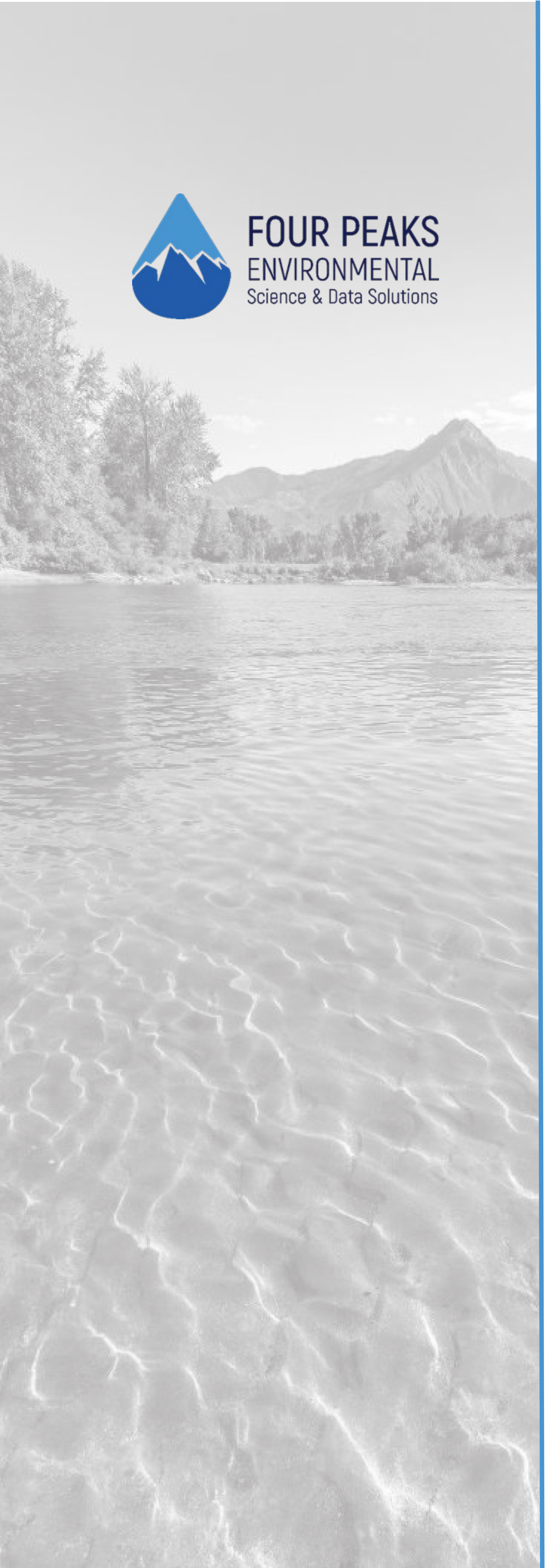

2021 LAKE CHELAN AQUATIC INVASIVE SPECIES SURVEY

February 2022

Prepared for
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Abbreviations

Abbreviation	Definition
.csv	Comma Separated Value
.kml	Keyhole markup language
.kmz	Keyhole markup language file with zipped attachment files
.shp	ESRI Shapefile
CLPW	curly-leaf pondweed
DASH	diver-assisted harvesting
Ecology	Washington Department of Ecology
ESA	Endangered Species Act
EWM	Eurasian watermilfoil
Four Peaks	Four Peaks Environmental Science & Data Solutions
IAM	invasive aquatic macrophytes
IFC	invasive freshwater clams
LCRI	Lake Chelan Research Institute
LiDAR	light detection and ranging

Executive Summary

Aquatic invasive species, such as Eurasian watermilfoil (*Myriophyllum spicatum;* EWM) and associated aquatic macrophytes are a major concern within Lake Chelan. To understand the extent of EWM and associated species, including curly-leaf pondweed (*Potamogeton crispus;* CLPW) within Lake Chelan, a boat-based invasive species survey was undertaken along the littoral habitats of the lake in August and September of 2021.

The survey aimed to achieve the following three goals:

1. Provide data on the extent of EWM invasion, including identifying new invasions and monitoring existing populations of EWM, and identifying additional invasive species such as invasive freshwater clams (IFC).
2. Describe the physical characteristics of invaded nearshore and shoreline habitats
3. Provide guidance on potential mechanisms of spread and generate hypotheses on areas that are likely to be invaded in the future and that merit future monitoring

Four Peaks Environmental Science & Data Solutions undertook a joint rapid-random-systematic survey designed to sample continuous shoreline and littoral areas across the lake and randomly sample suitable habitat locations within the littoral zone (to 30 feet [9.1 m] deep). The survey routes were systematically selected at reaches identified by the Lake Chelan Research Institute prior to sampling.

The survey began in the Lucerne Basin on August 30, 2021, and ended with surveys in the Wapato Basin between Manson and Chelan at lake surface elevations of roughly 1,098 feet (334.7 m). Surveying was undertaken during periods of low wind and during favorable light conditions using digital cameras and visual surveying corroborated by rake throws to estimate cover of each species.

The survey returned total patch-areas of 485.6 acres of EWM and 403.6 acres of *Potamogeton spp.*, beginning approximately at Twenty-Five Mile Creek State Park in the Lucerne Basin, and continuing down lake into the Wapato Basin (Figure ES.1). CLPW results for this survey are preliminary, as senescent putative CLPW was identified in several locations mixed in with native *Potamogeton spp.* The ability to definitively distinguish between the degraded senescent plants and other *Potamogeton spp.* was limited by the conditions of the plants themselves and the majority of observations used an underwater camera that precluded opportunities for detailed morphological examination. As such, the results are presented as inclusive of multiple *Potamogeton spp.* and should be interpreted as the potential distribution of CLPW.

The survey returned 296 positive sample points for EWM and 219 *Potamogeton spp.* points across this portion of the lower Lucerne Basin and the Wapato Basin. EWM was the most common of the species identified during the survey. EWM was often found as monocultures and occasionally as mixed assemblages with multiple native macrophyte species. Large patches of *Potamogeton spp.* were identified throughout the lake, consisting of largely native species with CLPW mixed in at certain locations.

EWM generally occurred at either low cover (0-50%) mixed with other species, or as a dominant species or monoculture with cover from 75-100%, in sand or silt substrate, and at depths ranging from 10 to 30 feet (3.0 to 9.1 m). Most EWM occurred at depths between 16 and 22 feet (4.9 to 6.7 m) below the water surface.

Potamogeton spp. occurred both as a monoculture or single dominant species in sand and silt, and in relatively low-energy littoral habitats along the Wapato Basin. Species were encountered at depths ranging from 10 to 30 feet (3.0 to 9.1 m), and primarily at depths between 18 and 22 feet (5.5 to 6.7 m) below the water surface.

Detection and assessment of IFC were limited due to a number of factors, including the difficulty of observing IFC in densely vegetated littoral habitats. However, IFC beds were mapped in three areas in the Wapato Basin and are known to occur as far up lake as 25 Mile Creek. Water quality samples collected during the survey showed minimal to no difference between waters directly above infested and non-infested lake beds. The extent of IFC invasion is still poorly known, especially the maximum depth of occurrence, which may not correspond to the depths targeted during this survey. Additional surveys will be required to map IFC beds and understand their ecological impact on Lake Chelan.

These results provide initial data from which hypotheses on EWM establishment and persistence can be generated. Additionally, these data provide current maps of invasion hotspots where removal or control methods can be deployed and experimentally tested.

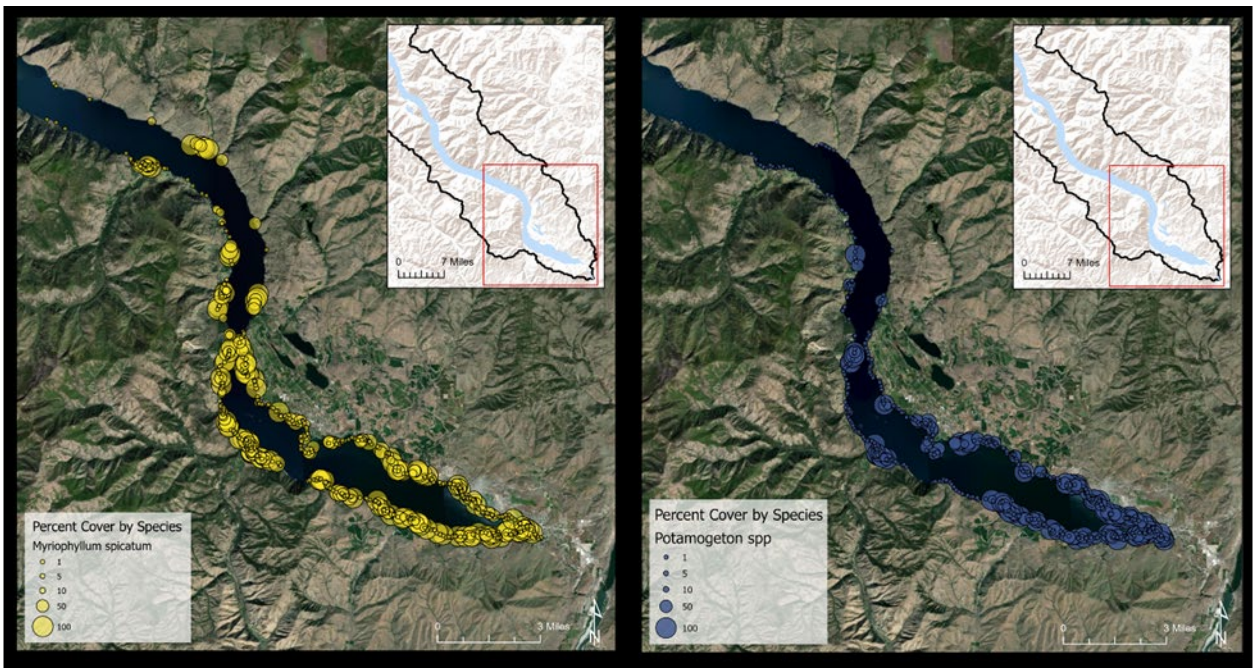


Figure ES.1. Map of Eurasian watermilfoil and *Potamogeton spp.* the lower Lucerne Basin from Twenty-Five Mile Creek State Park to the Narrows and the Wapato Basin.

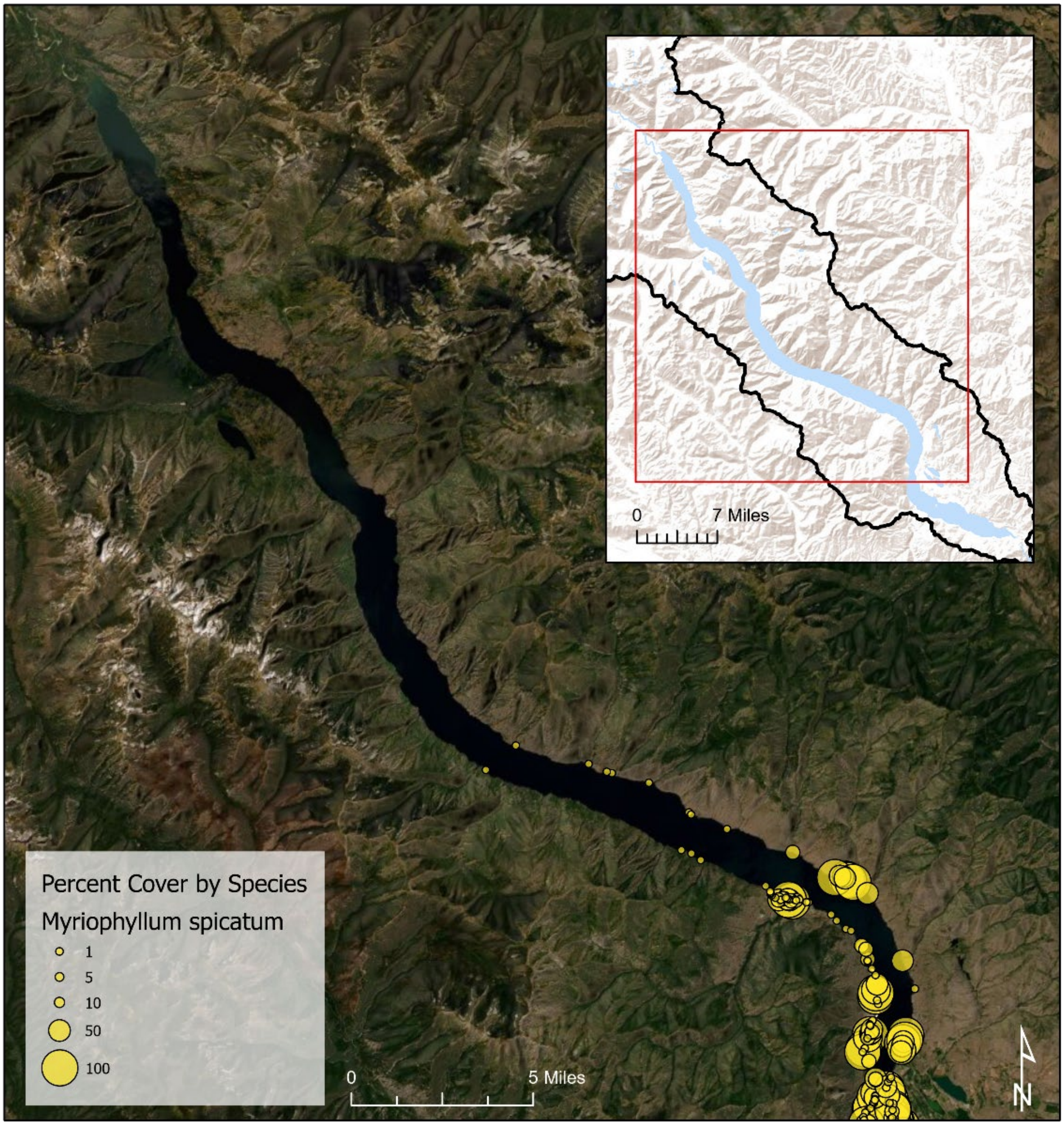


Figure ES.2. Map of Eurasian watermilfoil points within Lucerne Basin.

Introduction

The Lake Chelan Research Institute (LCRI) is a non-profit organization whose mission is to use interdisciplinary research to understand and sustainably steward Lake Chelan in the face of local and regional stresses.[1] To inform LCRI's strategic plan and their understanding of the state of Lake Chelan, Four Peaks Environmental Science & Data Solutions (Four Peaks) was retained to perform a lake-wide, rapid invasive species survey that identified where Eurasian watermilfoil (*Myriophyllum spicatum;* EWM), curly-leaf pondweed (*Potamogeton crispus*; CLPW), and other aquatic invasive species occur within Lake Chelan.

Four Peaks undertook a joint rapid-random-systematic point survey for EWM within Lake Chelan's Wapato and Lucerne basins in August and September of 2021 to accomplish the following three goals:

1. Provide data on the extent of EWM invasion, and opportunistically survey for additional aquatic weeds (e.g., curly-leaf pondweed Potamogeton crispus; CLPW) and Freshwater clams (Corbicula fluminea) across both the Wapato and Lucerne basins
2. Describe the natural characteristics and human uses of invaded nearshore and shoreline habitats
3. Provide guidance on potential mechanisms of spread, and generate hypotheses on areas that are likely to be invaded in the future and likely merit future monitoring attention

This survey was designed to aid the future development of control strategies for EWM within Lake Chelan and associated water bodies (e.g., Domke Lake). While the survey data reported here will allow initiation of planning for invasive species control, it also provides pre-treatment baseline data from which repeat surveys can be used to assess control actions' effectiveness and develop adaptive management strategies for littoral habitats.

This report provides the methods used in the 2021 survey, brief survey findings, metadata for the geospatial data collected during the survey, identified data needs, and recommendations on how and where future survey efforts should be conducted.

Lake Chelan Setting and Context

Lake Chelan, located 32 miles north of Wenatchee in north central Washington, is Washington's largest natural lake, and its watershed is an important tributary to the Columbia River (Figure 1). The lake is divided into two distinct basins: 1) the upper Lucerne Basin with a maximum depth of 1,486 feet (452.9 m) and length of 38 miles (61.2 km); and 2) the lower Wapato Basin with a maximum depth of 400 feet and length of 12 miles (19.3 km; Ecology 1989). The Wapato Basin drains water from the Lake Chelan Watershed to the Columbia River via the Chelan River, which is regulated by the Lake Chelan Hydroelectric Project at Chelan, WA (Public Utility District No. 1 of Chelan County). Water levels generally range from 1,100 feet to 1,085 feet (335.3 to 330.7 m) annually (Figure 2), with water levels peaking in mid- to late summer and reaching their seasonal low in late winter to early spring.

[1] https://lakechelanresearchinstitute.com

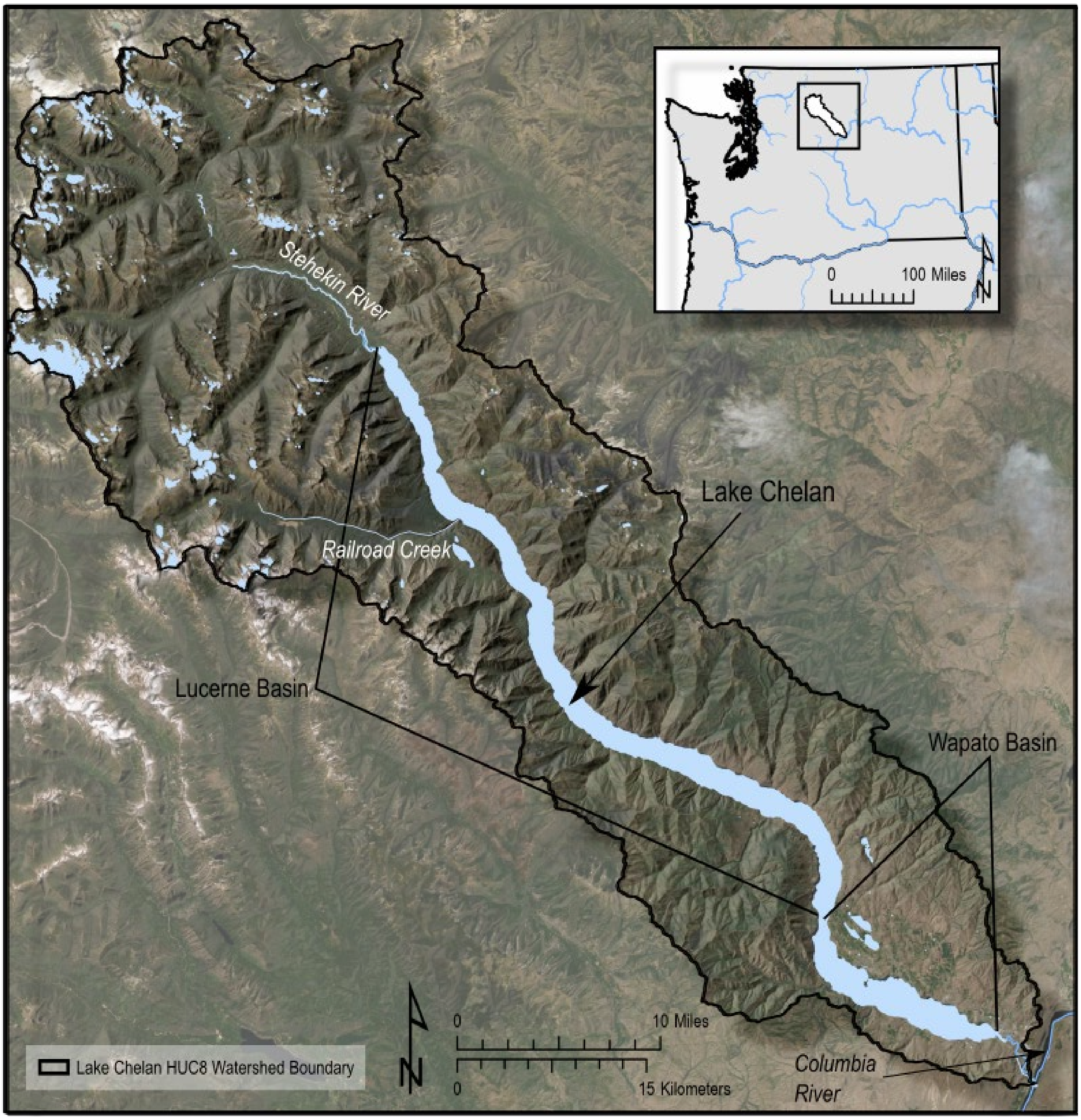


Figure 1. Map of Lake Chelan and its contributing watershed.

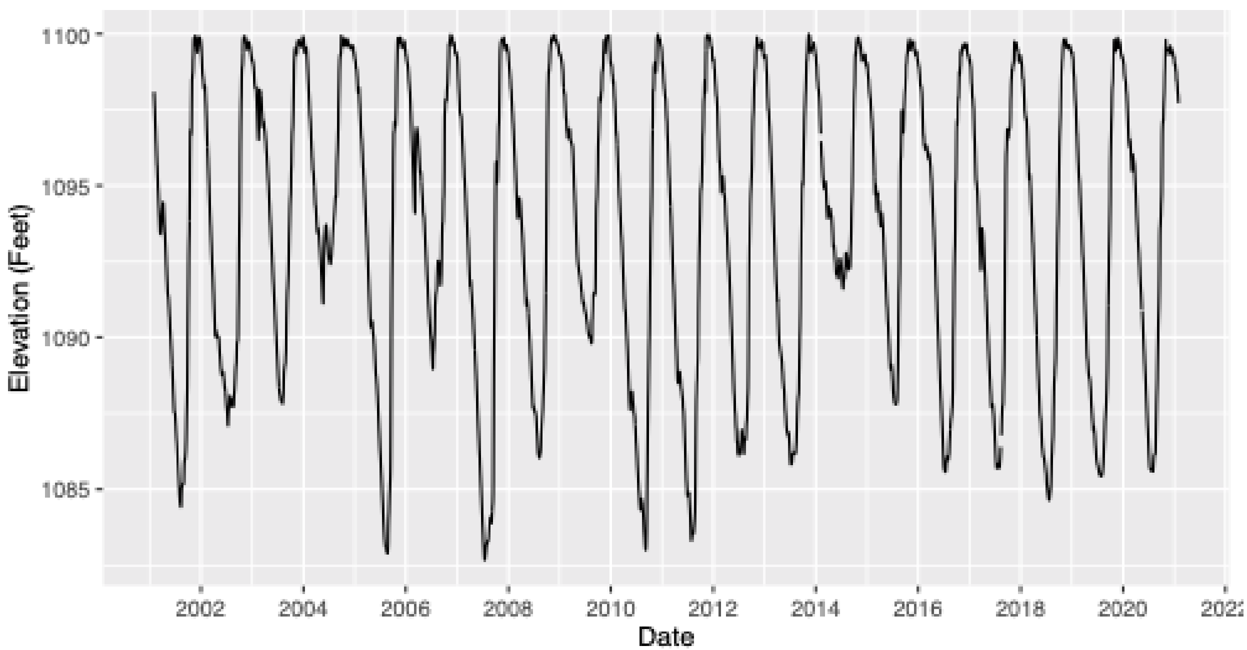


Figure 2. Lake Chelan water surface elevation from water years 2001 through 2021.

Lake Chelan and its surrounding watershed cover 920 square miles of predominantly public land. The Lake Chelan Watershed includes the Stehekin River and Railroad Creek and is surrounded by mountainous forests and shrublands managed by the Okanogan-Wenatchee National Forest and North Cascades National Park. Many parts of the North Cascades National Park and Okanogan-Wenatchee National Forest can only be easily accessed via Lake Chelan. As a result, these agencies offer boat-in recreation amenities and associated dock infrastructure to provide a gateway to these wilderness areas and high peaks. Twenty-Five Mile Creek State Park and Lake Chelan State Park also offer docks and boat ramps, as do Chelan and Manson in the Wapato Basin and the community of Stehekin Basin.

Lake Chelan serves both as an important corridor for recreation travel, and, as such, it is of high social, environmental, and economic value to central Washington.

Invasive Species of Interest

Aquatic invasive species are introduced species that spread aggressively in lake, river, stream, and wetland ecosystems, displace native species and habitats, and/or alter aquatic ecosystem processes such as nutrient cycling. Because of their propensity to dominate shoreline and littoral habitats in lakes, aquatic invasive species are an immediate threat to the habitat, recreational, and aesthetic values that Lake Chelan currently provides. Aquatic invasive species, whose current extent are not fully known, pose a particular problem as they cannot be managed or controlled until the extent of the invasion has been mapped. EWM and CLPW are two aggressive invasive plant species and Washington State-listed noxious weeds that have been previously documented within Lake Chelan (Figure 3; Figure 4), (AquaTechnex 2015).

Figure 3. Eurasian watermilfoil (*M. spicatum*).

Figure 4. Senesced curly-leaf pondweed (*P. crispus;* middle) co-occupies littoral habitats with other macrophyte species (left and right), often occurring in large mixed weed patches.

Eurasian Watermilfoil

EWM is a perennial, rooted, submerged aquatic plant that has invaded freshwater bodies across North America. Within Washington State, EWM has been listed as a Class B noxious weed since 1988 due to its adverse effects on lake ecology, its capacity to spread rapidly through fragments and seeds, and the potential for transport between water bodies by boaters and sportsmen. Within the Upper Columbia Basin, EWM has become increasingly common, including within Lake Chelan where it was documented as early as 1996.[2] Lake Chelan, an oligotrophic lake, has recently seen increases in EWM and other submerged aquatic vegetation density around its littoral habitat, especially within the increasingly developed Wapato Basin. These increases in submerged aquatic weeds have been hypothesized (ESA and Tetra Tech 2020) to coincide with the following anthropogenic changes around the Wapato Basin:

- Nutrient loads tied to increased development
- Outdated septic systems
- Increased boat traffic transporting aquatic invasive species from elsewhere in Lake Chelan and the Columbia River Basin

Because of anecdotal reports of recent increases in the Wapato Basin's density of watermilfoil, the Lucerne Basin is a priority for the early detection of and rapid response to additional EWM populations. EWM is actively being considered for potential control actions to reduce species abundance. The most common look-alike species are shortspike watermilfoil *Myriophyllum sibiricum* and other native milfoils, which can hybridize with EWM. These hybrids often resemble EWM and have similar ecological impacts.

Curly-Leaf Pondweed

CLPW is a perennial, submerged aquatic plant that is native to Eurasia and has been listed as a Class C noxious weed since 2005 within Washington State.[3] It is a global invader that uses early phenology to outcompete native pondweeds. CLPW grows in dense mats and invades still and flowing habitats at a range of depths. Within Lake Chelan, CLPW has been found to occur across shallow portions of the Wapato Basin and was documented as common in an earlier aquatic weed survey (AquaTechnex 2015).

Detecting CLPW late in the growing season can be difficult due to its early phenology and morphological similarity to Washington State's other native pondweed *Potamogeton* species, as it begins to die back in mid- and late summer. Many patches may manifest as mushy non-descript leaves by late in the growing season, making it difficult to see with underwater photography when it occurs in mixed patches.

Invasive Freshwater Clams

Invasive freshwater clams (IFC, *Corbicula fluminea,* commonly referred to as Asian Clams) were first documented in western North America in 1924 at Nanaimo BC Canada (Counts 1981; Kirkendale and Clare 2008). They were first observed on the lower Columbia River in 1938 (Counts 1981). The Nanaimo occurrence likely initiated invasion southward along the west coast of North America followed by invasion across the southern states of the U.S. (Crespo et al. 2015). Progress of invasion up the Columbia River is poorly known and only recently have detailed studies of IFC been conducted on the lower Columbia River (Henricksen and Bollen 2022 and references therein). IFC are commonly found in Lake Chelan and were first documented in 2010 (ESA and Tetra Tech 2020).

[2] http://naturemappingfoundation.org/natmap/water1/4mysppic.html

[3] https://www.nwcb.wa.gov/weeds/curlyleaf-pondweed

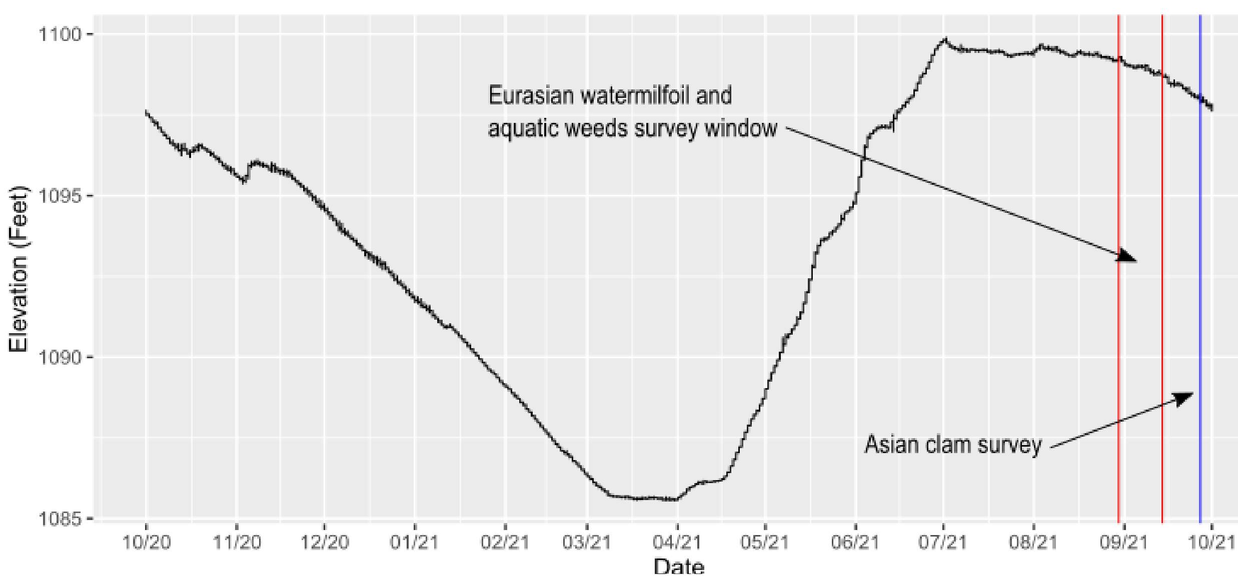
Methods

Survey Framework and Approach

To identify where invasive aquatic macrophytes occur along Lake Chelan's littoral habitat, Four Peaks designed and implemented a rapid-random-systematic shoreline survey. Given the spatial extent of Lake Chelan and the potential survey area, the sample frame was reduced prior to field sampling. Nearshore littoral habitat was gridded into 820.2-foot (250-meter) grid cells in GIS starting near the shoreline ordinary high water mark. Surveying occurred within these grid cells to depths of 30 feet (9.1 m) as defined by existing recreational-grade bathymetry data. Each grid cell was referenced against the existing map of invasive species (AquaTechnex 2015) prior to surveying to identify if it overlapped with a known EWM or CLPW patch.

The sample segment data provided by LCRI allowed Four Peaks to narrow the survey frame to areas with littoral habitats likely to support aquatic vegetation. Steep drops and rocky, mountainous shorelines often lack littoral habitat, and these areas were excluded from the survey extent, reducing the primary focal area to likely shallow, low gradient, littoral habitat where submerged aquatic vegetation can establish and persist.

Fieldwork was carried out in late summer when aquatic species biomass had peaked and summer weather was still stable for boat-based surveying. This late summer timeframe historically corresponds to falling pool conditions (Figure 2; Figure 5). The survey began August 30, 2021, in the Lucerne Basin at the mouth of the Stehekin River, working south and into the Wapato Basin (Table 1), surveying littoral habitats less than 30 feet (9.1 m) deep along LCRI-prescribed segments (Figure 6). During the survey, Lake Chelan's pool height was roughly 1,098 to 1,099 feet (334.7 to 335.0 m; Figure 5) and the maximum reliable Secchi depth was read at elevations as deep as 40 feet (elevation of 1,059 feet; 12.2 m [elevation 322.9 m]) in some littoral habitats. The total estimated length of the survey was roughly 100 miles (160.9 km), although the entire lake was surveyed by boat. Routes of the survey are provided in Figure 7.



Note: The red lines bracket the aquatic weed survey period and the blue line indicates the Asian clam and water quality sampling date.

Figure 5. Lake Chelan water surface elevation for the 2021 water year.

Table 1. Survey dates and areas and species surveyed.

Hitch	Dates	Lake Area Surveyed
Lucerne Basin	8/30 – 9/02	Lucerne Basin including Stehekin, Refrigerator Harbor/Lucerne, Twenty-Five Mile Creek State Park, and all boat-in campgrounds along the upper lake
Wapato Basin	9/07 – 9/14	Wapato Basin, including Lake Chelan State Park, Field's Point Landing, cities of Manson and Chelan
Wapato Basin	9/27	Freshwater clam water sampling and additional opportunistic vegetation surveys

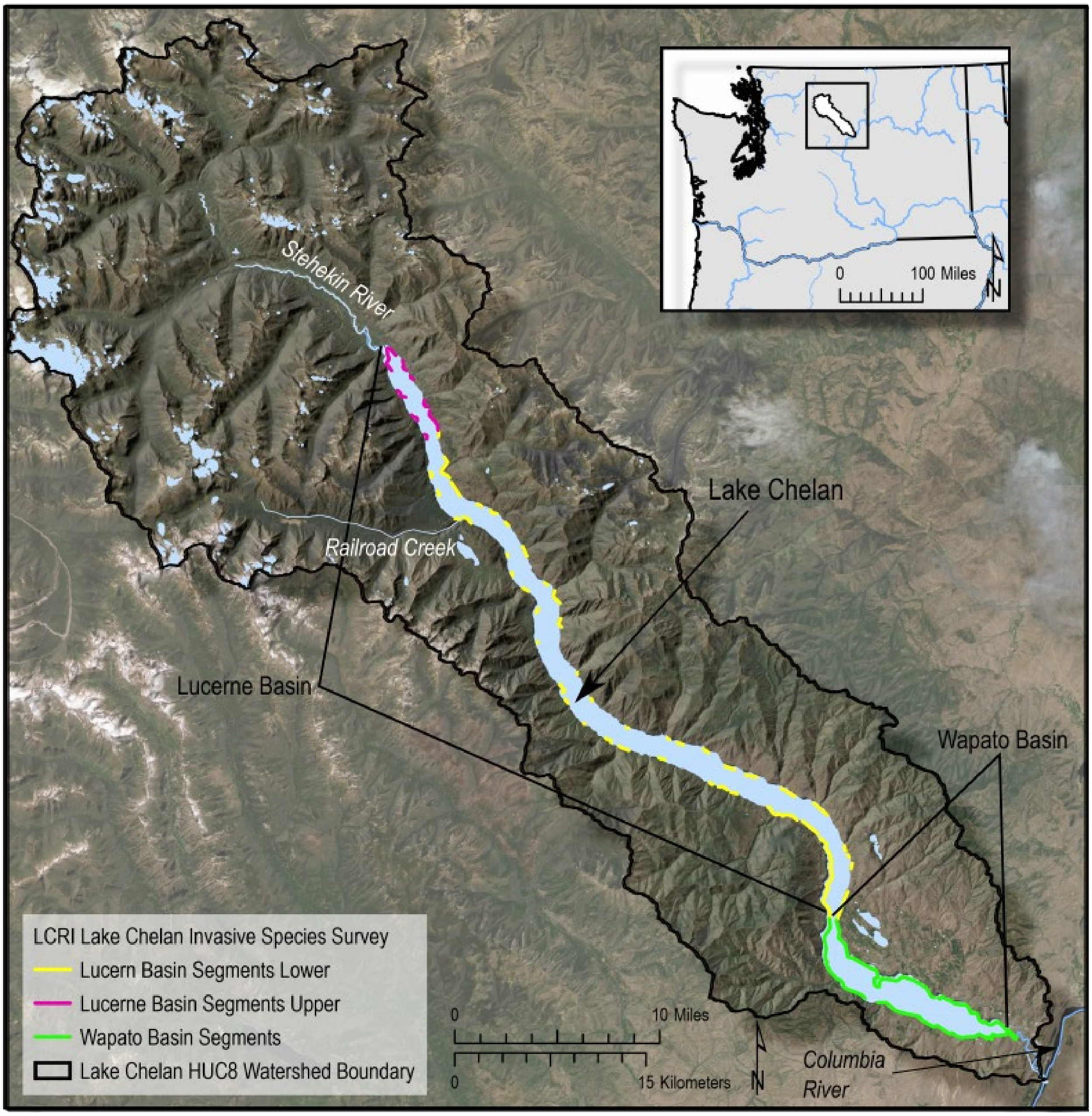
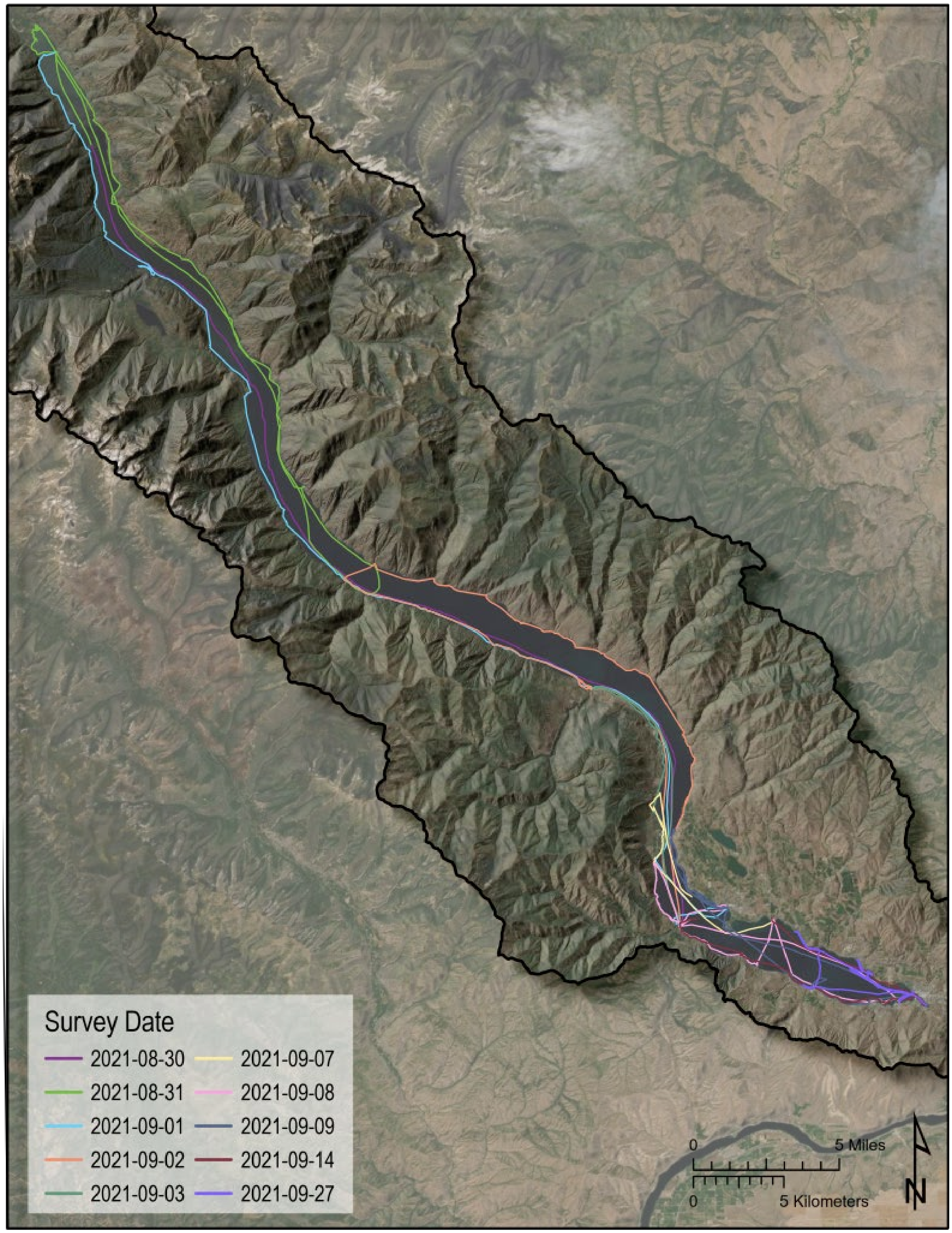


Figure 6. Distribution of random sample points located within Wapato and Lucerne basins.

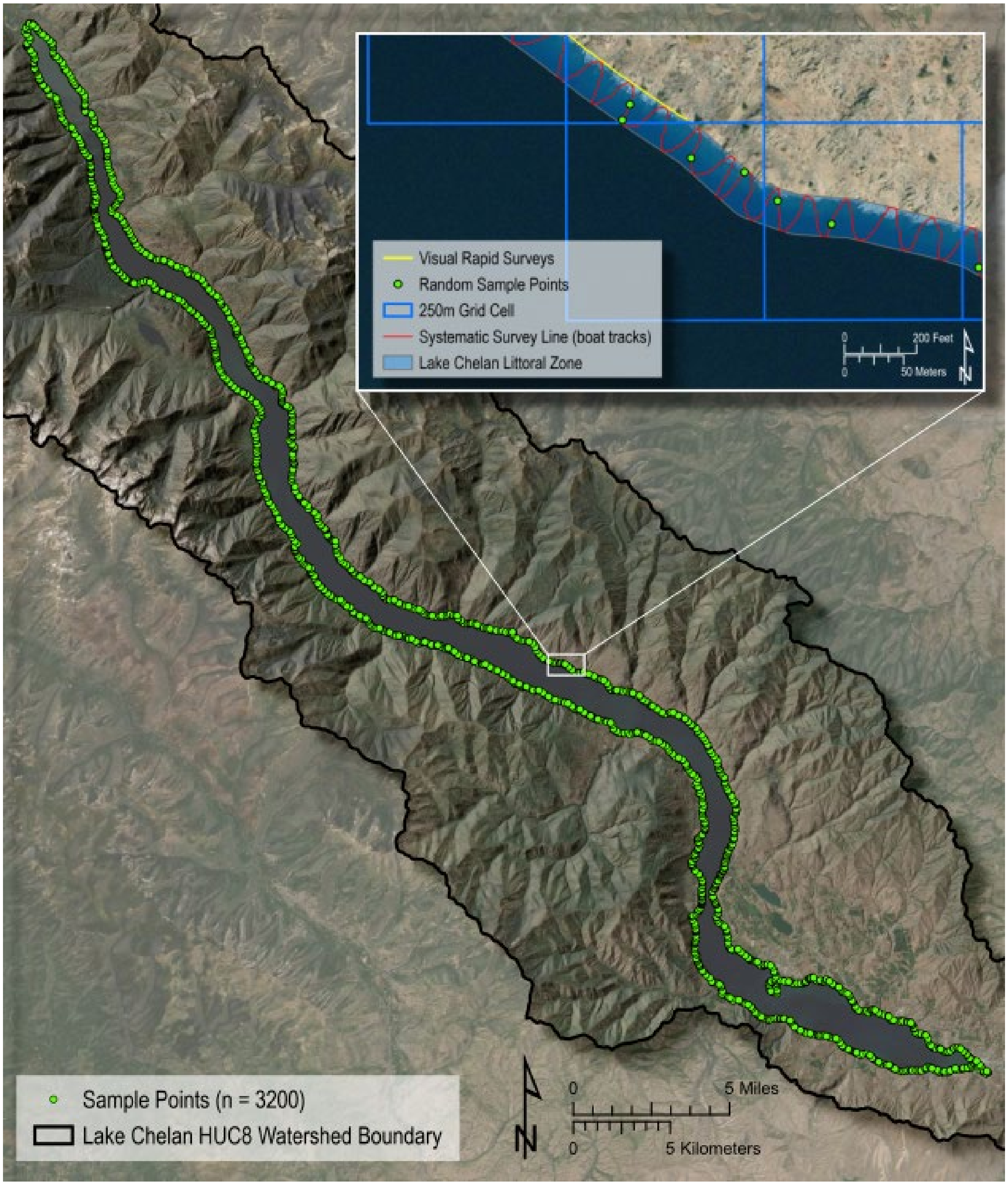


Note: An additional survey was conducted on September 13, 2021, in the Wapato Basin, but the GPS tracks from this day were corrupted and do not appear on the map. Each route includes surveying portions and portions returning to dock. Surveys were intentionally more concentrated in the Wapato Basin where aquatic weeds are more prevalent.

Figure 7. Eurasian watermilfoil survey routes by date.

Survey Methods

Three primary methods were used to identify and map invasive aquatic macrophytes (IAM): (1) visual rapid surveys along the shoreline of Lake Chelan paired with (2) random sampling at pre-determined points within each grid cell, and (3) systematic sampling near known invasion patches (Figure 8).



Note: The ordinary high water mark, systematic survey route, depth to 30 feet (9.1 m), and systematic surveying for a downstream invasion are illustrated in the middle grid cell. Two random sample points are shown within the 820.2-foot (250-meter) grid cell in the left while four points are shown in the right cell. Random points are projected to the littoral zone.

Figure 8. Schematic diagram of rapid, random, and systematic survey methods applied near a confirmed invasion.

Method 1. Visual Rapid Surveying

Four Peaks staff performed systematic, rapid surveys across the entire shoreline and nearshore habitat to depths to 30 feet (9.1 m), which was the maximum reliable depth for visual or underwater camera detection possible during at Lake Chelan's stage during surveying (Figure 2; Figure 8). The survey team used 12-megapixel, underwater GoPro cameras with 4K resolution and sonar imagery to survey for submerged and emergent aquatic vegetation. The boat moved between 1 and 4 mph through any low-energy habitat with sand, silt, clay, or cobble substrate and gradual banks, with two staff members observing the littoral habitat. Staff members took GoPro underwater camera imagery of submerged and emergent habitat and aquatic vegetation at points of interest where submerged aquatic vegetation occurred (Appendix C).

When submerged aquatic vegetation was observed, the boat was idled or stopped, and environmental attributes—infestation density (using rake throws; Figure 9), water depth (using the boat depth finder), estimated substrate type, and any notable physical and environmental characteristics (Table 2)—were recorded.

Note: when paired with visual observation of patches, percent cover can be estimated as 0-100% and attributed with other categorical classes—found, sparse, common, and dense. Sparse cover can also be broken down into cover classes of 1%, 5%, or 10%. Figure reproduced from ISDA 2019.

Figure 9. Estimates of plant cover classes from rake samples.

Table 2. Data attributes collected during the Lake Chelan Eurasian watermilfoil survey.

Data	Methods	Notes
Proposed survey lines	Pre-sampling stratified survey grid based on Lake Chelan bathymetry and shoreline slope and physical characteristics	Pre-mapped in GIS and provided by LCRI as a shapefile for the entire project and each hitch; data can be provided as .shp, .kml, .kmz, or .csv
Survey tracks (actual)	Measured tracking of the boat during surveying	Documentation of whether in-the-field tracks deviate from proposed transect routes; data can be provided as a polygon in .shp, .kml, .kmz, or .csv
Surveyor crew	Which Four Peaks team members collected the data	Four Peaks used crews of 2-3 individuals depending on the nature of the survey sites.
Site coordinates	Coordinates taken at even intervals along the edge of each infestation	Apple or Android-based mobile logger devices
Site description	Site description for each location at which IAM is found	Narrative description of each infestation, including attributes below and additional considerations for future access and/or control
Infestation perimeter	Mapped perimeter of documented IAM populations	Along the perimeter of each infestation, plant density and environmental attributes will be measured as listed below. Data can be provided as a polygon in .shp, .kml, .kmz, or .csv.

Data	Methods	Notes
Stratified survey points – presence-absence	Pre-selected systematic survey points at which sampling will occur	Locations of systematic survey points where rake throws and environmental measurements are taken; data can be provided as points in .shp, .kml, .kmz, or .csv
Percent cover and density	Estimated from rake throws and underwater camera viewing at three throws per direction; percent cover estimated first and converted to density	Data will be provided as points within the larger infestation perimeter polygon .shp, .kml, .kmz, or .csv, and can be averaged in GIS to estimate overall invasion intensity.
Water depth	Measured with depth finder in situ	Measured at sample points and infestation perimeter points. Data can be provided as .shp, .kml, .kmz, or .csv; field data on water depth can also be validated and cross-referenced with U.S. Bureau of Reclamation bathymetry data.
Physical and environmental site characteristics	Bed substrate, notable features such as tributaries, water intakes, etc.	Assessed at sample points and at infestation perimeter points; data can be provided as .shp, .kml, .kmz, or .csv
Site photos	Taken with a location-referenced camera to provide coordinates of each photo	Photos will be taken at sample points and infestation perimeter points. Photo point data can be provided as .shp, .kml, .kmz, or .csv.

Environmental and infestation data were collected at multiple points along each infestation patch's perimeter. The number of points collected at a patch was based on the estimated patch size using GPS and visual surveys. The perimeter of each invasion was mapped with the boat and the edge points around patches were connected within GIS. At each sample point, a weighted rake throw was used to sample IAM density at five levels 0%, 1-25%, 25-75%, 75%, and above cover, or 100% (pervasive cover; Figure 9). In cases of sparse EWM or other weed occurrence, cover was estimated as 1%, 5%, 10% to distinguish between low-density invasions. For example, a few individual plants sprouting from a crack in bedrock may be estimated as 1% cover while an isolated clump of plants on a sand dune may be 5% or 10% cover.

During visual rapid surveying (trolling), route tracks were plotted on the boat GPS unit to create a water surface track of routes traveled during rapid surveys (Figure 7).

Method 2. Pseudo-Random Point Sampling

Within each 820.2-foot (250-meter) grid cell of the shoreline and potential littoral zone, two survey points were randomly generated (3,200 total points). These points did not always fall between the shoreline and the maximum reliable depth of 30 feet (9.1 m) as estimated from existing bathymetry data and validated in the field. Visual rapid surveying took place as the surveyors traveled between points, as outlined in Method 1 above. At each random sampling point, at least one rake throw occurred regardless of visual detection of EWM or other species. When EWM was detected during the rake throw, the density of the infestation was estimated from rake throw samples and the environmental attributes listed in Method 1 (Table 2) were collected. If EWM did not occur at a randomly generated point, an absence was recorded and environmental attributes were characterized (Figure 9) if the point did not occur at a depth where aquatic species were improbable.

Method 3. Systematic Sampling

Where existing known patches of EWM or CLPW were mapped (AquaTechnex 2015), additional high-density visual sampling systematically occurred, surrounding the EWM patch and mapping the deep-water boundary. This systematic patch surveying focused on the extent of the nearshore environment between the shoreline and depths to 30 feet. Throughout sampling, photos were generated both below and above the water surface, geotagged, and are presented in Appendix C.

Invasive Freshwater Clams Observations

IFC were opportunistically observed and documented throughout the study. In three cases, specific areas were mapped including an area of Key Bay with known high-density areas of IFC shells observed at low water in the winter of 2020 (Phil Long, personal communication). In addition, water quality data were collected 1) immediately above and 2) distant from a clam bed near Key Bay to preliminarily assess if IFC in Lake Chelan have an obvious impact on water quality, especially dissolved calcium concentrations. Dissolved calcium concentrations are an important predictor of vulnerability to establishment by other invasive bivalves such as Zebra (*Dreissena polymorpha;* Ludyanskiy et al. 1993) and quagga (*D. rostriformis bugensis*; Davis et al. 2015) mussels.

Results

The surveys found multiple patches and points of EWM and *Potamogeton spp.* across lower Lake Chelan, beginning roughly at Twenty-Five Mile Creek State Park and continuing down lake into the Wapato Basin (Table 3; Table 4). CLPW results for this survey are preliminary, as senescent putative CLPW was identified in serval locations mixed in with native *Potamogeton spp*. The ability to definitively distinguish between the degraded senescent plants and other *Potamogeton spp.* was limited by the conditions of the plants themselves and the majority of observations used an underwater camera that precluded opportunities for detailed morphological examination. As such, the results are presented as inclusive of multiple *Potamogeton spp.* and should be interpreted as the potential distribution of CLPW.

The survey returned 296 positive sample points for EWM and 219 *Potamogeton spp.* points across this portion of the lower Lucerne and Wapato basins, with EWM being the most common of the species identified (Figure 11; Figure 12; Table 4). Corresponding patches for each species comprised roughly 485.6 acres of EWM and 403.6 acres of *Potamogeton spp.* (Table 3; Appendix A) as well as 200.3 acres of common elodea (*Elodea canadensis*) and 337.1 acres of other native species. Patches of EWM occurred as monocultures and as mixed assemblages of multiple species. Common elodea, coontail (*Ceratophyllum demersum*), and *Potamogeton spp.* were the most frequently encountered species in these patches (Figure 13).

EWM generally occurred at either low cover (0-50%) mixed with other species, or as a dominant species or monoculture with cover from 75-100% (Figure 14). EWM occurred most frequently in sand or silt substrate or in cobble with component areas of silt and sand (Figure 15). EWM points were encountered at depths ranging from 10 to 30 feet (3.0 to 9.1m; Figure 16). EWM occurred predominantly at depths between 16 and 22 feet (4.9 to 6.7 m) below the water surface; when adjusted to a water surface elevation of 1,099 feet (335 m), EWM occurred at elevations between 1,083 and 1,077 feet (330.1 to 328.3 m; Figure 16).

Potamogeton spp. also occurred both as a monoculture or single dominant species with cover from 75-100%, or in mixed communities with <50% cover (Figure 17). Most points for both species occurred within the Wapato Basin, where sand, silt, and relatively low-energy littoral habitats dominate the shoreline (Figure 18). *Potamogeton spp.* points were encountered at depths ranging from 10 to 30 feet (3.0 to 9.1m; Figure 19). *Potamogeton spp.* occurred predominantly at depths between 18 to 22 feet (5.5 to 6.7 m) below the water surface; when adjusted to a water surface elevation of 1,099 feet (335 m), EWM occurred at elevations between 1,081 and 1,077 feet (329.5 to 328.3 m; Figure 16Appendix A).

Invasive freshwater clams (IFC) were observed in the Wapato Basin during aquatic macrophyte surveys and intentionally targeted for survey on September 27, 2021. IFC were observed in the Wapato Basin and occasionally were observed in rake samples in the lower Lucerne Basin. The intentional survey results are shown in Figure 10 and represent areas of known or suspected high density of IFC.

Figure 10. Invasive freshwater clams (IFC) observed in the Wapato Basin on September 27, 2021.

No obvious difference was observed in the water quality parameters measured immediately and distant from known clam beds (Appendix D). Because the water quality sampling effort was limited to 10 total samples collected in one day, the interpretation of the data should be constrained to the small spatial and temporal scale of the sampling effort. It is possible that elsewhere in the lake, clam beds with higher densities of IFC cause locally elevated dissolved calcium levels. Additional studies are necessary to definitively conclude whether IFC can shape the habitat suitability of Lake Chelan for other invasive bivalves (e.g., ESA and Tetra Tech 2020).

Table 3. Acres mapped in weed patches.

Species	Acres Mapped
Eurasian watermilfoil *Myriophyllum spicatum*	485.6
Potamogeton spp.	403.6
Common elodea *canadensis*	200.3
Other species	337.1

Table 4. Number of points with positive aquatic invasive species encounters.

Species	Number of Positive Sample Points		
	Wapato	Lower Lucerne	Total
Eurasian watermilfoil *Myriophyllum spicatum*	243	53	296
Potamogeton spp.	211	8	219

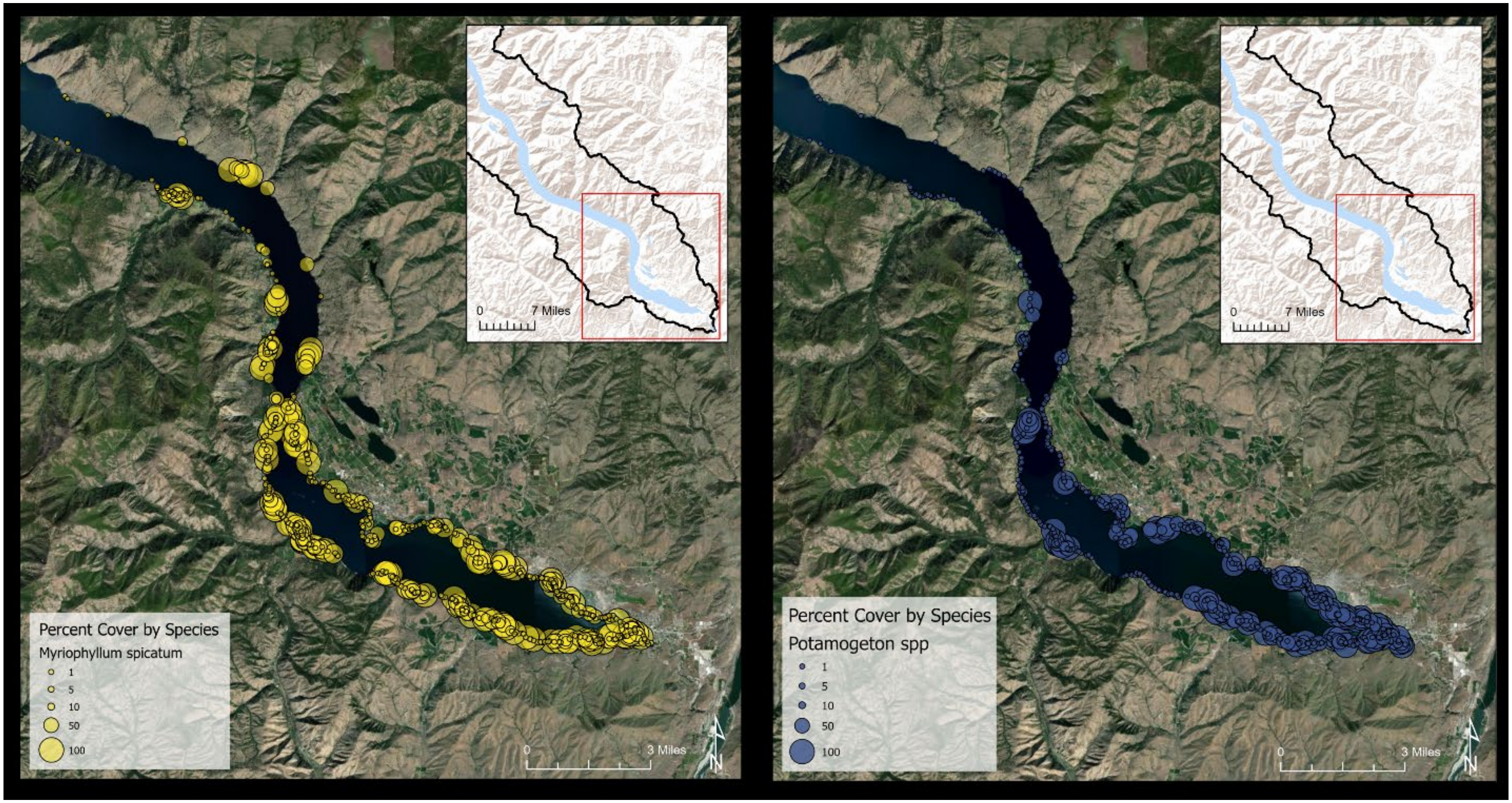


Figure 11. Map of Eurasian watermilfoil (*Myriophyllum spicatum*) and *Potamogeton spp.* points within the lower Lucerne Basin from Twenty-Five Mile Creek State Park to the Narrows and the entire Wapato Basin. Sparse cover estimates are broken down into 1%, 5%, and 10%, while point cover has been rounded to 50% or 100% cover to show estimated invasion density at each point.

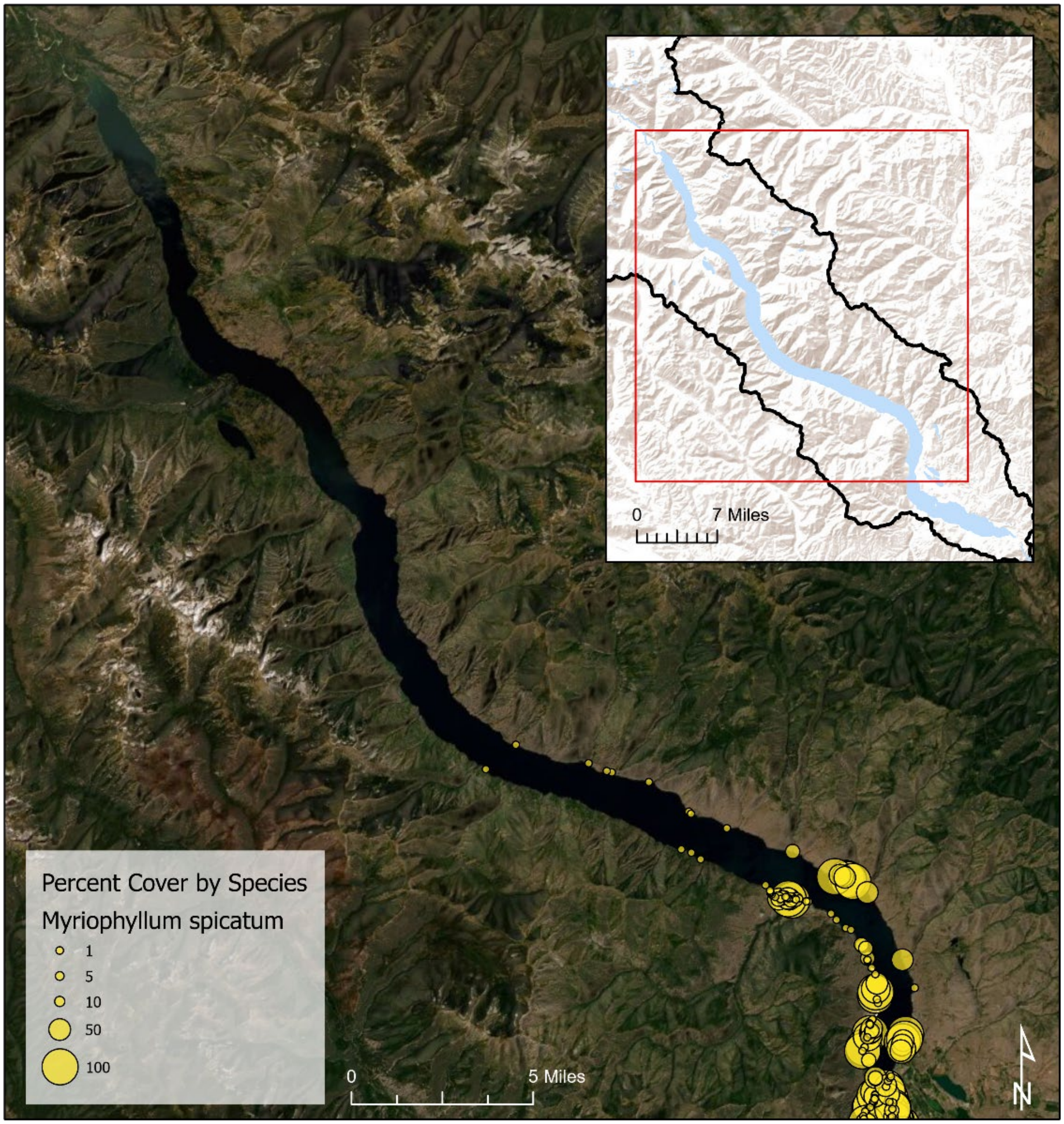


Figure 12. Map of Eurasian watermilfoil points within Lucerne Basin.

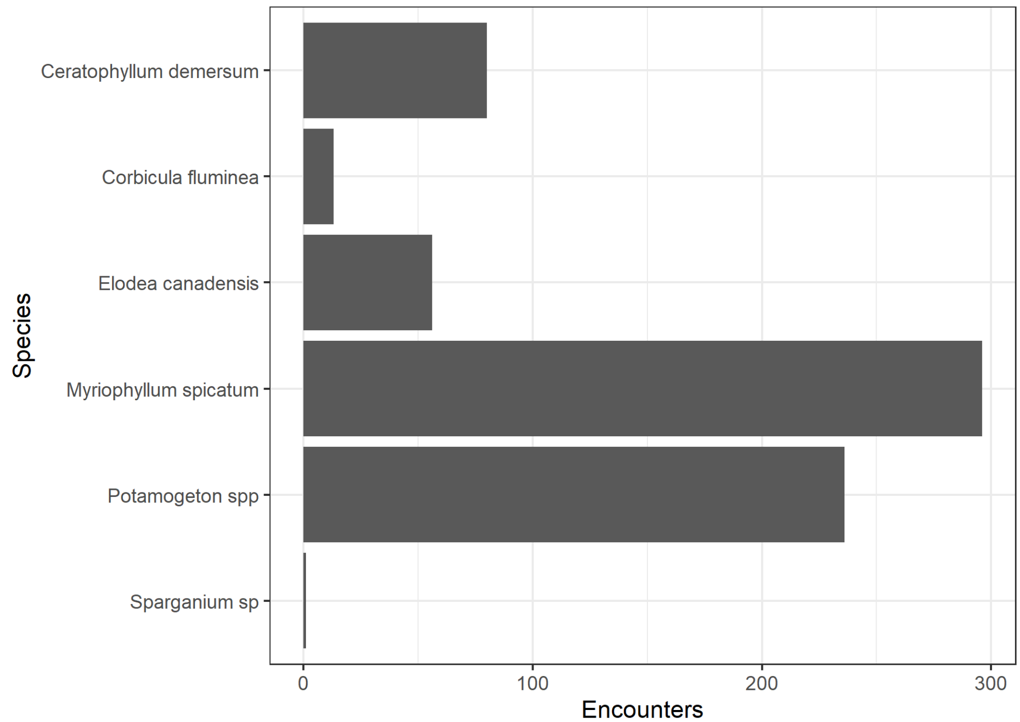


Figure 13. Frequency of positive sample points for Eurasian watermilfoil (*Myriophyllum spicatum*), *Potamogeton spp.*, and common native species: coontail (*Ceratophyllum demersum*), common elodea (*Elodea canadensis*), and bur-reed (*Sparganium sp*.).

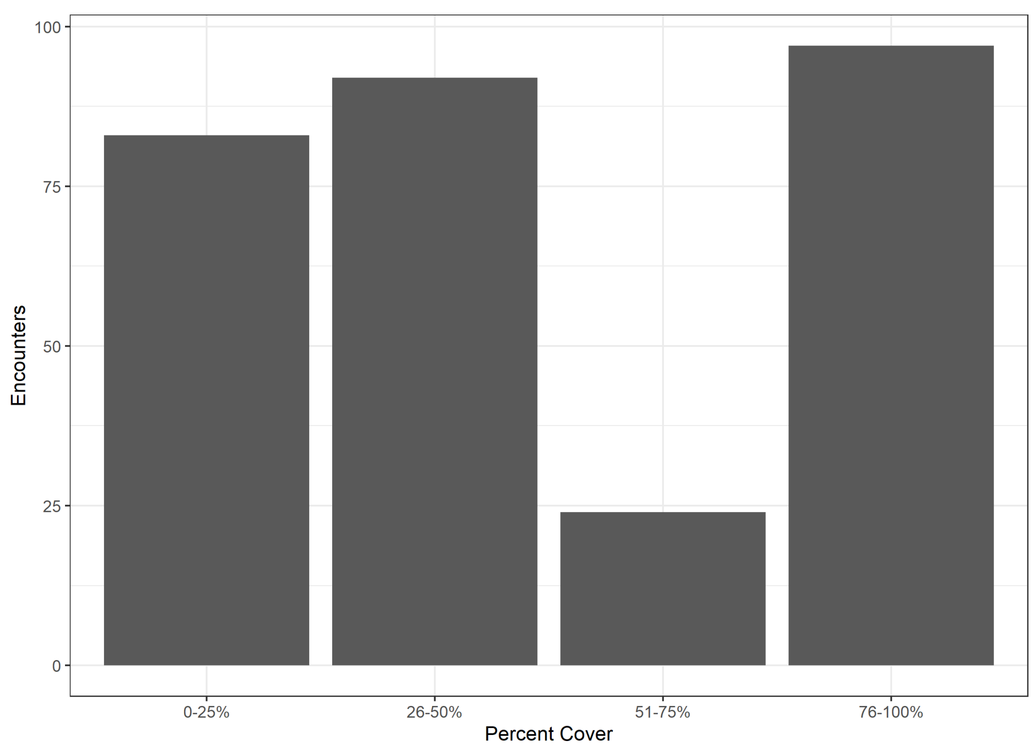


Figure 14. Eurasian watermilfoil encounters plotted by cover class.

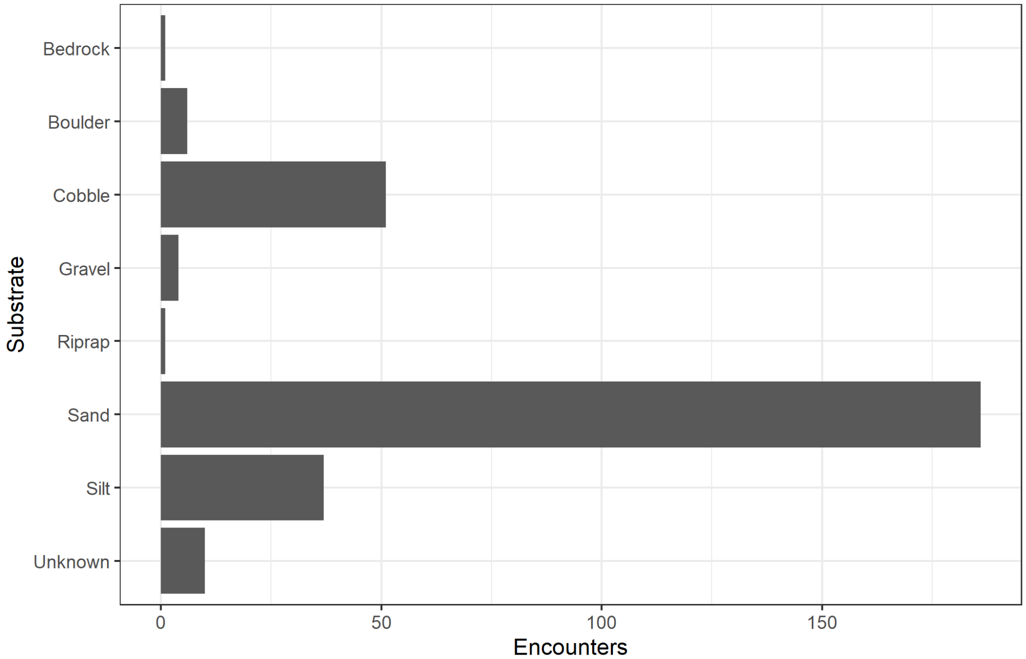


Figure 15. Eurasian watermilfoil encounters plotted by dominant substrate.

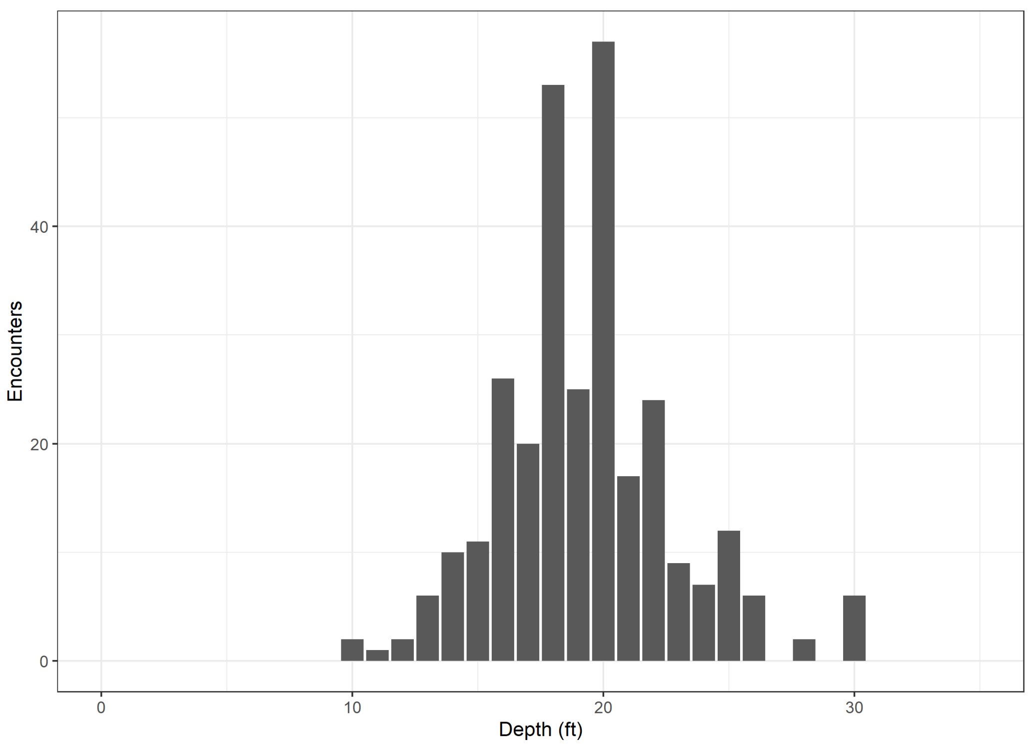


Figure 16. Eurasian watermilfoil encounters plotted by depth to lake bottom on date of survey (Lake Chelan elevation was roughly 1,099 feet [335 m] during the survey window).

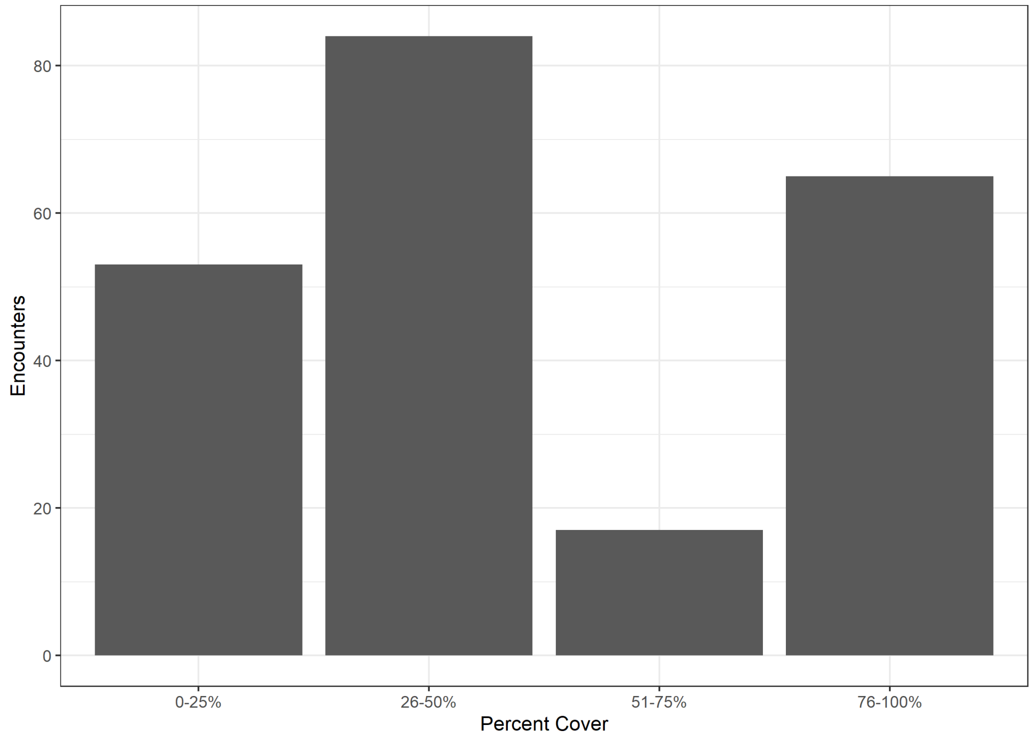


Figure 17. *Potamogeton spp.* encounters plotted by cover class.

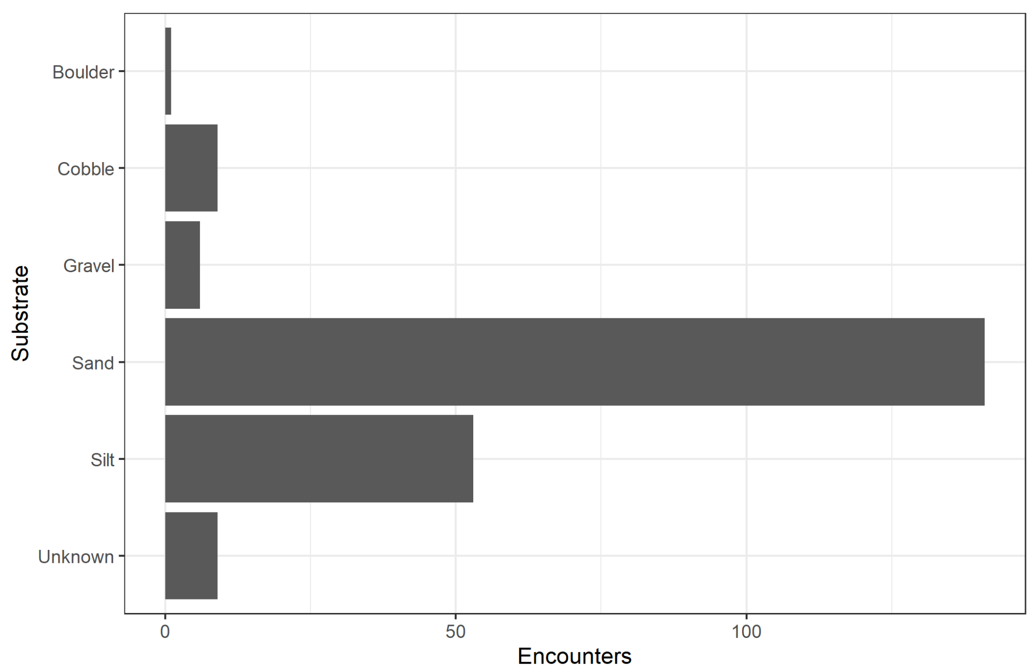


Figure 18. *Potamogeton spp.* encounters plotted by dominant substrate.

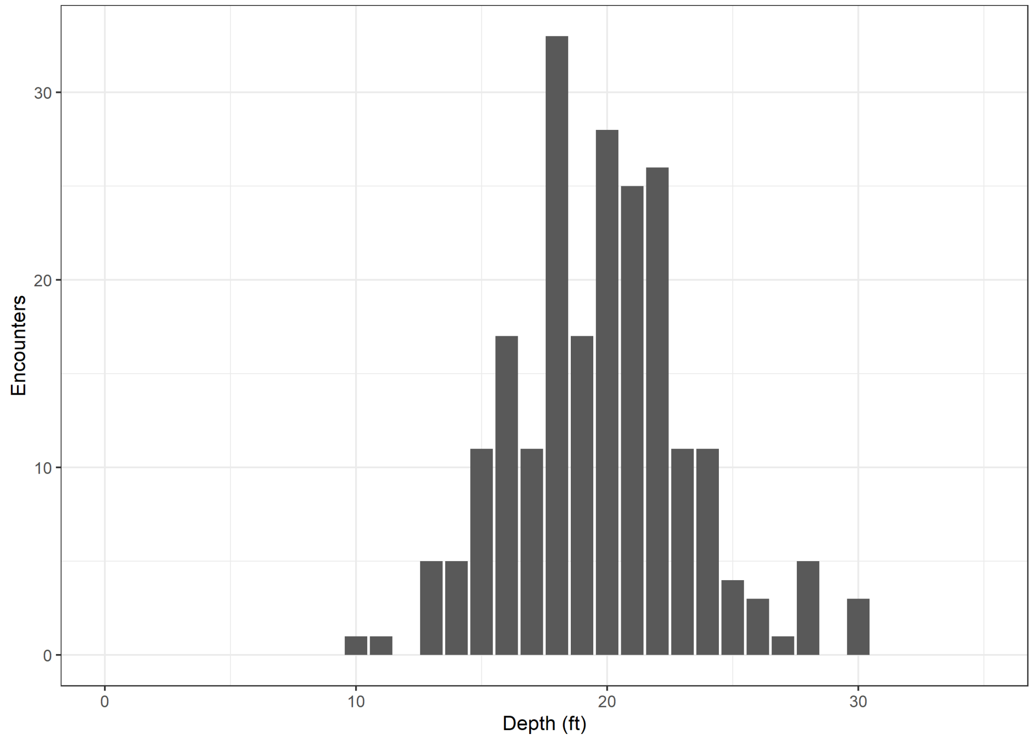


Figure 19. *Potamogeton spp.* encounters plotted by depth to lake bottom on date of survey (Lake Chelan elevation was roughly 1,099 feet [335 m] during the survey window).

Discussion

The Wapato Basin was highly invaded with EWM relative to the steeper, deeper, and less productive Lucerne Basin, which had several high-density, native emergent macrophyte communities, especially near the Stehekin River Delta. Broadly, the delineation of EWM and other macrophytes in the two basins is correlated with and reflective of the habitat types present in each. The Wapato Basin consists primarily of low energy habitats where fine sediment, propagules, and other organic matter settle out from the water column, whereas the Lucerne basin consists of high energy habitat shaped by wave action and erosion with substrates comprising bedrock cobble, and large gravel (Figure 20).

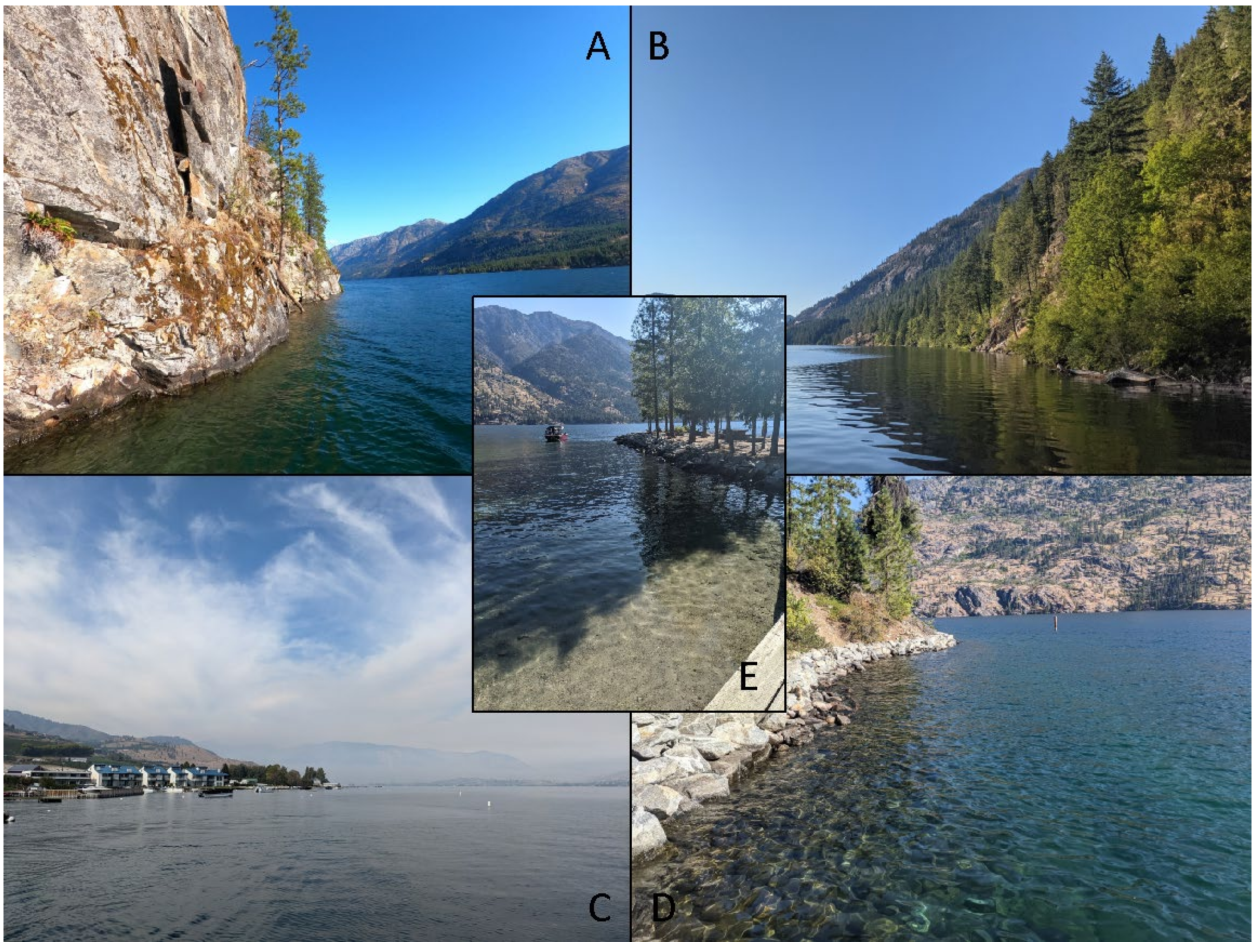


Figure 20. Areas along Lake Chelan that are exposed to different levels of energy that influence sediment deposition and erosion: Steep cliff areas with long fetch or rip-rap reinforced banks near steep drops are exposed to high wave and current energy (A, B, D,) compared to sheltered bays in the Lucerne and Wapato basins (C, E) where sediment deposition may occur.

Several small bays within the Lucerne Basin that provide off-lake boat use were invaded by EWM. The Lucerne Basin, being steep and often lined by cliffs or steep slopes that drop off to depths beyond the range of possible aquatic macrophyte establishment, has fewer potential habitat areas where EWM or other weeds could establish. However, the same scarcity of low-energy bays and off-lake sites with littoral habitat means that bays and docks where boats can anchor or dock are likely to be heavily used as there are few other refugia out of the wind and waves that the Lucerne Basin is known for.

Within the Lucerne Basin, the largest documented patches began at public boat docks and ramps adjacent to Twenty-Five Mile Creek State Park and continued through a steeper bedrock area alongside homes with private docks and into the narrows. The heavily trafficked Fields Point Landing ferry dock was also invaded by EWM.

EWM was common within the Wapato Basin because its littoral zone provides an ideal habitat for aquatic invasive species to establish and spread: boat use is high, fetch is shorter, wave energy is lower, and there are numerous low energy bays where silt, sand, and propagules can readily settle. External nutrients from lakeside development, agriculture, and septic tanks, as well as decomposing macrophytes, may also all contribute to a more productive Wapato Basin and associated littoral habitats. Additionally, much more of the Wapato Basin lakebed is at elevations 1,081 to 1,077 feet (329.5 to 328.3 m), just below the lake's seasonal low-water line of around 1,085 feet (330.7 m). These elevations support year-round depths within CLPW and EWM's preferred range of about 10 to 30 feet (3.0 to 9.1 m).

Temporal Changes in Eurasian Watermilfoil Distribution

The 2021 sampling efforts provide a limited basis for assessing temporal changes in EWM distribution between the fall of 2014 (AquaTechnex 2015) and 2021 (this survey). The general sampling approach and spatial extent of sampling efforts differed between the two studies, making rigorous quantitative comparisons difficult at best. Another confounding factor is year-to-year differences in aquatic growth related to specific weather conditions in a given year. Documenting temporal changes in the distribution and extent of EWM in the future will be enhanced by applying a systematic sampling approach. Such comparisons are beyond the scope of this report and will always be highly uncertain, constrained by the limitations noted above.

In addition to areas mapped in both studies, the 2021 sampling effort documented EWM at several locations in the Lucerne Basin (Figure 21) where EWM had not been previously observed by AquaTechnex (2015), but the new observations, in some cases, are outside of the areas evaluated by AquaTechnex (Figure 22) and therefore do not provide definitive evidence of a temporal change in distribution. It is appropriate to conclude that the extent of EWM in the Lucerne Basin is further north (i.e., Point No Point Creek) than previously documented (i.e., Fields Point Landing). It is uncertain if the extent of EWM has changed since 2014 because AquaTechnex did not sample north of Fields Point Landing (Figure 22).

The results of this study include other important observations of EWM that contribute to the baseline distribution of the species in Lake Chelan within areas either not previously examined by AquaTechnex (2015) or where EWM has invaded since the AquaTechnex survey in the fall of 2014. These include:

- Presence on the eastern side of Lake Chelan between Willow Point Park and the outlet of Point No Point Creek (Figure 21; Figure 22).
- Presence on the western side of Lake Chelan between Fields Point Landing and Corral Creek Boat-in campground (Figure 21)
- Presence on the western side of Lake Chelan within the Wapato Basin north of Lake Chelan State Park (Figure 22)

Given those constraints and uncertainties, visual comparison of maps from the 2014 survey and this survey allow the following *qualitative* generalizations:

- Where sampling clearly overlapped between the two studies within the Wapato Basin, the results from 2021 are generally congruent with the results of AquaTechnex (2015).

- In most locations that were mapped in both studies, the 2021 results show possible increases in area of EWM compared to areas mapped in 2014.
- In a few locations, 2014 mapped areas of EWM where no EWM was detected in 2021.
- On balance, it appears that the documented area in Lake Chelan occupied by EWM at the time of the 2021 survey was larger than in 2014.

The observations from 2021, unfortunately, do clearly indicate that EWM, covering 486 acres, is a well-established component of the Lake Chelan ecosystem and has the potential to spread further.

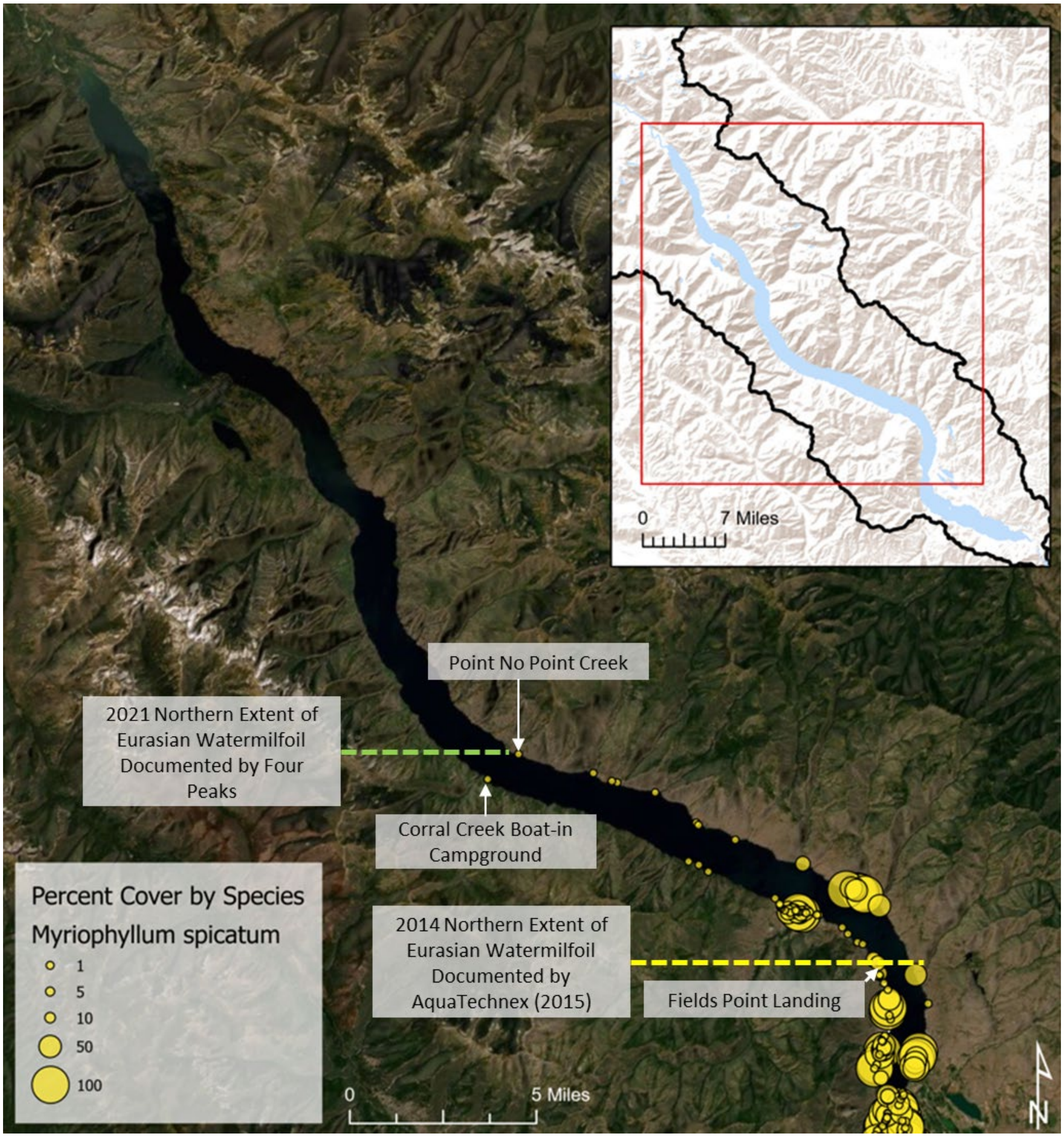


Figure 21. Qualitative comparison of the northern extent of Eurasian watermilfoil as documented by AquaTechnex (2015) and Four Peaks (2022). Note: The 2014 northern extent of Eurasian watermilfoil was approximated from maps contained within the AquaTechnex (2015) report.

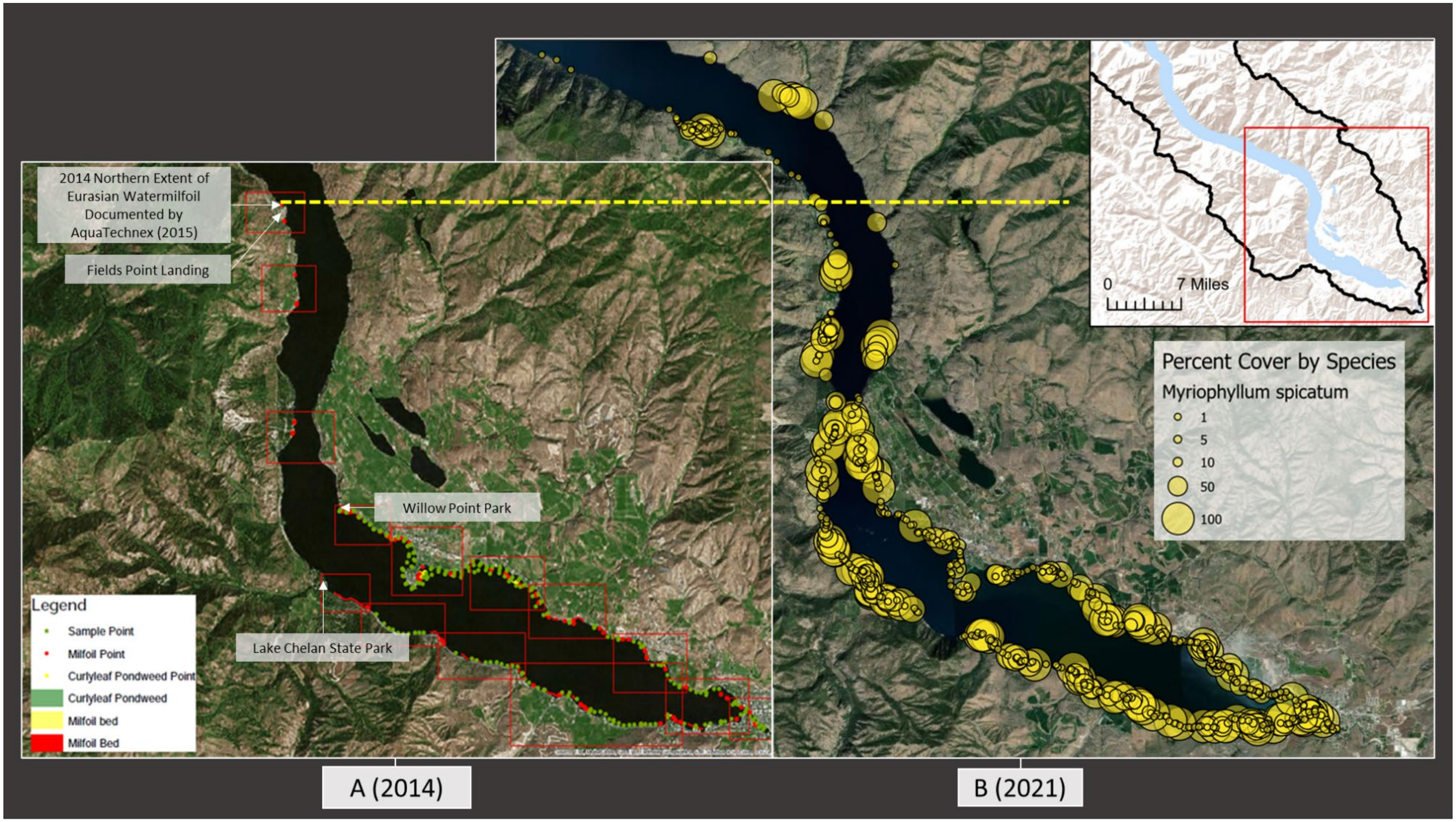


Figure 22. Qualitative comparison of Eurasian watermilfoil distribution observed in 2014 (Panel "A") and 2021 (Panel "B"). Notes: Panel A was excerpted from AquaTechnex (2015) and labeled to illustrate locations of relevant landmarks. Panel B reflects data collected in 2021 by Four Peaks

Other Species

While the results of this study provide an important update to the distribution and extent of EWM in Lake Chelan, the timing of the study was not ideal for CLPW. Although CLPW was documented during the study, sampling earlier in the summer, prior to CLPW senescence, is recommended to create a robust distributional baseline for this species. The opportunistic sampling of IFC also confirmed the continued presence of the species in Lake Chelan, but the significance of this species within the Lake Chelan ecosystem and its effect on water quality remain largely unknown. While outside the scope of this study, understanding the relationship between IFC and the creation of distinct microhabitats adjacent to IFC beds would shed light on the vulnerability of Lake Chelan to the establishment of other invasive bivalves (e.g., ESA and Tetra Tech 2020).

Future Applications

This study provided a rapid, lake-wide study designed to detect, map, and characterize where EWM occurred and provides a template for improving the CLPW distributional baseline. This study used similar methods as the AquaTechnex (2015) mapping effort, but differed in several ways:

- This study occurred earlier in the growing season for EWM.
- Cover was estimated using rake throws and camera-based methods.
- Depths and substrates were characterized at each invasion point.
- Both photo and geospatial documentation are presented in this study from which additional geospatial analyses can be undertaken.

While this study builds substantially on previous work, the sheer spatial scale of Lake Chelan provides a daunting task for any biological survey. This study was undertaken comprehensively and systematically; however, there are potential invasion areas that may not be reflected in the data. Future studies could be designed to detect invasive species presence or absence at repeated locations and could include aquatic eDNA methods with water grab samples, trolling with sonar-based sensors that detect depth and macrophyte canopy rapidly, providing full maps of the lake bed. Both of these methods have time, accuracy, and cost trade-offs with this study, but may be more easily built into long-term monitoring in the future. That is, repeat measures mapping of invaded and uninvaded patches could occur at key areas alongside parallel eDNA water sampling. Future monitoring data could also be obtained from citizen science-based collection efforts at marinas and public boat launches. These facilities may be hotspots for invasion, and an easy-to-implement rapid eDNA protocol or dock-based visual survey would augment the results from this study.

Study findings indicate that depth relative to lake stage is an important attribute that corresponds to invasive species presence. Given that high-resolution bathymetric data for Lake Chelan do not exist, it is difficult to quantitatively predict the spatial extent of likely invasion areas based on lake depth or lake bottom elevation. The application of remote sensing technology such as green wavelength light detection and ranging (LiDAR) could be used to build a high-resolution bathymetric data baseline. The collection of additional bathymetric data would significantly improve the ability to model and predict areas of likely future invasion. High-resolution bathymetry would thus contribute to subsequent documentation of how invasion extents are changing over time. These data would also inform diver-assisted harvesting (DASH) control, herbicide, or other control efforts. Regardless of the method used to collect additional high-resolution bathymetric data, obtaining such data is crucial to future AIS surveys and should be prioritized for future funding.

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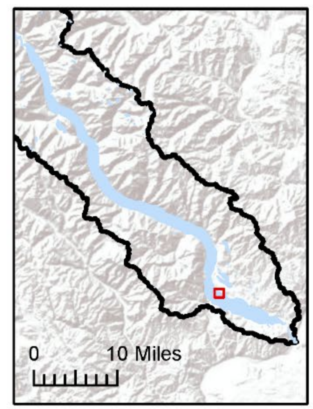
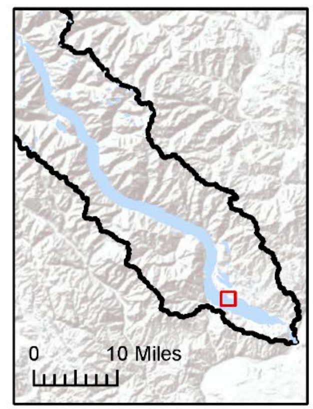
APPENDIX A Map Atlas of Invasive Species Points and Patches



FOUR PEAKS ENVIRONMENTAL
Science & Data Solutions



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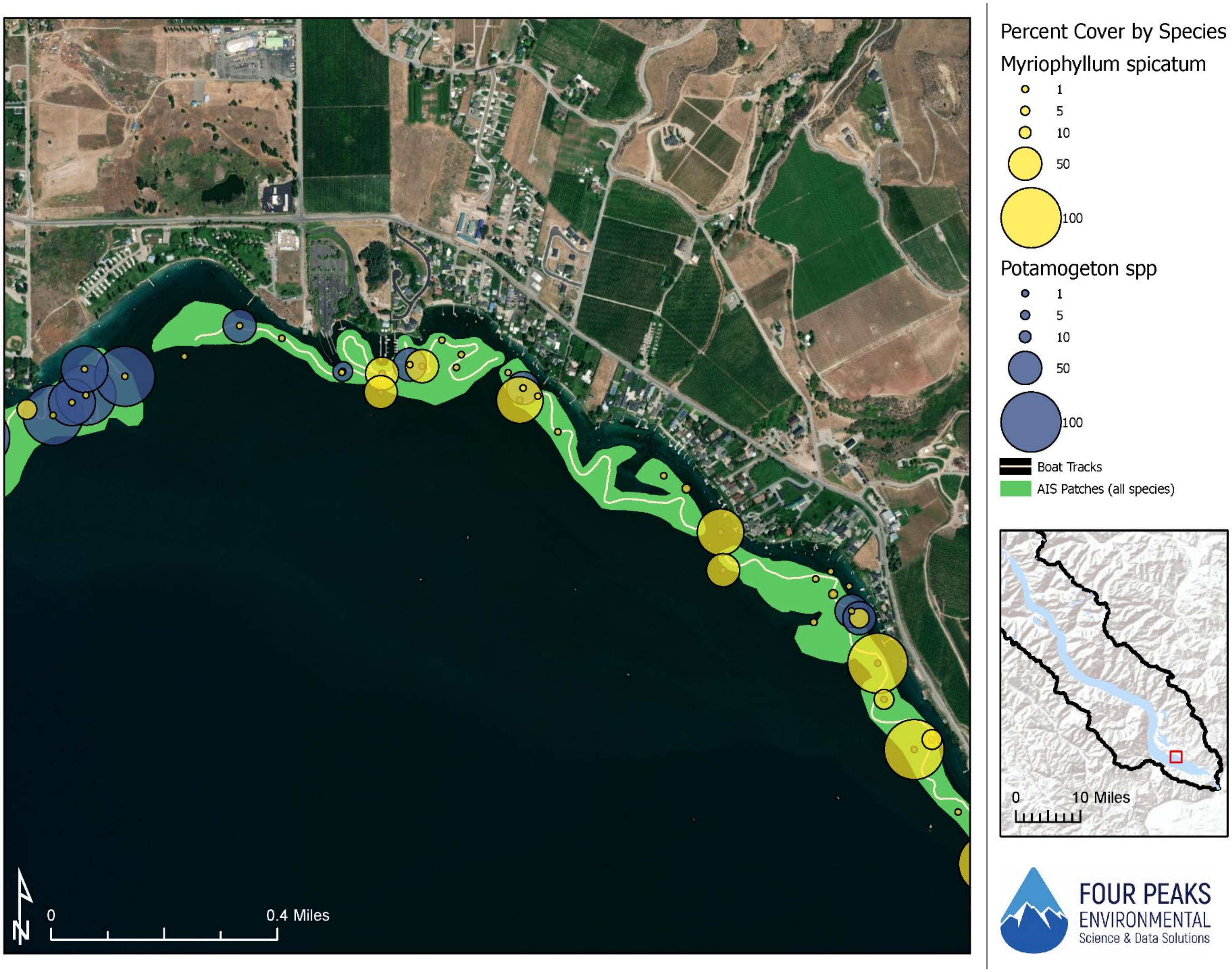
Science & Data Solutions


0
0.4 Miles
Percent Cover by Species
Myriophyllum spicatum
1
5
10
50
100
Potamogeton spp
1
5
10
50
100
Boat Tracks
AIS Patches (all species)
0
10 Miles
FOUR PEAKS
ENVIRONMENTAL
Science & Data Solutions

Percent Cover by Species

Myriophyllum spicatum

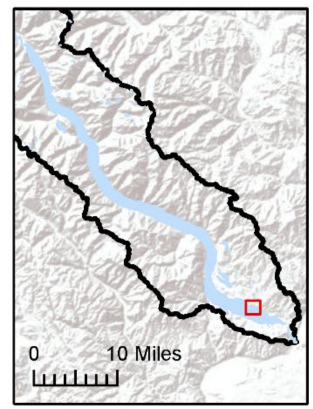
- 1
- 5
- 10
- 50
- 100

Potamogeton spp

- 1
- 5
- 10
- 50
- 100

Boat Tracks

AIS Patches (all species)



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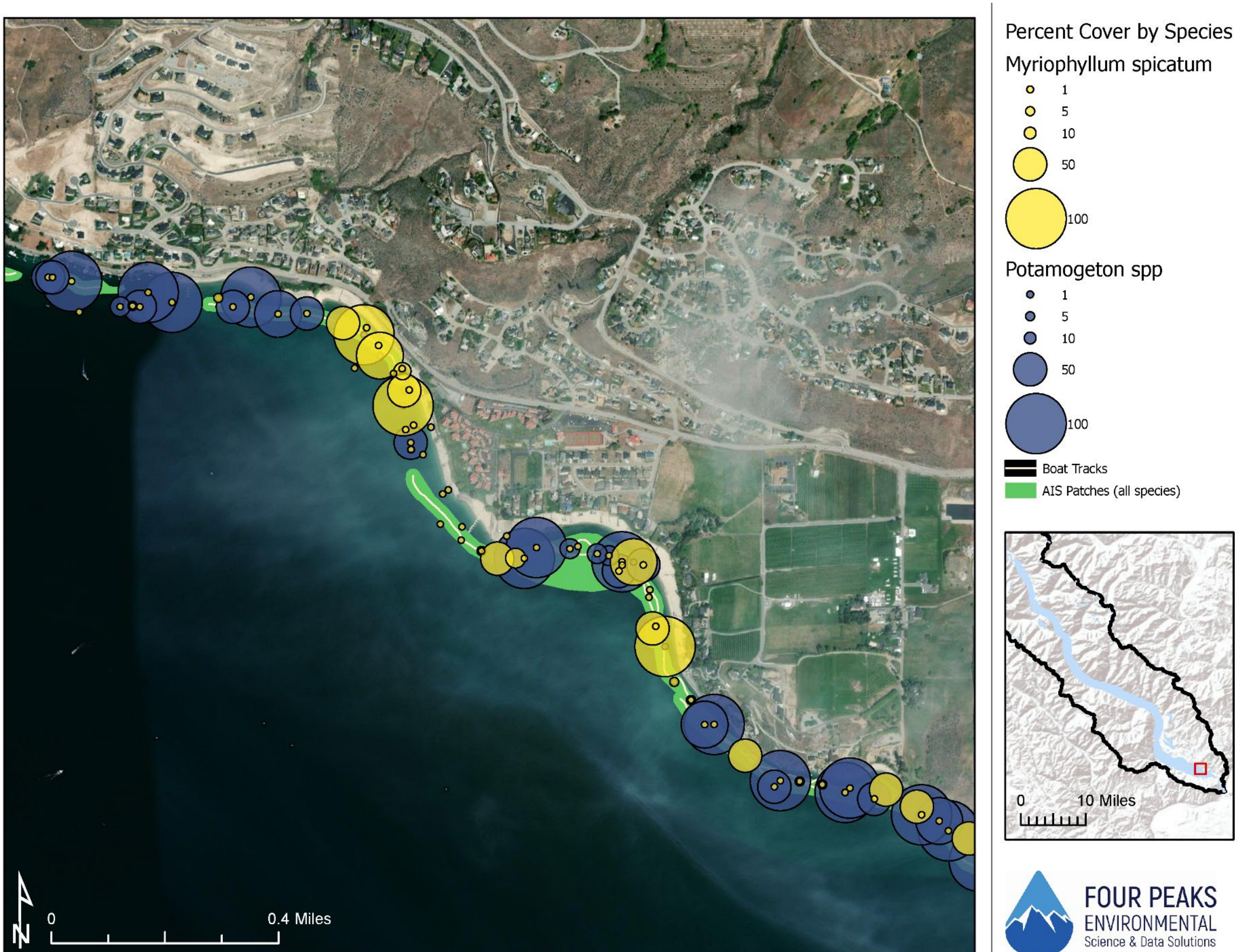

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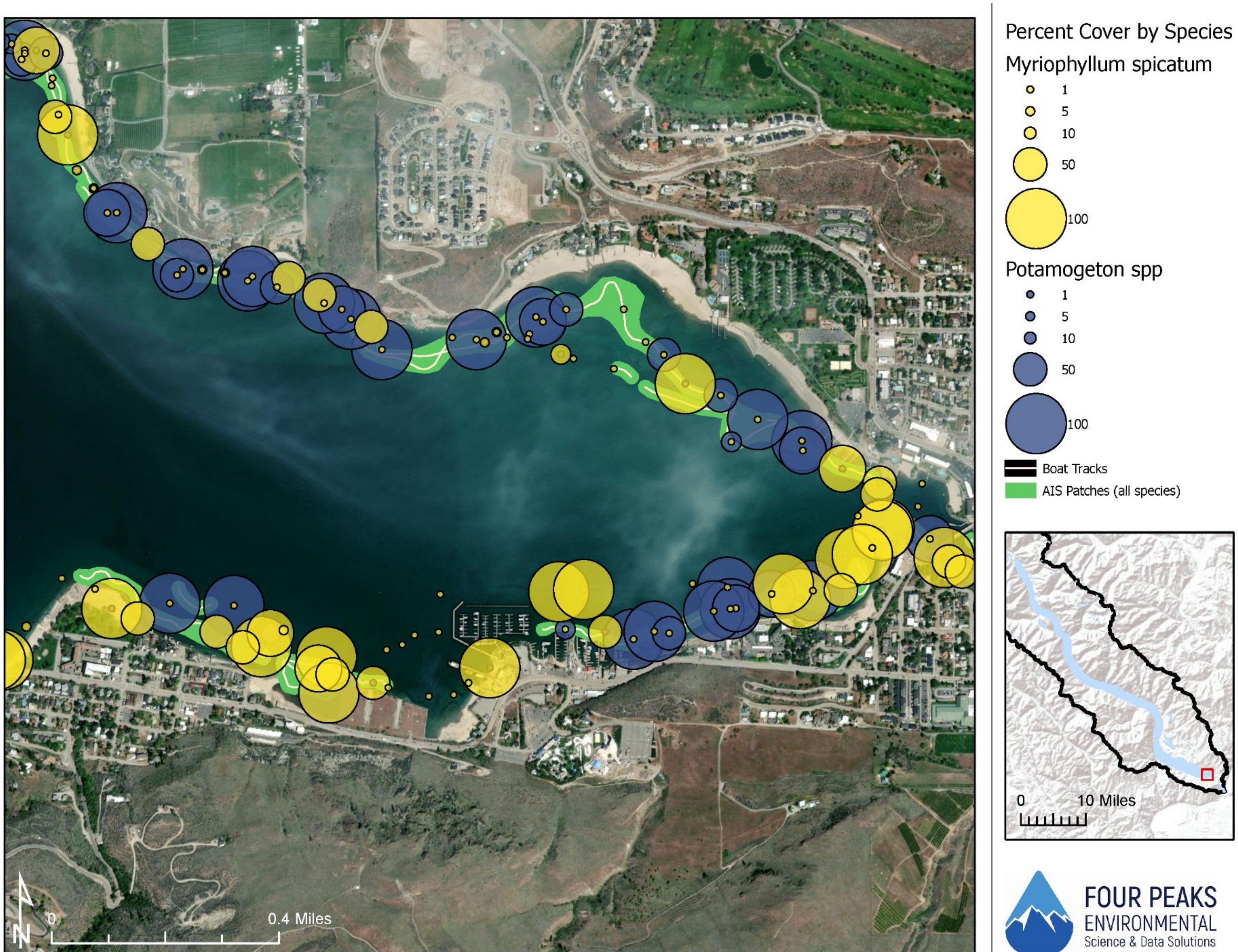

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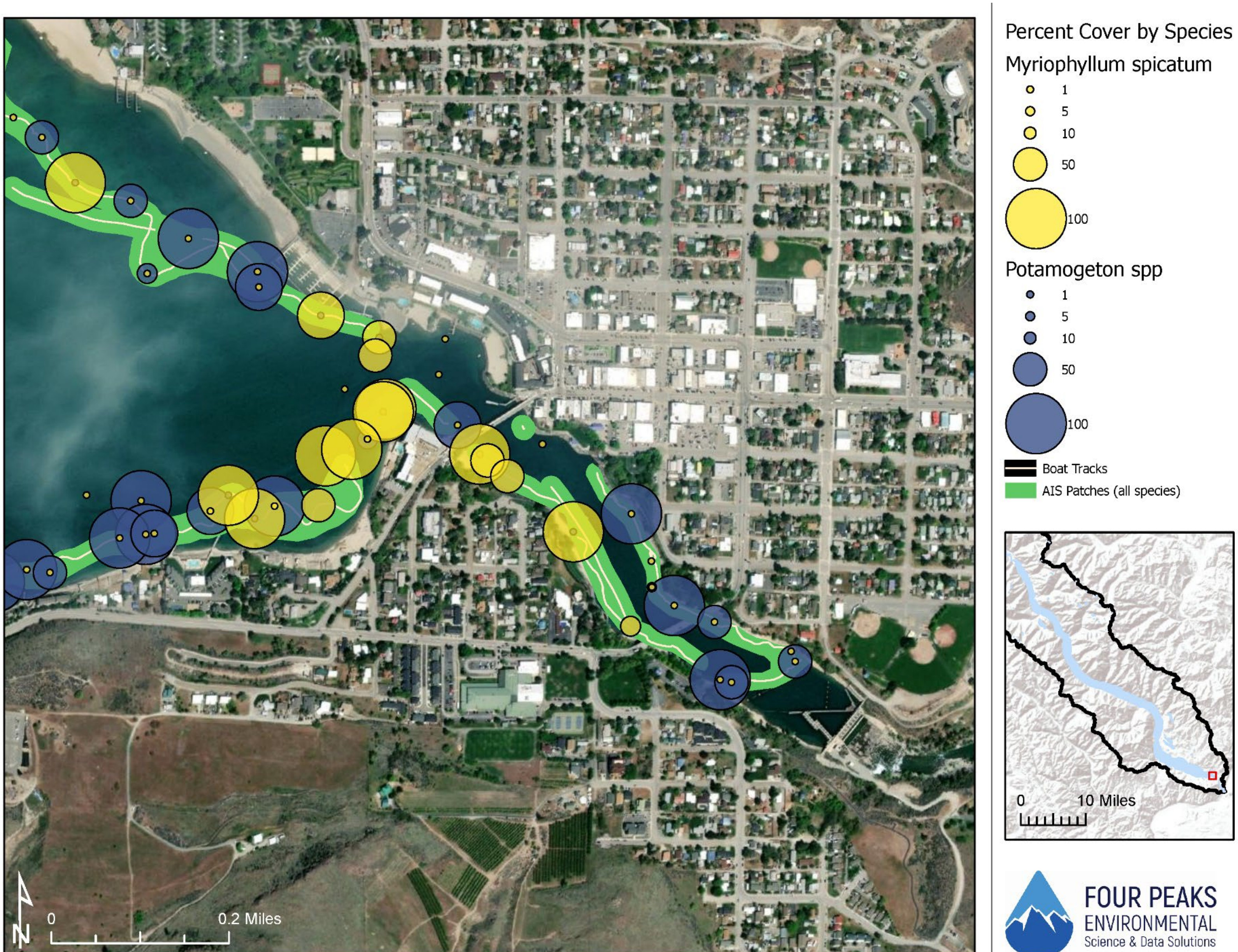

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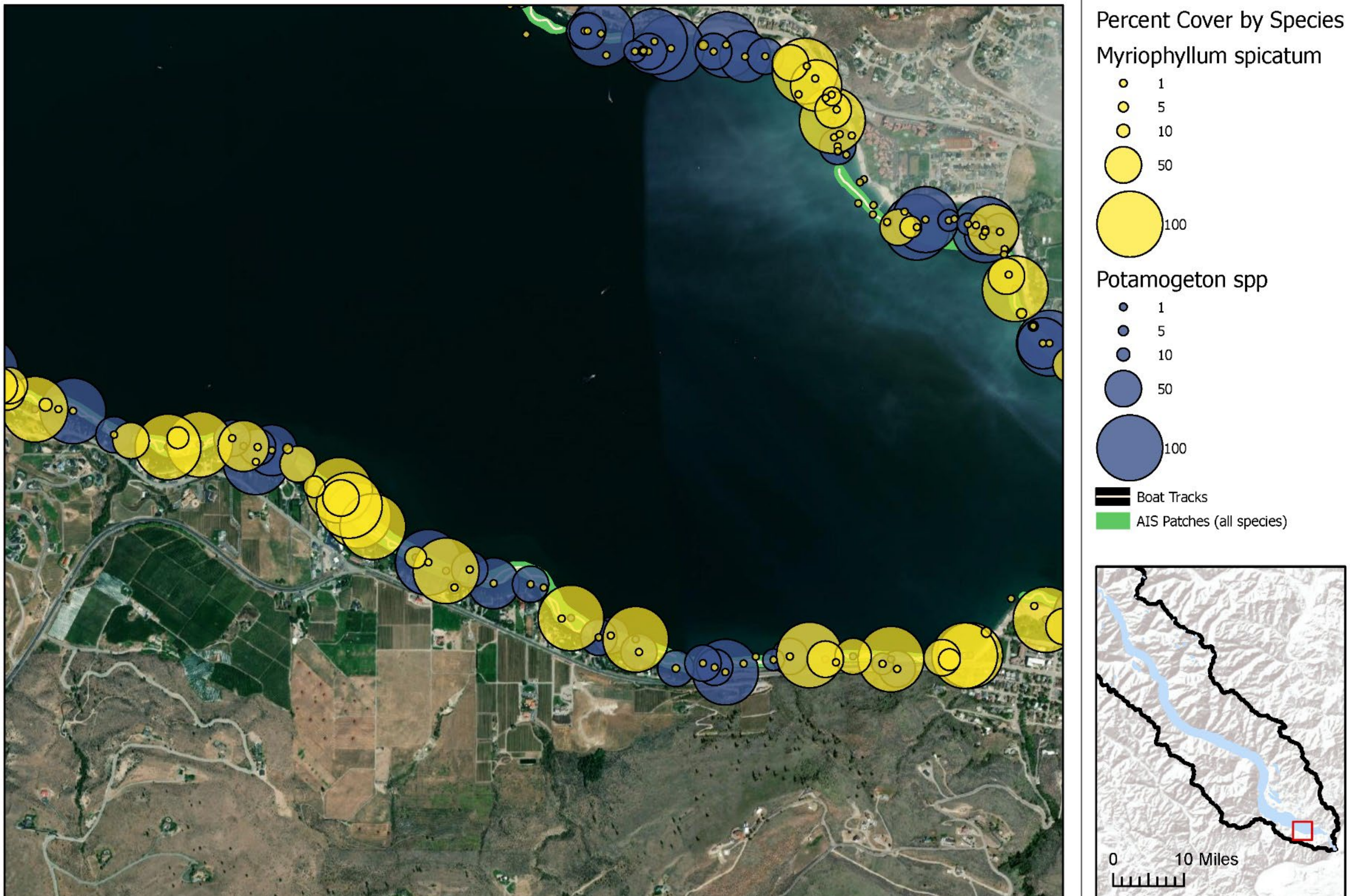
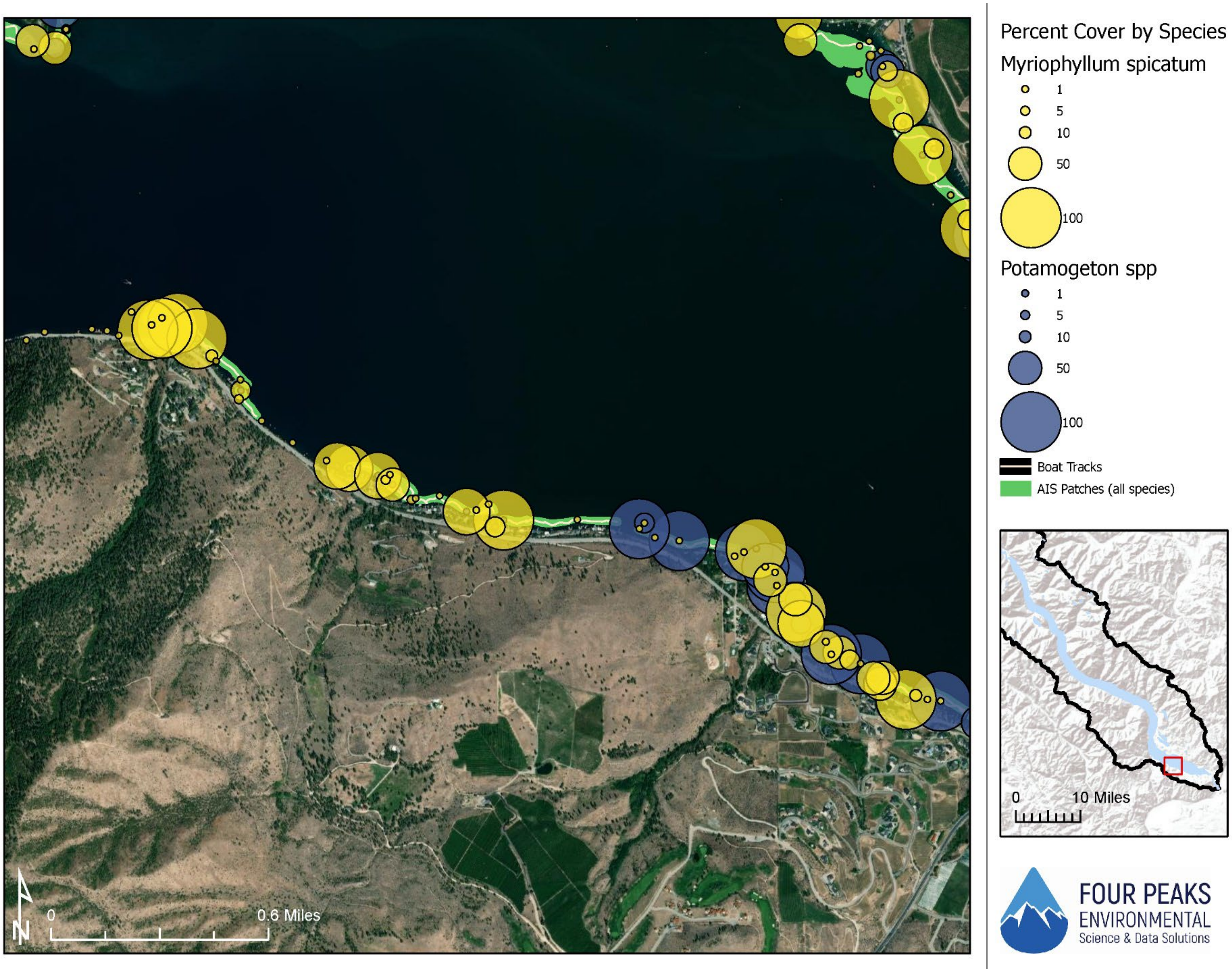
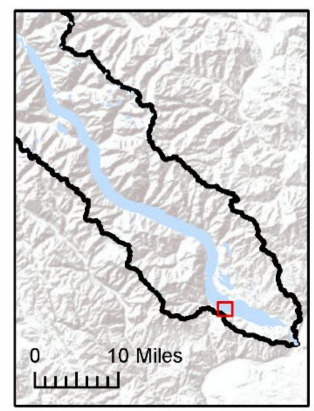
Science & Data Solutions


0
0.6 Miles
N
Percent Cover by Species
Myriophyllum spicatum
1
5
10
50
100
Potamogeton spp
1
5
10
50
100
Boat Tracks
AIS Patches (all species)
0
10 Miles


0
0.6 Miles
N
Percent Cover by Species
Myriophyllum spicatum
1
5
10
50
100
Potamogeton spp
1
5
10
50
100
Boat Tracks
AIS Patches (all species)
0
10 Miles
FOUR PEAKS
ENVIRONMENTAL
Science & Data Solutions



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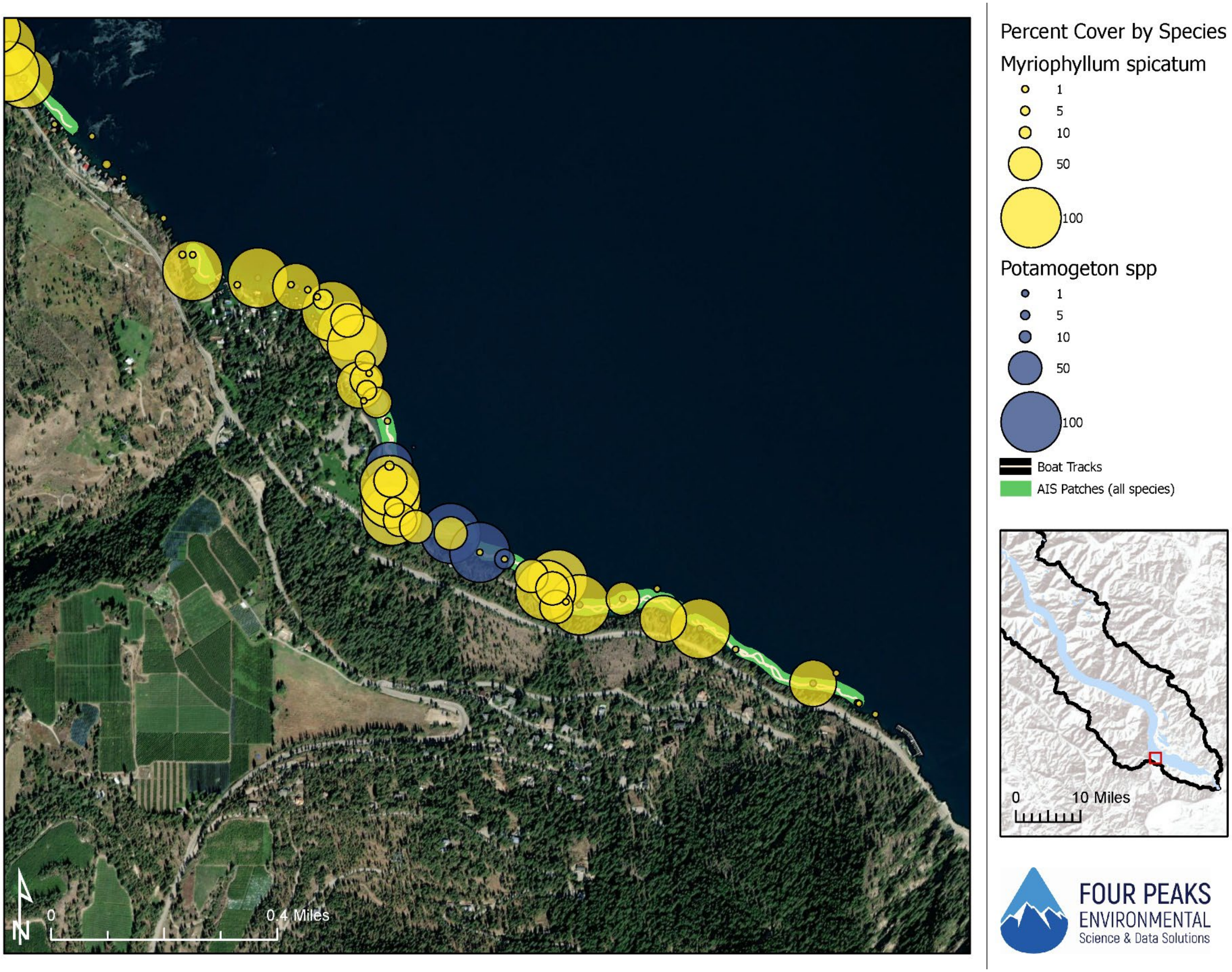
Science & Data Solutions



FOUR PEAKS ENVIRONMENTAL
Science & Data Solutions

Percent Cover by Species

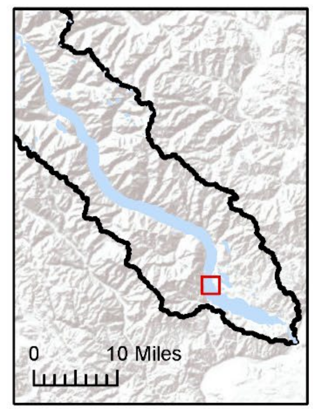
Myriophyllum spicatum

1
5
10
50
100

Potamogeton spp

1
5
10
50
100

Boat Tracks
AIS Patches (all species)



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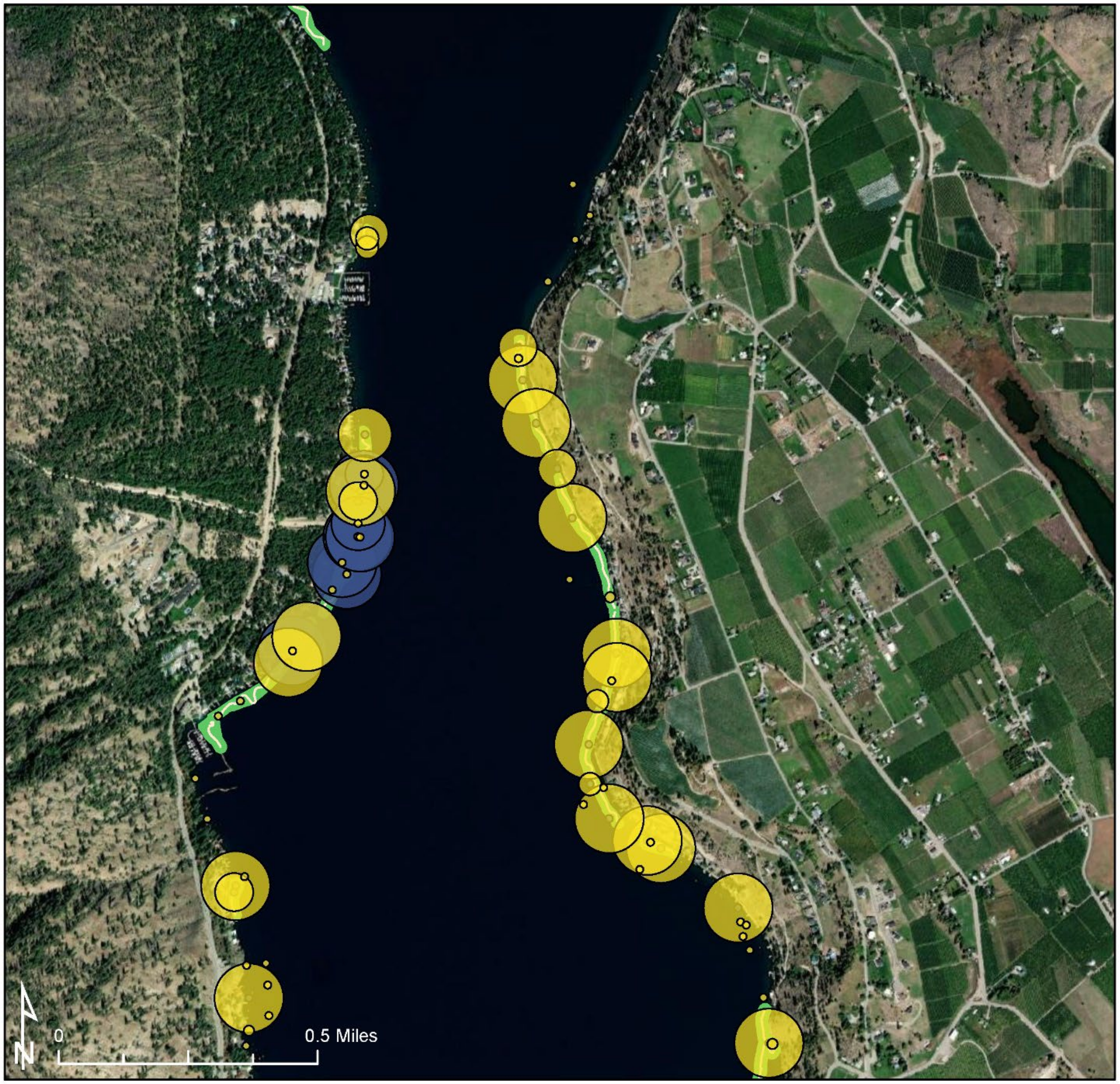


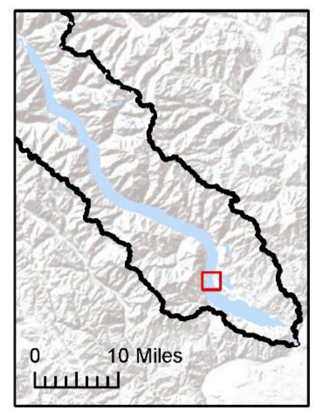
Percent Cover by Species

Myriophyllum spicatum
- 1
- 5
- 10
- 50
- 100

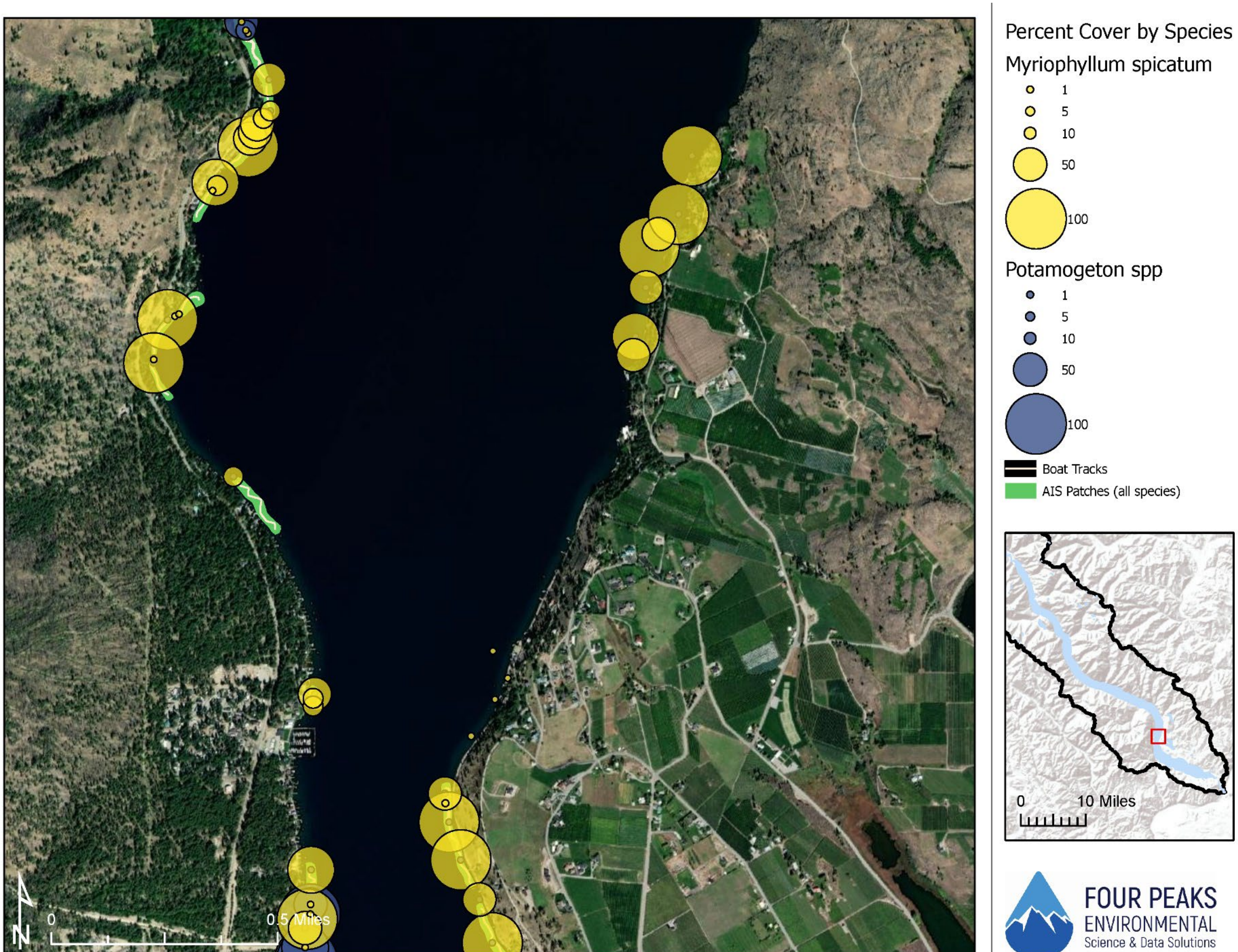
Potamogeton spp
- 1
- 5
- 10
- 50
- 100

Boat Tracks

AIS Patches (all species)



FOUR PEAKS ENVIRONMENTAL
Science & Data Solutions


0
0.5 Miles
N
Percent Cover by Species
Myriophyllum spicatum
1
5
10
50
100
Potamogeton spp
1
5
10
50
100
Boat Tracks
AIS Patches (all species)
0
10 Miles

Percent Cover by Species

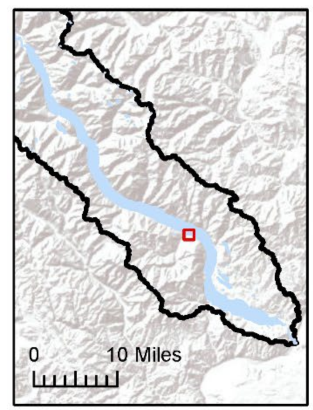
Myriophyllum spicatum

1
5
10
50
100

Potamogeton spp

1
5
10
50
100

Boat Tracks
AIS Patches (all species)



FOUR PEAKS ENVIRONMENTAL
Science & Data Solutions

APPENDIX B Data Links and Metadata for Survey-Generated Geospatial Data (click here, or copy and paste the link below)

https://drive.google.com/drive/folders/1ueVJ98rj3-wabJbABqYrUmPyDpS_E9d2?usp=sharing

APPENDIX C Survey Photos

Table C.1. Key to albums of field surveys.

Location	Dates	Link to Photographs
Lucerne Basin	8/31	LCRI AIS 31AUG2021
Lucerne Basin	9/1	LCRI AIS 1SEP2021
Lucerne Basin	9/2	LCRI AIS 2SEP2021
Wapato Basin	9/3	LCRI AIS 3SEP2021
Wapato Basin	9/7	LCRI AIS 7SEP2021
Wapato Basin	9/8	LCRI AIS 8SEP2021
Wapato Basin	9/9	LCRI AIS 9SEP2021
Wapato Basin	9/13	LCRI AIS 13SEP2021
Wapato Basin	9/14	LCRI AIS 14SEP2021
Wapato Basin – Asian Clam	9/27	LCRI AIS 27SEP2021

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APPENDIX D Water Quality Data Associated with Presence or Absence of an Invasive Freshwater Clam Bed

		Calcium, Dissolved	Chloride	Fluoride	Magnesium, Dissolved	Potassium, Dissolved	SiO2, Dissolved	Sodium, Dissolved	Sulfate	Total Kjeldahl Nitrogen	Total Organic Carbon	Ortho-phosphorus as P	Nitrate + Nitrite as N
Units		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Clam Bed	Sample 1	6.6	0.5	<0.10	0.9	0.7	4.9	1.3	3.6	0.2	1.04	0.003	0.01
	Sample 2	6.7	<0.5	<0.10	0.9	0.6	5	1.3	3.7	0.06	0.94	<0.003	0.02
	Sample 3	6.8	0.5	<0.10	0.9	0.7	4.9	1.3	3.7	0.12	1.02	<0.003	0.01
	Sample 4	6.6	<0.5	<0.10	0.9	0.7	4.8	1.3	3.6	0.025	0.924	<0.003	0.01
	Sample 5	6.7	<0.5	<0.10	0.9	0.6	4.9	1.3	3.6	0.025	0.942	<0.003	0.01
	Average	6.68	< 5.0	<0.10	0.9	0.7	4.9	1.3	3.6	0.09	0.97	<0.003	0.01
Ambient	Sample 1	6.7	0.5	<0.10	0.9	0.6	4.9	1.3	3.7	0.27	1.76	<0.003	0.01
	Sample 2	6.8	0.5	<0.10	0.9	0.7	4.9	1.3	3.7	0.13	1.25	<0.003	0.01
	Sample 3	6.8	0.5	<0.10	0.9	0.6	4.9	1.4	3.7	0.1	1.03	<0.003	0.02
	Sample 4	6.8	<0.5	<0.10	0.9	0.7	4.9	1.4	3.7	0.05	0.971	<0.003	0.02
	Sample 5	6.7	0.5	<0.10	0.9	0.7	5	1.4	3.7	0.2	0.93	<0.003	0.02
	Average	6.76	<0.5	<0.10	0.9	0.7	4.9	1.36	3.7	0.15	1.19	<0.003	0.02