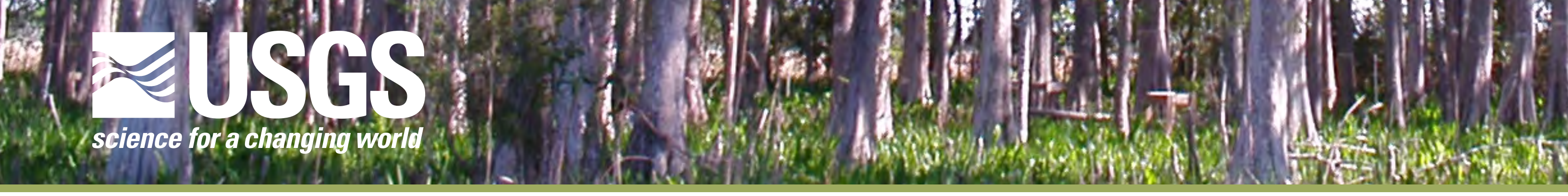

Physiological Ecology and Ecohydrology of Coastal Forested Wetlands

The form, function, and productivity of wetland communities are influenced strongly by the hydrologic regime of an area. Wetland ecosystems persist by depending upon surpluses of rainfall, evapotranspiration, soil moisture, and frequency and amplitude of water-level fluctuations. Yet, wetland vegetation can also influence ecosystem water economy through conservative water- and carbon-use strategies at several organizational scales.

Scientists have described leaf-level water-use efficiency in coastal mangrove forests as being among the highest of any ecosystem. These forested wetlands occur in intertidal areas and often persist under flooded saline conditions. Are these same strategies used by other types of coastal forested wetlands? Do conservative water-use strategies reflect a consequence of salt balance more than efficiency in water use per se? At what organizational scales do these strategies manifest? These are just a few of the questions being answered by physiological and landscape ecologists at the U.S. Geological Survey National Wetlands Research Center (NWRC).

Determining how vegetation interacts with water flow through wetlands is important for defining how atmospheric carbon and water vapor exchange will occur within forested wetlands as sea level rises or as hydrologic restoration projects are implemented. Studies are also important for learning more about ecosystem stress. At NWRC, we are evaluating water use, describing carbon cycling, and identifying stress at several scales by studying leaf-level atmospheric gas exchange [carbon dioxide (CO_2) and water vapor (H_2O)], quantifying individual tree water use, developing stand-level water budgets, and assessing ecosystem-level soil CO_2 exchange within mangroves and tidal freshwater swamp forests.

Experimental Studies

Leaf-level Gas Exchange

Studies at NWRC coordinate field and greenhouse investigations to determine how individual seedlings or saplings respond to combinations of flooding and salinity, which are common stressors to coastal wetlands. Observed leaf-level changes in net assimilation (atmospheric carbon fixation), transpiration (water loss), and stomatal conductance (CO_2 plus water vapor exchange) on field sites often lead to hypotheses designed to identify environmental controls (fig. 1*A*). Greenhouse studies are then constructed to manipulate factors that cannot be controlled under field conditions and that allow for more intensive investigations of leaf gas exchange at targeted stress levels. Parameters such as CO_2 and light can also be altered as plants are exposed to different stressors (fig. 1*B*).

Individual Tree Water Use

One of the best ways to quantify individual tree water use in natural field settings is through the use of sap-flow techniques. Water flowing through the outer portion of a tree's stem is determined with a heat dissipation process (Granier, 1985). Two probes are inserted into the outer portion of a tree's stem, embedded with thermocouples, and heated at the downstream probe; temperature differences decrease during the day as stem water transport increases.

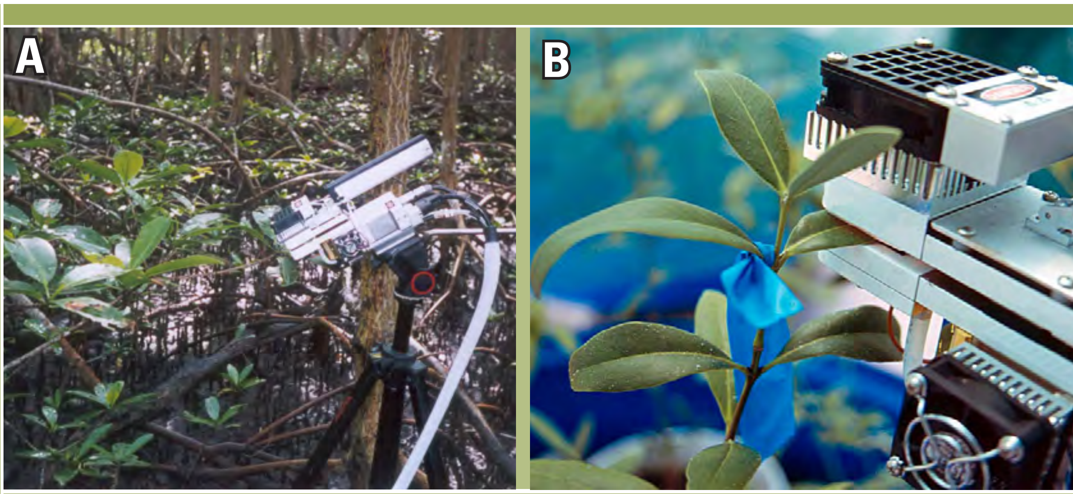

Figure 1. ***A,*** **Leaf gas exchange of a mangrove tree sapling in Everglades National Park, Fla., being evaluated at a constant light level with an infrared gas analyzer (IRGA);** ***B,*** **Leaf gas exchange for a mangrove tree sapling being measured across a range of light levels in a greenhouse study designed to vary hydroperiod while keeping salinity and fertility constant.**

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Fact Sheet 2007–3018
March 2007

Through an empirical formula, water flow at the location of probe insertion can be determined with a fair degree of accuracy and, with appropriate scaling metrics (e.g., sapwood area, total leaf area, etc.), can allow for an estimate of water volume and flow within an individual tree. These studies have been useful in confirming that conservative water-use strategies documented for seedlings and saplings at the leaf level also apply to mature mangrove trees in the field (fig. 2).

Soil Respiration

Leaf gas exchange drives CO_2 uptake by ecosystems, but CO_2 is lost from ecosystems through aerobic soil respiration (microbes) and belowground plant respiration. To understand ecosystem-level CO_2 exchange and how exchange is altered by different hydrologic and salinity regimes, it is useful to measure soil CO_2 efflux along with leaf-level processes. Several studies, both greenhouse- and field-based, have been conducted to determine how salinity, tides, and permanent flooding interact to affect soil CO_2 efflux from tidal freshwater swamp forests (fig. 3).

Figure 2. *A,* Individual trees in a mangrove forest stand in Rookery Bay, Fla., with xylem sap flow sensors embedded; *B,* Sap flow of individual trees of three mangrove species while stands were flooded versus drained. Flood state had a significant effect on individual trees of all three species in this evaluation.

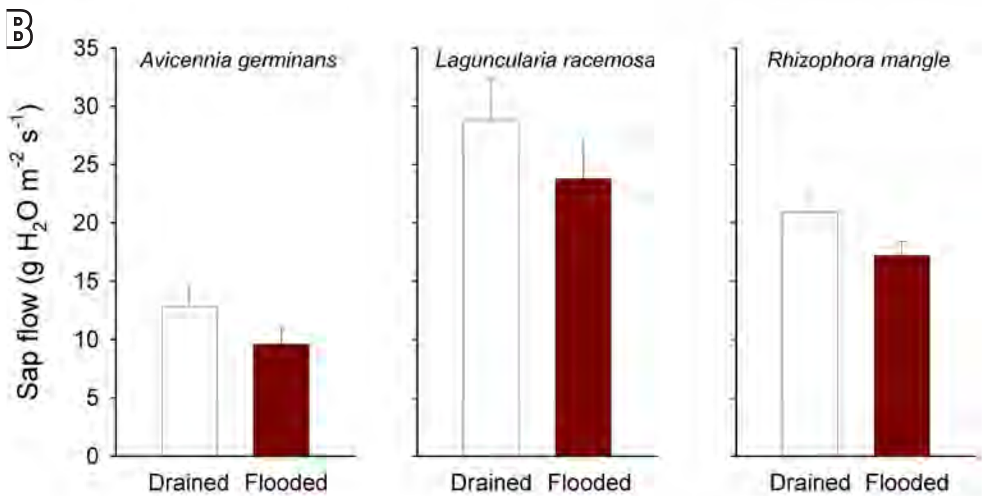

Figure 3. A tidal freshwater swamp forest in Savannah National Wildlife Refuge, Ga. Insets depict measurements being taken by a soil CO_2 efflux chamber and infrared gas analyzer (IRGA) during greenhouse and field studies.

Modeling

Stand Water Use

Sap flow investigations can be expanded to quantify water flow at multiple depths into the tree; not all sapwood is as effective as the outer portions at conducting water. In fact, water flow is approximately 60 percent less at a depth of 4 cm into the tree than at a depth of 2 cm in mangrove trees in south Florida (Krauss and others, 2007). Once absolute rates of sap flow are determined and depth profiles are constructed, stand water use can be calculated as a function of species distribution; tree diameter distribution; environmental stress regime (e.g., flooded versus drained); and daily, monthly, and annual meteorological state (e.g., vapor pressure deficit, light regime). This approach has indicated that stand water use in south Florida mangroves, for example, is extremely conservative overall and is affected little by relative site flood frequency, even though sap flow is reduced by flooding at the individual tree level. Additional studies by scientists at NWRC will attempt to verify these results from different mangrove locations and determine whether stand water use is as conservative in tidal freshwater swamps and other coastal wetland forests.

Landscape Assessments

To date, studies have suggested convergence among seedling, sapling, and individual tree responses in order to justify the extrapolation of many water use functions to the landscape. Accordingly, additional studies need to be conducted to determine the ultimate role of coastal forested wetlands in affecting water budgets as hydrologic regimes change. Our first step in this process is embedding empirical functions that describe stand water use as sub-routines within existing landscape ecological simulation models (e.g., Doyle and others, 2003). It is also important to design landscape-level studies; we are currently developing a surface water hydrologic budget for a marsh-mangrove complex on Ten Thousand Islands NWR, Fla., to help empirically identify the role of coastal wetlands in regional water budgeting (fig. 4). Coastal land managers and scientists can then begin to determine exactly how coastal forested wetlands respond to altered hydroperiods on a large scale.

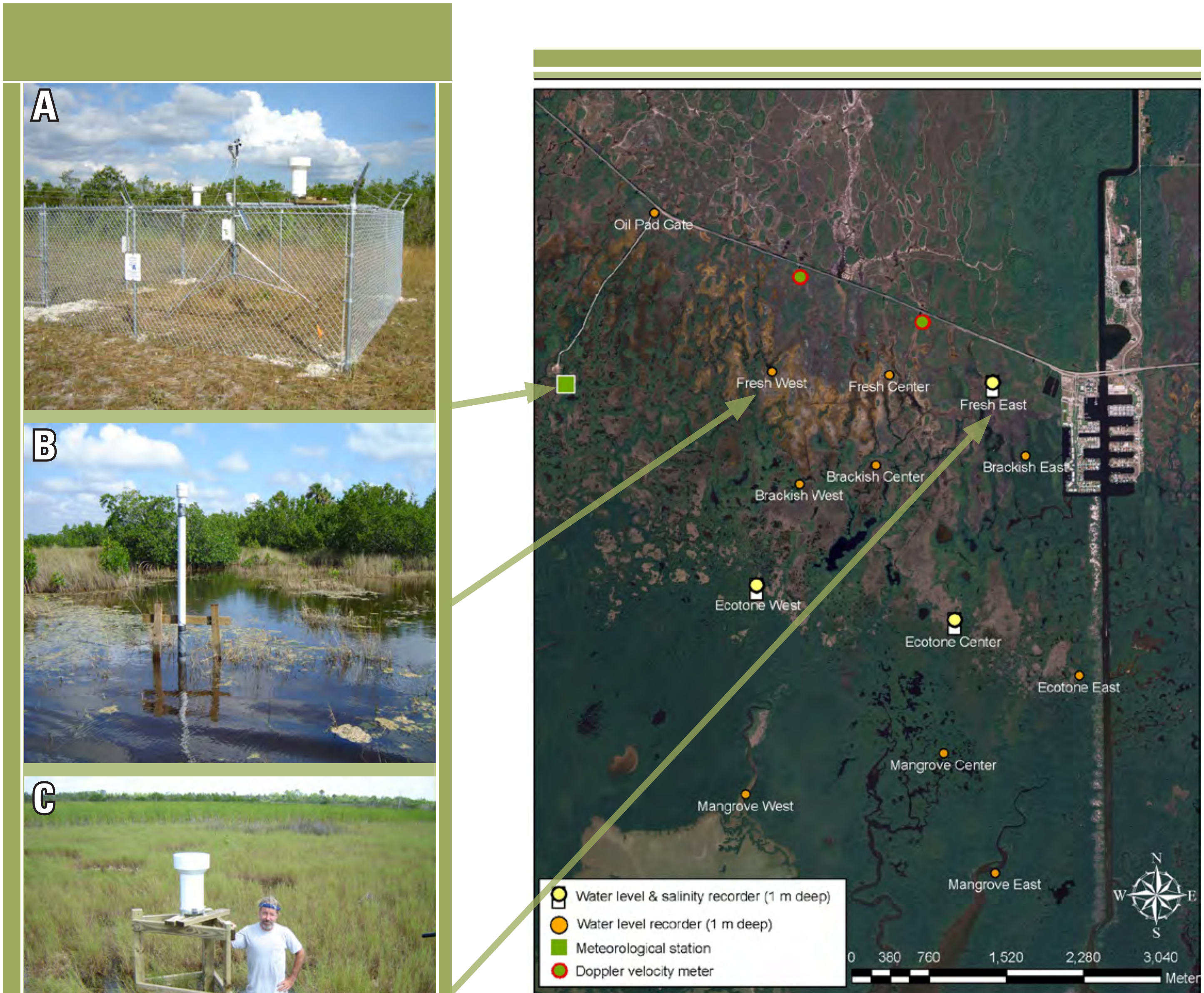

Figure 4. An aerial image of a marsh-mangrove wetland complex at Ten Thousand Islands National Wildlife Refuge, Fla., with depictions of parameter station locations. *A*, weather station used to model evapotranspiration; *B*, surface and ground water stage recorders; *C*, tipping bucket rain gage.

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For more information, contact

Ken W. Krauss, Ph.D.
U.S. Geological Survey
National Wetlands Research Center
700 Cajundome Blvd.
Lafayette, LA 70506
337-266-8882
kkrauss@usgs.gov