**1-In 1988, Walters and Collie published a provocative article suggesting we should not waste public funds on scientific research to understand the effects of environmental factors on fisheries. Now over 3 decades later, were they right? Give one example that best supports their argument and one that best refutes it.**

Walters and Collie posed in 1988 a call for fisheries scientists to put an end to the saturation of spurious correlations in our research endeavors. Their work asserted that spurious correlations in our fisheries assessments are too easy to find, and that long term climate assumptions and extrapolation are misleading to the field in their inability to accurately stand the test of time. One root cause of this opinion is the attempt by fisheries scientists to properly quantify environment - recruitment relationships. There is a long observed tenuous relationship between scientists looking to predict fisheries recruitment as it relates to environmental parameters, this is because recruitment is the product of independent life stage survival. In this case while we may be able to identify a relationship between an environmental parameter and an individual life stage, since they are independent of one another it is highly unlikely that we will see any one variable impact all life stage survival probabilities. It is especially unlikely to see them all respond in the same way. In order to have a strong recruit class, every single life history has to have a high survival rate, this is the result of any number of environmental variables and interactions a species may have within the system. This makes assertions that any one variable can lead to a stronger or weaker recruit class unlikely, however if a variable is found to have an effect it will likely be a mechanism acting early on in the fish’s life history as that is when recruit classes are largely determined (Shepherd 1984).

Even when there are observed correlations, one has to ask - how many correlations did I test to get here? Can I make the assumption that this is a proper assessment of the relationship between this parameter and recruitment? The answer to the former is usually too many and the latter is usually no. In our assessment of the environment, if you test even the most random and unrelated variables enough times, a spurious correlation will be found, it could even be a very strong one, however in reality it means nothing (Kerr 1987). This has not stopped many scientists from marketing such correlations as fact in the field, and is the central conundrum Walters and Collie are hoping to avoid in this recommendation.

In an assessment of “When do environmental recruitment relationships work?” by Meyers in 1988 an evaluation of notable environment recruitment relationships with updated data found that upon retest years later than almost none of the environment recruitment relationships were significant (1988). This is incredible proof of how developing management models and strategies around these relationships can be harmful and lead to failure. While in this assessment they found that environment recruitment relationships with species at the edges of their geographic range were more likely to be confirmed, it was still a general conclusion of failure on most all of the relationships explored. However, two method suggestions came from this assessment; the first, being that species at the edge of their ranges may the most valuable populations to assess for environmental relationships and the second being that when data is available it is important to use confirmatory tests, for example data splitting, that will be able to explore the relationship in the first part and then reserve a portion to confirm the nature of the relationship before drawing conclusions of a true correlation.

With the evidence mounting against environmental relationships up against the fact that ecologists will likely never stop musing about the environment’s role in our fisheries, it is recommended that a mechanism based hypothesis be the grounding point of any relationship with an environmental variable. An example in which an environmental relationship with fisheries was found is in the North*east* Atlantic cod stock, where there was an observed increase in abundance with the warmer climate due to a higher NAO. This increase in warm conditions had a number of proposed mechanisms that aligned with the increase in water temperatures, which included: an increase in the gonad growth and egg yield, higher zooplankton productivity and in turn food for the cod population as well as higher synchrony in the availability of food for the cod larvae and a bigger is better impact on survival that was caused by increased growth rates ( Parsons & Lear 2001). It has also been observed that the mean bottom temperature accounts for 90% of variation in growth rates between different Atlantic cod stocks in the North Atlantic (Lehodey et al. 2006). So all is not lost for those who continue to explore the relationship between fisheries characteristics and the environment, however proceeding in this direction must also come with caution.

In most cases historically, the major variability and collapse of fisheries has had two causes, one anthropogenic and the other environmental (Hamilton & Heidrich 1999). Further research has demonstrated that often the relationship between unideal environmental conditions for fish success in conjunction with overexploitation has been the cause of fishery collapse. This also brings us back to the concerns of Myers in 1988 with this critique on declarations of environmental conditions being the sole cause of fisheries collapse. When the cod stock collapsed in the North*west* fisheries, fishermen asserted it was due to the relationship between cod and cold water conditions. However, it was ultimately found to be a combination of both the environmental conditions and overexploitation in reducing the fishery’s capacity for resilience. This blame on the environment can make management regulation of exploitation more difficult to justify. To this point, it is recommended that flexibility in adaptive management strategies be a priority in being able to make rapid change with data monitoring of environmental conditions and fisheries dynamics. I agree with Walters and Collie, that our efforts are more valuable invested in adapting management, that takes into account relationships we may believe or have some evidence of being present, rather than diving deeper into efforts to predict the stochasticity of environmental variability and its impact. Additionally, our efforts should likely focus on the part of the equation that we can control, which is the overexploitation of these fisheries making them more vulnerable to changes in the environment in the first place. In conclusion, while the investigation into environmental variables is valuable, it is necessary for our research to further assess the mechanisms responding to these environmental changes and how our anthropogenic impact can be mitigated.

**2-You have been given an unlimited budget to set up an ocean observing system at the southern extreme of the Mid-Atlantic (box in right panel of figure below) to study the effects of climate on fish populations over the next 10 years. You can use any equipment that you would like. Describe a proposed study to investigate a topic of your choice. Your proposal must include a strong testable hypothesis, a brief background that provides the rationale for your hypothesis, a brief but referenced description of your approach (you are not expected to fully understand and explain sampling with which you may only be vaguely familiar), and a discussion of expected results.**

Title: The impacts of climate on fishery resilience mechanisms along a biogeographic barrier.

Background: The Northwest Atlantic is one of the fastest warming ocean basins in the world in addition to housing valuable fisheries along the eastern coast of the United States. In our assessments of the Northeast US Large Marine Ecosystem (NES LME) encompassing the NW Atlantic along the coast of the US, the system is broken into ecoregions defined by their distinct characteristics. Ongoing efforts to understand this community have been fueled by the availability of robust community and species data provided by long term ecological surveys conducted by NOAA, in addition to growing tension between fisheries stakeholders and managers seeking to function successfully in a community that is changing in response to shifting conditions. Previous research has demonstrated that within the NES LME there is a significant influence of subregion on community structure, this work identifies how the community-level change within subregions demonstrates variable patterns in response to abiotic and biotic conditions (Roberts et al 2022). Of particular interest are the dynamics of the Mid Atlantic Bight (MAB) ecoregion due to its growing distinction from the other ecoregions (as illustrated in my CTA) and its presence above the biogeographic barrier of Cape Hatteras. In the MAB strong sea surface temperature shifts and shifts of dominant fisheries northward have been seen, however the pattern of species shifting above the biogeographic barrier to the south of Cape Hatteras has not been seen as of yet.

This highlights a crucial question for the ecosystem within the MAB, how is it going to respond to the increase in climate pressure at the community level, and moreso, can we identify the mechanisms that may lead to the decline in resilience of the system’s current state? Previous research has suggested that within marine systems the connectivity of the large marine landscape and functional complementarity play key roles in the system’s ability to return to a similar state (resilience) and its ability to withstand changing to a novel state (resistance) (Hillebrandt & Kunze et al 2020, Lindegren et al 2016). Functional niche complementarity, the ability for differential responses to environmental drivers leads to increased population asynchrony, in particular this process is underscored by the diversity in the region. With general declines in biodiversity as one of the world’s leading ecological concerns, we can wonder how similar declines may be manifesting in this system and how that may leave this system vulnerable to climate change. The connectivity of any system is in part driven by the range shifts of species into and out of it. Changes in the range of species are expected to be taking place amongst species that were commonplace in the MAB historically. We have also seen the MAB approach a more distinct assemblage composition (Fenwick et al coming soon- CTA), and thus it begs the question of whether or not the community’s resilience mechanisms can handle the lack of connectivity between southern systems with the biogeographic barrier in between. Are species that are critical to the function of the system being lost? How has resilience changed as measured by its mechanism of functional complementarity and its relationship to community diversity? To evaluate these questions, the study will have two main components : first, a documentation of fish species distribution within the MAB to identify loss and gains of valuable species of interest and second, an evaluation of the asynchrony in species responses among trophic groups to identify if this mechanism is assisting in community resilience and if it has been declining due to the ecoregion lacking an influx of species to replace those lost to range shifts.

Hypothesis 1: The loss of species to northward distribution shifts will be significantly larger than the observed new species entering the MAB due to the presence of a biogeographic barrier causing a decline in diversity across all functional groups.

This hypothesis is driven by creating the foundation to explore the mechanism of community diversity facilitating stability in the form of compensatory interactions, keeping the MAB from entering a novel community state. While the MAB has been shown becoming more distinct from its other ecoregions, there is not a strong indication of a novel state. This is likely due to the high levels of diversity and interactions that compensate for one another and contribute to the community wide adaptive capacity in facing the rapidly shifting conditions.

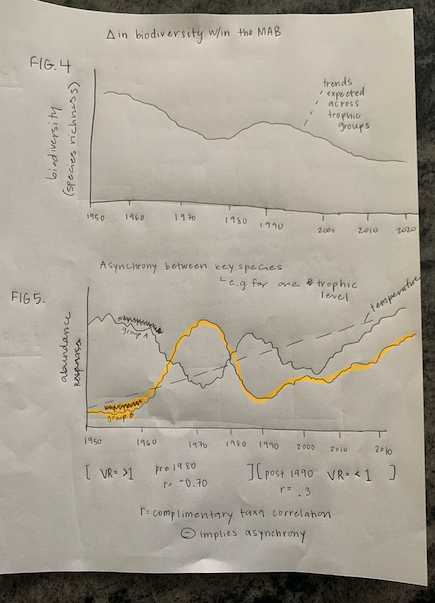
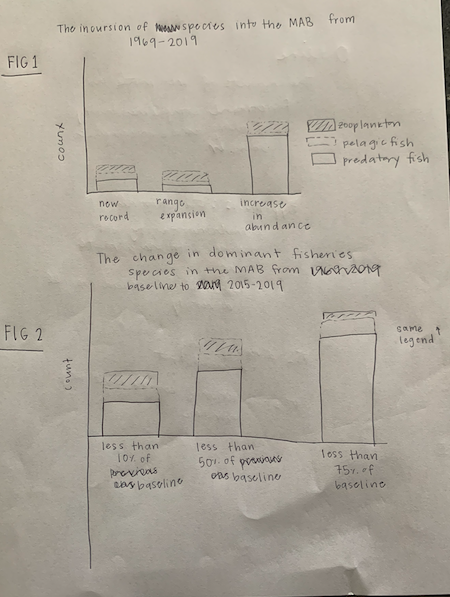
Hypothesis 2: The functional complementarity of species interactions will decline with increased climate stress and biodiversity declines in the ecoregion.

Diversity can influence a number of ecosystem stability factors, for example increased diversity can facilitate increases in recruitment and facilitate the increase in recovery of a system following disturbance (Bernhardt & Levin 2012). In general, the higher the species richness, the higher the potential is for asynchronous responses to change and differential species responses that can compensate for shifting environmental conditions. If the diversity of the region decreases due to the inability of species to shift above the biogeographic barrier then I hypothesize a shift will be visible in our measurement of these resilience mechanisms.

Methods:

Similar to the quantification of fish species distribution shifts used in Johnson et al 2011, I will quantify the documented shifts in distribution into and out of the MAB using biomass observations from fisheries independent surveys. The threshold of biomass for it to be considered a player in this analysis will be determined based on our fisheries management objectives. The incursion of species will be identified for three trophic groups, the predatory fish, the pelagic fish and the zooplankton, all of which represent key ecological players in the MAB system that may experience range shifts as an adaptive response to changing climate conditions. Per Johnson et al. 2011 I will similarly use species biomass to place species of interest into one of the following categories: **new record**, changing from absent to rare or uncommon, **range expansion**, characterized by seeing adult populations where juveniles were previously or a rare population observation was previously, and **increase in abundance,** the change from rare or uncommon to an established adult population. Secondly, I will evaluate the percent difference between baseline, average catches of the proportionally present species in each of the three categories and compare it to the difference in most recent sampling years. This will provide a picture of species departures taking place in the MAB. This would also be well complimented by CTA’s for each of the trophic levels in order to see how the structure of the community has become more or less similar to historic assemblages over time.

Next, to test the asynchrony of within trophic level responses to change over time, I would emulate techniques from Lindegren et al 2016 in order to quantify the degree of compensation taking place within functional groups. Notably, in their analysis they used two key species within each trophic group to explore their asynchrony, however in alignment with my other hypotheses I would develop a framework for grouping species, perhaps by historic average responses, so that a multitude of species can be in the analysis. This would provide an ideal situation for seeing when species become less abundant or leave the system, how their group is affected in relation to its asynchrony. I would similarly use a variance ratio test and correlation to conduct such assessments. A variance ratio of less than 1provides statistical support for negative species covariances and asynchrony as opposed to the variance ratio of over 1 which indicates synchronous responses to change.

Hypothesized Results & Discussion: \* note labeled incorrectly Fig 4 = 3 and 5 =4, apologies!

In Figure 1, I demonstrate how in the categories of new record and range expansion I anticipate low numbers across all trophic groups. This is because of the biogeographic barrier preventing species from establishing themselves above it. In this case I hypothesize some species may see an increase in abundance over time, as some previously negligible species may have found themselves in a more ideal environment with changing conditions and experience an increase in abundance to follow suit.

In Figure 2, I demonstrate how I anticipate across the three categories that species will differ significantly from their baseline abundance at the end of the 50 year period. This is because I anticipate species that can move, will adjust their ranges in search of more ideal conditions northward.

Figure 3 is a hypothesized decline in diversity over the course of the sampling period. With species moving northward and little to none moving over the barrier, I would anticipate that overall diversity as measured in species richness will decline across all trophic levels.

Figure 4 is a hypothesized visualization in the asynchrony of species groups. Where I expect asynchrony to be present at higher levels prior to the biodiversity decline in the 90s. This decline would be a result of temperature increase causing more species to flee from the system or cause die offs due to suboptimal temperature conditions, both of which will impact community composition. This will lead to a decline in system species’ ability to differentially respond to increasing temperatures, as shown in the increase in synchrony of species responses to rising temperatures. This prediction is also hypothesized in the degree of the correlation between the asynchronous species groups, when diversity is higher there is higher negative correlation demonstrative of their asynchrony and when diversity declines and response potential declines too, there is a correlation reflective of the similarity in response increasing. I also anticipate that looking at the variance ratio within trophic groups as a measure of the sum of covariances will indicate that over time, if the biodiversity declines then there will be less species to respond differentially and lead to higher variance ratio findings. Overall, I anticipate asynchrony to be a factor of biodiversity within the region.

My hypotheses align with my belief that diversity will likely decline due to a lack of species “replacement” in the MAB. This decline in biodiversity will likely lead to less differential responses to changes in environmental parameters such as temperature. The presence of more species to provide more potential for differential responses is a key concept in the diversity contributing to the resilience of a community and as such may provide a resilience proxy to be constructed for the MAB where we can investigate declines in resilience and explore the capacity of management intervention to facilitate more optimal conditions. The reason for exploration of functional complementarity is that is has been a demonstrated driver of resilience in pelagic marine ecosystems (Lindegren 2016) and as such perhaps the relationship is at play here, although I predict it will break down due to the presence of the biogeographic barrier of Cape Hatteras.

Some follow up questions I would implore other researchers to explore would be to dive deeper into the mechanisms driving whether we see significant changes between the trophic groups in those that change more or less than one another. In this hypothesized scenario I make the assumption of change being somewhat consistent across the board since all three trophic categories of interest contain species that will be influenced by sea surface temperature changes driven by climate.

**4-Ecosystem development can be defined as the process that involves structural changes in the system that are ordely, directional, predictable and ultimately lead to a more mature and stable ecosystem. The classic example is the succession in terrestrial systems from grassland to forest. What ecological interaction is more important as a community matures in marine systems - competition, predation, symbiosis and/or mutualisms? Support your answer.**

In my opinion, competition is the strongest force driving community level dynamics within marine systems. As communities mature, it is critical that they are able to remain resilient in the face of disturbances, particularly changes due to climate in marine systems. A key facet of resilience is the strength of interactions within a system, interaction strength can drastically impact how a community matures and how well it can handle changes due to disturbance. We know well that competition can shape a community’s structure, this is well illustrated when we look at the competitive exclusion principle and niches amongst species - its clear, competition drives structure and interactions. What is also important to know is that while competition can prove innovative in driving novel interactions, if the strength of these interactions is too strong then there is a higher likelihood of competition being a destabilizing effect on the community. In an effort to self organize in response to climate change and stochastic environmental change, competition can greatly impact the feeding strategies of species in response to change, and ultimately the success of a fishery. As the environment changes, some of the direct physiological effects of this on fish that may cause changes in competitive interactions include: changes in food abundance, changes in food quality, temporal mismatch between consumers and resources, shifts in the spatial distribution of food, and local concentrations of food (Shepherd 1984).

For example, when environmental conditions shift, competition may facilitate the success of one prey species over another in its ability to utilize community resources. This change in dominant prey due to competition can lead to declines in food quality if the species “winning” in the competitive interaction increases in abundance but has a lower nutrition value, which can lead to increased levels of competition and interaction strength along the food web. Another example is the spatial distribution of food, since change in climate has previously demonstrated the capacity to shift high food concentrations spatially, we may see that competition in areas that do not align with the newfound distribution of food is fiercer, and this interaction also becomes stronger thus pushing the stability of the system overall into a more precarious state. This is a similar case as climate changes the local concentrations of food, which can be observed with changes in wind strength due to ocean-atmospheric interaction drives patchiness at depth in which certain species may no longer have the capacity to feed in the different environments in the water column. In general, we have also seen that the increase in temperatures can drive higher levels of competition through an increase in metabolic rate and higher rate of food depletion. All of these instances can cause a reduction in the condition of fish as they attempt to compensate for these changes. They can also lead to higher levels of mortality and lower performance overall of species.

In general, these shifts suggest that the food web will become more constrained as climate change is perpetuated, as such it is a primary concern that the strength of interactions will leave the system even less resilient to disturbances as they come. The reason strong interactions are of concern is because it increases the destabilization potential of losing key species (Bernhardt & Levin 2012). An example of this is the removal of predatory sea stars, and the subsequent domination of mussels leading to a simplified community. This simplified community is now less resilient to disturbance because of the decreased diversity and capacity for differential species responses and is also more vulnerable to invasion than its more diverse counterpart. As climate change worsens we are expecting to see large scale redistribution of species, increased physiological stress, and altered food availability, all of which will change ecosystem interactions and can potentially change species competition. Another cause for concern is that competition serves as a key mechanism for alternate stable states (Scheffer 2009). If intraspecific competition is weaker than interspecies competition then we see a system in which both species would perform better in monoculture and so they settle into dynamics appropriately competing with one another. This overyielding effect, where species occur in greater biomass together than in isolation, is an example of functional complementarity in small populations and is support of competition being able to drive community dynamics (Loreau 2013). However this situation is only common in small populations and requires that the negative effects of stronger competition do not outweigh it. Oppositely, if we observe that one species is dominating in its competitive interactions then a shift in conditions to favor that species can lead to a cascading effect on the ecosystem. For example in lake experiments with certain cyanobacteria species and phytoplankton, the dominance of cyanobacteria can cause a state change. This is due to the cyanobacteria being more shade tolerant, so if conditions shift and they are favored and can reproduce to the point where they create even more shade, then they are able to create conditions in which they are the “winning” competitor thus leading to a state shift to a shaded cyanobacteria dominated lake state. This is another example of how strong competition driven interactions can have ecosystem level ramifications.

In conclusion, I argue that competition underscores all levels of community resilience, in that it impacts or shapes dynamics related to the diversity of the system, its connectivity to other populations and adaptability in the face of change. In our efforts to drive mechanism based hypotheses in the realms of community ecology in response to climate change and anthropogenic influence, competition is a critical mechanism to explore in the context of our marine communities.