Coastlines and People (CoPe) Synthesis Report

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Executive Summary

Coastlines and People Initiative

The emerging Coastlines and People (CoPe) effort seeks to build capacity and explore research focused on understanding the impacts of coastal environmental variability, coastal development, and natural hazards on populated coastal regions. CoPe explores the complex interface between coastal natural processes, hazards, people, and their natural and built environments.

Complex Grand Challenge

Coastlines are complex ecosystems that operate across multiple spatial and temporal scales— sub-meter to thousands of kilometers; fractions of a second to millennia— while interacting with human dimensions from individual to global species scales. The complexity of this challenge and its social urgency calls for research approaches that engage with local communities in ways that are locally relevant and that expedite knowledge creation for policies, management, and action. Therefore, the grand challenge for CoPe is to integrate human use and transformation of coastlines with an understanding of coastal processes, variability and hazards. CoPe-related efforts will forge new, transdisciplinary paths to integrate knowledge across physical, biological, socio-political, and economic processes with human dimensions.

Community Scoping Sessions

To define mechanisms for pursuing CoPe's goals, the University Cooperation for Atmospheric Research (UCAR), with a grant from the National Science Foundation (NSF), assembled a diverse group of over 400 scientists to provide ideas on the data and research needed to address the CoPe grand challenge, as well as the research infrastructure required for implementation. All white papers and presentations are publicly available at https://coastlinesandpeople.org. A small group of 12 attendees, representing diverse backgrounds, locations, and career stages, was selected to produce this synthesis report from the scoping sessions products. The major themes identified by the synthesis group's review are presented in Figure 1 and are: 1) inclusive diversity, 2) environmental change, and 3) data needed for innovative solutions.

Inclusive Diversity

Solving the CoPe grand challenge requires an inclusive and new interdisciplinary, trans-academic research agenda, as well as a revised paradigm for developing and implementing that agenda in meaningful ways. Achieving such inclusive diversity requires: a) establishing increased trust between researchers and communities; b) providing innovative and effective science communication; c) ensuring social equity and justice; and d) reinforcing, connecting, and create communities to build social capital. These efforts require paying special attention to individuals and populations that are currently and/or historically underrepresented.

Environmental Change

CoPe describes the convergence between dynamic social, economic, and environmental systems. These systems change through time as emergent states are shaped by the processes and conditions that come before them. Research in support of CoPe, therefore, must provide clarity toward understanding these complex dynamics and states, and inform responses to them. Sub-themes identified under environmental change include a) risk assessment, responses to changing coastal environments; b) understanding feedbacks at multiple scales; and c) extreme events and tipping points.

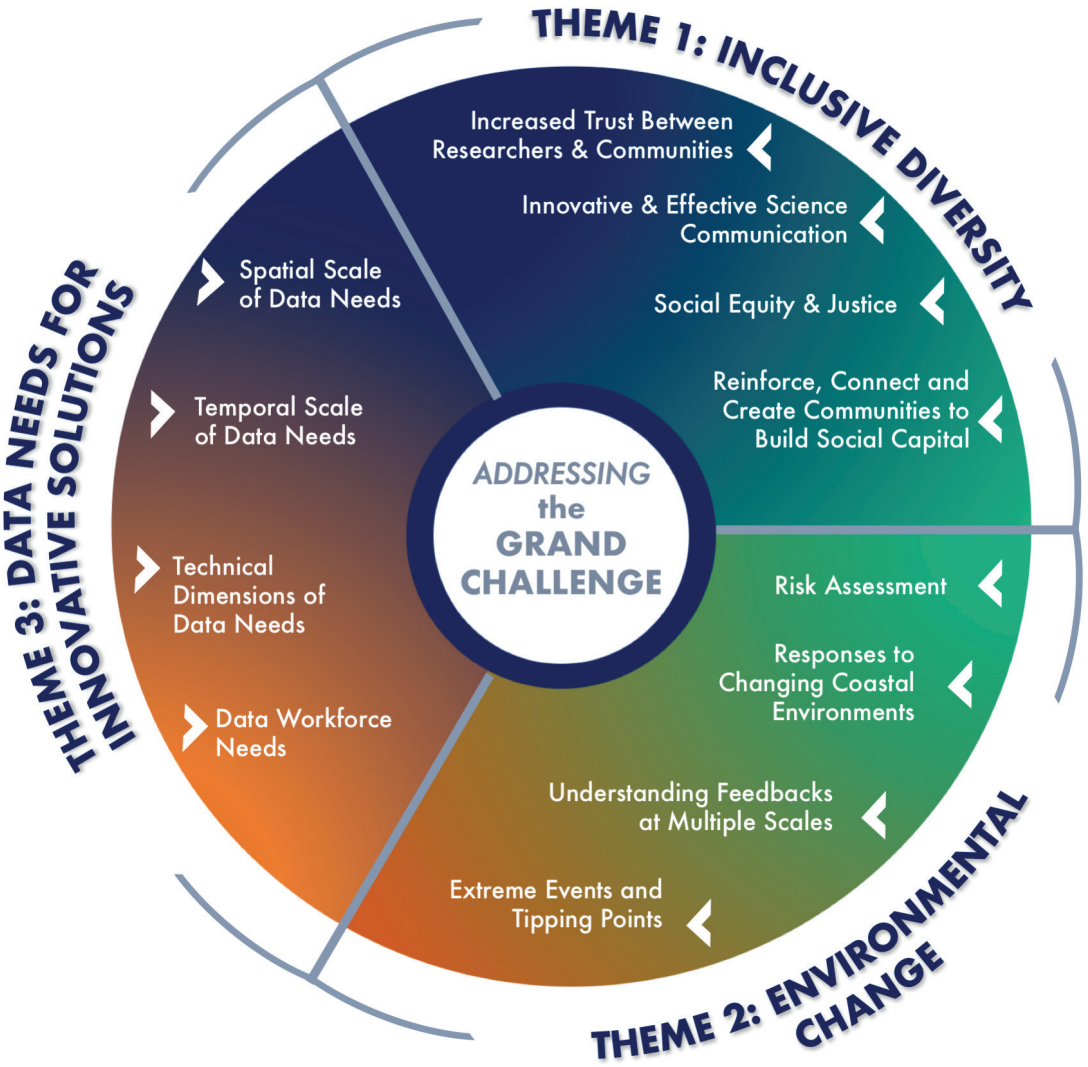

Figure 1: Major CoPe Themes

Data Needs for Innovative Solutions

Recognizing and representing the complexity of coastal systems, CoPe scoping session attendees identified a broad spectrum of data needed to understand fundamental coastal systems science, management and policy making, as well as community development and utilization. While data needs are significant, more data in and of itself does not necessarily translate to improved science or policy. Acquired data must be processed, analyzed, synthesized, and translated to customized output to serve the needs of varied stakeholders. Further, customizable data products must be flexible to meet changing demands of stakeholder-consumers, making continued communication and interaction with the data/science community an iterative process. Coordination and integration of the many observational data sets already being collected by agencies, communities, and academics requires new communication methods and data sharing techniques. Of paramount importance to the success of a CoPe initiative is the community-engaged prioritization of data gathering to meet immediate needs of coastal stakeholders as well as scientific needs. In a research landscape where co-production of knowledge occurs, data ownership and accessibility are important issues.

CoPe Framework

The proposed CoPe framework needs to stimulate connections that enable convergent approaches and development of locally relevant solutions. The framework also needs to be defined so that the research community understands the necessary elements for a CoPe project, as well as the flexibility that is intentionally built in to encourage discovery and innovation around the core intent of CoPe. The proposed CoPe Framework would ideally serve multiple roles, including as scientific observatories, places to build social networks and community around solving problems in constructive ways, and educational spaces with a focus on co-learning and co-production of knowledge.

The proposed CoPe framework should embrace the themes outlined above, with a focus on:

- Local coastal issue(s)
- Co-production of questions
- Inclusive diversity
- Convergence across natural, physical, and social sciences
- Data access and interoperability
- Fundamental research
- Actionable science

To have increased impact, the CoPe program must be far-reaching, holistic, and valuable in tackling relevant questions and problems. A clear message from the scoping sessions was that the way the CoPe framework is structured and how engagement is implemented, will shape how effectively results are translated into relevant, impactful solutions. The CoPe framework will require programmatic flexibility to provide the research infrastructure needed to conduct fundamental research and support actionable solutions related to the CoPe grand challenge. This can be built around a structure that allows for fundamental observations, research, and modeling; translation into actionable science; and training and capacity-building (see Figure 2).

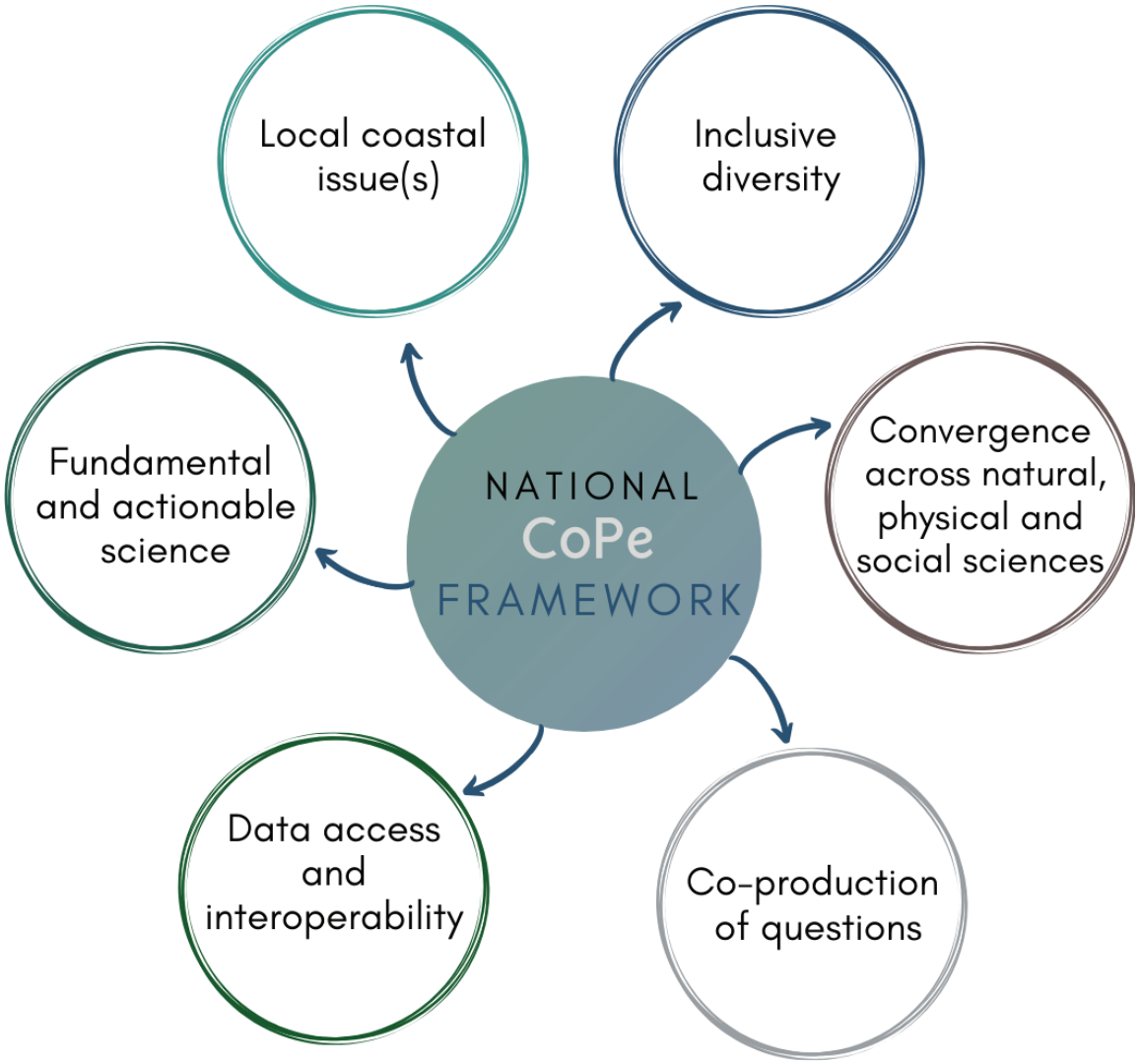

Figure 2: Potential CoPe Framework

Meeting Structure and Outcomes

1. Community Scoping Sessions

1.1. Attendees

To define mechanisms for pursuing CoPe's goals, the University Corporation for Atmospheric Research (UCAR) (https://www.cpaess.ucar.edu/) assembled over 400 scientists to develop ideas for CoPe implementation, via a grant from the National Science Foundation. UCAR posted an open call for applicants online, selecting a diverse group of participants to attend one of four scoping sessions (three- in-person and one virtual). Attendees were chosen to represent a diverse range of institution types, geographic locations, cultural backgrounds, ethnicities, genders, career stages, and disciplines. In September 2018, scoping sessions were convened in three cities (At-

lanta, Chicago, San Diego) and one virtual site. Scoping sessions were conducted over the same three days so that teams could report their work in sequence, based on their time zone, on the final day of the scoping session.

1.2 Goal

The stated goal of the scoping sessions was to *"imagine Coastal Research Hubs, structured using a convergent science approach, at the nexus between coastal sustainability, human dimensions, and coastal processes to transform understanding of interactions among natural, human-built, and social systems in coastal populated environments. Research Hubs could address issues operating at multiple scales, linking science, community involvement, broadening participation, and education into developing pathways to sustainability in changing coastal environments."* In addition, the attendees provided ideas on the data and research needed to address the CoPe grand challenge, as well as the research infrastructure required for the implementation of the CoPe initiative.

1.3 Results

Attendees at each scoping session formed small teams and prepared a three-minute presentation on the final day of the scoping sessions. In addition, each group prepared a short white paper to summarize their ideas. In total, over 100 white papers and presentations were generated from the four scoping sessions. All white papers and presentations are archived and available publicly from the CoPe internet portal (https://coastlinesandpeople.org).

2. CoPe Synthesis Group

In Spring 2019, a small group of twelve scoping session attendees representing diverse backgrounds, locations, and career stages, was selected to synthesize the results of the four scoping sessions. The charge to the group was to produce a synthesis report that provided a summary of the major takeaways from the white papers and presentations, as well as the community's suggestions for implementation of the CoPe initiative. Since all of the scoping session presentations and white papers are publicly available online, the report was meant to distill major themes and community recommendations that would help inform the CoPe initiative. The synthesis team met virtually in April 2019 to coordinate the plan for reviewing all of the CoPe session documents and for assembling the synthesis report. An initial draft report was discussed at an in-person meeting in June 2019, with another virtual meeting in early September 2019 to refine the report draft. The draft report was submitted to UCAR and NSF for comments on September 30, 2019. The final CoPe synthesis report is to be published by UCAR in early 2020.

3. Complex CoPe Grand Challenge

The overarching objective of the Coastlines and People (CoPe) initiative is to facilitate understanding of coastal systems by qualitatively and quantitatively characterizing and describing outcomes from interacting elements of the physical, chemical, biological, geological, and human spheres. The scoping session attendees all pointed to the complexity of the coastlines and people grand challenge, both from a scientific standpoint and from a program implementation and logistics perspective. The community emphasized the urgency of this grand challenge, as the human population

struggles to gain more complete understanding of coastal systems, while simultaneously coping with rapid and perhaps irreversible environmental change.

Since coastal systems link terrestrial and marine environments through shared and unique processes and phenomena, and are often characterized by urbanization, the resulting ecosystem has extraordinary complexity. The processes and phenomena in coastal systems interact as dynamic, non-linear systems via multiple positive and negative feedbacks, sometimes resulting in large material and energy fluxes. For example, interactions between the physical, ecological, and built environments can result in evolving (positive feedback) systems or stable (negative feedback) systems, , or in nonlinear tipping points, at which the system irreversibly changes. Coastal systems evolve on spatial and temporal scales spanning at least nine orders of magnitude (millimeters to thousands of kilometers; fractions of a second to millennia), while the human dimensions scale spatially and temporally from the individual (unit scale) through households, neighborhoods, towns/cities, county, state, and national entities. Furthermore, economic, political, cultural, and psychological responses to short-term storm impacts often lead to immediate recovery strategies that affect the long-term evolution and resilience of the coastal system. The complex mosaic of coastal environments—including but not limited to salt marshes, mangrove forests,

Figure 1: Major CoPe Themes

maritime forests, kelp forests, tidal flats, estuaries, coastal barriers, sandy beaches, fluvial deltas, rocky shores, coastal headlands, nearshore islands, coral reefs, protected bays, coastal plains, undeveloped wild shores and built environments—forms, perhaps, the most diverse ecosystem on Earth. In addition, the coastal community includes not only coastal system scientists (physical, biological, engineering, social), but also practitioners and other stakeholders (state, county, municipal authorities; coastal populations, etc.), adding to the logistical complexity of finding solutions to this grand challenge.

The Synthesis Group's review of the white papers identified three major themes, with multiple subthemes and research questions for each, as well as a number of CoPe implementation suggestions. These themes, presented in Figure 1 and described further below, are:

- Inclusive Diversity
- Environmental Change
- Data Needs for Innovative Solutions

4. Inclusive Diversity

Solving the grand challenge related to coastal environmental processes and system changes across multiple spatial and temporal scales requires an inclusive and new interdisciplinary, trans-academic research agenda, as well as a revised paradigm for developing and implementing that agenda in meaningful ways that enable the co-production of knowledge in service to society.

One hurdle to broadening engagement and inclusion identified by scoping session participants results from the existing top-down models of science to public engagement. Academic and funding institutions have set up clear guidelines and reward systems that make transdisciplinary, exploratory, or long-term research difficult, if not impossible. To overcome these institutional barriers, the CoPe initiative should incentivize new areas of research that capture the urgent questions and problems being faced by coastal communities today. The CoPe initiative needs to advance innovative approaches to actionable science and public engagement.

CoPe seeks to transform how coastal research priorities are identified, who is conducting the science, how science is communicated, how non-academic individuals and organizations participate in science, and how research and academic institutions judge the merits of research that strives for the co-production of knowledge in service to society. Specific sub-themes related to the theme of inclusive diversity are discussed in detail below and include increasing trust between researchers and communities; innovative and effective science communication; social equity and justice, and reinforcing, connecting, and creating communities to build social capital.

4.1. Increase Trust between Researchers and Communities

Community-identified research priorities and the co-production of knowledge. The concept of 'co-production' was ubiquitous throughout the white papers and scoping session presentations. Some of the elements under this sub-theme are also classified as 'science in service to society" and address how enabling scientists to be active listeners, responsive to community needs, can lead to creative knowledge produc-

tion and innovative solutions. While interdisciplinary research requires co-learning among disciplinary experts (typically inside academic institutions), trans-academic research requires engagement of disciplinary experts with individuals and institutions outside academic institutions. It should be noted that research questions co-developed with coastal managers may be different than those identified by stakeholders, but both have merit. Community teams will have to learn to discuss and prioritize potential solutions.

There was an emphasis on broadening participation in the scientific research agenda by incorporating community needs and priorities as a way to add to the societal relevance of the CoPe research agenda. Societal relevance, as mentioned throughout all the sessions, hinges on the concept of finding evidence-based solutions that incorporate and preserve cultural knowledge and ecological processes in the face of change while also ensuring equity, inclusivity, sustainability, and resilience.

One proposed approach for building institutional trust was having community-based associations, and not only universities, serve as grant recipients to help channel funds into the organizations that already have rapport with local stakeholders. This administrative arrangement would also facilitate greater community buy-in from the outset. Several session papers discussed co-production of knowledge as a central organizing feature to improve community engagement and centering of the program, data integration, and knowledge transfer through a non-centralized community-based participatory research hub, and creation of science advisory groups composed of researchers and community stakeholders to help set research agendas for CoPe.

Mentored community science to engage individuals and organizations outside of traditional research and academic institutions. It was also recommended that a national-level group should set standards of practice for engaging the public in data collection efforts. It is important that these community science projects follow best practices in both data collection, accessibility, and sharing to foster scientific discoveries for coastal communities.

Sustained engagement. The CoPe research agenda should support long-term community-engaged projects that create sustained relationships, build and maintain trust, create valuable outputs, and produce meaningful impact.

4.2. Innovative and Effective Science Communication

To broaden engagement, increase inclusion, and engage a greater diversity of the public into CoPe efforts, science communication needs to be reframed and imagined through the lenses of local and indigenous knowledge, various creative forms of expression, innovative pedagogical practices, and inclusion of bridging and boundary-spanning institutions and individuals. There is advantage and broad societal benefit to translating the language of science to the language(s) of different user communities.

Facilitate engagement. Attendees agreed that one role for the CoPe program would be training researchers and other stakeholders to improve their outreach and pub-

lic communication techniques, multi-disciplinary collaboration skills, collaborative decision-making skills, cultural competency, and ethical literacy, so they effectively create and participate in inclusive community-engaged research. Another potential CoPe contribution would be to implement diversity advisory boards that provide their unique perspectives on how best to engage diverse communities and be a central repository of coastal science information that is accessible to both scientists and non-scientists. CoPe would play an incubator role in defining, or refining, community questions, needs, and positions in a way that represents the diversity of disciplines, stakeholders, and decision-makers appropriate for a given region.

Connect science communication with the arts through creative forms of communication. CoPe engagement with the arts would expand audiences and reach new individuals and organizations outside the scientific research community and academic institutions. This involves leveraging successful communication and engagement methods already used by humanities organizations and creative artists, such as 'artists in residence' programs, public engagement around empathy-driven narratives and performance, and radically different tools for prototyping of coastline/people scenarios, such as science fiction writing. In addition, there was a call for CoPe to support the broader art community in efforts to reach out, educate, and inspire understanding of science, fragility of coastal systems and processes, and the importance of coastal systems, while creating awareness of sea-level rise impacts and actions. Art serves as a transdisciplinary bridge between different world views, by allowing for new and respectful ways of seeing and learning among scientific and non-scientific collaborators.

Partner with educators. Education (K to grey) was recognized across the sessions as playing an important role in all aspects of the CoPe agenda. Such partnering activities would take place through cross-generational outreach and education, cross-cultural mentoring, training of teachers, delivery of educational curriculum, and local community sessions. Education activities should include co-designing new curriculum and pedagogical formats for communicating CoPe research and outcomes to broader and more diverse audiences.

Support and collaborate with bridging and boundary-spanning individuals and institutions. CoPe should leverage existing avenues and resources already involved in community-based research and crafting of innovative and effective science communication messages and processes. Specifically, session participants encouraged engagement with boundary spanners, who are individuals or organizations that are skilled liaisons between science and local communities. Feedback of information and dialogue between science and community stakeholders is key to broadening participation and increasing diversity in community engagement, and there are existing individuals, institutions, organizations, and programs that can play this role.

4.3. Social Equity and Justice

When it comes to ensuring that social equity and justice are key aspects of inclusive diversity, there are four primary questions: *What is to be done? Who benefits? Who decides? And, what are the institutional barriers to equity, justice, and inclusion?* One specific idea was the development of CoPe hubs that increase capacity in under-

served and underrepresented communities that are vulnerable to coastal hazards. Issues of social equity must consider who will own community data, as well as who will be able to access data.

Compensate for participation. Compensation was seen as a way to ensure equity and justice, in addition to encouraging broader community engagement overall. Several papers specifically discussed incentivizing community partner relationships in solutions-oriented research projects through financial incentives or some form of giving back. One caveat was that care should be taken to carefully consider relevant incentives and currency differences across community members, collaborating scientists, and other stakeholders.

Address structural inequities. This sub-theme addresses the need for transformation within current research disciplines, academic institutions, and ways of communicating science to truly be able to implement science in service to society. It also requires a reevaluation of the types of research questions being asked, who is asking those questions, how those questions are formulated, and who is expected to answer those questions. There is the need to map out power differences in communities, particularly between scientists and non-scientists prior to conducting specific research projects. To understand the historical legacy of vulnerabilities in coastal communities, there is a need to examine the definition, creation, and reproduction of precarious communities (i.e., how vulnerable communities form and are perpetuated in societies). We also need to deconstruct existing structural barriers that suppress diversity within the academy and among academic partners and to build capacity for underserved and underrepresented communities to participate directly in scientific research.

Develop an inclusive STEM workforce. There was a strong call to address the structural barriers to diversity in STEM with a particular focus on the academy. In addition to considering indigenous and local knowledge as a central element in CoPe, participants also called for implementation of Diversity, Equity, Accessibility & Inclusion (DEAI) approaches that would significantly enhance workforce diversity across all dimensions.

- ***Incorporate equity metrics into merit review***. CoPe needs to develop merit review procedures that establish clear equity criteria and require that CoPe projects incorporate diversity and inclusion strategies holistically. In particular, CoPe should ensure meaningful stakeholder partnerships and the engagement of underserved communities that are particularly vulnerable to coastal environmental change. This would be implemented as part of proposal vetting, design and implementation of CoPe projects, or monitoring of progress.

- ***Support scientists outside of full-time academic practice***. There was a recognition that to support long-term engagement and participation by scientists in the CoPe agenda, especially with an overall emphasis on the co-production of knowledge (whether interdisciplinary or fully transdisciplinary), there must

be greater support for applied scientists, gig scientists, and those who have either had to leave STEM professions or those who have been underrepresented in STEM for various reasons. *Many of these scientists who have left or never entered full-time academic practice are women, people of color, immigrants, or individuals with disabilities.* One specific way participants proposed to do this was through a virtual network of short-term science consultants housed within a CoPe hub. Individual scientists would post their expertise to the network, and local communities, businesses, and academic labs would reach out for known research needs, with the hub essentially serving as a matchmaking service. In addition, ensuring that non-academic scientists are involved in CoPe will provide a network of professional mentors who not only fill in expertise gaps, but also work with students as they explore alternative career pathways.

4.4. Reinforce, Connect, and Create Communities to Build Social Capital

To enhance inclusive diversity, the CoPe initiative could build social networks within and between relevant scientific disciplines, coastal communities, and organizations, with special attention to individuals and populations that are currently and/or historically disenfranchised or underrepresented.

This effort would then lead to greater resiliency within coastal communities, as well as within the broader scientific community studying the grand challenge of coastal environmental processes and system changes and have a greater potential to lead to more useful outcomes for society. Sustainable and equitable solutions can only be achieved by fully integrating the opinions, perspectives, and worldviews of diverse stakeholders. This need for diverse network building and maintenance of those relationships requires a substantial time commitment, new ways of communicating, and a robust ethical framework. The CoPe program should act as a resource to provide training and support to scientists who may not yet have the skills, experience, or knowledge to engage in co-production of knowledge or community-engaged research.

Place-making. CoPe hubs would specifically serve as place-based exemplars of research to address national coastal problems. Creating a network of coastal centers would provide a community space for engagement with local issues through education, and serve as informal learning centers where physical space is dedicated to community learning and deep engagement with local issues that impact the coast and people.

Create online social networks and social media. In addition to place-making, establishing a system of virtual CoPe hubs would create a "coastal intelligence social network," that would be able to rapidly share, integrate, and synthesize information from existing multidisciplinary and cross-sector knowledge domains. Crowdsourcing would play an important role in identifying community-based projects and the co-production of knowledge and solutions within interdisciplinary and transdisciplinary teams.

5. Environmental Change

Coastlines and People (CoPe) describes the convergence between dynamic social, economic, and environmental systems. These systems change through time as emergent states are shaped by the processes and conditions which come before them. Research in support of CoPe, therefore, must provide clarity toward understanding these complex dynamics and states, and inform responses to them. Subthemes identified under environmental change include risk assessment, responses to changing coastal environments, understanding feedbacks at multiple scales, and extreme events and tipping points.

5.1. Risk Assessment

From a societal-economic standpoint, proposals identified a need to develop better vulnerability and risk-assessments of coastal communities. There is a need for advanced, comprehensive, or new risk assessment methods, such as predictive modelling. An overarching message here is that risk assessment methods supported by CoPe should connect to decision-making and use-value considerations, as well as socio-economic variability and outreach/education efforts. Long-term assessment of coastal vulnerability and resilience requires better understanding of linkages between human responses and future coastal risk. We also need to understand long-term or incremental environmental change (e.g. sea-level rise, weather patterns, extreme heat, air and water pollution), including the local/regional/global impacts, interactions with other processes/conditions/hazards, and far-field effects. There is a need for understanding extreme episodic events (e.g. earthquakes, tsunamis, tropical cyclones, flooding) and the impacts on the coasts, fisheries, human communities, and public health (including behavioral and cognitive changes). This need includes exploring the interactions between processes, conditions, and hazards, as well as understanding signals and predictability of individual hazards. Participants suggested developing and deploying new real-time sensors in support of models and datasets, forecasts, 'nowcasts', and management decisions. Many white papers focused on the dynamics of climate change as a global or multi-regional phenomenon. This goal was represented in potential research projects focused on mitigating climate change (e.g. carbon sequestration, economically viable renewable energy), as well as on research to understand risks and responses to geopolitical (in)stability.

5.2. Responses to Changing Coastal Environments

Long-term assessment of coastal vulnerability and resilience requires better understanding of linkages between human responses and future coastal risk under a variety of possible climate scenarios, including rising sea-level, intensifying storms, shoreward migrating coastlines, increasing high-precipitation events, etc. Simultaneously, there is a need to explore changing human perceptions and the impact on adaptation, as well as economic factors such as market dynamics, and changing coastal policy. There is a need to better understand and assess how people respond to changing coastal conditions, particularly through potential infrastructure developments and adaptation actions. This research would be specifically use-oriented, with application toward infrastructure development and realizing conceptual adaptation opportunities. Research and applications with high potential for scaling up at the community, regional, and national level should be identified when considering adaptation. There is also a need to assess performance of emerging infrastructure tech-

nologies compared with existing technologies (e.g., green infrastructure compared with grey infrastructure). Many papers cited a need for understanding performance as it relates to practical considerations that affect the ability to implement emerging technologies, such as reduced flooding, improved well-being, livability, economics, ability to recover following damage, etc. We also need to understand emerging adaptation and emergency response efforts, particularly the implications of adaptation actions and public perceptions surrounding adaptation.

5.3. Understanding Feedbacks at Multiple Scales

Coastlines are dynamic environments that support a wide range of ecosystem services, human infrastructure, and activities. Physical, ecological, and biological processes interact at many different spatial and temporal scales to impact the health and well-being of human and natural populations. As human activity and responses to coastal risk in turn affect geophysical and ecological processes, the coastal environment evolves through interactions between coastline dynamics, ecological dynamics, and socioeconomic processes. Physical and ecological processes occur at timescales ranging from hours to centuries, and over fine spatial scales to hundreds of kilometers. Human activity ranges from daily activity to policy responses that occur at decadal scales. Human activities cause future physical, chemical, and biological coastal change and thus produce two-way feedbacks; environmental change affects human behavior, and that behavior, in turn, influences environmental change. Also, human adaptation and mitigation at local scales affect coastal evolution at regional scales and over longer time frames. We need to understand how hazard mitigation impacts future habitability of coastal environments, as well as what thresholds trigger population retreat from coastlines. Equally important are the policies that regulate coastal developments and how those affect inequalities in coastal wealth and social justice.

Another common theme is the need to understand feedbacks at different spatial and temporal scales. This requires both empirical analysis and advances in modeling efforts to both explain observed patterns and predict future change. Beyond the need to advance knowledge in connecting local adaptation with regional and global outcomes, attendees highlighted the need to work closely with communities to both develop and inform research, and to produce actionable policy recommendations. To better understand the evolution of complex adaptive coastal systems, we need to examine interactions and feedbacks among many processes and over multiple scales. To identify and quantify key interactions occurring across this range of scales and how they may be represented in a hierarchy of models, collaborations need to be facilitated across broad-reaching disciplines to develop convergent approaches.

5.4. Extreme Events and Tipping Points

Extreme events and tipping points (when a system changes dramatically and irreversibly), especially in the context of climate change stressors, emerged as a common theme. Continuous long-term coastal change can create instability in the coastal system. However, these slow changes can remain hidden until observable change is triggered by a sudden perturbation to the system, such as a major storm event or policy change. Furthermore, extreme events often involve cross-discipline interactions that do not occur during more typical periods, and which can have lasting

effects. Short-term community responses to extreme events that do not consider the longer-term evolution may not benefit coastal resilience. Different types of extreme events, including a low probability large magnitude event or numerous sequential lower magnitude events, as well as an event with multiple hazards, can have different impacts on communities and lead to different responses and feedbacks.

Research is needed to understand interactions between physical and biogeochemical oceanic, atmospheric, and hydrologic systems, as well as feedbacks with social, economic, and political responses. An adaptive systems approach can help examine near-term investments in risk reduction that affect emergent dynamics in coastal systems. To understand the impact and response to extreme events there are critical data needs, including controlled experiments, that can inform coupled models, and eventually develop better response and adaptation/mitigation strategies. We also need historical data to inform understanding of anticipated future coastal change and inform decision makers.

6. Data Needs for Innovative Solutions

Recognizing and representing the complexity of coastal systems, CoPe scoping session attendees identified a broad spectrum of data needed to understand fundamental coastal systems science, management and policy making, as well as community development and utilization. Attendees also recognized that while data needs are significant, more data in and of itself does not necessarily translate to improved science or policy. Acquired data must be processed, analyzed, synthesized, and translated to customized output to serve the needs of varied stakeholders. For example, the individual seeking information and forecasts of surface ocean states for recreational boating requires different data products than the climate scientist investigating long-term regional wave projections. Further, customizable data products must be flexible to meet changing demands of stakeholder-consumers, making continued communication and interaction with the data/science communities an iterative process. Coordination and integration of the many observational data sets already being collected by agencies, communities, and academics requires new communication methods and data sharing techniques. Of paramount importance to the success of a CoPe initiative is the community-engaged prioritization of data gathering to meet immediate needs of coastal stakeholders as well as scientific needs. In a research landscape where co-production of knowledge occurs, data ownership and accessibility are important issues.

The summary of sub-themes below (and in Figure 1) provides an overview of strategies that scientists, practitioners, decision-makers, and managers may utilize for data acquisition, processing, synthesis, and translation with the varied stakeholders of coastlines.

6.1. Spatial Scale of Data Needs

Many white papers articulated the need for large quantities of environmental and social data across all spatial scales. However, spatial data needs within coastal systems are driven by the data requirements of the smallest spatial scale processes demanding the finest spatial resolution. Spatially dense multi-sensor arrays are a

means of maximizing data gathering for coastal environmental monitoring, modeling, management, and mitigation. Of particular value are nested arrays capable of up-scaling or down-scaling observations appropriate for monitoring of coastal environmental conditions and evolution. Ideally, such fine-resolution sensor arrays would be three-dimensional, encompassing the ocean, land, and atmosphere, and simultaneously gathering environmental data and telemetering data to data processing centers. Sensor arrays must include a high degree of interoperability and standardization to minimize post-collection recalibration or conversion. A majority of sensors should be sustainable over time so that long time series can be developed to monitor long-term environmental change and variability within coastal systems. Smaller-scale, shorter-term studies can then be conducted within this longer-term framework. Existing moored coastal ocean observing systems should be synchronized with increased utilization of unmanned autonomous systems across the ocean-land-atmosphere environs of coastal systems. The CoPe science community should also leverage emerging or underutilized technologies to provide sensors at lower costs without sacrificing data quality (precision and accuracy) and spatial resolution.

6.2. Temporal Scale of Data Needs

The temporal scales of coastal data needs that were identified by the CoPe science community are as daunting as the spatial scales. White papers detail temporal scales of measurement for various coastal processes from fractions of a second to millennia. Details of the temporal scales for specific coastal processes and the data needs to describe them were identified with a view toward defining strategies to improve coastal system science—monitoring, modeling, management, and mitigation.

One specific need identified by the CoPe session attendees was for detailed sensor arrays requiring very high temporal resolution for extremely long-term monitoring programs. A general categorization of temporal scales of variability and measurement includes short-term measurements and variability (fractions of seconds to diurnal rhythms); mid-term measurements and variability (weekly to annual process cycles); and long-term commitments to measure coastal system variability (over many years or decades). Measurements across all temporal scales are necessary to describe environmental variability, incremental environmental change, shifting baselines, or systemic tipping points. Construction of scalable models depends on fine temporal resolution sensor arrays that can aggregate data across multiple temporal scales. Specifically, sensor arrays are needed to gather data associated with a suite of event-driven coastal disturbances, such as various coastal hazards, changes in ocean chemistry, and toxic material mobilization within the coastal zone.

Another need is for rapidly deployable sensor arrays to monitor and evaluate coastal disturbance events. In some instances, these events occur without warning, whereas other events may be forecast hours, days, seasonally, or even years in advance. Deployment of sensor arrays in advance of disturbances would enable real-time, or near real-time tracking and measurement of the temporal evolution of such events. For example, pre-deployment of sensor arrays (e.g. airborne LIDAR systems) or teams of surveyors/scientists to make critical observations ahead of landfalling coastal storms would provide baseline data (e.g. coastal topographic data) useful for assessing post-event impacts and environmental changes, as well as data needed to

examine interactions and feedbacks during events. Increased data gathering from multiple sensor arrays deployed across air-sea-land will improve understanding of impacts from extreme events, and elucidate feedbacks with community systems and values particularly if event monitoring includes data gathering on socio-economic and socio-political parameters pre- and post-event. However, event-based data gathering also requires extraordinary strategic and tactical coordination among multiple federal, state, and municipal agencies, once more emphasizing the need for close and long-term associations of the coastal science community with relevant stakeholders.

6.3. Technical Dimensions of Data Needs

Foremost among technical recommendations were demands for interoperability of data gathering platforms and standardization of data formats to maximize interoperability across data clients. The operationalization of large sensor arrays across broad spatial and temporal scales also requires development and deployment of scalable arrays using inexpensive, mass-produced instruments. At least some sensor arrays should be mobile and able to be re-tasked to supplement data acquisition during coastal events. Event tracking, monitoring, and data gathering are crucial to improved forecasting and predictive models of natural disasters or anthropogenic disturbance events. Sensor arrays should also leverage advances in underutilized instrument platforms—such as drones and other unmanned autonomous systems—to augment observations derived from fixed sensor platforms. The CoPe science community envisions very large data flows emanating from massively deployed, high-resolution sensor arrays. These data flows (perhaps terabytes to petabytes) will require advances in data analytics, machine learning to assist managing and processing of data flows, and artificial intelligence (AI) to aid quality control and quality assurance of high data flows. Data needs should also leverage a variety of non-traditional data sources including traditional local knowledge, community systems such as traffic cameras, and public participants and mentored community science groups. Increasing dependence on digital data acquisition, data transmission, and data storage also requires large investments in safeguarding data networks, data integrity, and data security. Complexly integrated and networked sensor arrays, particularly those on which coastal communities rely for hazard forecasting, warnings, mitigation, and adaptation must have high reliability and sufficient redundancy to remain functional under adverse environmental conditions.

6.4. Data Workforce Needs

Establishment of massively deployed, multi-scale sensor arrays will require significant investment in development of human capacity to manage those sensor arrays. Society will need a highly trained, technically proficient workforce to effectively conduct the broad range of data acquisition, data processing, data synthesis, and data product development across coastal systems. Even with advances in machine learning and artificial intelligence (AI), a substantial workforce trained with skills in machine learning and AI will be required to realize the full potential of those applications. The technical workforce required to realize these data needs must be sufficiently large, well-trained, and dedicated to calibrate, deploy, retrieve, download, upload, maintain operational status, and understand nuances of sensors and sensor arrays to optimize data gathering and outcomes. There will need to be a significant investment to supply the capital, material, and human resources to support the train-

ing of a skilled workforce capable of conducting the proposed data gathering and data synthesis. Since this workforce is expected to span across educational institutions, federal agencies, state agencies, municipalities, private sector corporations, NGOs, consultants, etc., a national coordinated effort would be beneficial.

Further, the coastal science community will require training of boundary spanners capable of translating and ensuring dissemination of data into derived products, such as decision support tools, serving the needs of the many coastal stakeholders. Additional science education specialists with cultural competence will be needed to translate science to the varied coastal communities. Boundary spanners may be personnel engaged in the development of customized data products for distribution to various users within the coastal system or those engaged in community science efforts that will further support data collection.

7. CoPe Framework

The scoping session attendees and the synthesis group were asked to provide suggestions for developing a potential CoPe framework that would enable the research needed to address the grand challenge of resilient coastlines and people. The major themes and sub-themes discussed above point toward the complexity of coastal processes and human interactions, highlighting the need for convergence between physical sciences, social sciences, and local understandings. Support for research into these topics necessitates the formation of new relationships (across disciplines, sectors, agencies, etc.), with the exact team dependent on the specific research questions being addressed. The CoPe framework, therefore, needs to stimulate connections that enable convergent approaches and development of locally relevant solutions. The framework also needs to be defined so that the research community understands the necessary elements for a CoPe project, as well as the flexibility that is intentionally built in to encourage discovery and innovation around the core intent of CoPe. The proposed CoPe Framework would ideally serve multiple roles, including as scientific observatories, places to build social networks and community around solving problems in constructive ways, and educational spaces with a focus on co-learning and co-production of knowledge.

The proposed CoPe framework should embrace the themes outlined above, with a focus on:

- **Local coastal issue(s)**
- **Co-production of questions**
- **Inclusive diversity**
- **Convergence across natural, physical, and social sciences**
- **Data access and interoperability**
- **Fundamental research**
- **Actionable science**

Scoping session attendees emphasized the urgent needs for real-world problem solving, as well as basic research, in coastal communities. To have increased impact, the CoPe program must be far-reaching, holistic, and valuable in tackling relevant questions and problems. A clear message from the scoping sessions was that the way the CoPe framework is structured and how engagement is implemented, will

shape how effectively results are translated into relevant, impactful solutions. The CoPe framework will require programmatic flexibility to provide the research infrastructure needed to conduct fundamental research and support actionable solutions related to the CoPe grand challenge. This can be built around a structure that allows for fundamental observations, research, and modeling; translation into actionable science; and training and capacity-building (see Figure 2).

Suggestions for a CoPe Framework include the co-production of knowledge at local hubs, identification of data gaps and research needs, advances in technology and cyberinfrastructure, translation of research into action, funding structure, and a virtual national CoPe platform.

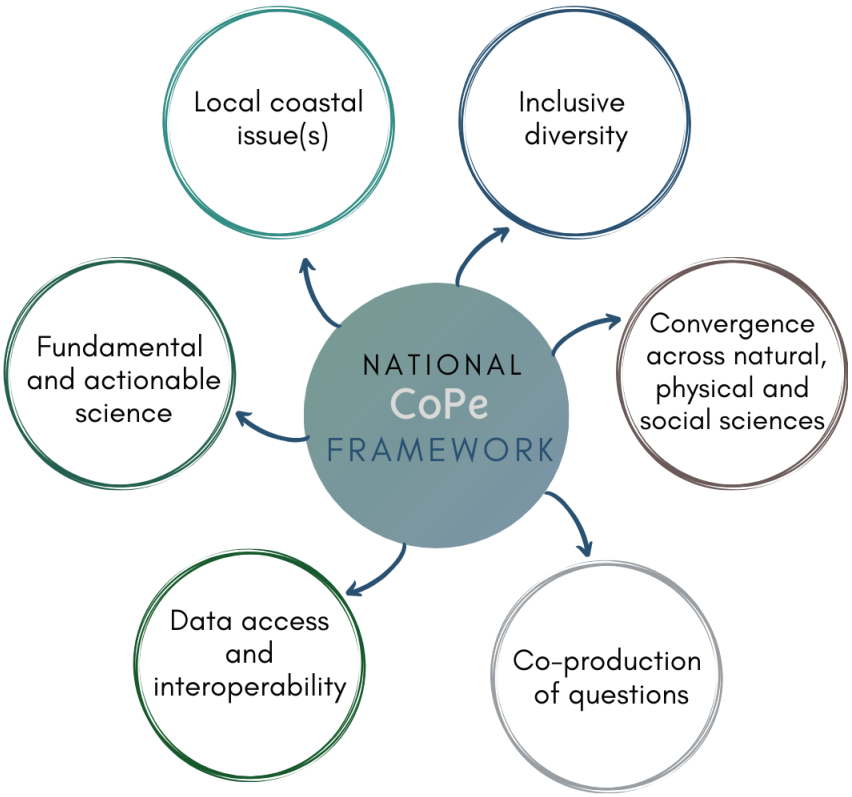

Figure 2: Potential CoPe Framework

7.1. Co-Production of Knowledge at Local Hubs

Local communities need to help identify prioritized research questions that must be answered to address their local coastal resiliency challenges, in partnership with researchers and practitioners. Collaborative partnerships are essential for understanding local coastal issues, developing research questions, and producing research that is meaningful to local communities. In a co-production context, local communities propose the coastal issue(s) that are most critical for their community to address

and the most critical questions that need to be answered. Early and continuous engagement with communities, from the development of research questions to communication of results is key, and will require researchers and practitioners with a knowledge of organizational systems and communication best practices. In addition, boundary spanners, such as social scientists and diversity specialists, who can talk speak among various audiences, are essential. It is important that the framework enables continuous learning across groups—local knowledge that shapes research and the communication of research discovery to local communities. Co-production should also take into consideration social justice and equity issues, with pathways for engaging with underrepresented communities. Building such partnerships requires a long-term commitment of both time and funding, which may require scaled implementation and multiple access points for full participation in the program. Because this model of research will be new to many excellent potential contributors from numerous disciplines, it is important to foster innovative ways to collaborate or provide collaborations with community engagement specialists. Each hub would connect to others in their region or across the country with similar local coastal issue(s). Individual hubs would be encouraged to build connections across multiple regions, enabling researchers to study coastal areas with contrasting environmental trends or responses to extreme events.

7.2. Identification of Data Gaps and Research Needs

The co-production of research with local communities, residents, scientists, and stakeholders, can drive the identification and prioritization of data needed to answer locally relevant research questions at each hub. Teams would be formed to identify relevant reliable data available from existing datasets, including state and federal agencies, universities, industry, NGOs, etc., and to determine data and research coverage gaps. Identifying resources and building capacity to fill critical data gaps should be prioritized. This would require convergence of data from many disciplines, including local knowledge, ecological, socio-economic, governance, cultural, heritage, etc. The novel feature of CoPe projects will be the creation of databases that enable this convergent research, and research teams that have the disciplinary diversity to enrich a research question with new combinations of data and analytical approaches to address specific issues of coastlines and people.

7.3. Advances in Technology and Cyberinfrastructure

Addressing the locally relevant community questions will require new data collection to augment what is currently available from existing coastal datasets. This effort will require development of new technologies, such as emerging low-cost sensor alternatives, use of drones for both air and water monitoring, as well as methods for rapid response data collection, including survey data to understand risk perceptions, behavioral responses and local adaptation efforts. Integrating community-mentored, citizen science into projects will provide opportunities to enhance existing datasets while building social capital and partnerships. Engaging local industry to support incubator hubs would facilitate co-production of research and advances in technology. In addition, emphasis will need to be placed on advancing data and modeling techniques to provide problem-solving assistance on spatial and temporal scales that are most important to community stakeholders. Integrating across multiple existing coastal datasets is needed for communities to derive locally relevant data interpretation. One major goal for the CoPe framework would be to develop a coastal data net-

work that is accessible, scalable, long-term, interoperable, and includes standardized and location-specific measurements.

7.4. Translation of Research into Action

The CoPe framework needs to enable researchers to answer fundamental questions, but also translate science into actionable solutions to local/regional coastal issues. This framework will increase the likelihood of both capturing relevant questions, as well as amplifying findings across the coastal community for greater impact. There was an emphasis on transdisciplinary team formation, since cultivating groups to work across disciplines leads to a greater likelihood of transformative and creative research. Coordination of multiple stakeholder types is essential, as is the creation of new types of partnerships (e.g. industry engagement, co-production models) and collaboration with federal agencies. There was also an emphasis on not reinventing the wheel, but connecting to existing initiatives at federal and state agencies, academic institutions, professional societies, NGOs. etc. One important outcome from the CoPe program would be leveraging existing efforts across the coastal community to synthesize case studies, best practices, and examples from ongoing efforts, as well as development of decision support tools for addressing coastal issues.

7.5. Funding Structure

Many session papers focused on the potential structure of CoPe funding. These included the suggestion that the program cultivate an incubation period necessary for building relationships and impact, such as via progressive timescales, tiered funding, demonstration projects, and iterative proposal opportunities. There was also emphasis on the need for long-term investment in a CoPe initiative since it takes time to develop teams, co-produce questions and knowledge, and implement actionable solutions.

7.6. Virtual National CoPe Platform

A successful CoPe framework would result in a national platform of hubs or observatories, linked through a virtual network. Local communities would be linked into regional hubs that coordinate data sharing and synthesis, disseminate best practices, training, and that create synthesis teams who bring together nationwide data to ask basic research questions. The network would facilitate information exchange and sharing of best practices across local communities and regions on resilient coastlines and people. The focus on engagement with underrepresented communities and co-production also creates a demand for training and facilitation at both the regional hub and national platform levels. Therefore, regional hubs would serve as outreach and education sites for the public and the future workforce. A virtual national platform linking regional hubs would require many technological and cyberinfrastructure advances, as mentioned above, for data interoperability and standardization. Establishing this national CoPe platform that provides mechanisms for convergence across multiple disciplines, sectors, stakeholders, communities, and regions would be a major advancement toward sustaining coastlines and people.

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