SCIENCE AND CULTURE

Journal entries, maps, and photos help ecologists reconstruct ecosystems of the past

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Ilka Feller has a penchant for mangrove hunting. Since the early 2000s, Feller, an ecologist at the Smithsonian Environmental Research Center, has periodically gone road-tripping in search of the northernmost mangrove tree in Florida. The red mangrove, *Rhizophora mangle*, has draping roots that hold fast in the tide. But all three of Florida's mangrove species anchor themselves and whole ecosystems—protecting the shoreline from erosion, forming nurseries for fish, and sequestering carbon.

Globally, mangroves are threatened by coastal development and shrimp farming. "More than half of the world's mangroves have already been destroyed," says Feller. Yet in Florida, Feller kept finding new mangroves farther and farther north, "solitary plants that are out there in this forever saltmarsh."

As part of a 2014 study, Feller's then postdoc, Kyle Cavanaugh, analyzed satellite images taken from 1984 to 2011 and saw that mangroves were indeed advancing northward (1). The spread was associated with a reduced frequency of extreme cold events. Climate change, it seemed, was replacing marshland, an important temperate ecosystem, with mangroves, an important subtropical and tropical one. But had they really revealed a trend pointing in one direction, or was the recent expansion of mangroves part of a

Ecologist Ilka Feller used archival records to investigate whether mangroves in Florida, like these in Indian River Lagoon, are expanding into new territories or returning to a historical range. Image credit: Ilka Feller.

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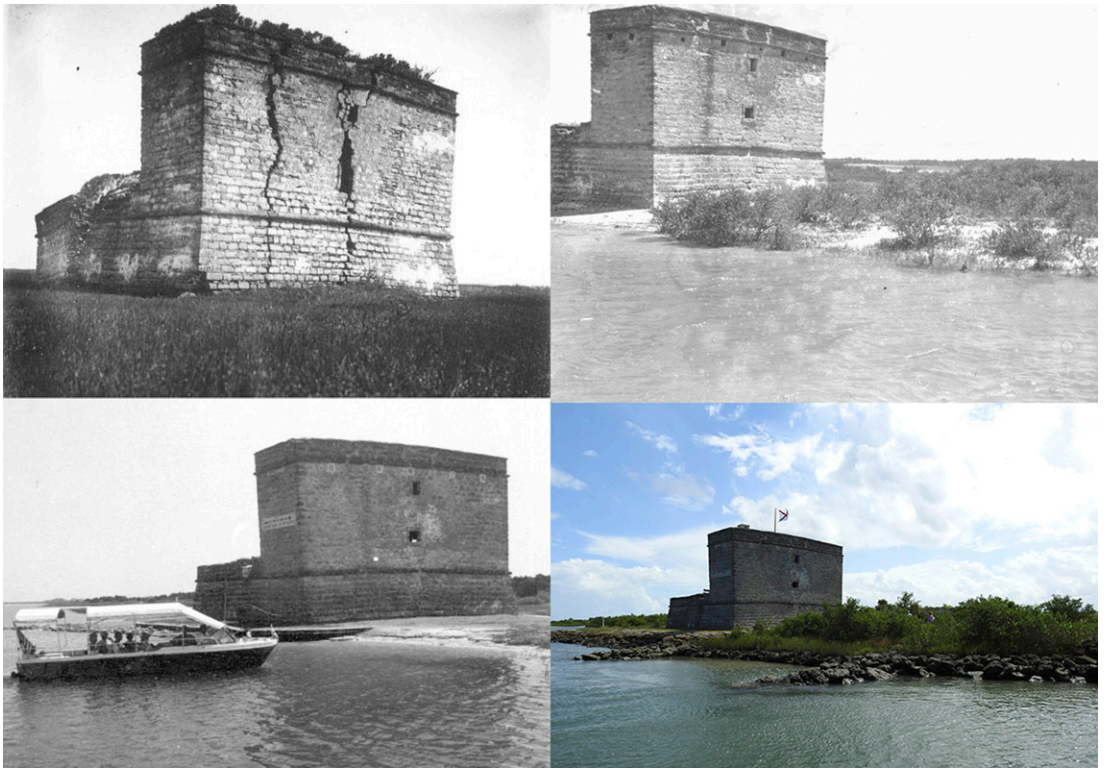

Photographs of Fort Matanzas National Monument, located south of St. Augustine, FL, offer visual evidence that the mangrove's range has expanded and contracted multiple times. Mangroves appear to varying degrees in photos taken in the early 1900s (*Top Left*), 1934 (*Top Right*), 1981 (*Bottom Left*), and September 2018 (*Bottom Right*). Archival images credit: State Library and Archives of Florida. 2018 image credit: Matthew Hayes (Villanova University, Villanova, PA).

continual cycle of mangrove and saltmarsh replacing one another? Feller needed more than just conventional scientific data to find out.

So she dug into Florida's past using tools more typical of historians. She found mangroves mentioned in the texts of famed naturalist John Muir, uncovered data in tourist photos, and parsed the writings of war surgeons and beekeepers.

Feller and a growing group of ecologists are piecing together historical records to understand how ecosystems have changed over timescales that extend beyond the memories of the current generation of researchers and residents. These portals to the past can help researchers better predict and plan for the future. But as historians already know well, ecologists first have to figure out how to find these records and whether to trust them.

Reading Between the Lines

After reading Feller's article on mangrove range expansion (1), US Geological Survey researchers Chandra Giri and Jordan Long published a letter to the editor noting that, because Feller only went back to 1984 when the satellite imaging began, she couldn't say definitively whether the northward spread was really just a return to a historical range (2). Feller responded that, either way, freezing determined the range (3). Still, she was curious.

At first, Feller wasn't sure how to approach historical records. She consulted textbooks on historical ecology, a growing field defined in a recent review as "the study of nature over time" (4). Historical ecologists use archival sources as well as biological ones, such as pollen records and tree rings, often with the ultimate goal of using a landscape's history to illuminate its potential. "We can draw on our understanding of the past to creatively reimagine what is possible in the future," says review author Erin Beller, an environmental researcher and historical ecologist at the San Francisco Estuary Institute and PhD candidate at the University of California, Berkeley.

Researchers have drawn on historical records to explore past landscapes since as early as the 18th century (5). The field took off with North American ecologists in the 1990s (5), as researchers used archival records to explore historical changes in a range of ecosystems—from shifts in vegetation since the establishment of Yellowstone National Park (6) to declines in green turtle abundance in Caribbean coastal ecosystems since Columbus (7).

Feller began her historical ecology exploration by searching the used books section of Amazon and online holdings of historical documents. She soon stumbled on an 1823 book by Charles Vignoles, a surveyor for the city of St. Augustine, FL (8). In one passage, he says nearby Ponce Inlet "affords water for vessels drawing ten feet: the anchorage is good inside and on the south shore a vessel may lay alongside and make fast to the mangroves." A book on historical ships revealed that a vessel "drawing ten feet" meant

a boat 100–150 feet long. And that meant tying up to a pretty large, robust tree.

In the journal of US Army surgeon Jacob Rhett Motte, Feller found evidence that freeze events could shrink the range. Motte described traveling by boat in 1836 during the Second Seminole War in the same region that Vignoles mentioned more than a decade earlier—except that in Motte's account, the mangroves are dead (9). Feller notes that 1835 is still on record as including the most severe cold event in Florida's history.

Looking to photographic evidence, Feller and her team searched Wikimedia and the online archives of the Florida Division of Library and Information Services for images of Fort Matanzas National Monument, a fort built by the Spanish in the mid-18th century that sits on a barrier island south of St. Augustine. Tourists have taken photos of this monument since the early 1900s. In some photographs, mangroves dominate. In others, it's saltmarsh. "This was months of struggling to find all of these little bits and pieces," says Feller. "The connection is not made for you. It's like reading between the lines."

Advance and Retreat

Cavanaugh, now an ecologist and geographer at the University of California, Los Angeles, placed these findings on a map using GIS Software. Looking at the points, they now know that the current northward expansion of mangroves has not, in fact, reached its historical limit. Their proof comes from the writings of John Muir. In 1867, Muir caught his first glimpse of Florida by boat, "a flat, watery, reedy coast, with clumps of mangrove" (10). Just south of Georgia, Muir was about 20 kilometers north of Feller's current northernmost record.

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The current hypothesis of Feller and Cavanaugh's team is that hurricanes sweep the mangrove propagules and, hence, the trees' range northward, whereas freeze events drive it back southward (11). Gleaning from all the records they've sifted through, the team now estimates that the mangrove range has contracted and then expanded three or four times since the early 1800s. The shifts occurred quickly, says Cavanaugh. "A single severe freeze can be enough to shift the system back to saltmarsh dominance."

Cavanaugh recently built a model that predicts past changes in mangrove abundance back to 1850 for an area near Fort Matanzas National Monument. The model employs temperature records, experimental data on cold tolerance, satellite images taken since the 1980s, and aerial images reaching back to the 1940s. When he compared the results with historical records Feller had collected, Cavanaugh found close agreement. With the historical records lending confidence in the model, Cavanaugh then modeled future mangrove abundance. "One outstanding question is: Is this more recent shift toward mangrove dominance going to be made more permanent because of climate change?" says Cavanaugh. His results, which he plans to publish soon, suggest that it will.

A Trove of Data

Ecologists might delve into historical archives for myriad reasons. Beller says history offers a "trove" of data that she and others at the San Francisco Estuary Institute use to help nonprofits, private companies, and government agencies see restoration opportunities. In Silicon Valley, her team discovered that, before around 1900, willow groves covered more than 2,000 acres. The group found written records and maps of willows, including some from before the Gold Rush, and a drawing of picnickers in a willow grove in what is now downtown San Jose, CA. Google, inspired by these findings, recently removed more than 100 parking spaces to expand a rare existing willow grove on its campus in Mountain View, CA.

To gauge changes in seasonal events, such as flowering and migration, plant ecologist Richard Primack of Boston University put out a call for local historical datasets that might capture changes in phenology (12). He and his team learned that Henry David Thoreau had made handwritten tables of the date of first flowering for more than 500 species in Concord, MA from 1851 to 1858. By combining Thoreau's and botanist Alfred Hosmer's notes with their own observations, the team discovered that plants in Concord now flower 10 days earlier, on average, than during Thoreau's time (12).

Looking to reveal long-term changes in marine ecosystems, marine historical ecologist Loren McClenachan of Colby College uses archival records to estimate species' population sizes before they experienced any appreciable human influence. Identifying these "historical baselines" can help managers make recovery targets closer to species' actual potentials (13). In a 2017 study, her team used 18th-century British nautical charts to estimate changes in the coral reef area in the Florida Keys (14). Typically, coral decline is measured by the percentage of loss of coral in existing reefs. But McClenachan's team discovered that about half of the coral observations marked on these charts are in places where coral reefs no longer exist today.

Outside the Lens

For ecologists, historical records are both a boon and a challenge. The first hurdle is simply finding the records. Students of McClenachan's recently asked historical societies in Maine for images of a seaweed called rockweed but came back empty-handed. When going to archivists, ecologists need be careful how they frame the question, explains McClenachan. Historical societies don't typically organize their photo

archives according to marine species. When the students instead asked for tourist pictures taken along the coast, the rockweed appeared alongside smiling vacationers.

But in some cases, the data may not exist. In addition to flowering time notes, Primack has also found Thoreau's records on bird and tree phenology (12). Insect data, however, are proving more elusive. He's uncovered records on butterfly flight times from a local butterfly club; other biologists have found bee records using museum specimens. "But for a lot of other insect groups, including flies and dragonflies," he says, "there is surprisingly little information."

Then there's the issue of veracity. "There is no document that gives us a transparent view into the past," says Joseph Taylor III of Simon Fraser University, a Western North America and environmental historian. "Even a photograph is literally framed by the lens, and what is outside the lens is outside the record." Historians, he notes, are trained to place evidence in context, thinking critically about where a document was found, who produced it, and for what audience. Some researchers follow this same practice, says Taylor. But others, in an attempt to arrive at a definitive data point, may run "roughshod over the limitations of their resources," pitfalls Taylor described in a 2013 commentary (15). Biases abound, notes McClenachan—in the case of fish-catch records, for example, a fisherman who's taxed on his catch might be tempted to underreport.

Feller, though, isn't finished. After retiring at the end of this year, she'll visit historical societies that haven't yet digitized their records. New discoveries keep her motivated. Only recently, for example, she found that beekeepers once placed hives in black mangrove forests. When freezes hit, the beekeepers wrote about them, hence offering another window into how past freezes affected mangrove health. "There's a lot to be learned," says Feller, "in reading these obscure beekeeping journals."

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