Inland wetland mapping with Earth Observation (EO) data and geospatial tools

Day 3 Training Workshop Module 1:
Introduction to National Wetland Inventories

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Inland wetlands: Definition

Ramsar Classification of Wetland Types has 42 types grouped into 3 categories: Marine & Coastal Wetlands, Inland Wetlands (, and Human-made Wetlands

Inland Wetlands broadly:

- marshes and wet meadows dominated by herbaceous plants
- swamps dominated by shrubs
- wooded swamps dominated by trees

Environmental characteristics can vary:

- freshwater(often) or saltwater (less common)
- permanent or seasonal/intermittent water
- occur on different types of soil (peat, inorganic...)

Ecological importance of inland wetlands

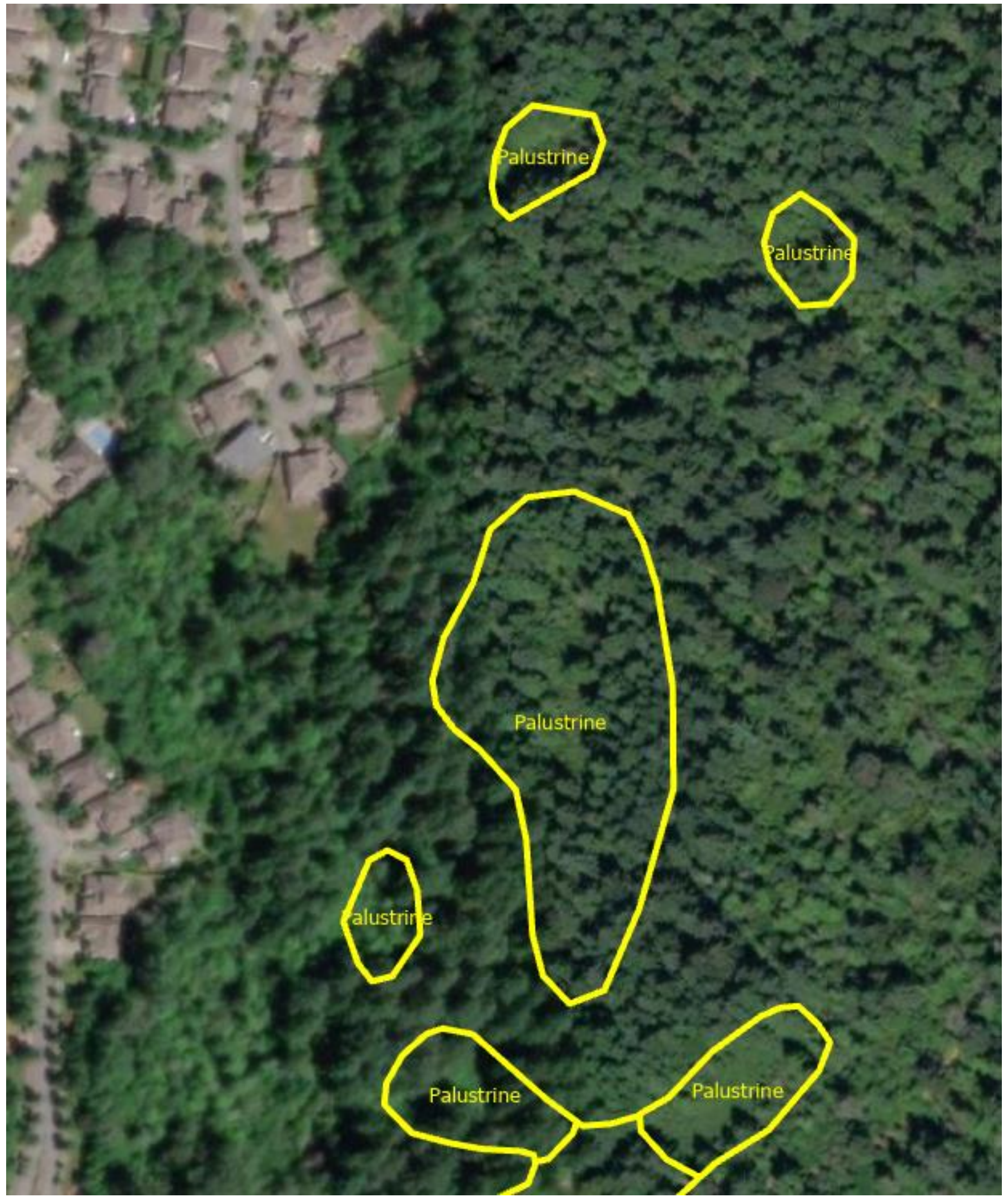
- Hydrological resources & connectivity
- Water quality regulation
- Habitat for terrestrial & aquatic plants & animals, biodiversity support
- Shoreline erosion control
- Recreation, aesthetic & other benefits

Opportunities & challenges of EO in inland wetlands

Strengths:

- EO provides comprehensive spatial coverage, including inaccessible areas & private lands
- Multi-temporal imagery can help identify wetlands based on characteristic plant phenology & hydrological regimes
- Spectral signals less impacted by tides compared to coastal wetlands

Opportunities & challenges of EO in inland wetlands

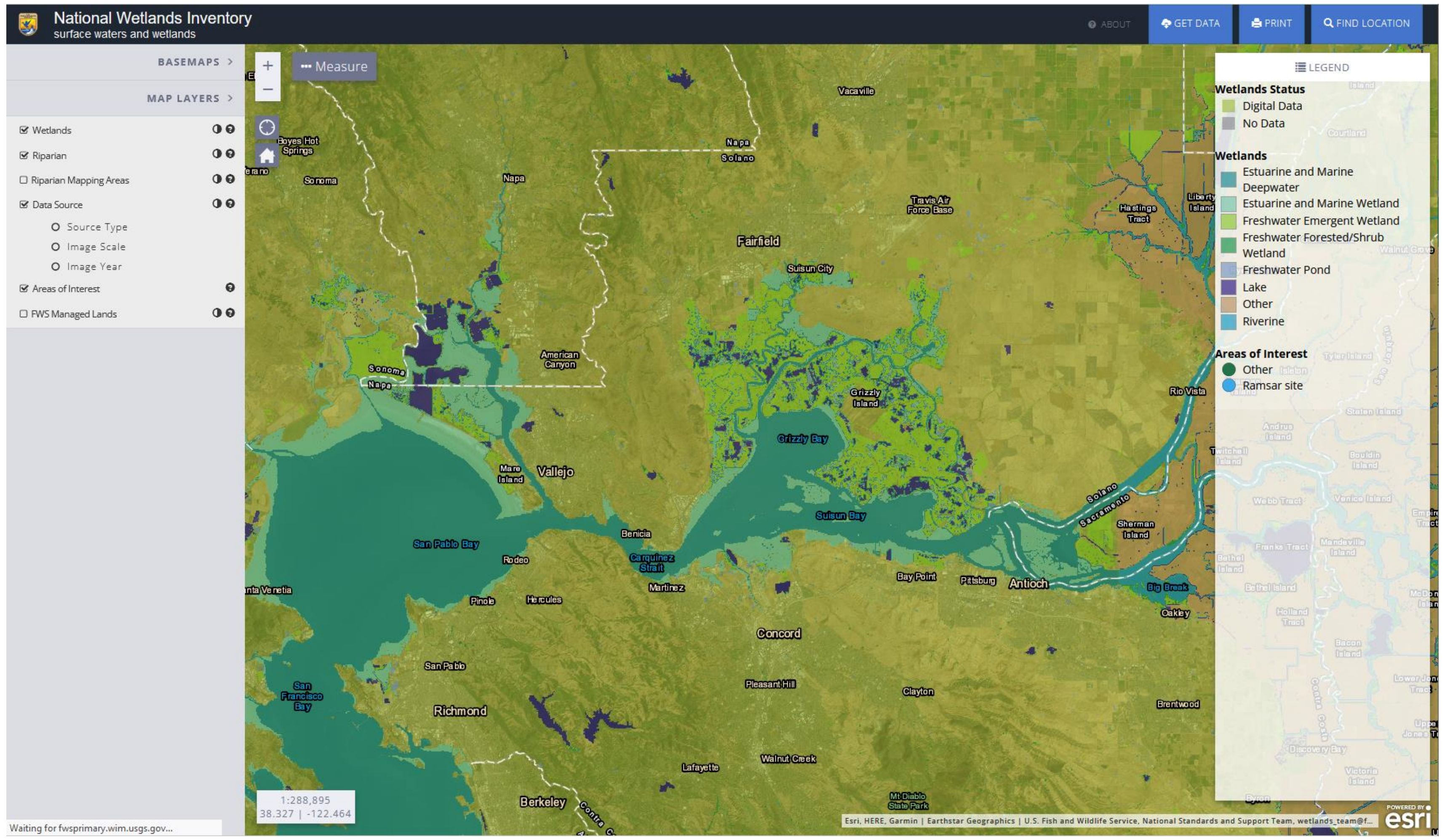


Challenges:

- Spectral signals can be obstructed by dense woody plants (e.g., forested wetlands)
- Difficult to detect small wetlands scattered across large landscapes & private lands
- Rapid changes in mapping data & methods reduce robustness of change analyses

Example: USA National Wetlands Inventory

A systematic effort to classify and map the USA's wetlands, started in 1977 by the U.S. Fish & Wildlife Service & continuing as a program with periodic updates on wetland status & trends



- Uses a standardized wetland classification system
- Spatial data now displayed & visualized via special online platform **Wetlands Mapper**
  - Users can download the data by different subsets (state, watershed, etc)
  - **Wetland data are updated twice a year**
- Designated its own spatial data & mapping standards
- Six Status & Trends reports published since 1954 (most recent 2009-2019)

By 2014 this effort mapped 100% of wetlands in the conterminous United States & completed the digital dataset, now asking more local stakeholders to contribute to mapping updates

Spatial data & EO application in USA NWI

Earth Observation & ancillary geospatial data such as topographic or soil maps provide a key basis for wetland mapping in the USA NWI

Figure 2. Aerial imagery showing wetland change between 2009 (left) and 2019 (right) for an urbanizing area in the southeastern United States. Note some examples of vegetated wetland loss (A) and pond gain (B).

https://www.fws.gov/sites/default/files/documents/2024-04/wetlands-status-and-trends-report-2009-to-2019_0.pdf

- **Main EO data: national aerial photography** programs from several government agencies
  - Ancillary data can aid (e.g., topographic data)
- Main approach: **On-Screen visual interpretation** of digital imagery by a trained analyst
  - Wetlands are identified & classified using color, size, shape, texture, patterns, locations & association of visible landscape elements
  - Image analysis verified by field-checking by trained biologists
- Early map efforts started at a small (coarse) scale (~1:250,000) but later more detailed, large-scale (1:24,000) maps became possible

Mapping standards

Wetland mapping techniques & rules developed by USA's NWI have been adopted by the Federal Geographic Data Committee as the federal wetland mapping standard (2009)

Example: Targeted Mapping Units & requirements of the USA's NWI

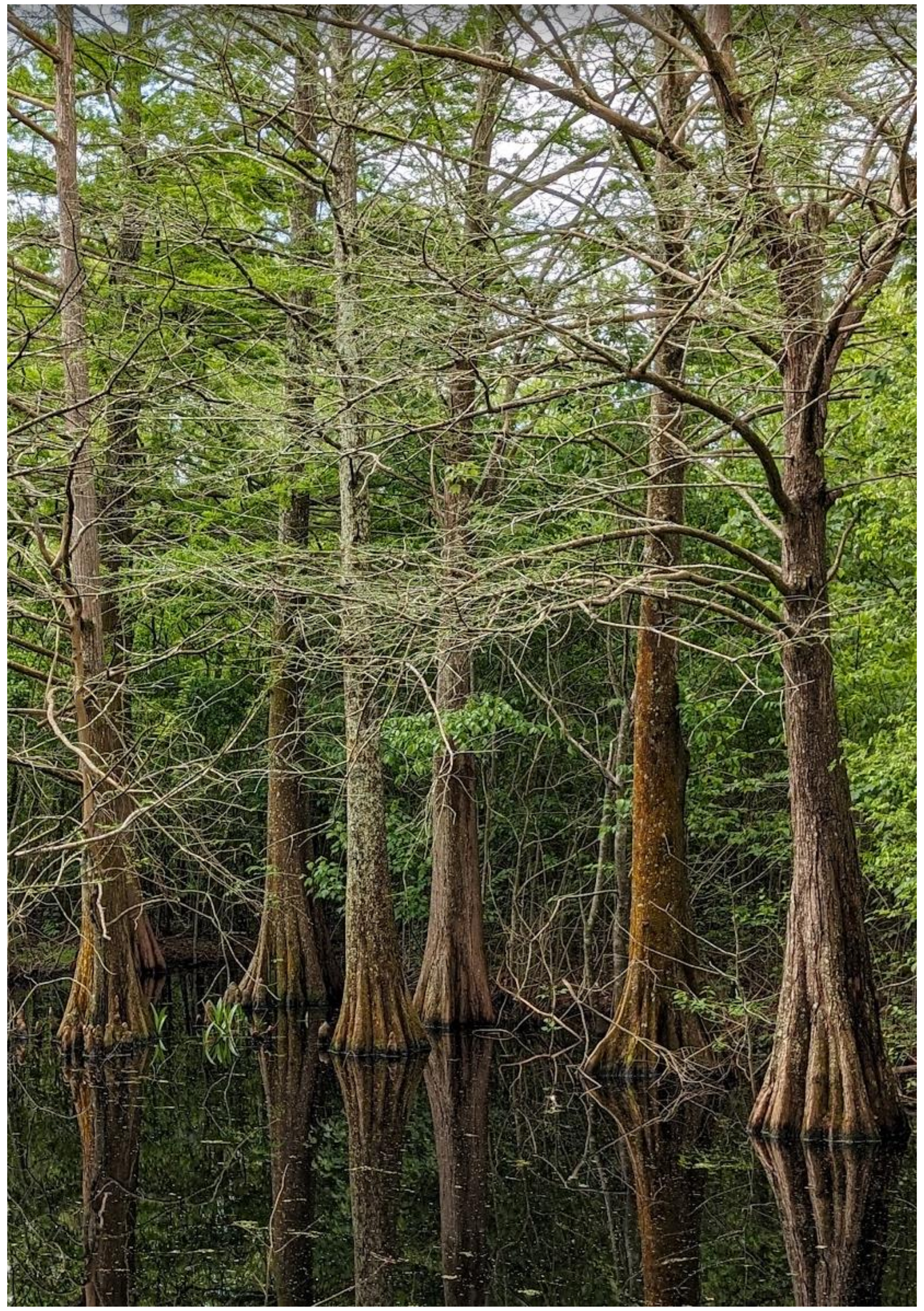
	Lower 48 states, Hawaii & Territories	Estuarine & palustrine Deepwater	Alaska (including Deepwater)
Targeted Mapping Unit	0.2 ha (0.5 acres)	0.4 ha (1.0 acres)	2.0 ha (5.0 acres)
Wetland **Identification Accuracy**	98%	98%	98%
Wetland **Classification Accuracy**	85%	85%	85%

Targeted Mapping Unit (TMU): an estimate of the **size class of the smallest** wetlands that can be consistently mapped & classified

- **Spatial resolution of source imagery:**
  - 1 meter for most states
  - 5 meters for Alaska
  - 3 meters for In-Shore Deepwater
- **Accuracy requirement:**
  - **98%** for wetland **identification** (wetland versus non-wetland)
  - **85%** for wetland **classification** (whether assigned wetland type is correct)
- Now wetland data can be contributed by many different partners but still must meet the USFWS NWI standards

Common known limitations

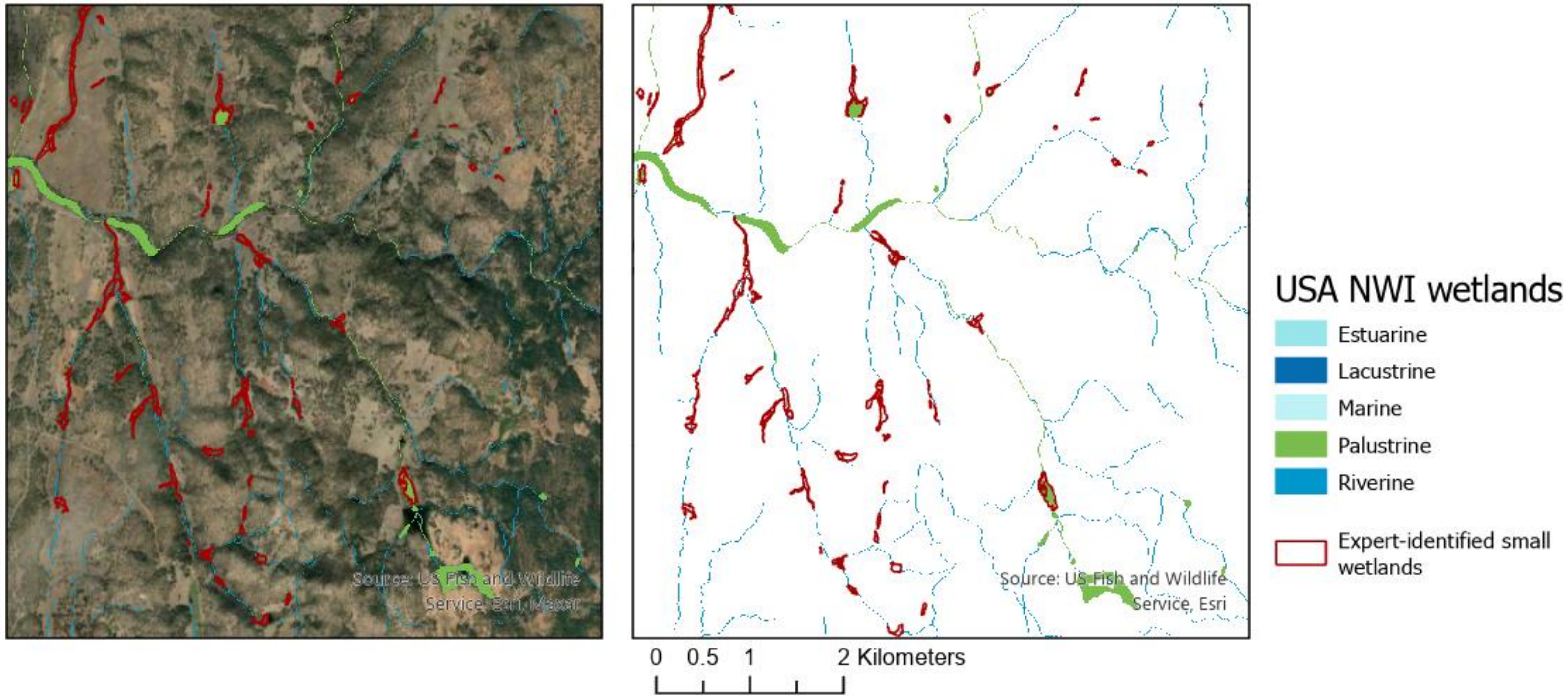
NWI reports & documentation acknowledge certain limitations that reflect both the aspects of mapping procedures & the landscape conditions on the ground



- Analysis of high-altitude aerial imagery may have **interpretation errors:**
  - wetlands are identified primarily based on visible vegetation, hydrology & geographic setting
- **Wetland boundaries may change** since the times of image acquisition or field surveys
  - Mapped boundaries may not fully match present status
  - Some wetlands are highly dynamic across seasons
  - Ephemeral wetlands are especially challenging (ephemeral waters flooded <7 days not included in USA NWI)

Example: USA National Wetlands Inventory

Small, geographically scattered wetlands can still be missed, especially on private lands. Example from a part of the Sierra-Nevada Foothills region in California, USA:



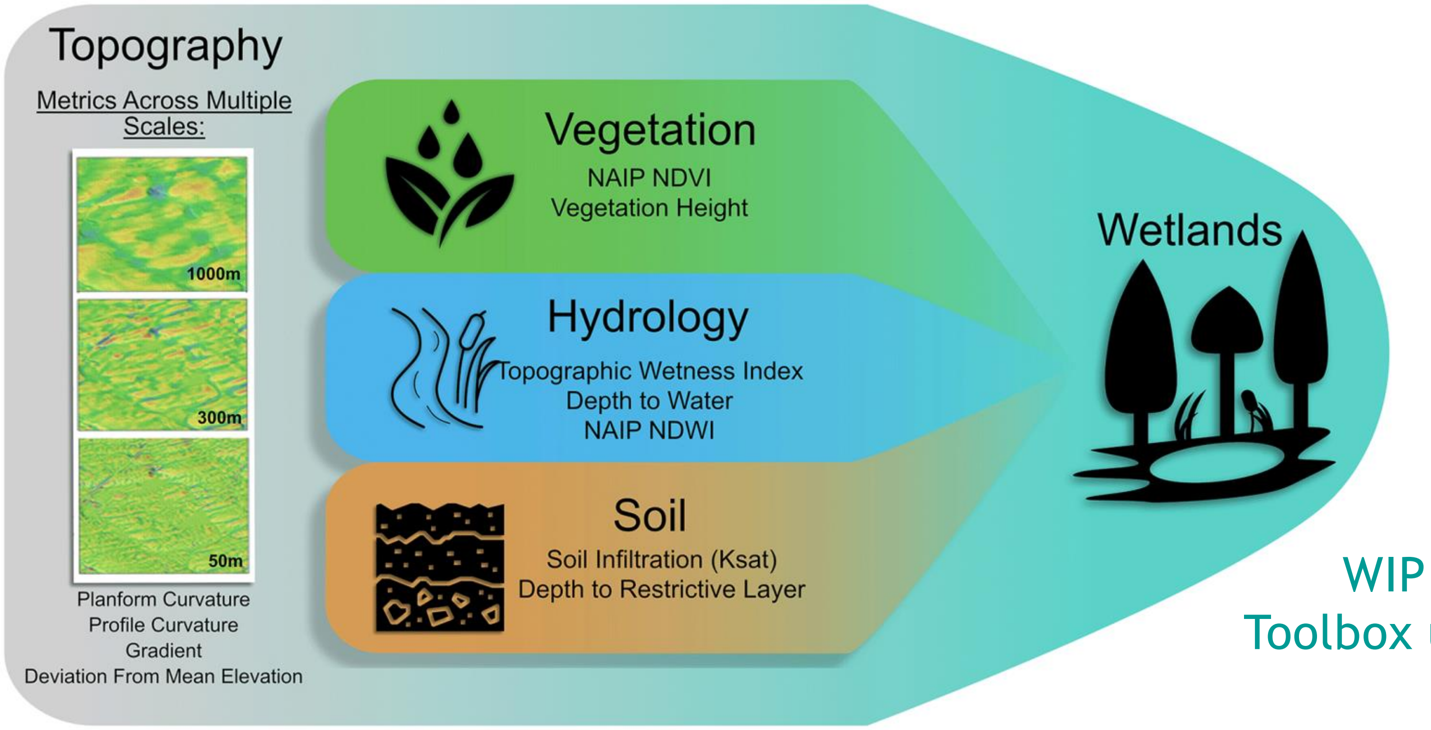
Small inland wetlands detected in the area by experts & field visits (red outlines) are not always captured by the wetlands mapped by the NWI effort

Potential solutions to the challenges

Major strategies:

- Combine EO imagery with non-EO spatial datasets (topography, soil, hydrology) & models
- Multi-source EO approaches: using complementary image products & sensors at different scales of observation for a combined outcome
- Spreading the effort: outsourcing mapping effort to partners & collaborators across multiple agencies & groups

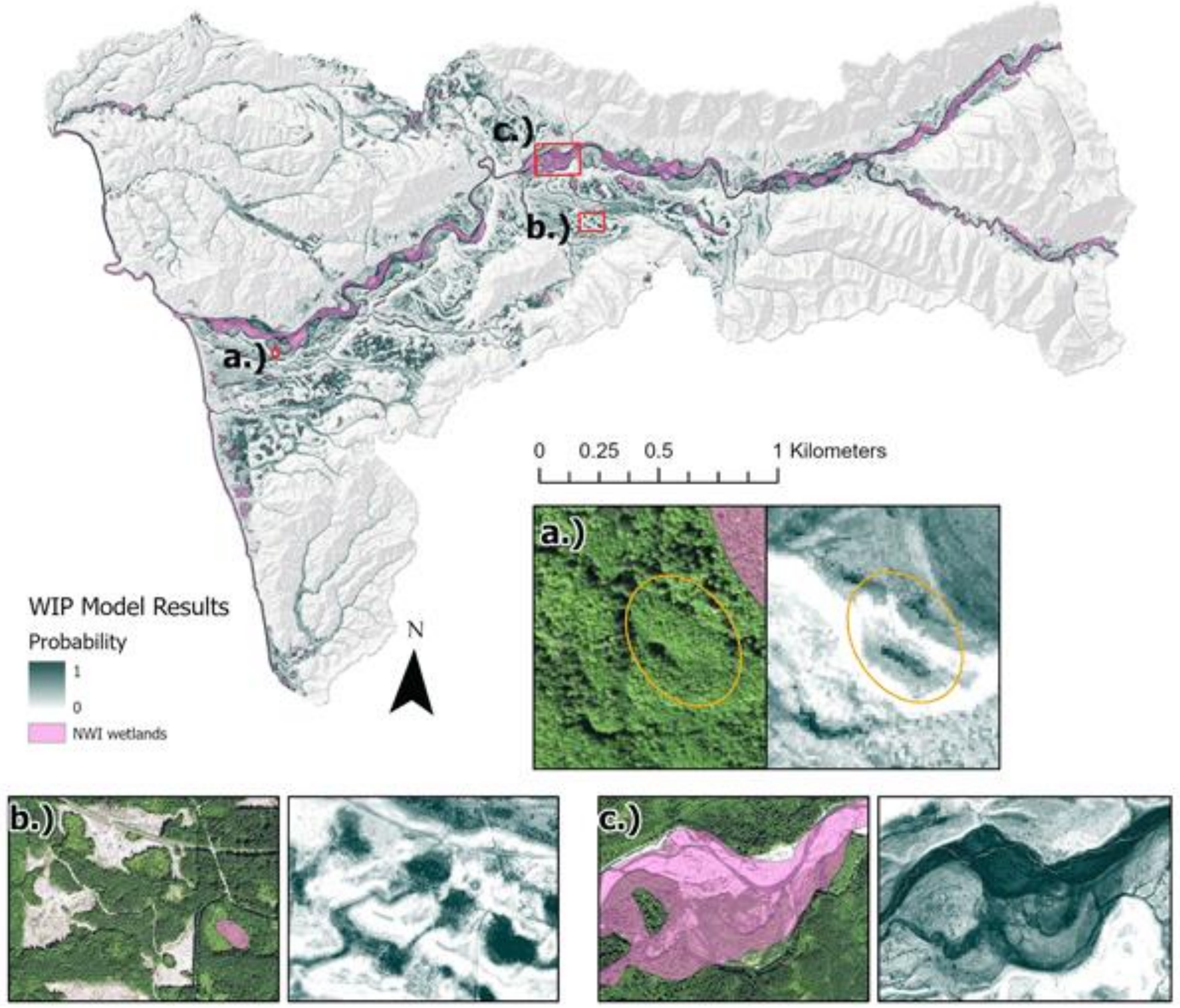
Solution: Combine EO data with other spatial datasets & models



WIP Tool available as ArcGIS Toolbox using R & Python scripts

Example: Wetland Intrinsic Potential Tool (Halabisky et al. 2023)

Figure 3. Wetland probability map of the entire study area with three examples: depressional wetland **(a)**, peatland **(b)**, and riverine wetland **(c)**. (Creative Commons Attribution License 4.0)



Improved prediction of wetland probability based on:

- Combination of EO-based vegetation & open water indicators with soil, hydrological & topographic data
- State-of-the-art machine learning-based modelling
- Identified >2 times wetland area than NWI in the test study area in Washington, USA

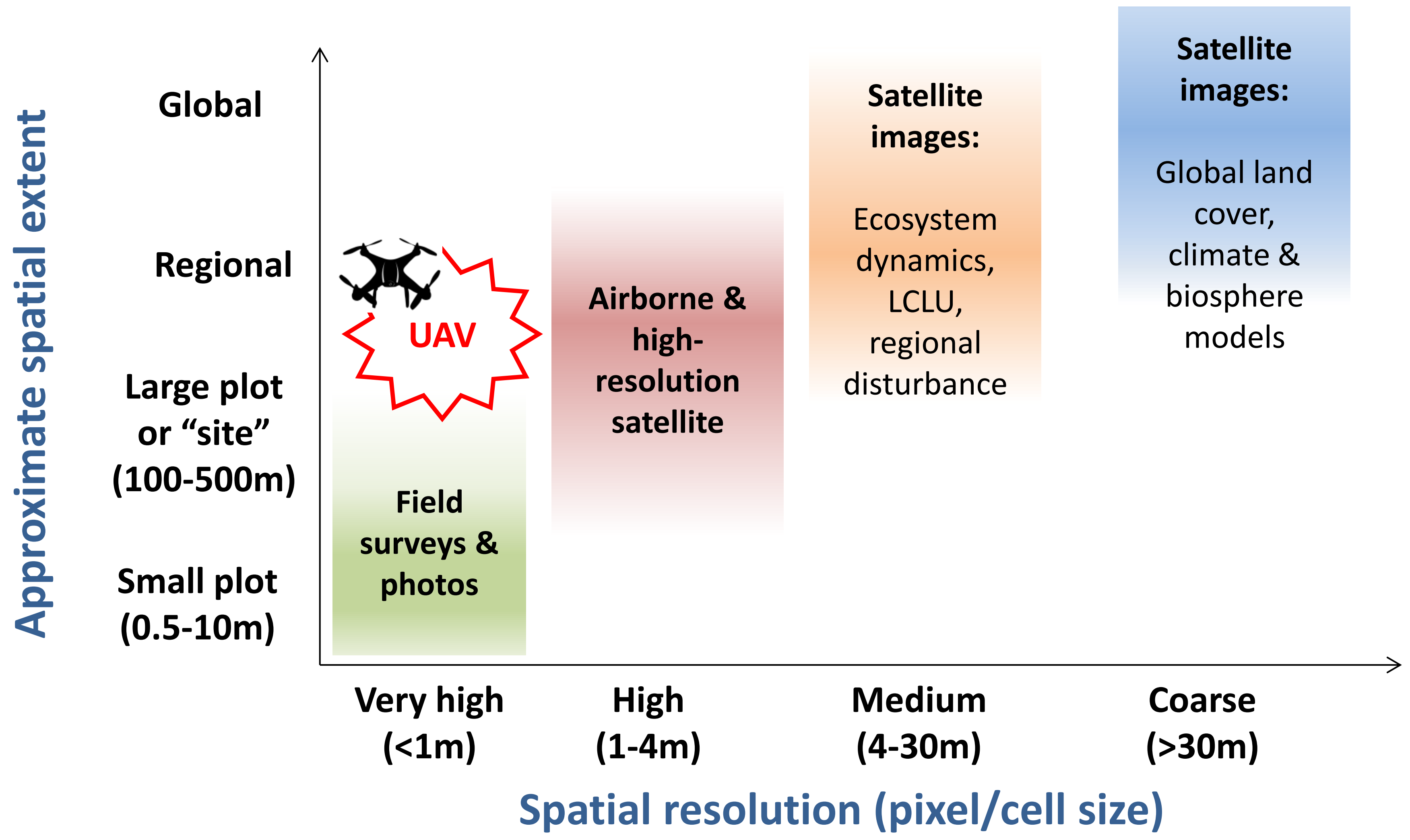
Halabisky, M., Miller, D., Stewart, A. J., Yahnke, A., Lorigan, D., Brasel, T., and Moskal, L. M.: The Wetland Intrinsic Potential tool: mapping wetland intrinsic potential through machine learning of multi-scale remote sensing proxies of wetland indicators, Hydrol. Earth Syst. Sci., 27, 3687–3699, https://doi.org/10.5194/hess-27-3687-2023 , 2023.

Solution: Multi-source EO Approaches

Advances in EO instruments, platforms & data access increasingly enable concurrent use of multiple sensors & across different landscape scales

- Historically, more accessible & more frequently collected EO data used to be at coarser spatial resolution (e.g., satellite)
- Higher-resolution aerial photography was costly, less frequent & less consistent
- Advances in unoccupied aerial vehicles provide new support for detailed local & subregional efforts which can help fill gaps in inland wetland inventories

Common spatial "scales" of landscape studies

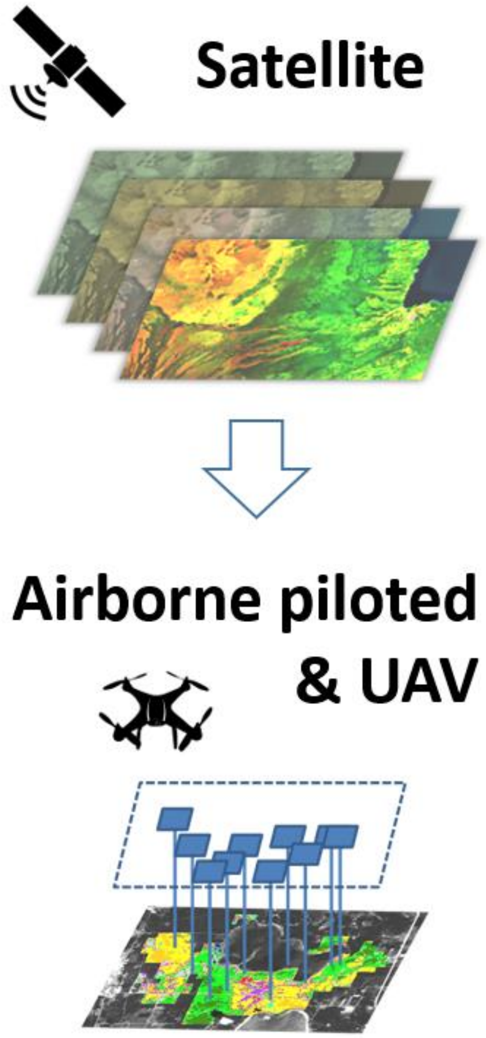


Solution: Multi-source EO Approaches

Broad-scale satellite data can be combined with strategic local observations to fill gaps in temporal coverage, inform spatial detail & validate broad-scale mapping outcomes

- Repeated satellite data can help in **broad-scale** wetland detection based on landscape seasonality & unique physical properties:
  - Inundation regimes, flooded area (radar)
  - Seasonal contrasts with other cover types in vegetation cover & composition (optical)

- Unoccupied (unpiloted) Aerial Vehicle (UAV) imaging can be customized for **fine-scale** support:
  - Refining wetland boundaries
  - Visual interpretation clues on wetland type
  - Validation of maps derived from satellite & high-altitude aerial photographs



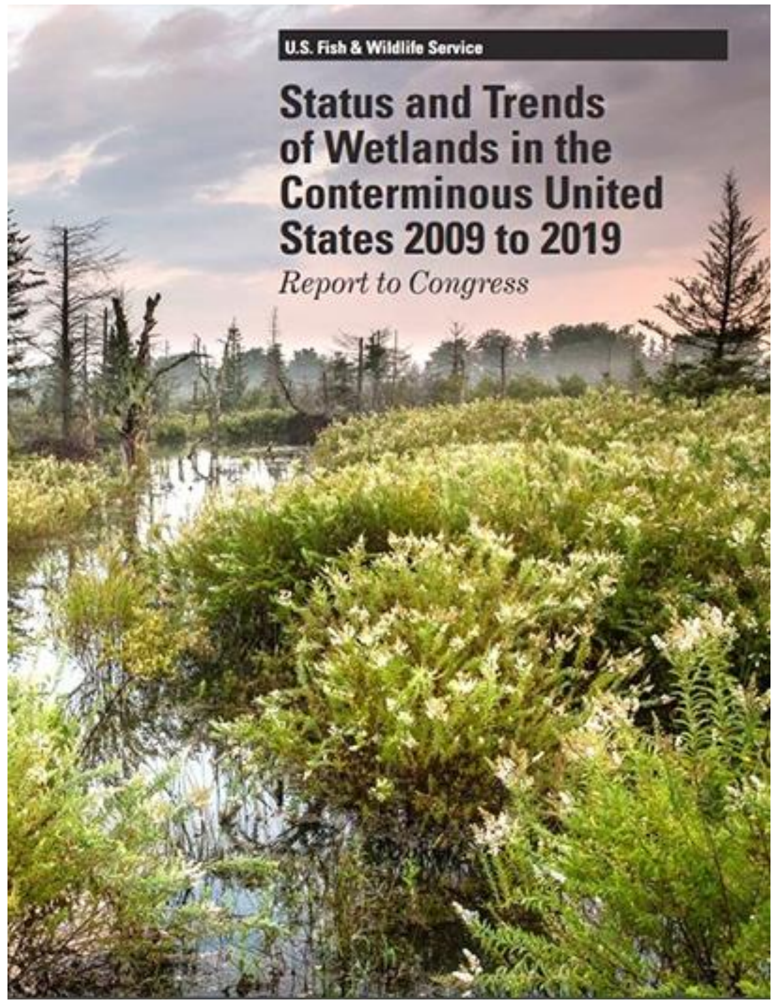
Solution: Outsourcing the effort to multi-agency partnerships

Spreading the NWI effort across multiple collaborating agencies can improve the efficiency, scope & timeliness of the effort

- Multiple agencies can contribute complementary data, knowledge and skills required for successful NWI
- Involving local partners in NWI efforts can help divide the geographic scope of work & improve the effort by contributing local knowledge of wetland sites & field survey capacity for validation
  - Especially important for "cryptic" & small inland wetland sites
- Partners can be contracted via the central effort but also leverage their own resources via "cost share" contract components

Solution: Outsourcing the effort to multi-agency partnerships

Example: USA's National Wetland Inventory



2019 Status & Trends update Report

Leading Agency: The U.S. Fish and Wildlife Service, Department of Interior

Contributors & cooperators:

- U.S. Environmental Protection Agency, U.S. Army Corps of Engineers + 14 other federal government agencies
- **more than 160 organizations & agencies total** (regional & local governments, Native American tribes, universities, non-governmental organizations) that have contributed wetlands data or cooperated in the creation of wetlands data
- Partnerships are critical for new updates & mapping

Solution: Outsourcing the effort to multi-agency partnerships

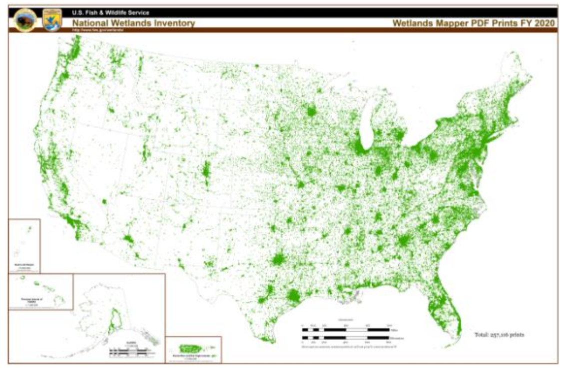
Collaborative multi-agency NWI effort offers additional benefits for long-term use & visibility:

- Reduced duplication of the effort among different agencies
- Improved visibility of the effort & accessibility to agencies & broader public
- Stronger network of government partnerships with administrative provinces, cities, tribes, organizations…
- Ultimately these benefits make it easier to **repeat the effort** for the longer-term monitoring or future NWI updates

USA NWI is intensively used:
https://www.fws.gov/story/national-wetlands-inventory-use-highlights

Use of the **Wetlands Mapper** – the primary NWI interface:

- >525,000 Mapper Views annually
- >40,000 datasets downloaded annually
- >270,000 unique users each year



Main takeaways

- Progress in EO data & technology creates new opportunities for improving inland wetland detection, mapping & monitoring
- Smaller, geographically scattered inland wetlands need special attention & approaches as they can be often missed in broader-scale satellite-based surveys
- Multi-source & multi-scale EO strategies have the potential to accommodate the challenges
- Advances in “big” geospatial data & landscape modelling make it easier to integrate EO into comprehensive workflows with topographic & other environmental information to better predict, detect & monitor inland wetlands
- Spreading NWI effort across multi-agency partnerships & user groups can improve the efficiency & longevity of the efforts & increase visibility & usage of the data

Selected references

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- Wetland Mapping Standard, draft: https://www.fgdc.gov/standards/projects/FGDC-standards-projects/wetlands-mapping
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Thank you for your attention

Questions?