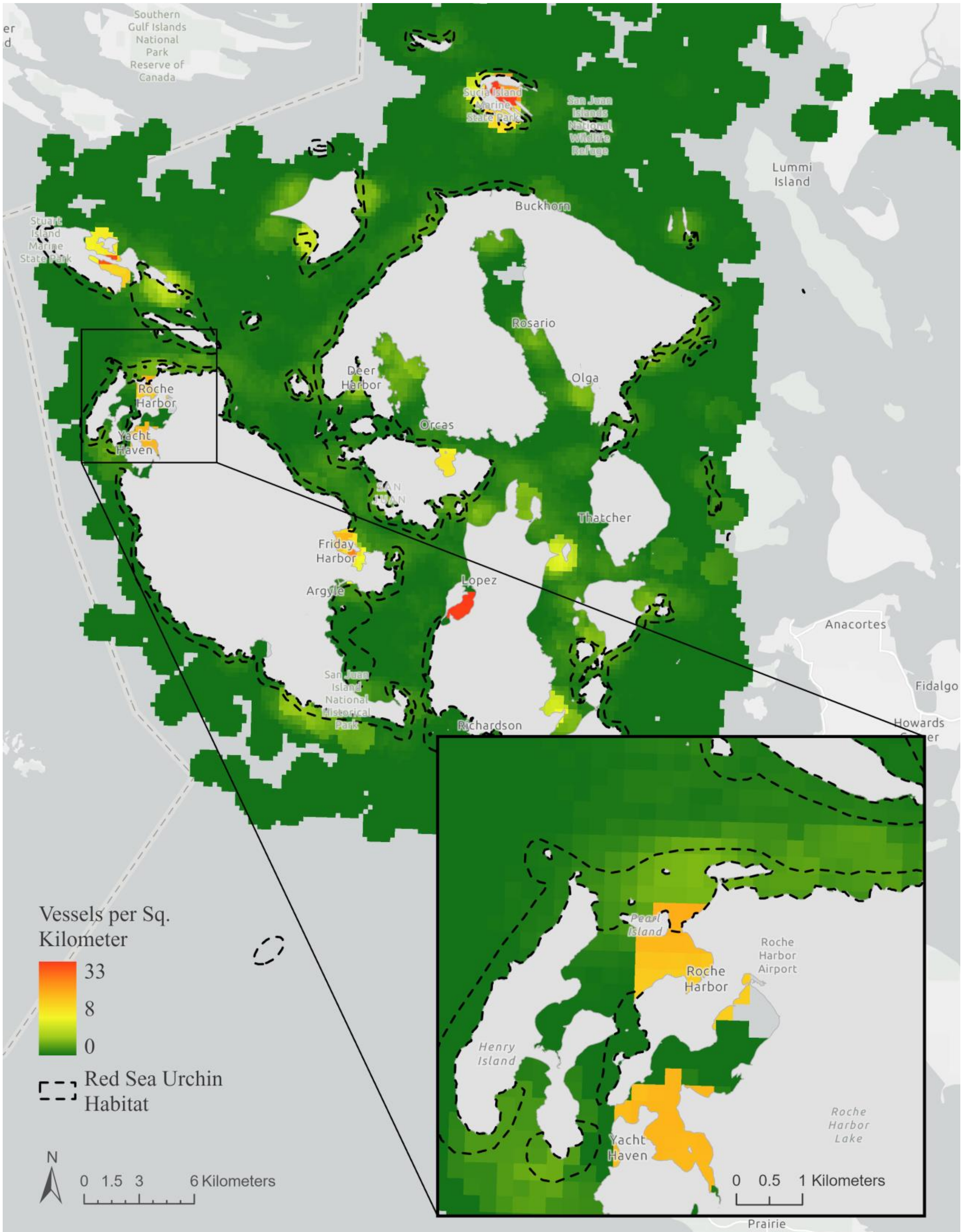

Southern Gulf Islands National Park Reserve of Canada
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San Juan Islands National Wildlife Refuge
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Orcas
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Anacortes
San Juan Island National Historical Park
Fidalgo
Richardson
Howards
Vessels per Sq. Kilometer
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Red Sea Urchin Habitat
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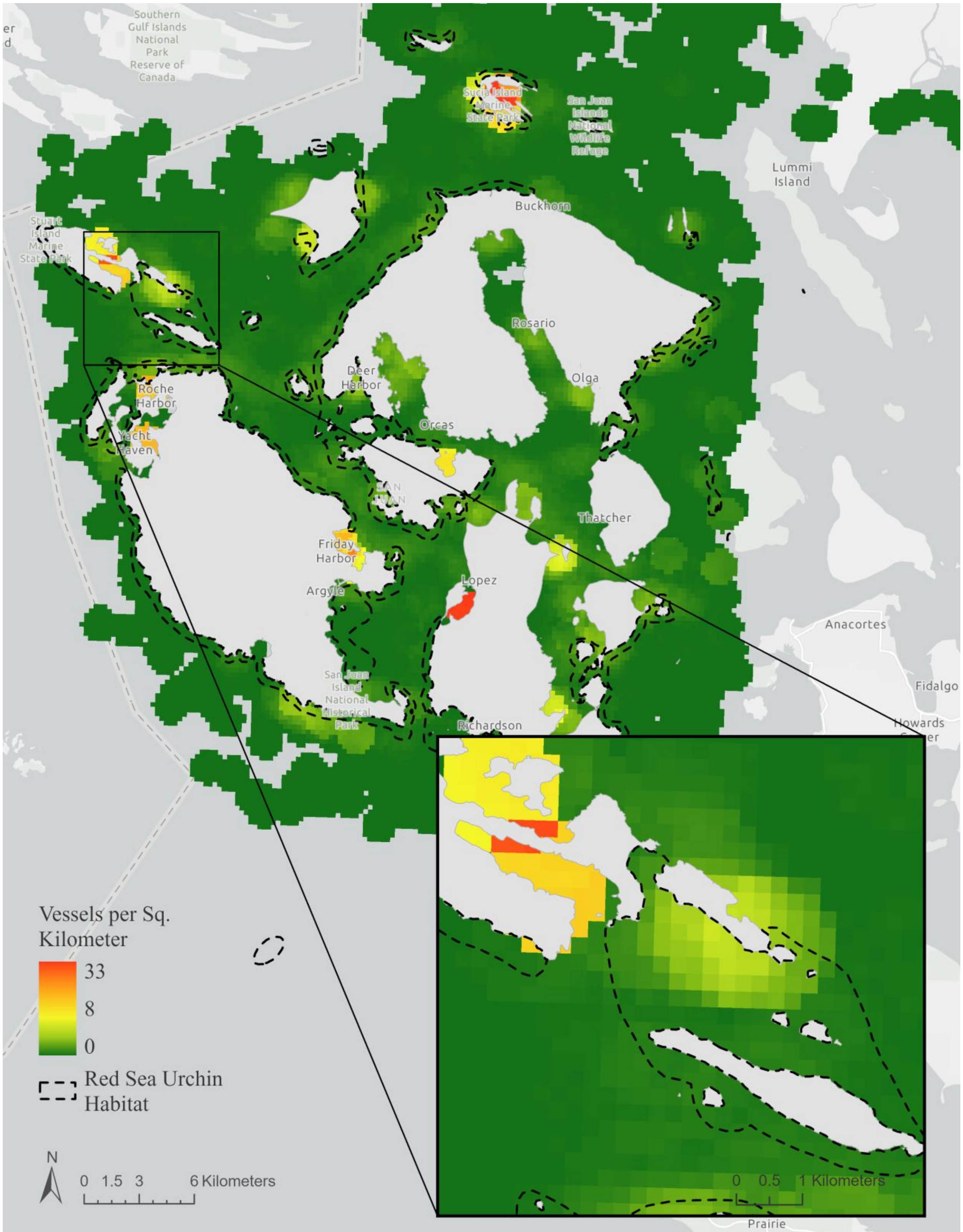
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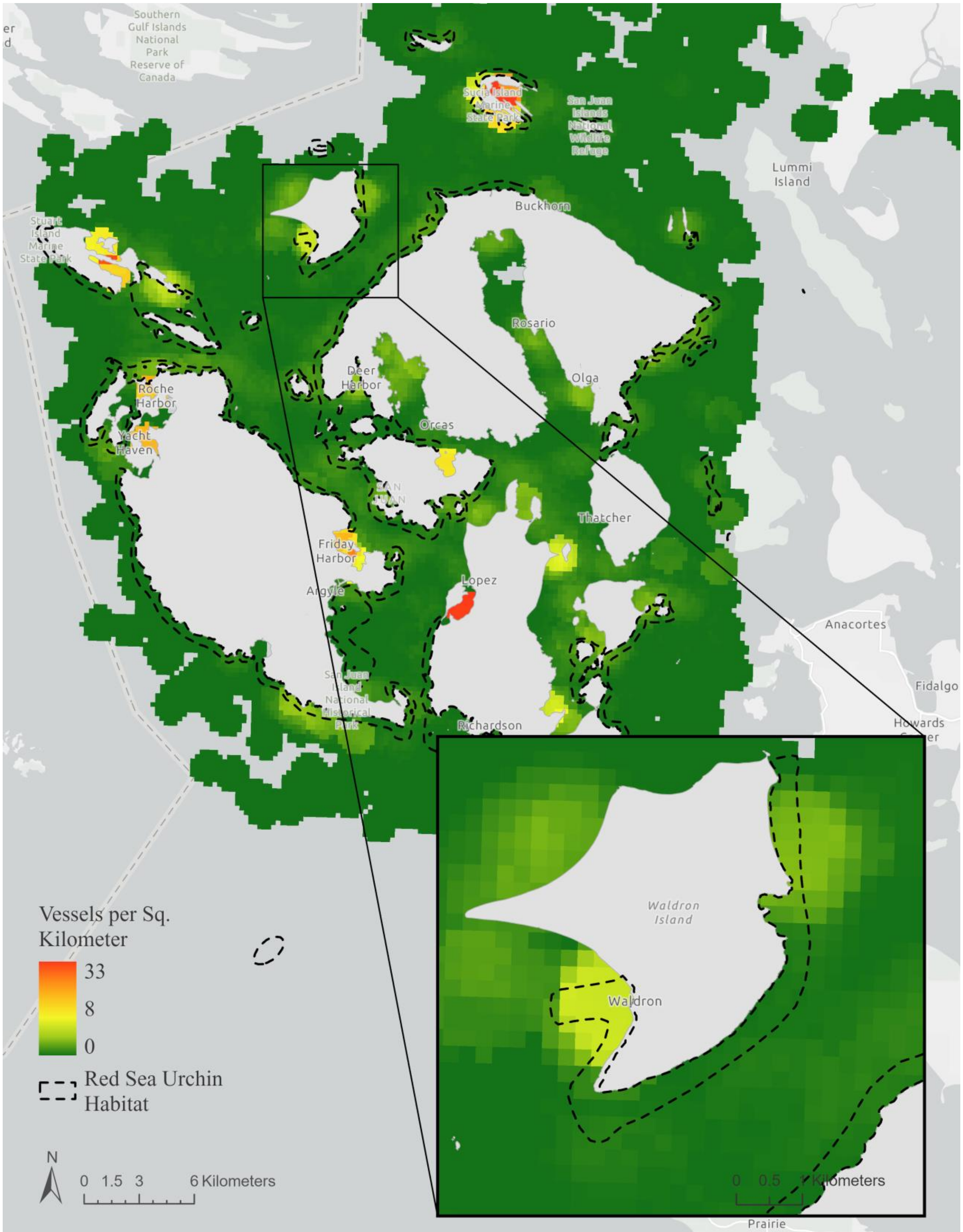
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Argyle
Anacortes
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San Juan Island National Historical Park
Richardson
Howards
Waldron Island
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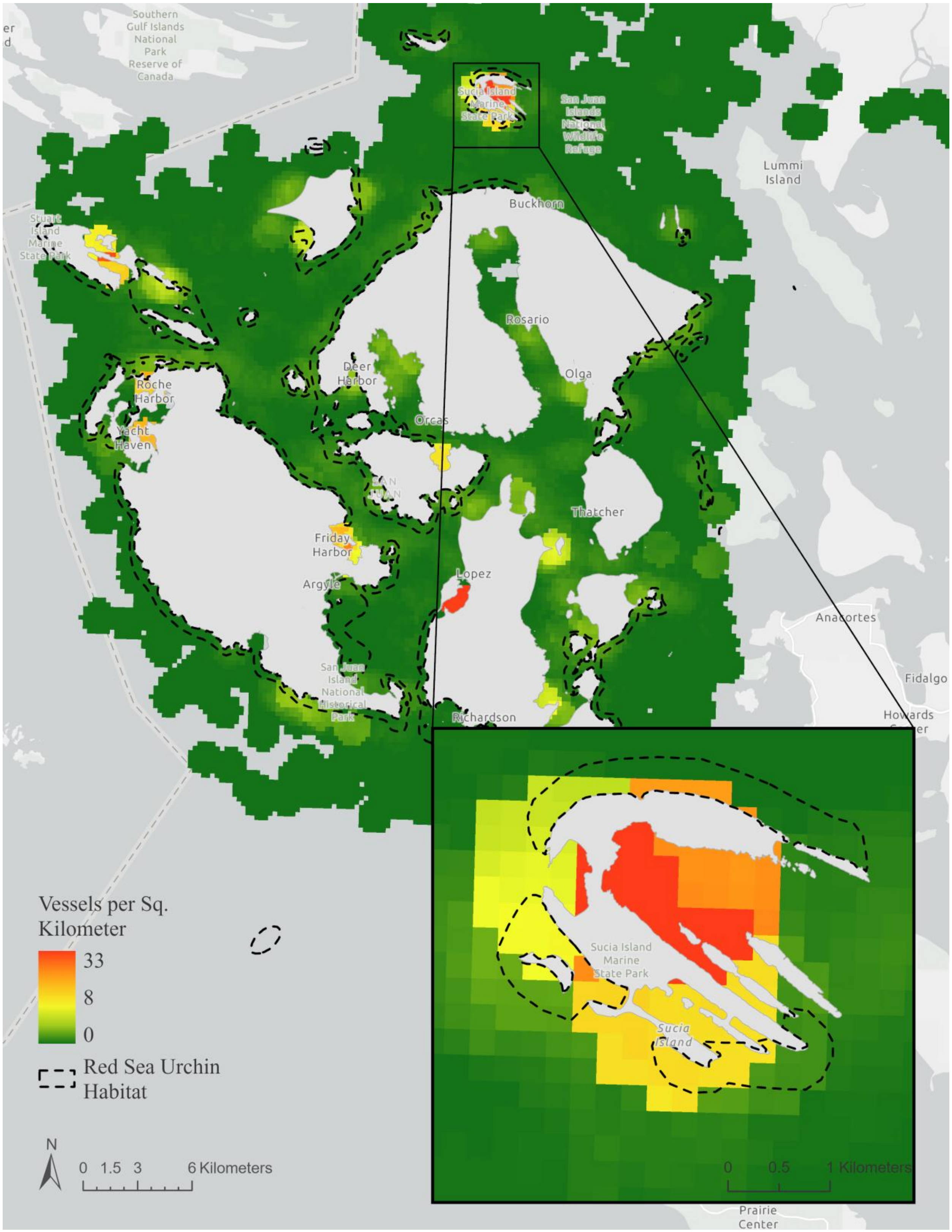
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Thatcher
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San Juan Island National Historical Park
Fidalgo
Richardson
Howards
Vessels per Sq. Kilometer
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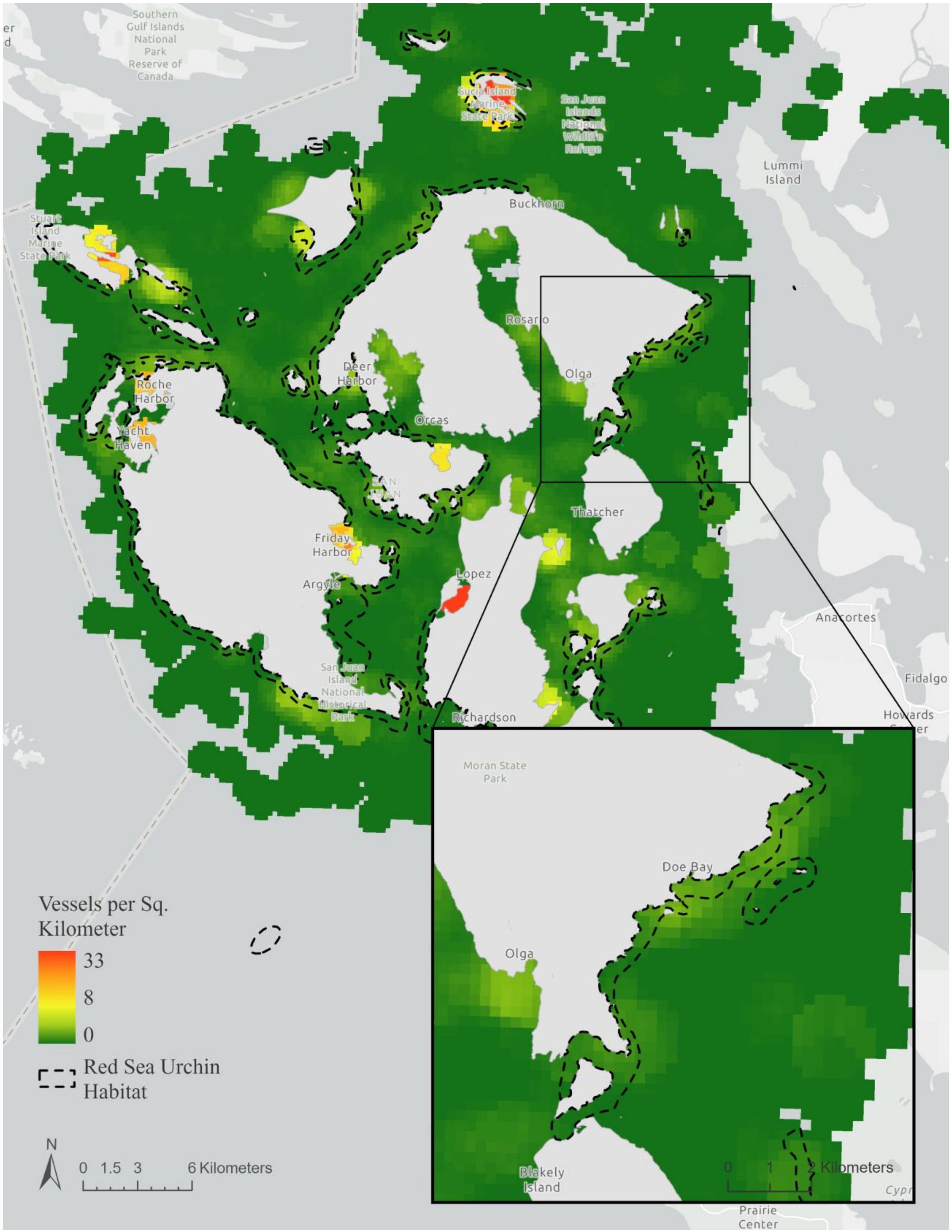
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Richardson
Howards
Moran State Park
Doe Bay
Olga
Blakely Island
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Vessels per Sq. Kilometer
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Red Sea Urchin Habitat
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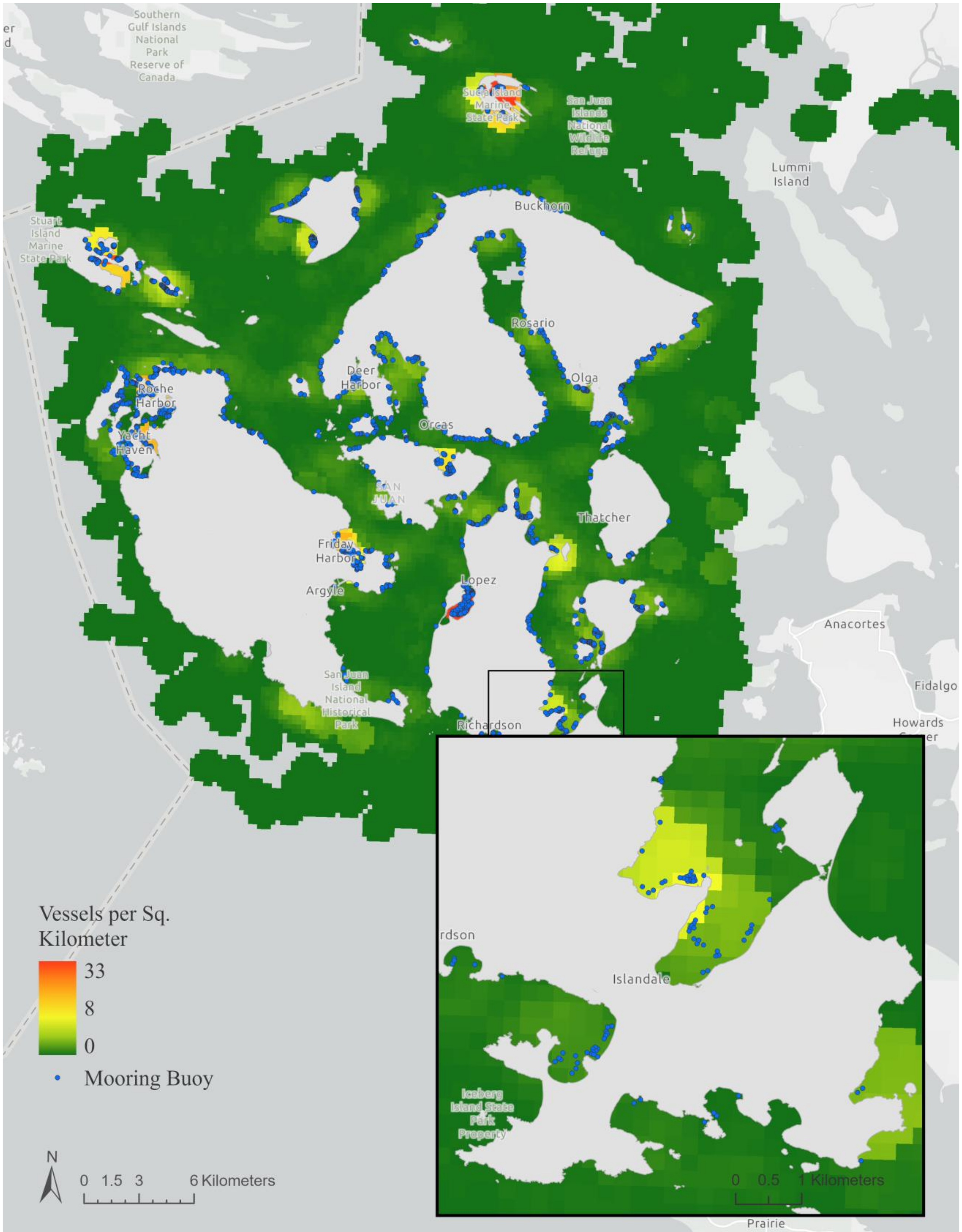
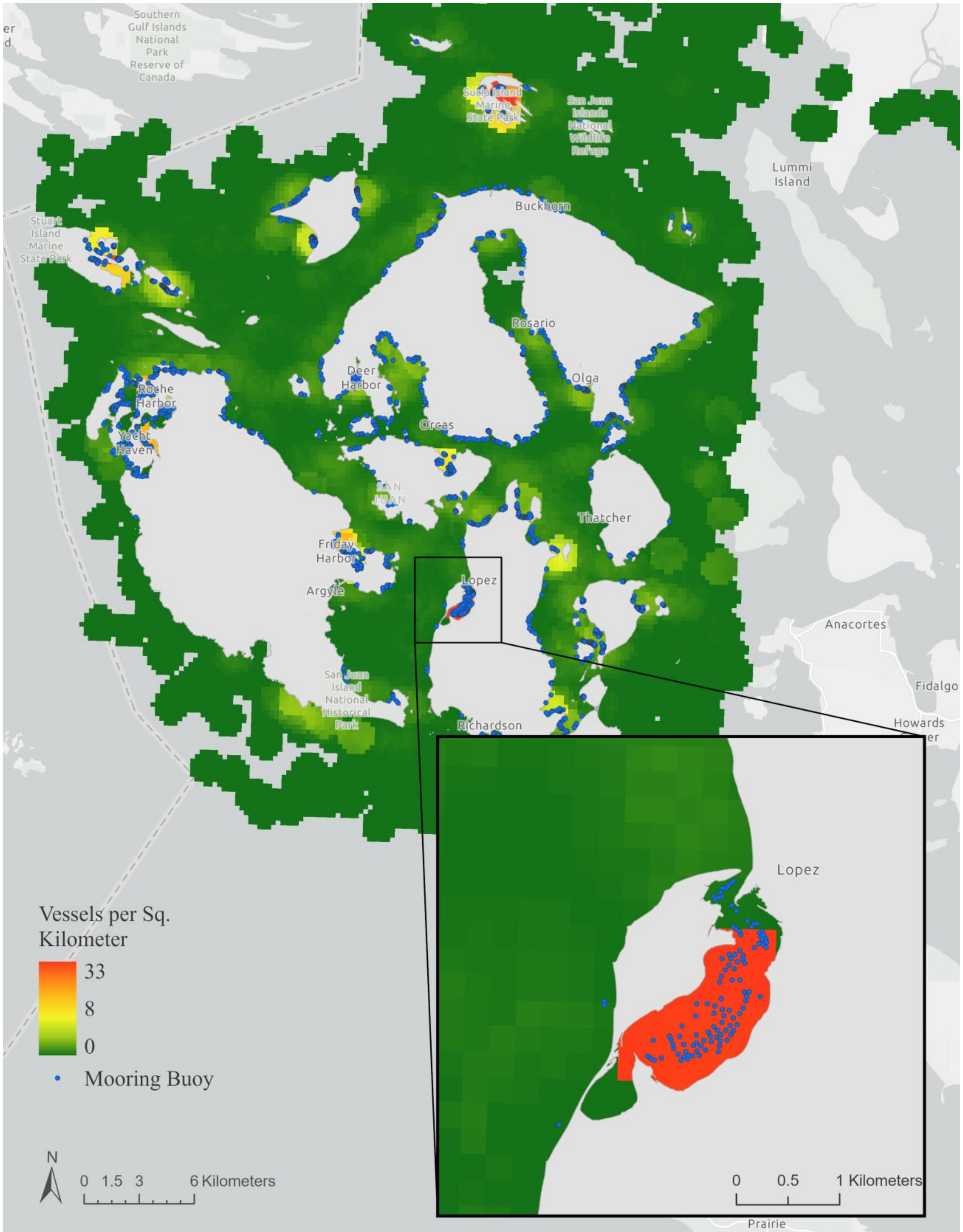
Mooring Buoys

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Lopez
Argyle
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Fidalgo
Richardson
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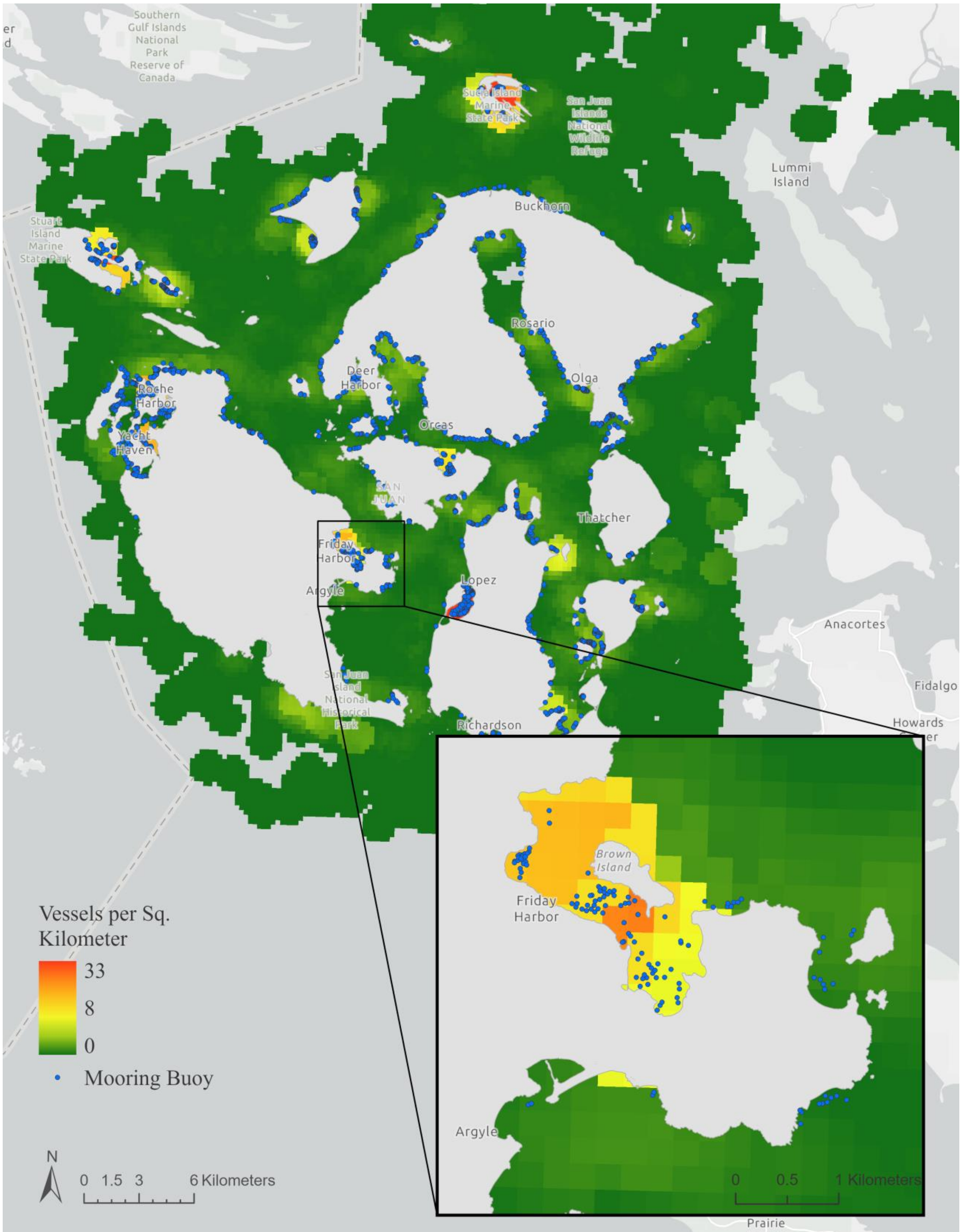
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Friday Harbor
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Fidalgo
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Howards
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Prairie Center
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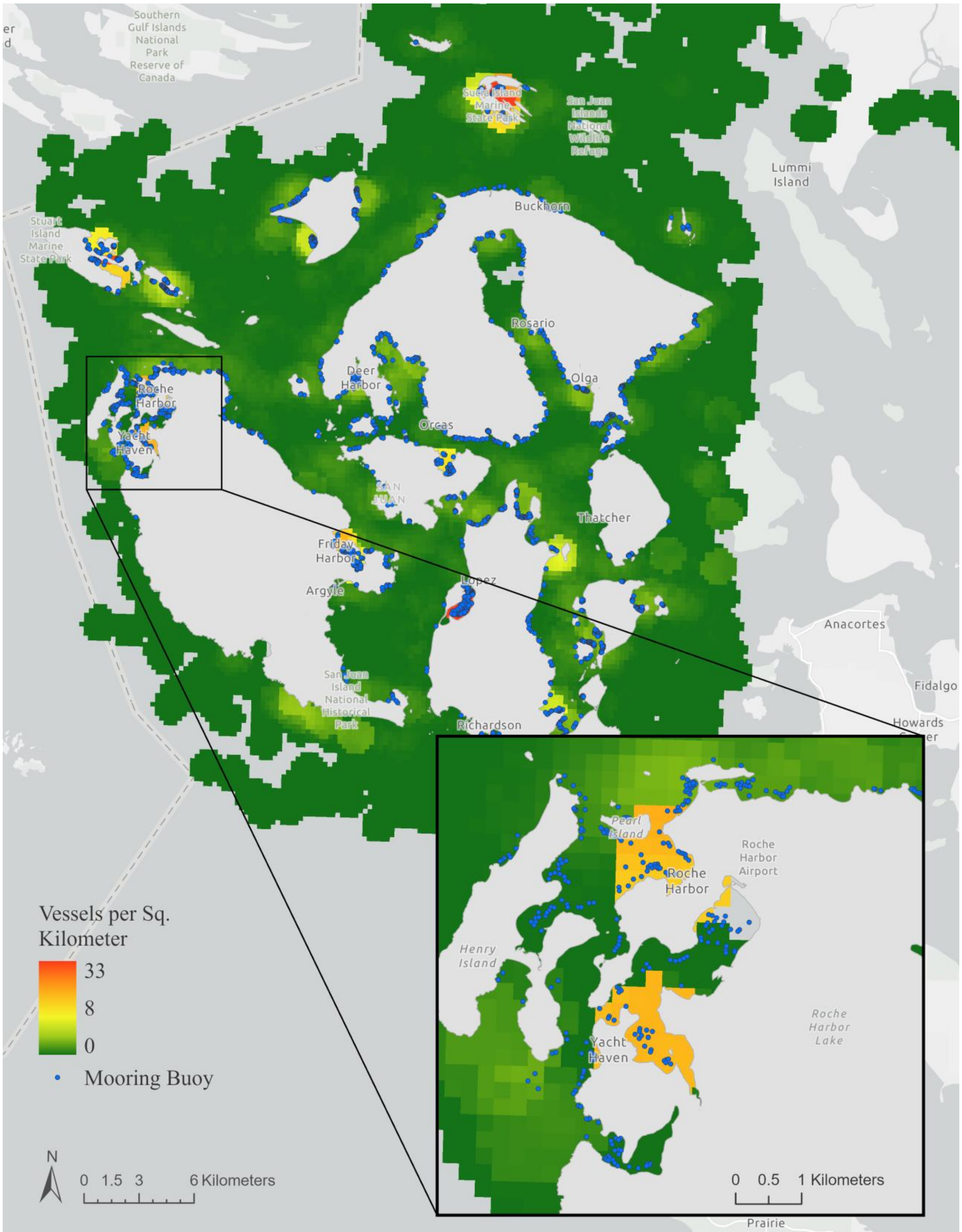
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San Juan
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Anacortes
Fidalgo
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Richardson
Howards
Pearl Island
Roche Harbor
Roche Harbor Airport
Henry Island
Roche Harbor Lake
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Prairie Center
Vessels per Sq. Kilometer
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Mooring Buoy
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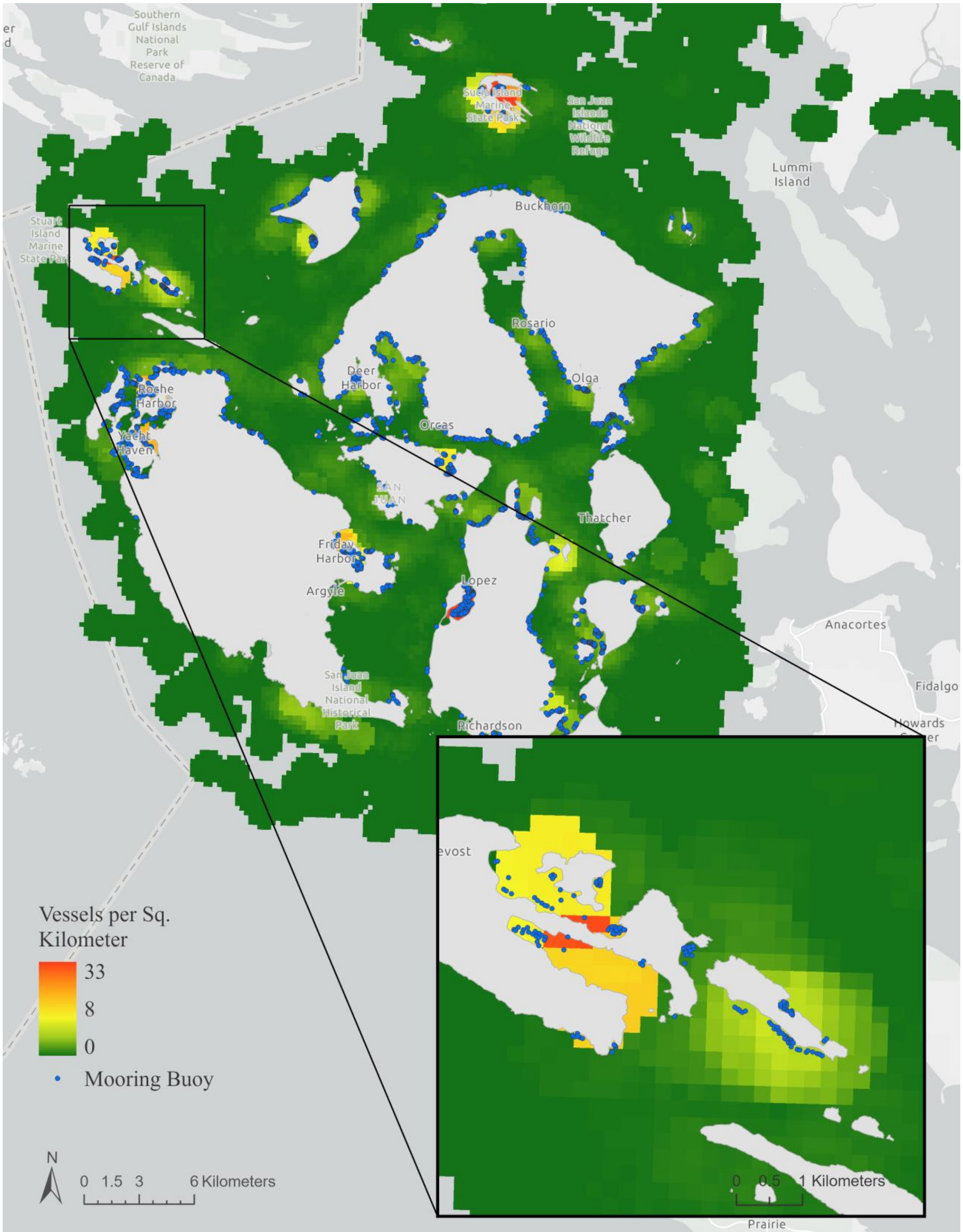
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Anacortes
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Richardson
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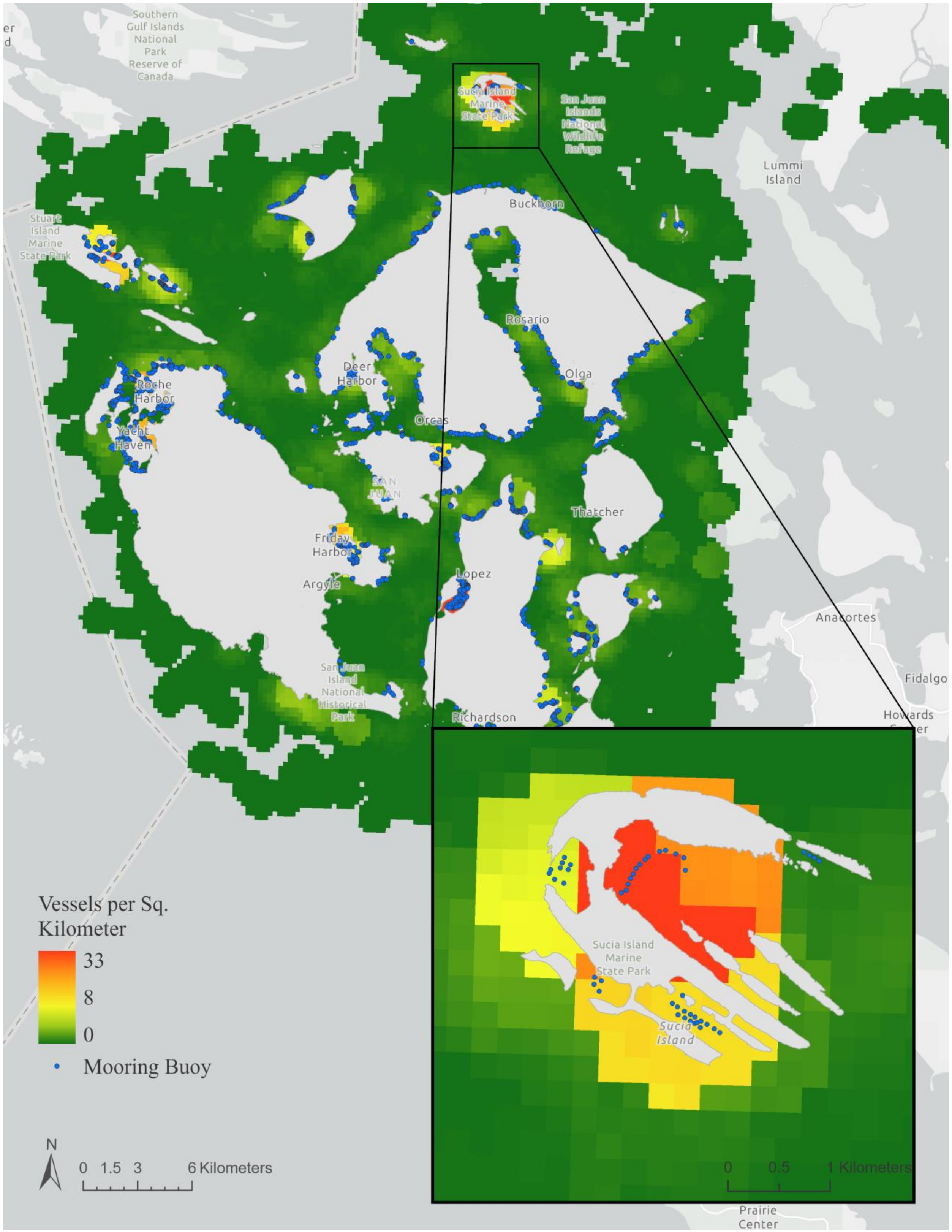
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Anacortes
Fidalgo
San Juan Island National Historical Park
Richardson
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Vessels per Sq. Kilometer
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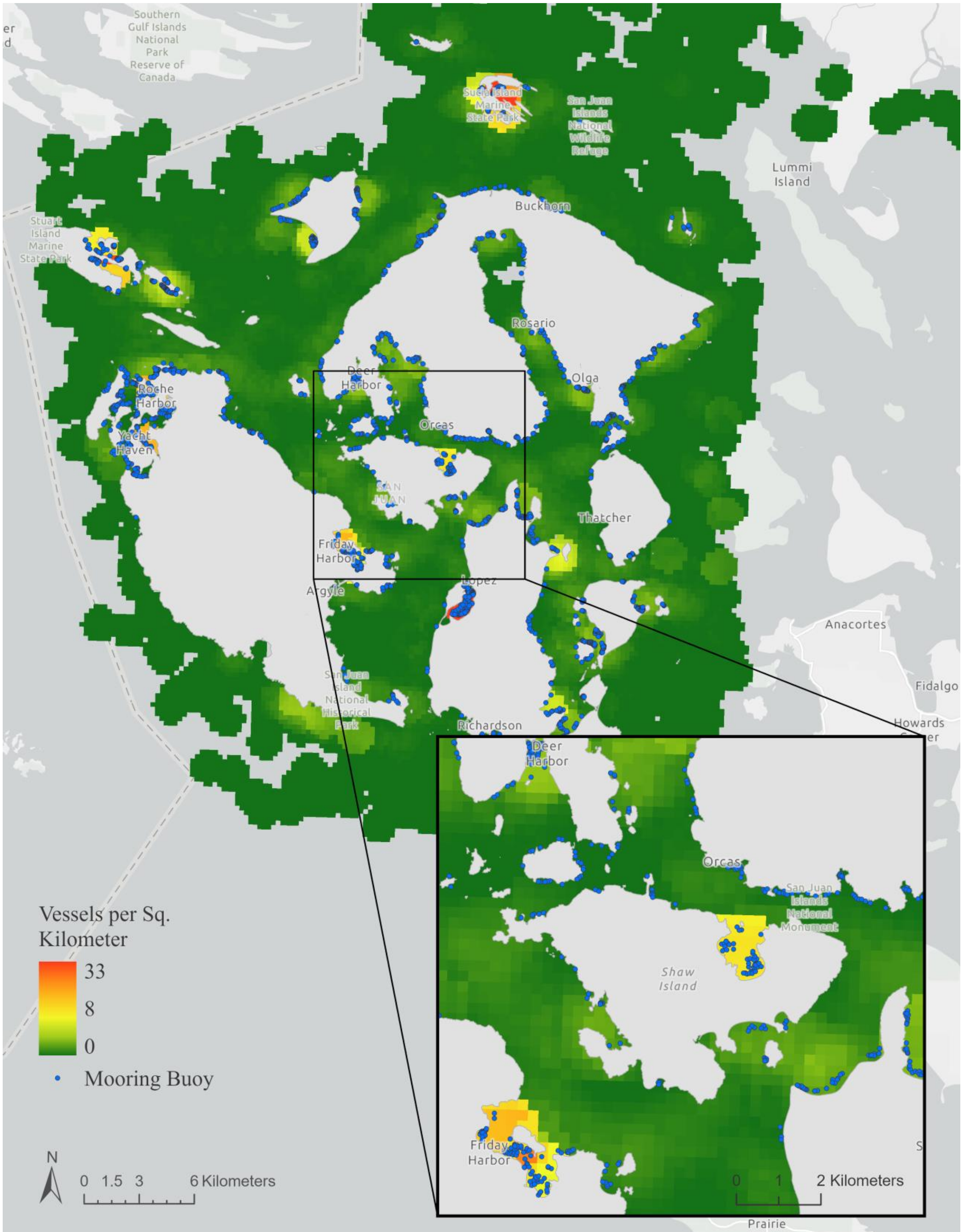

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SAN JUAN
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Lopez
Anacortes
Fidalgo
San Juan Island National Historical Park
Richardson
Prairie Center
Deer Harbor
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San Juan Islands National Monument
Shaw Island
Friday Harbor
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Vessels per Sq. Kilometer
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Mooring Buoy
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