N A T U R A L   R E S O U R C E S

Eelgrass abundance and depth distribution on Bainbridge Island

Final report to the City of Bainbridge Island
DNR IAA 16-239

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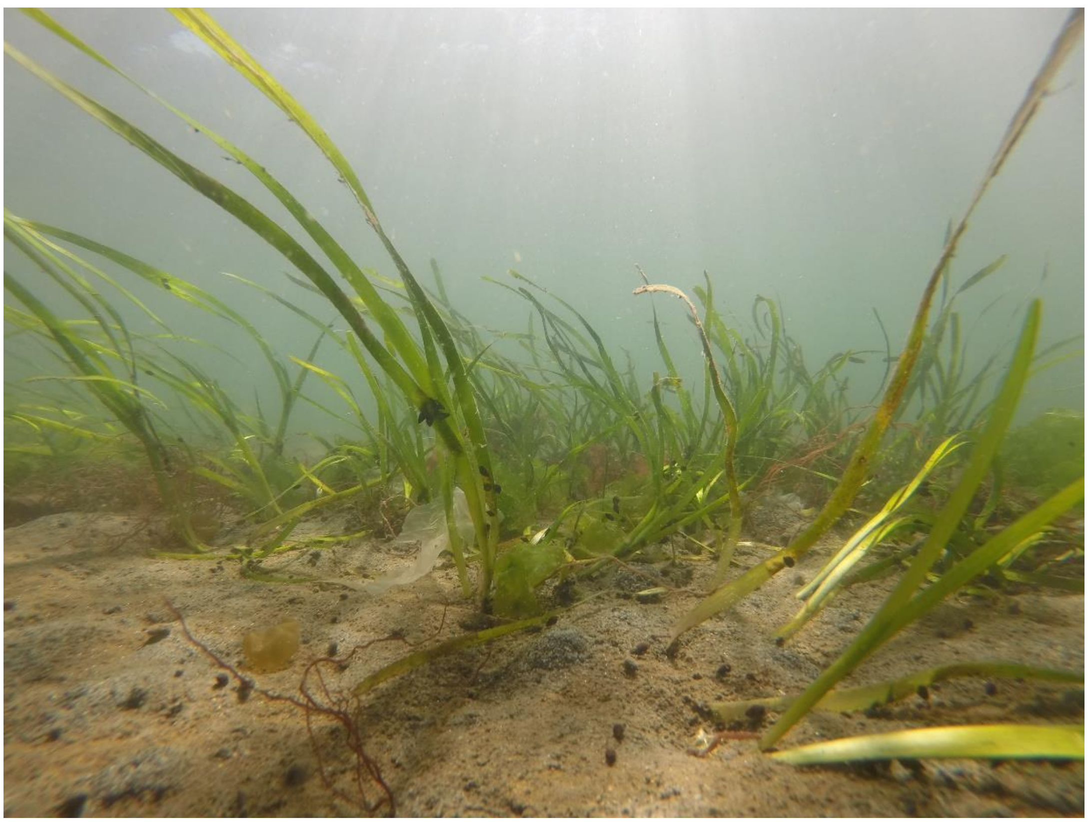
30 June 2017



Puget Sound Ecosystem Monitoring Program

Washington State Department of Natural Resources

The Nearshore Habitat Program supports the Washington State Department of Natural Resources' stewardship responsibilities for state-owned aquatic lands. It is also a component of the Puget Sound Ecosystem Monitoring Program (PSEMP) (http://sites.google.com/site/pugetsoundmonitoring/).

Cover Photo: *Zostera marina*, Photo by DNR

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Puget Sound Ecosystem Monitoring Program
Washington State Department of Natural Resources

Acknowledgements

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The following document fulfills deliverable 5.1 for Inter-Agency Agreement no. IAA 16-239 between the Washington Department of Natural Resources and the City of Bainbridge Island.

The principal authors of this report include Bart Christiaen, Jeff Gaeckle, and Lisa Ferrier. Several people played a critical role in the video data collection and post-processing for the work summarized in this report including Jessica Olmstead and Cailan Murray.

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Contents

Executive Summary

The Washington State Department of Natural Resources (DNR) manages 2.6 million acres of state-owned aquatic lands for the benefit of current and future citizens of Washington State. DNR's stewardship responsibilities include protection of native seagrasses such as eelgrass (*Zostera marina*), an important nearshore habitat in greater Puget Sound. DNR monitors the status and trends of native seagrass abundance and depth distribution throughout greater Puget Sound using underwater videography.

In 2016, the City of Bainbridge Island signed an interagency agreement with DNR to collect baseline eelgrass area and depth distribution data for 19 sites, using methods standardized by DNR's Submerged Vegetation Monitoring Program (SVMP). Field work took place during September and October 2016. Between 2014 and 2016, DNR sampled the entire shoreline of Bainbridge Island and a large section of the Kitsap Peninsula as part of agreements with the City of Bainbridge Island and the Suquamish Tribe. This report contains results for the entire shoreline of Bainbridge Island.

In addition to estimating current status, these projects have established a baseline for future, periodic surveys to document trends in eelgrass area and depth distribution at both a site and regional scale. This effort supplements existing and planned future sampling by the SVMP, and significantly increases the certainty in local estimates of eelgrass area and depth distribution over existing data from the Submerged Vegetation Monitoring Program.

Key Findings:

- The shoreline of Bainbridge Island was divided into 64 sample sites: 24 of those sites were sampled as part of IAA 16-239 (5 more than originally planned), 39 sites were sampled as part of a separate agreement with the Suquamish Tribe in 2014 and 2016, and one site was sampled as part of the SVMP in 2013.

- Out of the 64 sites sampled, there are 21 sites without eelgrass. Sites without eelgrass are predominantly located in Port Orchard Bay. Within the study area, eelgrass is most abundant along the eastern shore of Bainbridge Island.

- Our current best estimate is that there is approximately 167 ha of eelgrass along the shoreline of Bainbridge Island.

- Eelgrass grows to greater maximum depths along the eastern shores of Bainbridge Island, as compared to Port Orchard and Sinclair Inlet.

- Approximately 90 % of all eelgrass along the shoreline of Bainbridge Island grows between 0 and -4.5 m relative to Mean Lower Low Water (MLLW). The median depth is approximately -1.5 m (MLLW).

1 Introduction

Eelgrass (*Zostera marina*) provides a wide range of important ecosystem services. In Puget Sound, eelgrass offers spawning grounds for Pacific herring (*Clupea harengus pallasi*), out-migrating corridors for juvenile salmon (*Oncorhynchus* spp.) (Phillips 1984, Simenstad 1994), and important feeding and foraging habitats for waterbirds such as the black brant (*Branta bernicla*) (Wilson and Atkinson 1995) and great blue heron (*Ardea herodias*) (Butler 1995). In addition, eelgrass provides valued hunting grounds and ceremonial foods for Native Americans and First Nation People in the Pacific Northwest (Suttles 1951, Felger and Moser 1973, Kuhnlein and Turner 1991, Wyllie-Echeverria and Ackerman 2003). Eelgrass responds quickly to anthropogenic stressors such as physical disturbance, and reduction in sediment and water quality due to excessive input of nutrients and organic matter. This makes eelgrass an effective indicator of habitat condition (Dennison et al. 1993, Short and Burdick 1996, Lee et al. 2004, Kenworthy et al. 2006, Orth et al. 2006).

Since 2000, the Nearshore Habitat Program at the Washington State Department of Natural Resources has collected annual data on the status of eelgrass (*Zostera marina*) throughout Puget Sound as part of the Submerged Vegetation Monitoring Program (SVMP). The SVMP is one component of the broader Puget Sound Ecosystem Monitoring Program (PSEMP), a multi-agency monitoring program coordinated by the Puget Sound Partnership. The monitoring data is used to characterize the status of native seagrass and is one of 25 vital signs used by the Puget Sound Partnership to track progress in the restoration and recovery of Puget Sound (PSP 2014).

In 2016, the City of Bainbridge Island signed an interagency agreement with DNR to collect baseline eelgrass area and depth distribution data at 19 sample sites along Bainbridge Island, using methods standardized by the SVMP. Monitoring was initiated on 19 September 2016, and ended on 20 October 2016. During this period of time, we sampled the 19 proposed sites and an additional 5 sites which were located in Eagle Harbor and Agate Passage.

In 2013, 2015, and 2016, the entire shoreline of Bainbridge Island was sampled using the same methodology as part of interagency agreements between DNR, the City of Bainbridge Island and the Suquamish Tribe. This report summarizes the DNR sampling methods, and the eelgrass area and depth results at the 64 sites along Bainbridge Island.

2 Methods

Field sampling was conducted using the methods of DNR's Submerged Vegetation Monitoring Program (SVMP). The SVMP is a regional monitoring program, initiated in 2000, designed to provide information of both the status and trends in native seagrass area in greater Puget Sound. This program uses towed underwater videography as the main data collection methodology to provide reliable estimates of eelgrass area for subtidal seagrass beds in places where airborne remote sensing cannot detect the deep edge of the bed. Video data is collected along transects that are oriented perpendicular to shore and span the area where native seagrasses (mainly eelgrass, *Zostera marina*) grow at a site. The video is later reviewed and each transect segment of nominal one-meter length (and one meter width) is classified with respect to the presence of *Zostera marina* and *Zostera japonica*.

2.1 Study area description

This report covers seagrass beds along the entire shoreline of Bainbridge Island. Prior to sampling, the shoreline of Bainbridge Island was divided in 64 individual sample sites. Sites are labeled according to the SVMP dataset. Each code starts with 3 letters (cps, which stands for Central Puget Sound), followed by 4 numbers. The sole exception are the tidal flats, which are coded as "flats" followed by 2 numbers. The location of the individual sites is noted on the site maps in paragraph 3.4 of the results section.

The 24 sites sampled as part of IAA 16-239 are indicated in red on Figure 1. The majority of remaining sites on Bainbridge Island were sampled as part of an interagency agreement between DNR and the Suquamish Tribe in 2014 and 2016. One site (cps1035) was sampled as part of DNR's soundwide monitoring effort.

2.2 Field sampling

2.2.1 Equipment

Field sampling was conducted in September and October 2014 and 2016 from the 11 m research vessel *R/V* Brendan D II (Figure 2). The *R/V* Brendan D II was equipped with an underwater video camera mounted in a downward-looking orientation on a weighted towfish (Figure 3).

Parallel lasers mounted 10 cm apart created two red dots in the video images for scaling reference. The towfish was deployed directly off the stern of the vessel using an A-frame cargo boom and hydraulic winch. The weight of the towfish positions the camera directly beneath a DGPS antenna, ensuring that the data accurately reflected the geographic location of the camera (Figure 3).

Time, differential global positioning system (DGPS) data, Garmin and BioSonics depth data were acquired simultaneously during sampling. Differential corrections were received from the United States Coast Guard public DGPS network using the WGS 84 datum. Table 1 lists the equipment used to conduct the video sampling and acquisition of eelgrass depth data.

Table 1: Equipment and software used to collect underwater video and depth data

Equipment	Manufacturer/Model
Differential GPS	Trimble AgGPS 132 (sub-meter accuracy)
Depth Sounders	BioSonics DE 4000 system (including Dell laptop computer with Submerged Aquatic Vegetation software), Garmin FishFinder 250
Underwater Cameras	(2) SplashCam Deep Blue Pro Color (Ocean Systems, Inc.)
Lasers	Deep Sea Power & Light
Underwater Light	Deep Sea Power & Light RiteLite (500 watt)
Navigation Software	Hypack Max
Video Overlay Controller	Intuitive Circuits TimeFrame
DVD Recorder	Sony RDR-GX7
Digital Video Recorder	Sony DVR-TRV310 Digital8 Camcorder Datavideo DN-700 / DV Hard Disk Recorder

2.2.2 Site and sample polygons

Prior to field sampling, a site polygon was defined for each site, bounded by the -6.1 m MLLW bathymetry contour and the ordinary high water mark as described in the SVMP methods (Berry et al. 2003). Fringe sites are 1000 m along the -6.1 m contour on the deep edge, while the segment lengths vary for flats sites (e.g., depending on embayment size). In addition, we delineated sample polygons, which encompass all the eelgrass at a site, based on reconnaissance prior to sampling.

At each site, underwater videography was used to sample the presence of eelgrass along transects in a modified line-intercept technique (Norris et al. 1997). Video transects are oriented perpendicular to shore, and extend beyond the shallow and deep edges of the sample polygons. Transects were selected based on a stratified random approach with 1 transect per stratum (STR). Sites are divided in 10 sections of similar length (strata). In each of these sections, one transect is selected using simple random sampling.

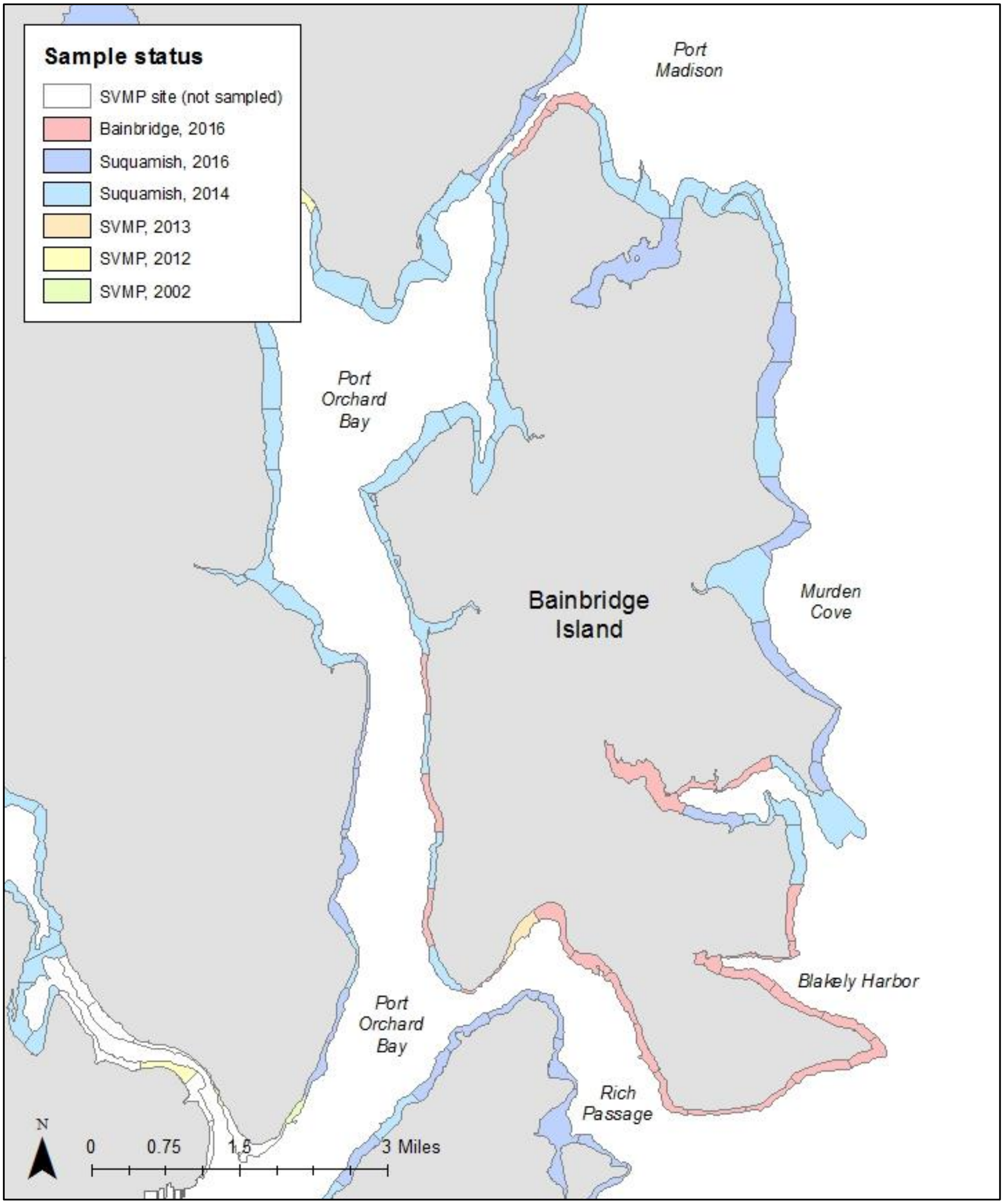

Figure 1: The entire shoreline of Bainbridge Island was sampled between 2013 and 2016. Sites that were sampled as part of IAA 16-239 are indicated in red. Sites sampled as part of agreement 15-17 between DNR and the Suquamish Tribe are indicated in light blue (2014) and dark blue (2016). One site (cps1035) was sampled as part of DNR's soundwide monitoring effort and is indicated in yellow.

Figure 2: Eelgrass (*Z. marina*) presence and depth distribution data were collected from the *R/V* Brendan D II using underwater videography and depth sounding instrumentation.

Figure 3: The *R/V* Brendan D II is equipped with a weighted towfish that contains an underwater video camera mounted in a downward looking orientation, dual lasers for scaling reference, and underwater lights for night work (A). The towfish is deployed directly beneath the DGPS antenna attached to the A-frame cargo boom, ensuring accurate geographic location of the camera (B).

2.3 Video processing and data analysis

2.3.1 Video processing

The video sampling resolution is nominally one square meter and eelgrass is categorized as present or absent based on the observation of rooted shoots within the video field of view. All *Z. marina* presence and absence classification results were recorded with corresponding spatial information. The fractional cover of eelgrass along transects was used to calculate site eelgrass area. The depth at which eelgrass grows along each transect was used to estimate mean maximum and minimum depth of eelgrass relative to Mean Lower Low Water (MLLW) within each sample polygon at each site.

All measured depths were corrected to the MLLW datum by adding the transducer offset, subtracting the predicted tidal height for the site and adding the tide prediction error (calculated using measured tide data from the National Oceanic and Atmospheric Administration website http://co-ops.nos.noaa.gov/data_res.html). These final corrected depth data were merged with eelgrass data and spatial information into a site database so the eelgrass observations had associated date/time, position and depth measurements corrected to MLLW datum.

2.3.2 Depth distributions

Each random video transect that contained *Z. marina* had a minimum and maximum depth relative to MLLW. Minimum and maximum *Z. marina* depth characteristics for each site were estimated using descriptive statistics (i.e., minimum, maximum, and the 5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th} and 95^{th} quantiles). For each site with *Z. marina* present, we represented the depth distribution with a histogram of depths of all sample points where *Z. marina* was detected at the site.

The regional depth distribution of *Z. marina* was calculated as follows. For each site, *Z. marina* observations were binned according to their depth relative to MLLW in 0.5m bins. The number of observations in each depth bin was divided by the total number of *Z. marina* observations at the site. This fraction was multiplied by the estimated eelgrass area at the site to estimate the area of eelgrass in each depth bin at the site. In other words, we used the following formula to estimate eelgrass area in each depth bin at each site:

$$a_{jk} = A_j \frac{c_{jk}}{\sum_{k=1}^{n} c_{jk}}$$

Where a_{jk} is *Z. marina* area in each histogram bin (k) at site (j), c_{jk} is the count of observations per bin, and A_j is estimated eelgrass area at site j. Per-bin area estimates from sites were combined into a depth distribution for the entire study area.

2.3.3 *Area calculations*

Eelgrass area at each site was calculated using ArcGIS software and the site database file in the following sequential steps:

1. Calculate the area within the sample polygon;
2. Calculate the fraction of eelgrass along each random line transect;
3. Calculate the mean fraction and associated variance[1], weighed by transect length;
4. Estimate the overall eelgrass area and variance at the site by extrapolating the mean fraction along random transects over the sample polygon area.

[1] We calculate variance for stratified random samples using the textbook variance estimator. This formula may overestimate actual variance for stratified random samples and systematic samples, and is thus a conservative estimator of variance for these sampling schemes (McGarvey et al. 2016).

3 Results

3.1 Seagrass species near Bainbridge Island

Out of the 64 sites sampled along the shoreline of Bainbridge Island, there were 43 sites with *Zostera marina* (eelgrass), 22 sites with the non-native *Z. japonica*, and 18 sites where seagrass was absent (Figure 5). *Zostera marina* is widespread along the eastern shoreline of the Bainbridge Island, but it is more limited near Port Orchard Bay. Eelgrass is sparse to absent in enclosed embayments such as Blakely Harbor (cps1085), Eagle Harbor (flats36), Manzanita Bay (cps1050), and the inside of Port Madison Bay (flats38). Note that while there is a trace amount of eelgrass at the mouth of flats38, the site has been indicated as eelgrass absent on figure 5 to better represent the spatial distribution of eelgrass at this location. *Zostera japonica* grows at higher tidal elevations than *Z. marina*, and is often too shallow for the sample vessel. As such, our data are conservative estimates for the presence/absence of *Z. japonica*. Nevertheless, the data suggests that *Z. japonica* is common on the northern shores of Bainbridge Island (from Battle Point in Port Orchard Bay to Yeomalt Point north of Eagle Harbor). *Z. japonica* usually occurs at sites where *Z. marina* is present. Only 3 of the 64 sites sampled contained only *Z. japonica* but no *Z. marina* (Figure 5).

Figure 4: A small patch of non-native *Zostera japonica*, surrounded by the native *Zostera marina*. *Z. japonica* is usually smaller than *Z. marina*, but at some locations it is difficult to differentiate between both species based on size. Other defining characteristics include the morphology of the leaf sheath and the root system.

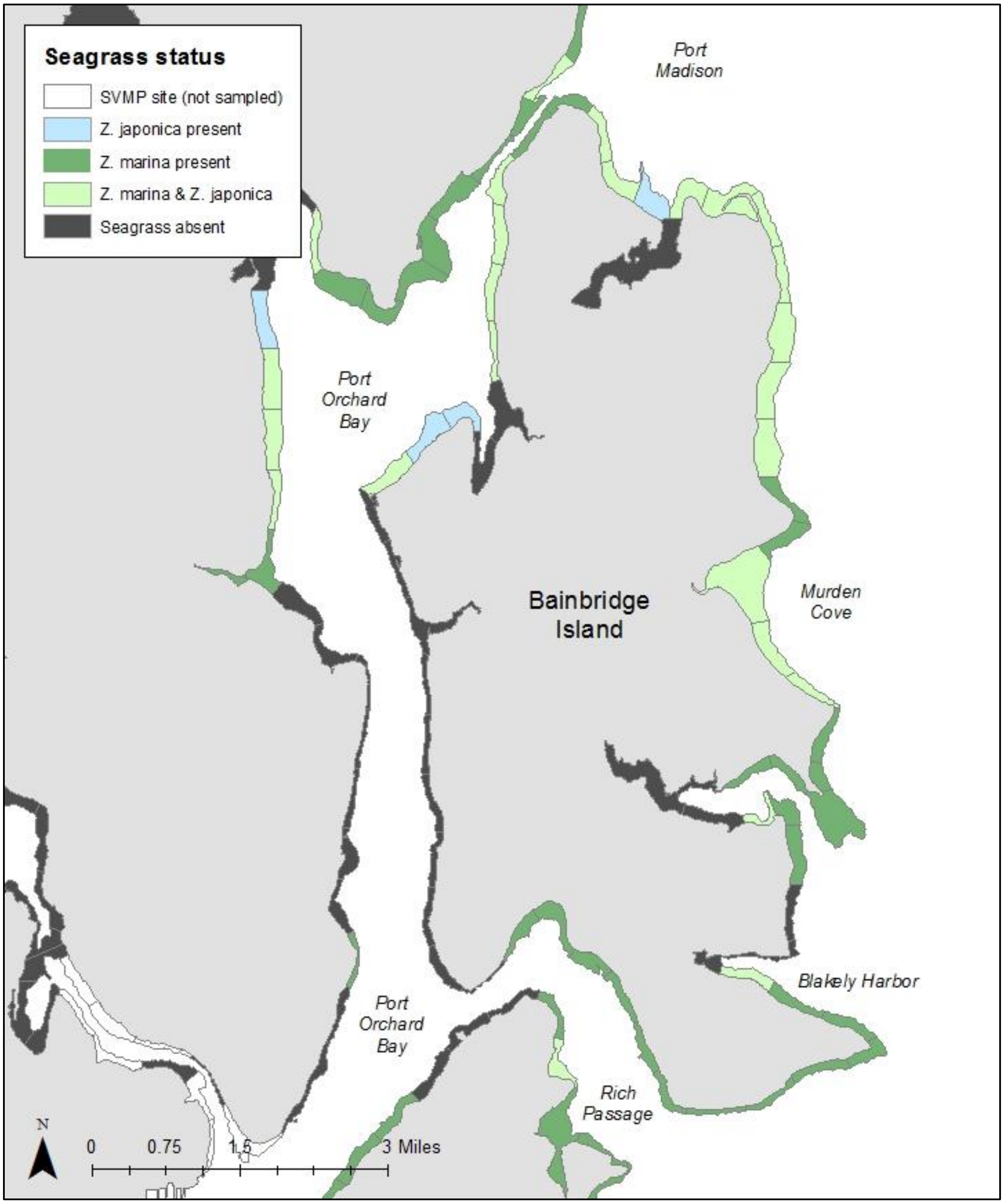

Figure 5: Seagrass status near Bainbridge Island. All sites were sampled between 2013 and 2016.

3.2 Area estimates of eelgrass beds along Bainbridge Island

The eelgrass beds along the shore of Bainbridge Island are are relatively small. This is to be expected, as most of these beds grow on relatively narrow fringes of shoreline. Out of the 43 sites with eelgrass**,** 13 sites have less than 1 ha of eelgrass present, 17 sites have between 1 and 5 ha of eelgrass present, 7 sites have between 5 and 10 ha present, and only 6 sites have eelgrass beds larger than 10 ha. As such, the distribution of eelgrass area in sites around Bainbridge Island is skewed (Figure 6). The sites with the largest eelgrass beds are Murden Cove (cps1069), Wing Point (flats37), N. of Rolling Bay (cps1065), and E of Madison Church (cps1064); with 15.31 ± 0.57 ha, 13.26 ± 3.51 ha, 12.63 ± 0.59 ha, and 12.06 ± 1.41 ha respectively. The sites on the southern end of Bainbridge Island tend to have the smallest eelgrass beds (Figure 7, Table 2).

The median size of the eelgrass beds around Bainbridge Island is approximately 1.8 ha (range 0.05 – 15.31 ha). This is very similar to fringe sites in general in greater Puget Sound (median size 3.5 ha, range 0.001 – 75 ha). Based on the site area estimates, there is approximately 167 ha of eelgrass on the shores of Bainbridge Island (as compared to ~22,000 ha in the entire greater Puget Sound area.

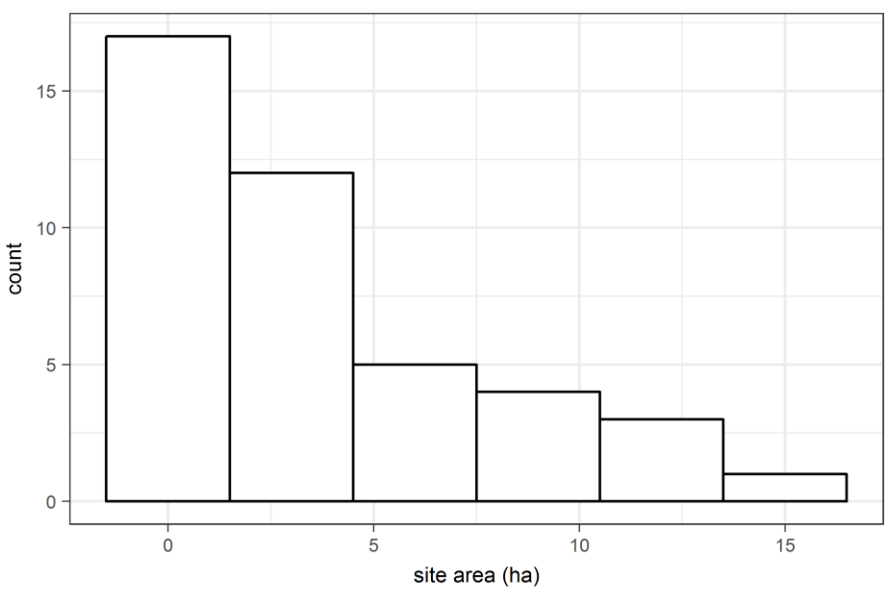

Figure 6: The size distribution of eelgrass beds around Bainbridge Island (ha). The majority of eelgrass beds in the study area is relatively small (< 10 ha).

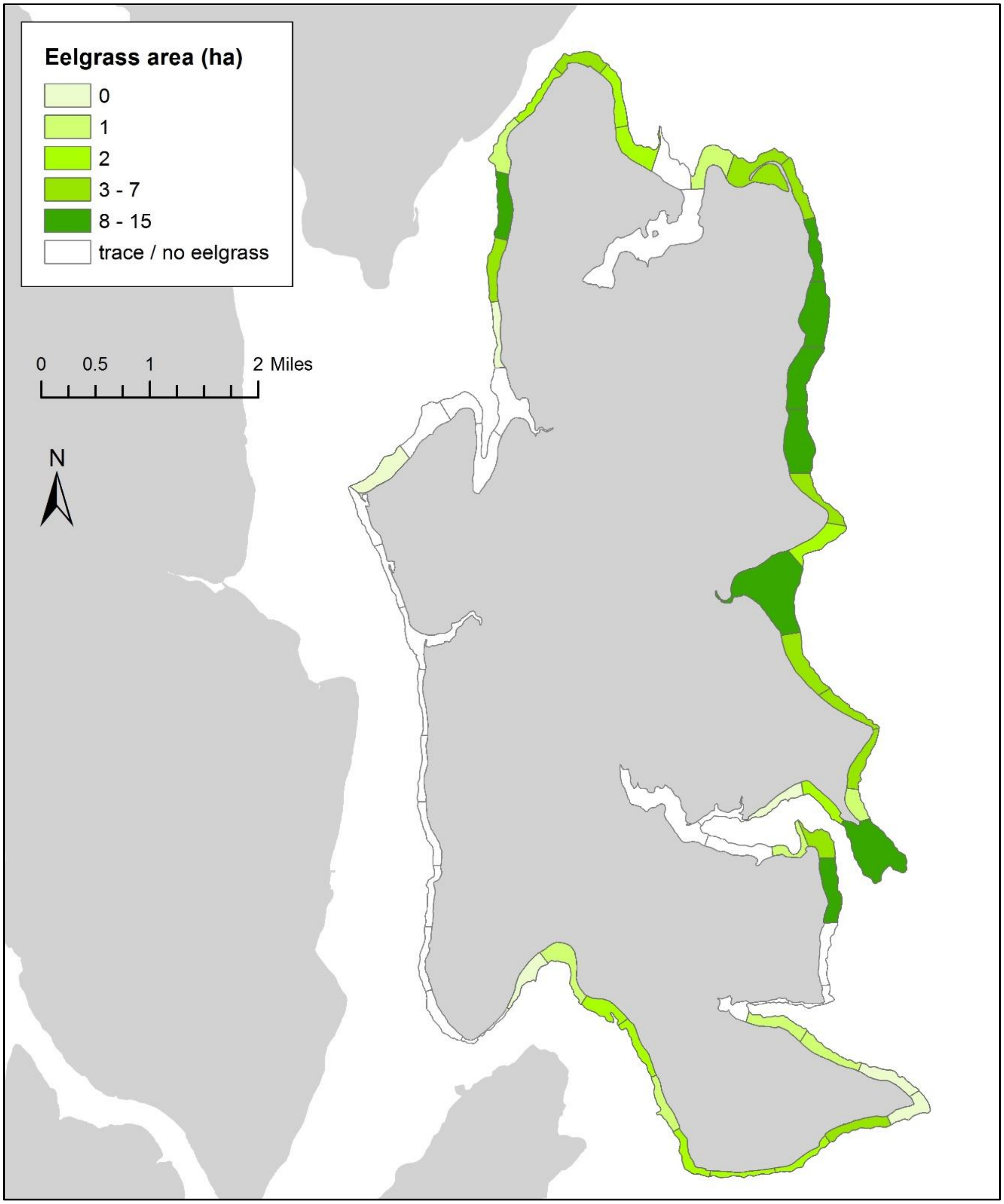

Figure 7: Size of eelgrass beds on the shores of Bainbridge Island. Darker green colors indicate sites with larger eelgrass beds.

Table 2: Size of eelgrass beds of sites along the shoreline of Bainbridge Island (ordered according to size)

site_code	site_name	special_study	survey_date	n_transects	fraction	sample area (ha)	veg area (ha)	veg area se (ha)	veg area cv
cps1069	Murden Cove, Bainbridge	Suquamish	22-Sep-14	10	0.4152	36.87	15.31	0.57	0.04
flats37	Wing Point, Bainbridge	Suquamish	23-Sep-14	9	0.2798	47.39	13.26	3.51	0.26
cps1065	N of Rolling Bay, Bainbridge	Suquamish	15-Sep-16	10	0.5626	22.46	12.63	0.59	0.05
cps1064	East of Madison Church	Suquamish	15-Sep-16	10	0.4133	29.19	12.06	1.41	0.12
cps1066	Roling Bay, Bainbridge	Suquamish	19-Sep-14	10	0.3401	30.59	10.4	1.37	0.13
cps1053	E of Sandy Hook, Bainbridge	Suquamish	30-Sep-14	10	0.6437	15.7	10.1	0.6	0.06
cps1082	S of Bill Point, Bainbridge	Suquamish	23-Sep-14	10	0.6346	15.62	9.92	1.33	0.13
cps1063	S of Fay Bainbridge Sate Park	Suquamish	24-Sep-14	10	0.6056	14.12	8.55	0.7	0.08
cps1062	Fay Bainbridge State Park, Bainbridge	Suquamish	24-Sep-14	10	0.6719	10.77	7.24	0.25	0.04
cps1070	S of Murden Cove	Suquamish	20-Sep-16	10	0.4511	15.01	6.77	0.33	0.05
cps1081	Bill Point, Bainbridge	Suquamish	23-Sep-14	10	0.5553	11.45	6.36	0.88	0.14
cps1027	SW of Restoration point, Bainbridge	Bainbridge	21-Sep-16	10	0.4565	11.36	5.19	0.76	0.15
cps1067	Skiff Point N	Suquamish	20-Sep-16	10	0.4993	10.24	5.11	0.44	0.09
cps1061	Point Monroe, Bainbridge	Suquamish	24-Sep-14	10	0.3778	11.45	4.33	0.81	0.19
cps1071	Yeomalt Point N, Bainbridge	Suquamish	20-Sep-16	10	0.6543	6.5	4.25	0.2	0.05
cps1052	East of Point Bolin, Bainbridge	Suquamish	3-Oct-14	10	0.4913	8.41	4.13	0.26	0.06
cps1056	Agate Point West	Bainbridge	10-Oct-16	10	0.4577	8.05	3.68	0.51	0.14
cps1072	Yeomalt Point S, Bainbridge	Suquamish	20-Sep-16	10	0.404	8.98	3.63	0.96	0.26
cps1032	W of Fort Ward State Park	Bainbridge	26-Sep-16	10	0.334	7.32	2.45	0.64	0.26
cps1033	Pleasant Beach NW	Bainbridge	26-Sep-16	9	0.4685	4.34	2.03	0.47	0.23
cps1028	SE of Fort Ward State Park	Bainbridge	21-Sep-16	10	0.2971	6.8	2.02	0.5	0.25
cps1057	Agate Point East, Bainbridge	Suquamish	1-Oct-14	10	0.2448	7.26	1.78	0.53	0.3
cps1029	W of Beans Point, Bainbridge	Bainbridge	21-Sep-16	10	0.3192	5.36	1.71	0.49	0.28
cps1058	S of Agate Point East, Suquamish	Suquamish	1-Oct-14	10	0.1552	10.15	1.57	0.4	0.25
cps1055	Agate Passage NE	Bainbridge	10-Oct-16	10	0.2574	6	1.54	0.53	0.34
cps2890	NW of Wing Point, Bainbridge	Suquamish	20-Oct-14	9	0.1627	9.13	1.49	0.53	0.35
cps1030	Beans Point	Bainbridge	21-Sep-16	10	0.2516	5.48	1.38	0.54	0.39
cps1068	Skiff Point S	Suquamish	20-Sep-16	9	0.1533	8.89	1.36	0.78	0.57
cps1054	Agate Pass SE, Bainbridge	Suquamish	30-Sep-14	10	0.2032	4.94	1	0.33	0.33
cps1080	West of Bill Point, Bainbridge	Suquamish	20-Oct-14	10	0.1699	5.91	1	0.7	0.69
cps2891	NE of Wing Point	Suquamish	20-Sep-16	10	0.1797	5.05	0.91	0.35	0.38
cps1023	N of Ft. Ward Naval Res.	Bainbridge	19-Sep-16	10	0.1678	5.08	0.85	0.36	0.43
cps1060	Haley Heliport, Bainbridge	Suquamish	1-Oct-14	10	0.0633	11.05	0.7	0.27	0.39

Table 2 (continued): Size of eelgrass beds of sites along the shoreline of Bainbridge Island (ordered according to size)

site_code	site_name	special_study	survey_date	n_transects	fraction	sample area (ha)	veg area (ha)	veg area se (ha)	veg area cv
cps1031	NW of Orchard Rocks	Bainbridge	26-Sep-16	10	0.1248	5.47	0.68	0.29	0.43
cps1024	SW of Blakely Rock	Bainbridge	19-Sep-16	10	0.1145	4.39	0.5	0.29	0.57
cps1034	Pleasant Beach SW	Bainbridge	27-Sep-16	10	0.0591	6.92	0.41	0.26	0.63
cps1025	NW of Restoration Point	Bainbridge	19-Sep-16	10	0.0757	3.75	0.28	0.15	0.54
cps1035	NE of Point White, Bainbridge	SVMP	2013	14	0.0689	6.39	0.25	0.11	0.44
cps1026	Restoration Point	Bainbridge	21-Sep-16	10	0.0313	5.71	0.18	0.18	1
cps1046	Battle Point North, Bainbridge	Suquamish	15-Oct-14	10	0.0175	4.88	0.09	0.08	0.98
cps1051	NW of James Dam, Bainbridge	Suquamish	3-Oct-14	10	0.0093	4.84	0.05	0.04	0.97
cps1077	Hornbecks Spit	Bainbridge	20-Oct-16	10	0.0105	4.69	0.05	0.03	0.62
cps1059	W of Haley Heliport, Suquamish	Suquamish	1-Oct-14	10	0	0	0	0	0
cps1043	Fletcher Bay, Bainbridge	Suquamish	14-Oct-14	0	0	0	0	0	0
cps1044	N of Fletcher Bay, Bainbridge	Suquamish	14-Oct-14	0	0	0	0	0	0
cps1045	Battle Point South, Bainbridge	Suquamish	15-Oct-14	0	0	0	0	0	0
cps1047	N of Battle Point Park Reservoir	Suquamish	15-Oct-14	0	0	0	0	0	0
cps1048	Arrow Point, Bainbridge	Suquamish	15-Oct-14	0	0	0	0	0	0
cps1049	Manzanita Bay, Bainbridge	Suquamish	15-Oct-14	0	0	0	0	0	0
cps1050	SW of James Dam, Bainbridge	Suquamish	16-Oct-14	0	0	0	0	0	0
cps1037	Point White NW, Bainbridge	Suquamish	29-Oct-14	0	0	0	0	0	0
cps1039	SW of Gazzam Lake, Bainbridge	Suquamish	29-Oct-14	0	0	0	0	0	0
cps1041	SW of C & H Johnson Dams, Bainbridge	Suquamish	29-Oct-14	0	0	0	0	0	0
flats38	Port Madison	Suquamish	16-Sep-16	10	0	37.63	trace	0	0
cps1085	Blakely Harbor Head	Bainbridge	19-Sep-16	0	0	0	0	0	0
cps1079	East of Eagle Harbor	Suquamish	26-Sep-16	0	0	0	0	0	0
cps1083	SE of Tyee Shoal, Bainbridge	Bainbridge	26-Sep-16	0	0	0	0	0	0
cps1084	NW of Blakely Rock	Bainbridge	26-Sep-16	0	0	0	0	0	0
cps1036	Point White East	Bainbridge	27-Sep-16	0	0	0	0	0	0
cps1038	N of Point White NW, Bainbridge	Bainbridge	27-Sep-16	0	0	0	0	0	0
cps1040	Gazam Lake	Bainbridge	27-Sep-16	0	0	0	0	0	0
cps1042	S of Fletcher Bay, Bainbridge	Bainbridge	27-Sep-16	0	0	0	0	0	0
cps2889	Eagle Harbor Dock	Bainbridge	20-Oct-16	0	0	0	0	0	0
flats36	Eagle Harbor Dock	Bainbridge	20-Oct-16	0	0	0	0	0	0

3.3 Depth range of eelgrass beds along Bainbridge Island

Eelgrass was observed between -12.3 and 1.2 m relative to mean lower low water (MLLW) along the shoreline of Bainbridge Island. The shallowest observations are at sites cps1063, cps1066, cps1067, and cps1070. The deepest observations are at cps1061, cps1066, cps1064 and cps1072 (see Table 3). The optimal depth range for eelgrass is more limited: approximately 90 % of all eelgrass in the study area grows between 0 and -4.5 m relative to MLLW (Figure 8). The median depth of eelgrass around Bainbridge Island is approximately -1.5m relative to MLLW.

We classify eelgrass as either intertidal or subtidal. We define the boundary between intertidal and subtidal as -1 m (relative to MLLW), which is a biologically relevant estimate of Extreme Low Tide depth in the Puget Sound region. For more information on this calculation, see Hannam et al. (2015). When comparing to this boundary, approximately 67 % of all eelgrass in the study area grows in the subtidal, while 33 % grows in the intertidal (Figure 8). This is similar to other sites in greater Puget Sound, where approximately 62% of all eelgrass occurs in the subtidal (Hannam et al. 2015).

The non-native seagrass *Zostera japonica* is common in the study area and has a different depth distribution as compared to *Zostera marina*. It usually grows shallower, and is able to thrive in the intertidal habitats.

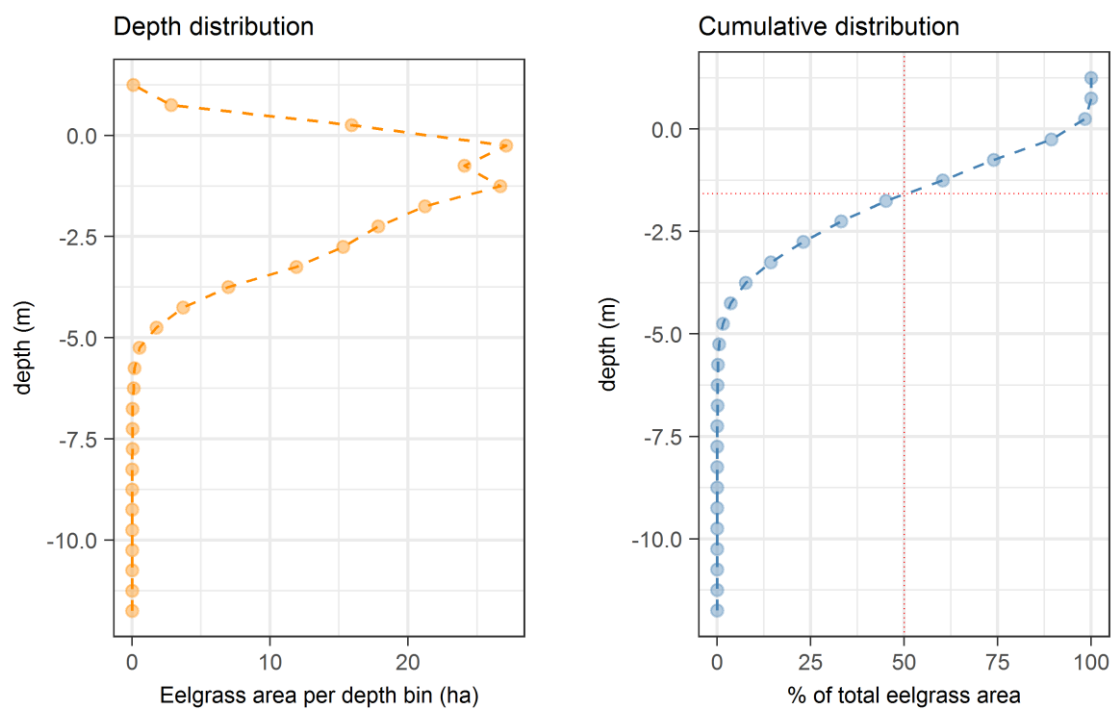

Figure 8: Depth distribution and cumulative depth distribution of eelgrass in the study area. The red lines delineate the median depth of all eelgrass observations.

There is high variability in the depth distribution and the maximum depth at which eelgrass is found among individual sites (Figure 9). Eelgrass has the widest depth range at sites on the western side of Bainbridge Island, and the smallest depth range at sites within Port Orchard and Sinclair Inlet. This is both due to the lower amount of intertidal eelgrass and the shallower maximum eelgrass depth at sites within Port Orchard.

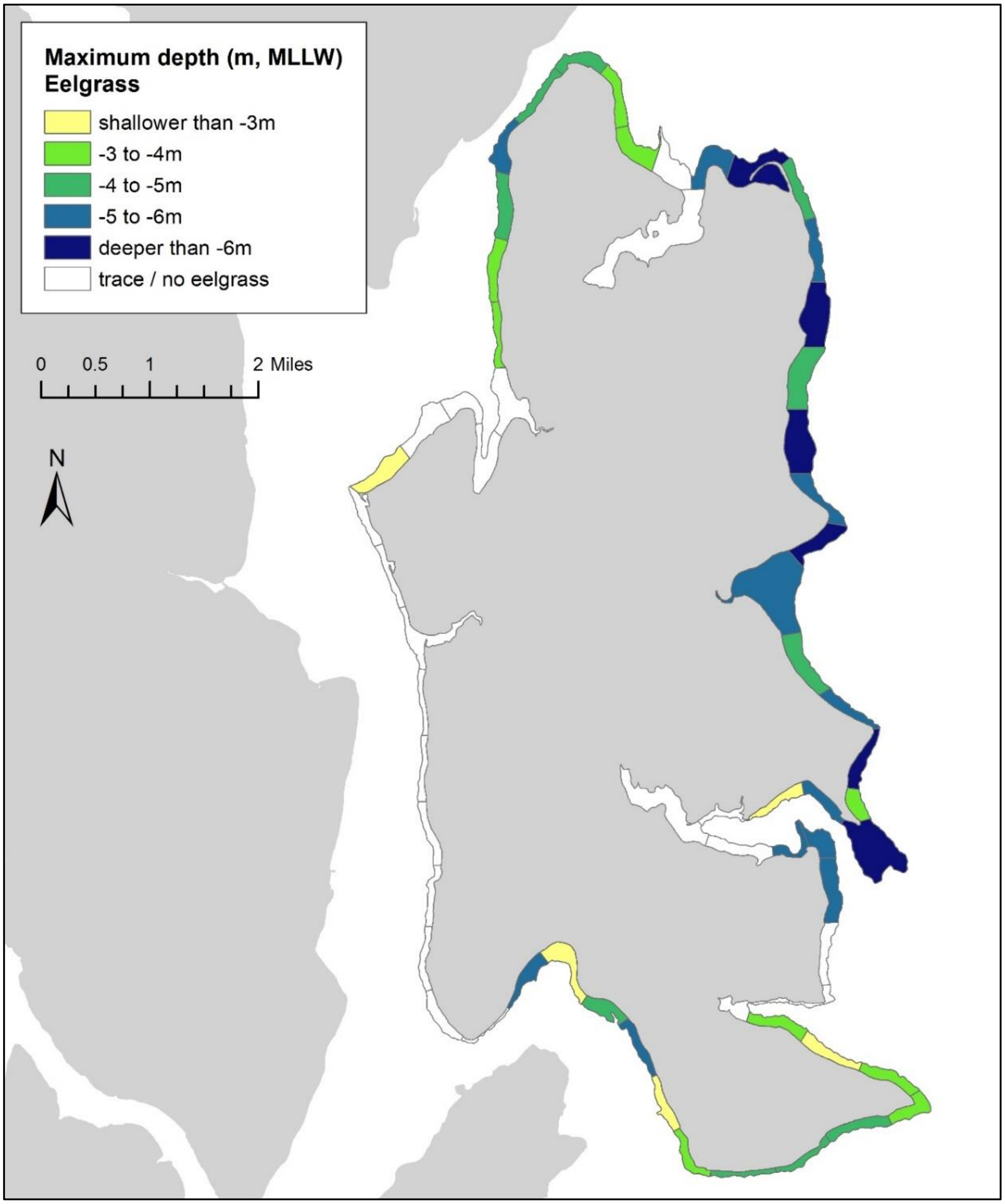

Figure 9: Maximum depth of eelgrass beds on the shores of Bainbridge Island. Eelgrass tends to reach greater maximum depths on the East side of Bainbridge Island. Maximum depth is not indicated for flats38, which had trace amounts of eelgrass present

Table 3: minimum depth, maximum depth and the quantiles of the depth distribution (m) of eelgrass at sites around Bainbridge Island (ordered according to max. depth). The median eelgrass depth per site is indicated by the 50th quantile (q50).

site_code	min	q05	q10	q25	q50	q75	q90	q95	max	n
cps1072	0.03	-6.01	-5.10	-3.66	-2.22	-1.41	-1.01	-0.84	-12.33	407
cps1064	0.81	-3.44	-2.59	-1.33	-0.34	-0.01	0.18	0.28	-7.48	1356
cps1066	1.11	-4.12	-3.71	-2.99	-1.67	-0.18	0.27	0.39	-7.20	2439
cps1061	0.41	-3.24	-2.68	-1.66	-1.15	-0.83	-0.26	0.05	-6.70	575
flats37	-0.50	-4.15	-3.70	-3.07	-2.34	-1.47	-1.04	-0.92	-6.56	1467
cps1068	-0.25	-4.73	-4.51	-3.73	-3.16	-2.01	-1.57	-1.36	-6.31	181
cps1067	1.09	-3.10	-2.52	-1.62	-0.74	-0.17	0.11	0.31	-5.59	651
cps1060	-0.74	-3.89	-3.29	-2.76	-2.55	-1.92	-1.43	-1.34	-5.54	169
cps1071	0.21	-4.28	-3.65	-2.27	-1.33	-0.54	-0.10	0.00	-5.51	558
cps1082	0.16	-3.98	-3.50	-2.61	-1.72	-1.16	-0.62	-0.42	-5.45	927
cps1081	0.15	-2.74	-2.28	-1.51	-1.10	-0.66	-0.48	-0.32	-5.42	1282
cps1032	0.54	-5.01	-4.84	-2.58	-1.55	-0.84	-0.23	0.18	-5.34	294
cps2890	0.21	-3.52	-3.07	-2.08	-1.27	-0.95	-0.23	0.11	-5.15	189
cps1069	0.75	-3.94	-3.63	-3.01	-1.91	-0.63	-0.11	0.21	-5.10	2662
cps1035	-0.91	-3.33	-1.64	-1.51	-1.34	-1.22	-1.15	-1.10	-5.09	84
cps1063	1.18	-3.57	-2.70	-1.62	-0.61	-0.03	0.41	0.66	-5.09	975
cps1054	0.89	-3.50	-2.73	-1.56	-0.79	-0.44	-0.18	0.04	-5.08	1340
cps1080	0.46	-2.42	-2.12	-1.67	-1.54	-1.33	-1.14	-0.58	-5.03	367
cps1070	1.02	-3.09	-2.60	-1.76	-0.88	-0.12	0.25	0.49	-4.81	791
cps1027	0.36	-3.95	-3.65	-2.61	-1.46	-0.52	-0.01	0.06	-4.76	621
cps1065	0.72	-3.15	-2.92	-2.35	-1.28	-0.40	-0.01	0.18	-4.74	1609
cps1053	0.83	-3.67	-3.26	-2.32	-1.21	-0.34	-0.03	0.11	-4.73	1059
cps1029	-0.21	-3.85	-3.38	-2.80	-2.09	-1.40	-0.73	-0.54	-4.70	201
cps1056	0.55	-4.11	-3.68	-2.83	-1.82	-1.06	-0.03	0.19	-4.58	518
cps1055	0.68	-3.46	-2.73	-1.46	-0.66	-0.13	0.19	0.41	-4.54	210
cps1062	0.93	-3.48	-2.90	-1.70	-0.51	0.11	0.39	0.56	-4.45	912
cps1028	-0.18	-3.71	-3.42	-2.95	-2.17	-1.51	-0.76	-0.54	-4.37	250
cps1033	0.09	-3.57	-2.85	-1.85	-1.16	-0.58	-0.24	-0.15	-4.34	308
cps1052	0.43	-3.13	-2.82	-2.34	-1.21	-0.56	-0.16	-0.02	-3.94	498
cps1030	0.53	-2.72	-2.30	-1.48	-0.83	-0.14	0.13	0.29	-3.84	191
cps1026	-1.68	-3.29	-3.24	-2.81	-2.52	-1.97	-1.78	-1.70	-3.69	44
cps1058	0.85	-2.54	-2.12	-1.67	-1.23	-0.76	0.36	0.51	-3.45	223
cps1057	0.68	-1.82	-1.68	-1.35	-0.86	-0.24	0.27	0.54	-3.43	219
cps1023	-0.19	-2.19	-1.94	-1.42	-0.87	-0.50	-0.30	-0.27	-3.30	110
cps1025	-0.50	-2.70	-2.47	-1.69	-1.06	-0.87	-0.77	-0.69	-3.29	52
cps2891	-0.30	-2.90	-2.71	-2.29	-1.75	-1.43	-1.01	-0.78	-3.06	196
cps1051	-0.21	-2.71	-2.47	-1.90	-1.57	-1.28	-1.03	-0.96	-3.01	136
cps1034	-0.81	-2.30	-2.03	-1.64	-1.29	-1.14	-1.00	-0.92	-3.00	53
cps1024	-0.21	-2.28	-2.14	-1.32	-0.70	-0.47	-0.32	-0.29	-2.51	69
cps1031	0.17	-2.14	-1.94	-1.52	-0.52	-0.14	0.06	0.11	-2.40	95
cps1077	-0.23	-1.51	-1.48	-1.39	-1.29	-0.50	-0.24	-0.23	-1.54	6
cps1046	-0.56	-1.24	-1.16	-1.01	-0.87	-0.75	-0.68	-0.64	-1.51	164

3.4 Spatial extent and depth distribution of eelgrass at the site scale

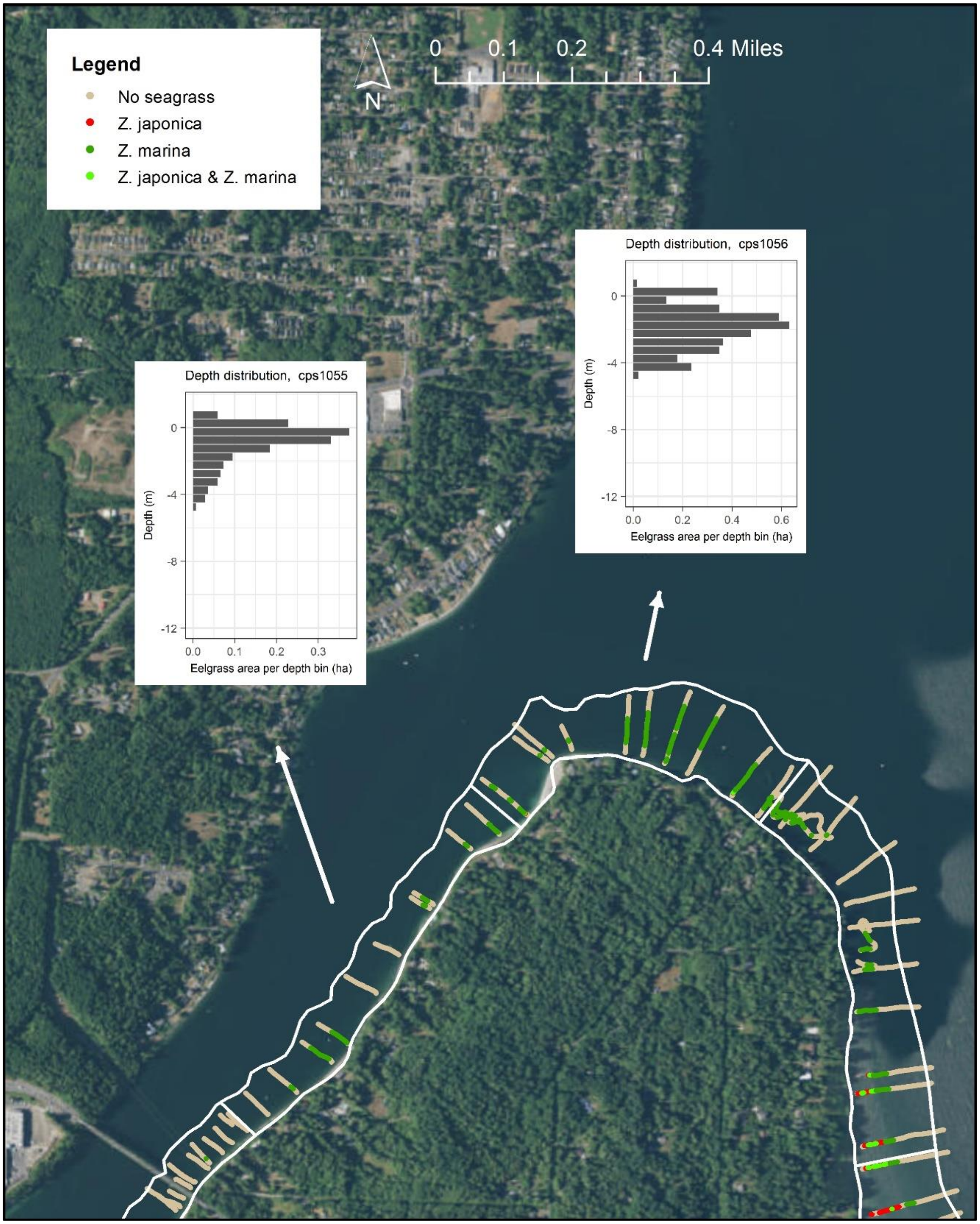

Figure 10: Depth distribution and spatial location of eelgrass along transects in cps1055 and cps1056.

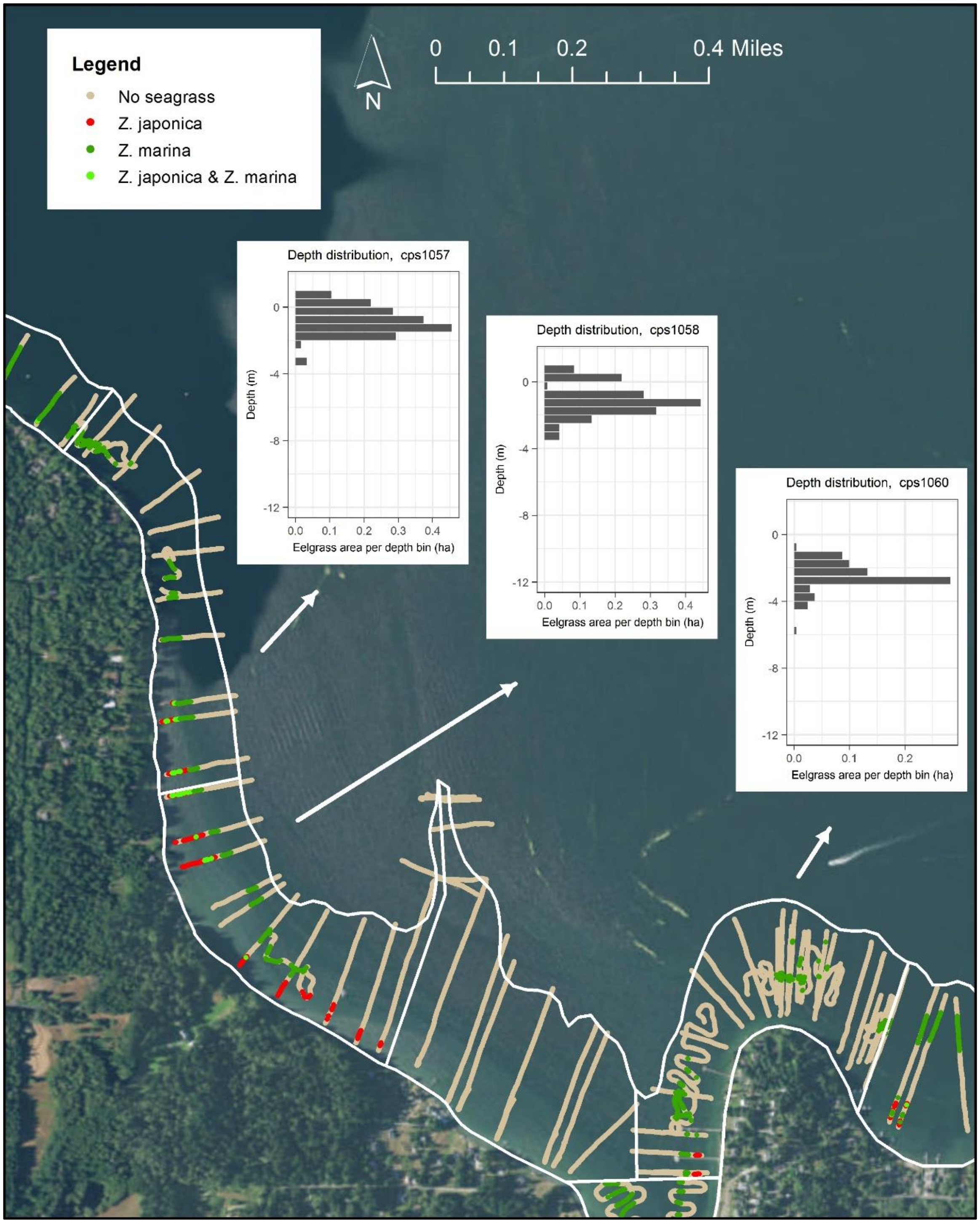

Figure 11: Depth distribution and spatial location of eelgrass along transects in cps1057, cps1058, and cps1060.

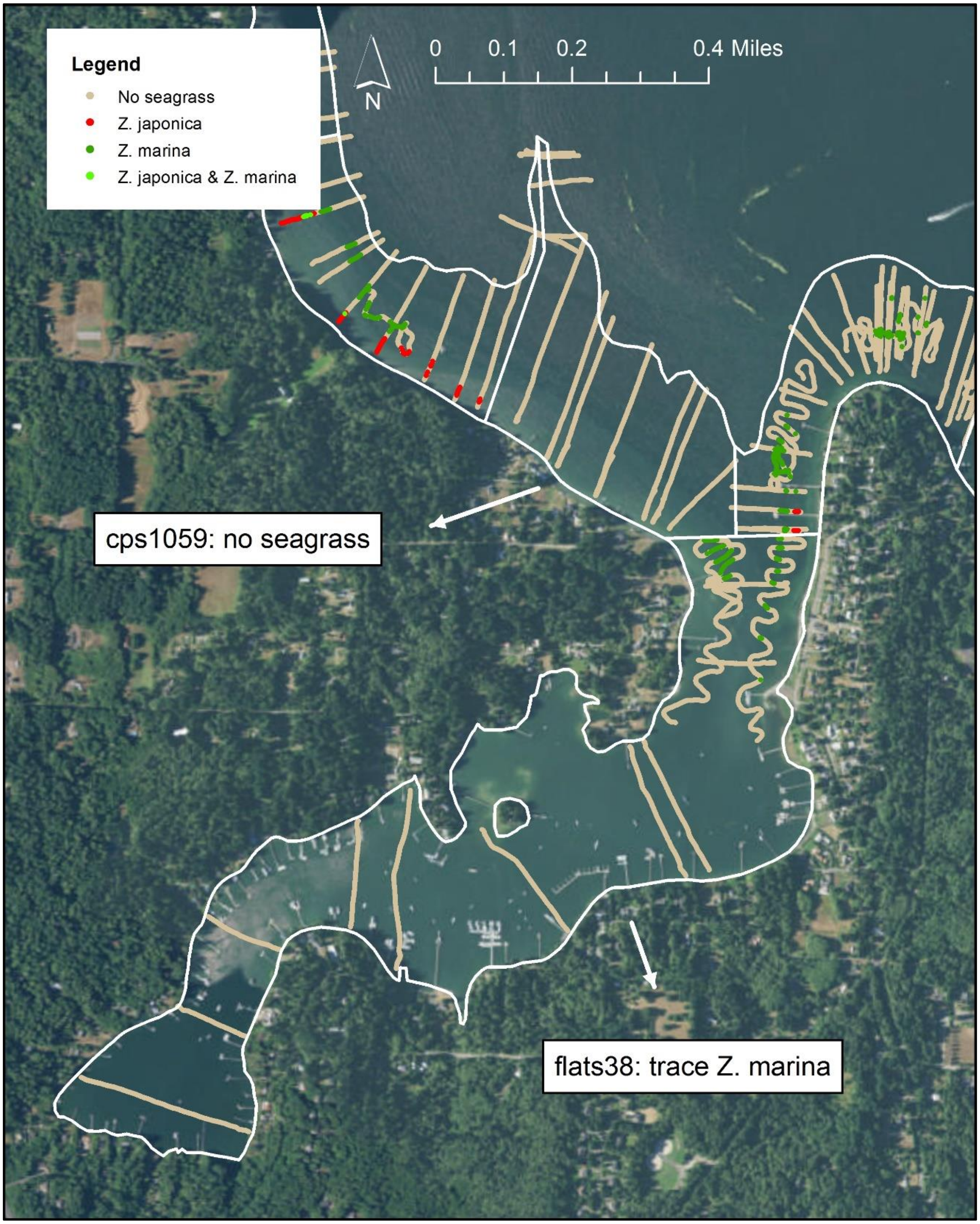

Figure 12: Depth distribution and spatial location of eelgrass along transects in cps1059 and flats38.

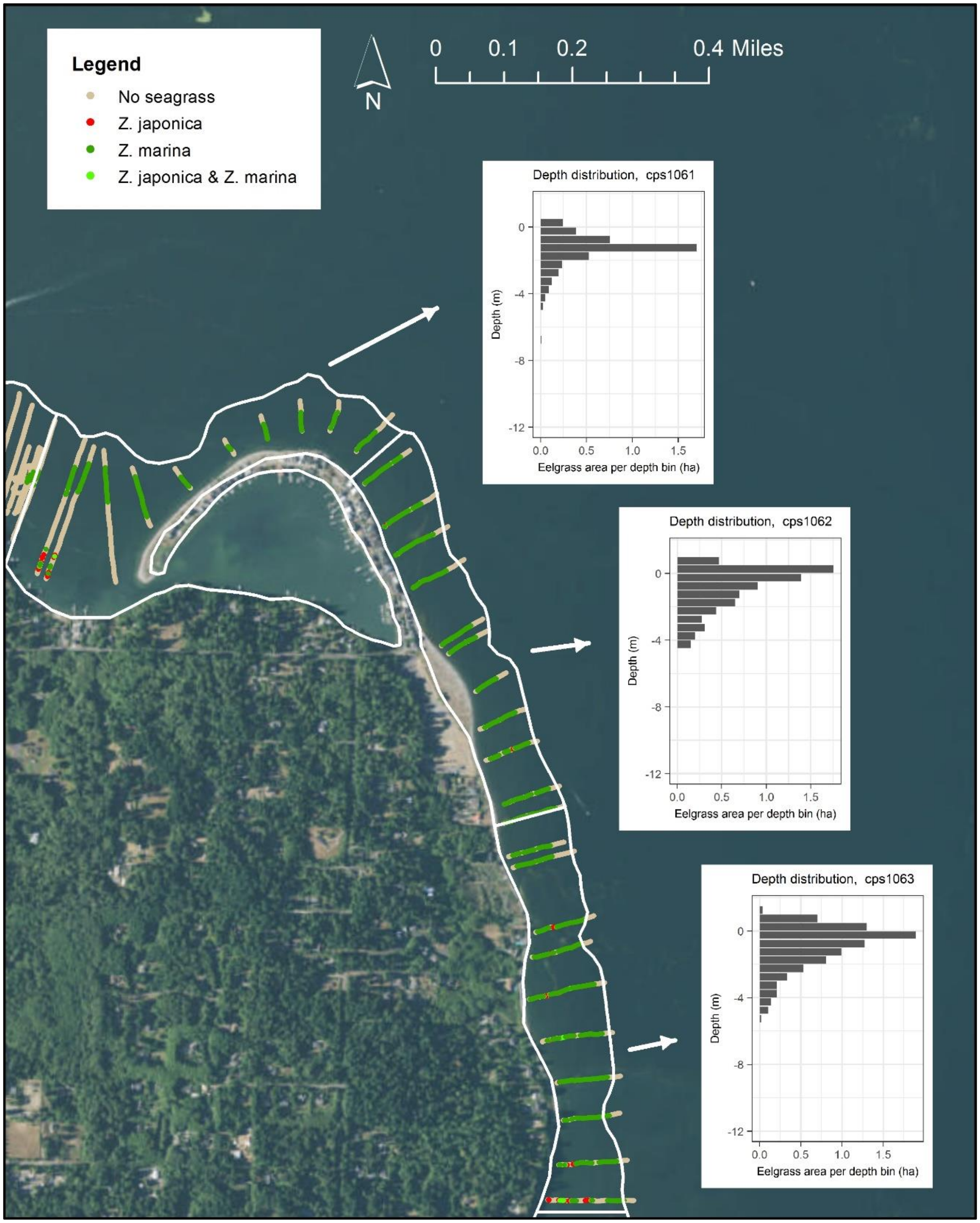

Figure 13: Depth distribution and spatial location of eelgrass along transects in cps1061, cps1062, and cps1063.

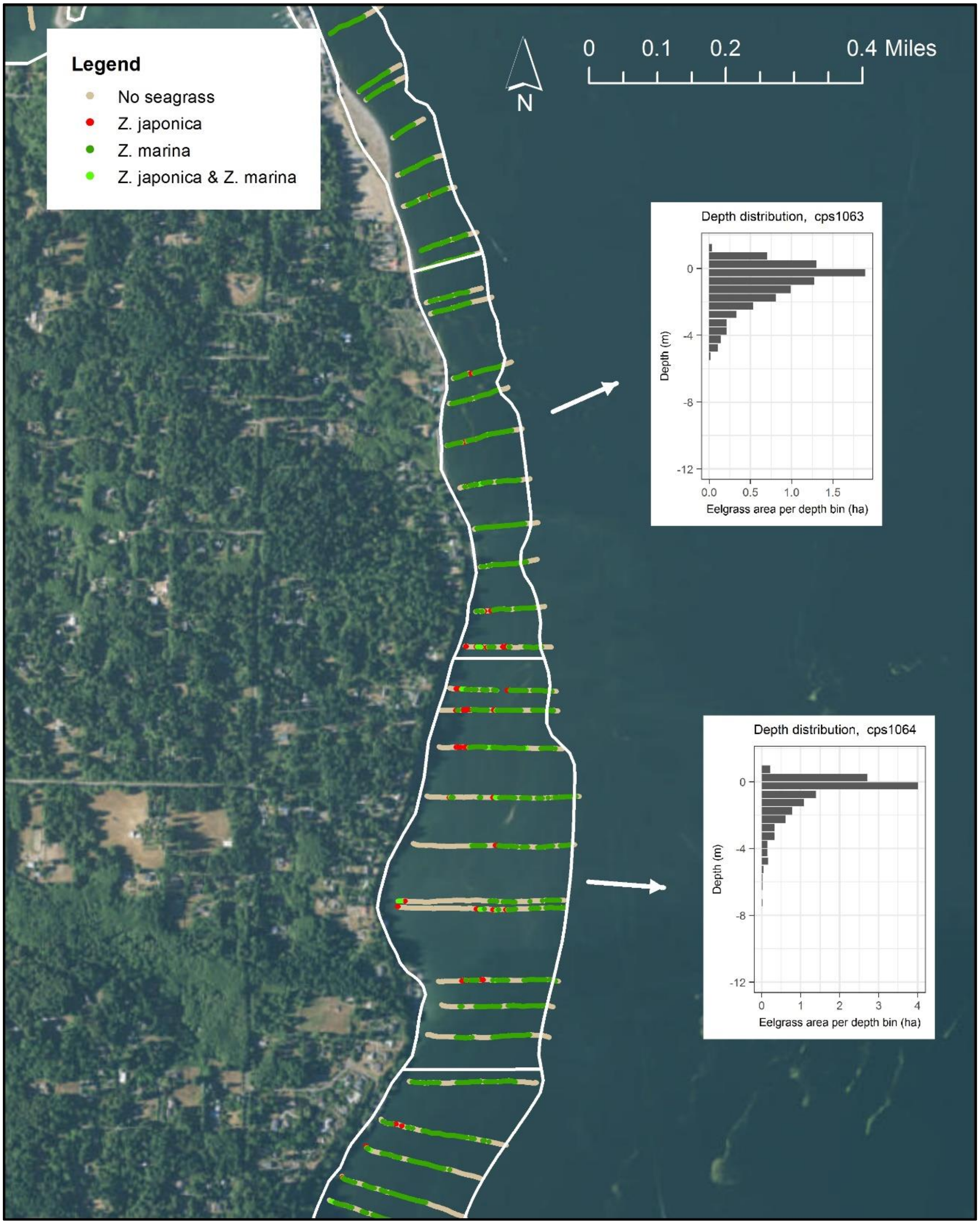

Figure 14: Depth distribution and spatial location of eelgrass along transects in cps1063 and cps1064.

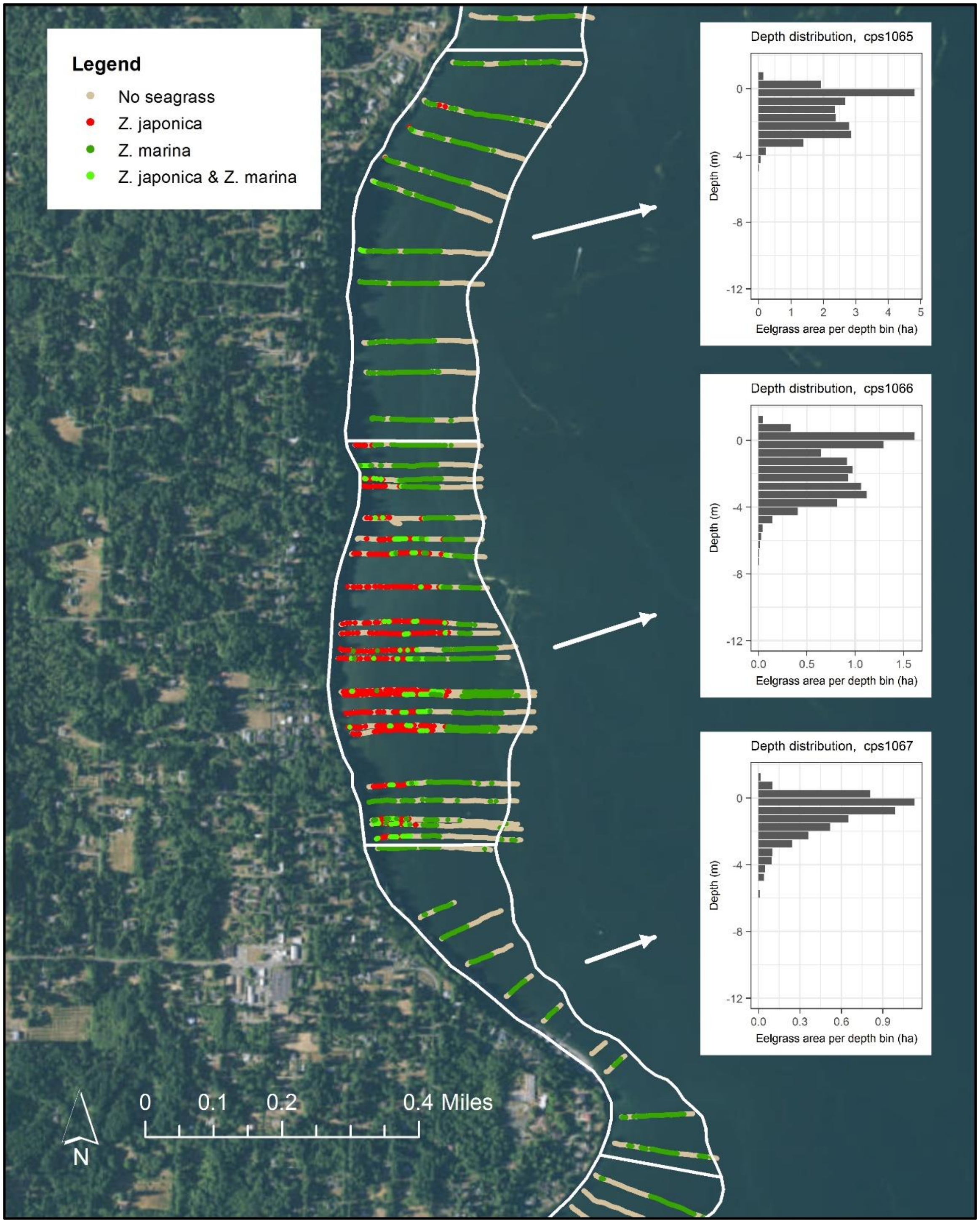

Figure 15: Depth distribution and spatial location of eelgrass along transects in cps1065, cps1066, and cps1067.

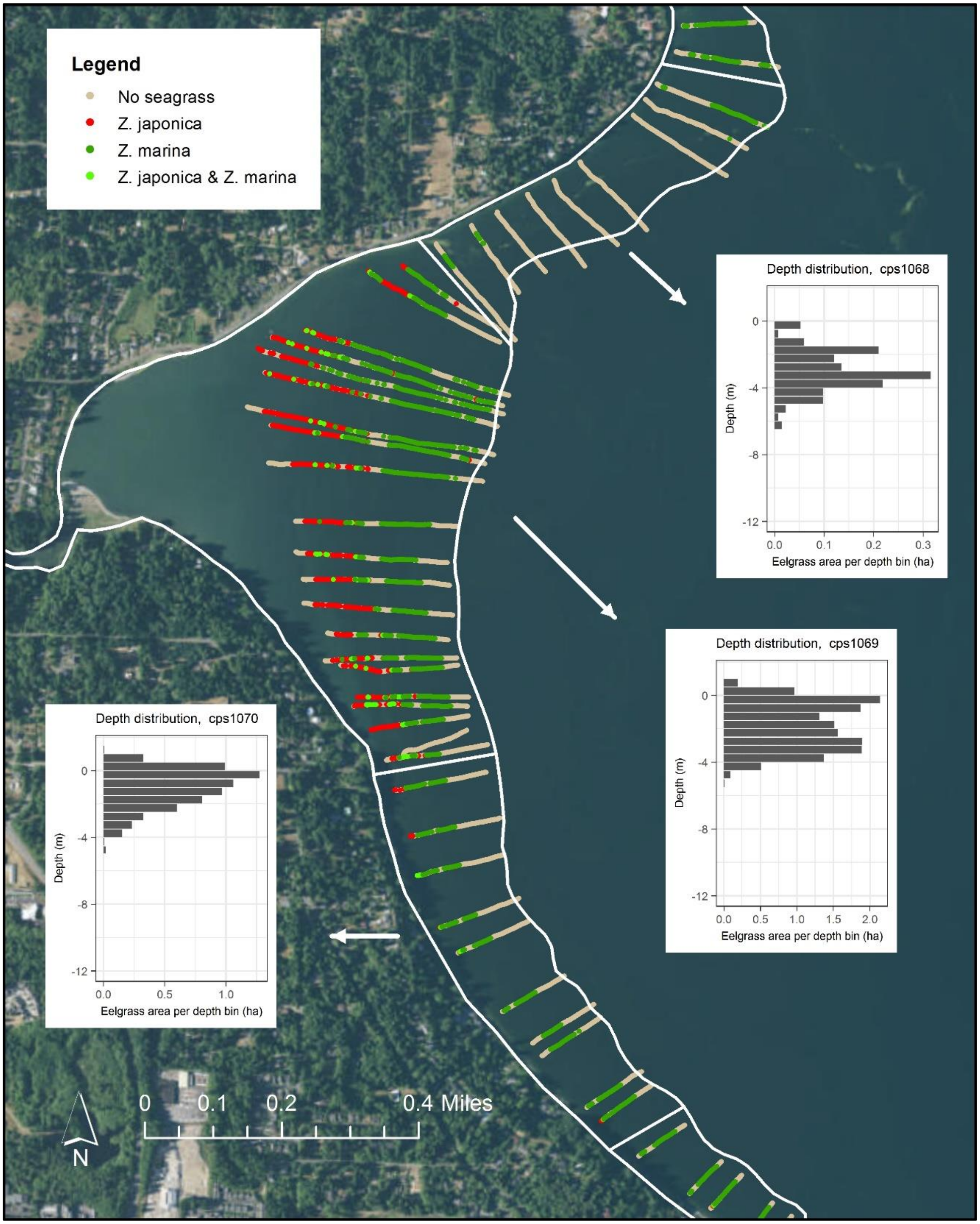

Figure 16: Depth distribution and spatial location of eelgrass along transects in cps1068, cps1069, and cps1070.

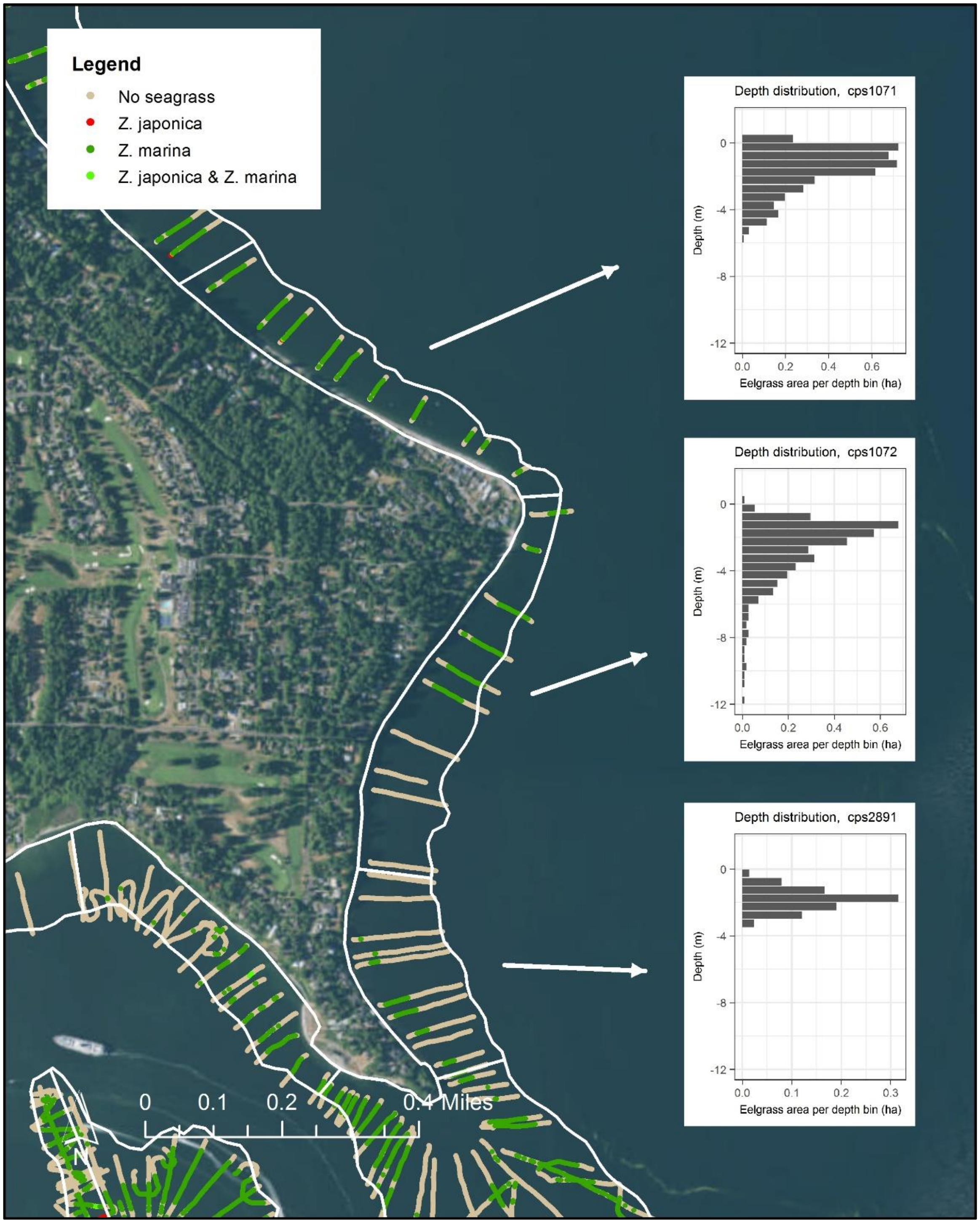

Figure 17: Depth distribution and spatial location of eelgrass along transects in cps1071, cps1072, and cps2891.

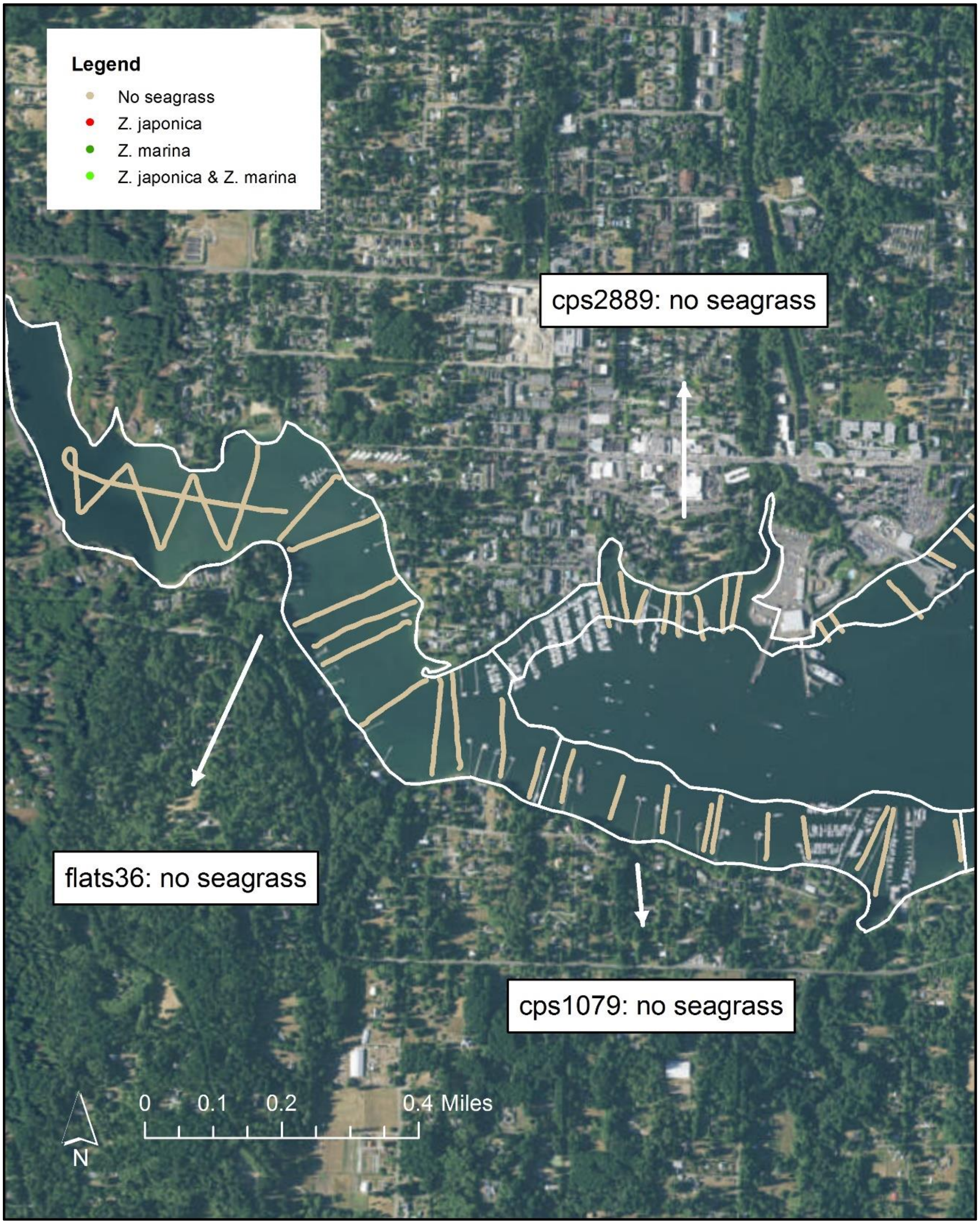

Figure 18: Depth distribution and spatial location of eelgrass along transects in cps2889, flats36, and cps1079.

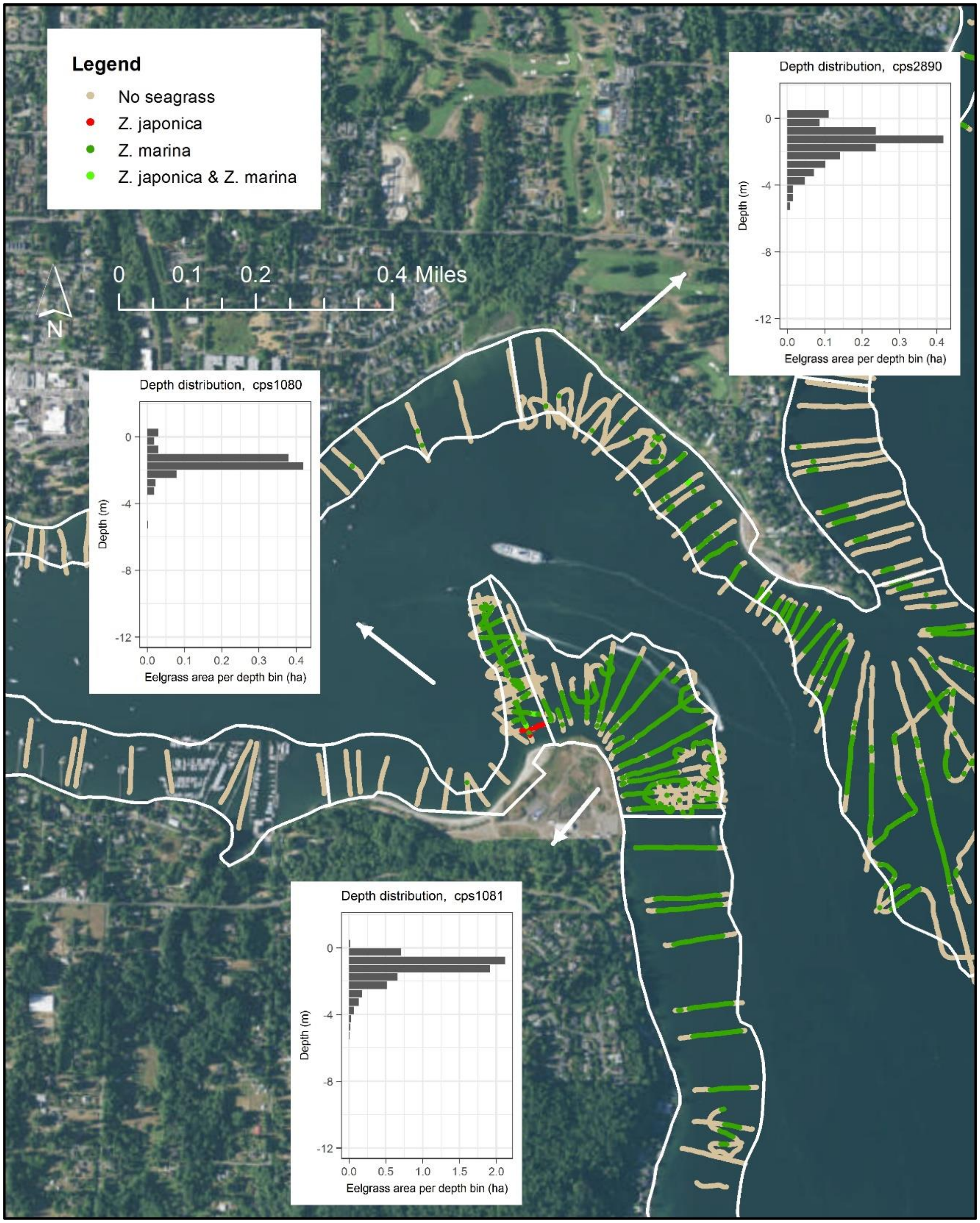

Figure 19: Depth distribution and spatial location of eelgrass along transects in cps2890, cps1080, and cps1081.

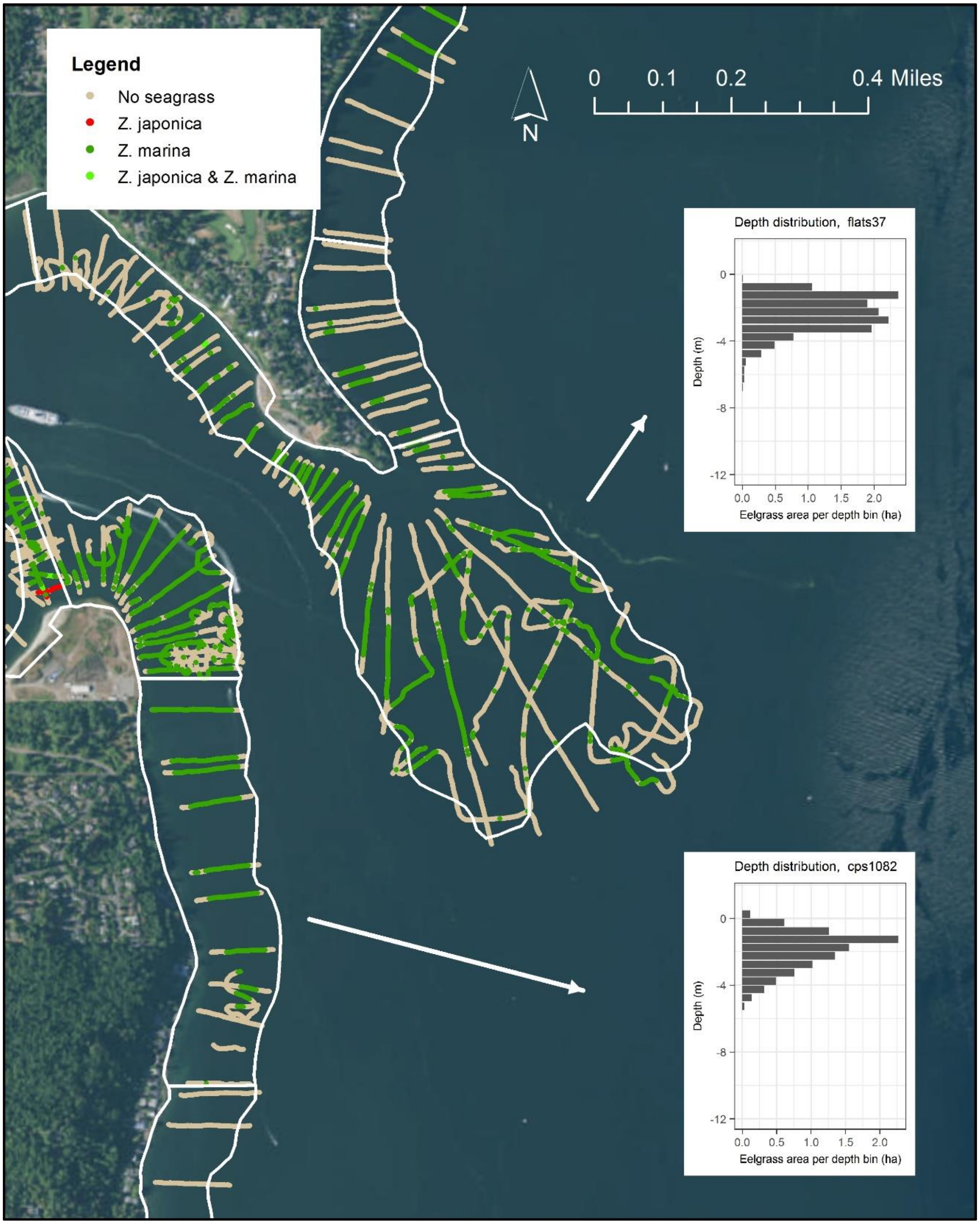

Figure 20: Depth distribution and spatial location of eelgrass along transects in flats37 and cps1082.

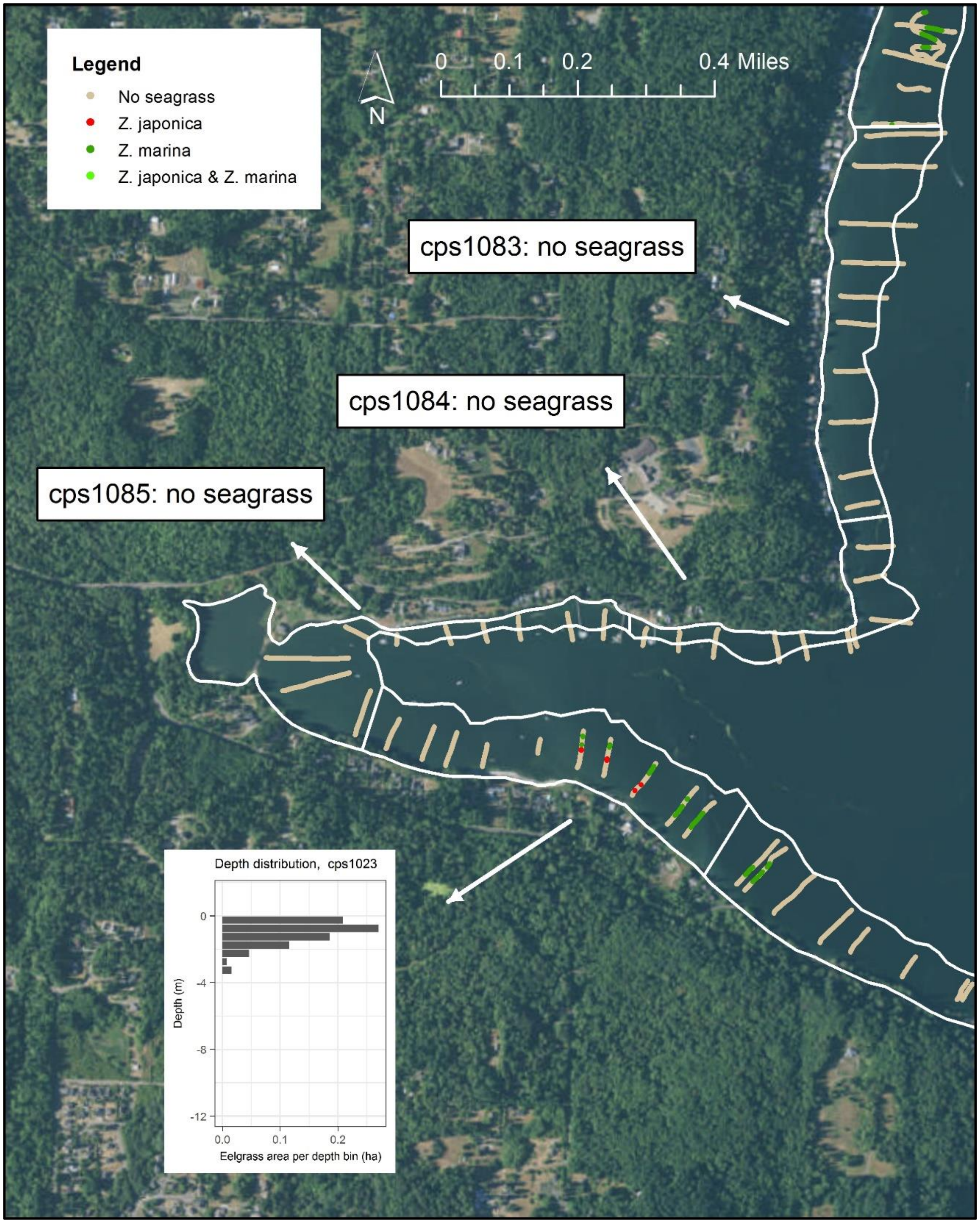

Figure 21: Depth distribution and spatial location of eelgrass along transects in cps1083, cps1084, cps1085, and cps1023.

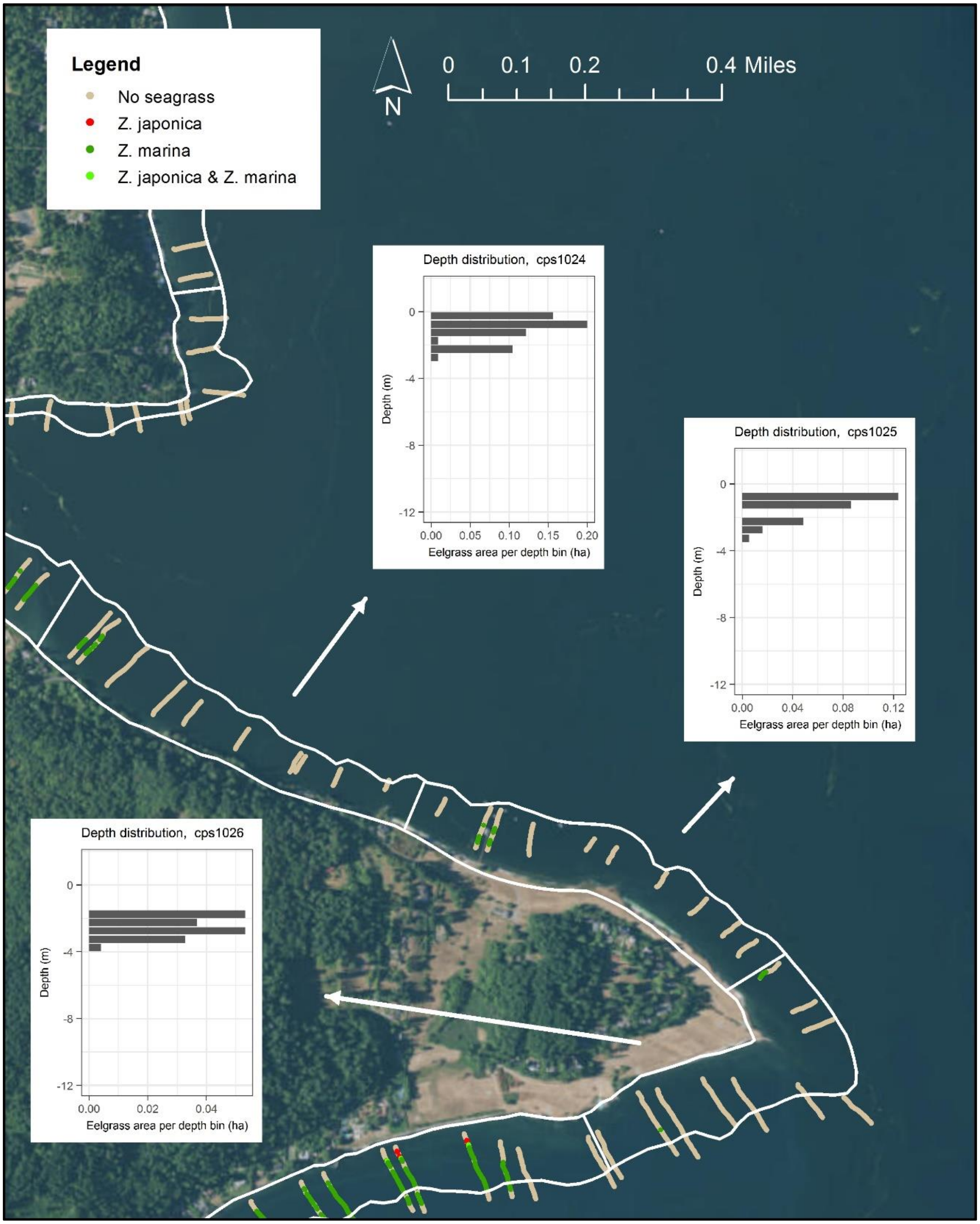

Figure 22: Depth distribution and spatial location of eelgrass along transects in cps1024, cps1025, and cps1026.

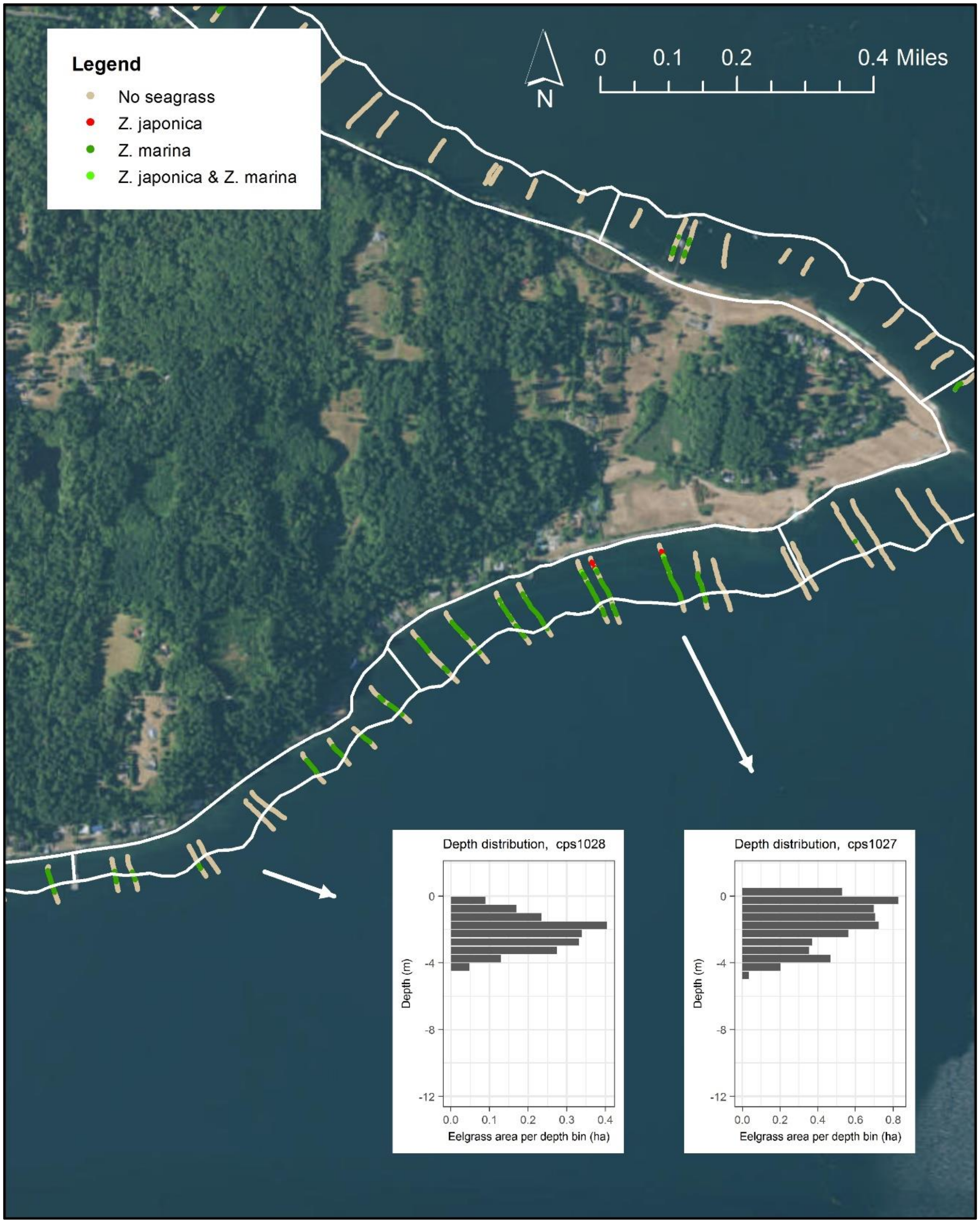

Figure 23: Depth distribution and spatial location of eelgrass along transects in cps1027 and cps1028.

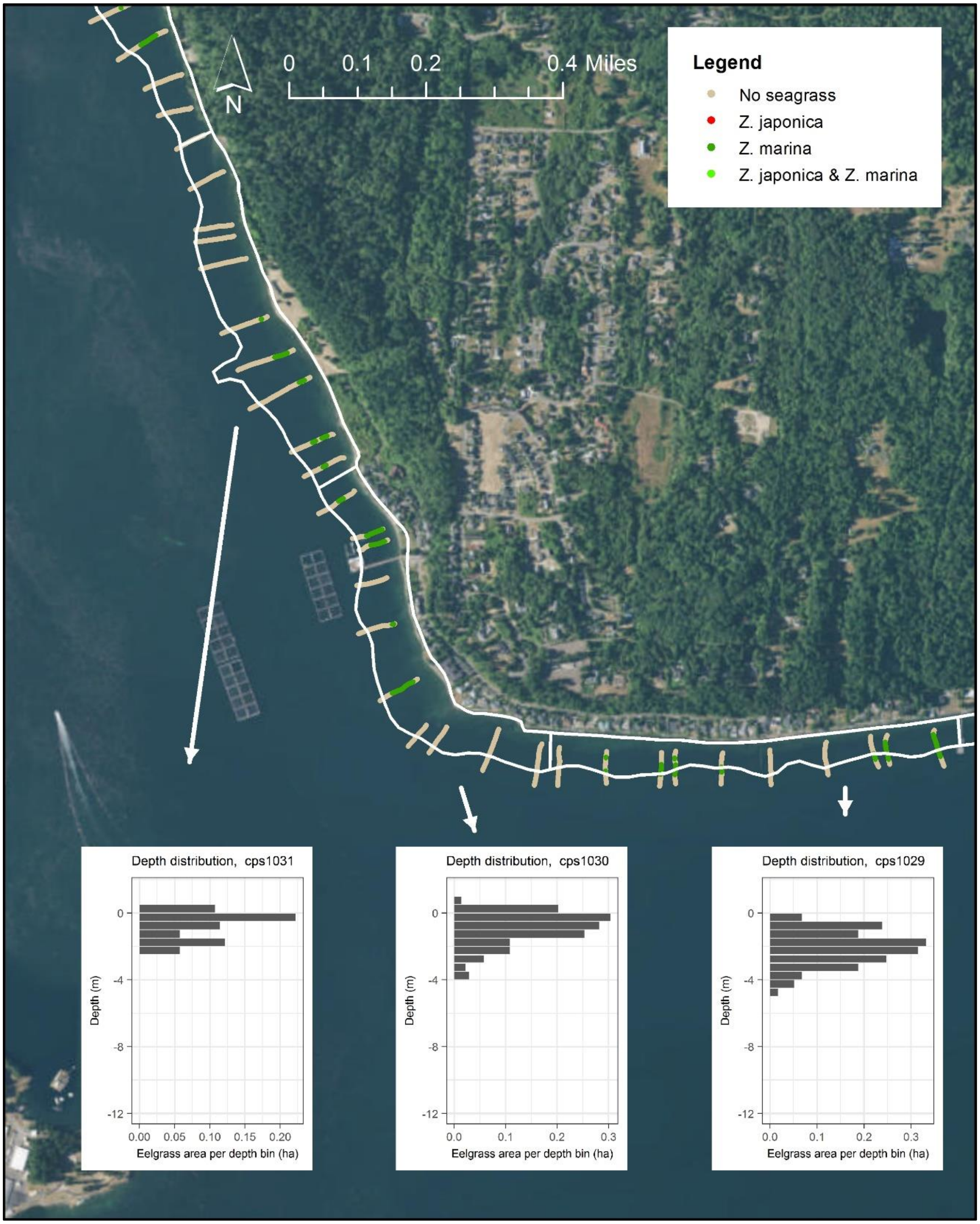

Figure 24: Depth distribution and spatial location of eelgrass along transects in cps1029, cps1030, and cps1031.

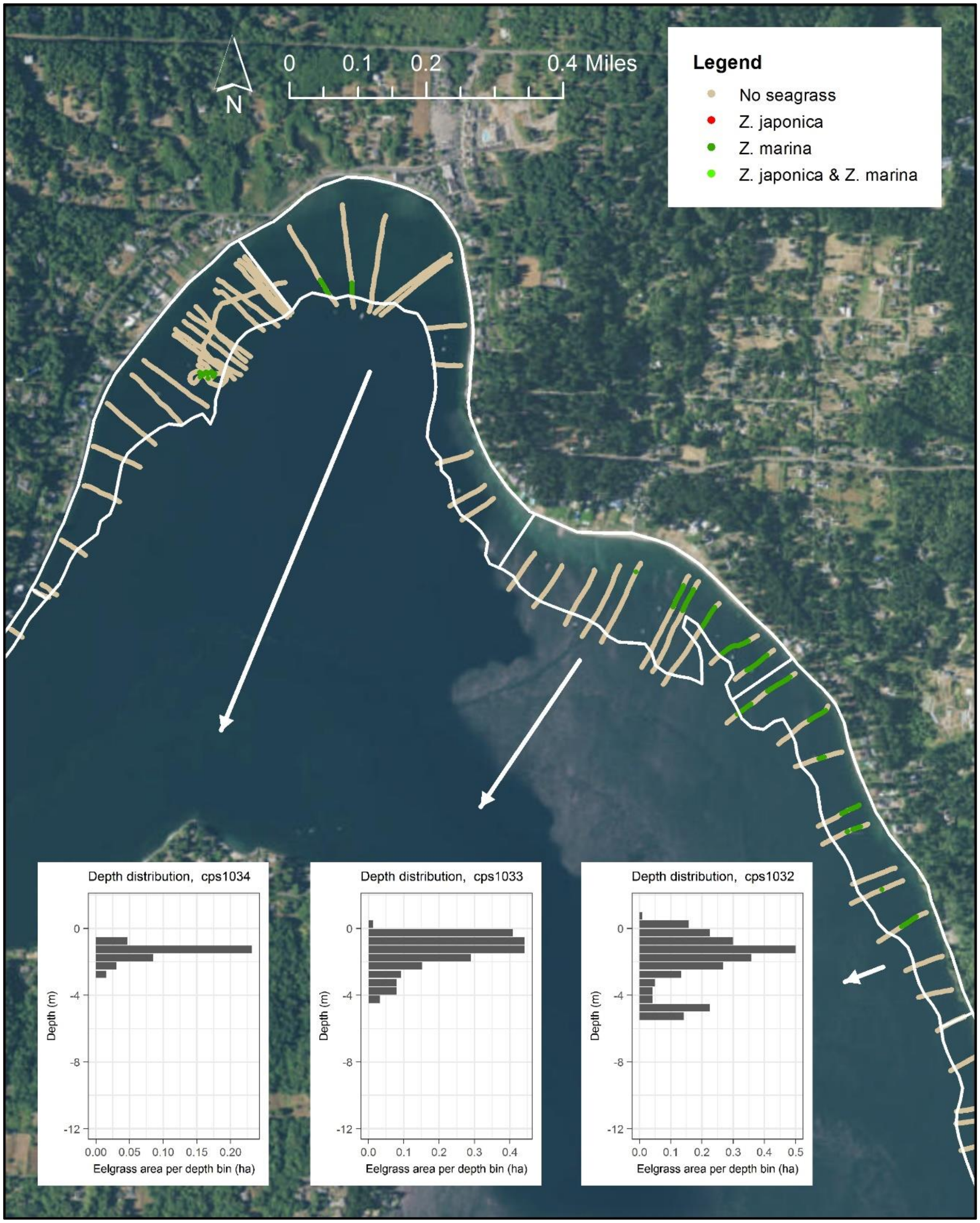

Figure 25: Depth distribution and spatial location of eelgrass along transects in cps1032, cps1033, and cps1034.

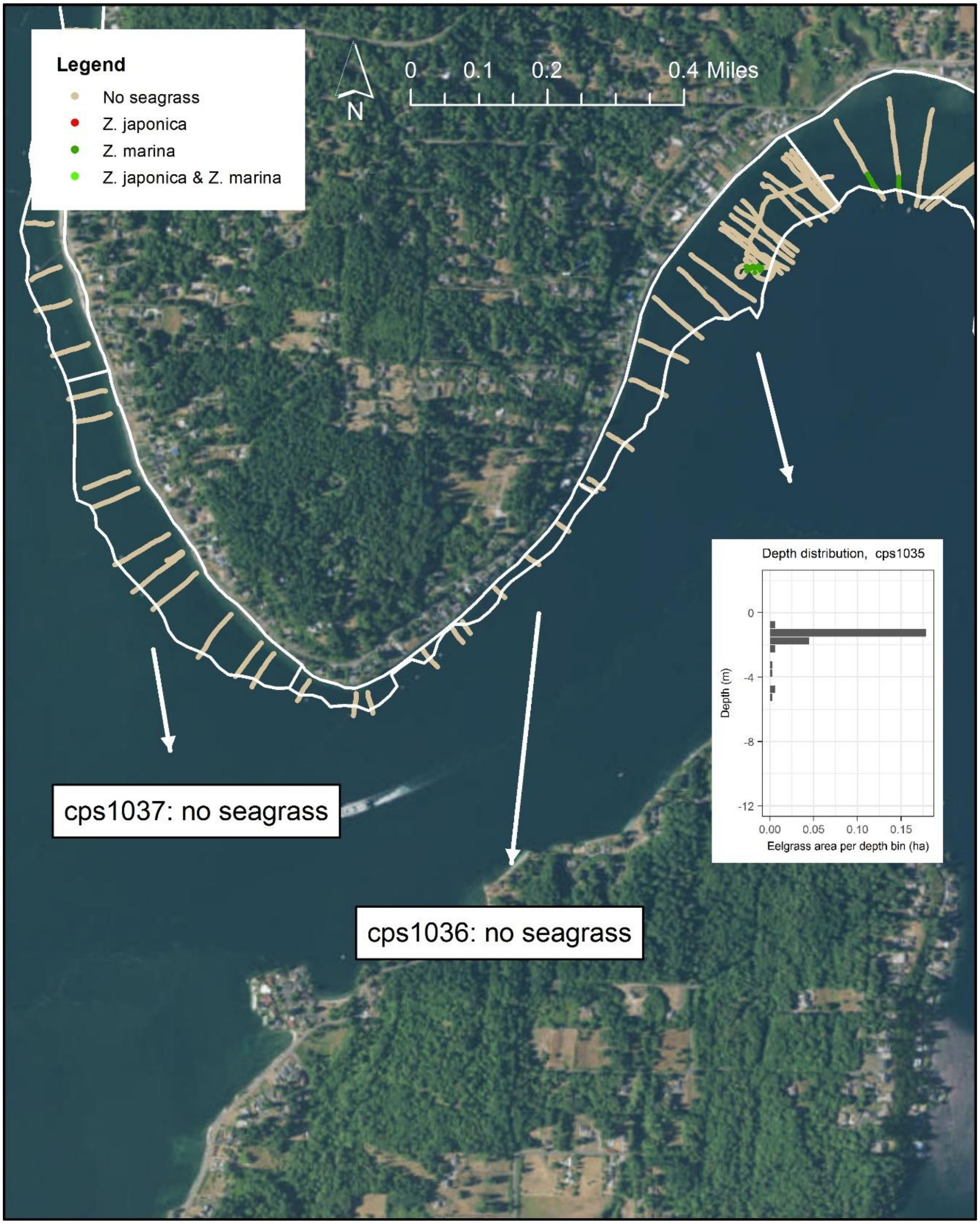

Figure 26: Depth distribution and spatial location of eelgrass along transects in cps1035, cps1036, and cps1037.

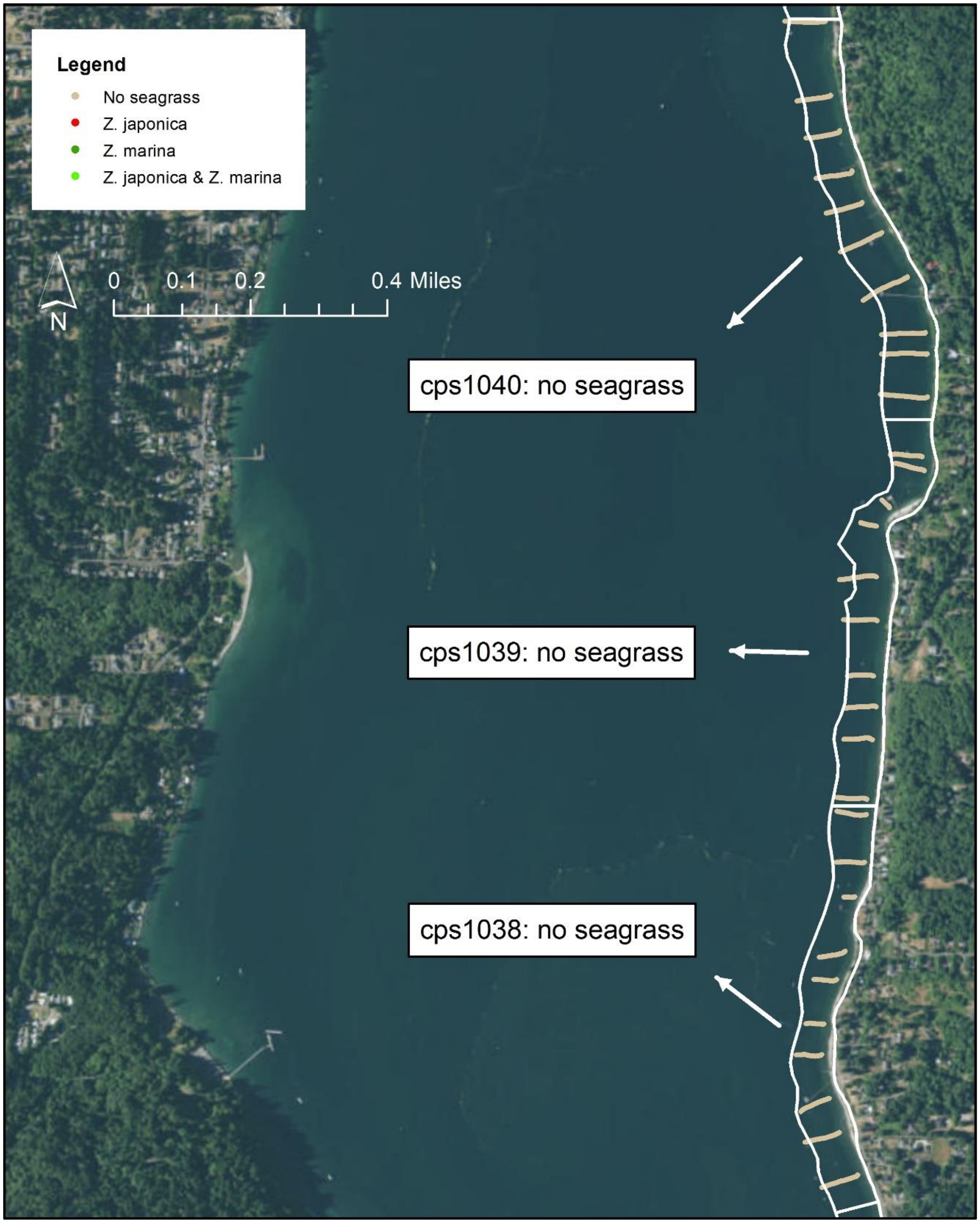

Figure 27: Depth distribution and spatial location of eelgrass along transects in cps1038, cps1039, and cps1040.

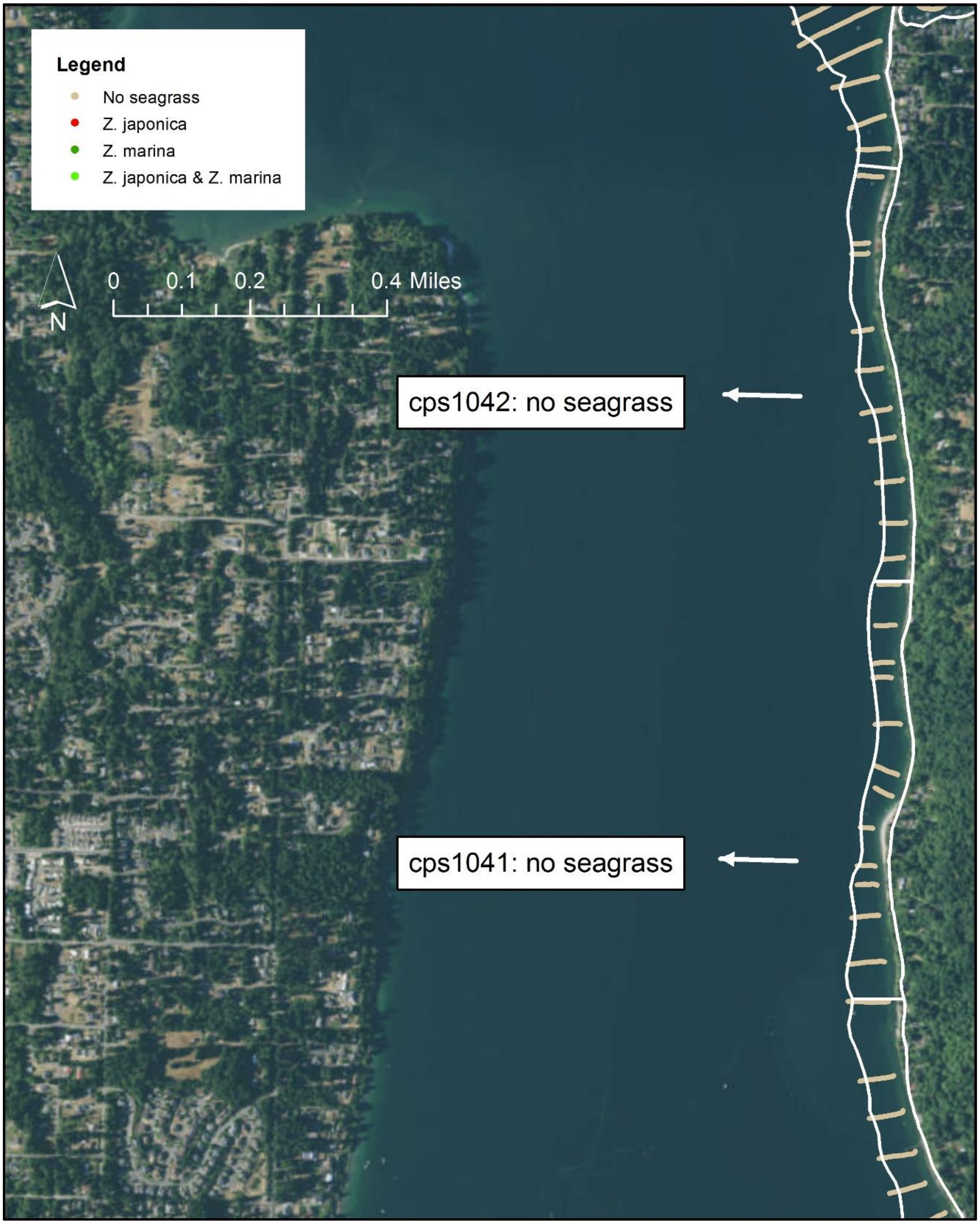

Figure 28: Depth distribution and spatial location of eelgrass along transects in cps1041 and cps1042.

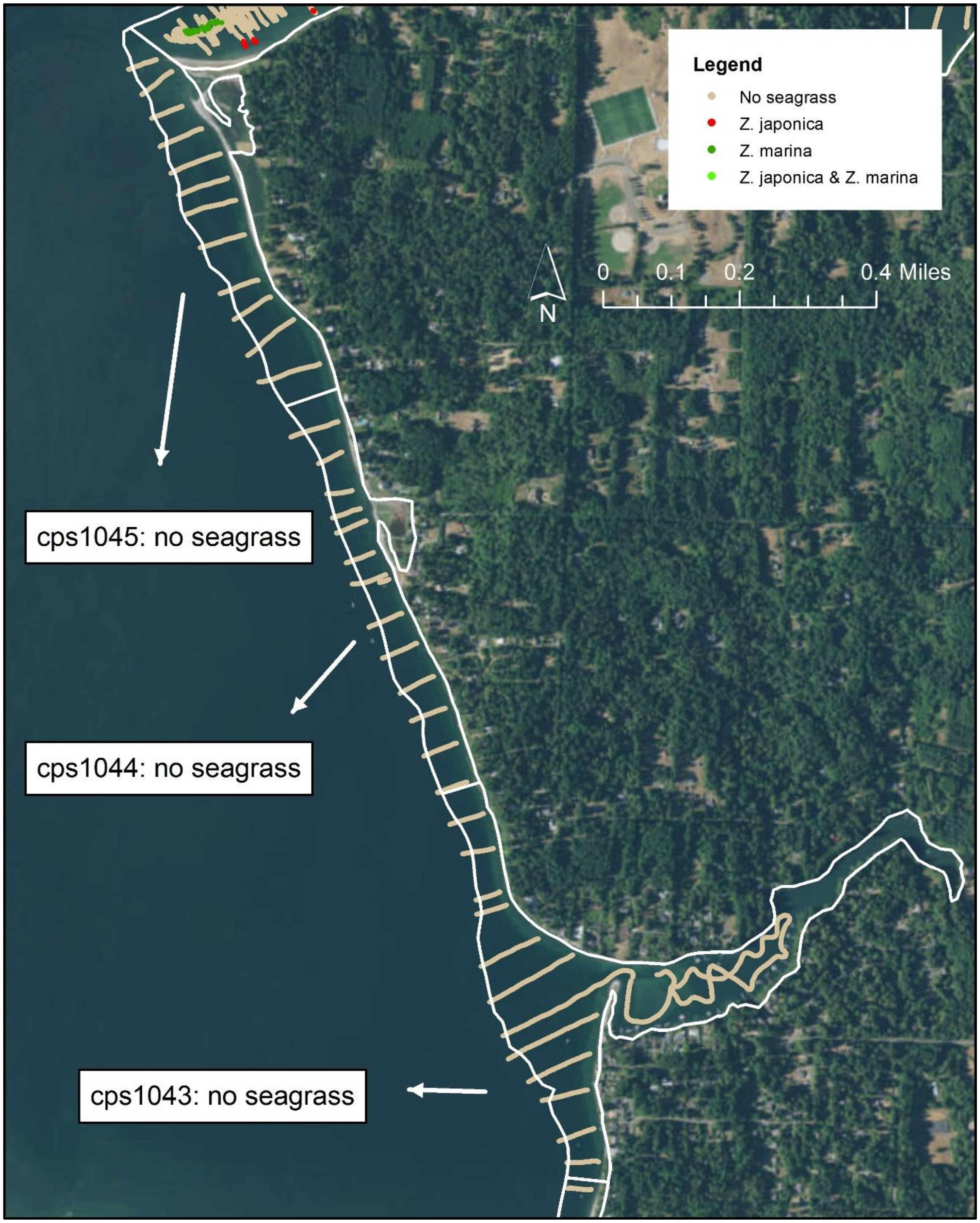

Figure 29: Depth distribution and spatial location of eelgrass along transects in cps1043, cps1044, and cps1045.

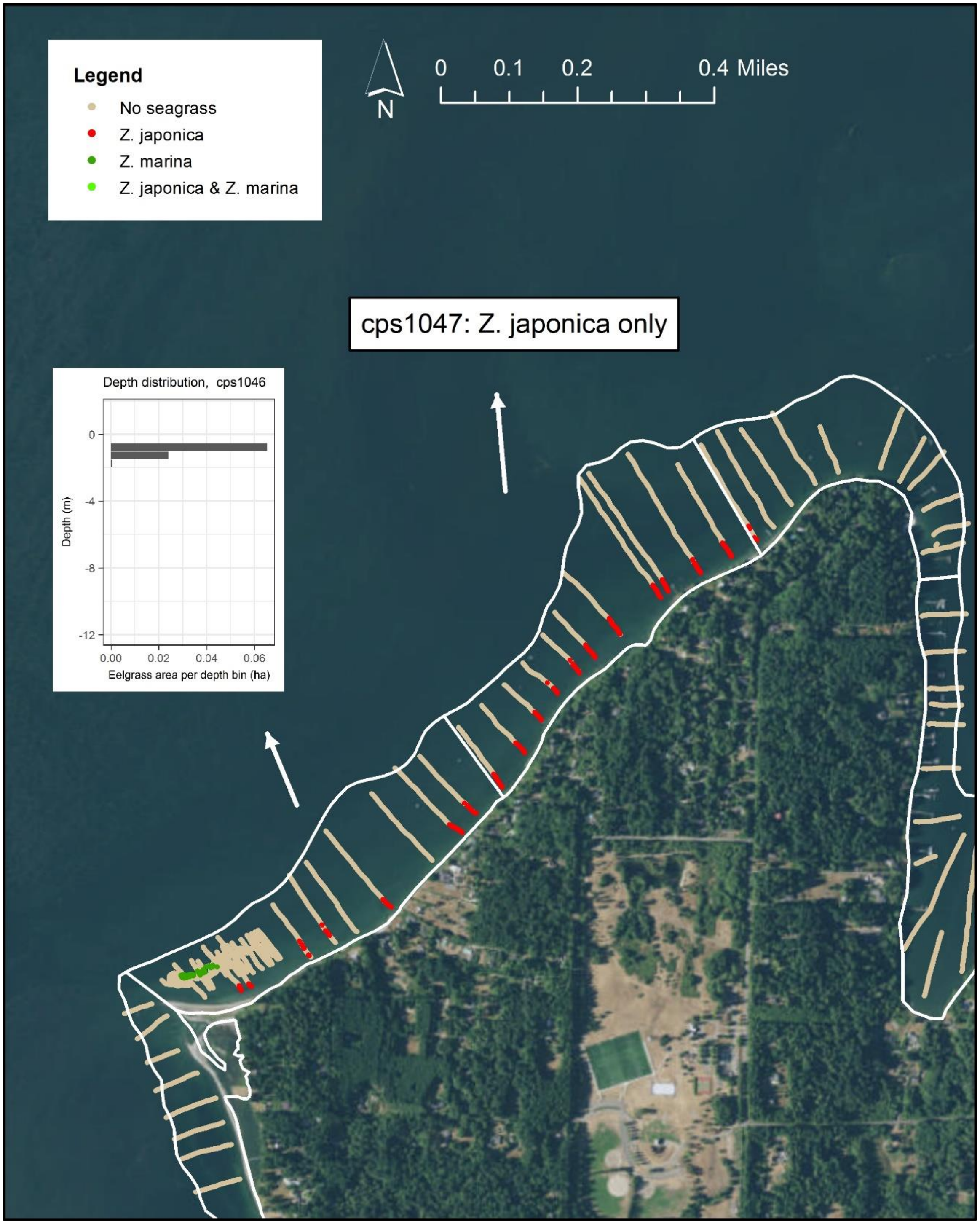

Figure 30: Depth distribution and spatial location of eelgrass along transects in cps1046 and cps1047.

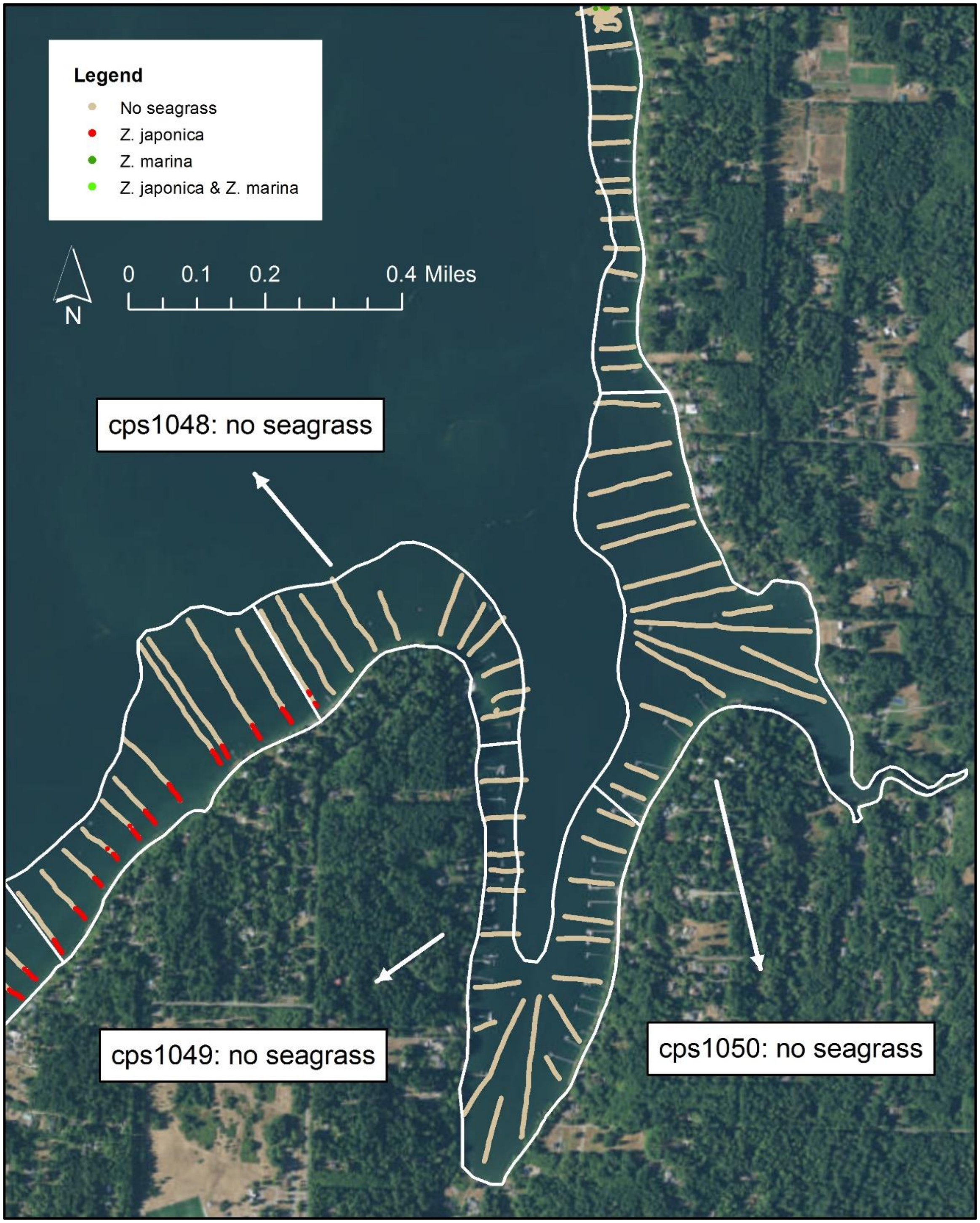

Figure 31: Depth distribution and spatial location of eelgrass along transects in cps1048, cps1049, and cps1050.

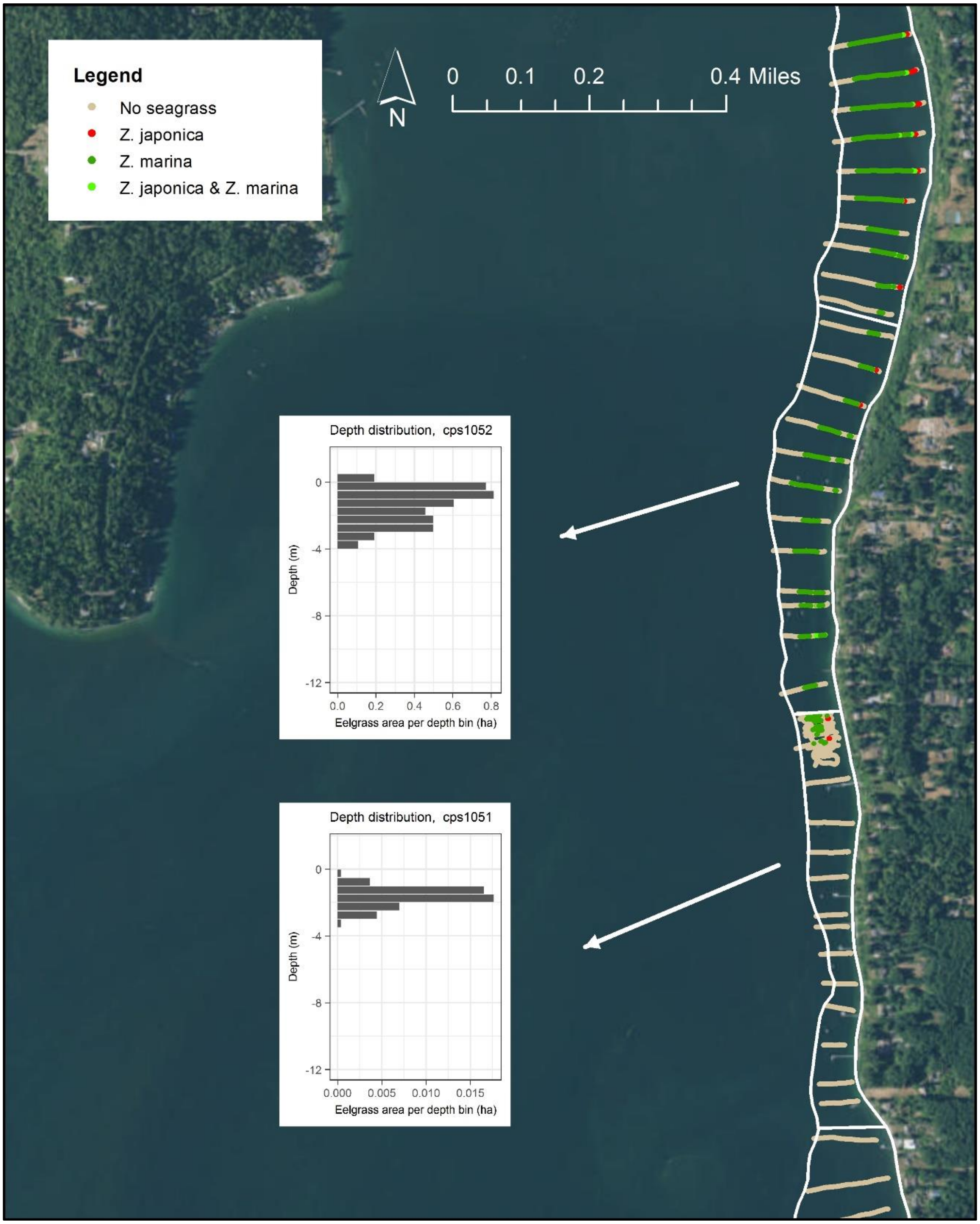

Figure 32: Depth distribution and spatial location of eelgrass along transects in cps1051 and cps1052.

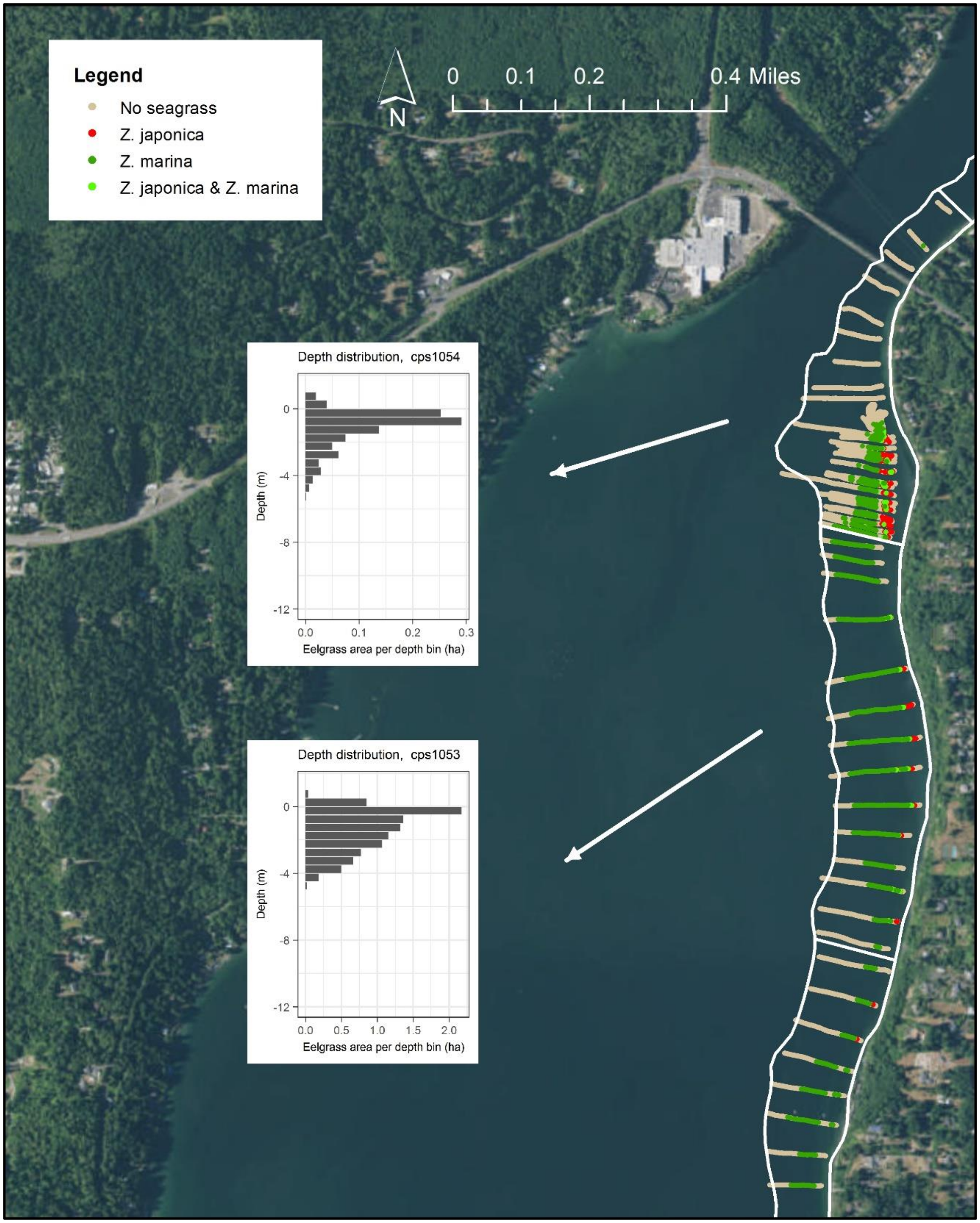

Figure 33: Depth distribution and spatial location of eelgrass along transects in cps1053 and cps1054.

4 Discussion

4.1 Eelgrass area around Bainbridge Island

Based on the site area estimates, we estimate that there is approximately 167 ha of eelgrass around Bainbridge Island. This is roughly 5% of the current best estimate for eelgrass area in Central Puget Sound, and less than 1 % of all eelgrass in greater Puget Sound (Christiaen et al., 2016). The majority of eelgrass in the study area grows along narrow fringes of intertidal and subtidal land along the shoreline. This is very similar to other eelgrass habitat in Central Puget Sound, where more than 90 % of eelgrass grows on fringe sites.

At the majority of sites surveyed, eelgrass beds were relatively small (between 0 and 20 ha per 1000 m of shoreline). Small seagrass beds at fringe sites may provide different ecosystem services than contiguous seagrass beds growing on large flats sites. Large contiguous seagrass beds tend to have more stable nekton communities over time, as they provide enough habitat to sustain a wide variety of species (Hensgen et al., 2014), while smaller eelgrass beds on fringe sites are important for habitat connectivity. Small narrow seagrass beds also tend to be more dynamic than larger beds, as they are more vulnerable to disturbance from hydrodynamic forces (Koch 2001, Greve and Krause-Jensen 2005), and have a lower ability to recruit new shoots through both sexual and asexual reproduction (Greve and Krause-Jensen 2005).

4.2 Eelgrass depth limits around Bainbridge Island

In the study area, eelgrass is found at depths between -12.3 and 1.2 m relative to Mean Lower Low Water (MLLW). However, the vast majority (90%) of plants is found between 0 and -4.5m (MLLW). There is only one site where eelgrass grows deeper than -7.5m (cps1072), and at that location there are only very few plants that extend to this depth. Overall, the depth distribution of eelgrass is very similar to other sites in Central Puget Sound, but more restricted as compared to the San Juan Islands and the Strait of Juan de Fuca (Hannam et al. 2015).

Approximately 67 % of all eelgrass grows in the subtidal (deeper than -1 m, MLLW), and roughly 56% of eelgrass grows deeper than the Extreme Low Tide Line[2]. This is slightly

[2] For the purpose of designating ownership boundaries, the federal government defined the Extreme Low Tide line (ELT) as the line below which it might be reasonably expected that the tide would not ebb. In the Puget

shallower than in greater Puget Sound as a whole, where approximately 62 % of all eelgrass grows subtidal (Hannam et al. 2015) and 50 % grows deeper than the Extreme Low Tide Line.

The depth distribution of eelgrass has implications for the protection of this vulnerable plant. The Extreme Low Tide Line forms the boundary between tidelands and bedlands for a large part of Puget Sound. Virtually all bedlands in Washington are owned by the State, while only 29 % of Washington State's tidelands remain in public ownership (Ivey 2014). This suggests that a large proportion of eelgrass is found on state owned aquatic lands, which emphasizes the importance of continued stewardship activities by DNR.

Eelgrass tends to grow to greater depths at the eastern side of Bainbridge Island, as compared to Port Orchard Bay and Sinclair Inlet. Eelgrass essentially disappears when moving further West into Liberty Bay and Dyes Inlet. However, there is a lot of variability in maximum eelgrass depth among individual sites. This site-scale variability in depth limits is typical for eelgrass beds in greater Puget Sound (Hannam et al. 2015). The maximum depth of seagrass beds is often limited by the amount of light that is able to penetrate throughout the water column (Duarte 1991). As such, a reduction in the maximum depth of eelgrass beds is a possible indicator of water quality impairments (Burkholder et al. 2007). However, many factors can influence water clarity in areas such as Puget Sound, including sediment resuspension due to wave action and tidal currents. Other factors, such as substrate type and bathymetric slope can also influence where eelgrass grows at a site. Further research is needed to ascertain a potential link between water quality, light attenuation, and spatial patterns in the maximum depth extent of eelgrass beds in Puget Sound.

4.3 Zostera japonica around Bainbridge Island

The non-native seagrass *Zostera japonica* has been detected at approximately 35 % of all sites around Bainbridge Island. Similar to *Zostera marina*, this species tends to be more prevalent on the Eastern side of Bainbridge Island than in Port Orchard Bay or Sinclair Inlet. *Zostera japonica* grows higher in the intertidal as compared to *Zostera marina*, and at most sites in the study area there is little overlap in the depth distribution of both species. This suggests that there is little competition between *Zostera marina* and *Zostera japonica*, and that these two species do not have negative effects on each other in areas where they do co-occur. (Shafer et al. 2014, Harrison 1982, Hahn 2003).

4.4 Data use and availability

As a result of the interagency agreements DNR, the City of Bainbridge Island and the Suquamish Tribe, the shoreline of Bainbridge Island has become one of the most densely sampled areas for eelgrass cover in greater Puget Sound. Surveying large contiguous stretches of shoreline, has generated detailed estimates of eelgrass area and depth distribution for the entire shoreline of Bainbridge Island. These data provide a good overview of the current

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Sound area of Washington State this line is estimated by the federal government to be a point in elevation 4.5 ± 0.5 feet below the datum plane of MLLW (Ivey 2014).

extent of both eelgrass (*Zostera marina*) and the non-native *Zostera japonica*, and can be used as baseline for future studies on trends in eelgrass area and depth distribution.

Eelgrass abundance, distribution and depth data identify sensitive habitat areas for consideration in land-use planning. Given the recognized ecological importance of eelgrass, planning should explicitly consider the location of eelgrass beds, its environmental requirements and potential habitat.

All data presented in this report will be made available online in the next distribution dataset of DNR's Submerged Vegetation Monitoring Program (scheduled for end 2017). For more information, visit http://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science

5 References

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