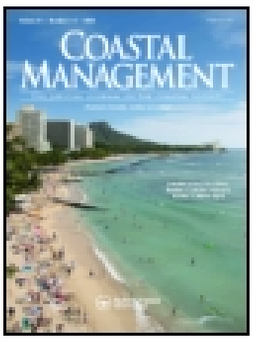

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Socio-ecological Mobility: A Research Strategy for a New Coastline

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ABSTRACT

Persistent development, population pressures, and increasing natural hazards are unequivocally changing socio-ecological systems in the coastal zone. This essay provides direction and initiates scientific dialog on the potential role of mobility in adapting to natural and social changes in coastal environments. The essay identifies four key research areas on information needed to develop coastal management actions and policies that support and recognize socio-ecological coupling in coastal areas. The proposed research includes: (1) modeling localized scenarios that illustrate the tradeoffs associated with various sea level rise adaptation, (2) assessing and consolidating mobility terminology for different applications and contexts, (3) developing solutions to synchronize the co-migration of natural environments and built infrastructure, and (4) evaluating existing or creating new transparent, equitable, and sustainable policies and incentives to support socio-ecological mobility by using case studies and social science methods to understand how people make mobility decisions in different contexts.

KEYWORDS

coastal, ecosystem; migration; mobility; relocation; sea level rise

The coastal dilemma

Coastal counties are growing rapidly with six times greater population density than inland counties (Cohen 2018). Terrestrial, oceanic, and atmospheric environmental conditions are reshaping coastal landscapes and human habitats, infrastructure, and ecological communities. Land cover/land use change from human activities such as urbanization, agriculture, deforestation, and resource extraction (Pinto et al. 2009, Hadley 2009, Masatoshi 2008) affect the distribution and quality of many coastal ecosystems, reducing their capacity to buffer hazards affecting coastal communities. Interdisciplinary and transdisciplinary research on coastlines and people can provide decision-makers with both a greater understanding of the dynamics of coastal systems and options for more sustainable approaches to protect coastal habitats and human communities from current and future environmental change.

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Coastal flooding and land loss due to sea level rise (SLR) increasingly affect coastal regions (NRC 2007, NASEM 2018). Accelerated SLR is projected to exacerbate nuisance flooding, change flood propagation within urban landscapes, and also reshape coastal ecosystems. These flooding events have already damaged or destroyed natural habitats and man-made infrastructure (Nicholls et al. 1999, Kirwan & Megonigal 2013). Considering the anticipated population growth in the coastal zone, exposure to, and flood risk from, both chronic and episodic events will only continue to increase over time (Hauer et al. 2016). Under the business-as-usual scenario (IPCC ~ RCP 8.5), 2.5 million existing homes in the U.S. will be at risk of yearly flooding or worse by 2100, affecting over 13 million people (Hauer et al. 2016). Those properties are currently worth $1.33 trillion, an amount equal to six percent of the U.S. economy (Climate Central 2018). Relocating human communities away from high-risk coastal areas has been increasingly considered a viable adaptation strategy (Adger et al. 2007, King et al. 2014, Leighton et al. 2011, McLeman & Smit 2006, Tacoli 2009, Warner et al. 2013, Williams 2013) and has already been applied in some small communities in response to both progressive environmental changes (Bronen 2015, Cronin & Guthrie, 2011, Lowlander Center 2015) and major disasters (Binder et al. 2015, Blue Acres Buyout Program 2016).

The RCP 8.5 scenario (IPCC 2018) further projects that the world will lose between 20 and 90 percent of present-day coastal wetland area by 2100 from SLR (Shuerch et al. 2018). Coastal wetlands can be self-sustaining in the long-term under rising sea level as long as a balance is maintained between (1) vertical dynamics, i.e., the habitats' ability to maintain elevation relative to the mean tidal height, and (2) horizontal extent, i.e., the habitats' ability to migrate upslope as mean water levels increase. Coastal ecosystem migration is a natural process that occurs in response to inundation (Kirwan & Megonigal 2013). Spatial extent can be maintained provided suitable upland areas exist for vegetation migration and coastal retreat (Scavia et al. 2002, Kirwan & Megonigal 2013). Therefore, the future sustainability of coastal wetlands will be primarily driven by their ability to migrate inland into suitable "accommodation space" (e.g., undeveloped land, gentle marsh-to-upland gradients, land continuity), while large-scale loss of these habitats can only be avoided through careful adaptive coastal management strategies (Borchert et al. 2018, Shuerch et al. 2018). However, in today's urbanized coastline, the amount of open accommodation space available for upland migration of natural habitats is becoming increasingly limited.

The natural environment in coastal settings also provides many important ecosystem services, such as flood protection (Barbier et al. 2011), that have already been highly degraded and challenged by human expansion (Lotze et al. 2006, Scavia et al. 2002). To ensure the continued long-term health and functionality of these natural resources and the ecosystem services they provide, it is important to identify planning interventions that help align land management with the natural upslope migration dynamics of coastal habitats. The avoidable loss of coastal wetlands not only reduces the extent of valuable habitat for coastal and estuarine species, but also increases the vulnerability of human settlements to coastal hazards because these areas attenuate the effects of storm surge (Gedan et al. 2011, Spalding et al. 2014).

Strategies to adapt to rising seas and storm surge can be broadly grouped into three categories: protection, accommodation, and relocation. This essay focuses on relocation,

also referred to as *mobility*. The United Nations Development Program (UNDP 2010, p. 1) defines mobility as a fundamental attribute of human freedom "to seek opportunities to improve living standards, and health and education outcomes, and/or to live in safer, more responsive communities." Mobility frequently refers to people's free or unconstrained movement in a space, while migration often involves movement across administrative or political boundaries (Boswell & Geddes 2011; Tacoli 2009). The U.S. Census Bureau (2017) refers to migrations and geographic mobility as the movement of people from one location to another. The scientific discourse on these terms' meaning and application is ongoing and varies between different contexts and disciplines. This paper applies *mobility* broadly to both human and natural habitat movement. This application of the term helps us view mobility as a socio-ecological system response to the substantial changes that will be caused by SLR in the coastal zone.

Discourse on the importance of different types of mobility in the coastal zone has been steadily increasing in response to accelerated SLR and increasing coastal hazards (Adger et al. 2007, Binder et al. 2015, Hauer et al. 2016). Both the scientific community (Borchert et al. 2018, Day et al. 2005, Kirwan and Megonigal 2013) and community of practice (Bronen 2015, Campbell et al. 2005, King et al. 2014, Tacoli 2009) focus on mobility. These studies identify the need for more research on both the human and ecological dimensions of mobility (e.g., sociocultural, legal, and security implications), the potential socioeconomic and environmental costs and benefits, and the barriers and opportunities that could emerge from this process in different coastal contexts.

In response to the emerging issue of accelerated coastal changes, we propose four topics of interdisciplinary research emphasizing the various aspects of mobility of coupled socio-ecological systems. This research agenda should help to better elucidate how the combined mobility of both natural and human systems can foster improved coastal resilience. Exploring mobility in this way will help identify how coastal relocation as a nonstructural planning strategy could unfold in synergy with the changes occurring in dynamic natural coastal ecosystems.

Research recommendations for incorporating mobility into coastal planning

Research to develop localized scenarios

Loss of natural habitats with SLR increases the risk of catastrophic damage to the built environment during storm events, while also reducing capacity for nutrient cycling, water clarification, and habitat for commercial and recreational fish species. Mapping and modeling products and future scenarios should be refined and scaled appropriately to effectively communicate these tradeoffs to communities and individuals, thereby empowering them to make more informed decisions. Thus, we recommend developing localized scenarios that illustrate the possible futures and outcomes stemming from implementation of different adaptation options for SLR in the coastal zone. For example, currently available visualization tools such as the NOAA Sea Level Rise Viewer (available at: https://coast.noaa.gov/digitalcoast/tools/slr.html) and Surging Seas Risk Finder (available at: https://riskfinder.climatecentral.org/) illustrate the range of potential future flooding scenarios along the nation's coastline. Scenarios typically range from +0.3 m (∼RCP 2.6) to +2 m (∼RCP 8.5) by 2100 and lie within the expected

ranges of global emissions, warming potential, and resulting eustatic SLR. However, local SLR can be greater or less than the eustatic rate due to seismic, tectonic, and sedimentary processes (NRC 2012). In Louisiana, for example, some of the highest national rates of local SLR have been recorded (up to +10mm yr^{-1} compared to the +3mm yr^{-1} eustatic rate) due to the combination of tectonic adjustment post-glaciation, sediment compaction, and the reduction in sediment supply from the Mississippi River to the coastal delta (Törnqvist et al. 2008). This rapid rate of local SLR leaves unprotected infrastructure at great risk of flooding even during a minor storm surge. Louisiana is the first state in the U.S. to use a federally funded buyout (costing $48.3 million) of an entire community, the Isle de Jean Charles band of the Biloxi-Chitimacha-Choctaw Tribe that is relocating further inland in response to repeated flooding that has decimated their properties and livelihoods over the past 15 years (State of Louisiana 2018). The need for locally-scaled scenarios of future flooding and inundation risk is illustrated by a recent study, which estimated that by 2050 there will be around 40,000 homes in the U.S. at risk of flooding at least once per year (Climate Central 2018) even if nations globally manage to meet the Paris Accord goals for reductions in emissions (∼RCP 4.5). However, the currently available scenarios generally fail to include losses to the natural ecosystem and do not fully capture the range of response options that need to be discussed by stakeholders. Therefore, future research needs to address the coupled natural-human coastal system and develop appropriate local scenarios that capture a broader range of conditions than simple inundation scenarios.

Research into terminology regarding climate induced population mobility

The second research topic pertains to the terms used to refer to climate-induced human population mobility. Currently, there is no consensus regarding such terms and their use. We also lack understanding of how different stakeholders understand different terms. In the coastal context, terms include [environmental/forced/climate] resettlement, migration, displacement, [assisted/managed/planned] retreat, and relocation. These terms have distinct meanings and connotations that often vary by geographic location and policy context (Bukvic 2015). For example, FEMA defines relocation as a process of physical transfer of a structure to an area outside of the floodplain (FEMA 2005). In contrast, the literature on disaster risk reduction and adaptation uses the term more broadly to describe a permanent or long-term movement of people or whole communities away from adverse circumstances (UNCRH 2014; McAdam & Ferris 2015; Campbell et al. 2005).

We recommend promoting a dialog between researchers and stakeholders on appropriate wording and definitions to describe mobility as an adaptive socio-ecological approach to coastal change. This dialog would assess terms such as *managed retreat* and *planned relocation* for their meaning to various stakeholders to ensure consistent and cohesive use. This assessment could also address the negative connotations of the terms like *managed retreat* and explore the potential impact of using more empowering, positive phrases such as *planned relocation*, *strategic advancement*, *moving up*, and *advancing to higher ground* on policy and public perceptions. We recommend using participatory data collection methods such as focus groups or interviews to capture

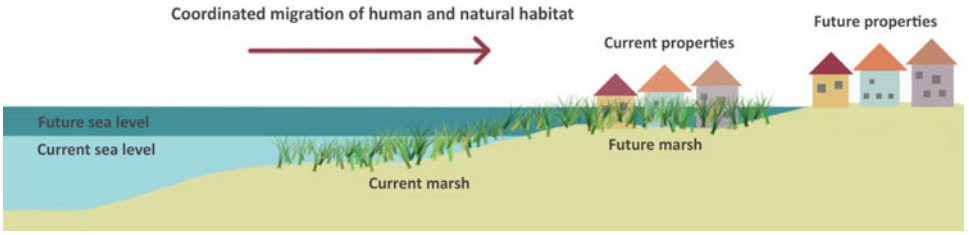

Figure 1. Coordinated socio-ecological mobility of both natural and human systems.

stakeholders' perceptions of relocation or retreat in different coastal settings nationwide. Such an approach could also help discern preferences for the design and type of policies and programs that would support mobility and pave a way for new outreach efforts to help communicate the need for coordinated movement of natural and human systems in response to SLR (Figure 1).

Research regarding policy tools to synchronize natural and human migration

We next recommend research focusing on solutions that synchronize the co-migration of natural environments and human infrastructure. For example, this could be achieved by developing innovative land-use plans to allow for the upland migration of natural habitats into accommodation space created by the relocation of homes and businesses away from the most flood-prone coastal areas. This adaptive pathway will require interdisciplinary and transdisciplinary research to: 1) develop and promote solutions and proactive approaches for adjusting the footprint of development to accommodate simultaneous changes in both the natural and built environments, and 2) monitor and evaluate the impact of upland migration on the surrounding human and natural environment to assess its sustainability, effectiveness, and social integrity. This approach should be aligned with other planning and policy efforts designed to promote natural resource conservation, economic development, and social justice.

One such example of proactive planning includes elevation-based zoning that guides future development and growth toward higher ground based on areas of different elevation within the community. This approach has been applied to the comprehensive plan for Crisfield, Maryland (Crisfield Comprehensive Plan 2010) and was addressed in the zoning ordinance for Norfolk, Virginia (Norfolk Zoning Ordinance 2018). Similarly, market-based responses to re-development in flood-prone coastal areas occurred after Hurricane Katrina (2005) along the Mississippi Gulf Coast. Although zoning ordinances did not change, the revision of the FEMA flood maps resulted in higher insurance rates on low-lying vulnerable properties (Chaney 2015) with "climate gentrification" of land parcels owned by those sufficiently wealthy to cover the high insurance cost and afford the expenses of managing their flood risks.

Research could also examine how other common coastal zone management and environmental planning tools might be adapted to support mobility, such as conservation easements, land trusts, regulatory setbacks, land acquisition, and buffer zones. Many federal and state agencies have policies that could be directly applied or adapted to support mobility in response to SLR and evolving coastal hazards. However, they

might benefit from inter- and intra-agency consolidation and coordination, and adaptability to address different needs to support mobility via individual or community relocation. Such synchronization of approaches may reduce administrative burdens and help human communities that prefer to move together tap into multiple resources to enable their collective relocation. Interdisciplinary researchers can aid this effort by assessing experiences and effectiveness of existing policies at different governance levels and exploring if and how consolidating these efforts could better support future mobility.

Research regarding policies and incentives to support mobility

Finally, there is an opportunity for research on transparent, equitable, and sustainable policies and incentives to support socio-ecological relocation processes. Such research could use case studies approaches and social science methods to understand how people make decisions related to relocation in different contexts. For example, qualitative analysis could help identify barriers and opportunities for developing relocation support mechanisms that would reflect household and community dimensions in different coastal settings (e.g., norms, culture, values, attitudes, and beliefs). Some remote and historically cohesive communities may prefer to relocate together as part of a planned process that would allow residents to preserve their social and cultural capital and traditional way of life. Others may prefer relocating individually via buyout programs, like the one offered to homeowners after Hurricane Sandy in New Jersey (Freudenberg et al. 2016). The research could also explore other relocation policies including purchase or transfer of development rights, retained use or occupancy until the property becomes unsafe for habitation, relocation trust funds, land banks, acquisition, and rolling easements.

Such research will be particularly important for disadvantaged individuals who are not capable of relocating due to financial, cultural, social, health, or other reasons, would remain in harm's way, and would be more vulnerable to future catastrophic loss resulting in costly government intervention. In addition, this research could help Federal and State agencies in their role in determining what financial mechanisms best support mobility through their programs, budgetary allocations, and political support.

In response to persistent and accelerating threat of SLR, localities can utilize a variety of planning, regulatory, and financial tools to proactively support mobility, such as comprehensive plans, zoning and floodplain regulations, setbacks, building permits and ordinances, rolling easements, taxes and fees, real estate disclosures, and others (Grannis 2011). For example, the City of Norfolk in Virginia recently adopted a new elevation-based zoning ordinance to address flood risk by directing future development to areas of higher elevation. The adopted ordinance introduces a Coastal Resilience Overlay (CRO) zone requiring that new development and redevelopment comply with an Upland Resilience Overlay to reduce the long-term flood risk and cost (City of Norfolk 2019). Additional research should focus on identifying and developing effective incentives designed to support relocation, ease potential adverse impacts of this adaptation strategy, and advance opportunities that could emerge from this process.

Conclusion: Impacts and value of mobility as a response strategy

The coastal environment is unequivocally changing with accelerated SLR. Fundamental and applied research is required to further develop, refine, and provide decision-making tools and robust science-based empirical evidence to support strategic planning for mobility in coastal areas. Such areas of research may include, but are not limited to, spatial hazard identification and communication, risk assessment and socio-economic cost analyses, novel geospatial mapping and modeling tools, and integration of these approaches into user-friendly and actionable products, web tools, mobile device apps, and other means of information transfer. The proposed mobility research topics would help better define future coastal conditions at the local decision-making scale. This is urgently needed to address the current lack of a range of scenarios available to stakeholders so they can make decisions on future coastal resilience and sustainability. These decisions have to incorporate a future where natural habitats may become less extensive and provide fewer ecosystem services than in the past.

This research needs to engage coastal communities, including vulnerable populations (e.g., economically disadvantaged urban residents and rural populations), in the co-production of knowledge by integrating local understanding and experiences to identify research questions and methodological design. Community participation will be important to delineate mobility options according to social and economic circumstances. This strategy may be performed in collaboration with local government, academia, non-governmental organizations, and the private sector to ensure full transparency and equity of the process. These new partnerships may play an important role in fostering dialog on the role of mobility to respond to coastal change among residents and other stakeholders, especially socially vulnerable groups who may have limited access to information or influence on political dialog about coastal adaptation. Such non-conventional alliances may also help accrue matching funds for state and federal funding opportunities, drive innovation at the local level, and serve as a liaison between different interest spheres. In all these partnerships and engagements, emphasis on and inclusion of broader socio-ecological co-benefits would not only open a route to access different streams of funding but also justify the necessity and long-term merits of such approaches that may help offset some of the social and environmental costs of relocation.

To facilitate these activities, we suggest the incorporation of information exchange platforms that would make the essential data and research results readily accessible to coastal managers and other decision-makers, practitioners, and concerned citizens. We further recommend peer-to-peer learning approaches through networking among coastal human communities vulnerable to SLR so that they can share concerns, challenges, and potential solutions. It will enable learning from examples of coastal communities that have been forced to adjust to land loss, demographic changes, loss of amenities, and in a few cases the abandonment of entire communities. Such cases from both the U.S. (e.g., coastal settlements in Alaska and Louisiana, and small island communities in Chesapeake Bay) and international locations (e.g., low-lying island nations including the Marshall Islands and Seychelles) provide potential case studies that other communities can learn from. To facilitate learning and communication about this adaptation strategy, a community of practice should be encouraged. This would provide

vulnerable communities with an opportunity to engage others in similar circumstances and create shared experiences in development of workable practical solutions.

The research products can help contribute to a framework for mobility pathways tailored to individual coastal communities. Coastal communities face important decisions on what approaches to use to address land loss from SLR, and hence they will need to understand the underlying processes, impacts, and proactive strategies that could be taken to maintain the many values of coastal areas. We strongly encourage further scientific discourse on what mobility in the coastal zone means and whether it is possible considering current coastal management and urban zoning policies.

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