**Maine Ecological Forecasting III**

*Utilizing Earth Observations to Monitor Federally Endangered Atlantic Salmon (Salmon Salar) Habitat in Maine: An Interactive Workshop*

**Project Team**

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**Project Overview**

***Project Synopsis:***

Atlantic salmon (*Salmo salar*) have become increasingly vulnerable to population decline from rapid changes in climate and landscape. The Maine Department of Marine Resources (DMR) and the Downeast Salmon Federation (DSF) work to conserve this Federally Endangered species and restore their habitat. This term’s NASA DEVELOP team conducted a workshop for these partner organizations on leveraging Earth observations in their work to prevent salmon extirpation. The workshop provided key insights into land change that may require intervention to mitigate salmon impacts from temperature and precipitation change.

***Abstract:***

Shifting patterns in land use and land cover (LULC), temperature, and precipitation have exacerbated a rapid decline in Federally Endangered wild Atlantic salmon (*Salmo salar*) populations. The team at NASA DEVELOP partnered with the Maine Department of Marine Resources (DMR) and the Downeast Salmon Federation (DSF) to create a comprehensive workshop designed to demonstrate the applicability of Earth observations in examining these threats using the Penobscot, Union, and Machias Rivers as case studies. This entailed curating tutorials for acquiring and analyzing satellite data using Google Earth Engine, EarthExplorer, and Earthdata. The team demonstrated how to classify LULC in ArcGIS Pro from 1985 until 2021 using Landsat 5 Thematic Mapper (TM), Landsat 8 Operation Land Imager (OLI), Sentinel-2 MultiSpectral Instrument (MSI), and datasets from the United Stated Geological Survey (USGS) National Land Cover Database (NLCD), showing an overall transition from coniferous forests to other LULC classes. The team also demonstrated how to use historical data from Terra Moderate Resolution Imaging Spectroradiometer (MODIS) and Integrated Multi-satellite Retrievals for Global Precipitation Measurement (GPM IMERG) to generate 2021 land surface temperature (LST) and precipitation maps, respectively, showing that Maine was abnormally dry during the summer in an increasingly warm region. These workshop materials will aid the partners in integrating NASA Earth observations into their future salmon habitat restoration initiatives.

***Key Terms:***

MODIS, Landsat, LULC, precipitation, land surface temperature, critical salmon habitat, data communication, environmental change

***National Application Areas Addressed:*** Ecological Forecasting

***Study Location:*** ME

***Study Period:*** 1985 – 2021, Forecasting to 2040

***Community Concerns:***

* Habitats for freshwater Atlantic salmon are threatened by land use land cover (LULC) changes including urban development, timber harvesting, dam construction, and historical succession patterns that influence stream quality, thermal refugia, and habitat connectivity throughout watersheds in Maine. This has resulted in the Gulf of Maine Distinct Population Segment (DPS) of Atlantic salmon becoming the last remaining wild population in the United States.
* Changes in air and stream temperatures, precipitation patterns, and forest cover within riparian areas directly affect water quality and nutrient availability which can further constrain the current geographic range of Atlantic salmon.
* Communities throughout Maine, including Indigenous peoples, have historically benefited from Atlantic salmon as a natural resource. Declining populations limit benefits to local communities.
* Experts working in the field are concerned that the public does not understand the extent of salmon extirpation and population decline. Lack of awareness and public support reduces the viability of habitat restoration and salmon population recovery.

***Project Objectives***

* Enhance partners’ Endangered Atlantic salmon (*Salmo salar*) recovery initiatives by providing case studies that demonstrate how NASA Earth observations can be used to monitor and assess salmon habitat
* Distinguish changes of forest cover type and other LULC classes in the Downeast region over time
* Use geospatial data to assess areas in salmon habitat undergoing warming and drought events over time and the relation of such phenomena to LULC
* Develop and deliver a workshop that transfers project methods to partner organizations to inform critical salmon habitat conservation efforts

***Previous Terms:***

2021 Fall (GSFC) – Maine Ecological Forecasting

2022 Spring (GSFC) – Maine Ecological Forecasting II

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **Maine Department of Marine**  **Resources, Division of Sea-run**  **Fisheries and Habitat** | Ernie Atkinson, Marine Resources  Scientist | End User | Yes |
| **Downeast Salmon Federation** | Dwayne Shaw, Executive Director | End User | Yes |

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

The DMR and DSF are involved in Atlantic salmon habitat restoration and population recovery initiatives throughout Maine. The DMR promotes stream restoration efforts by identifying areas of thermal refuge and by installing stream buffers where salmon habitat is degrading. The DSF is instrumental in maintaining Maine’s Atlantic salmon Distinct Population Segment (DPS) through conservation hatcheries and population surveys. This work informs habitat restoration efforts throughout critical salmon habitat. The DSF and DMR aim to increase juvenile survival and adult salmon spawning in Maine’s rivers, which improves the opportunity of successful oceanic migration and return to rearing streams. Neither organization currently uses Earth observations in their decision-making practices, but both have expressed an interest in incorporating remote sensing data, supported by adequate training for their staff. The DSF and DMR would also like to improve the communication of their efforts to the public and their partner organizations.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameter(s)** | **Use** |
| **Landsat 5 TM** | Land surface reflectance | Land surface reflectance was used to generate LULC maps across the study region over time. |
| **Landsat 8 OLI** | Land surface reflectance | Land surface reflectance was used to generate LULC maps across the study region over time. |
| **Landsat 9 OLI-2** | N/A | Specifications were detailed in the Earth Observation Written Tutorial for future partner reference. |
| **Sentinel-1 C-SAR** | N/A | Specifications were detailed in the Earth Observation Written Tutorial for future partner reference. |
| **Sentinel-2 MSI** | Land surface reflectance | Land surface reflectance was used to refine LULC maps by distinguishing forest cover types and for LULC validation. |
| **SRTM** | Elevation, slope, and aspect | Elevation, slope, and aspect were used as driver variables for LULC forecasting and LST statistics. |
| **Terra MODIS** | LST | Morning LST and LST anomalies were mapped across the study region over time. |
| **Aqua MODIS** | N/A | Specifications were detailed in the Earth Observation Written Tutorial for future partner reference. |
| **VIIRS** | N/A | Specifications were detailed in the Earth Observation Written Tutorial for future partner reference. |
| **GPM IMERG** | Precipitation | Precipitation totals and anomalies were mapped across the study region over time. |

***Ancillary Datasets:***

* Department of Marine Resources Salmon Survey Data – Atlantic salmon presence in Maine streams and rivers used to show the importance of Downeast Maine in the case study examples
* Spatial Hydro-Ecological Decision System (SHEDS) Stream Temperature Database – *In-situ* water temperature of known streams used in the tutorials and workshop to compare to LST
* U.S. Drought Monitor (USDM) – National drought assessment used in the tutorials and workshop to compare to GPM IMERG trends in precipitation
* USGS National Land Cover Database (NLCD) – LULC data used to compare to team generated LULC maps

***Modeling:***

* TerrSet Land Change Modeler (Contact: Sean McCartney, Science Systems and Applications, Inc., NASA Goddard Space Flight Center) – Used by Maine Ecological Forecasting II to model LULC between 1985 and 2021, forecast LULC to 2040; Referenced in the workshop

***Software & Scripting:***

* Google Earth Engine API – Used to acquire satellite data in the tutorials and workshop
* R v4.1.3 & RStudio v2022.02.0 – Used by Maine Ecological Forecasting II to generate time series plots and analyses of LST and forest cover type; Referenced in the tutorials and workshop
* Esri ArcGIS Pro 2.9.1 – Used in the tutorials and workshop to classify LULC and to produce maps for LULC, LST, and precipitation

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Product** | **Earth Observations Used** | **Partner Benefit & Use** | **Software Release Category** |
| **Earth Observation Overview Written Tutorial** | Landsat 5 TM  Landsat 8 OLI  Landsat 9 OLI-2  Sentinel-1 C-SAR  Sentinel-2 MSI  Terra MODIS  Aqua MODIS  VIIRS  GPM IMERG | The Earth Observation Overview Written Tutorial describes specific information about relevant satellites and sensors that the partners can reference in the future. | N/A |
| **Data Acquisition Written Tutorials** | Landsat 8 OLI | The Data Acquisition Written Tutorials provide the partners with step-by-step instructions for using Google Earth Engine, EarthExplorer, and Earthdata to access remote sensing data in the future. | N/A |
| **LULC Written Tutorial** | Landsat 5 TM  Landsat 8 OLI  Sentinel-2 MSI | The LULC Written Tutorial demonstrates how to classify and analyze LULC changes over time around riparian habitats. This provides a walkthrough for producing past and current LULC maps to plan salmon conservation initiatives in the future. | N/A |
| **Climate Written Tutorial** | Landsat 8 OLI  Terra MODIS  GPM IMERG | The Climate Written Tutorial demonstrates how to analyze geospatial LST and precipitation trends through time. This provides a framework to identify areas of compounding environmental stressors for salmon as Maine’s climate changes in the future. | N/A |
| **Case Study Examples** | Landsat 5 TM  Landsat 8 OLI  Sentinel-2 MSI  Terra MODIS  GPM IMERG | The case studies focus the results on the Penobscot, Union, and Machias Rivers. These examples demonstrate the use of Earth observations for monitoring LULC, LST, and precipitation. | I |
| **Interactive Workshop** | Landsat 5 TM  Landsat 8 OLI  Sentinel-2 MSI  Terra MODIS  GPM IMERG | All end products were presented in an interactive online workshop that guided users through Earth observations and data acquisition, along with a walk-through analysis of curated case studies. This interactive online workshop transferred the methods from this project and the last two DEVELOP terms to the partners. | N/A |

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

The partner organizations are focused on recovering Federally Endangered Atlantic salmon populations in Maine. Through curated tutorials and an interactive workshop, end users will learn how to apply Earth observations to their region of interest, which includes key regions of salmon habitat. These products will help the DSF and DMR by filling gaps in *in-situ* measurements, by analyzing patterns in temperature and precipitation, and by relating climate variables to LULC changes over time. Upon completion, attendees will obtain skills to inform their conservation efforts relevant to LULC adaptation and climate change mitigation. These insights will strengthen community awareness through data acquisition and application.

**References**

Dauwalter, D. C., Fesenmyer, K. A., Bjork, R., Leasure, D. R., & Wenger, S. J. (2017). Satellite and airborne remote sensing applications for freshwater fisheries. *Fisheries*, *42*(10), 526 –537. <https://doi.org/10.1080/03632415.2017.1357911>

Flye, M. E., Sponarski C. C., Zydlewski J. D., & McGreavy, B. (2021). Understanding collaborative governance from a communication network perspective: A case study of the Atlantic Salmon recovery framework. *Environmental Science and Policy*, *115*, 79 –90. <https://doi.org/10.1016/j.envsci.2020.10.001>

McCormick, S. D., Hansen, L. P., Quinn, T. P., & Saunders, R. L. (1998). Movement, migration, and smolting of Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences*, *55*(S1), 77 –92.

<https://doi.org/10.1139/d98-011>

Saunders, R., Hachey, M. A., & Fay, C. W. (2006). Maine’s diadromous fish community: Past, present, and implications for Atlantic salmon recovery. *Fisheries*, *31*(11), 537 –547. <https://doi.org/10.1577/1548-8446>

U.S. Fish and Wildlife Service and NMFS. (2019). Recovery Plan for the Gulf of Maine Distinct Population

Segment of Atlantic Salmon (*Salmo salar*). 74pp. <https://www.fisheries.noaa.gov/resource/document/recovery-plan-2019-gulf-maine-distinct-population-segment-atlantic-salmon-salmo>