Aquaculture | Community | Action | Engagement | Economic Development

MAINE EPSCoR

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Maine EPSCoR

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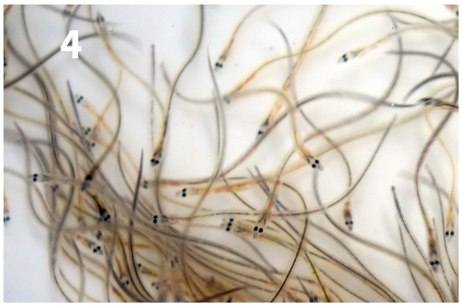
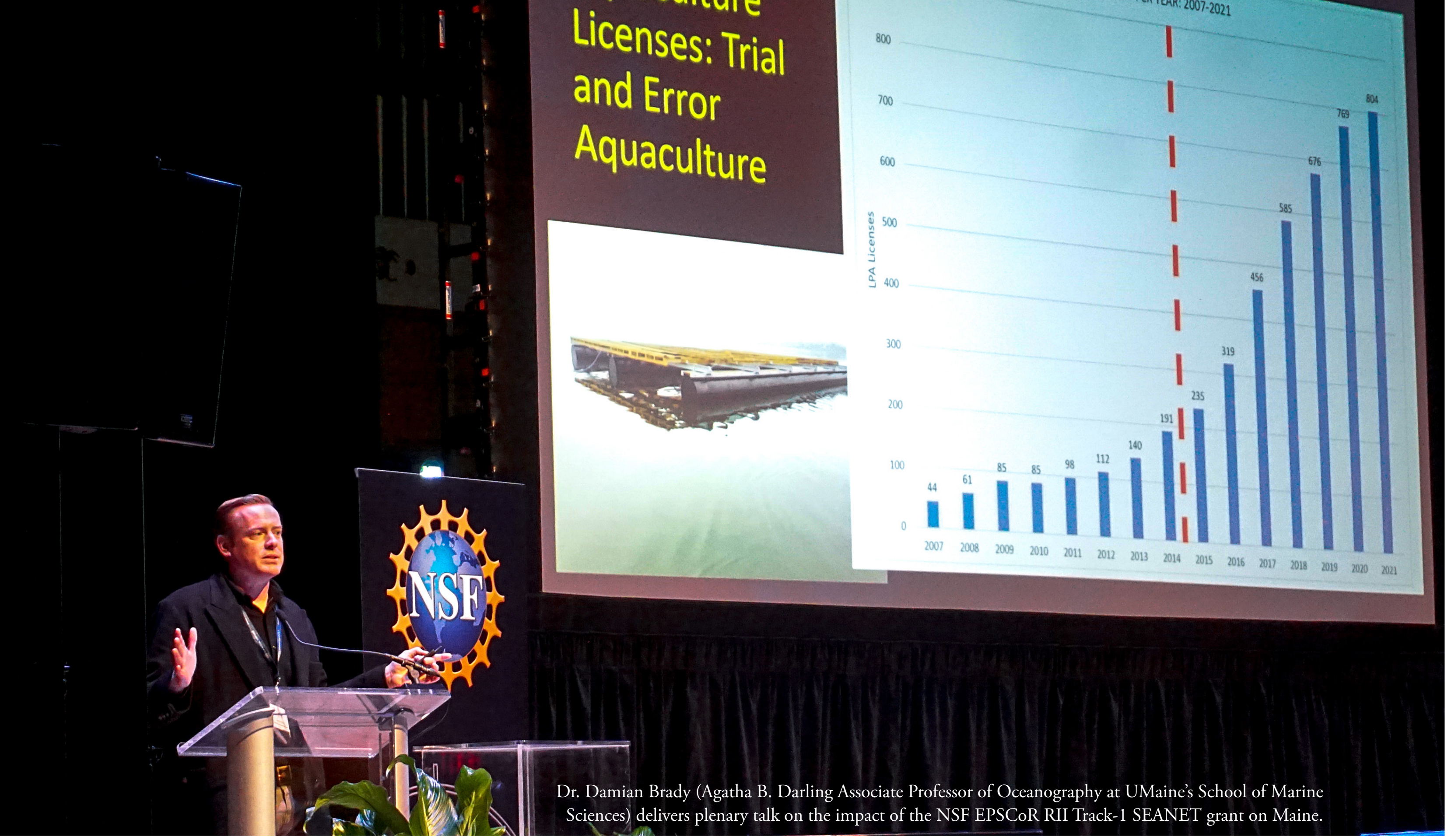


Contents

On the cover: Maine-eDNA graduate students, Julia Sunnarborg and Sharon Mann, lead index site sampling training for Maine-eDNA summer undergraduate interns at the Darling Marine Center in Walpole, ME.

What is Maine EPSCoR?

Maine EPSCoR (Established Program to Stimulate Competitive Research) at the University of Maine seeks to expand opportunities for more diverse faculty, staff and student populations. Diversity brings different perspectives and skill sets, and helps broaden our vision. We recognize that geographic and societal challenges exist that require pragmatic solutions with achievable and measurable goals. Maine EPSCoR strives to enhance diversity in all elements of EPSCoR programs while increasing participation of underrepresented minorities in science, technology, engineering and mathematics (STEM) disciplines.



Dr. Damian Brady (Agatha B. Darling Associate Professor of Oceanography at UMaine's School of Marine Sciences) delivers plenary talk on the impact of the NSF EPSCoR RII Track-1 SEANET grant on Maine.


Conference attendees gather for a panel on STEM career paths outside of traditional academia in the Portland Museum of Art.

From Maine EPSCoR
Leadership

Kody Varahramyan
Vice President for Research and Dean of the Graduate School

Shane Moeykens
Director of Maine EPSCoR

In November of 2022, Maine EPSCoR was honored to host the 27th NSF EPSCoR National Conference, the first one held in the three years. More than 430 individuals from across all 28 EPSCoR jurisdictions and beyond convened in Portland, Maine. This was an opportunity for colleagues and friends, old and new alike, to share accomplishments, discuss research, and generate new ideas that furthers EPSCoR's mission. Over three days, we heard compelling presentations from the conference's plenary speakers, and afternoon talks and panels were conducted across the conference's five concurrent tracks that engaged researchers, EPSCoR staff, stakeholders, undergraduate and graduate students, and postdoctoral fellows and early-career faculty.

This conference could not have come together without the help of our colleagues from across the national EPSCoR community and the NSF EPSCoR team. It was a pleasure hosting everyone, learning from other jurisdictions, and getting to show Maine off to our guests. We hope the conference inspired you and your colleagues as much as you inspired us and our research pursuits.

We are proud to present this newsletter to you, which presents a window into Maine's 2022 EPSCoR programming, and also shares impacts of past Maine EPSCoR research and participants — how they have and continue to impact workforce and economic development in Maine. Thank you for your continued support and interest in our work.

Sincerely,

Maine EPSCoR

Conference attendees watch morning plenaries at the Merrill Auditorium.

Maine-eDNA

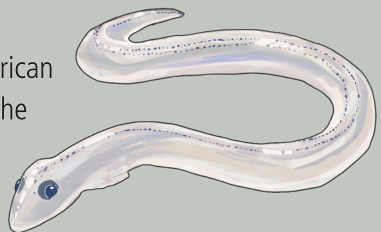
Research Learning Experience

BY CATY DUDEVOIR, MEDIA INTERN

Maine's forests, oceans, rivers, and land sustain vital economic and social opportunities, and understanding how to properly manage the state's resources requires a level of stewardship. Involving undergraduate students in research is a small step in addressing resource management and promotes exploration within scientific research environments. Last fall, Maine-eDNA (Maine's current NSF EPSCoR RII Track-1 grant) offered an academic course with the University of Maine (UMaine) that introduced students to environmental DNA (eDNA) through one of UMaine's research learning experiences (RLE). Environmental DNA is genetic material that organisms naturally shed into their surrounding water, air, or soil. In collaboration, Peter Avis (Adjunct Instructor, UMaine School of Biology and Ecology) and Mike Kinnison (Professor and Director of the Maine Center for Genetics in the Environment), created an RLE course that aimed to use eDNA to detect American eels in water samples from the Stillwater River in Orono, Maine. During the course, eleven students met once per week to gather and filter river water samples, extract DNA, and interpret the data. The data collected by the undergraduate students ultimately helped inform the Maine Department of Marine Resources (DMR) on how to better manage American eel populations in Maine's rivers.

Avis, who led the RLE course and is Maine-eDNA's undergraduate research coordinator, works to expand student engagement experiences. Avis explained, "I've worked with undergrads my entire career. The research that I do is almost always directly tied to undergraduates and having them learn how to do research. For me, it's a model for building their ability to be good scientists." Particularly for undergraduates, when research can help address real-world issues, there is more engagement and meaning behind the project. Recently, Maine's elver fishing industry saw one of its most successful seasons, being valued at roughly $20 million. However, a thriving season this year is not a guarantee for future years, so understanding how to best manage the elver population and create healthy fishing habits is vital.

Eels played an essential role as a food source for Indigenous communities and early European settlers in Maine. "Historically, American eels were a massive part of aquatic ecosystems in Maine. They were so abundant that they were one of the primary, staple foods for European colonizers as they learned to live on the land." Today, however, the construction of hydroelectric dams hinders eels' normal migratory patterns. Other factors like climate change and overfishing may also be affecting Maine's eel population, causing further uncertainty about eels' health and numbers.



In the early part of their lives, American eels hatch from eggs spawned in the middle of the Atlantic Ocean. The Gulf Stream carries the juvenile eels to the northeastern United States, where the eels migrate from the sea to rivers and lakes to grow to maturity, at which point they migrate back to the ocean during fall to spawn and die. When the eels first reach Maine's estuaries and rivers as juveniles, they are called "glass eels" or "elvers." At this stage, the eels have a transparent complexion other than their dark eyes. Maine fishermen harvest the elvers on their upstream migrations and work with brokers that sell them to aquaculture businesses in Asia. Due to increased scarcity, the price of elvers skyrocketed, and eels have become a lucrative industry for Maine fishermen. Currently, freshwater eels throughout Europe, Japan, and North America have been declared threatened by the International Union for Conservation of Nature, although Maine's populations have fared better than most others. Avis said, "Interest in preserving this fishery and restoring eels to their historical range in Maine has increased. State, tribal, and federal agencies, among others, have interest in assessing the current status and threats faced by this species."

To determine if eDNA is a viable tool to detect eel populations in the rivers of Maine, the undergraduate students, guided by Avis and Kinnison, developed and executed a research project that also considered sampling factors that could influence the detection of the eels. Avis explained, "We took advantage of the Maine-eDNA research infrastructure as well as the proximity of the University of Maine to the Stillwater Branch of the Penobscot River system." Since eels typically migrate during the night, students sampled twice per day along four location sites on the Stillwater River to "assess whether higher levels of eel eDNA would be associated with nighttime activity (4 a.m.) versus the day (4 p.m.)." Avis continued noting the students' enthusiasm for and engagement with the research.

Ultimately, the class found that eDNA analysis did detect the presence of the American eel in the river, and the water sampling location made some difference to the detection model. However, time of day did not affect the level of data collection. For instance, higher levels of eel eDNA were found below the dam, and the nighttime data collection did not provide any higher detection levels than during the day. "Our study suggests that eels shed eDNA at sufficient rates for detection," Avis explained, "This study also provides baseline information that can assist the Maine Department of Marine Resources, and other natural resource partners, in the monitoring and management of American eel in the rivers of Maine."

Illustrations: Development of the American Eel

Engaging undergraduates in research projects gives groups like DMR more data for their future projects and allows their projects to expand in various ways. Avis explained, "Answering those unknowns that normally wouldn't get addressed directly by the Maine DMR is a way to continue working with undergraduates." Students can provide valuable information about certain research topics that major management groups and natural resources partners may not necessarily have the time for. Researchers can strategically design questions and assignments that allow for true engagement and meaning for students. As the RLE course ended, several students joined the UMaine Environmental DNA Laboratory. Each summer, the Maine-eDNA team offers internships that provide undergraduates with a deeper knowledge of eDNA as a research tool and equips them with a group of professors and coordinators who support them. ■

Forest Biproducts Research Institute

BY DANIEL TIMMERMANN

The University of Maine is home to a number of prestigious research centers and institutes working on the cutting edge of their research fields. Many were developed by and grew out of research projects brought to Maine through NSF's Established Program to Stimulate Competitive Research (ESPCoR). One example of this is the Forest Bioproducts Research Institute (FBRI) at the University of Maine (UMaine) in Orono.

FBRI was launched by the 2006 NSF EPSCoR Track-1 grant Investing in Maine Research Infrastructure: Sustainable Forest Bioproducts. An important goal of the nearly 7.5-million-dollar grant was to create FBRI "to advance understanding about the scientific underpinnings, system behavior, and policy implications for the production of forest-based bioproducts that meet societal needs… in an ecologically sustainable manner."

Hemant Pendse, the director of FBRI who has been with UMaine since 1980 and was honored as the 2021 Distinguished Maine Professor, explained that collaboration among researchers in related disciplines predated the formation of FBRI and helped lead to the funding that established it. Prior to the 2006 Track-1 grant, "Chemical engineering researchers and pulp and paper researchers began working closely with

FBRI Director Hemant Pendse has built the institute's research agenda around fuels, chemicals, and advanced materials, all derived from wood.

researchers from what was then called the Advanced Engineering Wood Composite Center (now the Advanced Structures and Composites Center) and the UMaine School of Forest Resources," Pendse recalled.

While other universities have researchers in similar fields, the interdisciplinary group of researchers working together in Maine were well positioned to study sustainable forest bioproducts, leading to the NSF EPSCoR grant awarded in 2006. "We have built our reputation on interdisciplinary work," Pendse said, "It's in our DNA. To have four groups of researchers working together in this way only happens in Maine, and that's why everyone knows that UMaine is the place to go if you want to explore new ways to use wood."

FBRI focusses on three main areas of research: fuels, chemicals, and advanced materials. The deliberately broad approach allows FBRI to vary and shift its work depending on need, interest, and advances in research. "A lot of credit goes to our initial vision and FBRI's broad umbrella," Pendse explained. "It serves us well as a foundational set of principles. We believe that our focus on fuels, chemicals, and advanced materials will serve us well for another ten years."

Maine's sustainably managed forests are one of the state's most valuable natural resources, and FBRI is a vital partner to many wood suppliers and wood users across the state. The institute has embraced open collaboration and is a partner in the industry-led Forest Opportunity Roadmap Maine (FOR/Maine) effort to sustain and grow Maine's existing and emerging forest products economy.

Pendse explained the philosophy, "We believe in open innovation and putting sufficient experimental materials into the private sector, as well as broadening understanding of how those materials can be used. We function as a proving ground to support industry as they explore new uses for forest bioproducts and our research, demonstration and development capacities can help companies gain confidence to implement new materials and technologies."

These are not empty platitudes. FBRI embraced public-private partnerships and built three pilot plants that can operate at an industrial scale. The pilot plants are able to take new and developing technologies from the lab bench and demonstrate them on an industrial scale to collect and share engineering data and key performance metrics. Nearing two decades since its inception, FBRI is a launch pad that drives research, industry, education, and economic development in Maine.

FBRI
FOREST BIOPRODUCTS
RESEARCH INSTITUTE

FBRI's efforts to develop and help commercialize sustainable materials and technologies from wood meet a range of unique needs in Maine. In a state where a majority of households use fuel oil as their primary energy source for home heating, the institute has dedicated significant research to developing new fuel sources from forest bioproducts. FBRI aims to demonstrate that forest-based products can be manufactured at a commercial scale to replace fossil-fuel derived counterparts and inspire the creation of a small, commercial-scale biorefinery in Maine.

Seed funding from the Maine Technology Institute helped establish FBRI's Technology Research Center (TRC) in Old Town, Maine, the hub of the institute's wood-to-jet-fuel research program. While the name refers to jet fuel, this research program has broadened considerably thanks to ongoing

FBRI researchers use mixed acids derived from sawdust to produce thermal deoxygenation (TDO) oil in the Synthetic Crude Oil Pilot Plant.

support from the Defense Logistics Agency's Energy Readiness Program (DLA ERP). Since 2015, DLA ERP has allocated nearly $23 million to support biofuels research at UMaine, and the FBRI research team is exploring a range of renewable fuel co-products including heating oil, diesel and even gasoline. In a major recent milestone, an oil refinery technical team is testing jet fuel made at UMaine to explore possible avenues for its use in commercial aviation.

Turning from fuels to advanced materials, the seat of FBRI research is the nanocellulose pilot plant, part of the University's Process Development Center located in Jenness Hall on the UMaine campus. The pilot plant is capable of churning out two tons of nanocellulose per day, using not only pulp, but also wood particles and non-woody plants. The center distributes the material to researchers around the world to advance public and private R&D aimed at finding new commercial uses for this abundant, renewable, biodegradable substance. At UMaine, researchers affiliated with FBRI are exploring how nanocellulose can be used in a range of different materials from construction products to packaging, and researchers in other disciplines, including aquaculture, are innovating with the material in unique ways.

"Early on, we were using nanocellulose primarily as an additive for product enhancement," said Pendse. "Thanks to our production infrastructure, process innovations, and strategic recruitment, UMaine has become a true leader in this research area and we're now reaching into the development of novel nanocellulose composites."

When it comes to chemicals FBRI is active in converting wood into platform chemicals that can be economically transformed into a wide range of specialty chemicals. For example, levulinic acid, one of the top platform chemicals that is currently being produced and purified at TRC, can be used for applications in personal care products and flavors and fragrances in food additives.

FBRI continues to push research forward in part by recruiting talented faculty and researchers

Nanocellulose produced in the Process Development Center is crucial to FBRI's advanced materials research.

to Maine. As part of the initial EPSCoR grant, FBRI brought in Peter van Walsum (UMaine Associate Professor of Chemical and Biomedical Engineering) in 2007 and one year later Aaron Weiskittel (UMaine Professor of Forest Biometrics and Modeling). With FBRI, van Walsum develops bioprocessing fuels and chemicals that offer more sustainable and efficient solutions to Maine's energy and industrial needs. Weiskittel builds models and forecasts to predict biomass growth and yield across Maine's forests. Expanding on this work, Weiskittel currently leads two important research centers at UMaine, the Center for Advanced Forestry Systems and the Center for Research on Sustainable Forests.

Continuing to recruit talented researchers, FBRI hired Mehdi Tajvidi (UMaine Associate Professor of Renewable Nanomaterials) in 2013. Working with cellulose and nanomaterials, Tajvidi's research focuses around the development of advanced materials like new coatings, packaging, and building products. In 2018, Ling Li (UMaine Assistant Professor of Sustainable Bioenergy Systems) joined FBRI and works to develop more efficient biomass energy and woody industry solutions. FBRI faculty and researchers have produced nearly a thousand publications, and hundreds of graduate and undergraduate students have earned their degrees while working with FBRI, learning from the institute's faculty and researchers. One of those undergraduates was Tom Schwartz (UMaine Associate Professor of Chemical and Biomedical Engineering) who worked on FRBI's Thermal Deoxygenation (TDO) reactor, which produces hydrocarbon fuels from biomass. After earning his Ph.D. in Chemical Engineering from the University of Wisconsin, Schwartz returned to Maine as a UMaine faculty member working with FBRI.

While the institute was established through the initial NSF EPSCoR grant, it has subsequently earned several million dollars in external grant funding and other contracts every year since. The 224 grants (from 2010 to 2021) awarded to FBRI, totaling over 64-million-dollars, speak to the quality of the institute's leadership, faculty, researchers, and other personnel. It's the people, their research, and their pursuit of new horizons that has brought in this funding, built Maine's research capacity, and established Maine as a global leader in forest bioproducts.

FBRI is an exemplary example of what EPSCoR's mission to enhance research competitiveness of states like Maine in STEM fields looks like when it is fully realized. As Pendse explained, unique conversations and collaborations around forest bioproducts were already taking place in Maine. NSF ESPCoR gave Pendse and the FBRI team the ability to build a world-class research center that leverages Maine's natural resources to better the state, country, and globe. ■

Mind the Gap:

Ecology, evolution, and the impact of humans on the natural world

BY STEFANIA IRENE MARTHAKIS

The poet Charlies Baudelaire defined modernity as "the ephemeral, the fugitive, the contingent, the half of art whose other half is the eternal and the immutable." Given the time-sensitive nature of modernity, "this transitory, fugitive element, whose metamorphoses are so rapid" that once uncovered, offers yet more to unearth.

In the paper, The pace of modern life, revisited, Michael T. Kinnison and Zachary T. Wood (University of Maine Professor of Evolutionary Applications and Postdoctoral Researcher/Adjunct Professor, respectively), along with Andrew Hendry and a network of collaborators connected with McGill University in Montréal, aim to understand global patterns of human effects on ongoing evolution in nature. Specifically, how rates of phenotypic evolution (the evolution of expressed traits) in wild populations respond to environmental changes.

This paper is a long-term output of a project — which included the original paper, *Perspective: The Pace of Modern Life: Measuring Rates of Contemporary Microevolution* — that Kinnison and Hendry started in the 1990s. They began with a database, The Phenotypic Rates of Change Evolutionary and Ecological Database (PROCEED), of around 100 rates of evolution, asking how fast does evolution occur? Kinnison and Hendry concluded that evolution is very common and often very fast on humanly observable time scales of years to decades. This research revealed several often-overlooked patterns of what is commonly called contemporary evolution (i.e., evolution within a handful of generations), which can occur quickly enough to interact with ecology and be affected by human impacts. PROCEED now has over 6,000 measured rates of contemporary evolution, which opens the field to ask large-scale questions about the nature of evolution.

As Kinnison noted, "Even early in our database development, it seemed that many of the fastest rates of contemporary evolution were associated with human activities like fisheries harvest, pollution, and species invasions, but with only a limited number of case studies to work from the results were more tantalizing than conclusive. Fortunately, the tantalizing nature of those early analyses encouraged a lot more research by others that we were able to build into our database."

As part of the NSF EPSCoR RII Track-2 grant, GECO (Genomic Ecology of Coastal Organisms: A Systems-Based Research and Training Program in Genome-Phenome Relationships in the Wild), Kinnison and Wood lead part of the research effort studying links between ecological interactions and natural selection happening during those interactions. Specifically, when evolution is present during ecological dynamics

Zach Wood

(i.e., when living things interact), which is called eco-evolutionary (eco-evo) dynamics.

Looking at predator/prey eco-evo dynamics, Wood explained, “When a predator is consuming a prey, what happens when the prey can evolve defenses during those dynamics? For example, how fish develop a morphology for swimming away quickly, hiding behaviors, and predator inspection behaviors. How does that change the interactions between predator and prey?”

With more rates of evolution to work with, along with a strong underpinning of how evolution and ecology interact with each other (including an average rate of evolution), researchers can now be more specific and more conclusive—as well as break down this large amount of data from different impacts. Wood has focused on how human impacts affect evolution (e.g., pollution, non-native species, landscape change).

Wood stated, “Universally across the board, nearly all effects that humans have had on evolution are to speed it up. The differences are massive —doubling, tripling. For example, pollution causes the rate of evolution to speed up ten times faster than typical evolution in the wild.”

Researchers can now confirm earlier data with this new data and say with certainty: Yes, humans speed up evolution. Although, in the case of pollution, it is not known whether the increase in the rate of evolution will be sustainable enough to save many populations, as that is an ongoing question in eco-evo dynamics.

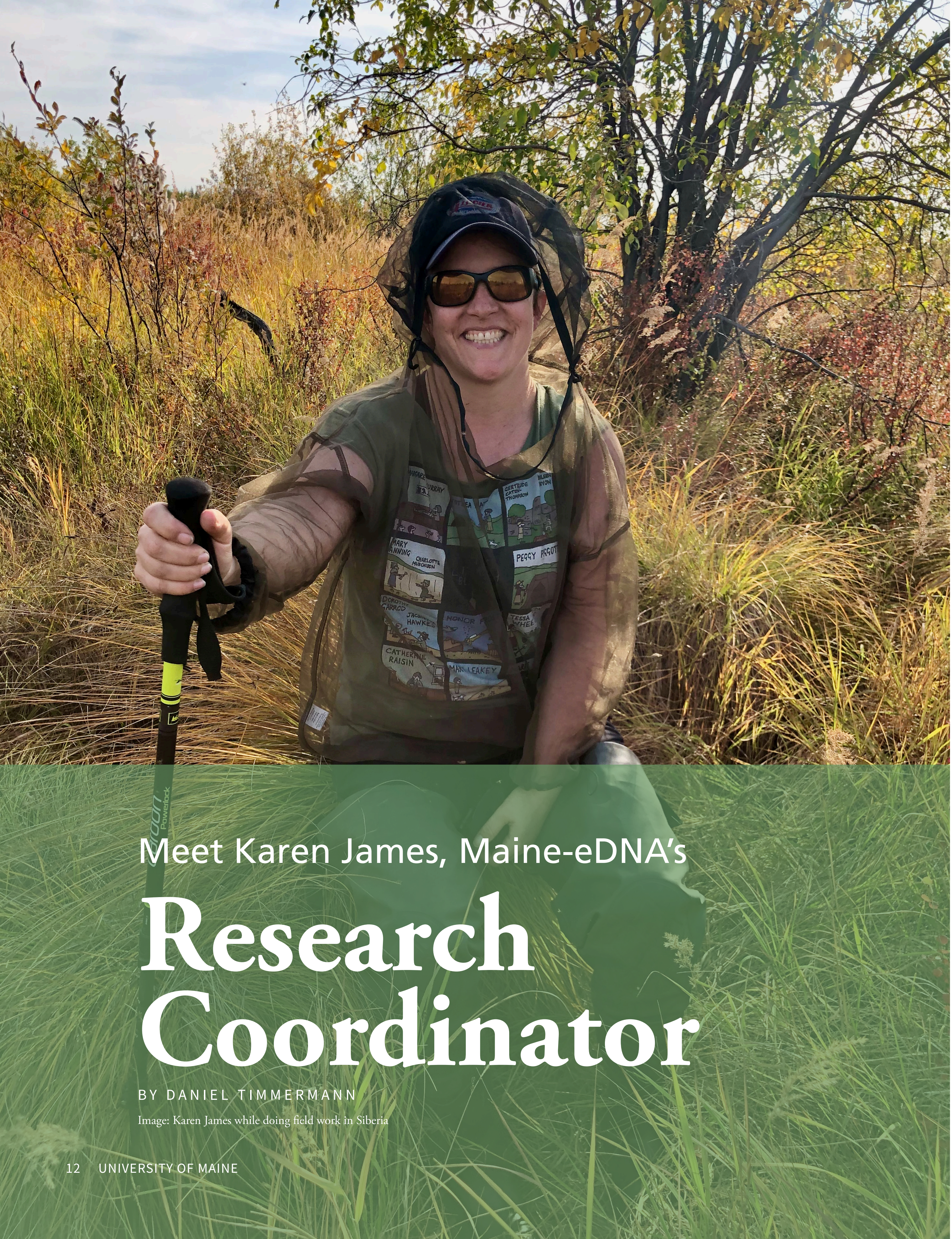
“What originally drew me to science was problem-solving,” stated Wood, who started a 2-year appointment in fall of 2022 at Colby College in Maine, designing inclusive courses for students that will weave ecology, evolution, and natural history together. “But what draws me to evolutionary ecology is that there is so much we don’t know—everywhere you look, there’s a gap that we need to fill in. There’s all this hidden evolution right before our eyes.”

Mike Kinnison

An inquiry into the gaps (the transitional zones that sometimes produce more gaps) is what follows, each year’s research allowing for the ability to ask more questions. Through the GECO project, Kinnison and Wood have studied whether the rate of evolution looks different in individual organisms, individual traits, or in response to different human impacts, and whether contemporary evolution is a source of resiliency.

Wood’s assumption is “humans are tightening the interactions between ecology and evolution”—an idea that Kinnison and Wood proposed in their recent paper, *The Importance of Eco-evolutionary Potential in the Anthropocene.* Mind the gap. The question now becomes: “What are the consequences of this new world of stronger, more intense eco-evo interactions?”

“Humans are having a profound impact on the natural world,” Wood concluded, “while we knew that, but through an evolutionary lens as well. The interaction of ecology and evolution and what that means is still unknown. ■



Meet Karen James, Maine-eDNA's

Research Coordinator

BY DANIEL TIMMERMANN

Image: Karen James while doing field work in Siberia

In early 2022, Maine-eDNA brought on new research coordinator Karen James. This inclusion to the project will help Maine-eDNA coordinate the grant's vast amount of work happening across the state. James brings with her a deep knowledge of genetics, environmental DNA (eDNA), and its application in marine and terrestrial habitats. While James is new to this position, she is not new to Maine-eDNA. James originally joined the RII Track-1 grant as a research scientist in 2020 after having worked closely with Jacquelyn Gill at the University of Maine's Climate Change Institute, helping build a DNA reference library for the Beringian flora in Siberia.

While earning her Ph.D. in genetics at the University of Washington, James worked primarily in biomedical research. During this time, James developed an interest in evolutionary developmental biology and, while unrelated to her area of study, botany. After graduating, James started a postdoctoral position at the Natural History Museum in London, England. James explained, "The postdoc at the museum was a way for me to move into botany, evolutionary biology, and natural history generally." During James' time at the Natural History Museum, the institution hosted the first conference for the International Barcode of Life, an important predecessor and underpinning of eDNA, and James was part of the working group that selected the "barcode" loci for plants (the pieces of DNA by which plants would be identified in DNA barcoding applications). When James came to Maine, she worked as a staff scientist at the Mount Desert Island Biological Laboratory and later the Climate Change Institute at the University of Maine.

As Maine-eDNA's research coordinator, James helps bring together the efforts of researchers across the state, which can be difficult on a grant as large and geographically diverse as Maine-eDNA. "On a project this big, where we have concerted and simultaneous parallel efforts like index site sampling, it is important to try and maintain consistency among different people and locations," explained James. Maine-eDNA's index site sampling involves researchers collecting data up and down Maine's coastline and into the interior. All of these samples need to be collected and treated in the same way as they make their way to the Environmental DNA Lab at the University of Maine in Orono for DNA extraction and processing. This is in addition to other coordinating efforts such as equipment and infrastructure deployment and installation and facilitating communications between research teams. She also coordinates the weekly Maine-eDNA research forum during the academic year and All-Hands meetings.


Karen James

James acts as a point person for everyone on the grant, ensuring they have what they need to do their research. And while James has moved into this role, she also continues to serve as a research scientist in support of the Maine Center for Genetics in the Environment (MCGE). James works on a range of research projects like one with Allison Gardner (UMaine Assistant Professor of Arthropod Vector Biology) that explores the use of eDNA as a means for monitoring mosquitoes, specifically ones that pose a potential public health risk, and another to develop a method for detecting ancient DNA in mixed-age environmental samples.

Maine-eDNA benefits greatly from the depth of experience that James brings to the grant, being someone who has been involved deeply with the eDNA field and its development for the past two decades. James explained why working in this capacity is important to her, saying, "I am really excited to be able to, with my background in DNA barcoding, continue in this trajectory using genetics to study natural history and the environment because I didn't necessarily know I would have an opportunity to do that with my background and training." ■

Climate Change Adaptation:

The bill morphology of tidal marsh sparrows through thermography

BY STEFANIA IRENE MARTHAKIS AND MACKENZIE ROEDER

Saltmarshes (a.k.a. tidal marshes) are one of the most productive eco-systems on earth. As protectors of coastal landscapes and communities—that absorb flood waters as well as carbon—saltmarshes can also provide insight into climate change adaptation. Among this dynamic habitat that is full of bugs, not a lot of predators, and plenty of places to nest, you will find the Seaside Sparrow, Saltmarsh Sparrow, and Nelson's Sparrow — each representing a different colonization from 2 million years ago, half-a-million years ago, and 5,000 years ago, respectively.

Mackenzie Roeder, a Ph.D. candidate in Ecology & Environmental Sciences at the University of Maine, studies genome-to-phenome linkages in tidal marsh adaptation, specifically from the unique perspective of the bill morphology of Seaside, Saltmarsh, and Nelson's Sparrows. As part of the NSF EPSCoR RII Track-2 grant, GECO (Genomic Ecology of Coastal Organisms: A Systems-Based Research and Training Program in Genome-Phenome Relationships in the Wild), Roeder brings a comprehensive approach to understanding this phenotype (this trait).

The sparrow's bill, with its large surface area—as compared to non-tidal sparrows—is the main tool it uses to interact with the environment. According to Allen's rule, warm climate-adapted animals have larger appendages than cold climate-adapted animals, which allows them to maximize or minimize heat loss, respectively. A corollary to Allen's rule known as the Greenburg-Tattersall Corollary suggests this pattern is also true along saline gradients. Roeder investigates whether larger bill size of these sparrows allows for increased levels of radiative heat loss rather than evaporative heat loss (which conserves water). This is especially critical in saltmarshes where freshwater is limited.

"This is a newly understood phenomenon in general," Roeder stated, "so it's not understood how common this is across avian taxa yet."

The bill of the bird—like the legs—is filled with blood vessels. Because heat flows from areas of high temperature to areas of low temperature, Roeder hypothesizes that if blood flow is increased to these areas, which raises the sparrow's body surface temperature (relative to ambient temperature), this allows the sparrow to lower its core body temperature without evaporation (i.e., no freshwater loss) as heat flows from the warm bill to the cooler air around it.

"These three birds represent independent colonization

Roeder pictured with the thermal chamber she built.

Roeder conducting field work.

events of tidal saltmarsh habitat," Roeder stated, "and, potentially, a degree of specialization to this habitat correlated with the time since colonization, which we refer to as an adaptive gradient. If these birds do phenotypically represent an adaptive gradient, then we would firstly anticipate that they would use their bills to dissipated heat—to some extent at a minimum—probably to a greater extent than other non-tidal taxa, and that this bill 'use' would increase proportionally with the time since colonization."

Roeder further explained, "This means we anticipate that Seaside Sparrows, who colonized first and have the largest bills, would use their bills more-so in a thermoregulatory capacity than Saltmarsh and Nelson's Sparrows, suggesting that their thermoregulatory strategies may be optimized to reduce freshwater loss."

Thermography (the use of thermal imaging cameras to monitor changes in heat patterns and blood flow) of wild animals can be complicated in a laboratory setting, because it requires capturing live animals and housing them for extended periods of time. To address this challenge, Roeder has built a portable temperature-controlled thermal chamber (electrical cooler box) that allows her to capture birds in tidal marshes and place them within the box in a safe and calm (dark) environment. Here the birds experience the same thermal gradient (a range from 10°C – 35°C), over the course of one hour while being monitored with a thermal imaging camera, before they are released back into the marsh. Roeder explained, "This standardized gradient exposure is essential for comparing the bird's physiological responses and mimics a common range of temperatures experienced by the birds during the breeding season."

Currently, Roeder is focused on thermography as part of her summer 2022 work in Maine, New Hampshire, and New Jersey. With the thermal chamber, Roeder can see what the sparrows do physiologically as the temperature increases. Already, these three sparrows are exhibiting different physiological behaviors.

Roeder's research has shown "Seaside Sparrows regularly dissipating 20% of their overall radiative heat from their bill. As temperatures increase beyond 25°C, Seaside Sparrows have increased blood flow to the bill such that 50-60% of all heat lost from the bird is from its bill, which is phenomenal!"

Next, Roeder compares her early results with other researchers' work on Song Sparrows along salient gradients, which inspired her current work. Though the methods are different, their results showed that tidally adapted Song Sparrows dissipated more heat from their bills than non-tidally adapted ones, and that the maximum percentage of total heat loss from the bill of these sparrows was ~15%, with an average of 10%. The much larger percentage of

GECO Researchers hold saltmarsh sparrows.

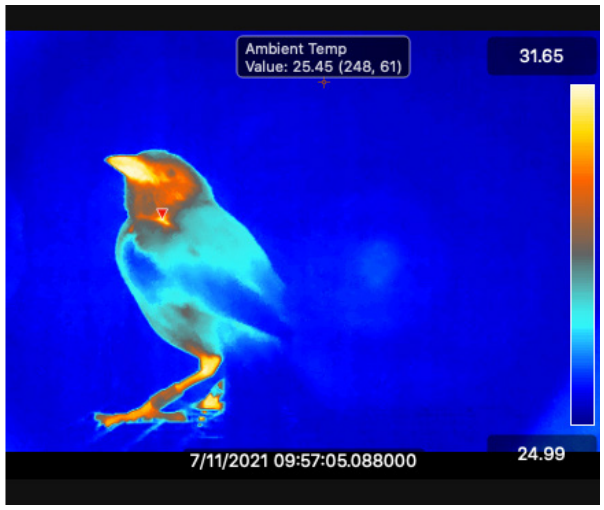
overall heat loss in these tidal marsh obligate birds is exactly what Roeder and her team would expect following our adaptive gradient hypothesis.

Since physiology is a behavior that is affected by the environment, Roeder contemplates whether she is capturing some local phenomenon of climatic acclimation. To address this question, she replicated sites for each species along a natural thermal gradient (from New Jersey to the north-eastern tip of Maine) during the breeding season. She repeated this work on their wintering grounds, where all three species co-occur in the same marshes and are adapted to the same climate.

This led Roeder to ask these critical, comparative questions: "Is the use of the bill, as a thermal window, to lose heat associated with their colonization order? Can we use this system to test hypotheses on the way evolution shapes traits— and helps in adaptation? And finally — what else is affected by this increase in bill size? Does this morphological difference affect their fitness? Does a larger bill mean they're better able to dissipate heat and compete for mates and territories, does it increase their ability to forage and provide food for their young when it's hot, does it affect their ability to sing and attract mates?"

Roeder and the GECO team run demographic sites where they monitor the breeding activity of these birds. By finding their nests, monitoring their success, conducting paternity analyses, and monitoring the growth rates of their chicks, they can determine levels of fitness (individual male reproductive success) that they can compare with bill morphology to look for correlations. She is also conducting research studying the songs the males sing to determine if bill morphology impacts song production, and in-turn if abiotic forces (e.g., heat) impact their song quality.

"These ideas are all interconnected and an attempt to comprehensively view the bill and the ways in



Thermal image of saltmarsh sparrow being studied.

which it is important to the birds," Roeder explained. "Finally, I will be using genetic data collected from these birds to determine the heritability (the level of variation in the trait that is due to variation in the genes) of bill morphology and will be conducting a genome-wide association study (GWAS) linking regions of the genome to bill size differences."

While Roeder studies tidal saltmarsh birds , her thermoregulation research has broad implications for all kinds of taxa, even freshwater-limited environments such as arid habitats and high mountain habitats. And applicable questions on whether the role of a phenotype in thermoregulation, in this case the bill, is different between species, within individuals, and at the level of within-population genomic variation, which can lead to further genome-to-phenome linkages in the study of climate adaptation.

"This is a newer phenomenon to us," Roeder stated, "a newer way of understanding the trait that is the bill. For a long time, people have just studied it as the way the bird gets food. Thinking of this trait as an integral part of a whole body, not a separate part of the bird, is important. It is the bird. And it takes part in all the things the bird does, so we must understand it from more than one context." ■

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Markus Frederich, University of New England Professor of Marine Sciences, holds a sea star while describing how the organism traverses its environment.

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