WOODS HOLE OCEANOGRAPHIC INSTITUTION

Coastal Resilience and Sea Level Rise

WORKSHOP REPORT | JUNE 2024

PREFACE

The Woods Hole Oceanographic Institution (WHOI) is located in a small coastal town in southeastern Massachusetts. Along with many other communities in a similar situation, it experiences the effects of climate change in a more visible and urgent way than most. It is no wonder that it feels the pressing need for a comprehensive and collaborative approach to building resilience against sea level rise. Working with our partners, WHOI developed an action plan called *ResilientWoodsHole*.

While WHOI is globally focused in its outlook and the research that its scientists conduct, it is intimately connected to its local community and works closely with the state of Massachusetts and the United States government. Massachusetts has been at the forefront of climate adaptation efforts in the United States, with its comprehensive resilience strategies serving as a model for other states. Not only did it establish the first in the nation cabinet position on climate, but it also introduced the ResilientMass Plan in 2023.

Around the same time that these efforts were getting underway, Alice Hill and Rafe Pomerance, were raising awareness for sea level rise to be prioritized in policies at national and international levels. A call that is taken up in various fora including one by the UN General Assembly when it called for a one-day high-level plenary meeting on the existential threats posed by sea level rise, on 25 September 2024. The unanimous advisory opinion of the International Tribunal for the Law of the Sea (ITLOS) declaring carbon dioxide as a marine pollutant and the impending decision by the International Court of Justice (ICJ) expected early next year will have a pivotal role in adjudicating disputes on matters related to maritime law and climate change.

Considering the above, my colleagues and I at WHOI decided to convene a small, but distinguished group of science and policy experts to address many of these issues. Our goal was to generate actionable recommendations that can guide future efforts to build resilience against sea level rise. The summary of the workshop represents a critical convergence of expertise and perspectives on one of the most pressing issues of our time. The resounding message from the deliberations is that the challenges we face are not insurmountable. Through science, policy, and international cooperation, we have the tools and knowledge necessary to address sea level rise effectively. Together, we can and must build a resilient future that

safeguards our communities, protects our ecosystems, and ensures a sustainable environment for generations to come.

Let me conclude by thanking all the participants (list at the end of the document) for their energetic participation in the workshop. The discussions were tremendously enriched by expert knowledge shared by Katherine Antos, Peter de Menocal, David Freestone, Di Jin, Leslie-Ann McGee, Zander Nassikas, Michael Oppenheimer, Christopher Piecuch, Rafe Pomerance and Nicholas Robinson. Special thanks to Alison Maksym for her help with the organization of the workshop. Finally, my grateful thanks go to Kalina Grabb whose abilities to multitask are simply amazing – in addition to arranging the program, liaising with participants – she had put together this very helpful workshop report.

Kilaparti Ramakrishna
Director, Marine Policy Center and
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Cover, WHOI Scientist Chris Piecuch and Andrew Kemp coring out a salt marsh peat sample for natural analogues tracking sea level rise. Photo by Meave Upton. Inside front cover, Group photo of in-person workshop participants listed from left to right. Back row: Dan Rizza, Christopher Piecuch, Paul Speer, Zander Nassikas, Tod Hynes, Shubhro Sen, Cody Friesen, Rafe Pomerance, Di Jin. Middle row: Shannon Hulst, Kim Ross, Katherine Antos, Leslie Ann McGee, Christina Brophy, Bala Sundaram. Front row: Hauke Kite-Powell, Kalina Grabb, Kilaparti Ramakrishna, Emiley Lockhart. Photo by Jayne Doucette.

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EXECUTIVE SUMMARY

To predict and adapt to future sea levels, we need to understand where and why the sea levels are rising now and have risen in the past. Institutions whether large or small, coastal communities whether rich or poor, cannot control sea level rise by their actions alone. But they can prepare well through a variety of adaptation measures.

The goal of this workshop was to review the latest scientific findings on sea level rise and coastal resilience to discuss community approaches to increase resilience and adaptation. While examples abound, the participants focused on what has been attempted in Woods Hole, a small coastal town in southeastern Massachusetts, and in the Commonwealth of Massachusetts at the regional and state level. A goal of this exercise was to assess the lessons learned and how they translate to other communities as participants critically reviewed what else is needed to increase coastal resilience. A select group of leading specialists from science institutions within Woods Hole, partnering organizations, coastal community members, the Commonwealth of Massachusetts, as well as those involved in policy formulation at the national and international levels were invited to discuss progress and plans while also sharing lessons learned with representatives from other states.

The goals of this workshop were multifaceted across sectors and were relevant throughout the community, state, national, and international levels. These goals include:

- Relate the most relevant science on sea level rise and shoreline change to community actions
- Discuss examples of community and state resilience plans
- Share lessons learned from community and state resilience plans and export to other communities
- Create science-based suggestions for policy and communities

The outcomes for this workshop include a list of suggestions for other communities based on the lessons learned in Woods Hole and Massachusetts. Some suggestions include:

At the community and state level

- Create more synergy between the ocean and climate across all sectors
- Recognize societal impacts can be complex and must be translated to community needs
- Build community trust and rely on strong partnerships through outreach and engagement
- Develop state and local adaptation and resilience plans
- Incorporate adaptation and resilience into regulatory measures
- Create capacity for communities, institutions, and organizations to address resilience
- Invest in climate tech and the blue economy to support innovative climate solutions and create economic and workforce opportunities

At the national level

- Consolidate resilience resources, knowledge, and networks in a national center
- Increase funding sources, streamline pathways, and expand eligibility for climate adaptation projects
- Create federal incentives for state governments to focus on coastal resilience
- Strengthen the connections between coastal resilience and the blue economy

At the international level

- Encourage countries, particularly the major economies, to accelerate the clean energy transition and accelerate emissions reductions on a trajectory consistent with 1.5°C
- Include coastal resilience and sea level rise in climate plans within National Adaptation Plans
- Increase global capacity to collect scientific knowledge
- Share lessons learned and develop policies that address them adequately
- Support countries and communities with all necessary tools to build resilience
- Prepare to adapt

INTRODUCTION

The workshop opened with high-level remarks about sea level rise and coastal resilience from Kilaparti Ramakrishna (WHOI), Peter de Menocal (WHOI), Katherine Antos (Massachusetts Executive Office of Energy and Environmental Affairs), and Rafe Pomerance (Climate Strategies), connecting the ocean to climate. Only recently has the ocean been recognized as a critical proponent of climate and incorporated into frameworks that link the ocean and climate. For example, in 2024, International Tribune for the Law of the Sea (ITLOS, which adjudicates disputes arising out of the interpretation and application of the United Nations Convention on the Law of the Sea, UNCLOS) issued a unanimous advisory opinion, recognizing greenhouse gases (GHGs) as pollutants, making climate change relevant to UNCLOS. Additionally, at the 27th and 28th United Nations Climate Change Conferences (COP27 and COP28), WHOI joined hands with Scripps Institution of Oceanography to bring together oceanographic institutions and philanthropic communities to host the Ocean Pavilion in the diplomatic Blue Zone. This is the first time in the history of climate negotiations that ocean science had a dedicated pavilion in the Blue Zone and it has also become the "home" for senior leaders, negotiators, and ocean scholars to come together and agree on how to make progress.

One priority identified within this link between the ocean and climate is coastal resilience and sea level rise. The United Nations Decade of Ocean Science for Sustainable Development (2021-2030, UN Ocean Decade) has hosted several events focusing on coastal resilience and this is a priority topic for discussion by heads of state at the 2024 UN General Assembly, with one day specifically dedicated to this topic. While these are high level goals, sea level rise impacts communities on the local level and varies regionally, putting cities and towns at the front line. Therefore, it is vital that at-risk communities prioritize their local needs, including scientific information that is translated to policy to establish the base knowledge and inform decision making. While it is a large task for cities and towns, developing a canvas to increase resilience can guide communities to develop their own plans.

Both Massachusetts and Woods Hole have taken the initiative to lead the way and develop the ResilientMass Plan and *ResilientWoodsHole* Plan, respectively. By paving the way, they hope to create a model that other states and towns can follow. The statewide ResilientMass Plan integrates a hazard mitigation plan and a climate adaptation plan and was developed in a fully collaborative manner. This is the first

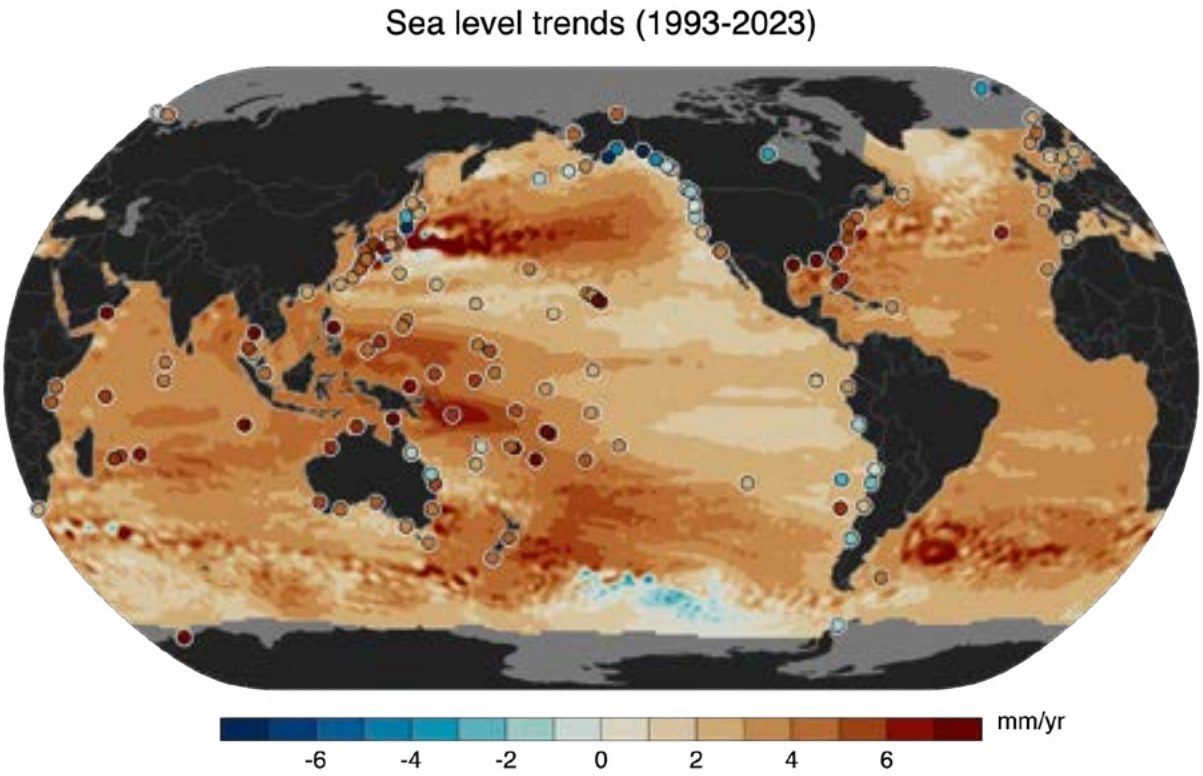
of its kind and demonstrates Massachusetts' commitment to prepare its communities for climate impacts. In fact, Massachusetts has ambitious climate goals and statutory requirements to be net zero by 2050, recognizing that the hardest part is between now and 2030. To make progress towards these goals, all branches of government within Massachusetts support climate action; Governor Healey has stated that climate change is the Commonwealth's biggest threat and opportunity. By prioritizing climate action, building capacity at the local level and establishing regional initiatives to address climate change, the Commonwealth of Massachusetts can reduce the disproportionate burden of those that are most vulnerable to climate change impacts. Massachusetts aims to assess the economic factors associated with climate impacts, identify innovative financing opportunities and develop a nature-positive future that balances the many needs of the community, including clean energy, housing, and a thriving economy. The Commonwealth is taking regulatory actions so that legal frameworks align with climate priorities. Underlying these efforts, they established an Office of Climate Science in 2023 and convened a Climate Science Advisory Panel to inform the Commonwealth's climate resilience efforts. This helps ensure that the management and policy decisions reflect the best-known science related to sea level rise, flooding, extreme heat and health impacts and that state agencies, local governments and partners are using this information. Massachusetts has prioritized climate impacts and established actions that can serve as tangible examples for other states that are also experiencing climate change impacts such as sea level rise and coastal erosion.

Workshop high-level remarks. Photo of workshop participants listening to high level remarks by (from left to right) Rafe Pomerance, Katherine Antos, Peter de Menocal, and Kilaparti Ramakrisna. Photo by Kalina Grabb.

SCIENCE BEHIND SEA LEVEL RISE

Christopher Piecuch (WHOI) outlined the latest scientific findings on sea level rise, based upon his research and the assessment carried out by Intergovernmental Panel on Climate Change (Oppenheimer et al., 2019; Fox-Kemper et al., 2021). Scientific data shows that global mean sea levels are rising, and the rates at which they are rising are faster within the 20th century than during any prior century over the last three millennia (Fox-Kemper et al., 2021; Sweet et al., 2022). Coastal ecosystems and communities around the world are threatened by a combination of sea level rise compounded with other climate-related impacts. Since 1901, sea levels have already risen 20 cm, with over half of that increase occurring since 1961, and half of that rise occurring within the last two decades (Fox-Kemper et al., 2021). Within the last few centuries, data on sea level rise has improved due to technological advancements and long-term monitoring. For example, tidal gauges, satellite monitoring, and autonomous profiling floats, such as Argo Floats, have been able to collect measurements around the world that confirm global mean sea levels are rising and highlight the local and regional variability. These measurements indicate that sea level does not rise uniformly, thus impacting communities differently. For example, at a basin scale, sea level has risen faster in the Western Pacific and slower in the Eastern Pacific (1993-2018).

Sea level rise is a result of several factors, many of which are accelerated by climate change. Sea level is relative to land, so both the sea level rising and/or changes in land height can result in sea level rise. Two major causes of global sea level rise include thermal expansion due to warming oceans as well as increased melting of land-based ice such as glaciers and ice sheets, both of which are a result of increased global temperatures. Many local effects that can influence sea level rise at specific locations include subsidence, erosion, regional ocean currents, and rebounding land from Ice Age glaciers. Due to these nuances and local variations, it offers challenges in predicting sea level rise and extrapolating across regions. Some of the most uncertainty lies within the process of ice melting and changes in ocean currents. For example, there are many different models and studies that simulate future scenarios for land ice melting and changes in ocean circulation, resulting in different predictions in regional sea level rise depending on how these processes may be impacted in the future by the changing climate.



Map of sea level rise trends, where red indicates increases in average sea level rise and blue indicates decreases in sea level. The dots represent data points whereas the background colors represent modeled projection. University of Hawaii.

While these local processes are more difficult to discern, it is virtually certain that global mean sea level will continue to rise through this century and beyond. Independent of future emissions, the past emissions and current temperatures have already committed us globally to a certain amount of sea level rise. Data shows that the rates of global sea level rise due to melting ice sheets, glaciers, and ice caps is linearly correlated to the global mean surface temperature (Grinsted et al., 2022). The near-term (2050) global, regional, and local projections of sea level rise are now narrower than previously reported across all emission scenarios (Sweet et al., 2017). After 2050, these projections start to diverge due to emissions and process

uncertainties as well as poorly constrained processes, such as ice formation and melting. Relative to the mean sea level between 1995 and 2014, it is predicted that global mean sea level will rise between 15-29 cm by 2050, 29-101 cm by 2100, and 38-188 cm by 2150. Beyond 2100, the predicted sea level rise is largely subject to the committed sea level rise resulting from global surface warming by 2100. For example, if temperatures rise 1.5ºC by 2100, sea levels can rise 0.8-3.1 meter in the next 300 years, 2-3 meters in the next 2,000 years, and 6-7 meters in the next 10,000 years. Alternatively, if the temperatures increase 5.0ºC by 2100, then the sea level can rise 1.7-6.3 meters, 19-22 meters, and 28-37 meters, over the same time frames, respectively.

While there are large uncertainties with complex Earth and climate processes that drive future sea level rise, enhanced observing in the last few decades have enabled scientists to closely track sea level rise and observe that it is rising at unprecedented rates. Additional sustained observations are needed to project future sea level rise and impacts. These scientific advances require partnerships between scientists and practitioners through avenues such as this workshop.

Workshop field trip to tidal gauge. Photo of workshop participants listening to Chris Piecuch explain the tidal gauge that he recently installed on WHOI's Iselin Pier.

SEA LEVEL RISE IMPACTS ON LOCAL COMMUNITIES

As the world is committed to non-trivial amounts of sea level rise within the next century, many communities are realizing that they must be prepared to adapt and build resilience. In doing so, there are some communities that have taken the lead to do so. During the workshop, Rob Munier (WHOI) introduced this session, where Leslie-Ann McGee (WHOI) presented on the *ResilientWoodsHole* Plan and Katherine Antos (Massachusetts Executive Office of Energy and Environmental Affairs) presented the ResilientMass Plan. Alongside these resilience plans, Di Jin (WHOI) also presented on the science that underlies decisions about shoreline changes and adaptation strategies.

ResilientWoodsHole Initiative

Given the local community risks to sea level rise, Woods Hole has taken the initiative to create the *ResilientWoodsHole* Initiative to ensure that the village of Woods Hole prospers into the future even with major climate impacts such as sea level rise, coastal flooding, shoreline loss, and associated challenges. Collectively, the three major science institutions that inhabit Woods Hole, Woods Hole Oceanographic Institution, Marine Biological Laboratories (MBL), and National Oceanic and Atmospheric Administration (NOAA) Woods Hole Laboratory, drive the local economy ($385M annual budget and $256M annual research budget) and employ over 1,700 individuals, with WHOI being the second largest employer on Cape Cod. This initiative is a collaborative community effort across these three major science institutions and key local stakeholders, including the businesses, residents, critical life-lines (e.g. U.S. Coast Guard and Steamship Authority) and the Town of Falmouth, MA, of which Woods Hole is a village. It is led by the private science partners in collaboration with public partners, and it is the first of its kind to pool resources, intellectual insights, and management skills to support collaborators' and community members' mutual interests.

Grounded by the Massachusetts Coastal Flood Risk Model, this initiative is based on the scientific data collected in Woods Hole as well as data that is projected into the future under different climate scenarios. Sea levels have already risen 10 inches in Woods Hole within the last century. Based on the scientific data, this

initiative intends to move beyond "admiring the climate problem" through identifying and setting a blueprint for adaptive pathways in nine neighborhoods in Woods Hole. WHOI is considering adaptive measures to rebuild the WHOI Iseline Marine Facility and associated buildings with more resilient infrastructure that will be raised several feet higher than the present infrastructure. WHOI has developed extensive plans in consultation with the community that includes considerations about the infrastructure as well as the regulatory environment. With this initiative, they have made a commitment to preserve direct access to the sea, which is fundamental to the science institutions' initiatives and is threatened by climate change.

In addition to these priorities at the science institutions, *ResilientWoodsHole* has done extensive outreach to the community, using citizen science data and incorporating the community's view on how they would like to adapt. Four different themes created by input from the community: (1) Develop adaptation plans that maintain character of our community; (2) Focus on nature-based solutions in our community; (3) Protect and connect; and (4) Learn to live with water. The community prioritized taking action and preferred nature-based solutions. Based on these community priorities, *ResilientWoodsHole* developed dynamic adaptations for each neighborhood that are trigged based on the combination of climate impacts realized and community preference. However, over time, as the environment changes, the identified trigger points indicate when an approach no longer works, at which point, they will have to switch to the next adaptation strategy, and so on. By mapping out these options ahead of time, each neighborhood is planning out its path to adaptation. To help showcase these efforts and increase access to such information, *ResilientWoodsHole* set up a walking tour with physical location markers and an associated application to share a brief history of Woods Hole, climate change projections, adaptation solution charts, current and historic images, and video interviews with *ResilientWoodsHole* leaders and community members. The Village of Woods Hole aims for this initiative to build resilience in the community and also for it to serve as an example for other coastal communities that most likely will face similar fates.

ResilientWoodsHole* Posts** (logo in center). Field trip during workshop where Leslie-Ann McGee showed workshop participants (left, photo by Kalina Grabb) the ***ResilientWoodsHole posts (right) marking significant locations around Woods Hole. Workshop participants scanned the QR code to see the multimedia associated with posts.

ResilientMass Plan

Massachusetts was the first state in 2018 to create a combined statewide hazard mitigation plan with a climate adaptation plan that is updated every five years. Governor Healey adopted ResilientMass Plan in 2023. The ResilientMass initiative was led by the Office of Energy and Environmental Affairs (EEA) and the Massachusetts Emergency Management Agency (MEMA) and was developed in a collaborative manner across all government agencies. It was informed heavily by the scientific data within the 2022 Massachusetts Climate Change Assessment, and it centers equity and justice. ResilientMass identifies specific actions that state agencies will take within five years to address risks of the communities and societies. The Plan aims to increase collaboration across agencies, employ science-based decision making, increase resilience of state assets and services, implement adaptation actions, and prioritize hazard reduction and mitigation of risks.

The 2022 Massachusetts Climate Change Assessment gathered the best available data on climate change impacts throughout the state to assess how hazards such as extreme heat, precipitation, extreme weather events, sea level rise, and storm surge and erosion are threatening the state. This assessment was advised by a technical advisory committee and was informed by engagement with stakeholders and

ReseilientMass Plan: Cover page of ResilientMass Plan, which was presented during the workshop by Katherine Antos.

community-based organizations. It investigated the impacts of each of these stressors across five sectors: people, built infrastructure, natural resources, state and local government, and the economy. They then prioritized climate impacts based on three criteria: (1) Magnitude of the consequence (e.g., how much flooding will occur due to sea level rise); (2) Disproportionality of exposure for vulnerable populations (e.g., how much more will flooding affect environmental justice communities vs the population at large); and (3) Adaptation gap (e.g., how much more needs to happen to address flood pathways). In relation to all these criteria, there are many risks that the state is considering in relation to climate impacts, including risks due to sea level rise. For example, sea levels in Massachusetts are projected to rise 2.5 feet by 2050 and 4.3 feet by 2070. The increased risk of coastal flooding due to sea level rise will add stress to the on-going housing crisis, decreasing availability and affordability, as well as impact the economy and damage infrastructure. To investigate closely the risk of coastal flooding, a collaborative group including EEA, Department of Transportation (MassDOT), and Woods Hole Group developed a Massachusetts Coastal Flood Risk

Model. This model highlights the areas with 1% chance of flooding, which will double in area and include the majority of downtown Boston, South and East Boston, Back Bay and Charlestown by 2070. By identifying these affected areas, they can assess other critical impacts, such as disruptions to emergency services, flood evacuation routes, degradation of coastal wetlands, loss of ecosystem function, erosion, economic losses, and more. The Massachusetts Climate Change Assessment also incorporated community-based knowledge and laid the foundation for the Commonwealth to adopt over 140 agency actions in the ResilientMass Plan to address these impacts.

After assessing and prioritizing the risks from climate hazards and resultant impacts, the ResilientMass Plan was developed to evaluate vulnerabilities and identify the actions that the state will take to address such climate risks and increase resilience against these threats. This plan recommends almost 150 different cross-government and state agency actions that will be taken within five years to address climate hazards and impacts. The ResilienceMass Plan is a living plan, which will evolve as actions are implemented, climate impacts evolve, and new data and information are incorporated into the planning process.

In relation to coastal resilience and sea level rise, this plan offers actions such as developing a comprehensive coastal resilience strategy, studying options for a buyout program to acquire at-risk land, developing mechanisms to incorporate flood resilience measures into the building code, updating wetlands restoration guidance and regulations to align with resilience priorities, expanding the Massachusetts Bay Transportation Authority's (MBTA's) Tunnel Flood Mitigation Program, and increasing resources and support for local resilience planning and action. ResilientMass is a living plan, and all of the actions are accessible and searchable online by a number of different categories (see table below for some example actions). The team will continue to amend the actions and use the ResilientMass Tracker to indicate progress and additional lessons learned. The team is working to raise awareness and gather additional input by presenting at different meetings, such as this workshop. The ResilientMass Plan has also led to the development and ongoing refinement of tools, such as the award-winning Climate Resilience Design Standards (CRDS) Tool, which enables users to enter their project ideas around the state and view the hazard exposure, environmental justice, and ecosystem benefits associated with any project. Major infrastructure projects funded by state grants or the capital budget must use the CRDS Tool to assess and mitigate climate hazards.

Table 1: Example actions within the ResilientMass Plan with the lead agency listed to demonstrate the whole-of-government approach. All actions can be viewed within the ResilientMass Tracker: https://resilient.mass.gov/actiontracker

LEAD AGENCY	EXAMPLE ACTION
Coastal Zone Management Program	Develop a coastal resilience strategy
Massachusetts Emergency Management Agency	Launch acquisition/buyout program study
Executive Office of Economic Development	Develop a local option "Stretch Flood Code" for residential and/or non-residential construction
Executive Office of Energy and Environmental Affairs; Executive Office of Administration and Finance	Increase funding to support municipal and agency resilience actions and access to funding opportunities
Executive Office of Energy and Environmental Affairs	Protect 30 percent of land and ocean by 2030 (aligned with global 30x30 goal)
Massachusetts Bay Transportation Authority	MBTA design standards update
assachusetts Emergency Management Agency	Statewide emergency management training needs assessment

The Commonwealth is now implementing the ResilientMass Plan. For example, EEA has established an Office of Climate Science and convened a Climate Science Advisory Panel and Community Climate Advisory Council to inform the state's climate efforts. In 2023, EEA's Coastal Zone Management (CZM) Program launched ResilientCoasts, a holistic strategy that binds together the 78 coastal communities to pursue a multipronged approach to identify regulatory, policy, and funding mechanisms for long term resilience. Rather than relying on each town to address these major challenges alone, collectively the coastal communities can develop best practices, apply for grants, protect and restore coastlines, and prioritize environmental justice communities. CZM hired a Chief Coastal Resilience Officer in 2024 to lead this effort. Also in 2024, the Healey-Driscoll Administration increased its resilience investments in the capital budget seven-fold to implement ResilientMass actions.

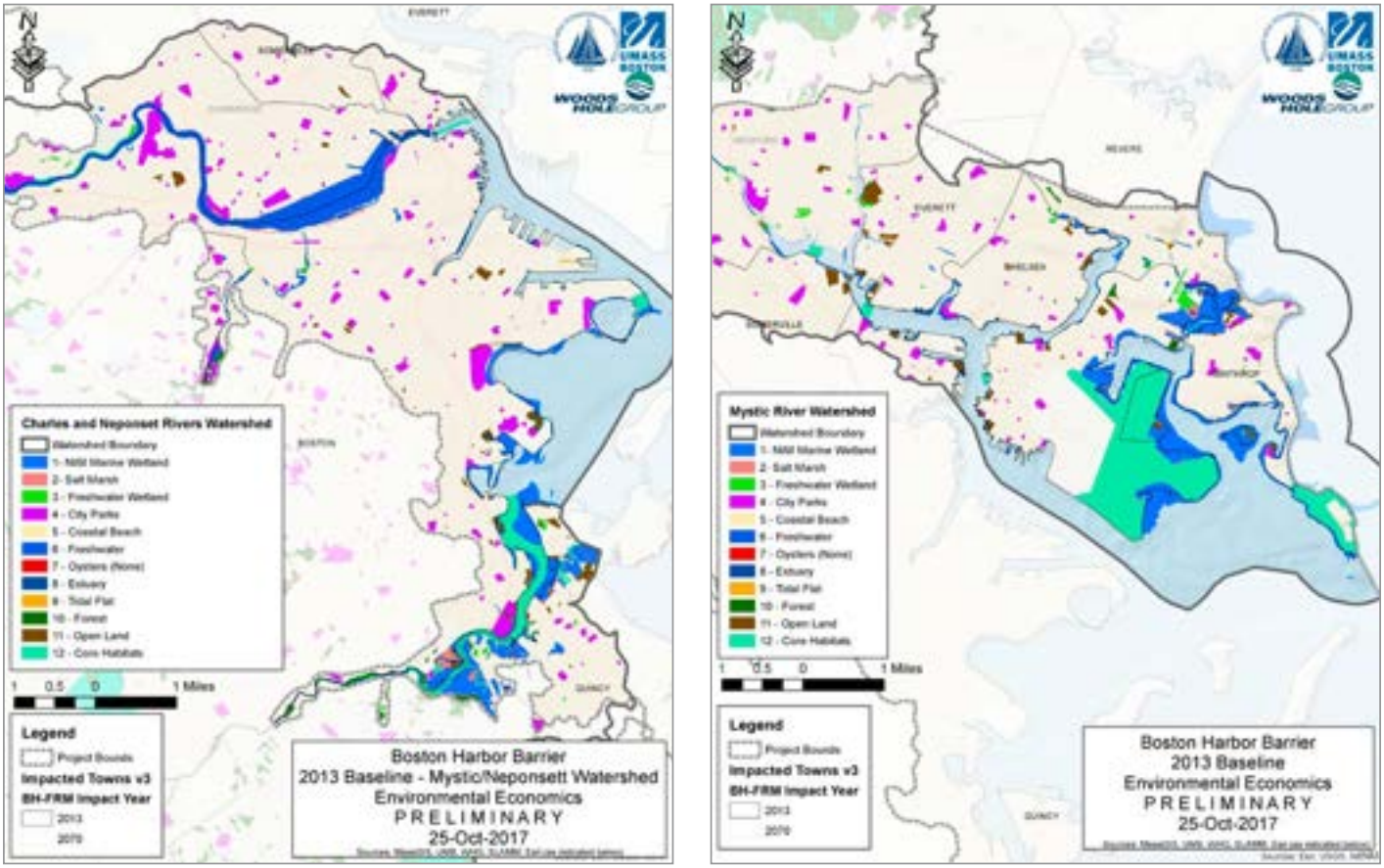
Economics of Sea Level Rise

Sea level rise directly connects the natural scientific research of changing shorelines with societal and human needs and impacts. The WHOI Marine Policy Center (MPC) focuses on social science within a predominantly natural science institution. During the workshop, Di Jin from the WHOI MPC presented on shoreline change research from an economic and human decisions point of view. For example, considering sea level rise, coastal communities have decisions to make such as to stabilize the shoreline with gray or green methods, or to leave the shoreline alone and implying the need for managed retreat. Such decisions play into both the environmental and economic sustainability of the area, which drives the long-term viability of a project to survive and benefit a community. To better predict the economic impacts of sea level rise, Di Jin has investigated the economic impacts on a micro level by building hedonic pricing models for homeowners. While coastal properties are of high value due to the view and recreational value, there is also an additional risk for houses that are close to the coastline. They found that if there were adaptive measures associated with a property, such as an effective seawall or a house that is raised on stilts, then this can increase the home value by a significant percentage. By developing a geoeconomic model, they also incorporated the geomorphologic dynamics into housing value analysis, including different shoreline protection decisions, such as beach nourishment, choice of the optimal beach width, and engineered coastal berm-dune renourishment.

With both engineered gray and living shoreline adaptations, there are many additional considerations on both the environmental and economic sides. Considering cost-benefit analysis (CBA), the investment can be higher for adding living shoreline features than traditional steel and concrete shorelines, and the benefit of flood protection alone may not outweigh the costs of green designs. However, living shorelines offer major social and ecosystem benefits such as recreational benefits, carbon sequestration, and habitat restoration. Including these social benefits can alter the result of a CBA in favor of the green option. Yet, these considerations must be made along with assessments of the natural environment. For example, low energy environments can be suitable for living shorelines, whereas in high energy environments these adaptations can be washed away.

With these analyses, there are tradeoffs financially, socially, and environmentally. The changing climates and environmental shifts make it further difficult

to predict future coastline threats. To help understand the current community priorities, colleagues within the WHOI MPC are working with Woods Hole Sea Grant and other Massachusetts agencies to conduct a survey of homeowners to understand their decisions on flood insurance purchase and other adaptive measures to protect their homes. In these changing times, it is vital that the social and natural sciences work together to assess this intersection within the environmental consequences on human impacts.



Assessing the effects of the proposed Boston Harbor barrier. Models showing changes in land cover and ecosystem service values in the Mystic River watershed (left) and Charles and Neponset Rivers watershed (right).

INTERNATIONAL ACTIONS RELATED TO SEA LEVEL RISE

On an international level, sea level rise and resilience have been topics that are rapidly gaining more attention and are urgent to address for many small island states. Within international policy and actions, the connection between ocean and climate is growing, yet this progress is still far behind where it needs to be. This session introduced and moderated by Kilaparti Ramakrishna (WHOI) had presentations by Michael Oppenheimer (Princeton University), Kilaparti Ramakrishna (WHOI), David Freestone (Sargasso Sea Commission/George Washington University Law School), Nicholas Robinson (International Council of Environmental Law/Pace University Haub School of Law), and Zander Nassikas (Office of the Special Presidential Envoy for Climate) shared their experiences with international policy related to sea level rise and the IPCC, Ocean Climate Dialogue, ITLOS Advisory Opinion, High-level Segment discussions at the UN General Assembly (UNGA), and the international engagement by the US government, respectively. Through presentations and discussion, this section of the workshop focused on the variety of on-going international actions that focus on increasing scientific knowledge, capacity enhancement, and policies to support coastal resilience.

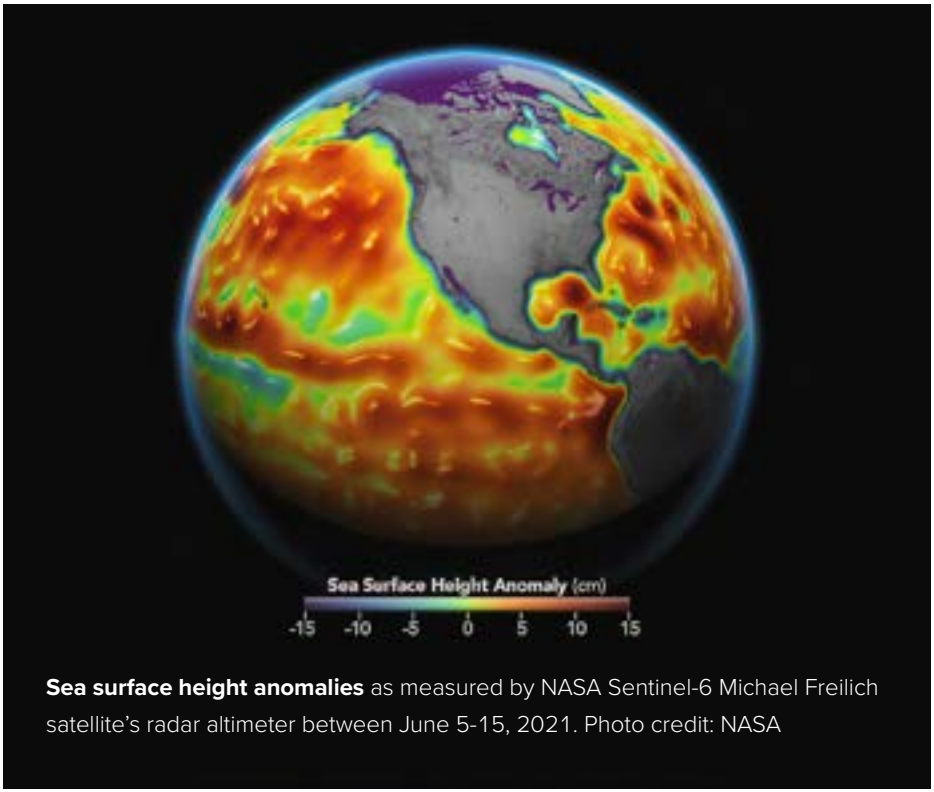
The recent IPCC special report on sea level rise (Oppenheimer et al, 2019) helped raise awareness about sea level rise and presented science in an accessible manner for decision makers. The 7th assessment report is currently underway and despite the emerging consensus on the urgency of the topic, it is unlikely that there would be another special issue on sea level rise. It is important to note however that there were many recent efforts along the lines of strengthening the scientific knowledge pertaining to coastal resilience and sea level rise. These efforts were followed by the United Nations International Law Commission (ILC) that established a study group to consider possible international legal implications of sea level rise, such as statehood, rights, sovereignty, and protection of persons affected by sea level rise. More recently, ITLOS issued an advisory opinion in May 2024 on the obligations of Parties to UNCLOS relating to climate change. Among other things, the advisory opinion found that anthropogenic GHG emissions meet the definition of "pollution of the marine environment" under UNCLOS. Another tool that acknowledged the link between ocean and climate recently is the Agreement on the

Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction Treaty (BBNJ). Similar to Article 206 of UNCLOS, BBNJ requires Environmental Impact Assessments (EIA), which can be used to monitor and assess sea level rise and other measures that may help with efforts underway towards climate stabilization. While these measures aim to improve resilience and adaptation, it is unclear how these avenues will be used to ensure that communities and countries impacted by sea level rise are adequately protected. The UN General Assembly (UNGA) has taken up this matter for consideration by the UN Member States by holding a high-level meeting to address the existential threats posed by sea level rise in September 2024 (UN GA Res. A/76/319, 1 August 2024). By prioritizing this issue, UNGA recognizes that sea level rise affects every continent and region, leaving no one immune from potential catastrophe. Increasing the dialogue around sea level rise to encourage national governments to prioritize coastal resilience is necessary to elevate the capacity, awareness, and action related to developing adaptive measures.

To help build scientific knowledge and capacity enhancement in the international community the U.S. has developed and contributed to several initiatives to increase resilience to sea level rise. Through the President's Emergency Plan for Adaptation and Resilience (PREPARE), United States government agencies are collaborating to help more than half a billion people adapt to and manage the impacts of climate change by 2030, including sea level rise. For example, NASA's Sea Level Change Team has developed high-resolution technical assessments of future sea level rise and associated impacts for Tuvalu and Kiribati. These technical assessments provide a scientific foundation for understanding future sea level rise and its potential effects on coastal communities (NASA Sea Level Change Team, 2023). The report for Tuvalu is contributing to Tuvalu's planning efforts with the Tuvalu Coastal Adaptation Project. The U.S. also is supporting the design and establishment of the Pacific Resilience Facility, which is a Pacific-led and Pacific-owned facility that will help vulnerable communities exposed to climate change and disaster risks by building resilience, preparedness, and adaptive capacity.

While sea level rise is included increasingly in international agreements and actions, workshop participants noted that it is important to ensure that these measures are based on science. The rising temperatures have already committed the planet to future sea level rise due to the current and past emissions of greenhouse

gases and their concentration in the atmosphere. Secondly, sea levels do not rise uniformly around the globe, with some areas experiencing faster rates of sea level rise than others, such as the Western Pacific. Additionally, the climate system is still trending towards equilibrium, and it is difficult to determine when or at what point the climate impacts will taper off and the rates of sea level rise will steady. Considering these factors, the IPCC special report predicts global mean sea level will rise between 15-29 cm by 2050, 29-101 cm by 2100, and 38-188 cm by 2150. Therefore, it is vital to raise awareness about sea level rise, encourage policymakers to incorporate and adopt coastal resilience and adaptation plans, and encourage nations to reduce greenhouse gas emissions to prevent further global warming and additional compounding factors that will contribute to additional sea level rise.



Sea surface height anomalies as measured by NASA Sentinel-6 Michael Freilich satellite's radar altimeter between June 5-15, 2021. Photo credit: NASA

CONCLUSIONS - LESSONS LEARNED AND SUGGESTIONS FROM THIS WORKSHOP

Sea level rise, driven by the accelerating pace of climate change, poses a profound threat to coastal communities worldwide. The ramifications are manifold, impacting everything from infrastructure and ecosystems to economies and human livelihoods. Understanding and mitigating these impacts requires not only scientific innovation but also robust policy responses and international cooperation.

At the Community and State level

Based on the information about sea level rise and coastal resilience presented during the workshop, the participants discussed the commonalities between different regions and lessons learned from coastal resilience plans that can be transferable to other communities. For example, similar to WHOI, the New England Aquarium is also experiencing threats to their infrastructure due to sea level rise and they exist in a community with a combination of private-public partnerships. Based on the experiences from the participants in the workshop, the following lessons learned seemed common to different communities and may be useful for other areas that need to increase coastal resilience:

- Create more synergy between the ocean and climate across all sectors
    - Reduce emissions to decrease climate impacts. The underlying cause of climate impacts is fossil fuel emissions.
    - Communicate the connection between the ocean and climate in all settings.
    - Offer additional climate education to all careers, including through micro-credential courses, since every job is a climate job.
    - Increase citizen science opportunities since it can be powerful in collecting data, increasing awareness, and supporting climate resilience.
    - Support interdisciplinary science to break down traditional siloes and help science be co-designed with applications.
- Recognize societal impacts can be complex and must be translated to community needs

  - Implement and relate to the human experience and impacts along with natural science.
  - Consider recommendations from other communities and adapt them to the specific communities at hand since each community is unique.
  - Evaluate the risk vs. consequence of specific climate impacts for each community to determine community and state specific priorities.
  - Understand the risk of doing nothing in terms of planning for climate resilience.
  - Enable solutions that stem from stakeholder influence and preferences.

- Build community trust and rely on strong partnerships through outreach and engagement

  - Develop public-private partnerships since they are crucial to move climate adaptations forward. Many coastal communities are a combination of entities that require collaborative action planning that will be unique to each location.
  - Engage the community and neighborhood to honor the neighbors' opinions and coordinate efforts to ensure maximum impact.
  - Consider that trust is hard to earn and easy to lose. It can take time to find the community members that want to be involved and that have the bandwidth to participate.
  - Reach out to the public and teach about the threats and options. This can also diversify the workforce.
  - Rely on storytelling to share information and increase engagement.

- Develop state and local adaptation and resilience plans

  - Develop scientific assessments to understand the science underlying the situation and generate local science-based knowledge.
  - Utilize the state's ability to play an important role in making climate science, data and tools accessible to communities and creating opportunities for them to learn from each other and work together.
  - Create adaptation and resilience plans to encourage communities to plan into the future for different scenarios.

  - Plan for the eventualities of sea level rise, since the risk of doing nothing is increasing.
  - Incorporate adaptation and resilience into EIA prepared under state procedures, and share with others undertaking climate related EIA
  - Facilitate collaboration among communities and institutions to enable peer to peer learning and address resilience at a regional scale

- Incorporate adaptation and resilience into regulatory measures
  - Incorporate resilience into building codes to require new structures to adhere with resilient practices.
  - Appoint dedicated representation on decision committees and/or boards with scientific and engineering backgrounds
  - Utilize regulatory measures to address not only how things are built, but also where they are built (i.e. zoning), including considering climate projections and possible restrictions in flood prone areas
  - Ensure regulations are designed to protect natural resources and to be responsive to climate change
  - Establish working groups that bring experts across disciplines and rightsholder groups together

- Create capacity for communities, institutions and organizations to address resilience
  - Develop human capacity to dedicate time to addressing resilience efforts and enforce resilience codes both for the local governments and the private institutions in coastal communities.
  - Break down silos and coordinate housing and resilience planning given that many coastal communities face housing shortages. It may be difficult for some workers to live nearby coastal institutions and/or take jobs in coastal communities that help build resilience or enforce resilience.
  - Establish forums (i.e. summits, working groups, etc.) that bring communities together
  - Work with municipal associations to increase opportunities to address resilience with communities

  - Increase access to funding, technical assistance resources, and incentives to support local and regional resilience efforts
  - Engage communities, regional entities and organizations early in the development of state resilience initiatives to ensure efforts are addressing key needs

- Invest in climate tech and the blue economy to support innovative climate solutions and create economic and workforce opportunities
  - Coordinate additional efforts for the blue economy
  - Recognize role of technology, economic development and innovation in developing resilience solutions and advance thru partnerships and investment

Rendering of proposed new dock and building at Woods Hole Oceanographic Institution. Photo Credit: WHOI

At the National level

Bringing together practitioners from other states, this workshop used experiences within Massachusetts and Woods Hole to talk about avenues that other states can learn from. Identifying strategies that work across different states can help build national policies that build resilience and increase science and policy interactions.

- Consolidate resilience resources, knowledge, and networks in a national center
  - Increased coordination is needed to share experiences and communicate about coastal resilience science, resilience plans, and adaptation practices.
  - Coordinated access to case studies could help communicate the different approaches that communities have taken, and track lessons learned and successes.
  - Rely on knowledge about the state of monitoring and data for different areas since it can be helpful to determine where additional resources are needed.
  - Build or expand an existing coordinated network that can help inform others who to call when needed.
- Increase funding sources, streamline pathways, and expand eligibility for climate adaptation projects
  - Enable non-municipalities to attract funds since most coastal resilience projects are funded on a grant and project basis.
  - Increase federal and state grant dollars, since they are currently not enough to support desired resilience efforts and plans.
  - Create more innovative financing strategies and identify private and alternative funding sources.
- Create federal incentives for state governments to focus on coastal resilience
  - Encourage coastal states to dedicate resources and personnel to take a whole-of-government approach to developing and implementing resilience plans, similar to how Massachusetts has prioritized resilience.
  - Provide coordination for States such as Massachusetts to communicate with other states and provide examples of their approach and progress.

  - Incorporate adaptation and resilience into EIA prepared under national procedures (e.g. National Enviornmental Policy Act, NEPA), and share with others undertaking climate related EIA

- Strengthen the connections between coastal resilience and the blue economy
  - Support state actions to accelerate blue economy at the state and community level
  - Link blue economy to coastal resilience and consider the potential economic co-benefits of building resilience.
  - Consider that the cost for inaction can be higher than the cost to increase resilience.

Hurricane Sandy flooded the New Jersey coastline in 2012" Photo by Master Sgt Mark Olsen.

At the International level

Given the diverse experience of the participants across international platforms, the workshop participants discussed the following necessary international actions to increase coastal resilience around the world:

- Encourage countries, particularly the major economies, to accelerate the clean energy transition and accelerate emissions reductions on a trajectory consistent with 1.5°C
    - Cut carbon dioxide emissions along with all GHGs, including methane, and make this a priority for nationally determined contributions (NDCs).
    - Consider that the pace of sea level rise after 2050 hinges directly on the emissions trajectory even though there is 20-40 cm of sea level rise "baked in" through 2050
- Include coastal resilience and sea level rise in climate plans within National Adaptation Plans
    - Elevate the issue of sea level rise within relevant international discussions, policy frameworks, and negotiations.
    - Encourage nations to create plans and commit funds to help increase coastal resilience.
    - Implement strategies that have a multi-prong approach that enables the strategy to be adaptive to specific times and places.
    - Sustain on-going dialogues around sea level rise by hosting side events for continued discussion during relevant conferences and meetings.
- Increase global capacity to collect scientific knowledge
    - Use environmental impact assessments to increase capacity to measure and monitor sea level rise across global locations.
    - Conduct scientific assessments of sea level rise risk to understand the threats and use such scientific knowledge to build resilience and adaptation plans.

- Share lessons learned and develop policies that addresses them adequately
  - Share knowledge and best practices to help inform low-lying coastal state, island nations and all vulnerable countries particularly those that have limited capacity and fewer resources to build resilience.
  - Share internationally EIA analysis on sea level adaptation and resilience from state and national initiatives
  - Communicate scientific knowledge to inform decision making and encourage decision makers to rely on scientific knowledge to inform their policies.
- Support countries and communities with all necessary tools to build resilience
  - Create tools that share information with countries and communities about how to build resilience and lessons learned
  - Build capacity to support countries and communities to build resilience
- Prepare to adapt
  - Make plans to adapt to sea level rise and increase coastal resilience, given that sea level rise is baked in for the near future.
  - Develop early warning systems that States can use to increase effective planning and response.

The advisory opinion of ITLOS, adoption of BBNJ Agreement, recognition in the outcome of the first global stocktake under the Paris Agreement at the 28th UN Climate Change Conference of the importance of the ocean in addressing climate change, the acknowledged role in the Global Biodiversity Framework and the proposed plan to consider sea level rise as part of the work programme of the United Nations are all important developments. Yet, it is also important that the world community increase its attention and allocate adequate number of resources both to increase its knowledge of local impacts to build resilience to sea level rise accordingly.

Based on the presentations and discussions that occurred during the workshop, this workshop report captures some of the lessons learned and suggestions that the participants created for local communities, states, nations, and international States to build coastal resilience and incorporate the science-based knowledge about sea level rise into policy.

ADDITIONAL RESOURCES

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WORKSHOP AGENDA

Friday June 21, 2024

Location: Smith Laboratory Conference Room, 86 Water St, Woods Hole, MA 02543

8:30-9am: Arrival and Coffee

9-9:30am: Opening remarks, moderated by Kilaparti Ramakrishna
Peter de Menocal, Katherine Antos, and Rafe Pomerance

9:30-10:30am: Discussion on SLR – view from IPCC AR6, led by Chris Piecuch

10:30-10:45am: Coffee Break

10:45am-12:30pm: Discussion on regional resilience implications, led by Rob Munier
Resilient Woods Hole, presented by Leslie-Ann McGee
ResilientMass Plan, presented by Katherine Antos
Shoreline Change Research, presented by Di Jin

12:30-2pm: Lunch and Group Photo

2-3:30: Discussion on extrapolating some regional resilience examples to other areas
Focus on – Massachusetts, Connecticut, Florida and Texas, led by Rafe Pomerance

3:30-3:45: Coffee Break

3:45-4:45pm: UNFCCC and UNGA Discussions on Resilience and SLR

- Intergovernmental Panel on Climate Chante (IPCC) – led by Michael Oppenheimer
- Ocean Climate Dialogue, UNFCCC, June 2024 – led by Kilaparti Ramakrishna
- International Tribunal on Law of the Sea (ITLOS) Advisory Opinion - led by David Freestone
- HLS Discussions at UNGA September 2024 - led by Nicholas Robinson
- Role of USG – led by Zander Nassikas

4:45-5:15pm: Conclusions and Deliverables

- Recommendations for policy interventions for UN General Assembly
- Recommendations for Law of the Sea Tribunal legal decisions
- Recommendations for actions that coastal communities can take to increase resilience

WORKSHOP PARTICIPANTS

Workshop Attendees:

Katherine Antos, Massachusetts Executive Office of Energy and Environmental Affairs
Christina Brophy, PhD, Mystic Seaport Museum
Bob Chen, PhD, University of Massachusetts, Boston
Sarah Das, PhD, Woods Hole Oceanographic Institution
Peter de Menocal, PhD, Woods Hole Oceanographic Institution
David Freestone, PhD, Sargasso Sea Commission / George Washington University Law School
Cody Friesen, PhD, Arizona State University
Kalina Grabb, PhD, Woods Hole Oceanographic Institution
Shannon Hulst, Barnstable County / Woods Hole Sea Grant
Tod Hynes, Massachusetts Institute of Technology
Di Jin, PhD, Woods Hole Oceanographic Institution
Hauke Kite-Powell, PhD, Woods Hole Oceanographic Institution
Ken Kostel, Woods Hole Oceanographic Institution
Emiley Lockhart, JD, New England Aquarium
Leslie Ann McGee, Woods Hole Oceanographic Institution
Rob Munier, Woods Hole Oceanographic Institution
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