Pamlico Pups • Drone Data • Angler Science • Wind Damage

Coastwatch

NORTH CAROLINA SEA GRANT • AUTUMN • 2018 • ISSUE 4 • $3.75

ENDURANCE TEST
Florence and Michael Pummel North Carolina

After the Storms: Lessons in Recovery and Resilience

As North Carolina continues to recover and assess immediate damages from Hurricane Florence and Tropical Storm Michael, community and individual needs are extensive. Long-term needs also will be a focus for years to come.

Unfortunately, many of the communities that these storms devastated also endured Hurricane Matthew's significant precipitation and related flooding in October 2016. As we learned from Fran and Floyd, multiple storms present compounding impacts that can last a decade or more. Thus, we anticipate economic and environmental changes across a significant swath of our coastal plain, from north to south, coastal and inland.

North Carolina Sea Grant already had been in the midst of post-Matthew efforts, including some noted in this issue, as well as online: *go.ncsu.edu/AfterMatthew*. Likewise, our team will lead and collaborate with key federal, state, local, community and nonprofit partners in timely responses to post-Florence needs for research, extension and outreach. We develop and deliver science-based information, tailored to actionable, on-the-ground applications that support long-term resilience in communities and enhance future preparedness.

This and future issues of *Coastwatch* will reveal challenges and opportunities related to this work — as well as the results and impacts from our team and our partners to better prepare for, respond to and recover from catastrophic events.

Although it certainly felt as if these storms were all-consuming this season, this issue shows there are, indeed, blue skies ahead for our team and programming. We are eager to introduce a few of our new Sea Grant team members, including Sarah Spiegler, marine education specialist and N.C. Sentinel Site Cooperative coordinator, and Frank Lopez, our new extension director. Both are looking to advance our programming and already have infused North Carolina Sea Grant with energy, enthusiasm and expertise.

We also say farewell to three advisory board members whose terms ended this fall: Jot Owens, a charter boat captain based in New Hanover County; Dave Meyer with the National Oceanic and Atmospheric Administration's National Marine Fisheries Service, Southeast Fisheries Science Center at the Beaufort Laboratory; and Laura Taylor, a natural resource economist who recently moved from NC State University to Georgia Tech. The board met with the management team recently at the coast, providing input that is critical to our program's success. I thank them all for their ongoing contributions and commitment.

This fall, North Carolina Sea Grant also successfully hosted NOAA's federal site review of our performance from 2014 to 2017. It was a testament to our partners' resilience as many traveled from across the state, only a few short weeks after Hurricane Florence, to join two days of panels and a student showcase. The review team offered great appreciation of the varied perspectives about impacts and contributions that Sea Grant brings to N.C. communities. The team's final report will be available soon, and we will share highlights.

Such opportunities for reflection, discussions on future improvements, and hearing from our team and partners first-hand about their work are energizing and invaluable, especially as we apply current and upcoming investments to achieve the goals in our new strategic vision (available at *go.ncsu.edu/SeaGrantVision*). We intend for Sea Grant to remain a key leader in addressing the state's urgent and long-term needs in ocean, coastal and watershed resource management.

Those topics clearly will be part of our planning for North Carolina's Coastal Conference, 2019 edition. Held every two years, the gathering will move to the fall — and to a coastal location. Watch for updates at *ncseagrant.org* and via our social media feeds.

In the meantime, I wish you the best as you close out 2018 with holiday celebrations and make plans for the new year.

As 2019 unfolds, I look forward to engaging with new programs and partners. Through them we will find success in enhancing sustainable use and conservation of ocean, coastal and watershed resources in order to benefit communities, economies and ecosystems across our state. Please feel free to reach out to me at *snwhite3@ncsu.edu*.

— Susan White, Executive Director, North Carolina Sea Grant

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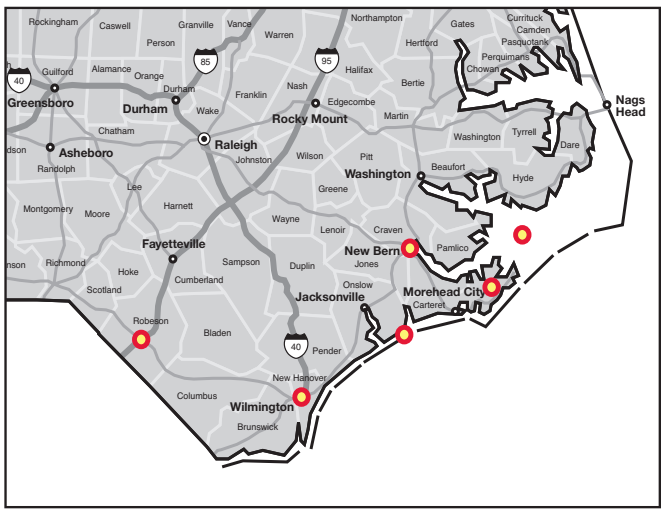

North Carolina's diverse coast offers countless interesting subjects. The map indicates story settings in this issue — including Carteret, Craven, New Hanover and Onslow counties, as well as the Pamlico Sound.

Coastwatch

FEATURES

Front Cover: Leland, North Carolina, after Hurricane Florence. Photo by Ken Blevins/ Star-News. Table of Contents image based on stock photo.

Coastwatch

North Carolina Sea Grant • 2018 • Autumn • Issue 4

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North Carolina Sea Grant is a federal/state partnership that promotes stewardship of marine, coastal and watershed resources through research and outreach. It joined the National Sea Grant College Network in 1970 as an institutional program. In 1976, it was designated a full Sea Grant College program. Today, North Carolina Sea Grant supports research projects, along with extension and communications teams. Susan White is executive director. The program is funded by the National Oceanic and Atmospheric Administration in the U.S. Department of Commerce, and by the state through the University of North Carolina.

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Mariculture Careers Come into Focus

A new North Carolina Sea Grant video highlights a variety of careers in marine aquaculture. Also known as mariculture, the industry focuses on the cultivation of plants and animals that live in saltwater.

Aquaculture accounts for half of seafood consumed worldwide. Although mariculture now plays a relatively small role in most local economies in North Carolina, it has potential to become an economic driver in the state's coastal communities, says Sea Grant coastal economist Jane Harrison.

Ryan Bethea

"We developed this video to be part of a suite of education resources that high school science and agriculture teachers can use to expose their students to mariculture science and career possibilities," Harrison says.

There are lots of jobs to choose from. Fish farms don't just rely on farmers. They need technicians, managers and entrepreneurs to succeed. Distributors, chefs and scientists also play important roles in moving seafood from the water to your plate. The video, produced and filmed by Baxter Miller and Ryan Stancil, provides a glimpse into these different career paths.

Shellfish grower Ryan Bethea is one of many featured voices. "I would have never thought I would be into oyster farming," he says in the film. "I wanted to be an attorney for a long time. I was bartending and teaching before this."

Sea Grant also is working with local educators to develop mariculture lesson plans and a mobile aquaculture laboratory. Stay tuned for more!

Watch the video: *go.ncsu.edu/TeachMariculture.* —J.H.

Mark Your Calendars

As 2018 winds down, North Carolina Sea Grant, Space Grant and the Water Resources Research Institute are gearing up for a busy season. Mark your calendars for these upcoming events.

- Prepare for **amplified tides** from Dec. 21 to 25. While not to the degree of a King Tide, amplified tides are higher and lower water level events that occur when the full and new moon cycle almost align with the moon being closest to Earth. You can share your photos with the new "What's your water level?" app. Learn more at *nckingtides.web.unc.edu*.
- At the **2019 Festival of Legal Learning**, North Carolina Sea Grant will partner with the University of North Carolina at Chapel Hill Law School to present coastal law and policy topics. The Continuing Legal Education sessions will be in early February at the Friday Center in Chapel Hill. Watch for updates and registration at *law.unc.edu/cle/festival*.
- **North Carolina Water Resources Research Institute** will host its Annual Conference March 21 to 22. The event will take place at the McKimmon Center at North Carolina State University in Raleigh. Registration is now open at *wrri.ncsu.edu/conference*.
- The **2019 N.C. Aquaculture Development Conference** will be March 28 to 30 at the DoubleTree in Atlantic Beach. Chuck Weirich, Sea Grant's marine aquaculture specialist, will lead sessions on shellfish aquaculture as growers, scientists, regulators and the public come together to share ideas about a growing industry. Visit *ncaquaculture.org* for more information.
- N.C. Space Grant will present its inaugural **SPACE Symposium** April 4 and 5 at the StateView Hotel on NC State's campus. This event will bring together STEM students, Space Grant scholarship recipients, aerospace industry professionals and North Carolina's Sea Grant-Space Grant joint fellows. Details can be found at *go.ncsu.edu/SPACEsymposium*. —L.C. & D.C.


Cliff Hollis/ECU News Services

Jasmine Hayes

Study Explores Community Resiliency

A new project is revealing what it means to be resilient after flooding. Jasmine Hayes, a North Carolina Sea Grant and Water Resources Research Institute joint fellow, held focus groups in socially vulnerable communities in Pitt and Robeson counties, where flooding from Hurricane Matthew still resonates deeply with residents.

"We chose to work with vulnerable populations because evidence indicates that people of low socioeconomic status and the elderly are more vulnerable before, during and after a disaster event," Hayes says. "Socially vulnerable communities need increased assistance over the course of a disaster response and recovery, but their needs tend to not be sufficiently considered during the planning, implementation or recovery phases."

Hayes, a master's student at the East Carolina University Brody School of Medicine, worked closely with Suzanne Lea in ECU's Department of Public Health, who served as her advisor. Their team conducted nine focus groups in which hurricane survivorship was common.

Over 90 percent of the participants had experienced Matthew, and more than 60 percent had lived through Floyd 17 years earlier. Both storms had impacted several of the same African American communities in the flood plain.

Residents explained how they had adapted to adversity and pointed to several changes that could improve short-term and long-term recovery. They also made a number of suggestions to reduce added burdens that disaster survivors face.

More about North Carolina Sea Grant and Water Resources Research Institute joint fellows: *go.ncsu.edu/JointFellows*.

— D.S.


Dave Scavone

Lee Cannon

Cannon Joins Communication Team

Lee Cannon will collaborate closely with the North Carolina Sea Grant team as the new primary communicator for the North Carolina Water Resources Research Institute (WRRI) and North Carolina Space Grant. She crafts messages and shares outcomes of the programs' research, education and outreach efforts with audiences across the state and beyond.

Cannon began her communications career in Washington, D.C., where she spent time at the Embassy of Japan, the Smithsonian Institution and arts and education nonprofits. She holds a bachelor's degree in English literature and writing from the University of North Carolina at Chapel Hill and a master's in creative writing from the University of North Carolina Wilmington.

In her new role with N.C. Space Grant, Cannon supports the mission of promoting aeronautics and STEM-related education in order to equip the aerospace workforce with a diverse talent base prepared to address future challenges. For WRRI, Cannon shares the results and impacts of program-supported research that is fostering improvements in water supply, exploring new solutions to water problems and expanding understanding of water-related science.

Justine Neville

Hurricanes Affect Stream Equilibrium

Justine Neville did not set out to study the effects of hurricane flooding on stream nutrients, but Hurricane Matthew intervened.

Neville was examining nitrogen in the surface water of streams and rivers. Initially, her research compared the nitrogen in surface water as it ran through different land-use areas. However, in the middle of her research Hurricane Matthew caused widespread flooding in the Lumbee River Basin, her project area.

The hurricane could have destroyed her data and halted her project, but Neville realized that it actually provided an opportunity to broaden the impact of her research. She would examine how long it takes for a stream to regain its equilibrium in nitrogen processing after a major storm or flood.

With the support of a North Carolina Sea Grant and Water Resources Research Institute joint fellowship, she gathered nearly five more months of data.

The extra time was enough to chart the progress of the Lumbee River to its original level of nitrogen fixing — which was faster than Neville anticipated. Although the storm flooding had disrupted the usual rate of nitrogen fixing in two of the three test areas, the rates returned to normal within a few months.

"This kind of research is important because we are experiencing more frequent and more intense storms," Neville says. "So this data can help build a body of information on water quality in streams."

She noted the streams recovered much more quickly than people in the affected areas, many of whom are still rebuilding their lives. — L.C.

Living Shorelines and Saltmarsh Resilience

As coastal North Carolina ecosystems rebound from Florence and Michael, new research shows that "living shorelines" helped to make saltmarshes more resilient to Hurricane Matthew.

Researchers have long known that nature-based solutions have the potential to restore critical ecosystems, enhance coastal sustainability and increase resilience to natural disasters. Living shorelines, for example, bring ecological benefits that include maintaining coastal saltmarsh and enhancing the value of coastal habitats for fish and crustaceans.

However, scientists had not measured structures like living shorelines during hurricanes to gauge how well they could buttress ecosystems when compared with traditional hardened shorelines. Thanks to a Sea Grant Coastal Policy Fellowship, Carter Smith, a graduate student at the University of North Carolina at Chapel Hill Institute of Marine Sciences, investigated a common living shoreline design that combines restored saltmarsh with a low-rising breakwater constructed of granite rocks that run parallel to shore.

"Our team's results revealed that these rock sill living shorelines were more resilient to the impacts of Matthew than either traditional hardened shorelines or natural marshes," Smith says. "The living shorelines demonstrated better resistance to landward erosion, and they additionally maintained landward elevation over the entire study period, without requiring any repair before, during or after the hurricane."

Carter Smith

Saltmarsh vegetation was never present at any hardened shorelines in her project, Smith adds, and over the course of the two-year study, the edge vegetation at natural marshes was almost completely lost. By contrast, at the inside edge of living shorelines the stem densities increased for saltwater cordgrass (*S. alterniflora*), an important ecosystem engineer.

"This suggests that living shorelines can help sustain coastal saltmarsh habitats over time when saltmarsh might otherwise be lost," she says.

Full study: *go.ncsu.edu/LivingShorelines*.

— D.S.

Is Sea Level Rise a Matter of National Security?

Hurricane Florence didn't stop military experts and others from gathering at North Carolina State University in late September to discuss the risks of sea level rise to national security and to discuss coastal resilience in North Carolina.

"The seas are not rising by magic," said Rear Admiral David W. Titley, USN (Ret.), who also was an opening speaker at the 2017 North Carolina Coastal Conference. "If we do not get our carbon emissions under control, if we do business as usual, we're locking in 30 feet of sea level rise by 2100."

Along with high-ranking military representatives, the panel discussion brought together professionals, researchers, community leaders and government officials, including Holly White, principal planner for the Town of Nags Head, who has worked closely with North Carolina Sea Grant to help her town prepare for sea level rise.

The event also screened the *Tidewater* documentary, which focuses on Virginia's Hampton Roads region, an area with 14 military installations spread across 17 local jurisdictions vulnerable to sea level rise.

North Carolina Sea Grant partnered with the Center for Climate and Security, Albemarle-Pamlico National Estuary Partnership and N.C. Department of Environmental Quality to sponsor the event.

Watch the panel: *youtube.com/watch?v=o1hjL7oF2PY*.

More on the *Tidewater* film: *amresproject.org/tidewater-film*. — M.I.

Robert Brown, NCWF's Immediate Past Chair of the Board (left), and Secretary Michael Regan of NCDEQ (right) present Jenna Hartley with the Environmental Educator of the Year award.

Hartley Earns Honor

Jenna Hartley has received the Governor's Conservation Achievement Award for Environmental Educator of the Year. The North Carolina Wildlife Federation presents the annual awards — the highest natural resource honors in the state — for unwavering commitment to conservation.

"I'm still so grateful to the people who gave me chances to explore the world outside of my rural community," Hartley says. "The impacts of those opportunities were immeasurable."

During a field trip in college to the Colorado River, Hartley became interested in geology, and new opportunities soon took her to Montana and Puerto Rico to conduct research. This encouraged her to go into teaching and to provide similar experiences for her own students.

After serving as a high school science teacher in North Carolina and New York, Hartley became an Association of Schools and Programs for Public Health Environmental Health Fellow, hosted by the U.S. Environmental Protection Agency. She created K-12 curricula through the EPA's EnviroAtlas Project to support teachers in environmental education, while also using her bilingual skills to reach diverse populations.

"I appreciate that the EnviroAtlas Project makes room for educational outreach," she says. "This project recognizes and values the significant contribution and expertise of classroom teachers."

In addition to her continued work with the EPA and EnviroAtlas, Hartley currently is studying for her doctorate at North Carolina State University, where she works with Kathryn Stevenson on a North Carolina Sea Grant project to study intergenerational learning and student empowerment through science. — M.I.

NOAA Study Funds Soft-Shell Crab Research

Chuck Weirich, North Carolina Sea Grant marine aquaculture specialist, is partnering with the University of Southern Mississippi Gulf Coast Research Lab on a National Oceanic and Atmospheric 2018 Aquaculture Research Award. The grant program funds research to advance development of a sustainable marine and coastal aquaculture industry in the United States.

Their project, submitted by Mississippi-Alabama Sea Grant, aims to expand sustainable soft-shell blue crab aquaculture through technology transfer and cost analysis.

Over three years, their work will involve researchers, private industry partners, Sea Grant extension expertise and two diverse geographic regions. In North Carolina, Weirich leads a collaboration that includes David Cerino at Carteret Community College and David Eggleston from NC State University's Center for Marine Sciences and Technology, as well as Sam Thomas, Clay Travis and Steven Tyler of Thomas Seafood.

"We are all excited about this opportunity," Weirich says. "It may allow us to establish the hatchery technology and pond production methods to raise blue crabs here in North Carolina, which could lessen the need to harvest wild populations to supply crab-shedding operations." — D.C.

Sarah Spiegler

Spiegler Takes on Dual Role

Sarah Spiegler has joined North Carolina Sea Grant as N.C. Sentinel Site Cooperative coordinator and a marine education specialist.

"I am very excited for this opportunity to positively affect the coasts, communities and incredible natural resources of North Carolina," Spiegler says. "I look forward to working with Sea Grant and a diverse set of stakeholders to help build resilient coastal communities that can adapt to the impacts of climate change and sea level rise."

The National Oceanic and Atmospheric Administration established the Sentinel Site Program to bring together science, management and technology to address the impacts of sea level changes on coastal habitats and communities. North Carolina's Sentinel Site Cooperative is one of five in the nation.

Spiegler will build partnerships, seek funding that expands the N.C. cooperative's reach, and coordinate research teams working within the site's boundaries. She also will collaborate with several NOAA offices, updating natural resource managers and coastal residents about the cooperative's projects.

Her goals include broadening Sea Grant's marine education extension presence in the coastal region by engaging K–12 students and teachers through workshops, field trips and trainings.

Spiegler spent the previous five years working with NOAA's Sentinel Site Program. Last year, she also co-taught a course at the University of North Carolina at Wilmington.

"We're pleased to welcome Sarah to the team," says John Fear, Sea Grant deputy director. "Her experience as an N.C. Sentinel Site Cooperative outreach specialist, her enthusiasm for teaching and her knowledge about North Carolina's coastal resources form an ideal blend for this dual role." — J.L.

Justin Kase Conder

When a hurricane like Florence strikes, onlookers may ask, "Who saw the worst damage?"

But enduring a major storm is deeply personal. "If you're a disaster victim and you're affected, it's the worst event for you," says Jessica Whitehead, North Carolina Sea Grant's coastal communities hazards adaptation specialist.

Powerful storm surges announced the hurricane's arrival on Friday, Sept. 14. During Florence's slow march, extensive rains inundated the Carolinas. Rivers poured over their banks and flash floods menaced.

"It's not a coastal-only issue," says Erik Heden, warning coordination meteorologist for the National Weather Service's Newport/Morehead City office.

Florence's impacts "are felt not just in Topsail, not just in Emerald Isle, not just in Wrightsville Beach. They're felt in Kenansville — or Duplin County — inland. They're felt in New Bern."

The storm took 41 lives in North Carolina, Gov. Roy Cooper reported in mid-November. Ongoing damage estimates were at $17 billion — more than from hurricanes Floyd and Matthew combined.

The photographs herein are just a small representation of what people and communities experienced during and shortly after Florence. Many will continue to face challenges, Whitehead says. "Recovery from a storm like this is counted in years, not months."

Continued

SKYFALL

Hurricane Florence inundated North Carolina and devastated communities. Here's a look at what areas in various southeastern and central parts of the state have endured.

CURATED BY JULIE LEIBACH

A man gets into his truck after evaluating the conditions of a flooded road in Wilmington on Sept. 14, the day Hurricane Florence made landfall.

TOP LEFT: *Pollocksville, in Jones County, saw historic flooding as the Trent River overflowed its banks.*

TOP RIGHT: *Flood waters from the Neuse River swamped parts of Kinston in Lenoir County.*

BOTTOM LEFT: *Hurricane Florence plunged Bald Head Island into a state of emergency. The island finally reopened to everyone on Oct. 1.*

BOTTOM RIGHT: *Bladen County experienced flooding in many areas.*

Continued

Ken Blevins/Star-News

Gray Whitley/Sun Journal

Ken Blevins/Star-News

Liz Roll/FEMA

Matt Born/Star-News

Justin Kase Conder

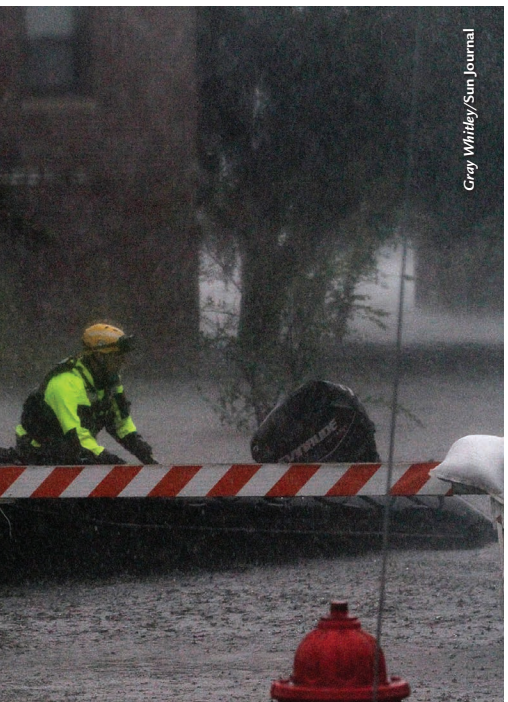
TOP LEFT: *On Sept. 15, a day after landfall, a line forms at a Speedway convenience store and gas station in Jacksonville, Onslow County.*

BOTTOM LEFT: *Lt. Keith Ramsey with the Pender County Sheriff's Office walks out to a boat while taking part in rescue operations in Burgaw.*

BOTTOM MIDDLE: *The greatest storm surge occurred in New Bern, in Craven County, swamping the riverside city.*

BOTTOM RIGHT: *Two brothers remove debris from their family's yard in Jacksonville on Sept. 15.*

Continued



Gray Whitley/Sun Journal

Justin Kase Conder

TOP LEFT: *Oriental, in Pamlico County on the Pamlico Sound, suffered major damage from Hurricane Florence.*

TOP RIGHT: *Friends, family and neighbors made quick work of gutting this house, one of many that flooded in a neighborhood off Oaks Road in New Bern, Craven County.*

BOTTOM LEFT: *Damaged possessions practically obscured a home in Harkers Island, Carteret County.*

BOTTOM RIGHT: *A capsized boat rests on the side of the Cape Fear River near the Isabel Holmes Bridge in Wilmington on Sept. 20.*

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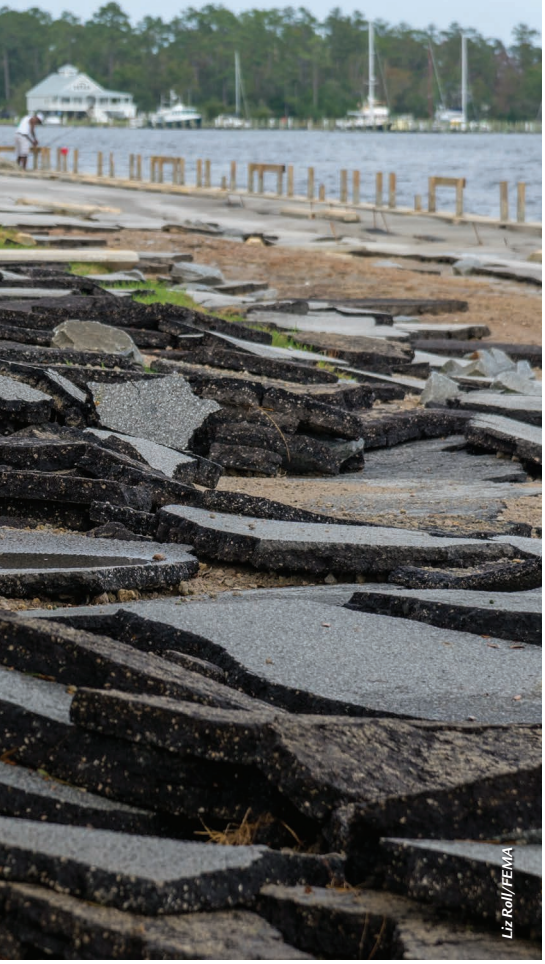
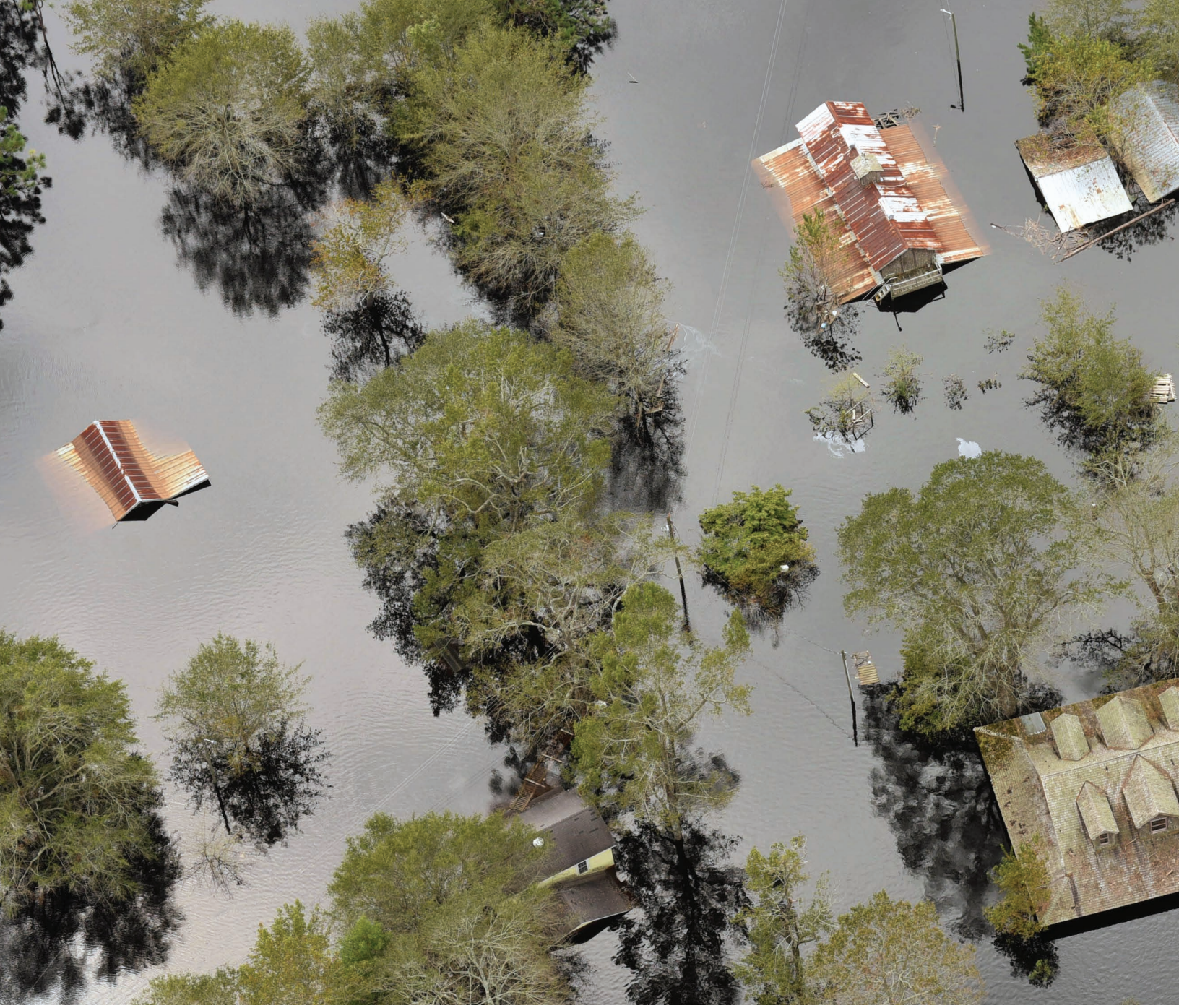


Liz Roll/FEMA

Sarah Spiegler

Liz Roll/FEMA

Ken Blevins/Star-News



Patsy Lynch/FEMA

Ken Blevins/Star-News

TOP LEFT: *Flood waters from the Black River submerged houses in Currie, Pender County.*

BOTTOM LEFT: *Hurricane Florence affected inland counties including Harnett, where this poultry building was destroyed..*

BOTTOM MIDDLE: *Chaney Creek flooded into Phillips Park in Jacksonville.*

BOTTOM RIGHT: *Waves slam the Oceanana Pier & Pier House Restaurant in Atlantic Beach on Sept. 13 as Hurricane Florence approaches the area.*

Continued

John Althouse/The Daily News

Travis Long/The News & Observer

TOP RIGHT: *Weeks after Hurricane Florence, dishes and other belongings were stacked outside a storm-destroyed house in the Oaks Road neighborhood in New Bern.*

BOTTOM LEFT: *With Hurricane Florence in full swing and water waist-deep, some residents decided to self-evacuate in Washington, Beaufort County.*

BOTTOM RIGHT: *A resident of Trenton, in Jones County, removes possessions from her flooded home. Water inundated hundreds of homes across the county.*

Gray Whitley/Sun Journal

Liz Roll/FEMA

Travis Long/The News & Observer

Florence originated where many hurricanes begin, off the west coast of Africa.

In late August, an area of low pressure developed in easterly winds blowing off the continent. Near the Cape Verde Islands, the disturbance became a tropical depression — a cyclone with relatively weak winds. By Sept. 1 it had transformed into a tropical storm.

The system waxed and waned as it churned across the Atlantic, morphing into a major hurricane, then back into a tropical storm, and again into a hurricane.

Florence finally made landfall near Wrightsville Beach on Friday, Sept. 14, at a quarter past 7 a.m. With winds whirling at an estimated 90 mph, it was a Category 1 hurricane.

That number, however, describes only one aspect of the storm — its sustained wind speed. Hurricane category doesn't reflect other attributes such as size, storm surge or moisture content.

"There's not much of a correlation between hurricane strength and the amount of rainfall production," says Chip Konrad, director of the National Atmospheric and Oceanic Administration's Southeast Regional Climate Center, located at the University of North Carolina at Chapel Hill. "A relatively weak system, for example, can produce incredible amounts of rainfall if it stalls out."

Continued

A Slow-Motion

Hurricane Florence was the wettest tropical system on record in

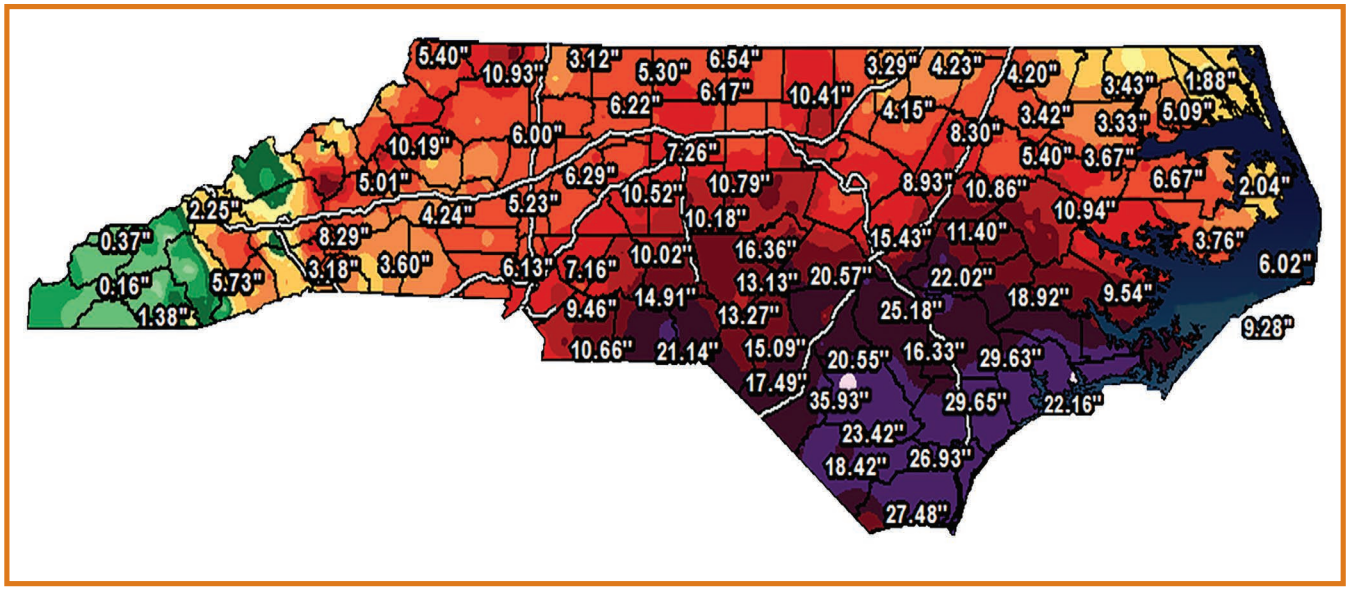
The GOES East satellite captured this view of Hurricane Florence shortly after the storm made landfall near Wrightsville Beach on Friday, Sept. 14, 2018.

NOAA

BY JULIE LEIBACH

Emergency

the Carolinas, with heavy rains that fueled widespread flooding.



NWS/NOAA

Preliminary rainfall totals from Florence indicate that Elizabethtown in Bladen County received the most, at 35.93 inches.

As North Carolinians know all too well, what caused so much devastation in so many communities wasn't so much the wind speed. It was water — in the form of surge, rain and flooding.

According to Corey Davis, an applied climatologist at the State Climate Office of North Carolina, "it's safe to say that Florence was the wettest single storm in North Carolina in modern recorded history, since at least 1851."

RELENTLESS RAIN

Florence markedly slowed down as it neared the N.C. coast. The day before landfall, the storm clocked 12 mph. The next morning, it chugged at 6 mph. By Saturday morning, the system crawled over land at a languid 2 mph.

"I think what was really unique was just the sheer amount of time that it was moving slowly along the Carolina coast," says Konrad, who is also a principal investigator with the Carolinas Integrated Sciences and Assessments, or CISA.

Two high-pressure systems had corralled the storm into an atmospheric cul-de-sac of sorts, blocking it from turning northeastward — as hurricanes typically do — and causing it to stall.

"Florence had no escape route," says Jessica Whitehead, coastal communities hazards adaptation specialist for North Carolina Sea Grant. The storm instead was forced to take a sluggish southwesterly detour into South Carolina. Along the way, it dumped copious rain.

As of 6 p.m. on Sept. 15, for instance, Swansboro in Onslow County near the Carteret County line had received more than an estimated 30 inches. Inland, Hoffman in Richmond County, near the state's southern border, had seen more than 2 feet by that time.

"The rainfall amounts were just unbelievable," Konrad says.

Preliminary estimates indicate that Elizabethtown in Bladen County received the most, at nearly 36 inches, according to the National Weather Service (NWS). That total breaks the state record for rainfall from a tropical system, set in 1999 by Hurricane Floyd, which drenched Southport in Brunswick County with a smidgen over 2 feet.

According to CISA's third-quarter newsletter, Elizabethtown "stands out as having received over twice the rainfall expected in a 1,000-year event." Such an event would be expected to have much less than a 0.1 percent chance of occurring any given year, Konrad says.

Many other locations in the Carolinas, including Wilmington on the coast and Mount Olive inland, also saw 1,000-year rain events, according to CISA.

"I think the prediction of rainfall and the amount that we observed were pretty darn close — and scary," says David Glenn, the meteorologist in charge for the NWS Newport/Morehead City office. "The reality is, that's a lot of rain."

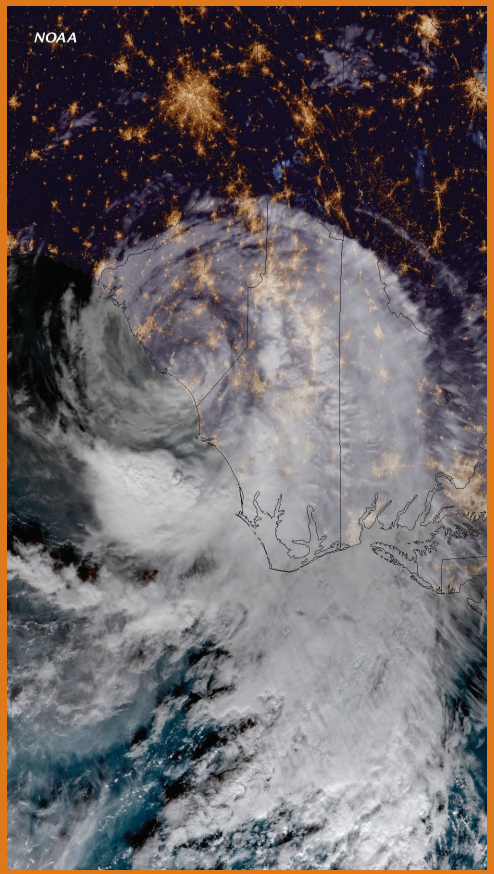
After ensuring their families were safe, Glenn and his colleagues hunkered down in the NWS office for three full days to fulfill their forecasting and warning duties. Their Wilmington counterparts also remained in place for several days, says Glenn, who slept on a broken cot in his office.

CATASTROPHIC FLOODING

Though Florence's winds weakened as it neared shore, the storm grew in size. Its earlier strength and slowing pace set in motion extraordinary surges — notably in riverside areas.

Continued

FACING PAGE: • *These satellite images chart Hurricane Florence's evolution from Sept. 10 to Sept. 16. Over that time, it rapidly intensified into a Category 4 hurricane, then evolved into a Category 1 storm upon landfall. Florence continued to drench the Carolinas in rain as a tropical storm and tropical depression.*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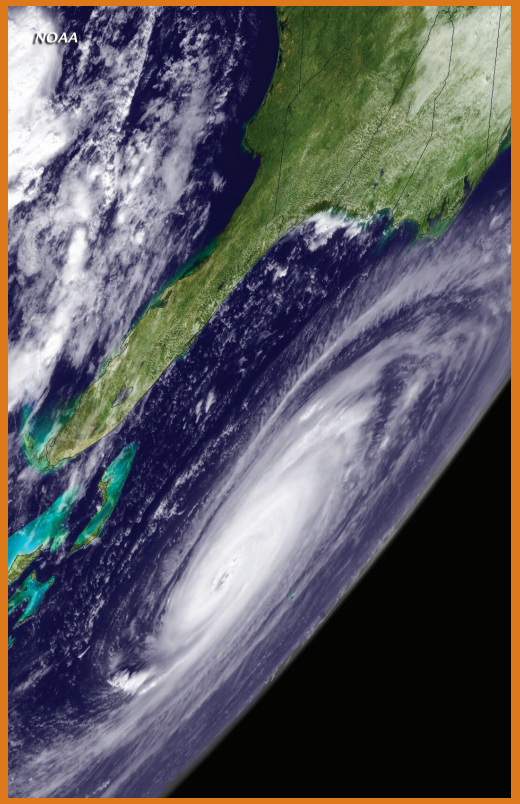
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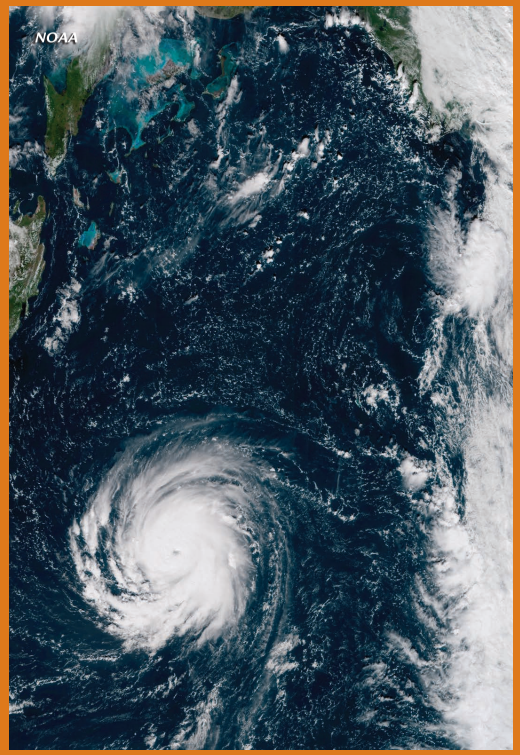
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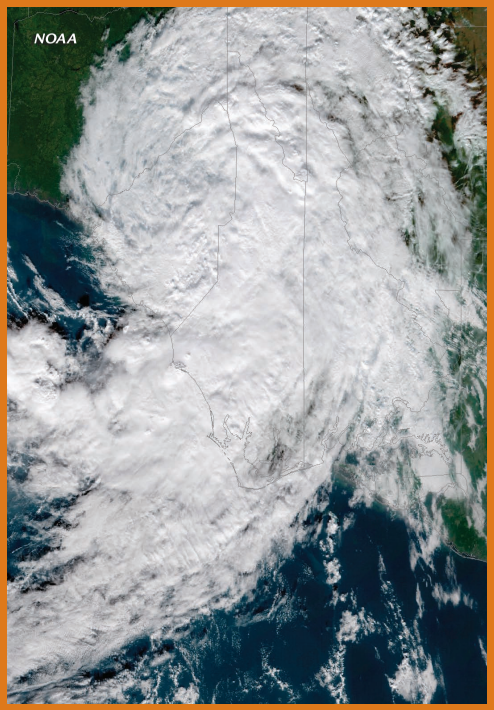
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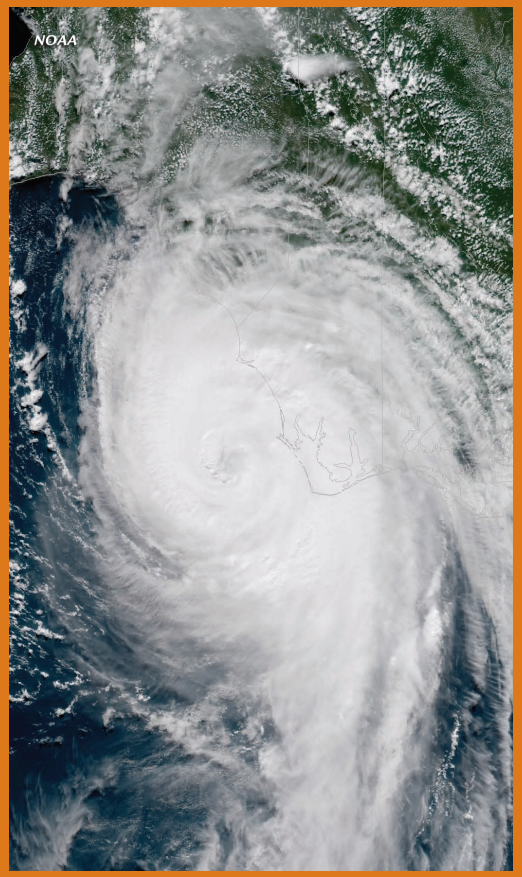
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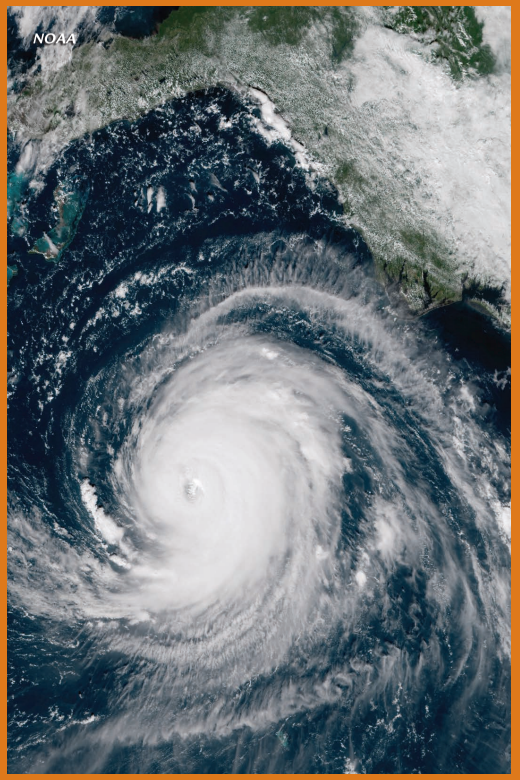
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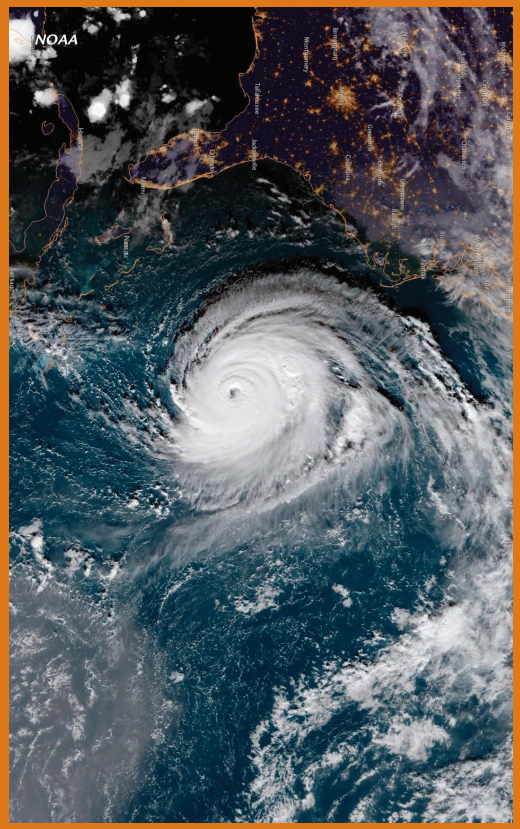
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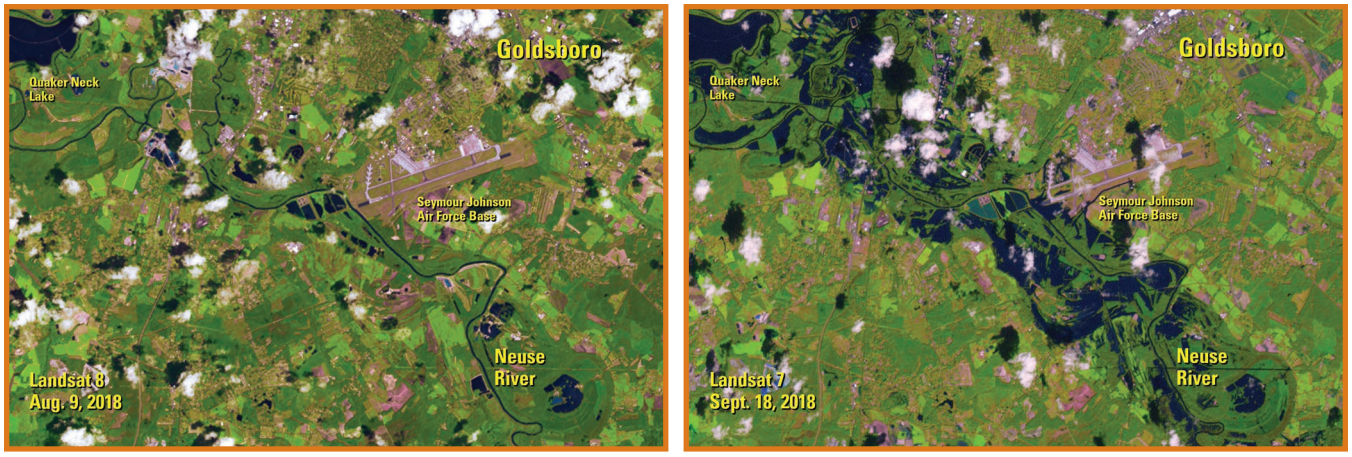


USGS

• ABOVE: *Satellite images show Goldsboro, located about a hundred miles from the coastline where Florence made landfall. In the image at left, taken Aug. 9, the boundaries of the Neuse River are clearly defined amid green vegetation. By Sept. 18, the river's thin black line had become a miles-wide blotch of floodwater. The image at right shows the water pooling onto Seymour Johnson Air Force Base and covering swaths of city land.*

The biggest surge in the state struck New Bern in Craven County, 50 to 60 miles from the hurricane's center, and inundated the town. Florence essentially funneled up the Neuse River, causing what NWS forecasters describe as a "catastrophic storm surge" that measured 10.4 feet, according to a rapid-deployment gauge from the U.S. Geological Survey.

Jacksonville, located on the New River in Onslow County, meanwhile saw a surge of more than 7 feet, according to a gauge owned by the N.C. Department of Public Safety. Another state gauge in Belhaven, on the Pungo River in Beaufort County, measured a surge surpassing 5.75 feet.

But storm surge was just a prelude to the deluge to come. Florence's relentless rains contributed to massive flooding — a hazard that remained for days, and even weeks, after the system made landfall.

Flash flooding transitioned into what the NWS describes as "historic" flooding in Trenton and Pollocksville, located on the Trent River in Jones County, as water crept up to second stories and even roofs. In Carteret County, the Newport River flooded for the first time in recent history, washing through homes and businesses, according to the NWS.

Rivers also saw historic crests, a term used to describe the highest point of a flood wave.

On Sept. 19 in Pender County, the Cape Fear River crested in Burgaw at more than 25.5 feet — almost 10 feet above the "major flood stage" benchmark. That peak surpasses records set by Floyd, as well as by Hurricane Matthew just two years ago in 2016.

In South Carolina, the Waccamaw River near Conway in Horry County crested on Sept. 26 at a hair above 21 feet, shattering the previous record by more than 3 feet.

"If you think about the timeline from when we first saw this storm was a potential threat to the Southeast to the time the floodwaters crest in the lower Pee Dee River Basin, it's almost two weeks," says Greg Carbone, a principal investigator with CISA.

"So, it's this emergency in slow motion," he says. "It's like knowing an asteroid's going to strike the Earth. It's not going to be now, but when it happens, it's not going to be good."

DISTINCTIVE STORMS

On Oct. 10, less than a month after Florence made landfall, Hurricane Michael roared across the Florida panhandle. A Category 4 storm packing 155-mph winds, Michael was the third most intense hurricane to make landfall in the continental United States, according to NWS records.

Whereas Florence had slowed as it approached land, Michael sped up. As a result, "the flooded area is relatively small, because it was a narrow, fast-moving storm," says Spencer Rogers, North Carolina Sea Grant's coastal construction and erosion specialist, who was recently on assignment in Florida. "But the wind damage was high enough that it was over a pretty wide area."

Michael became a tropical storm as it continued to whip across the Southeast. In North Carolina, the system left thousands without power. Wind gusts as high as 74 mph blew through Kitty Hawk, and the Outer Banks saw a sound-side surge of 2 to 4 feet, depending on location, north of Avon.

"There also was tremendous flooding with Michael in southwest Virginia and northwest North Carolina," Whitehead adds.

The comparisons between Michael and Florence underscore an important fact about hurricanes: No two are alike.

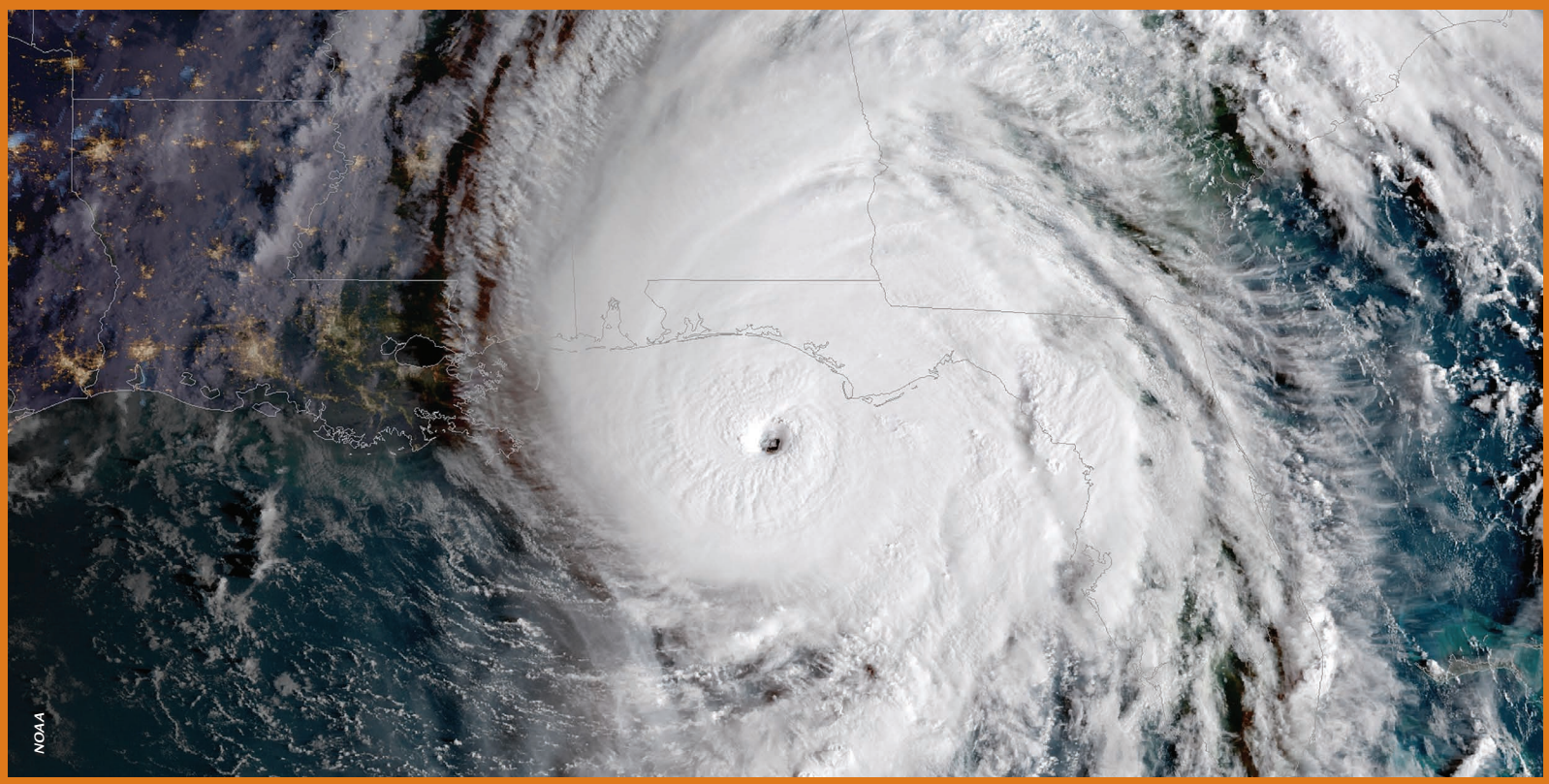
As Whitehead puts it, "each storm is its own storm."

FACING PAGE, clockwise from top left: • *Flood waters wash across a road in the Maysville area of Jones County.* • *A view of Water Street in downtown Wilmington on Sept. 25.* • *Folks wade through a flooded residential area in Jacksonville, Onslow County.* • *This satellite image from Oct. 10 shows Hurricane Michael in the Gulf of Mexico fewer than 90 miles southwest of Panama City.*

John Althouse/The Daily News

Ken Blevins/Star-News


John Althouse/The Daily News


NOAA

WIND DAMAGE?
Check Insurance Incentives When Making Repairs

BY KATIE MOSHER

Surf City, North Carolina, after Hurricane Florence.

Many coastal buildings are underprepared for wind and rain from hurricanes. As homeowners in North Carolina's coastal region repair damage related to Florence and Michael, they should take note of insurance incentives to increase wind resistance by selecting construction options.

"Installing wind-resistant features can protect buildings and potentially save homeowners money," says Spencer Rogers, North Carolina Sea Grant's coastal construction and erosion specialist. "Options to receive insurance rate credits for these protections are available through private insurance companies and state-mandated wind pools."

The wind pools presently are offering free policy endorsements that may reduce costs when repairing or replacing roof coverings on certain buildings, Rogers adds. "Speak with your insurance agent and

Town of Surf City

Justin Kase Conder

adjustor for details regarding your property."

Since 2011, insurance rate credits have been available for wind-resistance features in coastal buildings, as the North Carolina General Assembly directed through the N.C. Department of Insurance. The goal was to develop discounts to encourage better wind-resistant buildings. These discounts are available in 18 coastal counties. Private insurance companies and the state-mandated wind pools are required to offer them.

Residential Windstorm Mitigation Credits are available through private insurance companies and through the pools in coastal North Carolina. Two separate discount options are available for common homeowner or dwelling coverage. If you have a qualifying building, when you receive your annual renewal bill it should include the *Advisory Notice to Policyholders Residential Windstorm Mitigation Credits Available*. Credits are also available for framed buildings for homeowners, dwelling, and wind-only coverage.

With masonry buildings, the insurance territory numbers vary with time and building type, but the highest discounts are generally closest to the ocean shoreline.

The first type of these credits offers a discount for a hip roof and/or window protection via impact glass or certified storm shutters. Each option qualifies for about a 4 to 5 percent discount on the wind/hail coverage cost. You can combine them for a 9 to 10 percent discount.

A second discount option for "Fortified" buildings is based on an existing program developed by the Insurance Institute for Business and Home Safety, a nonprofit insurance trade group. Three levels of discounts are offered for existing or new houses, identified as Bronze, Silver and Gold, each providing about a 4 to 6 percent discount on the wind and hail premium.

The Fortified certificate is good for five years. An evaluator can re-inspect the house to extend the discounts for another five years.

A separate discount is available for new construction: Hurricane Fortified for Safer Living. In hurricane areas, the design requirements are for the local building code's wind speed plus 20 mph. There also are code-plus flood standards, if located in the floodplain. Hurricane Fortified for Safer Living offers the highest discounts: 10 to 17 percent on wind-only coverage.

More recently, the N.C. wind pools have added pilot endorsements that may reduce costs when repairing or replacing roof coverings on certain coastal buildings.

The first pilot endorsement is only available in the beachfront territories, generally the N.C. barrier islands. If the roof covering on an insured building is damaged more than 50 percent, the free policy endorsement offers to pay for the claim, plus the added labor cost of a Fortified Evaluation and the added construction cost to qualify for Fortified Bronze.

A second pilot endorsement is now being offered in 18 coastal counties. If an insured building is reroofed, with or without a damage claim, the building may qualify for reimbursement of up to $600 for the cost of the Fortified Evaluator that results in a Fortified Bronze certification.

Rogers also has prepared a detailed memo about potential discounts and credits available to qualifying insured homeowners. The document includes links to more resources and information: *go.ncsu.edu/WindInsuranceIncentives*.

LEFT: *Temporary solutions in Jacksonville, North Carolina.*

New NC Shellfish Initiative Aids in Florence Damage Assessments

BY KATIE MOSHER

Many shellfish growers in North Carolina use gear that cultivates single oysters for the half-shell market.

In early August, state, federal, university and community partners announced the new North Carolina Shellfish Initiative to support a variety of efforts to grow more clams, oysters and scallops by promoting aquaculture and shellfish restoration.

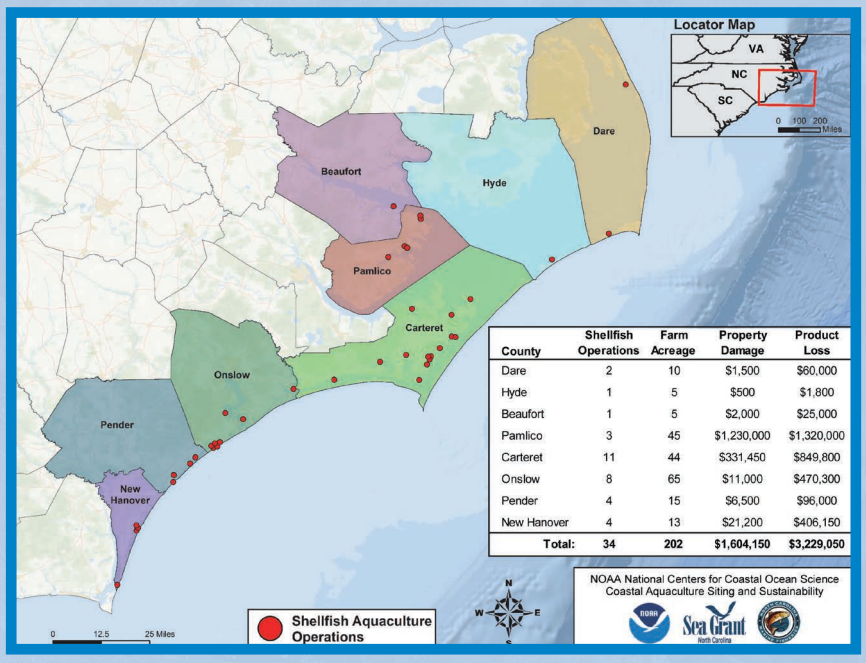
Less than six weeks later, initiative participants added disaster recovery to their tasks after Hurricane Florence brought record flooding to the state. "This is the partnership in action," explains Chuck Weirich, North Carolina Sea Grant's marine aquaculture specialist.

By late October, his survey of damage assessments by shellfish growers suggested losses from Hurricane Florence will top $5 million, with significant impacts to facilities, gear and crops. The tally is expected to rise in the coming months as businesses continue to assess farm and crop damage and provide updates.

Weirich is part of the team that had developed the Shellfish Initiative along with representatives from North Carolina Sea Grant, the National Oceanic and Atmospheric Administration, N.C. Departments of Environmental Quality and Agriculture and Consumer Services, the N.C. Coastal Federation, and the N.C. Shellfish Growers Association.

"Over the last 15 years, the state has garnered public attention with significant investment in shellfish restoration in addition to growth of shellfish farming. NOAA is pleased to partner with the state by contributing tools and expertise for siting shellfish farms and oyster restoration projects, which increase opportunities to sustainably harvest shellfish," says Ken Riley, a marine ecologist with NOAA's National Centers for Coastal Ocean Science.

LEFT: *Hurricane Florence's storm surge along estuarine shorelines damaged docks and gear, such as this site in Carteret County.*
BELOW: *North Carolina Sea Grant collaborated with partners from NOAA and the N.C. Division of Marine Fisheries to identify damage from Hurricane Florence.*



County	Shellfish Operations	Farm Acreage	Property Damage	Product Loss
Dare	2	10	$1,500	$60,000
Hyde	1	5	$500	$1,800
Beaufort	1	5	$2,000	$25,000
Pamlico	3	45	$1,230,000	$1,320,000
Carteret	11	44	$331,450	$849,800
Onslow	8	65	$11,000	$470,300
Pender	4	15	$6,500	$96,000
New Hanover	4	13	$21,200	$406,150
Total:	**34**	**202**	**$1,604,150**	**$3,229,050**

At the announcement event held at the NC State University Center for Marine Sciences and Technology, the partners cited four goals for the initiative: job creation, protection of water quality, protection of shellfish health and sustainable management.

Since Hurricane Florence, Riley and Weirich also have focused on business and job retention as they collaborate to document damage for the state's mariculture industry, which has seen tremendous growth in recent years.

"In particular, the state has seen an increase in water-column leases that allow growers to use culture gear such as cages to produce single oysters for the coveted half-shell market," Weirich explains.

This helped push the farm-gate value of the N.C. oyster aquaculture industry over $1 million for the first time in 2016. In 2017, that value doubled to over $2 million. The state also has a rich history of farming hard clams. Sea Grant is leading research to look into the potential for adding N.C. native sunray Venus clams and bay scallops as cultured species.

Hurricane Florence brought record-setting rain not only in the coastal region but also inland, which meant the flush of freshwater into estuaries — and into shellfish farms — continued for weeks. That flow reduced salinity and dissolved oxygen levels, leaving poor conditions for growing oysters and clams.

Powerful waves and storm surge also hit docks, sorting facilities and gear, and caused severe damage at shellfish hatcheries and nursery facilities.

"All 34 farms that reported had significant damage and a few farms had catastrophic losses," Weirich said. Also, some farms that had fared well through Florence had damage in October when Michael came through with tropical-storm winds driving waves and rain.

Weirich worked first-hand with growers to gather damage estimates. Then Riley's team at NOAA assessed the data and mapped the extent of loss in eight counties. The talley shows that a large storm like Florence can have devastating impacts to shellfish farms in coastal waters across the state. *(See map.)*

For example, Carteret County had 11 shellfish aquaculture businesses reporting losses, the highest count for any county.

Pamlico County had the highest dollar losses, with $1.23 million in property damage and $1.32 million in lost product. Onslow County reported the most impacts to total farm acreage at 65.

Business recovery efforts were ongoing in November — as the shellfish industry was celebrated by a series of stories in *Our State* magazine, a package that had been in the works for a year.

Weirich and Riley hope the photos and stories will keep the industry on the minds of consumers across North Carolina and beyond.

"The state has been carefully monitoring water quality, and has reopened many of the shellfish waters," Riley notes. "Now is a great time to enjoy North Carolina shellfish."

Once occasional visitors to North Carolina estuaries, bull sharks have now established a nursery in the state's largest lagoon. What brought them here?

Welcome to the Neighborhood

BY CHUCK BANGLEY

A diver swims amid bull sharks.

NORTH CAROLINA'S COAST IS A VERY SHARKY PLACE. THE FACT THAT IMPORTANT SHARK HABITAT INCLUDES THE STATE'S ESTUARIES OFTEN SURPRISES LOCALS AND VISITORS ALIKE.

I've spent a lot of time with sharks in these waters. During graduate school at East Carolina University, I worked with the N.C. Division of Marine Fisheries, or DMF, using their extensive fishery-independent survey data to study shark habitat within Pamlico Sound.

That work inspired a shark survey in Core and Back sounds that I conducted as a grad student, with support from a North Carolina Sea Grant minigrant. Now, as a postdoctoral fellow at the Smithsonian Environmental Research Center, or SERC, I've been surveying sharks in the lower Cape Fear River, with funding from North Carolina Aquariums.

So far, my surveys and DMF data have identified a dozen shark species in North Carolina estuaries. Many of those occur often enough to be considered regular members of these ecosystems. The murky waters conceal crucial feeding grounds for these predators, many of which are simply migrating through as they journey up and down the East Coast.

But some sharks grow up in these lagoons. For instance, young smooth dogfish show great affinity for seagrass beds on the sound side of the Outer Banks. Atlantic sharpnose sharks often give birth just inside the barrier island inlets.

My research suggests that lately, one species — the bull shark — has taken a particular liking to the protective nooks and crannies of the state's largest estuary, the Pamlico Sound. Instead of meandering through the lagoon as they've done for decades, these sharks are giving birth there.

NEW NURSERY GROUNDS

Bull sharks are well adapted to estuaries. These small-eyed, generally stocky sharks are among the few species that can tolerate low-salinity and even fresh water. For as long as people have been fishing in North Carolina estuaries, large bull sharks — they can grow upwards of 11 feet — have shown up on occasion. In contrast, juveniles apparently have been quite rare.

For example, in 2012, Frank Schwartz of the University of North Carolina at Chapel Hill's Institute of Marine Science published an extensive study that combined DMF survey data, fishery landings and sightings to identify patterns of bull shark occurrence in N.C. waters. In a data set covering 1965 to 2011, he found records of only nine sharks within the juvenile size range for the species.

When I reviewed the DMF catch data for Pamlico Sound, I really didn't expect to find many bull sharks.

But the survey years from 2007 to 2015 told a different story: Bull sharks were one of the six most common species in Pamlico Sound. What's more, most of these sharks were less than four feet in length, which is well within the juvenile size range.

Many of them were near their size at birth — around two feet in length. Nearly all of them were captured in an area along the western side of Pamlico Sound, stretching from the Long Shoal River on the border of Hyde and Dare counties to Rose Bay near the mouth of the Pamlico River.

I used the survey catch data to map areas of likely shark habitat. As it turned out, bull shark habitat was predicted along the northwestern shoreline of Pamlico Sound. Habitat for every other shark species mapped closer to the inlets and barrier islands on the east side of the estuary.

The presence of small bull sharks in Pamlico Sound raised a question I hadn't expected to ask: Is Pamlico Sound a bull shark nursery?

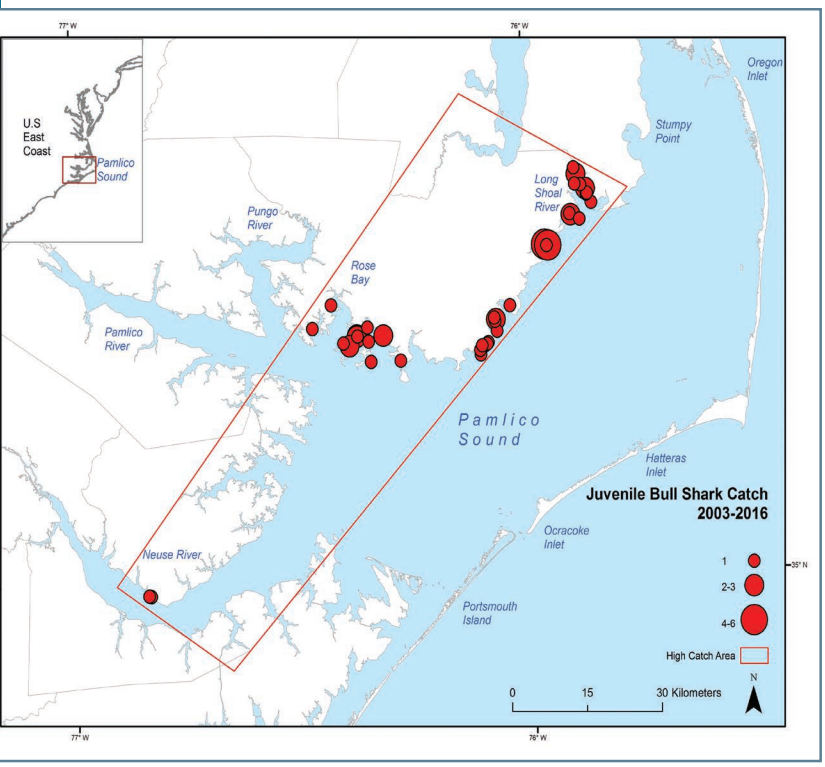
A 2007 paper by shark researcher Michelle Heupel, now at the Australian Institute of Marine Science, and colleagues identified three criteria for defining a shark nursery: Juveniles must be more common in an area than in nearby areas; they must spend an extended period of time in the area; and they are consistently found there over multiple years.

The catch data also showed that juvenile bull sharks are consistently found only in part of western Pamlico Sound from May to October every year since 2011. In other words, Pamlico Sound fit the definition of a bull shark nursery. The next question was why it had become one.

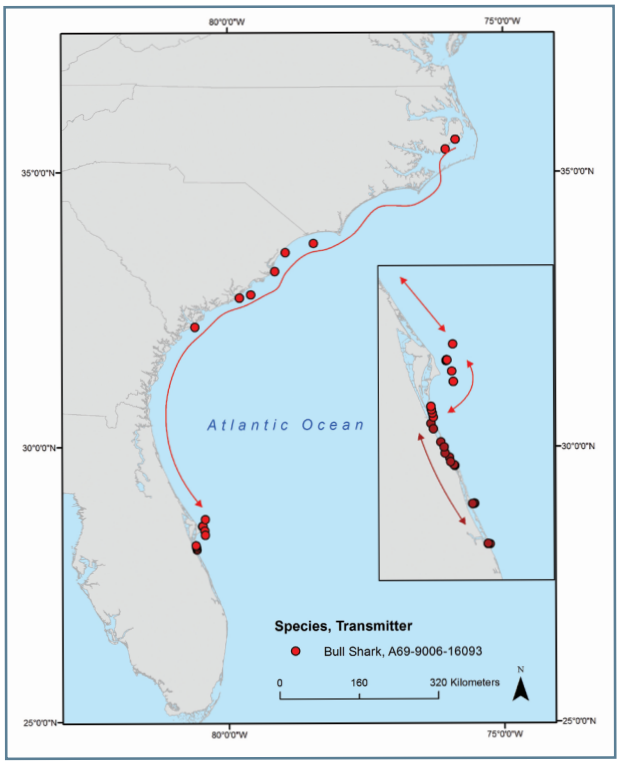
A CHANGING ESTUARY

With its limited ocean access and protected shallows, Pamlico Sound offers prime hideaways for juvenile sharks seeking refuge from larger predatory sharks accustomed to saltier ocean waters. Known bull shark nurseries south of North Carolina have similar features.

So why hadn't bull sharks used Pamlico Sound as a nursery in the past? Its geographic features haven't changed significantly. Another environmental feature must have shifted — and quickly — to make the estuary more inviting.



Bangley et al. (2018)



Bangley et al. (unpublished data)

LEFT: *This map illustrates locations and numbers of juvenile bull sharks caught in Pamlico Sound by North Carolina Division of Marine Fisheries surveys. The area of high bull shark abundance within the sound is outlined.* RIGHT: *A juvenile female bull shark that was tagged with an acoustic transmitter in Pamlico Sound was detected at various spots along the southeast coast.*

The DMF survey data and habitat mapping indicated that the juvenile bull sharks preferred warm water temperatures and brackish salinities. Data from the DMF gillnet survey showed an increase in water temperature and salinity in the sound during the late spring and summer, going back to 2003. The estuarine trawl survey, which has been conducted since 1972, confirmed the temperature trend.

The most pronounced temperature increases occurred from May to July, corresponding with the time of year that bull sharks typically give birth in other estuaries. Salinity increases were less consistent year-to-year and appeared to influence the distribution of the sharks within the sound rather than their abundance.

In other words, temperature was the most likely explanation for increasing numbers of juvenile bull sharks in Pamlico Sound. Once temperatures in late spring and into the summer increased enough to

Continued

LEFT: *A large juvenile bull shark caught and tagged in St. Helena Sound, South Carolina.* RIGHT: *A juvenile bull shark captured in Florida's Indian River Lagoon, previously thought to be the main nursery for the species on the U.S. East Coast.*

consistently average greater than approximately 71°F, juvenile bull sharks began to appear.

These conditions are similar to those under which female bull sharks give birth in Florida's Indian River Lagoon, the species' closest confirmed nursery habitat to Pamlico Sound. Put another way, temperatures in the sound had reached preferred levels for sharks to give birth.

The juvenile bull sharks of Pamlico Sound are a sign of a changing ecosystem.

FOLLOW-UP STUDIES

Learning that Pamlico Sound has become a bull shark nursery raises a lot more questions. Where did the sharks — or their parents — come from? Do they remain in Pamlico Sound all year? What other species are they eating or otherwise interacting with?

In search of answers, I've returned to Pamlico Sound. With minigrant support from Sea Grant, I've been working since last summer with partners at ECU and DMF to study the family history of Pamlico Sound's bull sharks.

We're using two approaches: tracking and genetics. By tagging sharks in their core habitat area with acoustic transmitters, we're gathering data on their movements. Through genetic sampling, we can compare their DNA with that of bull sharks in other areas to see if they're related.

The process of tagging sharks goes something like this: We catch healthy sharks and bring them onto, or alongside, the boat. Then we roll them upside-down to induce an unconscious state called tonic immobility. While the sharks are in this unresponsive state we can perform our tagging procedures without fear of sudden movements.

We make a small incision in the shark's underside and surgically implant an acoustic transmitter, then stitch the shark up and send it on its way. As the tagged shark travels, the tag transmits an ID code unique to that shark at a frequency higher than most animals can hear.

Those signals are detected and recorded on acoustic receivers deployed within Pamlico Sound and all along the coast. Not all of these receivers belong to us. We participate in research groups that use this technology, such as the Atlantic Cooperative Telemetry and the Florida Atlantic Coast Telemetry networks.

Researchers in these networks who detect one of our tags can look up the ID number in a database of tagged animals and send us the data, and we do the same for them. In this manner, we can track our tagged sharks coastwide. Based on their location data, we can piece together their seasonal migrations.

We collect genetic samples from sharks by removing a small piece of the trailing edge of the dorsal fin. Working with geneticists at the Smithsonian and Texas A&M, we've been sequencing regions of the sharks' mitochondrial DNA. Unlike DNA from the nucleus of the cell, mitochondrial DNA occurs in a part of an animal cell called the mitochondria. This DNA is generally passed to the next generation entirely from the mother.

We're focusing on mitochondrial DNA because research on bull shark nurseries in Australia has found that pregnant females will return to the estuaries where they gave birth. As a result, there are genetic differences between shark populations that can be used to identify the nursery where a given shark was born.

Our genetic analysis eventually should tell us whether Pamlico Sound's juvenile sharks are closely related to sharks from known nurseries in Florida waters or in the Gulf of Mexico — or if they're members of a previously unknown population native to the estuary.

Our acoustic tracking and genetic sampling are starting to provide intriguing results.

So far, we have data on a single shark tagged in Pamlico Sound — a female likely within her first year of life. Tagged in early September 2017,

LEFT: *Researchers Matthew Ogburn, left, Chuck Bangley and Michelle Edwards tag a juvenile bull shark from the Indian River Lagoon with an acoustic transmitter.*
RIGHT: *A juvenile bull shark tagged with an acoustic transmitter is released in Pamlico Sound.*

she remained in Pamlico Sound until mid-October before leaving the estuary. Her tag signal was detected traveling along the South Carolina and northern Florida coasts until she reached Cape Canaveral, where she spent the winter.

This shark already has revealed some significant differences in movement behavior from what is currently known about juvenile bull sharks elsewhere. For instance, juveniles in Florida's Indian River Lagoon remain within the estuary year-round until they're nearly six feet in length.

That this tagged bull shark risked a long-distance trip through ocean waters inhabited by potential predators could signify a response to colder winters in Pamlico Sound. We're still waiting to see whether she returns to the Pamlico Sound in the spring of 2019. If she does, it will suggest that Pamlico Sound provides enough beneficial habitat to make the long trip worthwhile.

As for our genetic analysis, we just finished sequencing some of the mitochondrial DNA from six sharks, including the one we've been tracking. Our next step is to make a detailed comparison with other bull shark nurseries.

Preliminary results indicate that there are two distinct genetic differences in the Pamlico sharks. One of those is represented by a single individual, so we still must confirm whether that genetic variation is widespread.

We'll continue to monitor the movements of tagged sharks and to sequence genetic samples. We're also investigating stomach contents and tissue samples to get an idea of what juvenile bull sharks might be feeding on.

Our findings will tell us a lot about the ecology of bull sharks in Pamlico Sound. They'll also give us insight into how the estuary's ecosystem is responding to larger-scale environmental shifts like climate change.

For more on sharks in North Carolina: *go.ncsu.edu/NCsharks.*

Meet the Bull Shark

Carcharhinus leucas

• ***Birth:*** 2–2.5 ft • ***Maturity:*** 6–6.5 ft • ***Maximum:*** 11.5–13 ft

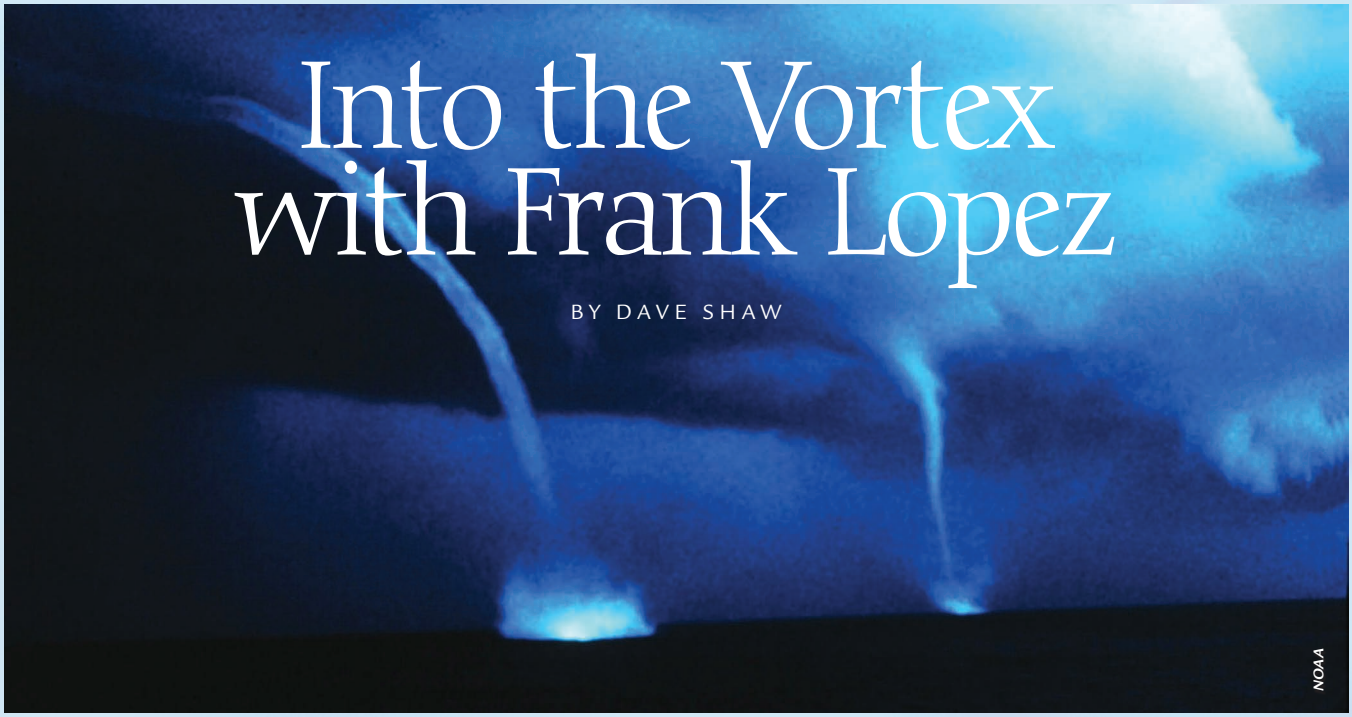
• ***Range and Habitat:*** Bull sharks are found worldwide in tropical nearshore and estuarine environments and are capable of entering and living in fresh water. The species gives birth in brackish areas of estuaries, where young sharks may live for the first 5 to 9 years of life. Both juvenile and adult bull sharks reside in fresh and brackish habitats in some areas, including Lake Nicaragua and some Australian rivers. Larger juveniles and adults also will migrate along entire coastlines and between nearshore waters and offshore reefs. Bull sharks have been found as far north in the Mississippi River as southern Illinois. The record distance upriver is held by a 6-foot shark captured in a tributary of the Amazon River in Iquitos, Peru. Bull sharks also will spend time within human-altered habitats like canals, power plant outflows and marinas.

• ***Diet:*** Bull sharks are apex predators in nearshore and estuarine environments, feeding on large prey including smaller bull sharks, stingrays, dolphins, and large fishes like tarpon and red drum. These sharks can exert an extremely strong bite force for their size, enabling them to take on prey nearly as large as themselves. Preliminary work investigating the stomach contents of juvenile bull sharks in Pamlico Sound also shows evidence of crabs. Fishing gear in the form of small hooks and sections of line also have turned up.

• ***Behavior:*** Much of the social behavior of bull sharks is poorly known. Juveniles will form groups in nursery habitats. Larger bull sharks are usually solitary but will sometimes gather in significant numbers around productive feeding areas. — C.B.

Into the Vortex with Frank Lopez

BY DAVE SHAW



"We actually had managed to get in most of the tour," Frank Lopez says. "Before the storm hit."

TEN YEARS AGO. FRANK LOPEZ IS ABOUT TO GO RIDING AROUND ON A METAL-BOTTOMED LANDING CRAFT IN THE MIDDLE OF A LIGHTNING STORM ON APALACHICOLA BAY IN FLORIDA. THE LIGHTNING WILL NOT BE THE MOST DANGEROUS PART. NOT BY FAR. He's touring the field facility and research projects along an island in Apalachicola National Estuarine Research Reserve as part of a national reserve system meeting. The air's thick — that early summer Gulf Coast soup — and everybody's sweating, thoroughly, as they disperse across the little island's shoreline or investigate inland.

Without warning, mystery stirs the afternoon. The boat captain calmly but insistently starts rounding up his passengers and telling them to please hop aboard and maybe to hop aboard without delay. They really need to get back to the mainland, yes, clear across on the other side of the bay, and it wouldn't be a bad idea if people more or less hurried.

To their credit, everybody diligently makes their way through the grasses and sand and muck. Soon the captain takes the landing craft back out onto the cobalt water, now under the sort of suddenly dark sky that only arrives in black and white films with a feverish string quartet. It's obvious the field experiments are about to be replaced by some real-life meteorology. On cue, the storm hits in full, as if Fate had been lying in wait until the little boat had made the open water. Lightning cracks through eyelids, thunder rattles eardrums, rain whips faces.

"We're in a metal boat in the middle of a lightning storm on a bay," Frank Lopez says later, very matter-of-factly. "So that was cause for a little bit of alarm." He smiles. "And then there was the waterspout."

The ominous journey across Apalachicola Bay was almost exactly one decade before Frank Lopez would become the new extension director for North Carolina Sea Grant and the state's Water Resources Research Institute. "We're lucky Frank made it out of Florida," says Susan White, executive director of both programs.

In fact, anyone who has heard this story is reasonably certain Frank Lopez should've been deposited over the rainbow instead of going on to head a group of specialists 10 years later who, among a long roster of other responsibilities, are helping North Carolinians plan for natural hazards. The variety of waterspouts that touch down during thunderous weather are, after all, notoriously violent. At the minimum, most people agree, Frank Lopez might have been lucky not to have been electrocuted. Yet, Mother Nature had something even more interesting in store for him and his fellow passengers that day on Apalachicola Bay.

At the time, Lopez was program administrator for the Old Woman Creek National Estuarine Research Reserve in Ohio, roughly 1,000 miles to the north of the bay. Some days he would kayak to work.

"It's very small," he says. "The National Estuarine Research Reserve System has all together over a million acres, and Old Woman Creek only has 573. But the thing that really helped us was that everything the people along Lake Erie were facing happened in our watershed, in our area."

He capitalized on the reserve's location, nuzzled as it is against a Great Lake, to help make Old Woman Creek a valuable pilot site for scientists and educators.

"I always liken the reserves to be a little like that movie with the baseball field cut into the corn," he says. "*Field of Dreams.* You know, if you build it they will come. We structured our research program around the premise that we could be the place where things could be learned that would be transferable to other places, too."

The National Estuarine Research Reserve System operates as a state and federal partnership, and by design the reserves serve as field laboratories that explore estuaries and how humans affect them. As part of the Coastal Zone Management Act of 1972, coastal and Great Lakes states had opportunities to establish these marine protected areas, which today function as platforms for research and education. At Old Woman Creek, in addition to managing research and education programs — and the facilities — Lopez regularly collaborated with decision-makers. It's a commonality that he says serves him well at North Carolina Sea Grant and the Water Resources Research Institute.

"What bridges my role at the reserve with my new role is working directly with people who are involved in the coast and who care about its stewardship and its conservation," he says. "That was my favorite part of that experience at the reserve, and that's how I see myself as an extension director."

It was also why, in the middle of his 15-year stint at Old Woman Creek, he trekked down from Ohio to Florida and out across a bay under searing sunshine to see firsthand how the Apalachicola National Estuarine Research Reserve was developing its infrastructure. How was *that* reserve attracting scientists and educators to its estuaries?

"I've always been an administrator," he says, "but you never pass up an opportunity to get out in the field and experience it." This was the very journey, of course, which, unbeknownst to him, would become a race against a waterspout.

The Apalachicola Reserve comprises over 12,000 acres and includes Little St. George Island, the St. Joseph Bay State Buffer Preserve, and land bordering Apalachicola Bay. Its mission includes restoring habitats, protecting rare or endangered species, and helping to maintain biodiversity in and around the bay. At one point most of the oysters that people consumed in the U.S. came out of Apalachicola Bay. The fishery has since crashed, but it was still a productive system at the time he was visiting the field site for the reserve system meeting.

"We actually had managed to get in most of the tour," he says. "Before the storm hit." The sun and humidity had been relentless, and although the brackish bay water exchanges out at Indian Pass and other channels, it doesn't flush very quickly. Despite the unforgiving air, though, he had enjoyed exploring the island with his fellow visitors. It was so hot that everyone was wearing Crocs, those ubiquitous plastic-foam clogs, which, while useful on the boat, brought a specific kind of pain later. "I mean, it looked like I had foot measles — all these red dots where the holes were."

After the captain calmly had gathered up his passengers, and after they set out on their return trip across the bay, under charcoal sky, through lightning and lashing rain, there was no way to know, of course, that one day years later Frank Lopez would actually thank that boat captain for saving his life.

"He was a long-time outdoor educator for the reserve," he says. "He was reading the clouds that day."

Although lightning zigzagged and rain pelted the landing craft, as far as any of the non-Floridians aboard the boat that afternoon could tell, there weren't any waterspouts in sight. Not yet, anyway.

In the end, it seemed almost as if Mother Nature had a plan when she spared Frank Lopez and sent him back to Old Woman Creek. Recently, in fact, The Friends of Old Woman Creek presented him with their annual Hero Award for outstanding stewardship of the reserve over his entire tenure there. After returning from Florida, he had continued to build partnerships, and, among other successful initiatives, he developed a signature watershed program.

"Old Woman Creek is surrounded by landowners that have wanted to keep their property, and so you couldn't really grow the boundary of the reserve," he says. "But we were able to really get people excited locally about watersheds. There's an element of education first, and then action second."

His explanation of watersheds is so easily digestible it seems more like a simple reminder: No matter where you place your feet on the planet, you're standing on a watershed. Whatever actions you take are going to have an impact on our water resources.

Continued

LEFT: *Gulf of Mexico, 2007.* RIGHT: *Tornado Alley native Frank Lopez, extension director for North Carolina Sea Grant and the state's Water Resources Research Institute.*

"From the collective standpoint, we should better collaborate to make sure we can take care of things upstream and downstream," he explains. "There are many opportunities to do good work, and they require us sometimes to step outside of our comfort zone and collaborate with a neighbor."

His new role as extension director for North Carolina Sea Grant and the state's Water Resources Research Institute brings synergy that allows for a focus on entire watersheds, and, he adds, on all of the things water provides for people.

"It's a challenge," Lopez says. "As a society, we haven't always structured ourselves to succeed in these ways. Watersheds don't necessarily correspond to political boundaries. We often have to facilitate cooperation between different entities and different communities on a watershed scale."

At Old Woman Creek, he also helped decisionmakers address stormwater management.

"Managing stormwater and making sure that waterways are healthy and that our water resources are protected is crucial," he says. "But I'm not a stormwater expert like Sea Grant's Barbara Doll, our water protection and restoration specialist. My interest is in the effect that management can have on all the parts of our natural and human systems."

But management wasn't even his first professional love.

"When I came to Chapel Hill for grad school my interest was in transportation," he says. "I went to their planning school, which had a strong emphasis on coastal management and in reducing the impacts of hazards on coastal communities. Lots of people were interested in addressing coastal hazards when I was in grad school. One of my classmates described it as getting swept into a vortex."

It's a particularly tornadic description, considering that Frank Lopez was almost vacuumed off a boat — and, also, that he grew up in the old heart of "Tornado Alley."

Geographically, the famous wind-torn corridor shifted eastward with climate change after his youth. But he spent his second night on earth sleeping soundly in a storm cellar in Potter County, Texas, during a tornado warning, while hail pelted the old sheet metal door. Over the course of his childhood, he took refuge in the cellar many more times, and as a college student, he worked for a local TV crew that once filmed a Plymouth minivan spinning in a twister in Plainview, Texas.

Old Woman Creek National Estuarine Research Reserve in Ohio, where Frank Lopez sometimes kayaked to work.

He offers no hint at all that anything from his formative years or the episode on Apalachicola Bay might have soured him in any way to the entire topic of hazards.

"There are two primary things to think about with respect to hazards," he says. "One is: How can you reduce people's vulnerability before the storm? But then, knowing that storms are going to occur: How can you create conditions following storms that create a better quality of life for everyone?"

As a grad student, he learned about the North Carolina coast and issues its residents face. Through North Carolina Sea Grant, he also successfully applied to be a National Oceanic and Atmospheric Administration Coastal Management Fellow, which took him to South Carolina's coastal management program.

"Then I went to Ohio," he says, "but I kept coming down to North Carolina through the years. I always loved the state, loved the Triangle, loved the Outer Banks and the rest of the coast, and so when this opportunity opened up, it wasn't a very difficult decision to pursue it."

His role as extension director has involved a wide swath of work on coastal ecosystems, marine education, community resilience and many other areas, all of which he has embraced. But where better than North Carolina to apply an interest in addressing coastal hazards?

"We've had some really busy hurricane seasons here," he says. "That's the episodic threat, obviously, as we well know, especially in the wake of Florence and Matthew. We've also got a chronic threat that's just not going to go away: the continuing effects of sea level rise on coastal communities. And some of the flooding that's contributing to."

According to Lopez, North Carolina Sea Grant is developing better tools so that the effects of hurricanes on property and loss are not as severe. "We've also got some great researchers, like Casey Dietrich of NC State, who's working on flood modeling and also on how overwash affects dune elevations."

In addition, he touts North Carolina Sea Grant's work with communities to try to reduce their vulnerabilities. "We've even seen some communities start to think into the future," he says. "Nags Head, for example, where they're starting to assess how they want to structure their community to accommodate sea level rise."

North Carolinians are already seeing the signs.

"Some of the state's rural folks are noticing that the seaward side of their fields are getting saltier," he says. "Local communities are starting to deal with sunny day flooding. It's time to think

about these things now, because they're not going to get better. The end of the story is that sea level rise will continue to be an issue and will probably be more so in the future. We're helping communities think in these terms."

Frank Lopez will tell you he isn't the typical candidate for a career in coastal management and a professional life that offers water no matter which direction he turns. Nor is he someone who you'd ever expect to find on a boat in a thunderstorm in the first place. Although he's no stranger to wind, the Tornado Alley of his childhood covered much of the relatively dry, landlocked Texas Panhandle.

"You know," he says, "it's just amazing. When I was a kid we'd occasionally get water in the streams, but we really didn't even have any surface water to speak of. And yet, I've spent most of my entire professional career working in and around water and the ocean. And coastal management has taken me a lot of neat places. I've been to Alaska, and they fed me just about every critter known to man, including bear. I've been to the Tijuana Reserve on the California-Mexico border, where their watershed lies in two different countries. Some of my absolute best travels have been to go and see some of these coastal places."

And the trip to the reserve on Apalachicola Bay?

"That's a memorable one," he smiles.

Waterspout lore and waterspout science sometimes — but certainly not always — intersect. Reportedly, water-born funnels have swept up entire schools of fish and rained them on land. People often misperceive fair-weather spouts as relatively benign, and although these certainly are weaker than their land-roving counterparts, they still can be dangerous. A popular YouTube video even features a daredevil with an outboard who attempts an ill-advised "ride" on one. The viewer will have to take his word for it, because the camera inexplicably films the boat's floorboards at the moment of truth.

Oysters at Apalachicola River.

However, tornadic waterspouts, which occur off-shore in tandem with thunderstorms, are less ambiguously lethal.

"So we get out on the bay," he says, "in the middle of all this lightning. And the captain was checking the sky, and he must have anticipated that the spout was about to drop. Suddenly he veers hard to the right. I mean, all of a sudden he's gone right full rudder. And so we all look back behind us to see what he's swerving around, and sure enough, the bay water's starting to froth, and then here comes a waterspout down onto the surface. It touches down on the water right *there*."

While the passengers had only begun to appreciate their captain's piloting skills, he quickly found temporary refuge for them from the storm.

"He pulled us off into a 'crack house,'" in Florida's common vernacular of the time. "An oyster shucking house. And there we stood crammed against the wall while the water came down in buckets for about 20 minutes."

At this point in the story, Frank Lopez chuckles. "It gave you an appreciation of life," he says. "When we finally got back to land, everybody made one of those *I love you, man* phone calls."

But why, we might ask, *didn't* that waterspout consume Frank Lopez a decade ago? Was it luck? Fate? Piloting skill?

Consider how he describes his own career.

"You just never know." He laughs. "That's how I always start off when I'm talking to young people. You can plan, but you just don't know. You wouldn't have guessed that when I was in high school in the Texas Panhandle I'd end up here, now, doing this."

And consider his excitement for his new role in North Carolina.

"It's really cool to see enthusiasm around the coastal economy and especially the buzz in our state around aquaculture and the growth of that industry," he says. "Our program has always had a focus on helping to develop and maintain and care for industry along the coast. And there's the potential here for doing a lot more good. We've got a lot of growth in North Carolina, which presents an opportunity — and presents a challenge — to do things well so that resources are sustainable. But this program is set up for continued success, and there's an opportunity to build something even bigger here."

And remember, too, how he described what it first was like to study hazards in graduate school, and how he, too, was swept into that "vortex."

To add to waterspout lore: Maybe the reason Frank Lopez wasn't whipped off Apalachicola Bay 10 years ago was that it would have been redundant. After all, a twister had already taken him. The tornado of his own interests had already plucked him from a bone-dry county in Texas and dropped him into a career where water is everywhere.

Hello, Saltwater Anglers!

BY SCOTT BAKER AND SARA MIRABILIO

Two fisheries specialists with more than 40 years of combined professional experience have launched a new blog for North Carolina Sea Grant that covers all topics related to recreational fishing.

Sunrise at Carolina Beach. Roger Winstead

TO SAY THAT MARINE RECREATIONAL FISHING IS A POPULAR AND IMPORTANT ACTIVITY IN NORTH CAROLINA IS A BIT OF AN UNDERSTATEMENT.

Consider the following: Approximately one in 13 North Carolinians holds a coastal recreational fishing license. In 2016 alone, almost 2 million anglers fished in our state. Of those, about 800,000 were N.C. residents, and just over a million came from out of state to fish our coastal waters.

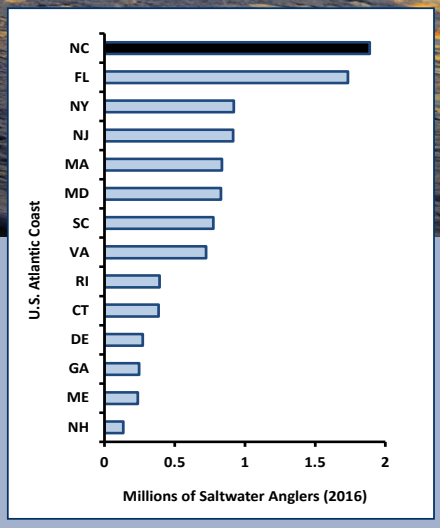
In fact, North Carolina ranks first among Atlantic states for the number of people who fish recreationally in saltwater off the East Coast. Florida is a close second.

No matter how you look at these figures, that's a lot of people enjoying our coast and its resources.

One of our duties as fisheries specialists with North Carolina Sea Grant is to share relevant scientific discoveries with individuals who work, play and live along the coast — including anglers. We also listen to ideas from all fishermen and share those observations with the research and management community.

To better serve recreational fishermen, we mailed a survey to 1,000 saltwater anglers across the state. One finding showed that respondents were keen on learning about fisheries research. We also found out lots of other cool things about N.C. anglers, and we plan to share more of those details soon.

The survey also inspired us to launch a new blog: *Hook, Line & Science.* Each week, we'll summarize new research that could affect anglers in our state.



The 13 U.S. Atlantic Coast states, ranked by total number of saltwater anglers in 2016 (includes Florida's east coast only), according to the most recent data available from NOAA Fisheries.

For example, which hook type works best for catching a certain species? What percentage of boating-related deaths are attributable to alcohol or lack of lifejackets? How do invasive species impact local, sought-after sport fish? If you only had time to go to one reef site on your next trip, should you seek out a natural reef or an artificial one?

How do hurricanes affect estuarine water and fishing?

Our focus will be on completed research that has been peer-reviewed in some capacity. But we also plan to profile research in progress, especially if we think that the work matters to anglers. Some research will take place in North Carolina, but certainly not all. And who knows? Maybe some of our articles will help anglers catch more fish!

Interest is high in this new project, and we hope you'll check it out. Here are three blogposts to get you started. You can read more at *HookLineScience.com.*

HOW MUCH WE LOVE TO FISH

An Insight into America's Popular Pastime

Participation and economic impact surveys are an important part of fisheries and wildlife management. Well-designed surveys, repeated every so often, allow managers to examine trends in the data as well as the absolute values. The study profiled below has been conducted in a similar fashion every 5 years since 1991.

- *Research Need*

Fishing is one of America's favorite pastimes, with outdoor recreation providing a huge contribution to the nation's economy. It's therefore important to understand to what extent we love to fish — and how much we spend on this much beloved hobby.

- *What did they study?*

The National Survey of Fishing, Hunting, and Wildlife-Associated Recreation is designed to interview U.S. residents, aged 16 and older, about their most recent activities related to fishing, hunting and wildlife viewing. To accomplish this, the U.S. Census Bureau selected 22,416 households for screening interviews, then narrowed down the sample to 5,782 potential respondents and surveyed them.

- *What did the results show?*

Fishing attracted 35.8 million people 16 years or older in 2016, an 8 percent increase from 2011. For some perspective, that's 14 percent of the U.S. population aged 16 years or older. Freshwater fishing was by far the most popular choice, with 29.5 million anglers dedicating a combined total of 373 million days to the sport. By comparison, 8.3 million anglers spent 75 million days saltwater fishing.

Altogether, American anglers spent $46.1 billion on trips, equipment, licenses and other fishing-related products and services in 2016. The average expenditure per angler was $1,290 for the year, up 3 percent from 2011.

- *What else did they find?*

While participants younger than 16 years were not surveyed, the study was able to provide a participation estimate for this group based on other factors. For example, of the 40.5 million 6- to 15-year-olds in the United States in 2016, 1.4 million hunted and 8.1 million fished.

- *Anything else?*

Comparing the results to the 2006 survey, spending decreased by 8 percent, but the number of anglers aged 16 or over had increased by 19 percent. With results like these, fishing clearly remains one of the nation's favorite pastimes.

- *Reading*

U.S. Department of the Interior, U.S. Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau. 2016 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. Final report, summary facts and infographics: *https://www.census.gov/programs-surveys/fhwar.html*

Summary compiled by Caitlin Cunningham and Scott Baker

Charter boats in Pirate's Cove Marina, Manteo, North Carolina.

Continued

CAN SAND TIGERS SURVIVE CATCH AND RELEASE?

Effect on a Prohibited Shark Species

Sand tiger at the North Carolina Aquarium at Pine Knoll Shores.

Scott Taylor for NC Aquariums

While interviewing saltwater anglers at the dock as part of a study more than a decade ago, we learned that anglers rarely recall the actual species identity of sharks that they encounter. More often than not, the response to my catch query was, "Oh yeah, I also caught and released a shark."

Fast forward to today, and classifying the number and release condition of correctly identified sharks is more important than ever. The article profiled below examines the effects of catch and release on a prohibited shark species.

• *Research Need*

The catch and release of sharks, even for species where harvest is not allowed, is a popular activity among saltwater anglers. In the last decade alone, anglers along the U.S. East Coast released 66 million sharks, including 1.2 million among prohibited species.

A popular species for catch and release is the sand tiger — that large, toothy shark that is often the main exhibit at saltwater aquariums. However, science shows us that catch and release does not necessarily ensure 100 percent survival. Documenting the survival rates of released sharks can better assist with the management of these species.

• *What did they study?*

Scientists teamed up with anglers who were actively targeting sand tiger sharks in coastal Delaware waters. While not influencing fishing practices, the scientists documented the capture of 35 sharks, noting the different fishing styles of different saltwater anglers and the final position of the hook in each shark. Scientists then placed an acoustic tag on the sand tigers in order to track their short-term movements in surrounding waters and to infer whether the animals lived after catch-and-release events.

• *What did the results show?*

Analysis of tagging data revealed that 2 of 33 sharks (6 percent) likely died as a result of catch and release events. Anglers landed one shark with a circle hook and the other a J hook, and both hooks lodged internally, leading to probable death several days after release.

• *What else did they find?*

Although anglers land most sharks using circle hooks (71 percent), sand tigers tend to swallow both hook types, which could lead to internal injuries. Swallowing hooks may be the result of the feeding style of these large sharks.

While the catch-and-release mortality rate of tiger sharks by saltwater anglers may be low, fishing pressure on this and similar shark species appears to be increasing.

• *Reading*

Kilfoil, J. P., Wetherbee, B. M., Carlson, J. K., & Fox, D. A. (2017). Targeted Catch-and-Release of Prohibited Sharks: Sand Tigers in Coastal Delaware Waters. *Fisheries*, 42(5), 281-287. *https://doi.org/10.1080/03632415.2017.1306974*

Summary compiled by Anna Greene and Scott Baker

SAFETY AT SEA

The Dangers of Boating under the Influence

When we conducted our assessment of education needs of saltwater anglers in 2017, the results confirmed they were interested in boating safety. We were glad to see that, because safe boating practices can impact everyone on the water — not just anglers.

The study profiled below is not recent but is still considered a seminal review article for this subject. According to the journal that published the study, the article abstract has been viewed more than 11,000 times.

- *Research Need*

Have you ever spent a relaxing day out on the water and decided to have a drink or two? Would you still drink the occasional beer knowing it increased your risk of drowning? Alcohol is an important risk associated with drowning while boating. This study aimed to determine to what extent alcohol increased this danger.

- *What did they study?*

Researchers looked at databases of scientific articles that included such keywords as "drowning" and "alcohol." They included every article published up until October 2003, with the oldest dated 1959. Then, they separately analysed drowning deaths that occurred during boating activities by looking at recorded blood alcohol levels and, in turn, examined these cases further, assessing whether alcohol was a causal or contributing factor.

- *What did the results show?*

Researchers concluded that alcohol contributed to between 10 percent and 30 percent of all recreational drowning deaths. In fact, 30 to 70 percent of drowning victims had measurable blood alcohol levels after death. The range was broad because blood alcohol levels can increase after death due to decomposition and also decrease before death as natural metabolic processes occur.

- *What else did they find?*

The risk of death associated with boating increases at *all* blood alcohol levels. For example, a blood alcohol level of 0.1 grams per 100 millilitres increases your risk of death during recreational boating *tenfold*.

Everyone absorbs and metabolizes alcohol at different rates. But for the average male weighing 196 pounds, this blood-alcohol level would be obtained after consuming six 12-ounce cans of U.S. domestic beer (5.0 percent alcohol) over a 2.5 hour period.

Of course, it is important to clarify that 0.1 g/100ml is above the blood alcohol limit in all 50 states.

- *Anything else?*

Further research, with more consistent data collection, would be very valuable in determining a more precise relationship between drinking and boating deaths. In the meantime, next time you're out on your boat, *it would be wise to stay sober.*

Heading south down the Intracoastal Waterway near Figure Eight Island.

Roger Winstead

- *Reading*

Driscoll, T., Harrison, J. and Steenkamp, M. (2004). Review of the role of alcohol in drowning associated with recreational aquatic activity. *Injury Prevention*, 10(2), pp.107-113. Read the full article here: *http://injuryprevention.bmj.com/content/10/2/107.*

Summary compiled by Caitlin Cunningham and Scott Baker

MaRRS Lab

Drones Deliver Data on Oyster Reef Health

BY ANNA WINDLE AND SARAH POULIN

Using aerial imagery from unoccupied aircraft systems, researchers can efficiently assess the condition of oyster reefs.

The joint North Carolina Sea Grant and North Carolina Space Grant Graduate Research Fellowships support students whose work focuses on nearshore environments and coastal watersheds. To date, the annual joint fellowships have backed fascinating projects and rising stars.

These projects apply relevant measurement instruments or other data sources from the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration and other data sources.

"We see many synergies linking the remote-sensing expertise of Space Grant and Sea Grant's applied research with coastal communities, businesses and resource managers," says Susan White, who heads North Carolina's Sea Grant and Space Grant programs.

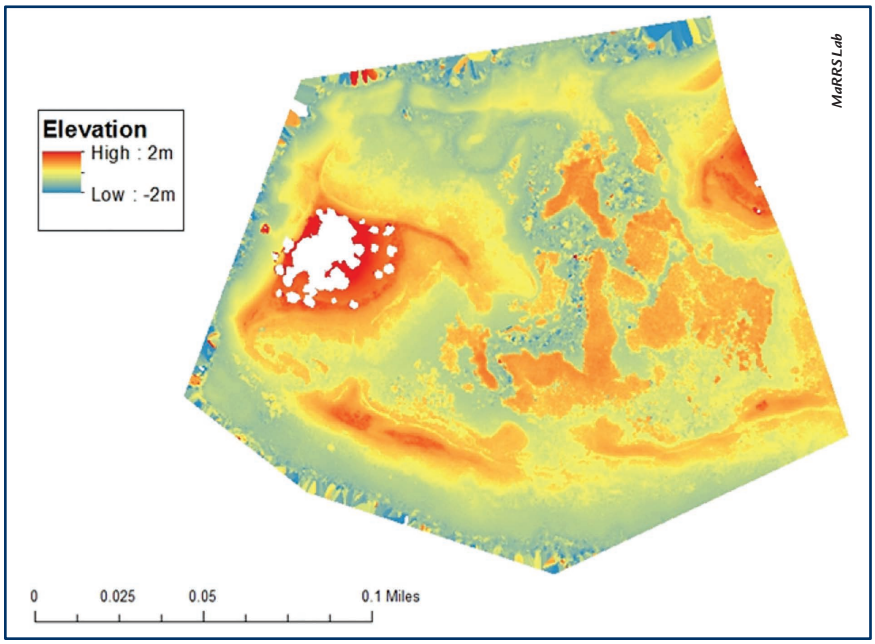
Anna Windle's 2017 joint fellowship supported her collaboration with Sarah Poulin to use aerial imagery from drones in order to assess oyster reef health at the Rachel Carson Estuarine Research Reserve in Carteret County.

This summer they wrote about their project for our online Currents *blog. Their post, which follows, quickly became one of the most popular of the year.*

OYSTER REEFS PLAY AN ESSENTIAL ROLE IN COASTAL AND ESTUARINE ENVIRONMENTS. They provide a suite of ecosystem services, such as providing habitat for juvenile fish, serving as buffers to storm and wave energy, filtering pollutants from the water, and much more.

They're also pretty tasty. Oysters have been harvested for consumption for centuries. However, today water people in North Carolina only bring in 15 to 20 percent of what was once harvested annually.

How come? Since the early 1900s, North Carolina's oyster population has



FACING PAGE: *Anna Windle, right, Sarah Poulin, left, and Wendy Folfas, an undergraduate assistant, measure oysters.* ABOVE LEFT: *Poulin, left, and Windle used drones to survey oyster reefs in the Rachel Carson Estuarine Research Reserve in Beaufort, N.C.* ABOVE RIGHT: *Oysters in the Rachel Carson Estuarine Research Reserve.* LEFT: *A digital surface model of marsh and oyster reefs located in the Rachel Carson Reserve.*

declined by an estimated 50 to 90 percent due to overharvesting, disease, poor water quality and habitat loss, according to the N.C. Coastal Federation. Vast stretches of coast-hugging, or fringing, oyster reefs have disappeared, leaving fishermen, conservationists and others concerned about the sustainability of their populations.

In response to the decline, in 2001 the N.C. Division of Marine Fisheries (DMF) implemented management plans and restrictions designed to limit overharvesting. The agency based these new plans and restrictions on the results of a decades-long mapping project. In 1988, DMF began using GPS and geographical information systems, or GIS, to delineate and map habitat types in every estuarine ecosystem in the state.

One of the goals was to determine area and abundance of shellfish, including oysters. Thirty years later, the agency has mapped 90 percent of bottom-dwelling shellfish in those estuarine ecosystems.

Now that baseline mapping efforts of these estuarine ecosystems has been achieved, a quicker and more efficient method is critical to continue monitoring of important shellfish species, such as oysters. A lot can change in three decades, including oyster health, abundance and the area they cover.

In recent years, managers have used aerial imagery from satellites and occupied aircraft to monitor oyster reefs over time. One advantage of these remote-sensing techniques is that they don't disturb the landscape. However, low-resolution images from sensors on occupied aircraft and satellites can leave out smaller-scale patches of oysters and can inaccurately classify similar-looking habitat types. These methods also can be costly and time-sensitive, and they're reliant on clear weather.

Unoccupied aircraft systems (UAS), or drones, are transforming the way we collect scientific data. They bridge the gap between sampling in the field and established remote-sensing approaches. Drones can collect significantly higher-resolution imagery, enabling us to see fine details, such as small oyster reef patches.

With increasing battery life and advancements on platforms and sensors, we can now collect thousands of centimeter-scale-resolution images of an environment during a 45-minute drone flight across close to 3,000 acres. While established methods can measure

Continued

to the nearest meter of an oyster reef, drone imagery has the ability to measure individual oysters to the nearest millimeter.

For our project, we used drones to collect data on oyster reefs located in the Rachel Carson Estuarine Research Reserve in Beaufort, North Carolina. We explored different types of drone platforms, sensors and processing options to determine which were the most effective for oyster reef monitoring.

We studied intertidal fringing reefs located on the east end of Town Marsh, an island portion of the reserve, as well as manmade intertidal reefs in Middle Marsh, an area of interconnected marshland located on the west side of the reserve.

All of the aircraft provided hundreds of high-resolution images. When we got back to the lab, we used a processing software that stitches the images together to form a highly accurate photo representation of an area, known as an orthomosaic. The orthomosaic was geometrically corrected and aligned to a known coordinate system.

Using elevation measurements, the software can also create digital surface models — maps that represent the earth's surface, including all objects on it. These maps allowed us to analyze the entire area we surveyed.

Reef area and height are widely used metrics for oyster reef monitoring. Using the high-resolution orthomosaic, we delineated the edges of oyster reef patches in order to calculate total oyster reef area. Using the digital surface model, we calculated oyster reef height. We calculated these metrics for a one-square-mile area in just a matter of minutes.

Brandon Puckett, research coordinator for the N.C. Coastal Reserve, had informed us that managers at the Rachel Carson Reserve did not have an accurate estimate of oyster reef habitat in its total 2,315 acres. In a couple days, we were able to identify 11.83 total acres of intertidal oyster reef from analyzing drone imagery of the entire reserve.

This research will undoubtedly transform the way researchers and managers monitor oyster reef habitat. As our advisor, David W. Johnston of the Duke University Marine Laboratory, noted in a recent article appearing in *Annual Reviews of Marine Science*, "Drones are poised to revolutionize marine science and conservation, as they provide essentially on-demand remote sensing capabilities at low cost and with reduced human risk."

Methods involving UAS are quicker, more accurate and less environmentally disturbing than traditional, time-consuming field methods. We hope that the results from our research — which we plan to submit for publication — will help managers and researchers alike to choose the best type of aircraft and sensor for their intended purpose.

For more on this project, check out this interactive story map: *go.ncsu.edu/marrsLabStoryMap*.

The researchers used a fixed wing drone called the eBee Plus (left), equipped with a Sensor Optimized for Drone Applications sensor. They used two rotary wing drones: the DJI S900 hexacopter (middle), equipped with a Sony 6000a digital camera, and the DJI Mavic Pro, equipped with a 12-inch megapixel CMOS camera.

FIXED WING AIRCRAFT

PROS

- Covers larger areas in less time (30 acres in about 20 minutes)
- Faster speeds: longer flight (45 minutes with one battery)

CONS

- Need large area for launch and landing runway
- Must stay in motion; cannot hover
- High altitude: lower-resolution imagery

ROTARY WING AIRCRAFT

PROS

- Can take off and land from a small area, such as a boat
- Can hover and maneuver around obstacles
- Low altitude: higher-resolution imagery

CONS

- Lower speeds: shorter flight (15-20 minutes with one battery)
- Low altitude: unsuitable for large-scale surveys

For more on the drones used in this project, visit North Carolina Space Grant at *go.ncsu.edu/DronesAndOysters*.

After earning master's degrees in environmental management, Anna Windle and Sarah Poulin are continuing to pursue research opportunities. Windle is now a doctoral student at the University of Maryland Center for Environmental Science at Horn Point Laboratory in Cambridge, where she uses satellite and UAS remote-sensing methods to assess water quality of the Chesapeake Bay. Poulin is a research associate for the Marine Geospatial Ecology Lab at the Duke Marine Lab, with plans to apply to a doctoral program.

Adapting to Climate Change

BY DAVE SHAW

THE AMERICAN SOCIETY OF ADAPTATION PROFESSIONALS HAS RECOGNIZED JOHN FEAR, DEPUTY DIRECTOR OF NORTH CAROLINA SEA GRANT AND THE STATE'S WATER RESOURCES RESEARCH INSTITUTE, AND HOLLY WHITE, PRINCIPAL PLANNER FOR THE TOWN OF NAGS HEAD. Both received honors at the Carolinas Regional Adaptation Leadership Awards ceremony at the Carolinas Climate Resilience Conference in October.

The awards celebrate the exceptional work of people who have spearheaded climate change adaptation, and nominees included distinguished leaders from all sectors. White won the top regional honor. Fear received an honorable mention for building capacity and fostering connectivity.

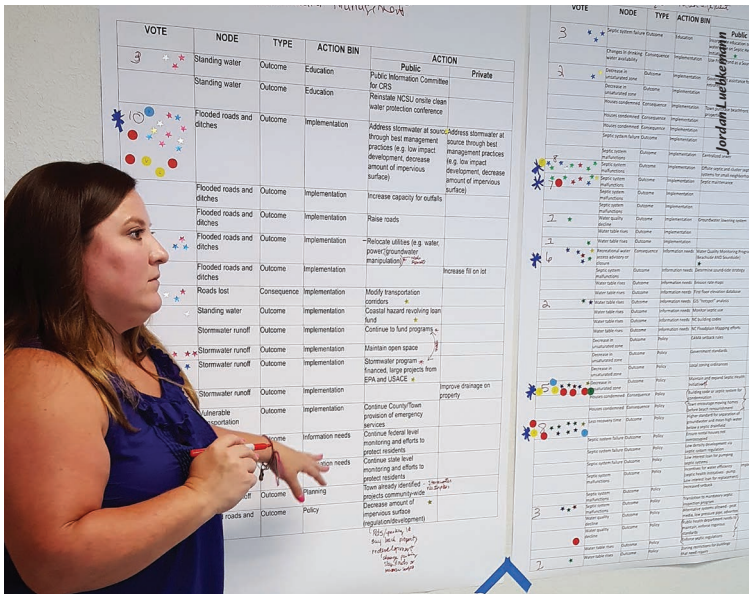
"John leads by initiating significant funding, engagement, and educational opportunities that enable others to work on the ground, implementing adaptation options. Without these opportunities that John strategically develops, in funding and in partnerships, the breadth of adaptation impacts in North Carolina would be much more limited."

– SUSAN WHITE, EXECUTIVE DIRECTOR FOR THE STATE'S SEA GRANT AND WRRI PROGRAMS

"With John's thoughtful input, climate change topics — and related adaptation responses at a variety of levels — are integrated not only into strategic plans but truly into daily operations," says Susan White, executive director for the state's Sea Grant and WRRI programs.

Fear's foresight matches an ability to set up projects for real-world success, she adds.

"John leads by initiating significant funding, engagement and educational opportunities that enable others to work on the ground, implementing adaptation options," she says. "Without these opportunities that John strategically develops, in funding and in partnerships, the breadth of adaptation impacts in North Carolina would be much more limited."



ABOVE: *John Fear in the field, St. Johns River, Florida.*
BELOW: *Holly White at a Town of Nags Head planning session.*

The society honored Holly White, a longtime partner of North Carolina Sea Grant, in large part for driving the Town of Nags Head's planning for sea level rise and helping to nest that process within a broader planning effort for the town. For the past four years she has served as the town's principal planner, following positions with Currituck County and the Town of Kitty Hawk.

"Word about Nags Head is getting out," says Jessica Whitehead, coastal communities hazards adaptation specialist with North Carolina Sea Grant. "Within the last month, North Carolina Sea Grant has received four requests from communities throughout the state for similar assistance, and all have cited Nags Head as the driving example leading them to ask us for help. None of this would be possible without Holly White's commitment to co-producing this work — to understand the science and to find solutions that work on the ground in a way only a true practitioner can."

Continued

The awards committee agreed: "It is impressive that she was able to make this a reality in Nags Head."

The selection committee additionally noted Fear's successes, particularly in identifying and addressing big picture challenges, along with his ability to train the future workforce. The committee called special attention to his emphasis on helping students conduct more outreach and real-time communication.

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– JESSICA WHITEHEAD, COASTAL COMMUNITIES HAZARDS ADAPTATION SPECIALIST WITH NORTH CAROLINA SEA GRANT

Fear chairs the North Carolina Sentinel Site Cooperative, which addresses climate change impacts along our state's coast. A program of the National Oceanic and Atmospheric Administration, the cooperative promotes a network of organizational partners from scientific and academic communities, resource managers, and nongovernmental organizations. Its research and monitoring programs enhance understanding of the coastal environment, including sea level rise, marsh ecosystems and living shorelines.

He also oversees the research portfolio for the state's Sea Grant and WRRI programs. As such, he serves as a primary strategist for the Community Collaborative Research Grant Program, which funded the innovative RISING project, among many other successful initiatives that have addressed climate change impacts directly and indirectly. The RISING project generated community-level discussions of sea level rise, providing forums for meaningful public dialogue, in some places for the first time.

The society's third regional honoree this year was Steven Frank, associate professor of entomology at North Carolina State University. He received an honorable mention for adaptation integration. His core interests include the exploration of urban warming and its relationship to global warming and climate change.

TOP: *John Fear and Susan White* MIDDLE: *This Town of Nags Head planning session included Holly White (middle), former North Carolina Sea Grant law, policy and community development specialist Lisa Schiavanto (right), and many other stakeholders.* BOTTOM: *Brainstorming, Town of Nags Head planning session.*

Fisherman's Blues


Lillian Dunn


Jane Harrison


Jane Harrison


Jane Harrison

This fall, North Carolina Sea Grant co-sponsored "Radical Transformation of Our Seas: Stories from *Fisherman's Blues*," an event to explore global views of fishing and seafood. Author Anna Badkhen read from her new book, an intimate account of life in a West African fishing village. Ryan Speckman, co-founder of Locals Seafood in Raleigh, joined her to help compare experiences on the Atlantic's east and west coasts. Jane Harrison, North Carolina Sea Grant's coastal economics specialist, moderated the discussion.

TOP LEFT: *Harrison (left) first met Badkhen (right) in Senegal while the author was immersed in a coastal village's fishing culture. Abdou Karim Sall, Badhken's host and a fisherman, sits in the background.* BOTTOM LEFT AND TOP RIGHT: *For centuries, fishermen have launched their pirogues (narrow canoes) off the Senegalese coast, where villagers still tell stories about the days when fish once were large and plentiful.* BOTTOM RIGHT: *Badhken's translator, El Hadji Faye, was instrumental in helping her discover village tales to carry across the Atlantic.*

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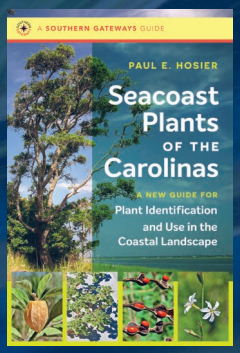
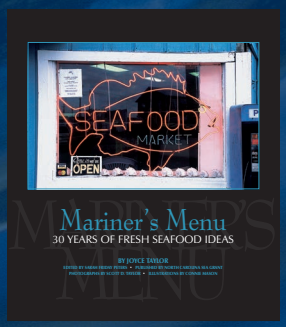
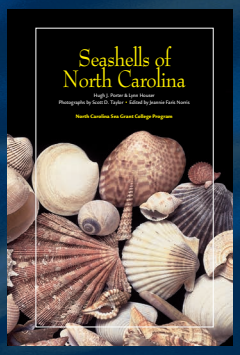
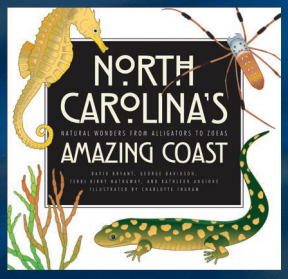
Enjoy the North Carolina coast year-round with North Carolina Sea Grant's publications, available in local bookstores across the state. Several items are available directly through UNC Press at *uncpress.org*.

- *Seacoast Plants of the Carolinas: A New Guide for Plant Identification and Use in the Coastal Landscape* — published earlier this year — provides the latest insight into N.C. plant life.
- *Mariner's Menu: 30 Years of Fresh Seafood Ideas* is perfect for any cook, cookbook collector or seafood enthusiast.
- *Seashells of North Carolina* features photographs and descriptions of 261 shells found along our beautiful coast.
- *North Carolina's Amazing Coast: Natural Wonders from Alligators to Zoeas* will appeal to teachers and others who love the coast and is published by the University of Georgia Press.









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Please keep in mind that our office will be closed for the university's winter break.

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