THE LAKE MICHIGAN
NEARSHORE
FOOD WEB

CHARTING NEW WATERS

ILLINOIS-INDIANA SEA GRANT | WISCONSIN SEA GRANT

On the cover: Quagga mussels, along with associated algae, thrive in the waters of Good Harbor, near Sleeping Bear Dunes in Michigan. PHOTO BY EMILY TYNER

INTRODUCTION

What are the most critical concerns facing Lake Michigan? The Great Lakes Regional Research and Information Network (GLRRIN) Lake Michigan team set out to answer this question by bringing together more than 50 government and academic researchers over several meetings to share what's known, what isn't, and what information would be most valuable to inform resource managers and others interested in the health of the lake.

Researchers agreed that the Lake Michigan food web has changed in recent years. As priorities were defined, a timely question clearly needed to be answered: How has the influx of invasive species impacted the lake's food web? Zebra and quagga mussels, in particular, have completely changed the dynamics of the lake.

Zebra and quagga mussels have changed the dynamics of the lake.

Illinois-Indiana Sea Grant (IISG) teamed up with Wisconsin Sea Grant to support studies that, through old-school methods and cutting-edge technology, would identify who's eating whom in today's Lake Michigan food web, especially in the less documented nearshore environment, and where invasive species fit into the mix. The federal Great Lakes Restoration Initiative funded some related projects and Michigan Sea Grant provided additional support.

The GLRRIN meetings also served as a springboard for planning the U.S. Environmental Protection Agency-led 2010 and 2015 Cooperative Science and Monitoring Initiative (CSMI) Lake Michigan field years. CSMI rotates, focusing on one Laurentian Great Lake each year—seeking an in-depth understanding of the lake through a binational effort of coordinated sampling between agency and university researchers. IISG has helped coordinate CSMI on the U.S. side over the last five years.

CAROLYN FOLEY

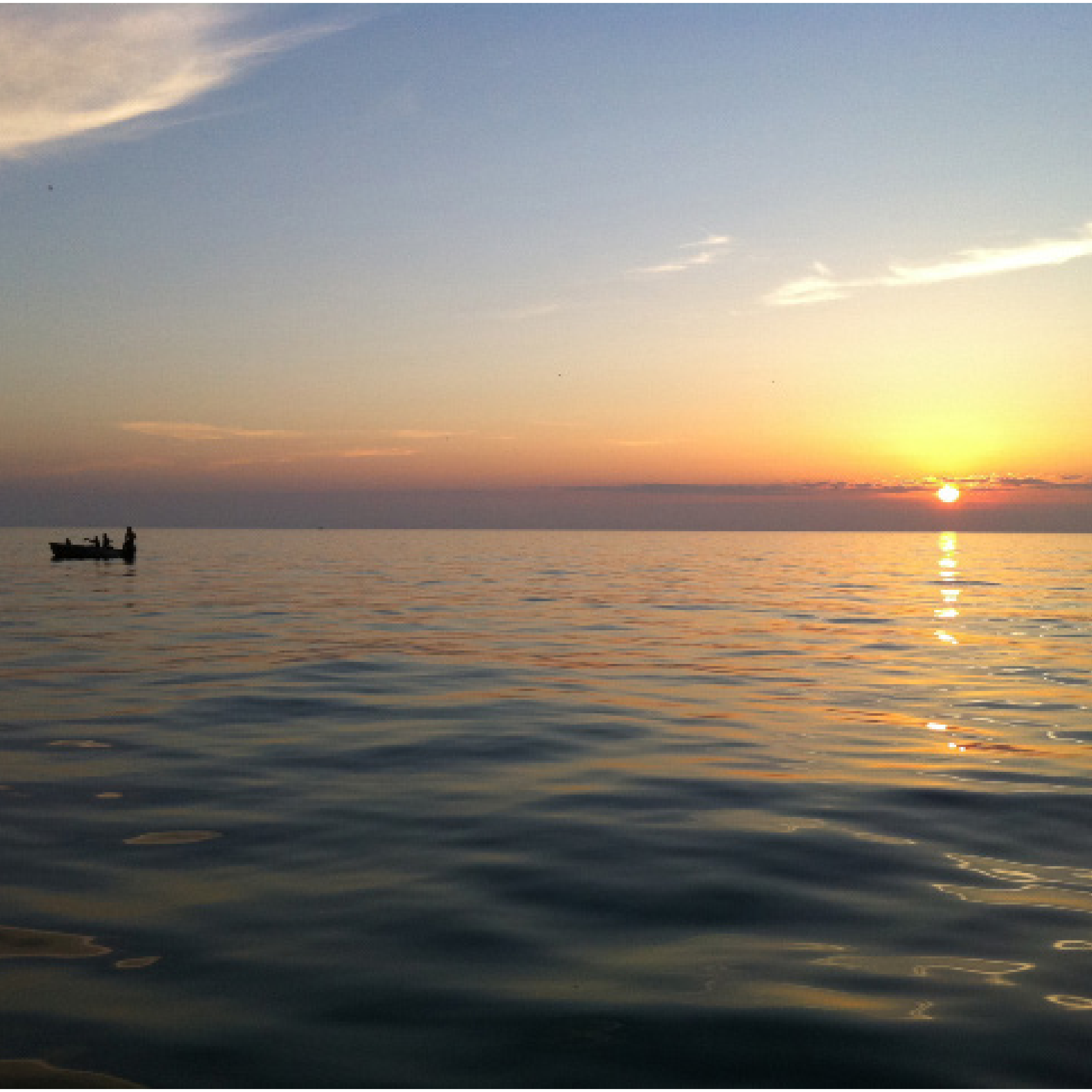
Who's eating whom in today's Lake Michigan food web, especially in the less-documented nearshore environment, and where do invasive species fit into the mix?

This publication tells the stories of projects funded by Sea Grant that examined key food web processes in nearshore Lake Michigan. They bring to light changing food sources and how quagga mussels and round gobies, for example, are shifting the food web's energy pathways. This research shows how key food sources and energy pathways differ between eastern near-shore waters and western shores. In short, these studies reveal insights into the new Lake Michigan food web.

These new understandings can allow resource managers to make informed decisions based on the lake's current conditions as well as anticipate how key components of Lake Michigan's food web may change in the future.

Because historically, most research in Lake Michigan has focused on deeper waters, scientists have considered near-shore zones as something of a mystery. Other understudied areas include the very base of the food web, like bacteria and picoplankton, and how lower food web processes link up to big fishes. The Lake Michigan Sea Grant programs have been able to help fill in these gaps too, but the full results of these studies, their stories, are yet to come.

Purdue University graduate student Sarah Stein removes a Lake Michigan fish from a micro-mesh gill net set near Michigan City, Indiana.



CONTENTS

SARAH STEIN

THE NEARSHORE FOOD WEB IS AN EAST-WEST SIDE STORY

These are tough times for the Lake Michigan food web. Invasive species and a loss of nutrients have wreaked havoc on native populations with species up and down the food chain competing for less food. But there may be some good news. Differences in the lake's nearshore food webs may be providing some much-needed stability.

The biggest difference lies at the base of the food webs on the lake's eastern and western shores. Fish and other aquatic species living off of Wisconsin and Illinois rely more on organisms living on the lake floor, while their cousins to the east are mainly dining on zooplankton.

> The biggest difference lies at the base of the food webs on the lake's eastern and western shores

For many species, these differences mean more options at the nearshore buffet. And there is less risk that whole populations will collapse when food supplies are low in some areas. The yellow perch population, for example, may dwindle if zooplankton continues to decline, but the lake as a whole could still have enough yellow perch to support fisheries and feed larger fish.

The most likely driver behind regional differences is the lake itself. Much like its bordering states, the shores of Lake Michigan are very different. The east has mostly sandy nearshore environments, more river mouths, and warmer water. Shorelines on the west are rockier and home to more upwellings that force nutrients and aquatic life from the lake bed to the surface, making bottom-dwelling prey a more readily available food source.

> Resource managers may need different, more regional, approaches for managing the fish population and protecting the health of nearshore waters.

Researchers from Illinois, Indiana, and Wisconsin discovered the east-west divide after analyzing the diets of round goby, yellow perch, and spottail shiner taken from around the lake in 2010. They relied on three techniques that are not usually combined.

"Stomach contents reveal what the fish are eating at the exact moment of capture while fatty acid signatures allow us to tease apart what they have been consuming over several weeks. Stable isotopes provide a picture of an even longer time frame," said University of Illinois graduate student Austin Happel.

"All these approaches have unique advantages, which, when combined, provide detailed information on the nearshore food web structure," said Sergiusz Czesny, Illinois Natural History Survey, Lake Michigan Biological Station director.

The results suggest that resource managers may actually need different, more regional, approaches for managing the fish population and protecting the health of nearshore waters.

"This is the first study to document very important regional differences in food web structures across Lake Michigan," said Tomas Hook, IISG associate director of research and a project lead. "Researchers have been studying Lake Michigan's food web for decades, but many linkages in the nearshore have been under-described until now."

"Our objective is to describe the nearshore food web structure and how this varies with location, season, and bottom substrate," said Czesny. "We are also interested in how invasive species interact with native biota, which will ultimately help us manage this unique ecosystem that is Lake Michigan."

COASTAL WETLANDS PROVIDE HABITAT FOR SPORTFISH

While the influx of invasive species has taken a toll on the Lake Michigan food web, the loss of habitats like coastal wetlands may be having impacts too. Researchers who are looking at how coastal wetlands contribute to lake habitats have, thus far, documented that various fish species like yellow perch and smallmouth bass use these wetlands at various points in their lives.

Biologists Gary Lamberti, University of Notre Dame, and Patrick Forsythe, University of Wisconsin-Green Bay, are leading a team whose goal is to quantify the role of coastal wetlands in

University of Notre Dame researchers use electroshocking to collect fish data in wetlands of Burns Harbor in Indiana.

KATHERINE O'REILLY

Scientists are using three measures from 50 species of fish, both prey and predators, to map out the story.

sustaining sportfish. The project is in progress, but is making promising steps forward.

They are building the food web in wetland and nearshore habitats at nine paired wetland-nearshore sites around Lake Michigan, with the wetlands representing a variety of landscapes and distances from the lake. The scientists are using three measures from 50 species of fish, both prey and predators, to map out the story.

The first two measures are commonly used—carbon and nitrogen stable isotopes. Carbon isotopes reveal location in terms of food source. It reveals what the base of the food web looks like.

"In a wetland, carbon cycling happens faster than in nearshore waters so the carbon signature is more depleted and that gets propagated up the food chain," said Katherine O'Reilly, who has taken on this work as part of her doctorate at Notre Dame.

KATHERINE O'REILLY

The newly restored Roxana Marsh in Indiana provides a study site for assessing the importance of wetlands to Lake Michigan sportfish.

SARAH STEIN

The nitrogen isotope indicates where a species sits in the food chain and can reveal what species are more predatory and are eating other fish versus those that are primary consumers, eating solely invertebrates or zooplankton.

The third measure is a technique first pioneered in marine studies. The researchers are analyzing trace element chemistry of otoliths, which are fish ear bones. Since they are always growing, otoliths provide a timeline of where the fish have been. "The otolith is comprised of trace elements in the water and we've learned that water samples from wetlands and the near-shore are very different," said O'Reilly.

"We have found in the otolith that the fish are using wetlands at different times in their life cycles. This preliminary look at the microchemistry reveals that important sportfish like yellow perch and walleye are not staying in one habitat," said O'Reilly. "They are moving energy between wetland and nearshore waters."

As analysis progresses further, the researchers will be able to understand more about the connection between the two habitats. Ultimately, they are hoping to demonstrate the value of wetlands to the lake food web and sportfish. "The question might need to be answered: How much is a wetland worth to a fishery?" said O'Reilly.

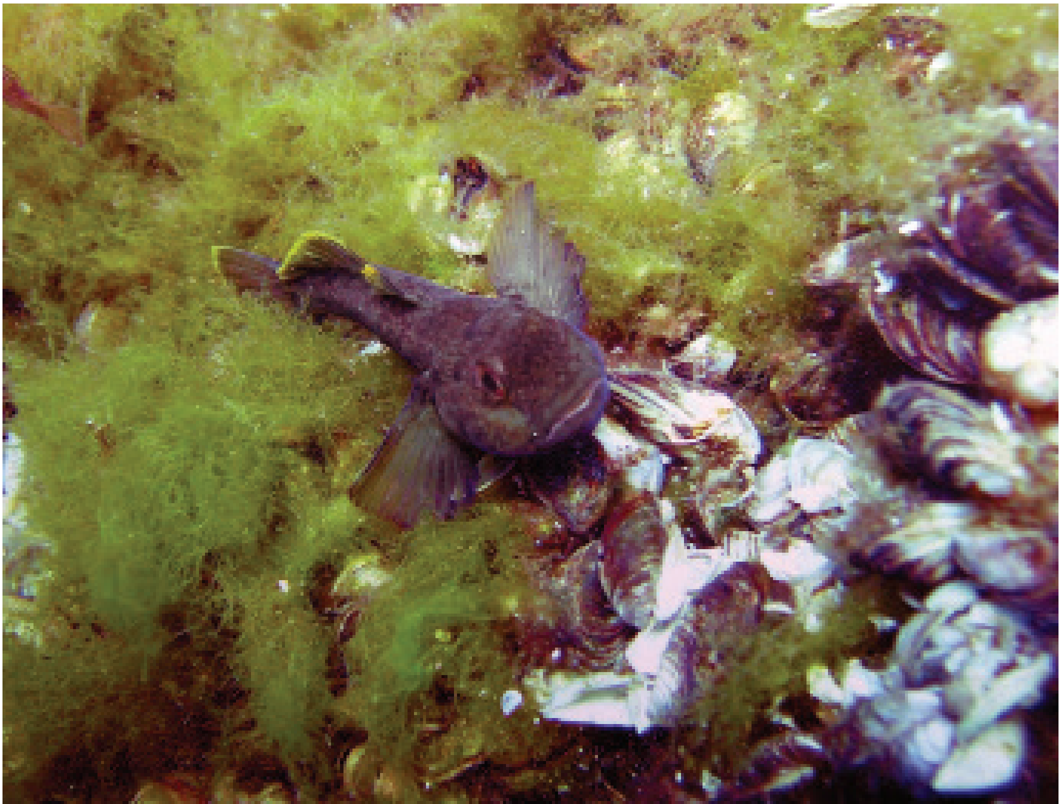
Nearshore areas, including wetlands, may play important roles to yellow perch and other sportfish.

THE KEY TO THE ROUND GOBY DIET IS LOCATION, LOCATION, LOCATION

A round goby stakes out territory in the nearshore waters of Lake Michigan.

Round gobies have become big players in the Lake Michigan food web. A small but invasive fish, their success may be due to being masters of survival. More specifically, they make themselves at home in a variety of conditions with a variety of food options, settle in for the long haul, and protect their territory.

IISG Assistant Research Coordinator Carolyn Foley took part in a study to learn more about the round goby's place in the food web. The research team sampled three sizes of gobies from many locations and in multiple seasons. They analyzed the goby diets using three techniques—stomach contents to learn what



HARVEY BOOTSMA

SARAH STEIN

University of Illinois graduate student Austin Happel and Carolyn Foley, Illinois-Indiana Sea Grant assistant research coodinator, head out to collect fish and invertebrate samples in the waters near Manistee County.

the fish are eating when caught, fatty acid signatures, which reveal what they have been consuming over several weeks, and stable isotopes, providing a picture of an even longer time frame.

They found location was the driving factor in terms of what the gobies ate and the fish tended to stay put over time. "It's striking how they tend to stay in the same spot," said Foley. "This makes sense for them because they are very territorial—they aggressively defend their home turf."

Gobies are known to prefer hard, rocky areas and to eat zebra mussels, but the reality may be more complicated. "We caught more gobies over hard substrate, which makes sense, but we found them over soft substrate too," said Foley. "And since the diet analysis—stomach contents, fatty acids, and isotopes—are conveying the same information no matter what the timescale, we think it means they are taking advantage of whatever food sources are nearby."

That gobies have become major players in Lake Michigan and that they are survivors may have the potential of providing some stability to the food web. "Their adaptability suggests that they will likely persist for a long time," said Foley. "And as part of the food web, they too are being eaten—smallmouth bass and birds are eating gobies and are growing."

But this brings up a concern. As bottom dwellers, round gobies hang out where the contaminants are. As these fish become entrenched in the food web, scientists wonder whether contaminants are more likely to move up through the food web to birds, top predator fish, and eventually, people.

GETTING TO THE BOTTOM OF ANOTHER QUAGGA MUSSEL IMPACT

EMILY TYNER

University of Wisconsin Milwaukee student Emily Tyner scuba dives in the waters at Good Harbor near Sleeping Bear Dunes in Michigan to study nearshore algal growth.

Descend 55 meters to the floor of Lake Michigan and you'll find the bottom carpeted with tens of thousands of one of the most prolific invasive species in the Great Lakes—the quagga mussel.

Researchers have long known that these voracious filter feeders impact water quality in the lake, but their influence on water movement had remained largely a mystery.

Purdue University Ph.D. student David Cannon, working with Hydrodynamicist Cary Troy, used water velocity sensors to measure dynamics in the deep waters of Lake Michigan near Milwaukee, Wisconsin, and determine the filtration effects of the invasive mussels.

ALLISON NEUBAUER

Quagga mussels have colonized vast expanses of the Lake Michigan bottom, reaching densities as high as roughly 35,000 mussels per square meter. This invasive species that can have major economic impacts filters up to 4 liters of water per day, and so far seems unaffected by any means of population control. It is also a constant threat to other systems, as it is readily transported between water bodies.

"Quagga mussels filter by sucking in the water around them and then spitting out what nutrients and particles they don't want," said Cannon. "While they're doing this, they're able to directly move a very small amount of water around them—only about 10 centimeters above the lake bed."

The measurements taken near Milwaukee suggest quaggas do not strongly influence movement throughout the entire water column. But the movement they cause in the thin layer immediately above the lake bed—a phenomenon consistent throughout the year thanks to stable temperatures at the bottom of Lake Michigan—is an element missing from most mussel filtration models.

Cannon and Troy's results could lead to the development of better models to study the effects of these organisms on lakes and reservoirs around the world.

"It's generally accepted that the ecosystems of smaller, shallower lakes, Lake Erie, for example, are at the greatest risk of quagga mussel invasion," he added. "Our results could help show other researchers that the effects of mussels on large, deep lakes cannot be ignored and, more importantly, how they can be accounted for."

Quagga mussels are colonizing vast expanses of the Lake Michigan bottom, reaching densities as high as roughly 35,000 per square meter.

QUAGGAS COMPLICATE THE LAKE'S PHOSPHORUS STORY

Limnologist and researcher Harvey Bootsma studies the effects that quagga mussels have on the lake's phosphorus cycle.

The introduction of invasive quagga mussels into Lake Michigan has had wide-ranging and complicated impacts on the lake's food web. Harvey Bootsma and Qian Liao at the University of Wisconsin-Milwaukee looked specifically at the effects quagga mussels had in the deep parts of Lake Michigan on plankton abundance and the phosphorus cycle.

The team discovered two key findings. The first is that quagga mussels in Lake Michigan are eating more plankton than what is reaching them by sinking from above.

> Bottom-dwelling filter feeders…have changed the rules for how Lake Michigan works.

NARAYAN MAHON

"We think that food delivery to the bottom of the lake is not just determined by the passive settling of phytoplankton as it's sinking through the water, but that plankton is always being circulated in the lake," said Bootsma. "It's like the plankton are on a kind of conveyor belt where they're going up and down in the water column. We suspect the mussels are dependent on currents and mixing in the lake for plankton delivery. As the conveyor belt transports plankton near the bottom of the lake, plankton are removed by the filter-feeding mussels."

The second finding was that the mussels are changing the phosphorus cycle in the lake. "The nutrient-loading models used to set limits for phosphorus aren't accurate anymore because of these new components to the ecosystem—bottom-dwelling filter feeders," Bootsma said. "They have changed the rules for how Lake Michigan works.

"Lake managers have a conundrum right now. They've got too much algae in the nearshore zone and they want to reduce phosphorus to solve that problem. But there's not enough phytoplankton in the offshore zone because of the mussels. So if they reduce phosphorus loading in the lake, they could make that offshore problem even worse so that there's virtually no food left out there for the rest of the food web," Bootsma said.

In a future project, Bootsma said his team hopes to determine what the "sweet spot" is for phosphorus loading. "There may not be one perfect phosphorus load that solves both the nearshore and offshore problem, but we'd like to try and find one that minimizes the nuisance algae while at the same time keeps the offshore animals alive with enough plankton production."

INVASIVE SPECIES MOVE ENERGY TO THE NEARSHORE

The Lake Michigan food web is in transition—not just in the question of who's eating whom, but where fish and other organisms are finding food. In recent years, the nearshore has become the go-to location.

Ben Turschak and Harvey Bootsma, biologists at the University of Wisconsin-Milwaukee, set out to characterize the food web in Lake Michigan by capturing the dynamics of what's happening in the waters near Milwaukee. They use carbon and nitrogen stable isotopes from fish tissue to learn what they are eating, and to understand where each species fits in the food web.

"Carbon stable isotope ratios tell us what a species eats or its primary energy source," said Turschak. "Predators have a similar carbon isotope ratio to their prey. For instance, a fish that eats zooplankton might have a very different carbon isotope ratio than one that eats bottom-dwelling insects. By contrast, nitrogen stable isotopes become heavier as they go from a prey source to a predator, so they can reveal where a species is positioned in the food chain."

Researchers mark the ends of their gillnets with floating flags.

The Milwaukee shoreline is characterized by a mixed sand and boulder bottom, with frequent cool water upwellings caused by wind pushing warm surface water towards Michigan. The researchers found the food web there could generally be separated into species that eat phytoplankton or those that dine on algae on the lake bottom in shallower nearshore areas. Generally, however, most fish species have begun to rely more heavily on nearshore energy sources.

The likely culprits in shifting the balance of productivity to the nearshore waters are invasive species. In particular, quagga

SARAH STEIN

> Nitrogen stable isotopes become heavier as they go from a prey source to a predator, so they can reveal where a species is positioned in the food chain.

mussels filter large quantities of water to feed on phytoplankton, this process clears the water and, in shallower nearshore areas, allows more light to reach the bottom. The mussels also excrete nutrient-rich waste that fertilizes the lake bottom. With more light and nutrients, bottom-growing algae can proliferate and support more bottom-dwelling invertebrates and the fish that feed on them.

"On the other hand, in offshore waters, mussels also filter phytoplankton and make the water clearer, but the increased water depth prevents enough light from reaching the bottom to support much algae. As a result, quagga mussels are leaving the deep offshore waters depleted relative to nearshore waters," said Turschak.

"Decreases in offshore energy sources and increases in nearshore energy sources likely account for the fact that fish appear to be feeding more on nearshore energy sources," explained Turschak.

The researchers also observed that typical patterns of diet change that occur as fish get larger have also shifted for some species. "This indicates that some fish species may have greater reliance on nearshore energy at particular stages of their life because of these food web changes," said Turschak.

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