Development of a Continuous Aquatic Plant Tracking and Imaging Network to Monitor Surface Water Bodies in Connecticut

Title:	Development of a Continuous Aquatic Plant Tracking and Imaging Network to Monitor Surface Water Bodies in Connecticut
Project Number:	
Start Date:	9/1/2023
End Date:	8/30/2024
Funding Source:	104B
Congressional District:	
Research Category:	Research
Focus Category:	INVASIVE SPECIES, MANAGEMENT AND PLANNING, SURFACE WATER, METHODS MODELS
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Summary

Hydrilla (*Hydrilla verticillata*) is recognized as one of the most problematic invasive aquatic plants in Connecticut's freshwater ecosystems. Tracking hydrilla activity through repeated observations at regular intervals is difficult due to the significant costs and logistical challenges associated with conventional survey methods. Our goal was to develop a monitoring framework (Continuous Aquatic Plant Tracking and Imaging Network (CAPTAIN)) that combines satellite imagery and machine learning to track hydrilla activity in the Connecticut River. A Sentinel-2 satellite imagery based machine learning model was developed to detect northern hydrilla in the Connecticut River. Large infestations of northern hydrilla were successfully classified by the model. The majority of the errors are found in over-predicting northern hydrilla. The model suggests there is northern hydrilla more frequently than found by Agricultural Experiment Station in the field, especially in the main stem where flow is too high and the water is too deep for northern hydrilla to grow. Overall, the study finding suggest that the importance of machine learning models combined with moderate resolution satellite imagery to detect and track hydrilla activity without compromising spatial extent. Further research is needed to optimize machine learning models based on field observations and additional training samples.

Introduction

Over the last few decades, IAPs have caused considerable decline in native aquatic plant populations throughout New England (Les et al. 1997, 1999; Caper et al. 2005; Capers et al 2007; Caper et al. 2009). The state of Connecticut harbors a rich freshwater system – a mosaic of rivers, lakes, and ponds- that has been vulnerable to the invasion of non-native aquatic plants over last few decades. Long-term aquatic plants surveys conducted by the Connecticut Agricultural Experiment Station (CAES) Invasive Aquatic Plant Program (IAPP) over ~250 Connecticut lakes found that approximately 56% of the lakes and ponds contain invasive plant species that can cause rapid deterioration of aquatic ecosystems and recreation values (Bugbee and Stebbins 2021, CAES IAPP 2023). Among other invasive plants, hydrilla (*Hydrilla verticillata*), Eurasian watermilfoil (*Myriophyllum spicatum*), fanwort (*Cabomba caroliniana*), curlyleaf pond-weed (*Potamogeton crispus*), water chestnut (*Trapa natans*), and variable-leaf watermilfoil (*Myriophyllum heterophyllum*) have been recognized as high priority species that threaten Connecticut's freshwater bodies (CTDEEP 2005). In particular, the CASES IAPP highlighted the serious risk of hydrilla invasion in Connecticut River in specific and other freshwater bodies in the state at large. Surveys from the CAES IAPP found dense distribution of hydrilla in certain parts of the Connecticut River (Bugbee and Stebbins 2021; Bugbee and Stebbins 2021).

The Connecticut River hydrilla is genetically unique and far more robust than that found in elsewhere in the state. Genetic testing conducted by Tippery et al. (2020) found the Connecticut River hydrilla is not similar to any previously found in North America and is most closely related to strains in eastern Asia. Spread of hydrilla affects the health of the Connecticut River and its tributaries (Bugbee and Stebbins 2021). Hydrilla shades all other native aquatic plants, alters water chemistry, causes dramatic swings in dissolved oxygen levels, increases water temperatures, affects the diversity and abundance of fish populations, limits recreation, impedes navigation, and reduces property values (Bugbee and Stebbins 2021, CT RC&D 2021; CAES IAPP, 2023). Hydrilla also affects the food chain, because aquatic wildlife can die after consuming this invasive plant, which is associated with toxic epiphytic cyanobacteria (Breinlinger et al. 2021). In addition to damage to the Connecticut River and its tributaries, the spread of hydrilla to lakes and ponds by fragments on boat trailers or waterfowl is a grave concern (Bugbee and Stebbins 2021). In 2019 and 2020, the CAES surveyed the Connecticut River from the Long Island Sound to Agawam, MA, reporting 774 acres of hydrilla (Figure 1). Thick mats of hydrilla have inhibited access for boaters, anglers, and other recreationists on the Connecticut River. Marinas and municipalities have reported that they can no longer access boat slips and docks due to the severity of the hydrilla infestations, limiting business opportunity. Overall, hydrilla is a threat to the economic and environmental integrity of the Connecticut River valley (CT RC&D 2021).

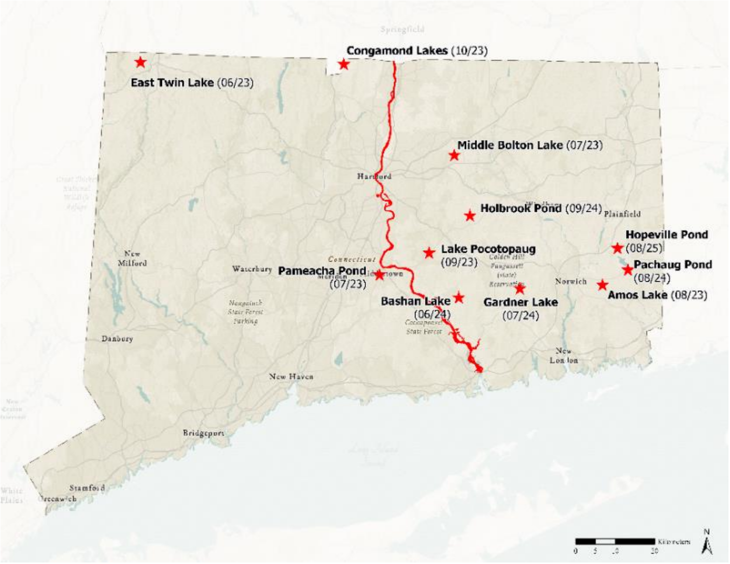


Figure 1 Waterbodies currently infested with northern hydrilla. The river highlighted in red is the Connecticut River. Each star represents a lake with the name in bold and the date of discovery

Managing hydrilla populations, even at small scales, is a very expensive undertaking. Average cost of applying herbicides to control hydrilla in Coventry Lake, CT exceeds $100,000 annually (Bugbee and Stebbins 2021). Early detection is the key to manage invasive aquatic plants including hydrilla because once established eradication is very difficult or impossible and management is expensive (Caper et al. 2005). Thus, continuous surveillance on both invasive and native aquatic vegetation is critical to assess invasion and facilitate adaptive management by measuring the efficacy of control efforts. In-situ measurements and field surveys (e.g., using boats) are time intense. For instance, the boat-based survey of IAP conducted by the CAES IAPP took nearly two years to complete the Connecticut River (G. Bugbee and S. Stebbins, Pers. Comm., Nov. 2022). It is difficult to collect repeated observations at regular intervals or on-demand (*when and where* needed) basis due to cost and deployment limitations associated with conventional survey methods. Researching on state-of-the-art drone and satellite remote sensing platforms will enable us cost-effective mechanisms to detect, monitor, and map IAP activity in near-real time fashion and to conduct predictive modelling of IAP distribution

without compromising spatial details and geographical extent. In this study, we seek to close existing knowledge and technological gaps pertaining to the adaptation of satellites and drone technology in Connecticut's aquatic plant monitoring and management applications

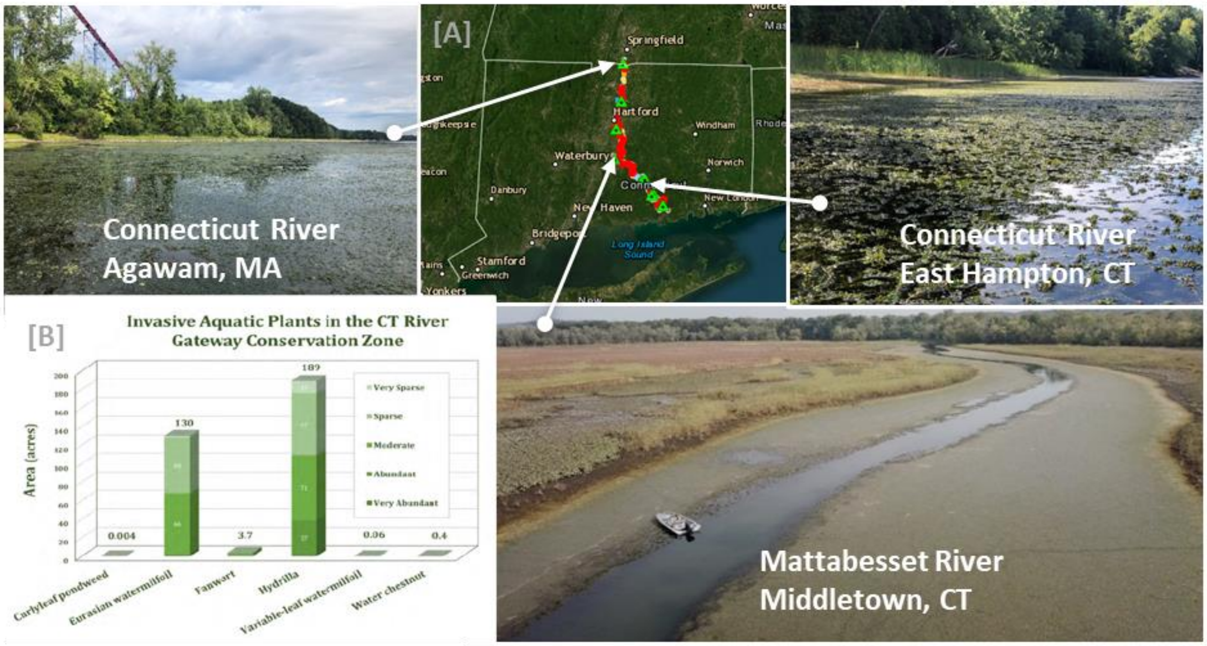


Figure 2. [A] Invasive plant survey along Connecticut River conducted by CASE IAPP in 2019-2020 [CASE IAPP online geospatial portal]. [B] Acreage of invasive aquatic plants in the Gateway Conservation Zone stacked by abundance levels (1-5) (Bugbee and Stebbins 2019). Example field photos from CAES IAPP survey shows heavy hydrilla invasion in Connecticut River and its tributaries (Photos: Bugbee and Stebbins, CAES IAPP)

Objective(s)

The central objective of this study was to investigate the utility of satellite remote sensing in conjunction with machine learning to monitor hydrilla activity in Connecticut River.

Approach, Results, Discussion

There is hydrilla and submerged aquatic vegetation (SAV) location data for the Connecticut portion of the Connecticut River that will be used to develop and test the models for this study.

In 1994, Barret et al (1997) performed an intensive SAV survey of the lower portion of the river, from Middletown/Portland, CT to Long Island Sound. They found no hydrilla, so this data will be used to test the false positive rate of the models. The Connecticut Agricultural Experiment Station Office of Aquatic Invasive Species (CAES OAIS) has performed survey work on the Connecticut River in 2019, 2020, and 2021, mapping over 400 ha of northern hydrilla throughout the system. This data will be used to both train and validate the models. Amos Lake in Preston, CT, Bashan Lake in East Haddam, CT, and Pachaug Pond in Griswold, CT are three lakes with recent infestations of northern hydrilla. CAES OAIS has survey data before and after infestation that will be used to test the model outside of the Connecticut River and with very small population sizes of northern hydrilla.

Modeling Framework

The northern hydrilla detection model is a three-step process: 1. Data Preparation, 2. Model Training and Validation 3. Accuracy assessment. For the training data, equally sized training polygons will be created using ArcGIS Pro for two classes: no_hydrilla, and hydrilla. The training data will be created using the 2019 survey of the lower Connecticut River by CAES OAIS. Using R statistical software, I will perform a time-series analysis from June 2019 – October 2019 of Sentinel-2 imagery calculating various vegetation indices. The values will be used in a Random Forest (RF) model to predict hydrilla occurrence. The accuracy assessment will be performed using CAES OAIS data from the CT River in 2020 and 2024 and the CAES OAIS data from Amos Lake, Bashan Lake, and Pachaug Pond.

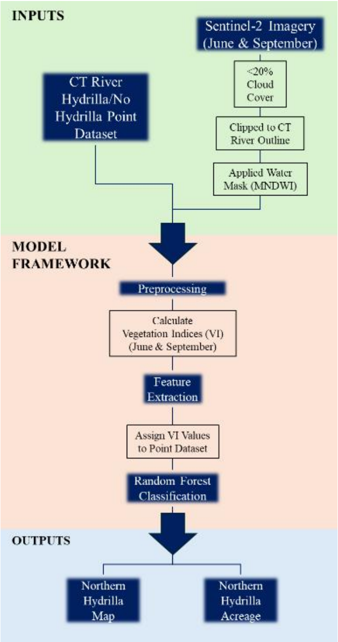


Figure 2 Model workflow for northern hydrilla detection

Random Forest Classification

The training data will be input into R to calculate various vegetation indices and spectral bands for Sentinel-2 imagery from June 2019 to October 2019 (Table 1) (Ade et al 2022, Wang et al 2025). Sentinel-2 images will be filtered to only images with 20% or less cloud coverage (Figure 3). The values will be exported into a table for analysis in R Studio. Using R Studio, an RF model will be created based on the training data with the vegetation indices and spectral bands. The RF model is an algorithm that builds classification tree models and selects the most frequent solution based on a subset of the training data. For this model, 70% of the training data will be used for training, 15% for validation, and 15% for testing. The model will be evaluated based on precision, accuracy, and recall results. The RF model will be used to classify Sentinel-2 imagery near the survey dates for CAES OAIS data to determine the model's ability to track changes in hydrilla over time and at small populations.

Table 1 Vegetation indices calculated in R on Sentinel-2 imagery

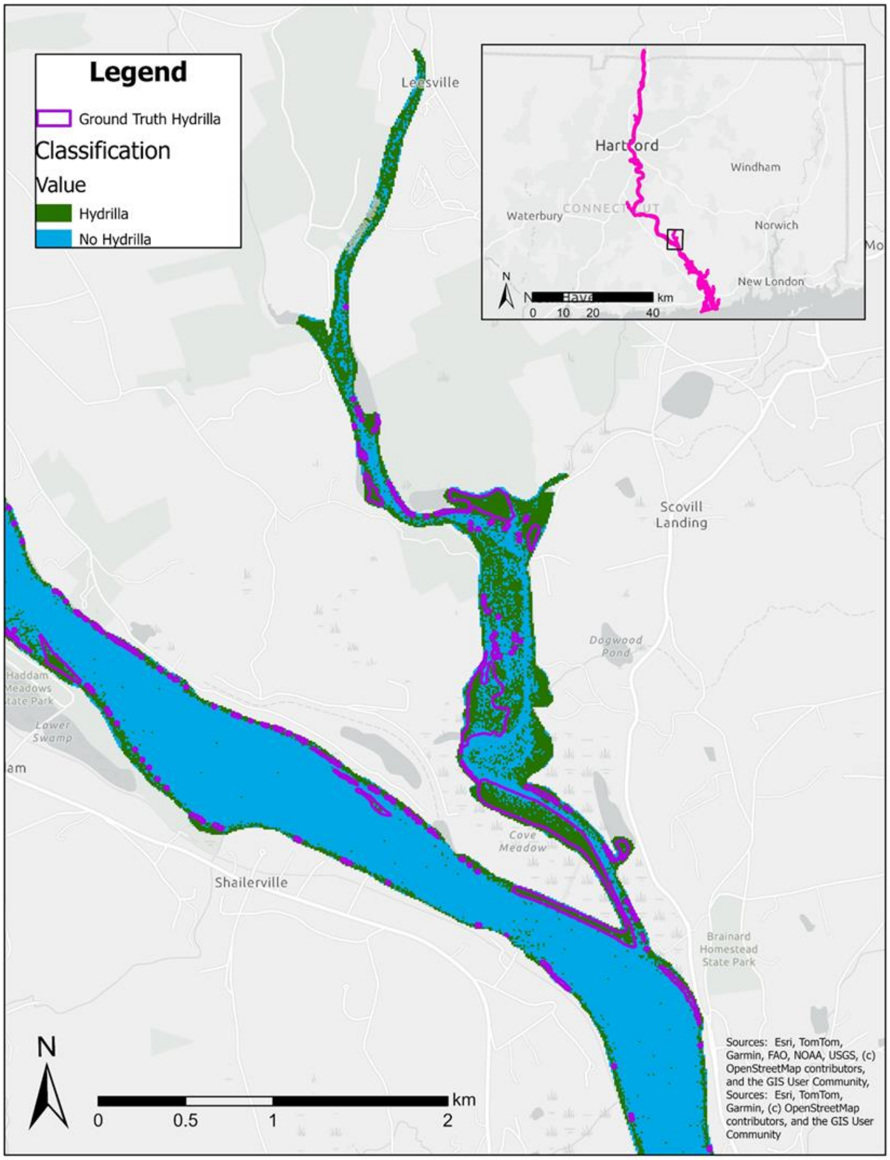
Index	Formula
NDVI	$\frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$
NDAVI	$\frac{\rho_{NIR} - \rho_{BLUE}}{\rho_{NIR} + \rho_{BLUE}}$
NDWI	$\frac{\rho_{GREEN} - \rho_{NIR}}{\rho_{GREEN} + \rho_{NIR}}$
NDMI	$\frac{\rho_{NIR} - \rho_{SwIR}}{\rho_{NIR} + \rho_{swIR}}$
MNDWI	$\frac{\rho_{GREEN} - \rho_{SwIR}}{\rho_{GREEN} + \rho_{SwIR}}$

Table 2 Accuracy assessment of the classification model.

Predicted/Actual	Hydrilla	No_Hydrilla	Error Rate
Hydrilla	649	163	0.2007 (163/812)
No_Hydrilla	166	792	0.1733 (166/958)
Totals	815	955	0.1859 (329/1770)

A Sentinel-2–based image classification model was developed to detect northern hydrilla in the Connecticut River, achieving an overall error rate of 18.6% (Table 2). Large infestations of northern hydrilla were successfully classified by the model (Figure 4). The majority of the errors are found in over-predicting northern hydrilla. The model suggests there is northern hydrilla more frequently than found by CAES OAIS in the field, especially in the main stem where flow is too high and the water is too deep for northern hydrilla to grow.

Next steps will focus on transitioning the model from R to Google Earth Engine to enable the incorporation of a larger temporal archive of Sentinel-2 imagery as well as incorporate spectroradiometer data from other experiments. The model successfully distinguished northern hydrilla presence from non-hydrilla areas, indicating strong potential for remote detection of this invasive species at a landscape scale.



Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, (c) OpenStreetMap contributors, and the GIS User Community, Sources: Esri, TomTom, Garmin, (c) OpenStreetMap contributors, and the GIS User Community

Figure 3 Map of the classified Sentinel-2 imagery from September 2019. Purple polygons are the locations of northern hydrilla mapped by CAES OAIS in 2019.

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