Convergence Accelerator Track Recommendation: "Nature-based Solutions for Sustainable and Equitable Coastal Communities"

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I. Executive Summary

Coastal ecosystems and communities are vital to planetary and human health, yet numerous environmental threats and human activities are undermining and will continue to undermine their sustainability. We convened diverse stakeholders from across the nation to discuss these challenges and the solutions to them, with particular emphasis on the value of nature-based solutions that can be implemented on short time scales with substantial impact. Our **Convergence Accelerator Track: Nature-based Solutions for Sustainable and Equitable Coastal Communities** was motivated by these conversations and the application of mental modeling and scenario analyses that identified existing barriers and potential catalysts for accelerating implementation of nature-based solutions. The team identified three ***Focal Areas*** (**Aquaculture**, **Connected Watersheds**, and **Sustainable Shorelines**) where convergent research will result in novel innovations that improve sustainability and four ***Enabling Tracks*** (**Cognitive and Social Science**, **Ecological and Geophysical Science and Engineering**, **Stakeholder Engagement**, and **Equity and Justice**) that define the transdisciplinary, convergent research domains that we think are essential for accelerating change in the coastal zone. A central finding of our analyses is that integrated research in the areas defined by our ***Enabling Tracks*** is absolutely essential to the rapid and impactful implementation of nature-based solutions to achieve sustainable coastal ecosystems and human communities. Key ***Deliverables*** identified by the team include **Best Practices**, **Decision Support Systems**, and **Demonstration Projects**.

II. Problem & Significance

Supporting 40% of the world's population and generating over 50% of global GDP, coastal ecosystems are among the most socio-economically valuable places on Earth. Yet, ongoing environmental change will continue to drive complex interactions between geophysical and socioecological systems that amplify threats facing coastal societies and their well-being. Major threats include inundation of coastal infrastructure by sea level rise and coastal storms, increasing intensification of watershed land use by expanding human populations, deteriorating coastal water quality, and the impacts of warming oceans on coastal fisheries and attendant consequences for food insecurity. Many past attempts to address these threats have failed to achieve sustainability and have perpetuated social inequality, in part because of limited engagement with diverse and often marginalized stakeholders. Moreover, applying best practices informed by current available science has been hampered by traditional disciplinary silos within academia, historical separation of fundamental from applied and translational science, and by barriers to effective two-way communication between academic researchers and local communities. The urgent need to address these challenges opens the door for opportunities that (1) move away from an entrenched and outdated perspective on the relationships between people and nature, (2) co-develop solutions that are environmentally sound, socially equitable, cognitively and politically plausible, and technologically feasible, and (3) promote creative financing solutions, innovative procurement processes, and streamlined permitting processes that facilitate and accelerate the implementation of nature-based solutions in coastal regions throughout the United States and beyond.

III. Convergence and Acceleration of Nature-based Solutions for Sustainable and Equitable Coastal Communities

The goal of the Convergence Accelerator program is to support convergent research activities that develop and rapidly implement (1-3 year time frame) solutions that benefit society. We propose an NSF Convergence Accelerator track on **Nature-based Solutions for Sustainable and Equitable Coastal Communities** to stimulate research that promotes the integration and implementation of pathways to potential sustainability solutions within and across coastal communities. The goals, pathways to potential solutions, and deliverables of this Track will resonate with the urgent global focus on coastal sustainability across multiple efforts including UN

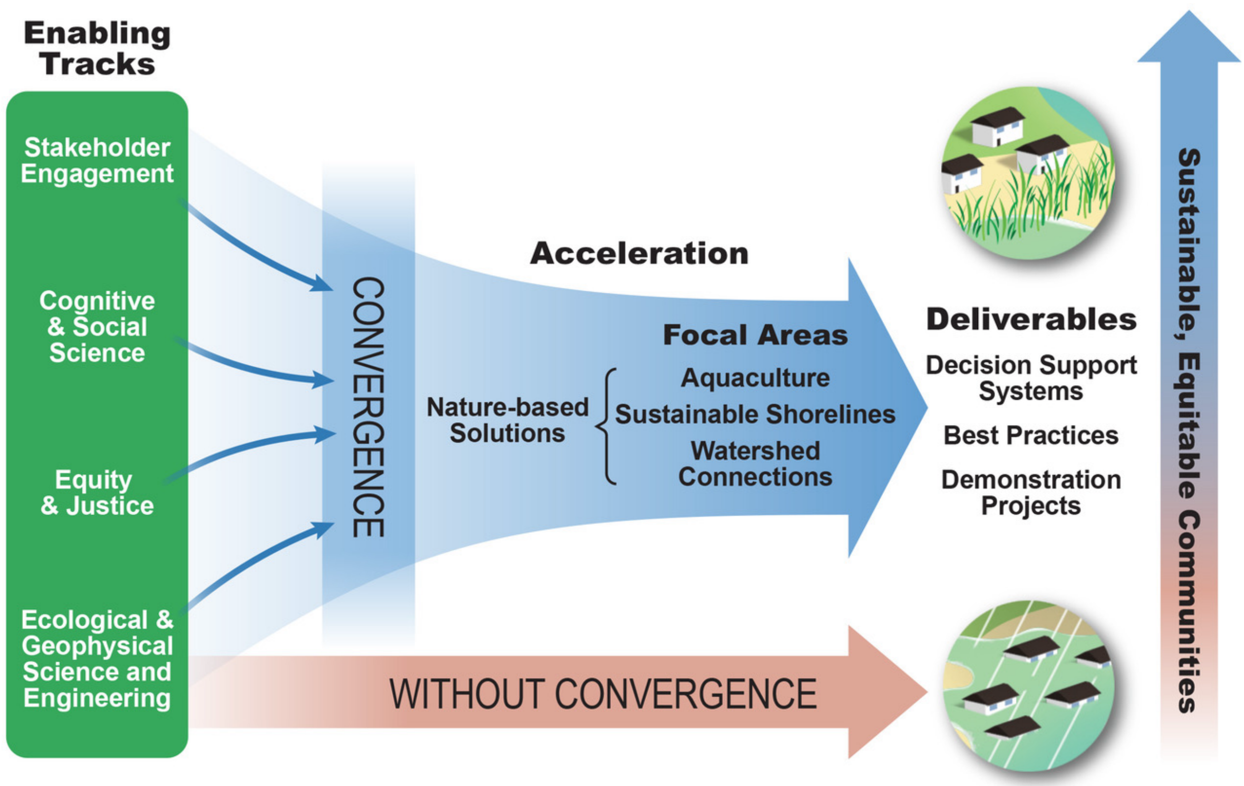

Figure 1. Key factors identified by workshop participants via Session discussions, mental modeling and scenario analyses that define the convergence across research domains essential to accelerating nature-based solutions and deliverables. The inability to solve current and future coastal sustainability challenges has been largely driven by the failure of ecological and geophysical science, and engineering, to (1) more fully engage stakeholders, (2) integrate cognitive and social science, and (3) address the persistent inequities that are amplified by current research approaches and solutions.

Sustainable Development Goals (SDG's), NSF's Coastlines and People (CoPe) program, the UN's Decade of the Ocean, NSF's 10 Big Ideas (e.g., INCLUDES and Rules of Life), NOAA's Adaptation Sciences (AdSci) and Effects of Sea Level Rise (ESLR) programs, ACoE's Engineering with Nature Program, and NFWF's Coastal Resilience Fund, among others. While each of these programs address fundamental science gaps (i.e., CoPe, AdSci) or focus on implementation (i.e., NFWF Coastal Resilience), what is lacking is a program that inclusively integrates convergent collaboration with key stakeholders and marginalized voices, adaptive implementation, and transdisciplinary science on nature-based solutions. Hence, knowledge and solutions emerging from the Nature-based Solutions track have the potential to (1) enhance the fundamental and translational research mission of multiple NSF programs, (2) stimulate substantial interagency collaboration and research investment, and (3) shape changes in communities of practice, policy, decision-making, and governance approaches necessary to equitably advance the sustainability of coastal communities.

To identify the catalysts and friction points that shape the viability and implementation of nature-based solutions, we invited diverse stakeholders from across the nation and from multiple sectors, who work across the land-sea interface on three ***Focal Areas:*** **Connected Watersheds**, **Sustainable Shorelines**, and **Aquaculture**. Across three sessions of the workshop, "*Coastal Sustainability: Clean, Safe, Smart and Equitable Communities*", we listened to a broad range of stakeholder groups, held focused conversations with discipline-based clusters of experts to identify areas ripe for convergence and acceleration, asked interdisciplinary groups to construct mental models (as detailed in Appendix A), and performed scenario analyses of interrelations among key concepts (as described in Appendix B). The overwhelming message was the same regardless of ***Focal Area***: friction points were driven by a lack of (1) effective stakeholder engagement, (2) integration of social and cognitive sciences with ecological and geophysical sciences, and (3) understanding of inequities perpetuated by historical decisions that have led to suboptimal solutions. Hence, we have identified four ***Enabling Tracks*** where convergent research will enable greater equity and sustainability in the coastal zone: **Cognitive and Social Science**, **Ecological and Geophysical Science and Engineering**, **Stakeholder Engagement**, and **Equity and Justice.** Taking a systems approach across these tracks that bridge natural and social sciences is essential to overcoming existing friction points and accelerating understanding and implementation of nature-based solutions that promote sustainable coastal communities. Together, ***Enabling Tracks*** and ***Focal Areas*** should yield tangible deliverables including **Decision Support Systems**, **Best Practices**, and **Demonstration Projects** that will accelerate adaptive learning and behavior change in support of more sustainable coastal communities. All deliverables should be co-developed with stakeholders and include equity and justice as foundational and measurable components.

Although a successful proposal could emphasize work in a single ***Focal Area*** (i.e., **Connected Watersheds**, **Sustainable Shorelines**, or **Aquaculture**), proposals that identify pathways that lead to sustainable solutions across some or all areas will be particularly competitive. Within their ***Focal Area***, proposals should integrate the ***Enabling Tracks*** (**Stakeholder Engagement**, **Cognitive and Social Science**, **Ecological and Geophysical Science and Engineering**, and **Equity and Justice**). As evidenced by workshop analyses, proposals integrating all four ***Enabling Tracks*** will be the most competitive, especially those emphasizing stakeholder engagement, and equity and justice. Moreover, the proposed research should produce at least one deliverable and an accompanying framework for evaluating the efficacy of the deliverable (s) to promote rapid and lasting change.

IV. Enabling Tracks

Cognitive and Social Science – A key outcome of these community deliberations is that robust sustainability solutions must ultimately consider the social, cultural and cognitive factors that individual and collective human actors bring to the table. Humans understand the world through conceptual constructs; internal representations of knowledge, beliefs, and experiences that simplify the complexity of the external world in ways that are manageable, consistent, and predictable. These representations have strengths, but can also result in cognitive biases and misconceptions that can perpetuate mistrust and amplify uncertainty in the viability of nature-based solutions. Our workshop highlighted that understanding the strengths and the weaknesses of human cognition, and the social and cultural contexts in which humans operate, is a necessary but often ignored component of successfully developing and deploying coastal sustainability solutions. Specific social and cognitive factors identified as relevant to coastal sustainability by workshop participants included: knowledge, conceptual organization (general & domain-specific causal-explanatory commitments), mental models and maps (e.g., GIS, social systems mapping) of local social-ecological systems, values, shared beliefs and culture, capacity and power dynamics, risk assessment, social norms, decision making, and communication (among disciplines within the scientific community as well as with stakeholders and community members). ***In sum, the convergence of cognitive, behavioral, and social science with expertise in areas such as anthropocentric thinking, causal reasoning under uncertainty, and situated systems thinking can accelerate strategies that overcome the cognitive and social structures that currently impede moving towards nature-based solutions.***

Ecological and Geophysical Science and Engineering – Coastal communities are increasingly confronted with geophysical hazards such as erosion, sea level rise, and storms that are amplified by climate and land use change. Unfortunately, societal responses to geophysical hazards (e.g., funding more gray infrastructure such as seawalls after a hurricane) often result in negative impacts on the functioning of ecosystems, thus impairing recovery from historical legacies of pollution, resource overharvesting, and extensive coastal development. These adverse impacts deteriorate the health, well-being, and economic vitality of human coastal communities, which in turn influences people's willingness to implement nature-based solutions. The difficulty of achieving sustainable solutions is amplified by uncertainty in how critical coastal habitats and ecological functioning will respond to future climate change, and in how social structures influence human willingness to adapt to those changes. ***Hence, to develop and implement pathways toward nature-based coastal sustainability solutions, we need convergent research that addresses key areas of uncertainty in ecological, geophysical, and engineering knowledge and how that uncertainty influences cognition and decision making, across a broad range of social settings.***

Stakeholder Engagement – Nature-based solutions seek to address climate risks in ways that improve people's health and well-being. Such solutions must be co-created in collaboration with diverse community members and integrate stakeholder values and needs in order to be successful. Early and sustained engagement is particularly important for groups that are often marginalized from the decision-making process. In the absence of such engagement, well-intentioned efforts such as urban "greening" can have severe socio-economic impacts on disadvantaged populations through indirect effects like "green gentrification". This risk is particularly relevant in the hidden coast – the non-oceanfront coastal regions where rural, minority, and impoverished communities reside, often in support of their more affluent neighbors. The limited connectivity between residents of the hidden coast and those involved in adaptation planning often results in approaches or solutions that fail to achieve long-term sustainability or to address social equity. Moreover, workshop participants identified that while positive steps are being made, the use of “loading dock” or “information deficit” models, where researchers simply aim to provide information to stakeholders unidirectionally rather than through co-development, remains a common path. Likewise, there is a need to identify strategies to ensure that the science being conducted is directly informed by stakeholder needs. Research must take concrete steps to broaden participation both among the stakeholders engaged in coastal sustainability research and within the educational efforts that are developing the next generation of coastal sustainability researchers and advocates. ***To achieve broad convergence, nature-based solutions to coastal challenges must be co-developed with stakeholders that represent the full range of relevant constituents.***

Equity and Justice – A framework that explicitly includes equity and justice is essential to successfully meeting the multi-faceted challenges that arise in coastal communities in response to climate change, because marginalized communities face the greatest risk. However, projects focused on nature-based solutions are rarely developed or evaluated using social metrics, precluding an assessment of their effects on social equity and justice. In fact, recent analyses show that habitat restoration efforts in the U.S. are positively correlated with county-level GDP per-capita, suggesting that we currently do a poor job of equitably aligning nature-based investments with societal needs. This inequitable distribution is amplified by the lack of representation of indigenous peoples and marginalized communities of the hidden coast in the climate adaptation and resilience process mentioned above. A recent Presidential Executive Order (13985) requires each agency to assess whether, and to what extent, its programs and policies perpetuate systemic barriers to opportunities and benefits for people of color and other underserved groups, with the goal of developing policies and programs that deliver resources and benefits equitably to all. While it remains unclear how this order will be operationalized in the context of nature-based solutions, it provides a critically important opportunity for cross-agency collaboration to prioritize equity and justice for coastal communities. ***To solve the challenges facing coastal communities, researchers need to incorporate an equity and justice perspective into the prioritization, development, implementation, and sustained assessment of nature-based solutions.***

V. Focal Areas

Aquaculture – Aquaculture is the fastest growing food production system globally and is key to increasing domestic food production, addressing the $14 billion U.S. seafood trade deficit, and enhancing coastal economies. Yet aquaculture growth is dominated by China, which accounts for 60% of global production. In addition to providing local economic growth and sustainable seafood, evidence indicates that shellfish and more integrated forms of multi-trophic aquaculture can provide valuable ecosystem services, including improved water quality and habitat provisioning for economically important finfish species. For example, the nature-based restoration of oyster reefs and marshes in the Gulf of Mexico could prevent $50 Billion in storm and climate change related damages by 2050. Despite these benefits, significant barriers to coastal aquaculture expansion remain, including a wide range of perceptions held by the general public, the lack of investment in securing the “social contract” for more sustainable forms of aquaculture, and a growing list of regulatory challenges during the permitting process, particularly in coastal communities where land values are increasing dramatically. ***Convergent research is urgently needed to understand how human cognition, technological innovation, and enhancement of ecosystem health and services can be leveraged in a socially just way to overcome real and perceived barriers and accelerate the implementation of sustainable aquaculture across the country.***

Watershed Connections – The ecological and geophysical processes operating across watersheds are intricately linked to water quality and the health of coastal ecosystems. Yet, these connections remain poorly understood to many who live, work, and play within these systems. Moreover, there are substantial disconnects between stakeholders (e.g., upland vs. near-coast) in terms of how their perception and understanding (cognitive and social) of landscape processes (e.g., surface vs. groundwater) and where they derive their ecosystem services (estuary vs. freshwater), affect decision making. Moreover, recent work shows that upland communities receive some of the greatest benefit from wetland management downstream. Discussion and implementation of nature-based solutions must therefore connect with watershed management and land-use planning that integrates protection strategies, and with the concerns and perceptions of residents living distant from shorelines, particularly among the impoverished residents of the hidden coast. Connecting the perspectives of urban planners and designers with expertise from engineering (hydrology), water quality and ecology, geophysical sciences, and social justice and equity organizations can inform how decisions made in upland systems adversely impact coastal communities (and vice versa), and how these impacts can be mitigated with nature-based solutions. ***Hence, convergent research that combines expertise in ecology, geophysical science and engineering with cognitive and social science will accelerate the implementation of solutions at the landscape scale that extend beyond the land-sea margin, thus positively impacting communities and resources across coastal watersheds.***

Sustainable Shorelines – Sustainable shorelines consist of nature-based solutions that address coastal hazards such as erosion and storm flooding while also maximizing ecosystem health. Over the past two decades, scientific, public, political, and private-sector interest in one key component of sustainable shorelines, living shorelines, has increased dramatically; yet, for a variety of reasons, implementation has been slow and patchy at best. Despite private-sector innovation yielding commercially available living shoreline designs, the release of Nationwide Permit 54 by the U.S. Army Corps of Engineers, and several federal funding mechanisms for living shorelines (e.g., FEMA's BRIC program, the NFWF Coastal Resilience Fund), choosing between living shorelines and traditional armoring still comes down to individual decisions by local communities, private landowners, and resource managers. These decisions are complex and require a high degree of mediation and communication skills weighing the trade-offs of various options across spatial scales and diverse social, cognitive, ecological, and economic contexts. ***Hence, convergent research must inform the development of blueprints for acceleration by building on case studies in diverse communities that have successfully navigated these challenges.***

VI. Deliverables Sub-tracks Leading to Implementation of Nature-based Solutions

Best Practices – As noted above, stakeholder engagement and equity/justice are critical to efforts to achieve coastal sustainability, and the convergence of these efforts with social/cognitive science, and ecological and geophysical science and engineering is what defines the novelty of this Convergence Accelerator track. Recent commitments to engage marginalized communities and evaluate equity, including the recent Presidential Executive Order 13985, are important, yet they do not provide a clear pathway for practitioners to achieve these goals. Best practices, including the development of both human capital and tangible products that provide concrete, implementable steps for equitable co-creation and evaluation of nature-based solutions, combined with technical guidance for project design, will accelerate coastal sustainability. Moreover, case studies illustrating practices that didn't work as expected, and adaptive management processes that include stakeholder engagement and communications are especially needed. Finally, cross-agency collaboration and integration are needed to allow prioritization of projects that have multiple, significant benefits for diverse groups of people rather than focusing on any single benefit to a more narrowly defined (and often affluent) population. For example, integrative designs for gray and green infrastructure projects within a watershed may achieve larger ecosystem and social goals, but cost-benefit analyses (typically conducted separately for individual projects) are unlikely to advance projects to construction.

Decision Support Systems – An issue repeatedly identified by workshop participants is that a plethora of decision support tools exist but uptake rates by stakeholders, and thus their effectiveness, remains low. Several barriers to implementation were identified. First, decision support tools that enable the design, prioritization, and implementation of nature-based solutions are often not co-developed with end-users, and thus may be incorrectly focused or are applied at the wrong scales. Similarly, "generic" tools seldom work, and best practices that are often considered "best" may be highly site-specific and not applicable elsewhere. First, decision support systems need to be mapped and understood to better see how the relevant governance system operates. Second they must be sufficiently flexible to account for the idiosyncrasies of any particular location or context. Third, end-users are almost always band-width limited, and training, education, and other mechanisms that soften the learning curve for a particular tool or sets of tools that are embedded in the decision support system are needed. Finally, multiple federal, state and local agencies produce decision support systems but these frequently lack integration across agencies, thus making it difficult for stakeholders to use more than one system. This last point highlights the need for better integration across federal agencies (e.g., NSF, NOAA and NASA) in developing tools that can be used by coastal managers and decision-makers as part of a decision-support system that can be customized to local needs, yet be sufficiently broad and flexible to avoid "reinventing the wheel" for each specific case study.

Demonstration Projects of Nature-based Solutions – The private sector (e.g., engineering and architecture firms) and several mission-oriented agencies, including The World Bank, NOAA, ACoE, and USFWS, are increasingly funding and implementing nature-based solutions for coastal protection. Most recently, in September 2020, FEMA took a big step to encourage communities to use nature-based solutions for flood hazard protection. The new policy (FP-108-024-02) revises the benefit-cost analysis used to evaluate state-submitted Hazard Mitigation Assistance (HMA) grant applications to allow all projects to include their environmental and social benefits, in addition to flood protection. The update acknowledges the important role that the natural environment plays in a community's resilience and allows applicants to demonstrate the effectiveness of nature-based approaches, such as floodplain restoration and expansion in flood protection. Because FEMA bases their strategies around established precedent and only a very small (~3%) fraction of funds have historically gone to nature-based solutions, there is a significant need to develop demonstration projects that establish precedent for successful implementation of nature-based solutions that will propel future funding under the new policy. However, a lack of convergent, interdisciplinary science approaches for designing and evaluating these demonstration projects has precluded the acceleration of successful implementation. There is an excellent opportunity for collaborations across cognitive and social science, ecological and geophysical science and engineering, stakeholder engagement, and equity and justice to advance our understanding of nature-based solutions, and to effectively demonstrate their utility through robust demonstration projects that will rapidly accelerate their implementation. We envision integrative and scalable nature-based demonstration projects that involve direct collaborations among academic researchers, practitioners, and diverse local communities.

VII. Conclusion

Coastal ecosystems and communities are vital to planetary and human health, but are threatened by complex environmental threats and human activities that continue to undermine their sustainability. The complexity and urgency of these threats demand responses that are timely and informed by cross-disciplinary cooperation. To discuss these challenges and potential solutions, we convened diverse stakeholders from across the nation, with particular emphasis on nature-based solutions that can be implemented on short time scales with substantial impact. Based on listening to a broad community of stakeholders, focusing groups of experts within a range of relevant disciplines, and documenting mental models of cross-disciplinary groups of experts, our **Convergence Accelerator Track: Nature-based Solutions for Sustainable and Equitable Coastal Communities** identified existing barriers and potential catalysts for accelerating implementation of nature-based solutions. Based on intensive deliberation both within and across academic disciplines and stakeholder groups, we specified three ***Focal Areas*** (**Aquaculture**, **Connected Watersheds**, and **Sustainable Shorelines**) where convergent research will result in novel innovations that improve sustainability. We also identified four ***Enabling Tracks*** (**Cognitive and Social Science**, **Ecological and Geophysical Science and Engineering**, **Stakeholder Engagement**, and **Equity and Justice**) that represent essential areas that need to be represented in any successful effort to accelerate convergence on nature-based solutions to the complex threats standing in the way of coastal sustainability. Key ***Deliverables*** identified by the team include **Best Practices**, **Decision Support Systems**, and **Demonstration Projects**.

In sum, the qualitative and quantitative results of three days of cross-disciplinary workshops make it clear that we need proposals exploring the integration of **Cognitive and Social Science**, **Ecological and Geophysical Science and Engineering**, **Stakeholder Engagement**, and **Equity and Justice** as applied to **Aquaculture**, **Connected Watersheds**, or **Sustainable Shorelines** in order to enable the rapid and impactful implementation of nature-based solutions to achieve sustainable coastal ecosystems and human communities.

Appendix A. Summary of Workshops

The workshops were designed and facilitated in collaboration with Knowinnovation Inc. (hereafter KI). A collaboration platform, called KIStorm, served as the central hub for all registration, pre-reading, in-workshop idea capture and collaboration, and all asynchronous activity that happened between the scheduled session times. All zoom meetings were coordinated and driven via KIStorm. Project management for the event was led by KI, with weekly meetings between KI and the organizing team to ensure the best opportunity for the participant community to bring their issues and expertise to the table.

The CA event consisted of three scheduled workshop sessions. Each session commenced with a brief reminder from NSF of the objectives and scope of the Convergence Accelerator Program.

Session I, Listening to Stakeholders: This session focused on engagement with diverse stakeholders to learn about their needs and concerns, with the ultimate goal of identifying barriers/friction points associated with the implementation of nature-based solutions and how variation in such barriers is shaped by stakeholder and community context. The focus was for the community to discuss, identify, and capture "challenges"; challenges that stand in the way of coastal sustainability. All challenges that the participants identified were written by them on virtual Post It Notes on the KIstorm site. The session consisted of 3 breakout sessions:

- In similar discipline groups
- In multi-disciplinary groups
- Looking at the challenges through a lens defined by a specific Focal Area

Following this session, and in advance of the next, participants were invited to prioritize the challenges by voting (10 votes per person). From this voting, the PI's/organizers were able to identify 7 specific themes that fed into Session II:

- Watershed Connections
- Aquaculture
- Cognition
- Data
- Decision Support
- Sustainable Shorelines
- Stakeholders

Session II, Consolidation and Refinement: This session convened a more focused group of stakeholders and scientists to facilitate a deeper dive on the major themes identified during Session I. The PIs presented the themes that had emerged from Session I to the participants, who endorsed them. Participants then self-selected into themes for further work.

Each theme had an associated Google document embedded with prompts that could be used as a foundation for discussion and collaboration by the breakout groups. The key purpose of this exercise was to more clearly identify challenges that are ripe for convergence and acceleration. After the initial work of completing the templated document, each group gave a brief report back to the full community on their decisions. This then enabled the full community to comment and leave feedback (via KIStorm Post It Notes) on each of the group's work, ensuring everyone in the community had an opportunity to have their voice heard in all of the themes.

From the emerging documents, the organizing team decided to explore the interdependent complexity of all the themes with a visually orientated systems modeler; “Mental Modeler”.

Session III, Mental Modeling: In Session III, we conducted a group modeling activity that involved using fuzzy cognitive mapping (FCM) to build conceptual models around the three themes or “lenses” of nature-based solutions: sustainable aquaculture, shorelines, and watersheds. We started with a base model containing 16 key concepts that were identified and refined during Sessions I and II (Figure A-1).

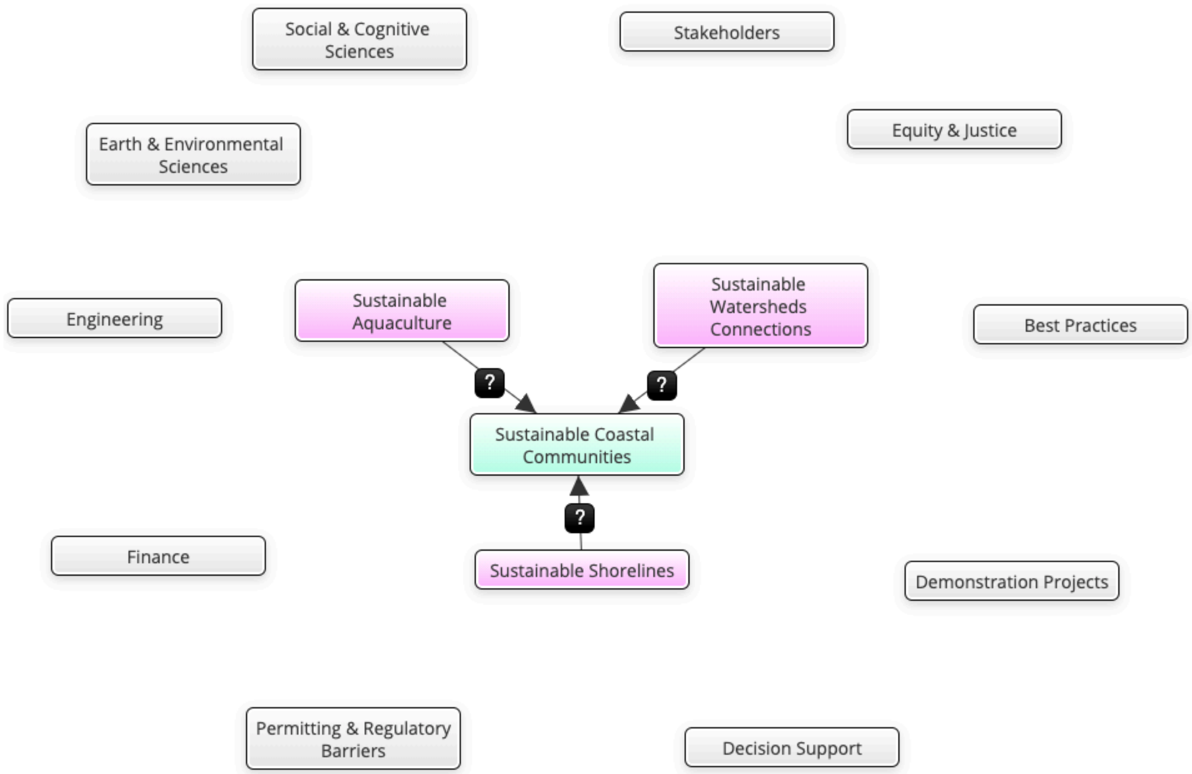

Figure A-1. Image of the base model used in Session III’s collaborative modeling activities.

Participants were split into 5 breakout groups (of mixed disciplines and expertise, see Appendix C), each led by an expert in the Mental Modeler software, and supported by a note-taker to capture the nuance of discussion in those breakout sessions. Each group was tasked with the same job of creating a systems map by assigning directional, weighted arrows representing causal relationships among concepts and themes, thereby identifying positive (catalysts) and negative (friction points) impacts on nature-based solutions to coastal sustainability. In a second breakout session, each group continued refining their models, assigned measures of scientific confidence to each relationship, and added notes summarizing the discussion on the context of each relationship. After the second breakout, all groups reported on their group’s model and focused on identifying friction points limiting convergence or acceleration of nature-based solutions.

We conducted a series of analyses on the models produced by the workshop. First, we evaluated the structural characteristics of the 5 group models including the number of concepts and connections, density, concept type (i.e., driver, receiver, ordinary), and model complexity. The five independent models were then merged into a mean model that was used in subsequent centrality and scenario analyses to identify areas ripe for convergence and acceleration (Figure A-2).

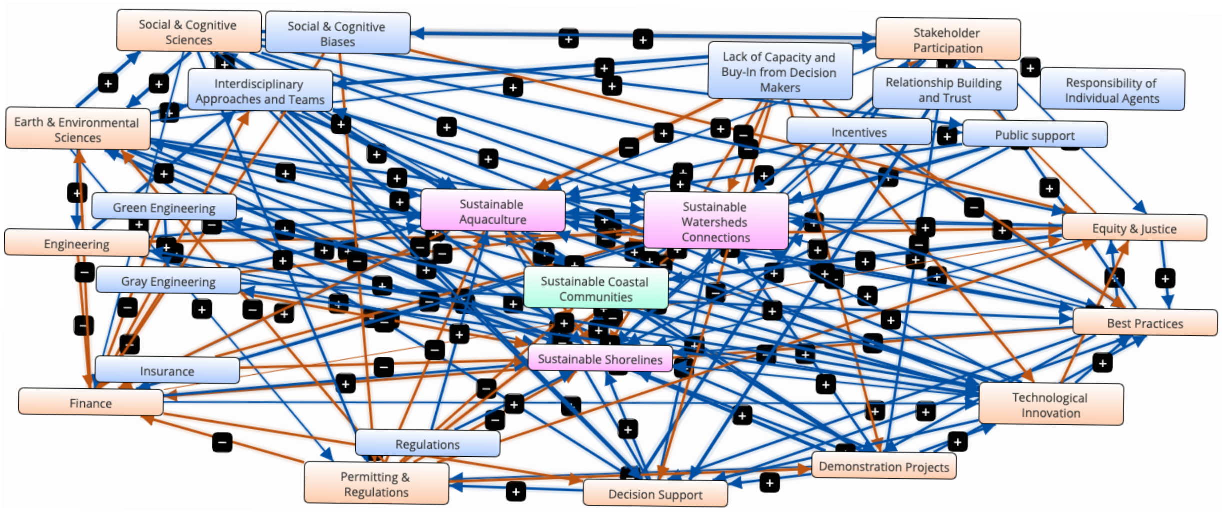

Figure A-2. Overall model of key concepts and relationships associated with nature-based solutions. This model was produced by aggregating the individual models of 5 groups that were stratified by interest and expertise in Session III.

This unique approach yielded graphical representations of interdisciplinary consensus on qualitative and quantitative relationships among the key themes. A few key findings of this session were as follows (for more details see Appendix B):

1) status-quo technological innovation does not benefit nature-based solutions and in contrast leads to negative impacts on equity and justice,

2) promoting equity and justice requires broadening stakeholder participation but is only effective when coupled with increased emphasis on social and cognitive sciences,

3) demonstration projects that are underpinned by interdisciplinary science and effectively navigate policy landscapes are promising pathways for promoting nature-based solutions.

Appendix B. Results and Implications of Collaborative Modeling Workshop

Characteristics of Group Models: Each of the five groups successfully produced collaborative models of the complex relationships, including catalysts and friction points, associated with nature-based solutions (Figure B-1). However, the specific relationships within each group's model were quite variable. For instance, the total number of concepts included in group models ranged from 15, largely representative of the base map, up to 21 (Table B-1). Additional concepts were added by groups in three general ways. First, some groups split apart multiple-item concepts, such as separating "Permitting and Regulations" into "Permitting" and "Regulations", as well as adding new concepts not included in the base map. Second, some groups added more refined versions of base model concepts to differentiate positive versus negative influences, such as modifying "Engineering" into "Green Engineering" and "Gray Engineering". Finally, several groups added new concepts that were not reflected in the base maps, including "Public Support", "Incentives", "Insurance", and "Lack of Capacity and Buy-in from Decision Makers".

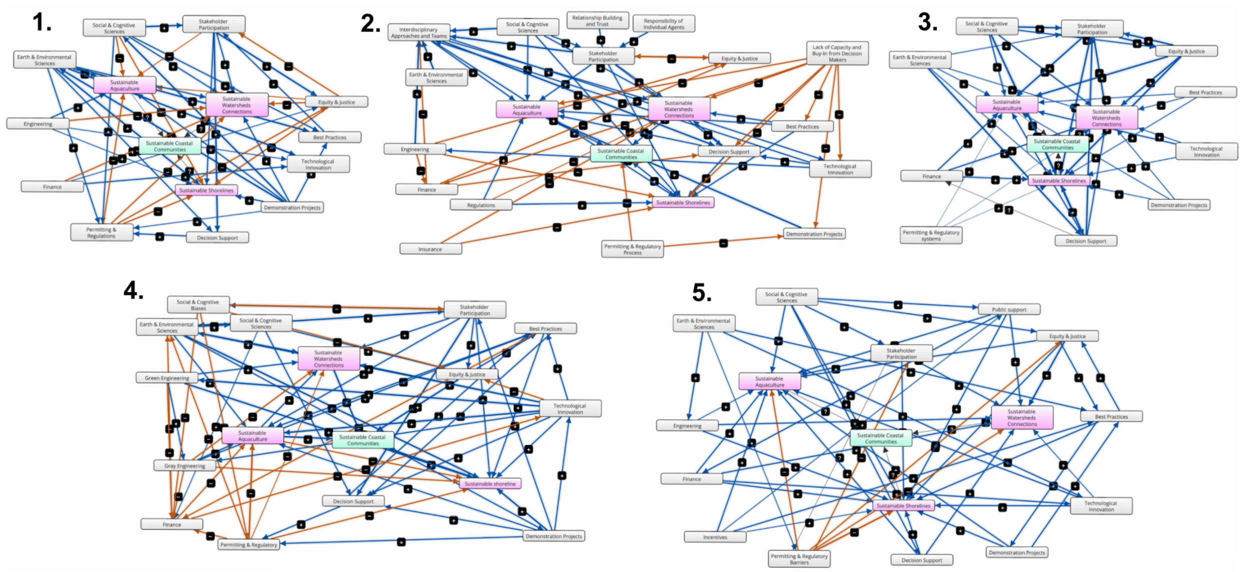

Figure B-1. Final models developed by each group in Session III.

Similar to the overall number of concepts, the number and nature of connections and density of models also varied across groups (Table B-1). The most common Drivers were Earth and Environmental Sciences (n = 3 groups), Social and Cognitive Sciences (n = 3), Permitting and Regulations (n = 2), Finance (n = 2), and Demonstration Projects (n = 2). In general, Permitting and Regulations were perceived as negative influences, or friction points, while Demonstration Projects and the natural and social sciences were positively viewed as catalysts for nature-based solutions.

To identify the most prevalent relationships across groups, we created a similarity matrix of all possible relationships among model concepts (Figure B-2). The three nature-based solutions lenses of Sustainable Aquaculture, Sustainable Shorelines, and Sustainable Watersheds were the most prevalent receiving concepts with Demonstration Projects, Permitting and Regulations, and Stakeholder Participation the most common direct drivers. Similar to the pattern for overall network structure, Demonstration Projects and Stakeholder Participation were most often viewed as positive influences or catalysts, while Permitting and Regulations was typically perceived as a

Table B-1. Summary of model structure characteristics across all 5 groups from Session III.

	Group 1	Group 2	Group 3	Group 4	Group 5
N Concepts	15	21	15	17	17
N Connections	45	55	42	65	53
Density	0.214	0.131	0.2	0.249	0.195
# Drivers	3	8	7	0	3
# Receivers	4	1	3	1	3
# Ordinary	7	12	3	16	10
Complexity	1.333	0.125	0.429	Infinity	1

Driving Concept

Receiving Concept		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Best Practices	1		1	2	2		2		1		1			1							1						1
Decision Support	2	1		1	2			1					1	1							3	3					2
Demonstration Projects	3	1			1									1	1												
Earth & Environmental Sciences	4			1				1							1						1						1
Engineering	5				1																						1
Equity & Justice	6	1				1		2							2					1	3	4					1
Finance	7	1				1			1	1				1	1	1				1	1						
Gray Engineering	8									1																	1
Green Engineering	9																										1
Incentives	10																										
Insurance	11																										
Interdisciplinary Approaches and Teams	12				1	1		1													1	1					1
Lack of Capacity and Buy-In from Decision Makers	13																										
Permitting & Regulations	14		2	2	2															1	1	1					
Public support	15										1										1						
Regulations	16																										
Relationship Building and Trust	17																										
Responsibility of Individual Agents	18																										
Social & Cognitive Biases	19																					1					
Social & Cognitive Sciences	20			1	1																						
Stakeholder Participation	21	1	1	1	1		3								1			1	1	1	5						
Sustainable Aquaculture	22	3	3	5	3	2	3	3	1		1		1	1	4	1	1				4	5					3
Sustainable Coastal Communities	23						1								1								3		3	3	
Sustainable Shorelines	24	4	3	4	3	3	3	2	1	1	1	1	1	1	4	1	1				4	5	1				3
Sustainable Watersheds Connections	25	2	3	2	3	2	3	3	1	1		1	1	1	4	1	1				3	5	1				3
Technological Innovation	26			1	2	1		3					1	1													

Figure B-2. Matrix showing the prevalence of pairwise relationships among all concepts. Darker colors represent more common relationships with numbers representing the number of groups out of 5.

negative influence or friction point. Notably, however, group discussions often suggested that permitting and regulatory hurdles were not necessarily rigid barriers so much as complex landscapes that could often be successfully navigated with knowledge and expertise.

As a measure of overall importance of each concept within models, we calculated the average degree centrality. Degree centrality (hereafter, centrality) is the summed absolute value of all edge weights. In addition to the three nature-based solutions lenses, which had high centrality in part due to their focal position in our conceptual model and interview approach, the concepts with the highest centrality were Earth & Environmental Sciences, Stakeholder Participation, Best Practices, Decision Support, and Social and Cognitive Sciences (Figure B-3).

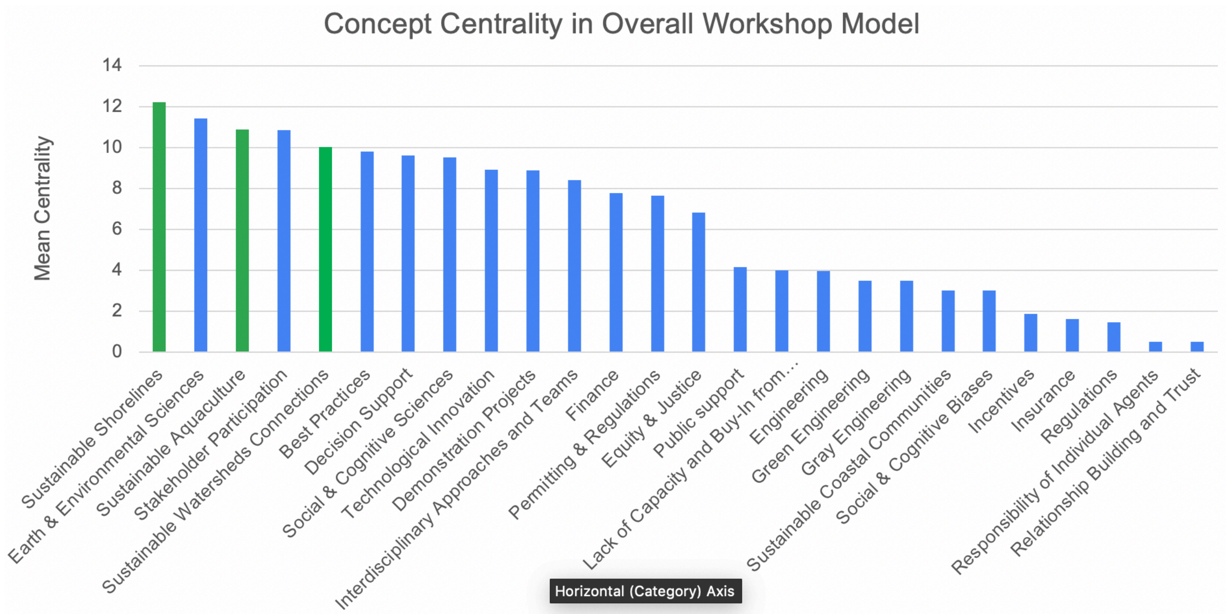

Figure B-3. Graph showing mean degree centrality of concepts across groups. Degree centrality is a measure of overall influence or importance within the system.

Demonstration Scenario Analyses: We merged the models produced by each group into an overall workshop model to broadly assess perceptions of nature-based solutions and connections with other key themes that emerged in earlier workshops using scenario analyses. An overarching takeaway from our scenario analyses is that exclusive emphasis on technical or engineering solutions magnifies social inequities. However, overcoming social inequities driven by technological innovation can be achieved by integrating stakeholder participation simultaneously with cognitive and social science. We also found demonstration projects that are underpinned by interdisciplinary science and effectively navigate policy landscapes are promising pathways for promoting nature-based solutions.

Appendix C. Participant Statistics, Expertise, and Sectors

A total of 257 individuals registered for the workshop sessions. As part of our registration process, we asked registrants to indicate their primary area of interest within the theme of coastal sustainability, their sector, organizational representation, and other demographic data. Registrant data revealed most people were interested in “Living Shorelines” (30%) and “Other Areas of Coastal Sustainability” (37%) but there was also strong interest in “Marine Food System Sustainability” (15%) and “Watershed Planning” (18%). Importantly these areas set the initial conditions for workshop discussions but these areas were clearly refined as a result of these discussions. In terms of sector, workshop registrants largely hailed from academia (48%) but there was also strong representation from government (14%) and nonprofits (17%). Other represented sectors included: engineering, business and finance, law and policy, and media and communications. In terms of organizational representation, 44% of registrants were from R1 Universities, 28% from NGOs, 9% from primarily undergraduate institutions, and 10% from minority serving institutions and historically black colleges and universities. Other represented organizations included: national laboratories, small businesses, and community colleges.

We also asked registrants to identify their primary (Figure C-1) and secondary (Figure C-2) areas of research interest as well as topics that they were interested in learning more about (Figure C-3). This information was used to help within disciplinary and trans-disciplinary working groups, as appropriate, during workshop activities.

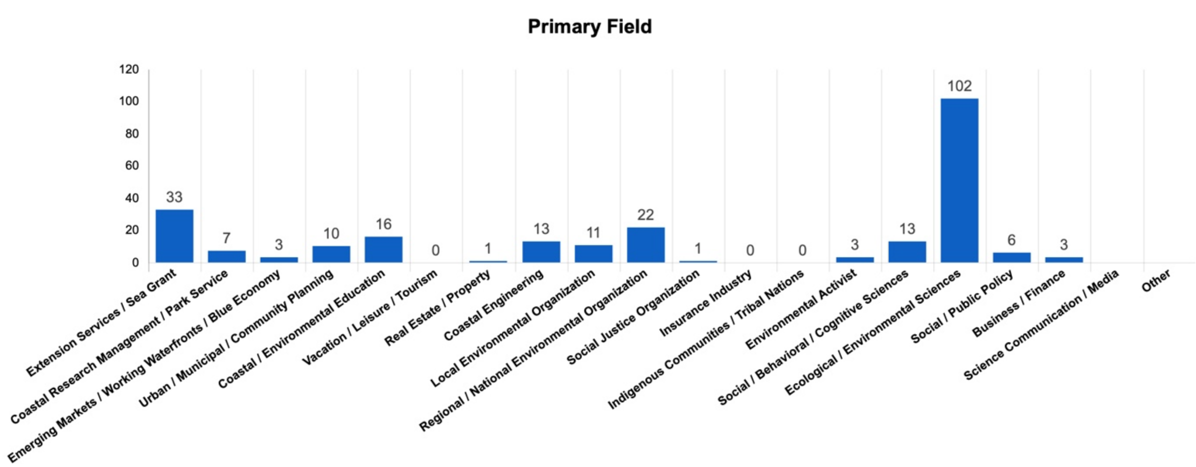

Figure C-1. Summary of registrants in terms of primary research field.

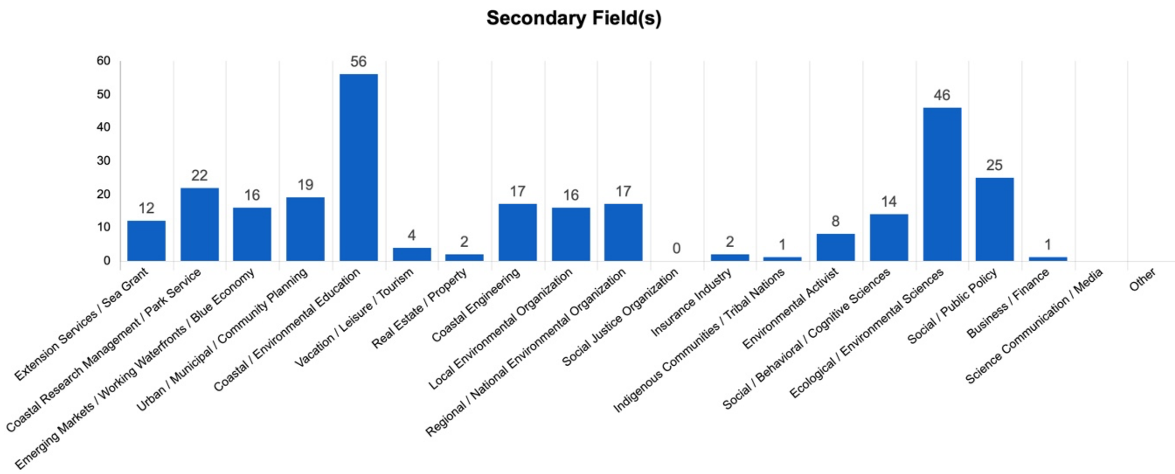

Figure C-2. Summary of registrants in terms of secondary research field.

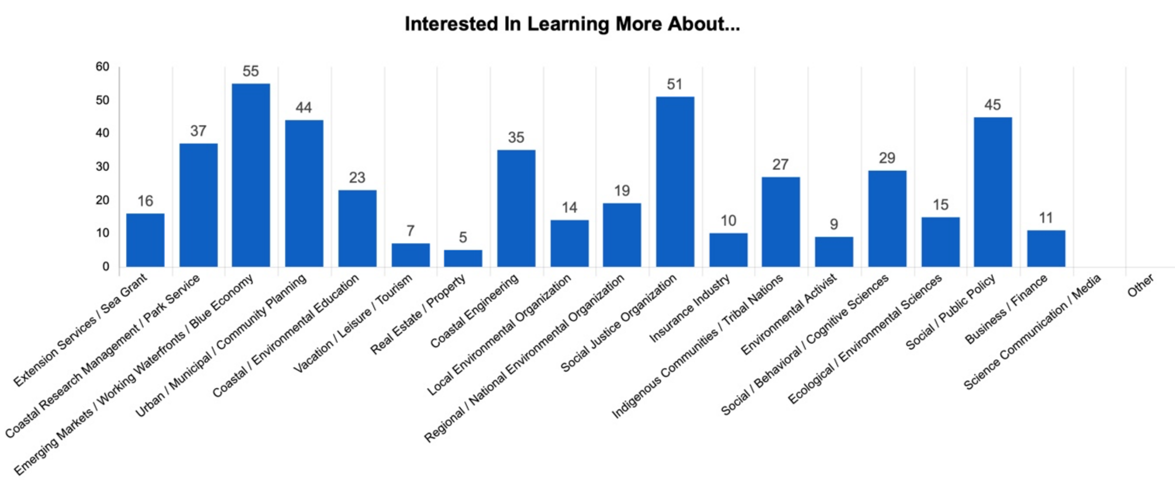

Figure C-3. Summary of registrants in terms of what they were interested in learning more about.