Modeling Land Cover Change and Potential Management Impacts on Carbon Stocks of US Coastal Wetlands

Eric J. Ward[1], Camille Stagg[1], Colin Daniel[2], Bronwyn Rayfield[2], Rachel Sleeter[1], Lisamarie Windham-Myers[1], Kevin D. Kroeger[1], Jinxun Liu[1], William Conner[3], Richard Day[1], Ken Krauss[1], Benjamin Sleeter[1], Meagan Eagle[1], Karen Thorne[1], Kevin Buffington[1], Scott Jones[1], Bergit Uhran[1], Zhiliang Zhu[1]

[1]U.S. Geological Survey, [2]Apex Resource Management Solutions, [3]Clemson University

Background, Mission and Approach

To fulfill requirements of the Energy Independence and Security Act of 2007, the **U.S. Geological Survey LandCarbon Program** conducted a national assessment of carbon storage and greenhouse gas (GHG) fluxes of the Nation's ecosystems under current and future conditions of climate and land use change, released as series of five regional reports from 2012 to 2017. This geographically broad assessment captured all major terrestrial and aquatic ecosystems **with the exception of coastal wetlands**. Coastal wetlands store significant amounts of carbon in the soil and serve as substantial GHG sinks but are also extremely vulnerable to changes in climate and land use. In addition to disturbances such as sea-level rise and hurricanes, coastal wetlands are impacted by high-intensity land use change, which has resulted in alarming rates of coastal wetland conversion and potential loss of these carbon sinks. Yet, the effects of land use and land cover (LULC) change on carbon and GHGs in coastal wetlands, and the implications for the national carbon budget, remain uncertain. To improve national-scale accounting of carbon stocks and GHG fluxes, the LandCarbon program established the **USGS Wetland Carbon Working Group** to conduct a national assessment of coastal and inland wetlands. Here we present our initial adaptation of the Land Use and Carbon Scenario Simulator (LUCAS; Sleeter et al. 2018) for evaluating the GHG fluxes of wetlands. LUCAS consists of a series of ecosystem-specific carbon stock and flow models nested within a state-and-transition simulation framework (ST-Sim SF; Daniel et al. 2018).

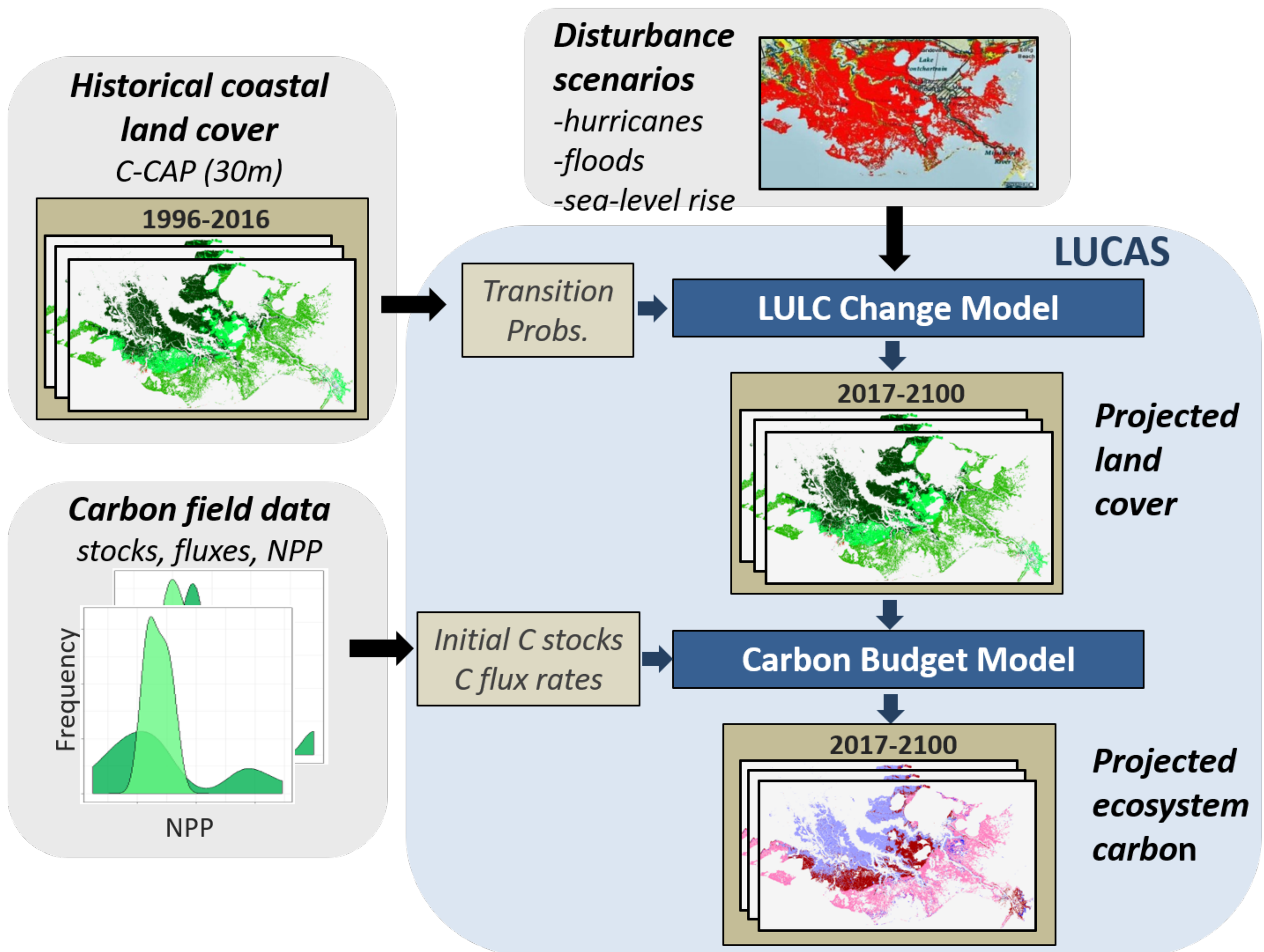

Fig. 1: Basic structure and workflow of Land Use and Carbon Simulator (LUCAS) for coastal wetlands

Model Prototype: Tidal Portion of Mississippi River Alluvial Plain

We used LULC data from NOAA's Coastal Change Analysis Program (C-CAP) to estimate transitions from 1996 to 2016 of the portion of the Mississippi River Alluvial Plain (MRAP; Ecoregion 73). Ecoregion 73 was selected as a sentinel site for multiple reasons: 1) It contains 40% of CONUS coastal wetlands, 2) Land use land cover change in this region is dynamic and has the highest rates of wetland loss in the nation, 3) This region is data-rich, making it an ideal candidate for carbon stock-flow model parameterization (Fig. 2). Our study extent (~18,000 km) included tidal herbaceous and forested wetlands, unconsolidated shore, and open water. An important update to this assessment is the quantification of soil pools for open water state classes. Whereas Tier 1 IPCC assessments assume that the top 1 m of soil is emitted to the atmosphere following conversion to open water, in this model the soil is preserved and quantified based on field data from unvegetated and open water systems (Osland et al. 2016).

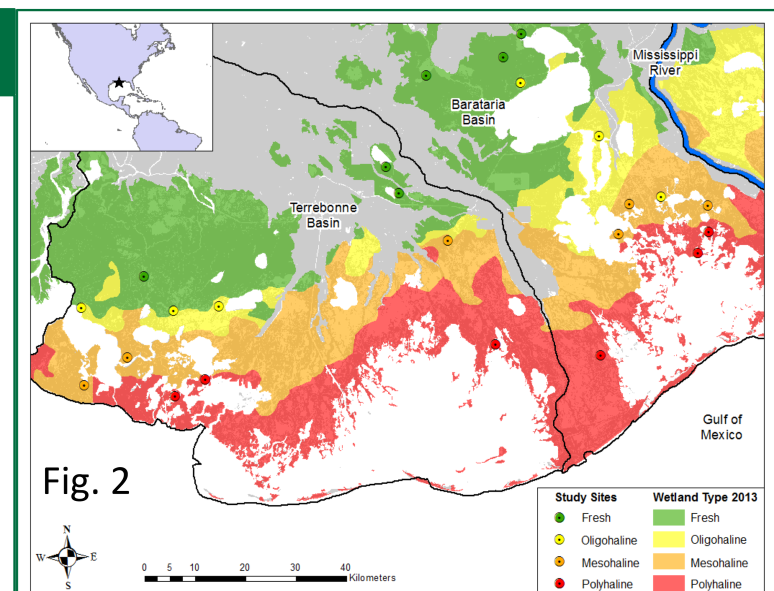

Fig. 2

State-and-Transition Simulation with Continuous Stocks and Flows (ST-Sim SF)

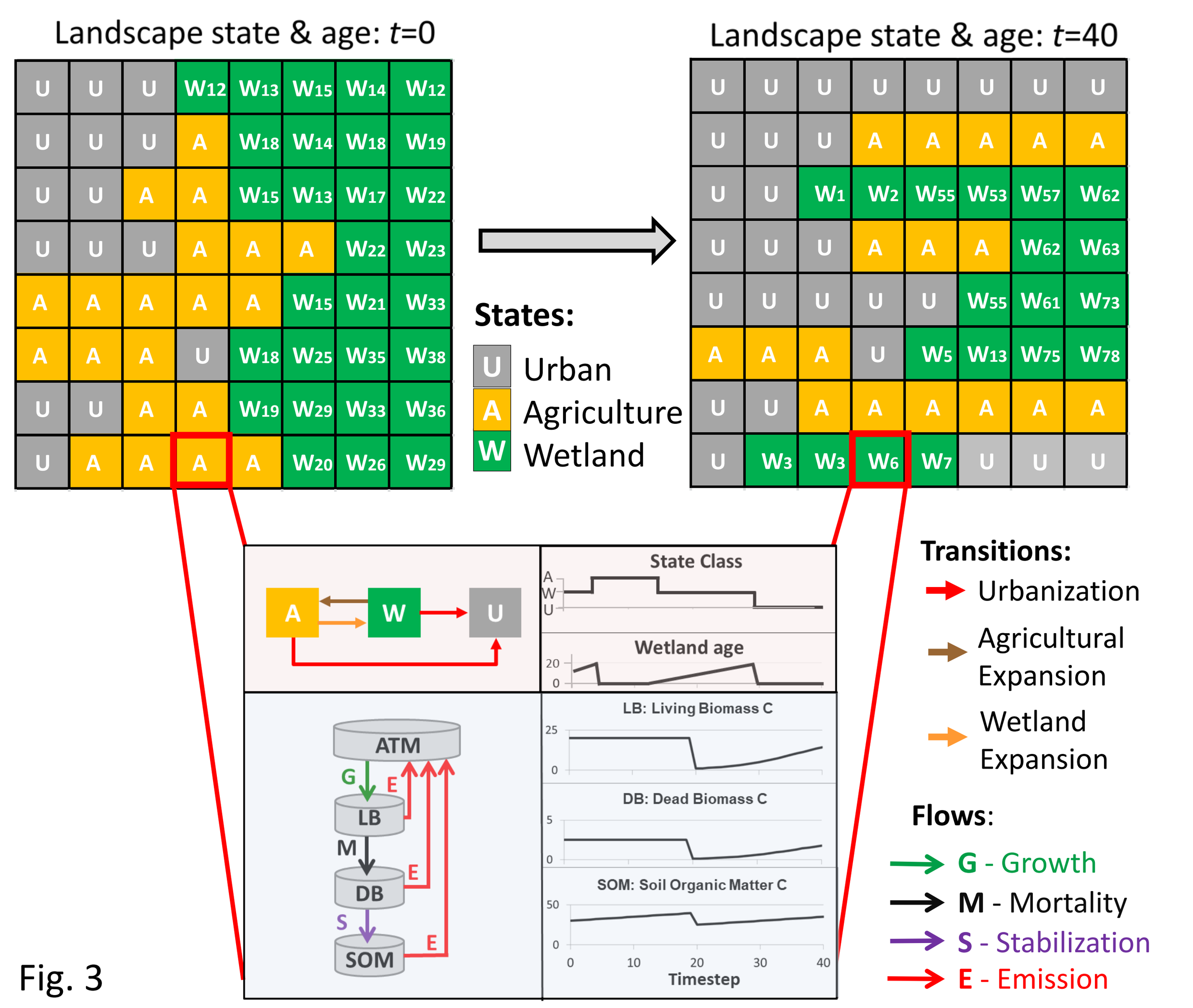

Fig. 3

Fig. 3 shows a simplified version of the ST-Sim SF framework (Daniel et al. 2016, 2018). Important features:

- Space represented as pixels
- Time is in discrete steps
- State is a discrete class
- Ecosystems have a discrete age since previous disturbance
- Change is modeled as a stochastic process
- Some transitions are unidirectional (e.g. urbanization)
- Some transitions are reversible (e.g. agricultural expansion)
- Living biomass (LB), dead biomass (DB) and soil (SOM) carbon stocks can be tracked through multiple transitions using a coupled carbon stock and flow model
- Net exchange with atmospheric (ATM) pool is tracked regionally

Ecoregion 73 Prototype Model Results

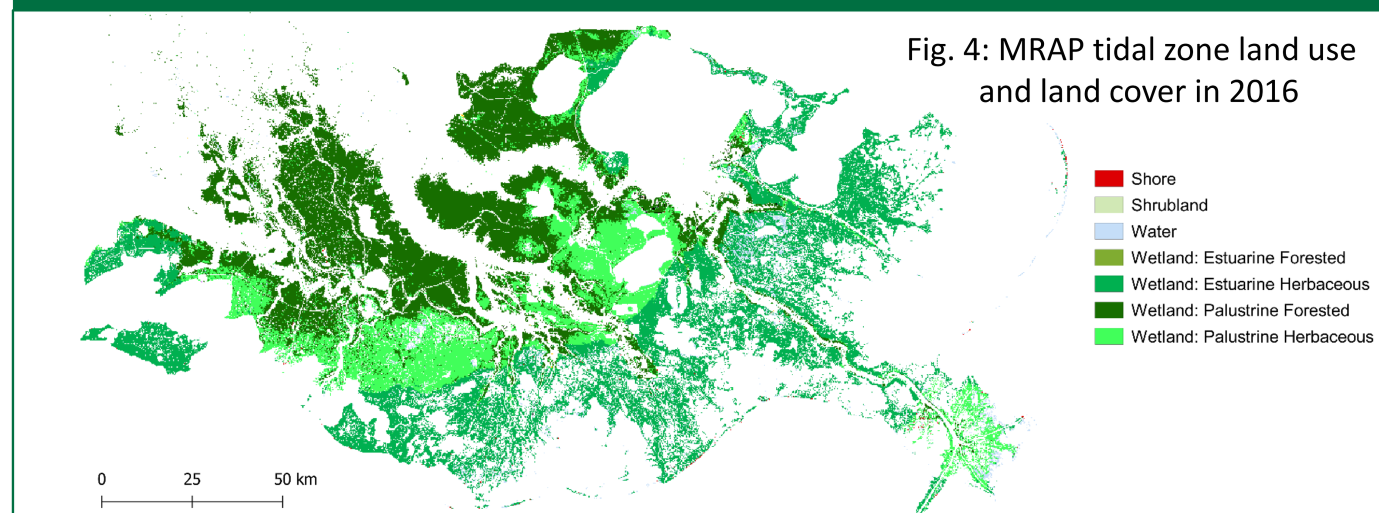

Fig. 4: MRAP tidal zone land use and land cover in 2016

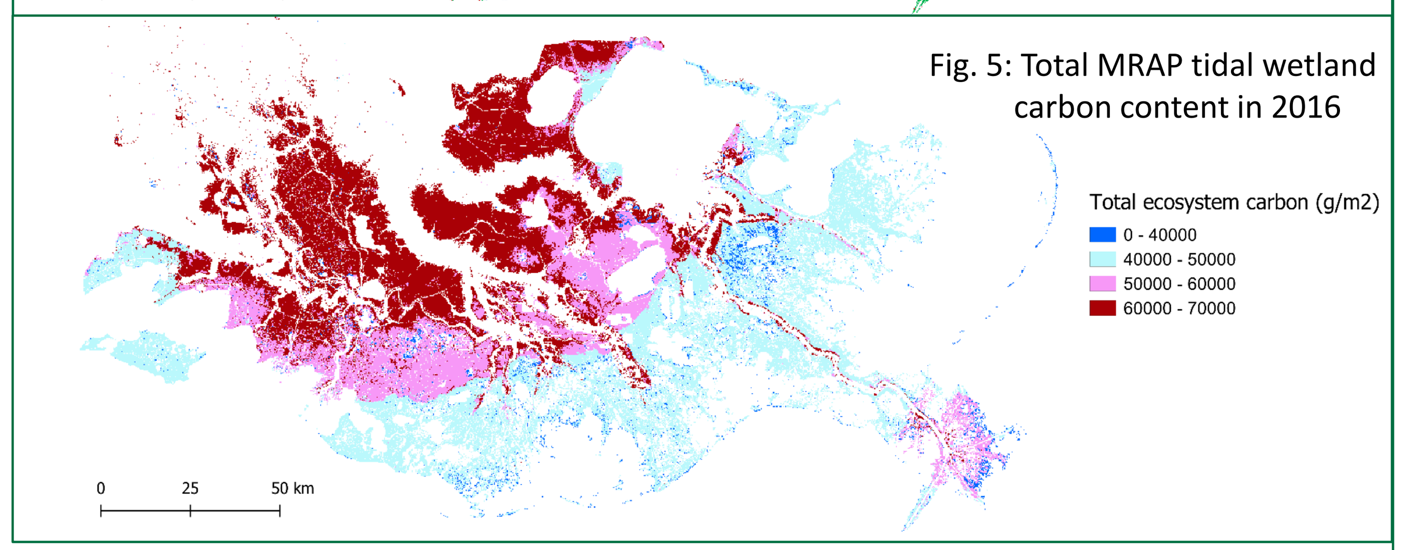

Fig. 5: Total MRAP tidal wetland carbon content in 2016

In areas of coastal wetland loss, where tidal wetlands converted to open water, there was a decrease in total ecosystem carbon. However, when accounting for the entire study extent, including all land cover classes (wetland, water and unconsolidated shore), we estimated a net gain in total ecosystem carbon over the 20-year period for the entire study area, which is associated with:

1) Wetland soil C burial in remaining wetlands.
2) Maintenance of deep soil carbon stocks in the open water state.

Importantly, the potential for carbon sequestration declined with the loss of coastal wetlands. These preliminary results illustrate the importance of accounting for open water carbon stocks and the potential of wetland soil processes to sequester carbon on management time scales.

Ecoregion 73 Sites and Field Data

Models were calibrated for tidal portions of Ecoregion 73 using data collected from 24 sites along a salinity gradient over a two-year period (Stagg et al. 2017, 2018), including:

- Above/belowground NPP from sequential harvests
- Above/belowground winter biomass standing stocks
- Aboveground and belowground decomposition rates from litterbag deployments
- Soil carbon stocks to 1 m depth using peat core samples

Carbon Stock and Flow Model for Herbaceous Wetlands

To adapt the Land Use and Carbon Scenario Simulator (LUCAS) model for application to wetlands (Fig. 6), we created two external pools in addition to the atmospheric pool used for terrestrial ecosystems:

1. An aquatic pool that can both import and export carbon from the ecosystem as lateral fluxes.
2. A deep soil pool that receives carbon as vertical accretion moves soil below the 1-m depth of our modeled stocks.

These pools track total regional C fluxes/sequestration.

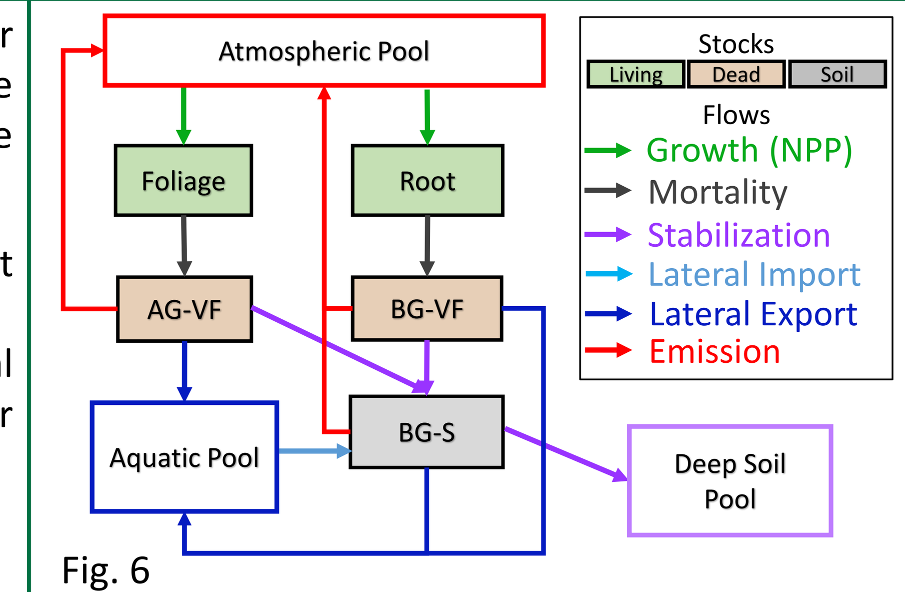

Fig. 6

Final Steps for Ecoregion 73 Prototype

The final steps for the Ecoregion 73 model include:

- Estimating spatial uncertainty with Monte Carlo simulations drawing from distribution of stocks and flows from individual sites (Fig. 7), with joint draws where covariance is high.
- Incorporating lateral flux estimates to better partition carbon outflows to the aquatic and atmospheric pools.
- Incorporate data from forested wetlands in the region using a stock and flow model with additional large and small woody live and dead biomass stocks.
- Complete a regional carbon budget estimating net carbon sequestration of wetlands, both herbaceous and forested.

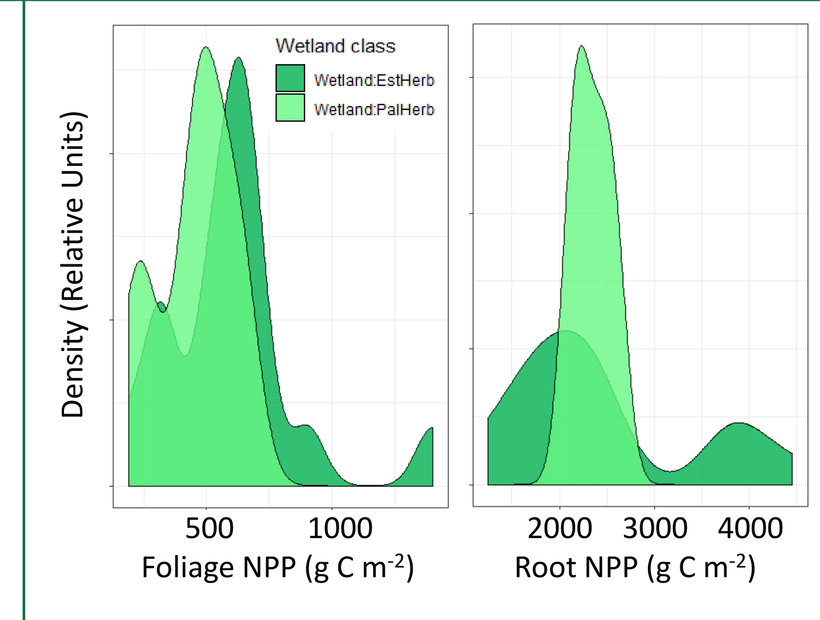

Fig. 7 Distributions of site-level NPP in Ecoregion 73

Scaling Up to a National Assessment

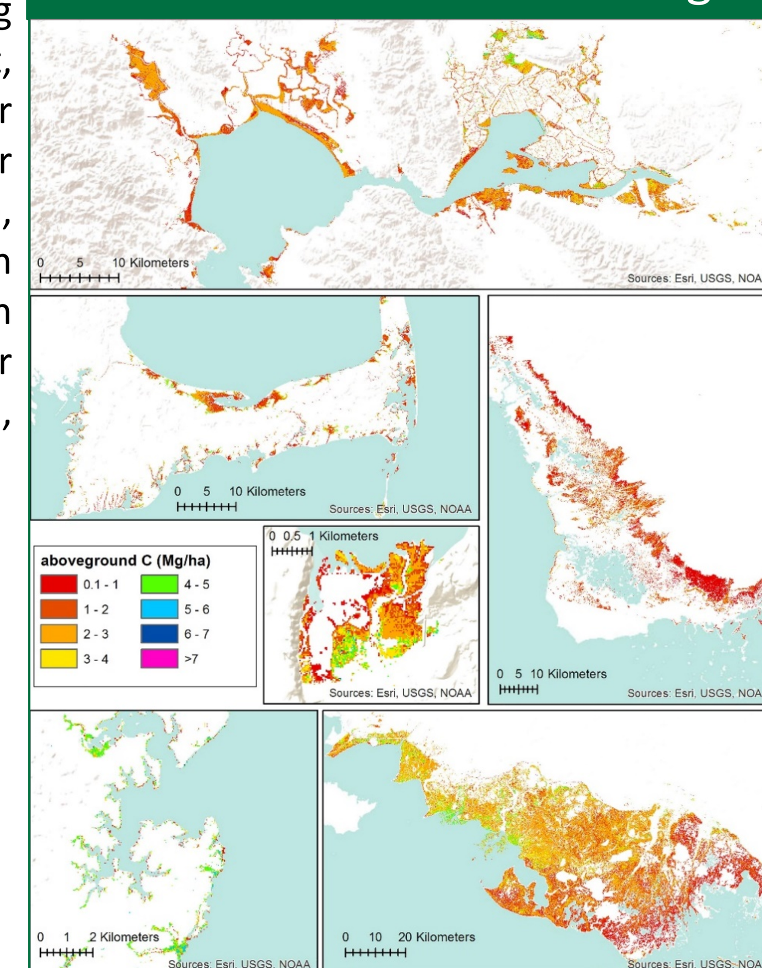

Fig. 8: Aboveground NPP in 6 USGS Sentinel Sites

- The final assessment will utilize parameter and initial stock distributions (similar to Fig. 7) within each coastal ecoregion of CONUS, drawn from a comprehensive literature review and spatial data products in a Monte Carlo framework.
- The CONUS model will produce estimates at a 300 m scale. In addition to baseline estimates with historic LULC change, scenarios of land management and climate change will be incorporated into the model. Sea level rise scenarios will be simulated with the WARMER Model (Swanson et al. 2014) for each coastal ecoregion.
- Additional datasets and analyses needed to scale the prototype model to all of CONUS tidal wetlands include:
- Aboveground NPP- we will generate a spatially explicit NPP map based upon the work published by Byrd et al. (2018), which provides aboveground biomass for six sentinel sites (Fig. 8). This update will generate aboveground NPP estimates for all of CONUS tidal wetlands.
- Land cover analysis- we will use NOAA C-CAP land cover data for all of CONUS tidal wetlands to estimate historic changes in land cover from 1996 to 2016. The tidal boundary will define the study area based on analysis by Holmquist et al. (2019).
- Soil carbon density- estimates according to Holmquist et al (2018), who found that soil carbon density did not vary significantly spatially.

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