**Carolina Coastal Plain Ecological Forecasting**

*Utilizing NASA Earth Observations to Map Suitable Venus Flytrap Habitat in an Effort to Inform Conservation, Seed Banking, and Reintroduction in the Carolina Coastal Plain and Sandhills regions*

**Project Team**

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**Project Overview**

***Project Synopsis:***

Venus flytrap (*Dionaea muscipula*) is a plant species endemic to a small portion of North and South Carolina, and half of its populations have been lost since 1958. This project, in partnership with the North Carolina Botanical Garden (NCBG), the University of North Carolina at Chapel Hill Herbarium (NCU), and the North Carolina Natural Heritage Program (NCNHP), utilized Earth observations to create a predictive 2050 land-use change model and a current suitable habitat model for the Venus flytrap. Maps generated from these models will help partners identify areas of conflict between suitable habitat and development and help inform management of this iconic species.

***Abstract:***

Although the carnivorous plant Venus flytrap (*Dionaea muscipula*) is recognized globally, its native range is restricted to a small portion of the North and South Carolina Coastal Plain and Sandhills. Within this limited range, Venus flytrap populations are threatened by habitat loss, fire suppression, and poaching. NASA DEVELOP partnered with the North Carolina Botanical Garden (NCBG), the University of North Carolina Herbarium (NCU), and the North Carolina Natural Heritage Program (NCNHP) to support Venus flytrap conservation. The team developed models based on species presence data and environmental variables using the Software for Assisted Habitat Modeling (SAHM) to create a 2021 habitat suitability map for Venus flytrap. These models incorporated Earth observations collected by Landsat 8 Thermal Infrared Sensor (TIRS), Terra Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Land Observation Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR), and Sentinel-2 Multispectral Instrument (MSI). To predict areas at high risk of development, the team produced a 2050 land-use change map using TerrSet Land Change Modeler. The team found potential areas of conflict between predicted habitat and forecasted future development. Many areas of suitable habitat were concentrated along the coast where development was likely to occur, placing populations there at risk of extirpation. Overlaying suitable habitat with forecasted land change also identified suitable habitats with minimal risk of development, which may serve as lasting Venus flytrap habitat. These results can inform the NCBG and NCNHP’s conservation decision-making, including targeted seed banking, reintroduction, and prioritization of enduring habitats for protection and management.

***Key Terms:***

Habitat suitability modeling, Random Forest, MARS, MaxEnt, Generalized Linear Model, Boosted Regression Tree, Google Earth Engine, vulnerable species

***National Application Area Addressed:*** Ecological Forecasting

***Study Location:*** Carolina Sandhills and Coastal Plain of NC & SC

***Study Period:*** January 2021to December 2021, Forecasting to 2050

***Community Concerns:***

* According to plant researchers, two out of five of the world’s plant species are threatened with extinction. This potential loss in plant biodiversity could bring about unforeseen ecological impacts as well as lost potential medicinal, food, or energy crops.
* Protection of the vulnerable Venus flytrap is necessary due to its rarity and unique habitat requirements. Venus flytrap populations, currently distributed across only 23 counties of North and South Carolina, are at imminent risk of further range reduction due to fire suppression, habitat degradation, land development, hydrological changes, poaching, and climate change.
* As a key species in both the biodiverse wet pine savanna and Carolina Bay transition zone habitats, Venus flytrap has an impact on the survival of some associated species. For example, at least one insect species, the critically imperiled Venus flytrap cutworm (*Hemipachnobia subporphyrea*), which depends on the Venus flytrap as a food source for larvae, could be lost if Venus flytrap populations decreased.
* The extinction of the Venus flytrap species, the only terrestrial carnivorous plant with an active snap-trap and only species of its genus, would represent a tremendous loss to genetic diversity. Its absence could disrupt evolutionary processes and limit our understanding of evolutionary history.

***Project Objectives:***

* Model current habitat suitability for Venus flytrap to determine the extent of habitat for the species within and outside of its known range and inform seed banking and reintroduction efforts
* Identify areas of key lasting habitat for Venus flytrap by modeling areas that have a high probability of transitioning to developed lands by 2050
* Create an ArcGIS Online StoryMap as an outreach tool for project partners that educates the public about Venus flytrap protection and conservation and that communicates the project’s results

**Partner Overview**

***Partner Organizations:***

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| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **North Carolina Botanical Garden**  | Dr. Johny Randall, Director of Conservation Programs; Dr. Damon Waitt, Director | End User | No |
| **University of North Carolina Herbarium** | Dr. Alan Weakley, Director | Collaborator | No |
| **North Carolina Natural Heritage Program** | Misty Buchanan, Director | Collaborator | No |

***Decision-Making Practices & Policies:***

The project partner and end user, NCBG, is a botanical garden operated by the University of North Carolina at Chapel Hill. Its primary mission is to promote and display the native flora of North Carolina for research, education, and conservation. As such, the vulnerable Venus flytrap, endemic to North and South Carolina, is a focal species in their efforts. The NCBG leads a seed-banking project which involves collecting and preserving seeds from Venus flytrap populations for future reintroduction. Towards this effort, conservationists at NCBG search for unknown populations as well as areas where populations may be reintroduced and protected from habitat loss and degradation. To date, they have not incorporated remote sensing methods to locate potential habitat. The NCBG has also worked in partnership with the NCNHP, the U.S. Fish & Wildlife Service (USFWS), and other members of the Venus Flytrap Working Group in a recently completed three-year, range-wide survey of Venus flytrap populations across North and South Carolina. One goal of this collaborative survey was to aid in the USFWS’s conservation status assessment of Venus flytrap. Venus flytrap is protected from unauthorized harvesting at the state level by fines and felony charges in North Carolina and by fines in South Carolina. However, federal listing as endangered would provide greater protection for the species.

**Earth Observations & End Products Overview**

***Earth Observations:***

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| **Platform & Sensor** | **Parameters** | **Use** |
| **Landsat 8 TIRS** | Land surface temperature | Land surface temperature variables were used as inputs into Software for Assisted Habitat Modeling (SAHM). |
| **Terra MODIS** | Land Surface Temperature | Land surface temperature variables were used as inputs for SAHM. |
| **Sentinel-2 MSI** | NDVI, MSAVI2, NDWI, TB, TG, TW | Vegetation indices such as Normalized Differenced Vegetation Index (NDVI), Modified Soil Adjusted Vegetation Index 2 (MSAVI2),Normalized Differenced Water Index (NDWI), Tasseled Cap Brightness (TB), Tasseled Cap Greeness (TG), and Tasseled Cap Wetness (TW) were used as inputs for the SAHM habitat suitability model.  |
| **ALOS PALSAR** | Elevation, slope, TD, landform, mTPI, CHILI | Elevation, slope, Topographic Diversity (TD), landform, Multi-Scale Topographic Position Index (mTPI), and Continuous Heat Insolation Index (CHILI) used |

***Ancillary Datasets:***

* The Natural Heritage Program of the North Carolina Department of Natural and Cultural Resources– Venus flytrap presence and absence points to train the habitat suitability model in SAHM
* USDA Soil Survey Geographic Database – gSURRGO database for soil type, soil available water storage (25 cm, 50cm), flooding frequency, ponding frequency, drainage class, hydric class, soil moisture, and water table depth to use as environmental predictor variables in the SAHM model
* The United States Geological Survey (USGS) – LANDFIRE dataset for fire severity, historical fire regimes, and vegetative classes, to use as predictor variables in the SAHM model
* USGS National Land Cover Dataset - used as a variable in the SAHM model and to predict land use change in the TerrSet Land Change Modeler
* NASA Land-Cover/Land-Use Change Program – Landsat Vegetation Continuous Fields (VCF) as a variable to depict canopy cover in SAHM
* **International Soil Reference and Information Centre (World Soil Information) – used to obtain information on nitrogen, soil pH, soil texture, clay content, and sand content for variables in the SAHM model**
* Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) **–** precipitation variable in SAHM
* ArcGIS Online U.S. Golf Courses – Polygon layer used to determine distance to golf courses
* ArcGIS Online U.S. Census Populated Place Areas – identified populated areas according to the U.S. Census Bureau used to determine distance to major urban areas

***Modeling:***

* Land Change Modeler, Idrisi TerrSet (POC: Sean McCartney, SSAI, NASA Goddard Space Flight Center) –landcover change modeling within TerrSet 2020 to inform areas at risk of development in the future
* Software for Assisted Habitat Modeling (SAHM)(POC: Peder Engelsted, Colorado State University) – habitat suitability modeling software
* Random Forest (RF) (POC: Dr. Anthony Vorster, Colorado State University) – used for habitat suitability modeling within SAHM
* MaxEnt (POC: Peder Engelsted, Colorado State University) – used for habitat suitability modeling within SAHM
* Multivariate Adaptive Regression Spline (MARS) (POC: Peder Engelsted, Colorado State University) – used for habitat suitability modeling within SAHM
* Boosted Regression Tree (BRT) (POC: Peder Engelsted, Colorado State University) – used for habitat suitability modeling within SAHM
* Generalized Linear Model (GLM) (POC: Dr. Catherine Jarnevich, USGS Fort Collins Science Center) – use during habitat suitability modeling process in SAHM

***Software & Scripting:***

* Esri ArcGIS Pro version 2.8.2 – Image processing and final map generation
* Google Earth Engine Application Programming Interface (API) version 0.1.263 – Access to remotely sensed imagery and raster datasets, large-scale image analysis, and generation of modeling predictor variables
* RStudio version 1.4.1106 – Statistical analyses and data visualization
* SAHM version 2.0.1 – Habitat suitability model builder
* TerrSet 2020 – Maintains Land Change Modeler, which generated the land transition potential map

***End Products:***

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| **End Product** | **Earth Observations Used**  | **Partner Benefit & Use** | **Software Release Category** |
| **Current Venus Flytrap Habitat Suitability Map**  | Landsat 8 OLI, Terra MODIS, Sentinel-2 MSI, ALOS PALSAR | Project partners can use this model to understand the range of Venus flytrap in North and South Carolina. This can also inform their conservation efforts, including Venus flytrap seed banking and potential reintroduction efforts.  | N/A |
| **Future Transition Potential Land Cover Map for The Year 2050** | Landsat (National Land Cover Database, Landsat-based landcover database) | This map will identify which suitable habitat locations are most likely to be affected by anthropogenic development, which can help identify long-lasting suitable habitat for seed banking efforts and inform decision-making on conflict areas.  | N/A |
| **ArcGIS StoryMap**  | Landsat 8 TIRS, Terra MODIS, Sentinel-2 MSI, ALOS PALSAR | This interactive online story underlines the importance of the Venus flytrap and ecosystems in the Carolina Coastal Plain and Sandhills regions. The StoryMap will support project partners in their public outreach and education efforts to further Venus flytrap conservation. | N/A |

***Product Benefit to End User:***

This project’s partner organizations have not previously incorporated satellite imagery into their Venus flytrap conservation practices. The NASA DEVELOP team has created a habitat suitability map that identifies areas of predicted high suitability for supporting Venus flytrap populations. This map can guide the NCBG to conduct surveys for undiscovered Venus flytrap populations, particularly smaller populations on private lands that are harder to identify if there is no prior record of collection. The NCBG can use the 2021 habitat suitability model along with the 2050 transition potential map to identify areas with lasting habitat and areas of potential conflict. Partners can focus their seed banking and potential reintroduction efforts in areas of suitable habitat with little threat of development and prioritize the protection of areas that have large Venus flytrap populations but also high potential for development. The NASA DEVELOP team produced an ArcGIS StoryMAP as an outreach tool, which the project partners can use to educate the public about the Venus flytrap and highlight this project and its role informing partner efforts. This public-facing product will support the NCBG’s mission to inform and encourage public engagement to advance the protection and conservation of their native plants and natural communities.

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