I am a postdoctoral research associate in the Jensen Lab at the UW-Madison Center for Limnology. Broadly, we study fish and the people who fish those fish. I am delighted to submit this essay as a small contribution to the program "Sharing UW-Madison Postdoctoral Scholarly Research with Non-Science Audiences," sponsored by the Wisconsin Initiative for Science Literacy (WISL). This program, made possible by the dedication of the WISL staff, specifically Cayce Osborne, Elizabeth Reynolds and Professor Bassam Shakhashiri, is instrumental in fostering connections between scientific exploration and a wider audience. Science is nothing more than a method of inquiry that we use to understand the world around us. Anyone can do it. Yet despite its simple underpinnings, the discoveries that science yields have the power to enrapture. By outlining the scientific process in plain language, my hope is that more people will be emboldened to embark on their own journey to uncover the true grandeur of nature.

~ George Brooks, August 2025

Batten down the hatches: building resilience in global fisheries

A smooth sea never made a skillful sailor

~Franklin D. Roosevelt

High and Dry

The vomit streams from my mouth like a fire hose onto the decaying wooden boards of the pier. As soon as the crab stick registered on my taste buds I knew I was in trouble. Undoubtedly the previous hour of funfair rides and blinding arcade lights did not help the situation. My senses were overloaded. In hindsight it was a perfect storm. But I was only 7 years old, and thus still found it difficult to successfully predict the consequences of my actions. But once bitten, twice shy – I have never eaten imitation seafood since.

This formative experience took place in Brighton, on the south coast of England. Just an hour's drive from my childhood home, trips to the seaside were a staple of my youth. Despite the occasional mishap, I have extremely fond memories from those family vacations. Fossil hunting on the Jurassic coast, eating dinky donuts on the Worthing promenade, rock pooling in Lyme

Regis. England has the best beaches; England has the worst beaches. Devoid of sand or sun for the most part, this is not the Caribbean. Picture more grey skies, the threat of rain, as people try to lay down beach towels onto the gravel without them being carried away in gale force winds. Also, the seagulls are unaccountably menacing. This is an England beach. Yet they have a charm beyond compare. And of course, if you are judicious, access to the most delicious, fresh seafood, straight off the dock. Prawns, cod, haddock, plaice, mussels. And to go with it some tartar, mushy peas, curry sauce. Our love of fish and chips is not unfounded. After all, England is a small island, you are never more than 70 miles from the coast. Seafood is the local delicacy. But this was something I took for granted as a kid. Clearly, I was eating fake crab. But I paid the price, and I learned my lesson.

Almost two decades later I emigrated to the United States to pursue my graduate education. I found myself in southwest Virginia, in the heart of the Appalachian Mountains. Stunningly beautiful – dense hardwood forests that stretched for miles, with endless peaks tinted blue in the morning mists. Paradise. But no saltwater in sight. You had to drive at least 5 hours before the Atlantic honed into view. It was only here that I realized what I had left behind. When you are surrounded by something you are blind to it. But then my eyes were opened. There are many who live far enough away from the ocean to where it doesn't feature in their day-to-day existence. I was now one of those people, and it made me bereft. I didn't know what I had until it was gone.

Through my studies I came to learn about the precarious nature of fisheries. The seafood industry has a sustainability crisis. Overfishing and global change are threatening food supplies and livelihoods. In the not-too-distant future, it may not matter whether you live a stone's throw from the coast or in the heart of a continent, the ocean's coffers will run dry. One day, we will all lament our complacency, we will all long for what we once had.

Learning the Ropes

Physics has laws. Universal truths that all physical bodies obey. The law of gravitation is followed by grains of sand and galaxies alike. As a Zoology undergraduate at the University of Sheffield, I quickly learnt that things are not so simple in the biological world. There are no laws

that all living things rigidly adhere to. Cat owners are well aware of this fact. There are no forces, no set of equations, that fully describe the menagerie of behaviors exhibited by Earth's biodiversity. The best we can do in Biology, therefore, are rules. General truisms or conventions, patterns that are pervasive enough in nature to be notable, but far from universal.

The species-area relationship is one such rule, whereby larger areas tend to contain more species. This is a very intuitive idea, one that is borne out by common sense and personal observation. And yet, a million and one caveats and qualifications emerge that prevent this observed trend from being an immutable law. Different ecosystems of the same size – a desert and a tropical rainforest, say – can contain vastly unequal species' richness. Species communities on islands are subject to atypical dispersal and colonization dynamics that prevent a direct comparison with continental landmasses. Someone counting beetles will come up with a different result from someone counting butterflies. And the list goes on. Even if you manage to avoid all these confounds, limiting your investigation to one group of organisms in one ecosystem on one continent, you will still find small areas with a surprisingly large number of species and large areas maddeningly empty. There are always exceptions to rules.

I first heard about the temperature-size rule whilst studying salamanders in the Appalachian Mountains of Virginia. Most of the salamanders live in the foothills and are no bigger than your pinky finger, but there are a few species that you can only find living at the tallest peaks, specially adapted to the harsher winters at higher elevations, and those salamanders are big, or at least as big as your thumb. The temperature-size rule describes how living things tend to grow differently when it's hot versus when it's cold. When it's hot, individuals grow faster early in life, but mature at a younger age, such that they ultimately reach a smaller maximum size when fully grown (Figure 1). Over 80% of species studied have exhibited these patterns in growth, from seahorses to seaweed. And again, whilst some physical scientists may balk at 80% as a mere statistical aberration, in biology, four out of every five species following the same pattern is almost unheard of.

This ubiquity, however, generates a new problem, namely, why does this rule exist? Alternatively, why are such a menagerie of species affected by temperature in the exact same way? Some have proposed that temperature only impacts an organism's growth indirectly through its impact on ecosystem productivity and hence food availability. However, the pattern

persists in laboratory studies where food is controlled. This has led some to conclude that temperature directly impacts growth by influencing the rate of metabolic processes at the cellular level. The speed of the chemical reactions that take place within cells is intrinsically linked to temperature. At sub-optimal temperatures, cell division (i.e., growth) proceeds slowly.

The effects of temperature on growth and development, whilst well established in the lab, have never been formally tested on wild populations. I had originally planned to test these theories in Virginia, including predicting whether salamanders might shrink under climate change, but could never get the project funded. It was not until I moved to Wisconsin, to a fisheries department, that the ideas gained traction; unsurprisingly, there is a lot more money available to study the things that we eat. Testing the temperature size rule in Haddock or Herring, say, can be framed as an issue of food security or economics. Smaller fish = less meat = lower profit margins = lost livelihoods. My goal was to test whether these concerns were warranted.

In agriculture, environmental change is less at the forefront of people's minds. For thousands of years, we have selectively bred crops and livestock to tailor them to our desires. And we can design climate-controlled barns and greenhouses to effectively isolate and buffer farm life from external conditions and the vagaries of weather. Through these efforts, dairy cows produce milk year-round, seedless fruit varieties abound, and meat animals are big. Commercial chickens are now so big they can barely walk. Our intentional influences on farmyard life easily overwhelm any of the marginal effects of global warming.

In fisheries however, we do not have the power to select genetic strains that attain larger body sizes to combat climate-induced shrinking. In fact, over centuries of exploitation, we have achieved the opposite. Fishing imposes higher mortality rates on adult fish. In evolutionary theory, this high mortality regime favors a 'live fast die young' life-history strategy. If there is a concern that you will not survive until next year, it is safer to mature earlier and pump out babies while you can. One consequence of this strategy is smaller average body sizes. For one, individuals are afforded less time to grow, and for two, energy is diverted from growth and allocated towards reproduction much sooner in the life cycle. Cod in the North Sea for example, now mature two years earlier than they did at the start of the 20th century, at half their former size. For populations already struggling to keep pace, continued warming could be the straw that breaks the camel's back.

I partnered with employees at the Wisconsin Department of Natural Resources, who have spent decades surveying fish in thousands of lakes across the state. This intensive monitoring provides the necessary data to track changes in growth across time and space in response to changing temperatures. Of the seven species we looked at, all but one showed the expected pattern of shorter lifespans and earlier maturity at warmer temperatures. For the one species that did not show any response to temperature, Northern Pike, Wisconsin represents the southern tip of its range. As such, every lake we had growth data from is close to the upper thermal limit for Pike, and therefore every population has low survival and early maturity – fringe populations are, by definition, at the limit.

At Loggerheads

Fish are rapidly adapting to the dual pressures of human harvest and warming waters. But evolution can only compensate for so much. Fish populations at the southern edge of their range are faced with two options - go extinct or move north. Fishers, in turn, face a similar dilemma. Once where fish were abundant and coastal towns supported entire communities of fisheries, the coffers have run dry.

I have studied these social dynamics in the North Atlantic Summer Flounder fishery. Summer Flounder were once abundant in the Chesapeake Bay near Washington DC and represented the second most profitable fishery in Virginia. Now, however, they have largely disappeared from these waters due to rising temperatures that have shifted the species range northwards. A small contingent of Virginia trawlers now travel hundreds of miles up the coast to New Jersey to land their quotas. This, however, comes at great financial cost – diesel is not cheap. At a certain point, the enterprise becomes too expensive; in the last 20 years, many of Virginia's Summer Flounder operations have folded.

The Summer Flounder fishery highlights the shortcomings of current management regulations for US fisheries. In the US, stock assessments for commercially targeted species are performed every five years. As a result, catch limits reflect past abundances and distributions. The quota for Virginia is still quite high, despite there no longer being any fish to catch. The quota for New Jersey is still quite low, causing ire amongst the local fishers that feel the regulations are now

unnecessarily strict. Essentially, the wheels of big government turn too slowly to keep up. The degree to which people adhere to regulations depends on how much they trust them. My work shows that if ruling bodies are slow to update regulations, people will start to ignore them. For species that are already struggling, a loosening of the grip of managing agencies is the last thing they need.

Walleye, a popular sportfish in the upper Midwestern United States, resembles the plight of the Summer Flounder. Populations in lakes at the southern edge of their range have seen dramatic declines. Further, given the modern ease of driving hundreds of miles for a fishing weekend trip, we are seeing the same phenomena of fishers chasing the remaining Walleye populations further and further north. Compounding the plight of Walleye in the south is increasing competition with species adapted to warmer climates.

Largemouth Bass, a warmwater species from the central United States, has itself been shifting poleward and encroaching on Walleye territory. Where it was once too cold for Largemouth Bass, they now thrive. Although the increasing overlap of Bass and Walleye is cause for concern, it presents an interesting alternative path for how humans might respond to climate change impacts on fisheries. Rather than chasing Walleye north, sport fishers may instead opt to stay local and fish for something else. I have shown in my work that this dynamic behavior might be the most effective way to curb Walleye declines; by reducing the fishing pressure on the struggling species, whilst also suppressing the population of the competitive species, the benefits are twofold. Given the proclivity for fishers to ignore strict regulations, a more prudent management strategy might be to encourage the public to diversify their target species. Only a small change in the behavior of the angling community can have a dramatic impact on the persistence of vulnerable species like Walleye.

Modern fishing regulations have been designed to limit harvest pressure to levels that species can compensate for. These regulations, however, do not account for environmental change. There is a need therefore, for agencies that manage fisheries to adapt. Current practices are far from new - setting lower harvest limits and banning certain types of nets in response to low fish abundances is documented from medieval Europe, as are instances of animosity toward authority for such regulations. However, in the theatre of climate change, these methods may be insufficient. Indeed, in the Middle Ages, the Baltic Sea’s Herring fishery, a fishery that had been operational

for over four hundred years, unexpectedly collapsed at the onset of the Little Ice Age. Novel problems require novel solutions.

On the Horizon

To ensure commercial fisheries are sustainable industries we must accept their dynamic nature, as well as the dynamic nature of our planet, and focus our efforts on building resiliency to change. We are still in the early stages of understanding how fishing communities will respond to climate-induced changes in fish distribution and abundance. In contrast to the well-documented ecological impacts of climate change, we know very little about how people will react. But it is precisely how people react that will determine a fisheries' fate. A change in the fish triggers a change in the fishers, which in turn will lead to further change in the fish, and so on. Only by understanding this feedback loop can we take steps to safeguard fisheries from extinction. And we must accept the 'human' element of fisheries in its entirety. It is human to defy authority. Particularly in the face of perceived unfairness or overreach, people are apt to scoff and skirt around the powers that be.

My journey in science - my quest to find inscrutable facts and concrete numbers - has led me to conclude that the way you sell an idea is often as important as the idea itself. For the sustainability of fisheries, public awareness may be just as impactful as tight, top-down regulations. After all, true sustainability can only be achieved if people alter their behavior willingly; if by force, then the system is only sustainable for as long as the regulating body maintains power. For many, changes don't come easy, regardless of whether they come about through encouragement or force; old habits die hard. But the writing is on the wall. Something has to give. If not, then there is a distinct possibility that, someday, we will be left with nothing but imitation crab sticks on our dinner plates. Even the thought makes me sick.