



Commentary

Toward science-informed public policy: A conceptual framework for contributing to and studying Great Lakes coastal shoreland management

Richard K. Norton

Urban and Regional Planning Program, Taubman College of Architecture and Urban Planning, University of Michigan, Ann Arbor, MI 48109, USA

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ABSTRACT

Great Lakes coastal shorelands encompass valuable environmental and social resources. Most are privately owned. Governments play an important role in managing the use of those shorelands to ensure adequate conservation of the natural and social benefits they provide. Scientists have demonstrated that imprudent land uses are yielding significant ecological harms and increased risks to coastal shorelands, and yet those uses persist. Public coastal shoreland management appears to be poorly informed by the best available science. In addition to generating good science, scientists are themselves members of the public well-positioned to contribute to improved coastal shoreland management. Two prominent proposals for doing so include calls for scientists, first, to better communicate their knowledge through direct engagement with decision-makers ('contributing to') and second, to co-produce the knowledge that decision-makers require by participating in multi-disciplinary, community-engaged research ('studying'). For either endeavor, scientists need to understand public coastal shoreland management processes to engage effectively with them. Drawing from multiple literatures, this paper presents a conceptual framework to assist scientists working to contextualize and more effectively convey the knowledge they have, or to engage in research designed to co-produce knowledge, in order to better promote science-informed public coastal shoreland management. The framework is set within the institutional arrangements that structure coastal management processes, and it highlights the ways in which key decision-maker attributes—their collective knowledge, capacities, and commitments—influence decision-making actions and outputs. While situated specifically within the context of coastal management, the framework is adaptable to other policy arenas more broadly.

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Introduction

Several starting premises of this special section of the *Journal of Great Lakes Research* on the social and organizational dimensions of community revitalization through environmental remediation and restoration are that such processes are often local, that effective local groups and governments are necessary for effective ecosystem management, and that there is yet room to understand better how the public engages or contributes to environmental remediation, restoration, and similar programs in practice. Given those premises, the call for this special section is to draw from social science and organizational theory to provide insights on how local communities and groups engage with and contribute to environmental management.

Several premises underlying that framing are that governments make environmental management decisions (i.e., many if not most

of those decisions), that the community and other groups comprising 'the public' are non-governmental actors who contribute to governmental decision-making, and that those contributions have the potential to improve the decisions made. Natural science researchers are sometimes governmental decision-makers themselves. When not, they can be members of the public capable of contributing meaningfully to governmental decision-making, in ways beyond merely publishing their work. They might, for example, participate on governmental advisory boards, make presentations to legislative hearings, participate in public decision-making workshops or other working groups, or even collaborate with integrated research-and-decision-making efforts.

The purpose of this article is to provide insight on how governmental decision-makers receive and incorporate scientific information through the decision-making processes they engage, hopefully in a way helpful to Great Lakes natural science researchers looking to participate in environmental management decision-making as members of the public, working with community groups

E-mail address: rknorton@umich.edu

seeking to contribute to such decision-making, or simply looking to better understand how and why the scientific knowledge they and others have to offer is (or is not) used in governmental decision-making efforts. That insight, in turn, should be helpful for discerning when governmental decision-makers who are making decisions that appear to be ‘science-uninformed’ are doing so because they truly lack the best and appropriate scientific information available (thus suggesting the need to find better ways to provide that information), or because other factors that influence decision-making are at play (suggesting the need to attend more to those other factors instead).

The focus of this article is on public management of the development and use of privately owned Great Lakes coastal shorelands, and especially the role that scientific knowledge plays in those public coastal shoreland management efforts. The goal is to promote the resilience and sustainability of the natural functions of Great Lakes coastal shorelands into the future. Great Lakes natural systems researchers have much to contribute to that effort. They are well positioned to convey their expert knowledge of the geophysical and ecological functioning of coastal shorelands, for example, as well as the ways in which those natural processes and systems respond to perturbations caused by various shoreland development activities and ongoing uses.

Scientific knowledge, however, is not by itself self-executing within public policy-making processes. Rather, knowledge interacts with decision-makers’ capacities and their differing levels of commitment to various policy goals, all within decision-making processes that are structured by complex institutional arrangements. Scientists looking to promote the use of good scientific knowledge within public decision-making processes (or to ensure those decisions are ‘science-informed’) will better succeed by doing so with a good understanding of how and why public decision-makers use the knowledge available to them within the decision-making processes they employ. That understanding can also help natural scientists looking to contribute their knowledge of natural systems to interdisciplinary, community-engaged research efforts designed to better understand the ongoing functioning of complex coupled socio-ecological systems and to generate decision-relevant and useful knowledge.

This article offers a conceptual framework to assist Great Lakes natural science researchers engaging such efforts. The framework is built around a basic input-action-output-outcome model of change, addressing specifically the roles of resource setting, institutional setting, decision-making processes, and the deployment of knowledge within decision-making processes. The article summarizes first the kinds of environmental impacts that coastal shoreland development activities and ongoing uses can yield, including ecosystem degradation and increased risks to people and developed properties from imprudent development, and it discusses several explanations for why coastal shoreland management efforts appear not to be well informed by available scientific knowledge. The article then summarizes the intergovernmental institutional arrangements that guide and constrain coastal shoreland management decision-making, focusing on Michigan as illustrative of those arrangements in general, along with the decision-making process that public decision-makers engage within that institutional framework. The article focuses on the role played by knowledge within the decision-making process, addressing both how scientific knowledge is introduced into that process and how it is used by decision-makers, particularly in the context of other key factors shaping and motivating their behaviors. Finally, the article concludes with discussion of some key implications for future efforts.

Resource setting: land use threats to resilient and sustainable Great Lakes coastal shorelands

Great Lakes and ocean coastal shorelands are the terrestrial component of the larger coastal zone, including lands influenced by lake and ocean-water dynamics and encompassing barrier islands, beaches, dunes, wetlands, marshes, and other transitional areas within that dynamic coastal setting. Ocean coastal shorelands also encompass estuaries and intertidal areas, while Great Lakes coastal shorelands encompass inland areas influenced periodically by longer-term fluctuations in standing lake water levels, such as coastal wetlands connected to the lakes hydrologically during high lake levels (see generally [Pilkey et al., 2001](#); [Beatley et al., 2002](#); [Norton et al., 2018b](#); [Tribal Adaptation Menu Team, 2019](#); [Norton, 2022](#)). Much of those coastal shoreland areas are in private ownership, especially in the United States. It has been estimated that about 80 % of Great Lakes coastal shoreline alone in the U.S. is privately owned, for example, while about 20 % of Canadian shoreline is privately owned ([Gibb, 2015](#)).

Scientific research has long demonstrated myriad ways in which these coastal shorelands are valuable ecologically, most notably because they provide vital habitats for diverse flora and fauna. Scientists in the 1990s, for example, found that “26 percent of the species and natural communities that are restricted to or have their best distribution in the Great Lakes basin occur along the [Great Lakes] coast; another 22 percent occur on the adjacent lake plain. On an acre-for-acre basis, shoreline sites are on average much richer in biodiversity than inland sites” ([Reid and Holland, 1997, pp. 2-3](#)).

Like wetlands and other riparian lands adjacent to water bodies everywhere, coastal shorelands also perform vital environmental protection functions, such as filtering nonpoint source pollutants from surface waters, and by providing natural storage for floodwaters (see generally [Beatley et al., 2002](#); [Randolph, 2012](#)). Finally, coastal shorelands immediately adjacent to shorelines are highly dynamic, continually shifting and reforming as water levels fluctuate, dynamics that are heightened when storms bring surges of high-energy waves and flooding from overwash and inundation ([Pilkey et al., 2001](#); [Beatley et al., 2002](#)). Today, global climate change is stressing these important ecological functions and further heightening shoreline dynamics, especially during increasingly fierce coastal storms ([Burkett and Davidson, 2012](#); [Fleming et al., 2018](#); [Tribal Adaptation Menu Team, 2019](#)).

Not only are coastal shorelands environmentally vital and remarkably dynamic, they are also heavily used—increasingly so. Early in the country’s history, communities along both Great Lakes and ocean coasts used their coastlines primarily for industry, commerce, and transportation, turning their backs from the shore otherwise and, incidentally, allowing coastal regions to become degraded from a variety of assaults ([Beatley et al., 2002](#)). Since the second half of the 20th century, increased wealth, ease of transportation, the desire for coastal amenities, and tourism-based economies have all led to substantial increases in coastal shoreland residential and recreational development, along with attendant commercial and infrastructure development ([Beatley et al., 2002](#); [Beatley, 2009](#)).

As a result of historical and contemporary shoreland uses, the ecological habitat and environmental protection functions that coastal shorelands provide have been degraded substantially in numerous ways. In addition to persistent legacy pollution, impacts have occurred directly through degradation of natural beaches, dunes, wetlands, and other habitats. These losses have been caused mostly by the placement and construction of structures like homes and businesses, along with the placement and construction of infrastructure like the roads provided to serve them and shoreline

armor structures intended to protect them (e.g., Reid and Holland, 1997; Pilkey et al., 2001; Beatley et al., 2002; Beatley, 2009). There are indirect ecosystem and environmental impacts as well, such as modified water flows caused by increased impervious surfaces, which increase stormwater runoff and nonpoint source pollution in turn, and lowland filling that decreases flood storage capacity (Reid and Holland, 1997; Beatley et al., 2002; Randolph, 2012).

Finally, in addition to causing such ecological and environmental harms, nearshore coastal shoreland development near both the Great Lakes and the oceans is increasingly putting substantial investments in properties and public infrastructure at risk (Beatley, 2009; Gaul, 2019; Peterson, 2019; Kousky et al., 2021). Not only are more structures going into high-risk settings, the risks in those settings are getting higher from global climate change, especially from accelerated sea level rise along ocean coasts, accelerated shoreline recession on Great Lakes coasts, and heightened storminess along both (Folke et al., 2002; Burkett and Davidson, 2012; Fleming et al., 2018; Tribal Adaptation Menu Team, 2019).

In sum, compelling scientific knowledge is available to demonstrate, first, the many benefits of natural coastal shorelands; second, the harms and risks to those resources caused by contemporary coastal shoreland uses; and finally, effective ways to modify those uses so as to mitigate harms and risks (Reid and Holland, 1997; Beatley, 2009; Tribal Adaptation Menu Team, 2019). Beyond that, new knowledge will undoubtedly be generated as environmental conditions and development pressures continue to evolve. Even so, knowledge by itself is not self-executing. And despite the knowledge that is currently available (let alone predictions on where things might be headed), harmful and risky coastal shoreland development continues apace. More broadly, science appears not to be adequately informing Great Lakes coastal shoreland management policy (Krantzberg, 2004). Why not, and what to do?

Possible explanations for science-uninformed coastal shoreland management

One possible explanation for why the best available science appears not to be informing coastal shoreland management is that while the people making decisions about how to use coastal shorelands have access to scientific knowledge, they are not using it to inform their decisions. The problem from this perspective is not so much a lack of available scientific knowledge as it is decision-making processes that do not adequately or appropriately enable or encourage the use of that knowledge. In response, researchers point to the need for more and better public planning or policy-making, which would presumably do a better job of incorporating appropriate scientific knowledge (e.g., Reid and Holland, 1997; Norton, 2005a). Others call for improved use of science through, for example, innovative planning methods such as scenario-based planning (e.g., Laurent et al., 2015), along with better inter-governmental coordination and community engagement (e.g., Lemos and Morehouse, 2005; Krantzberg et al., 2015) and the cultivation of ‘boundary organizations’ (e.g., Dilling and Lemos, 2011; Williams, 2015), both as mechanisms to improve engagement between scientists and science users. Science-user or community-collaborator engagement from this perspective focuses especially on enhancing the decision-maker’s acceptance of the legitimacy and applicability of the scientific knowledge available.

Another possible explanation for why the best scientific knowledge available appears not to be informing coastal shoreland decision-making is that the people making the decisions do not have the best scientific knowledge readily available to them,

specifically, in the first place. That suggests the problem is more one of inadequate or poor science communication, or perhaps even flawed generation of scientific knowledge such that it is not all that useful for decision-making purposes. It is worth noting here that focusing on inapt science communication and production as causes of uninformed decision-making is not unique to coastal management settings. That diagnosis has long been, and continues to be, prominent in many contexts, including most prominently today the context of global climate change.

Indeed, ongoing work on science communication related to climate change offers a helpful way to think about improving science communication (and even knowledge production) for coastal shoreland management as well. Drawing from that literature to help organize concepts presented here (without attempting to critique or add to that literature itself), there are in general four related but distinct approaches to improving climate-change science production and communication as a way to better inform climate-change-related action. They are based on the ‘information deficit,’ ‘contextual,’ ‘public engagement,’ and ‘lay-expertise’ models of communication, respectively (Suldovsky, 2017). The information deficit model starts with the premise that people take imprudent or inadequate climate-change-related actions because they lack good or sufficient scientific knowledge to inform their actions (Suldovsky, 2017, pg. 2). Given that premise, the best solution is to find better ways to convey such knowledge. This diagnosis and corresponding response are both correct and appropriate, to a point; having good and apt knowledge is necessary for making good decisions, but merely making it generally available may not be sufficient.

The other models, accordingly, respond to critiques of the information deficient model, specifically that it is both too simplistic and too linear (i.e., moving only from science producer to user). The context model (referred to as ‘tailoring’ here) calls for framing scientific knowledge in ways that account for the science user’s particular context: “know your audience and utilize what you know to construct appropriate messaging” (Suldovsky, 2017, pg. 14). Going a step further, the public engagement model (or ‘dialogue’ model) calls for making science more “democratic,” inviting the public to comment on and question the scientific knowledge conveyed in an iterative rather than linear way (Suldovsky, 2017, pg. 15). Supplementing the other community engagement goals noted above, this approach should also improve the science user’s comprehension of the scientific knowledge conveyed. To the extent that scientists tailor their scientific knowledge to make it more relevant for decision-makers’ use, or ‘democratize’ it through dialogue, scientists enhance the potential and ability for decision-makers to learn that knowledge themselves through the decision-making process (Innes and Booher, 2004).

Finally, beyond decision-maker learning through enhanced science communication and education, the lay expert model (or ‘participation’ or ‘knowledge co-production’ model) calls on the scientist to acknowledge that local residents or other non-scientist actors often have valuable knowledge from lived experience with the resource. That model also calls on scientists to recognize the benefits of working directly with residents and officials to generate new knowledge relevant and useful for decision-making needs. As such, local or ‘lay’ knowledge should be accounted for and incorporated into a fuller understanding of the phenomena at issue (Suldovsky, 2017, pg. 16). In Great Lakes settings, the incorporation of Indigenous or Traditional Ecological Knowledge offers similar promise as well (see, e.g., Tribal Adaptation Menu Team, 2019). This co-production approach aligns with calls in the Great Lakes science community and beyond for increased interdisciplinary collaboration (specifically, for more engagement between natural and social scientists; see, e.g., Krantzberg, 2004; Williams, 2015), along with increased co-production of knowledge through

enhanced scientist-community engagement and enhanced participation by boundary organizations in decision-making efforts (e.g., Innes and Booher, 2004; Lemos and Morehouse, 2005; Dilling and Lemos, 2011; Krantzberg et al., 2015; Meadow et al., 2015; Williams, 2015).

For all the reasons discussed above, there are pressing reasons to ensure that public coastal shoreland management decisions fully deploy the best scientific knowledge available. Continuing to generate that knowledge is a necessary precursor to making science-informed policy decisions, and scientists who prefer to focus their efforts on generating new knowledge and making that knowledge available for use through conventional dissemination mechanisms make a contribution by doing so; not every natural scientist needs to do more.

Even so, for those Great Lakes natural systems researchers looking to do more, another way to inform public policy decision-making yet more effectively is for those scientists themselves to engage in public decision-making processes directly. Drawing on insights gained through study of climate science communication efforts as just described, Great Lakes researchers might do so, at one level, by helping decision-makers better learn scientific knowledge relevant for their tasks. Scientists might, for example, make overview presentations specifically tailored to state and local legislative working groups or committees, provide more in-depth training sessions tailored to public officials, participate in webinars that allow for participant interaction, or even participate actively in local planning workshops. Through those efforts they might convey, again for example, the best available knowledge about how and why Great Lakes water level fluctuations affect shoreline profiles and dynamics over time; how modifications from seawalls and other armoring structures degrade natural shoreline dynamics and ecosystems over time; how the placement of buildings and related construction activities can harm valuable coastal wetlands, habitats, and ecosystems more broadly; and how imprudent building placement can put those structures unnecessarily at heightened risk from coastal storms.

In the author's own experience, and the experience of colleagues, local officials are increasingly recognizing the need for help, and they are reaching out to researchers directly for assistance, offering opportunities for scientists to engage in various ways. In addition, governmental and non-governmental programs increasingly offer opportunities for researchers to provide their expertise through focused training programs and workshops, again providing Great Lakes researchers with opportunities to engage (see, e.g., the array of training programs and related materials offered in Michigan via the [Michigan Coastal Management Program, 2022](#)).

Beyond those enhanced educational efforts, natural scientists might also fully engage with social scientists and community members to co-produce scientific knowledge for specific applications through interdisciplinary, community-engaged research efforts. Such efforts might be undertaken, for example, to develop new coastal management program initiatives or to assist in crafting model shoreland management ordinances—ensuring they are adequately science-informed. That is, scientists might engage the participation model of science co-production and communication. This approach entails not just developing collaborative relationships with co-investigators from other disciplines, it also requires building relationships with local officials themselves that build trust and that fully incorporate their insights, understandings, and concerns into the knowledge co-production effort (e.g., Meadow et al., 2015). Opportunities to engage in these ways are similarly increasing through federal and state funding initiatives looking to support exactly that kind of transformative work.

Researchers undertaking either of these modes of direct engagement in the arena of public coastal shoreland management

are more likely to be successful if they have at least a working understanding of the attributes that motivate coastal management decision-makers themselves, along with the contexts that frame the decisions those actors are charged with making and the processes they must follow in making their decisions. As noted, the purpose of this article is to provide a conceptual framework for developing such a working understanding. The framework focuses on the coastal management decision-making process specifically, both for explication and with hopes of improving that process.

Institutional setting: public coastal shoreland management decision-making

Numerous actors make decisions on how to use Great Lakes coastal shorelands. For privately owned shorelands, the most immediate decisions are made by the property owners themselves. Property owners typically make decisions intended to generate income from the land, to reside on it, or sometimes just to conserve and enjoy more passively the natural features the land provides. Shorelands owned by public agencies, in contrast, are typically owned for a specific public purpose, such as providing parkland for recreation, conserving nature, or housing governmental offices. Governmental decisions regarding the use of those lands are driven primarily by those purposes, accordingly, but they may not always account for the environmental or resource conservation impacts they might yield (see generally Porter, 2008; Daniels, 2014).

All these coastal shoreland users are land use decision-makers, and in a sense they all manage the use of those shorelands. Nonetheless, the term 'coastal shoreland management' is used here in the way that community planners and public administrators use the term 'development management' more broadly (Porter, 2008); that is, decisions made by government actors to manage the land use decisions or actions made in turn by private landowners (and sometimes public landowners) for the purpose of advancing public goals, as well as decisions made by government actors to shape land use development more directly by, for example, providing roads and other infrastructure (see, e.g., Norton, 2008).

The public goals advanced by development management efforts broadly include, first and foremost, ensuring that land use activities do not yield public harms. They also typically include promoting public benefits, such as prompting private land uses that conserve open space (Norton, 2008; Porter, 2008; Daniels, 2014). The government actors making development management decisions include various elected, appointed, and employed officials, each doing so for specified purposes and following prescribed procedures. The kinds of decisions they make generally include deciding whether and how to: tax real properties (i.e., both to discourage disfavored activities or incentivize desirable activities, in addition to generating revenue); spend public funds on public facilities (e.g., parks) and infrastructure (e.g., roads); regulate private land use activities directly (e.g., federal or state wetlands regulations or local zoning controls); provide incentives otherwise (e.g., grants to incentivize improved stormwater management); and require or provide public informational or broader educational activities (e.g., real estate transfer disclosures of hazards, public information campaigns) (see generally Berke et al., 2006; Porter, 2008; Cullingworth and Caves, 2013; Daniels, 2014). Logically, these decisions should be developed and justified through formal planning and policy analysis efforts, but that is not always the case (see, e.g., Norton, 2011).

Given these broad development management purposes, actors, and tools generally, coastal shoreland management occurs more specifically through a complex, decentralized, and somewhat fragmented multi-governmental array of institutional arrangements, especially in the U.S. (see generally Beatley et al., 2002). (The Cana-

dian and U.S. coastal management systems are similar in many ways, but the focus here is on the U.S. system for illustration.) Fig. 1 presents a conceptual diagram illustrating the complex array

of institutional arrangements that frame those public coastal shoreland management efforts. The institutional arrangements that shape decision-making processes and motivations for coastal

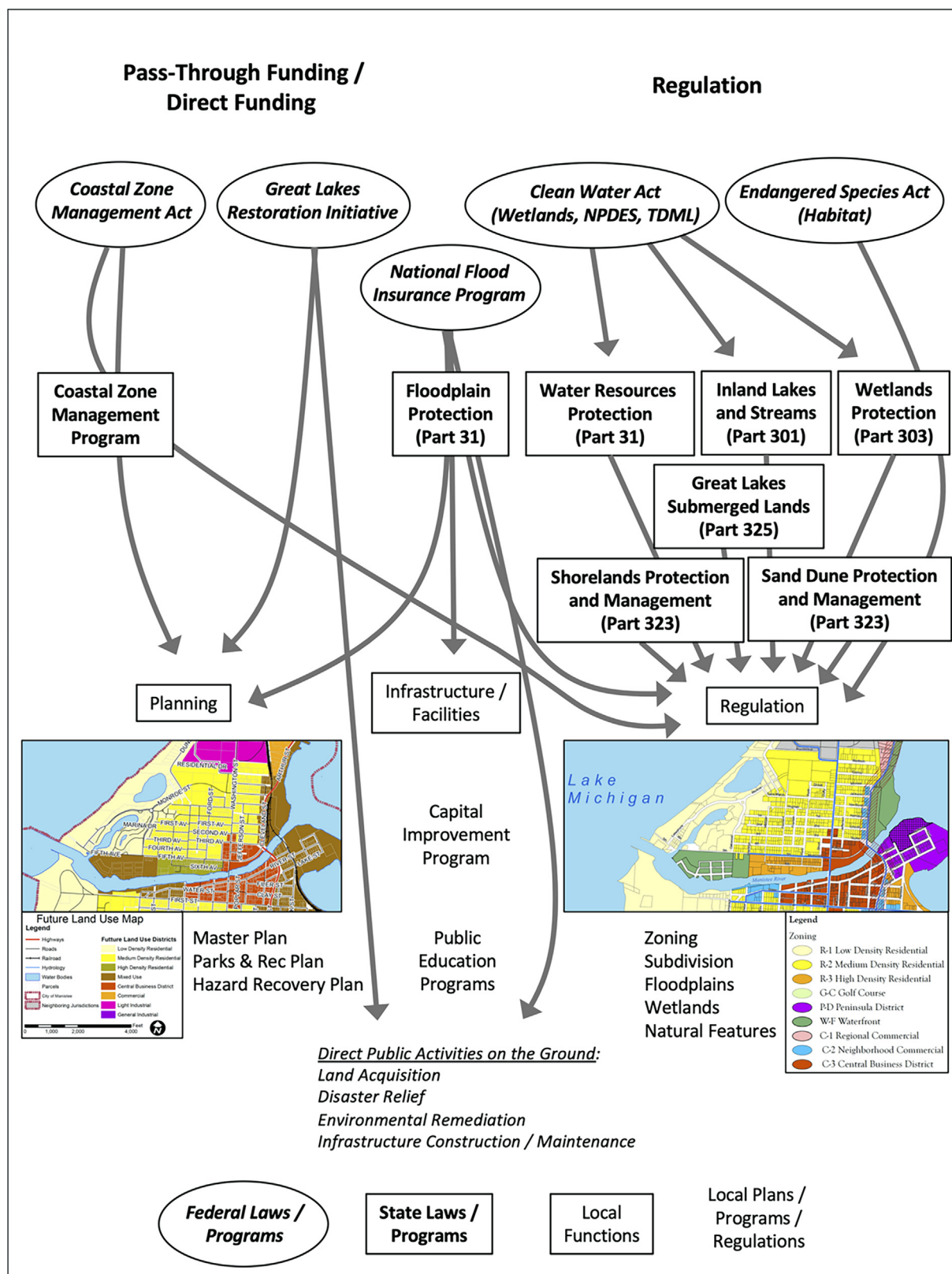


Fig. 1. Conceptual diagram illustrating the Great Lakes public coastal shoreland management system, highlighting selected federal, state, and local programs and laws as they exist in the state of Michigan. Representative state laws are drawn from selected parts of the Michigan Natural Resources and Environmental Protection Act (NREPA).

shoreland management, like other policy settings, are state-specific in important ways, and decision-makers may interact with scientists and scientific knowledge in different ways across those settings accordingly. Nonetheless, and for purposes here, Fig. 1 summarizes key institutional arrangement specifically for the state of Michigan, which encompasses about 60 % of U.S. Great Lakes shorelines and is generally representative of parallel arrangements for the other Great Lakes states (Norton et al., 2011).

Public development management, including coastal shoreland management, is in general comprised of intergovernmental grant-making, direct spending, and regulatory components. At the federal level, for example, the Coastal Zone Management Act (CZMA) functions mainly to encourage and support state and local coastal zone management activities through intergovernmental grant funding, rather than managing land development at the federal level directly (Beatley et al., 2002). The recently established Great Lakes Restoration Initiative (GLRI) provides funding to support project planning by different governments and non-governmental actors, as well as to support environmental restoration and resource conservation efforts directly (U.S. EPA, 2019). The National Flood Insurance Program (NFIP), administered by the Federal Emergency Management Agency (FEMA), provides incentives for state and local hazard mitigation and adaptation planning, and FEMA provides direct assistance for disaster relief following extreme storms (Beatley et al., 2002). Finally, a variety of federal pollution control and other environmental protection laws apply to coastal shorelands. These include, for example, water pollution, wetlands protection, and endangered species protection laws (Beatley et al., 2002; Daniels, 2014).

Despite that federal presence, however, there has never been a comprehensive national-level land use or development management policy or program in the U.S. (even recognizing the CZMA). Moreover, federal remediation and regulatory programs address only focused activities (e.g., discharge of pollutants into waterways) or focused areas spatially (e.g., wetlands, designated endangered species habitats). Given that limited presence, the states play the predominant role in shaping land development and ongoing use within their jurisdictions, and most of the states long ago delegated most of their authorities and responsibilities to do so down to their local units of government (see generally Porter, 2008; Platt, 2014).

Thus, states today have typically enacted a variety of environmental protection laws, especially within their coastal zones, and they typically engage a variety of programs for environmental and social benefits (Beatley et al., 2002; Daniels, 2014; Porter, 2008; Platt, 2014). Sometimes those laws and programs are free-standing, but often they work in concert with federal laws and programs, such as the state coastal zone management programs, or through state administration of federal law. The state of Michigan, for example, administers federal wetlands protection laws (Ardizzone and Wyckoff, 2010). Of the various public development management activities described above, state decision-making that manages directly coastal shoreland uses and activities occurs mostly through permitting programs for designated areas. Such programs include, for example, permitting requirements that apply when coastal shoreland owners want to place structures on submerged Great Lake bottomlands or within state-designated high-risk areas (as illustrated by Parts 325 and 323 of NREPA in Michigan, respectively, shown on Fig. 1; see Ardizzone and Wyckoff, 2010, for a discussion of relevant national and state programs in the state of Michigan).

Given that background, and recognizing the important role that state governments play, local units of government, typically counties, towns, townships, cities, villages, make many if not most of the coastal shoreland development management decisions described above. They do so especially through their planning

and zoning efforts that determine comprehensively how various private shoreland property owners can use their properties (e.g., for residential, commercial, industrial, or other uses) and what kinds of activities they can engage on them (e.g., through the placement of various structures or other activities affecting the landscape). Local governments, therefore, substantially influence whether structures are situated in a way that degrades high-value coastal ecosystems or that places those structures within high-hazard coastal areas, largely determining whether and how coastal development patterns, local remediation efforts, and community revitalization efforts affect natural coastal ecosystems more broadly (see, e.g., Beatley et al., 2002; Ardizzone and Wyckoff, 2010; Peterson, 2019).

To be sure, those decisions are framed both by state authorities that directly address shoreline and shoreland activities such as those just described, and more directly by state laws that enable and constrain local governmental actions (e.g., planning and zoning enabling authorities). They are also framed, importantly but more indirectly, by national policies and programs that influence state and local actions in coastal settings (e.g., national flood insurance, disaster relief, and infrastructure funding programs). Even so, local decision-makers typically have substantial authority to act for a variety of coastal shoreland management purposes, as well as substantial discretion in deciding which public policy goals to promote in doing so.

Given that institutional structure, the state and local public officials who plan for, adopt, enact, and administer the various policies, regulations, and other activities that directly affect coastal shoreland development are the coastal shoreland management decision-makers of interest here. They include, for example, state agency permitting staff, local elected city councils, local appointed planning commissions, and local employed planning staff and zoning administrators. They make their decisions acting through state legislation and administrative rules and through local planning, infrastructure policy, zoning, and related authorities (see Fig. 1). And there are a lot of them in the Great Lakes region, including both coastal governments and local public officials. The state of Michigan, for example, beyond its state government, has 292 counties, townships, cities, and villages that touch one of its Great Lakes coasts (Norton et al., 2018a). Each of those local governments typically has a 5- to 9-member legislative body, most typically have 5- to 7-member planning commissions, and most if not all have at least one (many several) administrative officials who address directly development management programs. Altogether, there are easily over 4,000 public officials managing coastal shoreland use in one way or another in Michigan alone.

Coastal shoreland management decision-making framework

Starting premises

Public coastal shoreland management systems encompass complex interactions across several dimensions. They encompass the interactions of the intergovernmental policy and regulatory programs that cross all levels of government (vertical intergovernmental relationships); the large number and largely fragmented array of state agencies and local governments with coastal management authorities that interact with one another at their own level (horizontal intergovernmental arrangements); and the internal interactions of the various sub-agency officials, local councils, boards, and administrators of a given state agency or coastal community as just described (intragovernmental relationships). They also encompass the political and legal authorities, constraints, procedures, and other institutions that shape all those various relationships. And they encompass the arrays of relationships and

interactions of the other key stakeholders who influence and are influenced by coastal development-management decisions as well, including shoreland property owners, other residents, consultants, shoreland development contractors, other business interests, various interest group representatives, and so on (Beatley et al., 2002; Norton et al., 2018a; Norton et al., 2019; Norton, 2022). And, of course, coastal shoreland management encompasses the coupled socio-ecological systems within which all these relationships and interactions unfold.

Despite all that complexity, it is possible to distill out some basic attributes and structures of coastal shoreland management systems that researchers might use to engage with them to better infuse relevant and useful scientific knowledge into them. Because a given system consists at its core of human action, the framework integrates a basic model of human behavior into a basic model of systems relationships. Of the two, the human behavior component is more difficult to unpack. Before presenting the conceptual framework in full, therefore, it is helpful to contemplate some basic attributes of human behavior and decision-making, individually and collectively.

First, people are not automatons, responding in mechanistic (if somewhat unpredictable) ways to given conditions or stimuli. Rather, people have predispositions, and when charged with making decisions—especially political or other social-regarding decisions—they do so purposefully, integrating their perceptions of relevant conditions with their predispositions and their belief systems to advance or to avoid a particular end (see, e.g., Haight, 2013; Hibbing et al., 2014; Lakoff, 2016). Belief systems incorporate simplified or working beliefs about how and why the natural and social worlds work as they do (causal heuristics), along with beliefs about how they should work in terms of right versus wrong and good versus bad (values or morals) (see, e.g., Jenkins-Smith, et al., 2018). Decision-makers, in other words, are both boundedly rational and inherently moral actors, unavoidably so on both accounts.

Second, the process of making public management decisions requires engaging planning and policy analysis processes, whether they are formal, transparent, extensive, or otherwise. Those processes are, inherently, forms of argumentation (Fischer and Forester, 1993; Elster, 1998). They require combining relevant facts (scientific knowledge) with relevant values (morals, policy goals, or mandates and proscriptions) to yield conclusions about what the best or most appropriate decision is, based on what the most likely outcomes of the possible decisions evaluated would be and what the most desirable (or required) outcomes should be. It is neither possible to conceive of every potential option, nor to assess fully the potential outcomes from each option. Moreover, making arguments and decisions necessarily incorporates value assertions about what policy goals *should* be advanced (e.g., economic vs environmental, private property rights vs public welfare), typically prioritizing some competing values over others in doing so. Decision-making processes, therefore, just like the actors engaging them, are boundedly rational and inherently moral as well.

Basic framework for contemplating public coastal shoreland management

With those initial premises, Fig. 2 provides a starting point for framing public coastal shoreland management decision-making processes. The framework builds upon a basic systems approach and model of change that is well-established and widely used, linking initial conditions (or inputs) to interventions (or actions) that yield immediate outputs, which then ultimately yield outcomes, all of which feed iteratively back into a new set of initial conditions.

The *inputs* conceptualized here include extant environmental and social conditions, along with the institutional arrangements that structure decision-making behaviors (e.g., laws, procedures, broader social norms). Because the focus here is on public policy decision-making and the role played specifically by decision-makers' knowledge of extant resource and institutional conditions, the framework calls out specifically the available knowledge of those conditions, rather than specifying the existence of those conditions alone. The *actions* conceptualized here consist of the decision-making process itself, explained more next, while the *outputs* consist of the immediate products generated by the decision-making process, including documented and adopted plans, policies, regulations, and other actions (e.g., spending on infrastructure maintenance). The *outcomes*, finally, are the changes in land use, natural conditions, and social conditions that ultimately result from the outputs, also explained further below. As with all such models, the representation of this system by Fig. 2 (and subsequent figures) is illustrated as a linear process for simplicity in presentation, but in fact the elements of the system are interactive and dynamic, and the entire process is continuously iterative.

Public planning, policy analysis, and coastal shoreland management decision-making processes

The actions component of the coastal management system illustrated by Fig. 2 consists of two key sub elements, including first the process that public decision-makers engage in making the planning, spending, and regulatory decisions they make, and second several key attributes of decision-makers themselves. Regarding the first sub element, Fig. 3 illustrates two models or frameworks for analyzing decision-making processes, situated within the larger coastal shoreland management system. The first is drawn from long-established and continually refined analytical and decision-making processes as studied and practiced through the urban and regional planning, public policy analysis, and public administration disciplines (e.g., Jenkins-Smith, 1990; Innes and Booher, 1999; Berke et al., 2006; Cullingworth and Caves, 2013), while the second is a more recently presented framework coming out of the environmental management discipline and referred to as structured decision-making (e.g., Gregory et al., 2012). Both decision-making frameworks envision essentially the same steps and activities, albeit configured in slightly different ways.

Importantly, both frameworks recognize the need to clarify the decision-making context and engage community visioning, identify reasonable alternatives for achieving desired goals, analyze those alternatives using specified criteria and methods, implement those alternatives through appropriate means, and then monitor and evaluate outputs and outcomes so as to revisit and improve future decisions (e.g., Berke et al., 2006). Because of that evaluative and iterative approach, both frameworks promote adaptive management (e.g., Lessard, 1998). Both recognize the need for meaningful public engagement to enhance the accuracy and utility of the knowledge used for decision-making and to enhance the legitimacy of decisions made (e.g., Innes and Booher, 1999). Both recognize the value of developing models that can be used to predict potential futures—including ecosystem responses to policy actions—and an array of analytical approaches to contemplate data and analyses, from more traditional predict-and-plan to more adaptive approaches (e.g., characterizing pros and cons of options rather than making definitive recommendations). Finally, both also recognize the increased uncertainties arising from global climate change and the benefits of using innovative approaches like scenario-based analysis to better incorporate those uncertainties into findings and recommendations (e.g., Norton et al., 2019).

This basic decision-making approach or method is generally applied for two purposes within development management pro-

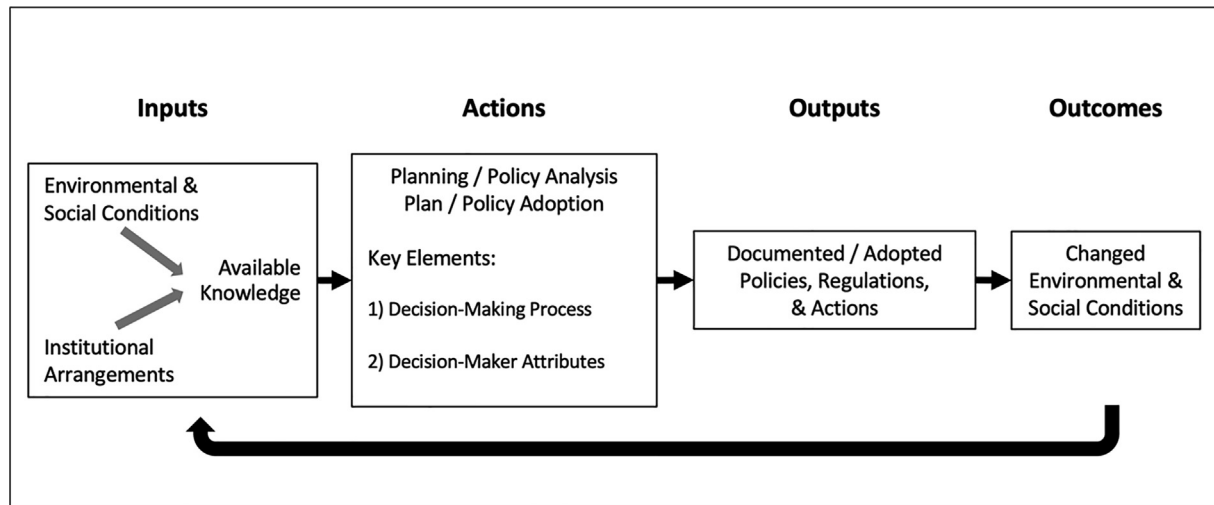


Fig. 2. Overview of coastal shoreland management system, based on an input-activity-output-outcome model of change.

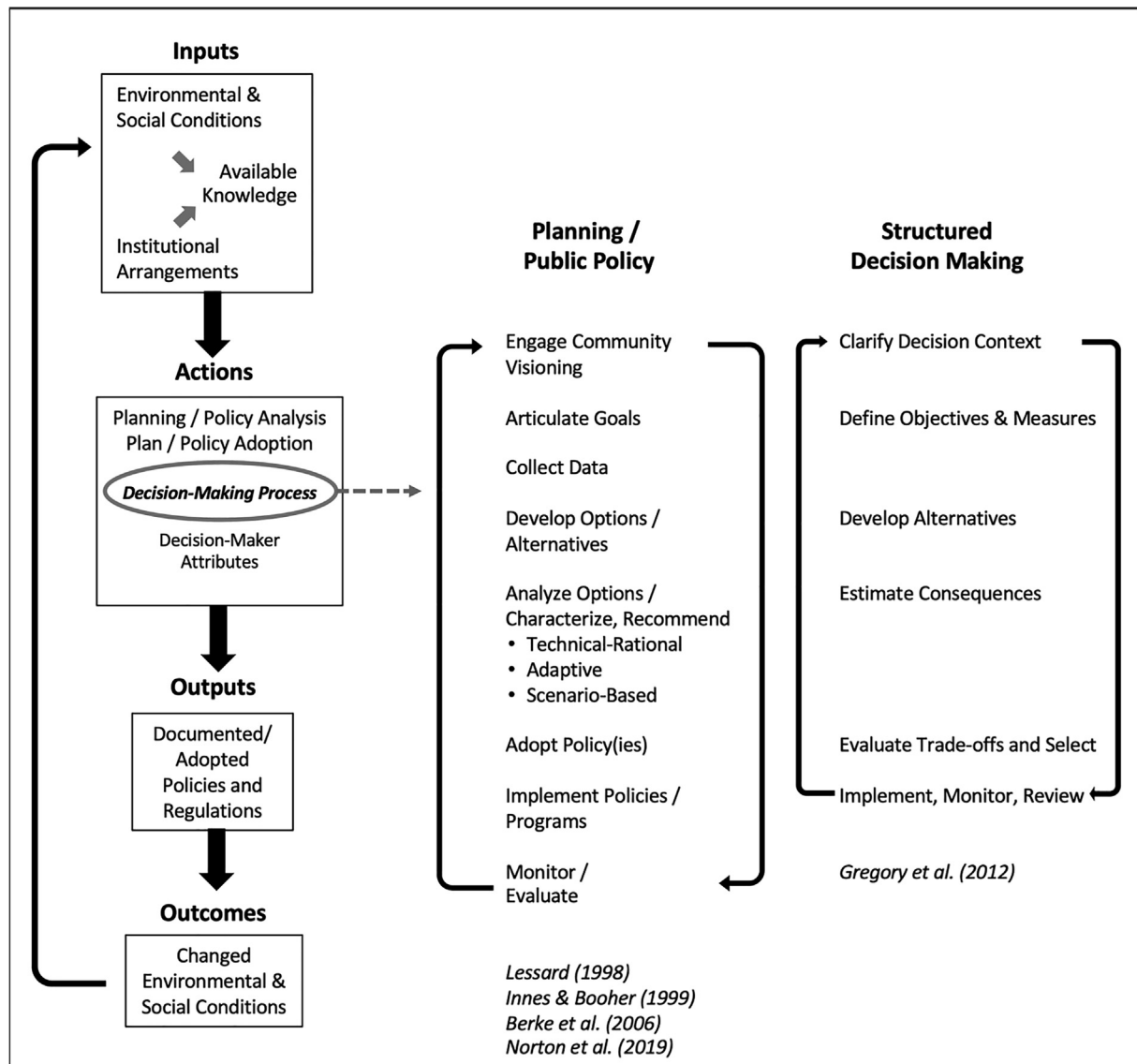


Fig. 3. Conceptual diagram illustrating two frameworks describing public policy decision-making processes within the public coastal shoreland management system, drawing from the planning, public policy analysis, and environmental management literatures.

grams broadly (and coastal shoreland management more specifically): plan or policy making (planning/policy analysis) and plan or policy implementation (plan/policy adoption) (Berke et al., 2006; Norton, 2008; Cullingworth and Caves, 2013). Planning includes the stakeholder engagement, information gathering, goal setting, data analysis, and other preparatory and analytical steps just described that officials engage to both identify reasonable options for action and to subsequently evaluate them iteratively (e.g., Elster, 1998; Innes and Booher, 2004; Berke et al., 2006). Planning and policy making also typically entails documenting the process engaged and the outputs produced from that process to guide implementation actions and for future reference (e.g., through a master plan or policy report).

Plans and policy reports are generally not enforceable legally, however; rather, they require implementation or adoption actions that are enforceable or legally significant (Porter, 2008; Norton, 2011). For development management, those actions typically include infrastructure decisions (e.g., specific scheduled expenditures for road building and maintenance); public facilities decisions (e.g., actual expenditures to site and maintain public facilities such as a town hall or park); regulation (i.e., the adoption or amendment of state resource protection laws or local zoning and subdivision ordinances); and public outreach or educational expenditures (Porter, 2008; Norton, 2011). These plan and policy implementation activities may or may not involve the extensive data gathering and public participatory elements typically engaged for plan making, depending on the nature of the particular decision itself and the legal requirements that structure it.

In engaging all these planning and plan implementation decision-making activities, public officials must follow a variety of legal and administrative policies and procedures, such as procedures specified both by state law and by a local zoning ordinance itself for amending and administering that ordinance. Those legal and administrative procedures also largely shape if not strictly prescribe the ways in which local officials engage non-governmental stakeholders in their decision-making efforts, such as through minimal, mandated public hearings for a permitting decision, or through more expansive public participation and community engagement workshops, working groups, and related methods for a master plan update.

Through these data collection, public outreach, and analytical processes, public decision-makers consider and weigh various economic, environmental, social, hazards-related, and other relevant conditions, along with the need for policy action and the potential consequences of alternative policy actions with regard to those conditions. Decision-makers also necessarily contemplate the legal requirements that frame their decision-making efforts, choices on how to conduct necessary analyses (e.g., using in-house staff or engaging consultants), the costs they face in conducting those analyses, the potential for controversy from their actions, their own views regarding the appropriate purposes of and roles for governmental action, considerations such as the imperatives of private property rights relative to potential governmental action, and so on (see generally Jenkins-Smith, 1990; Berke et al., 2006; Cullingworth and Caves, 2013; Platt, 2014; Norton et al., 2018a).

The conceptual frameworks for decision-making presented here do not prioritize a particular analytical discipline (e.g., economics vs environmental management), beyond acknowledging the necessity for ensuring meaningful public engagement and adequate consideration of the full array of relevant issues and perspectives implicated by the decision at hand (e.g., social and environmental as well as economic). Because public coastal shoreland management decisions typically implicate environmental and natural resource considerations, it is through the analytical elements of these decision-making processes—including especially the data (knowledge) gathering and public engagement elements of those

processes—that Great Lakes natural systems research scientists are most likely to engage. To maximize the potential for that engagement to be fruitful, it is also helpful to contemplate relevant attributes of public decision-makers themselves.

Decision-maker attributes

In addition to the analytical processes that decision-makers engage, the actions component of the conceptual framework presented here incorporates several key attributes of decision-makers themselves—attributes especially relevant for understanding the role of scientific knowledge within those decision-making processes. Fig. 4 situates those attributes within the public coastal shoreland management system.

Natural scientists deploying basic systems models, including socio-ecological models that expressly incorporate human decision-making processes, rarely if ever disaggregate or attempt to explain in any detail the human decision-making processes they incorporate, or contemplate relevant attributes of the decision-makers themselves undertaking those processes (see, e.g., Gunderson and Holling, 2001). Because the coastal management system is inherently a human decision-making system, however, and because the goal of this framework is to explain that human dimension in sufficient detail to assist scientists looking to engage with it, the framework presented here integrates expressly a model of human behavior. That model is adapted from the well-established theory of planned behavior presented by Ajzen several decades ago (1991), drawing from psychology and organizational behavior research. Ajzen was summarizing work designed to study systematically the factors that influence actual human behavior in general.

The theory of planned behavior, which is robust theoretically and well supported empirically, is useful for understanding the factors influencing behaviors in specific situations (i.e., as opposed to explaining general relationships), such as within a structured decision-making process. Beyond that, it is useful here in several additional respects as well. First, it highlights the fact that human behavior, including the act of making decisions, is purposive or ‘planned,’ not just mechanistic or automatic (e.g., Friedmann, 1987; Fischer and Forester, 1993; Haight, 2013; Hibbing et al., 2014; Lakoff, 2016).

Second, it distinguishes between a person's intent (or desire) to act, and her perceived self-efficacy—or capacity to act. As shown on Fig. 4, perceived capacity can influence intent directly, such as by diminishing an actor's intent or desire to behave in a way she believes she cannot act (or cannot execute well). Perceived capacity can also influence directly the performance of the behavior itself. A person may intend or want to act in a certain way, for example, but forebear because she believes she cannot (i.e., irrespective of her actual capacity; Ajzen, 1991). In a public decision-making context, an actor's perceived capacity to act may also be a function in part of how she perceives her legal authority to act, which may not comport with her actual legal authority to act (e.g., declining to support the adoption of new requirements through zoning for fear the authority to do so has not been duly enabled, even though objectively it has).

Third, the theory of planned behavior posits two additional independent sources of intent, including first the actors' attitude regarding the intent, and second social norms influencing the actor. Ajzen characterized these as independent variables, but he also conceptualized them as capable of influencing one another (i.e., not strictly independent). Drawing from the premises about human behavior noted above, these two factors can be conceptualized for purposes here as, first, an actor's heuristic understanding of extant environmental and social conditions, along with her heuristic causal understanding of the effectiveness or appropriate-

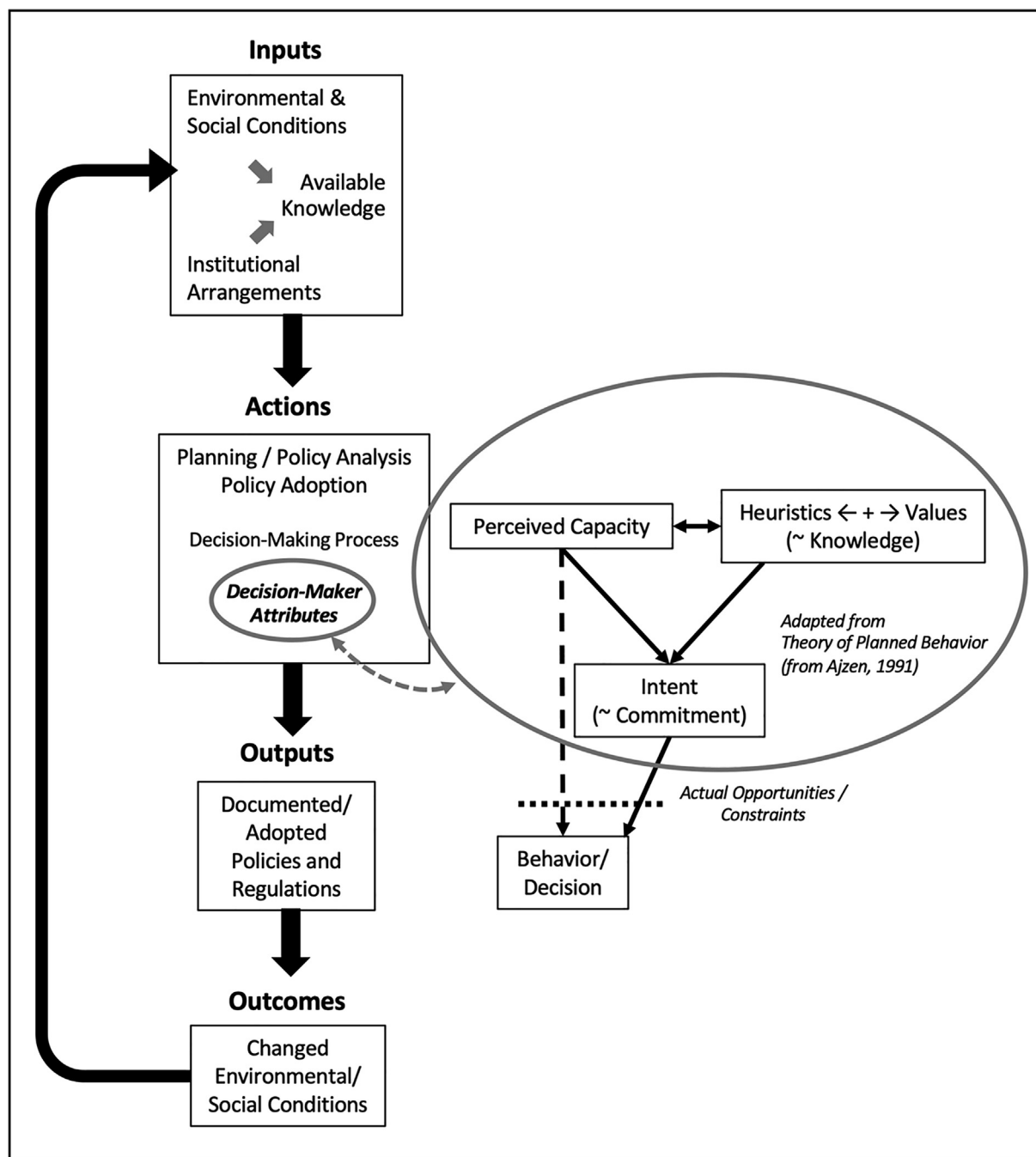


Fig. 4. Conceptual diagram illustrating key decision-maker attributes within the coastal shoreland management system, drawing from and adapting the theory of planned behavior.

ness of a potential action ('heuristics' on Fig. 4), and second her understanding of the importance and force of the rightness or wrongness of that action ('values'), respectively.

Note that while this model of human behavior acknowledges the importance of heuristics and value systems in shaping decision-makers' understanding of relevant facts, in conjunction with their commitment to policy goals or public action, it does not presume or fix those heuristics or values for analytical purposes. Use of this model, for example, does not presume that decision-makers are first-and-foremost utility-maximizing economic actors, as does rational choice theory in the policy science literatures (e.g., Lupia et al., 2000), or alternatively that they do or should prioritize biophilic values over others.

Great Lakes public coastal shoreland management decision-making

As noted, the analyses and other activities decision-makers undertake as described above, combined with selected key attributes of those decision-makers themselves, together comprise the actions element of a development management system. A basic public decision-making framework is helpful for understanding that system more generally, but it can be improved through slight modification to better represent coastal shoreland management decision-making processes specifically. Figs. 5, 6, and 7 present variations on the basic model just described that each highlight several important aspects of it. First, Fig. 5 integrates the elements

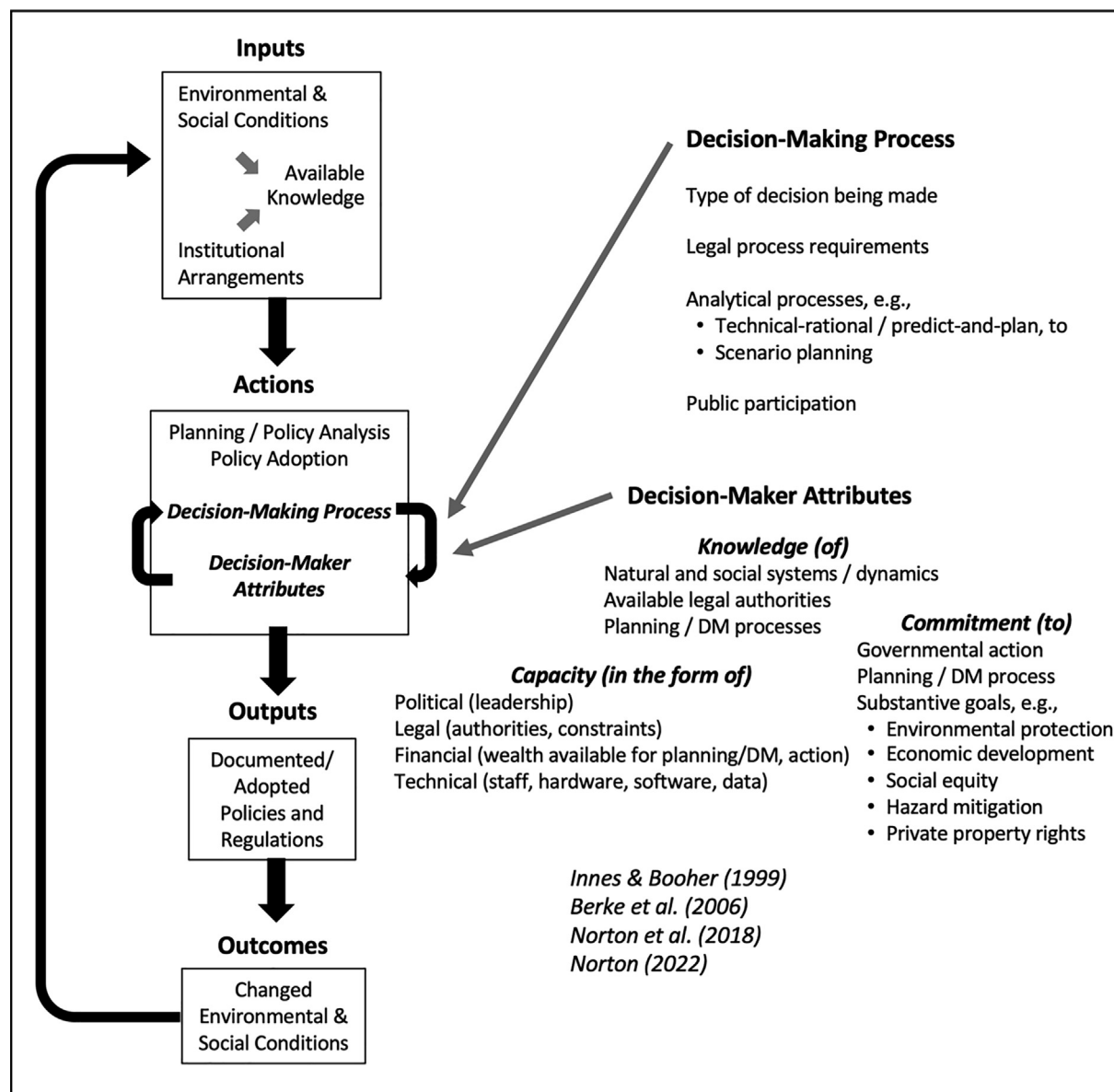


Fig. 5. Public coastal shoreland management conceptual framework integrating and detailing the sub elements of the 'actions' or decision-making component of that framework.

presented by Figs. 3 and 4, and it translates the theory of planned behavior into a coastal management context.

The modifications shown on Fig. 5 are drawn from urban planning and public administration literatures that have addressed land use planning and development management processes particularly in the contexts of coastal management, environmental protection, and hazard mitigation (adapting and synthesizing primarily from the work of May et al., 1996; Burby et al., 1999; Beatley, et al., 2002; Norton, 2005a, 2005b, 2005c, 2008; Beatley, 2009; Platt, 2014; Hamin et al., 2014; Norton et al., 2018a; Peterson, 2019; Kousky et al., 2021). The various elements of this framework are largely consistent with parallel conceptualizations provided by scholars from other disciplines, such as extensive work on concepts of community capacity drawn from the environmental management literature (see, e.g., deLoe et al., 2002; Ivey et al., 2004; Cheng and Sturtevant, 2012), although the particularities of each reflects the traditions, topics of interest, and purposes for the various frameworks as deployed by each discipline.

As with the prior figures and for ease of illustration, Fig. 5 frames the decision-making process as linear and looping. In reality, again, the interactions between the components of this framework are more interconnected, recursive, and iterative than shown. Moreover, despite the busyness of this conceptual framework, it still simplifies considerably the multiple and overlapping roles of the various public officials involved in coastal shoreland management decision-making; the complex, multi-layered, and interrelated decisions those local officials make; and the various procedures they follow in doing so.

The first modification to note, particularly with regard to decision-maker attributes, is that planning and public administration scholars have characterized those attributes in terms of 'knowledge,' 'capacity,' and 'commitment' (i.e., in place of heuristics, perceived capacity, and values/intent as shown on Fig. 4). Second, all these attributes can be conceptualized as attributes that are held individually when a single official is acting alone, such as a zoning administrator issuing a permit, and collectively when a public body is acting as a body, such as a planning commission

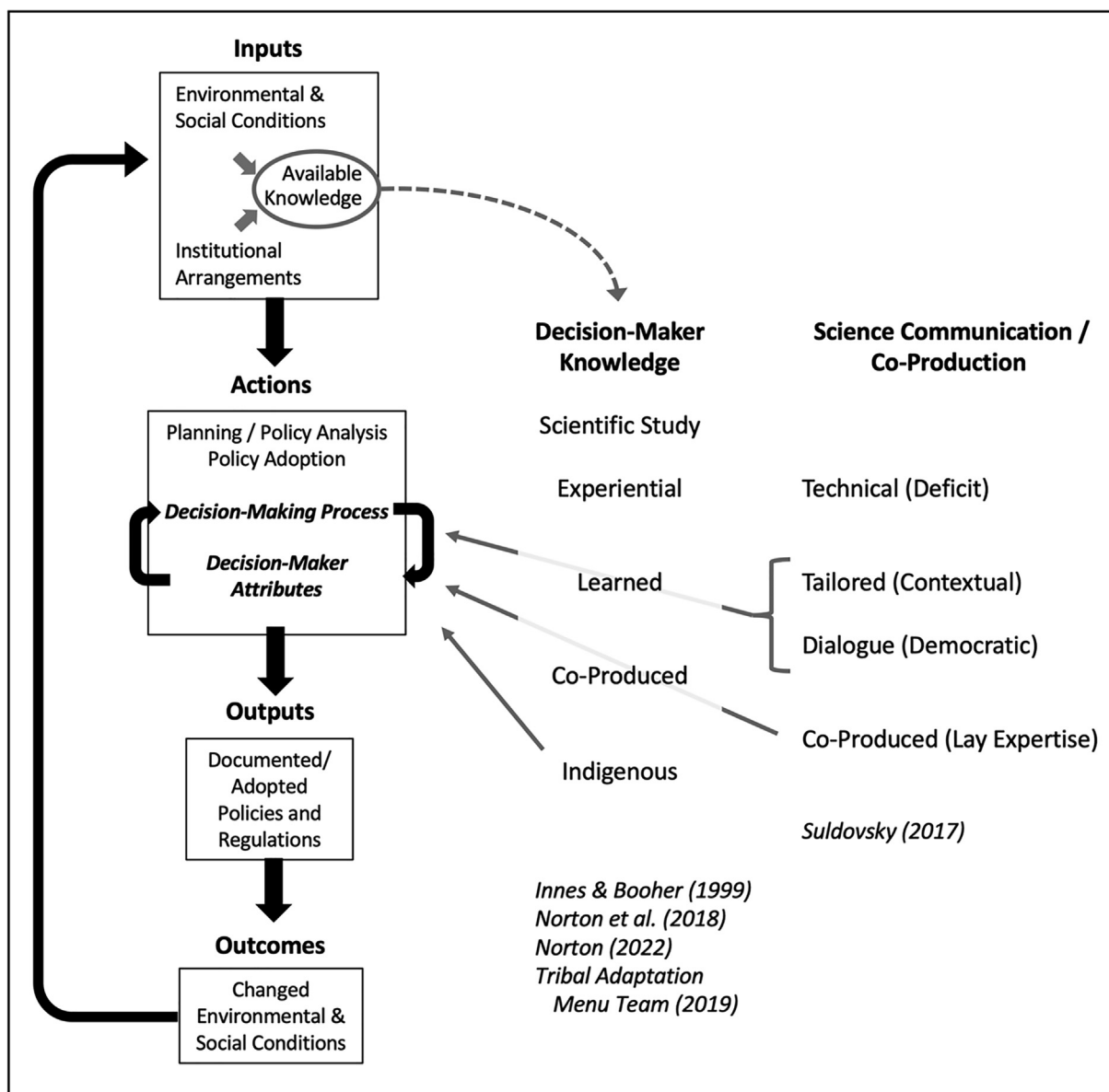


Fig. 6. Modes of science communication in relation to public coastal shoreland management decision-makers' understanding and use of scientific knowledge.

or city council adopting a master plan or amending a zoning ordinance (i.e., contemplating the collective knowledge, capacity, or commitment of a majority of the commission or council; see, e.g., Norton et al., 2018a).

With those initial observations, it is important to recognize that while public officials may understand a given phenomenon and be committed to addressing it, they may lack the capacity to do so at all, or they may be constrained in their ability to address it fully (or perhaps perceive that they lack capacity that, in fact, they have). Public decision-maker capacity to act encompasses several dimensions (Norton et al., 2018a). It includes, first, the reach and limits of decision-makers' legal authorities to act, such as their authorities to impose taxes, provide incentives, enact regulations, and so on. Second, it includes their collective political capacity to act, enlivened particularly in the form of entrepreneurial and courageous political leadership. Third, it includes the availability of technical capacity, typically in the form of professional staff, along with access to needed hardware, software, and data for analytical tasks. And finally, it includes financial capacity, typically conceptualized as the level of community wealth available to engage in coastal

management decision-making processes (which, in turn, can provide or enhance technical and political capacity).

Commitment to act similarly encompasses several dimensions (Norton et al., 2018a). It is important to recognize initially that public decision-makers may themselves be more-or-less committed to governmental action as an appropriate means to address coastal hazards mitigation or ecosystem health in the first place. Beyond that, commitment can be distinguished in terms of commitment to the planning and plan implementation process, on the one hand, and commitment to any number of substantive policy goals, on the other. Procedurally, for example, public officials may be more or less committed to the use of planning and public policy analysis processes to inform governmental action (Norton, 2005a; Norton et al., 2018a), even if they agree that government should play some role (i.e., possibly preferring political decision-making alone). This aspect of commitment to process is shaped largely by public officials' own ideological beliefs, constituent demands, and prevailing social-political climates (Norton et al., 2018a). Substantively, public decision-makers are typically committed both individually and collectively to multiple policy goals,

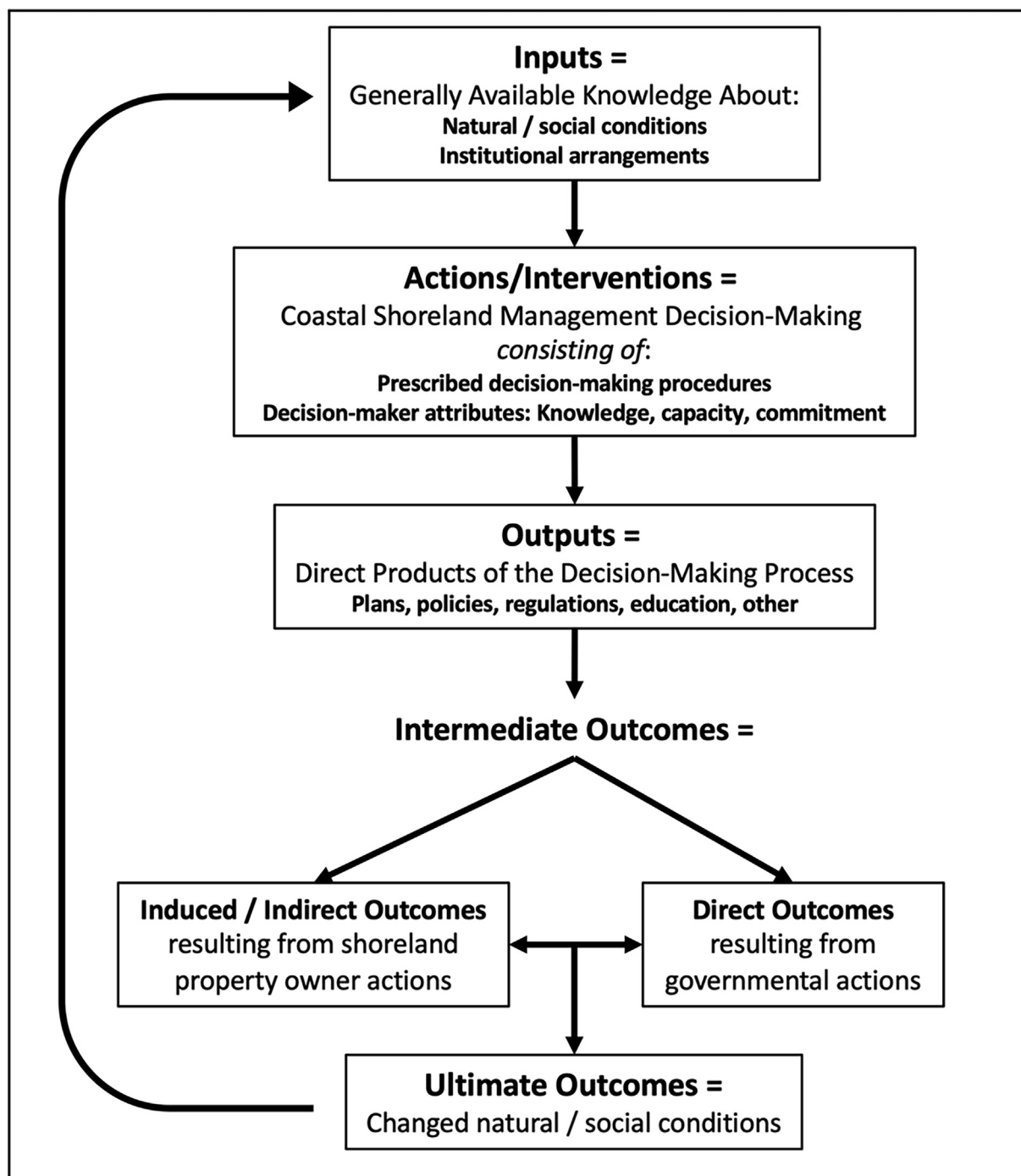


Fig. 7. Overall public coastal shoreland management framework, distinguishing intermediate from ultimate outcomes.

including goals such as environmental protection, economic development, hazards mitigation, and safeguarding private property rights (Norton 2005b, 2005c; Norton et al., 2018a). Because one or more of those goals may be directly contradictory to others, especially in highly dynamic coastal settings, reconciling those goals (and enhancing commitment to any one of them) can necessitate prioritization and trade-offs, whether acknowledged explicitly or not.

Finally, decision-maker 'knowledge' similarly encompasses both procedural and substantive knowledge. Procedural knowledge includes, for example, decision-makers' individual and collective understandings of the legal authorities they actually enjoy. As

discussed above, numerous actors are involved in complex coastal shoreland management systems and each often plays a unique role legally as a governmental actor, such that public officials may not fully comprehend what responsibilities or authorities they have, or what constraints they face (see, e.g., Norton 2011). Similarly, they may vary substantially in their individual and collective understandings of the planning, policymaking, regulatory, and other public administrative processes they need follow to engage those authorities (Norton, 2011; Norton et al., 2018a).

In addition to procedural knowledge, substantive knowledge includes, for example, familiarity with ongoing changes to natural and social systems because of things like impacts from global cli-

mate change or the placement of seawalls on shorelines; that is, it speaks to the kinds of knowledge Great Lakes natural systems researchers are most likely to contribute to public coastal shoreland management decision-making processes.

Fig. 6 integrates concepts from the science communication literature discussed above with the decision-making framework presented here, illustrating that both procedural and especially substantive knowledge can be obtained by decision-makers in several ways. Decision-makers themselves may have scientific knowledge gained through direct systematic empirical investigation, if they are trained scientists knowledgeable about the phenomena at hand—sometimes the case, but often not so for public coastal shoreland management. Beyond that, all decision-makers bring some level of experiential knowledge to their tasks, including knowledge obtained through life experiences, or through direct experience with the decision-making process itself, or through experience with external phenomena while in office (e.g., experiencing an extreme coastal storm while in office and having to respond to it as a public official; see, e.g., May et al., 1996). Finally, public decision-makers may learn new knowledge through the decision-making process itself by, for example, participating in training programs or community planning workshops (learning through the tailored or dialogue models of science communication), or they may participate in the co-production of new knowledge through participation in a community-engaged research effort (learning through the knowledge co-production model of communication).

Outputs and outcomes

It is important to restate again that decision-makers learn and engage scientific knowledge in these various ways in conjunction with their capacity to act and their commitment to doing so for any given decision-making process or action. Commitment especially, in terms of both the strength and prioritization of commitment to various, often competing, policy goals, shapes the way decision-makers approach their tasks, and capacity and/or commitment may ultimately determine their decisions despite whatever scientific knowledge is put in front of them (see, e.g., Hibbing et al., 2014; Lakoff, 2016). At the same time, the decision-making process itself can provide feedback that modifies one or more core attributes. New and compelling scientific information presented by researchers through stakeholder-engagement activities, for example, can change the way public officials know of a given policy problem, or their understanding of potential solutions to that problem, or their commitment to competing policy goals, or the commitment to undertaking public action to advance those goals, and so on (Innes and Booher, 2004; Hibbing et al., 2014; Lakoff, 2016).

Having completed the decision-making process, the outputs from them flow directly from the activities engaged. As noted, they typically include: the policy reporting or planning documents adopted, which serve especially to document the key facts found, goals prioritized, analytical methods employed, and policies adopted; training programs designed to provide broad public education on key topics and community actions; the variety of infrastructure and related policies adopted and administered (e.g., policies speaking to infrastructure provision and redevelopment, public facilities siting); and the variety of regulations enacted and administered (e.g., state permitting programs, permitting actions taken, local zoning code and subdivision ordinance provisions enacted, zoning actions taken). These outputs can be characterized collectively as the plan or policy implementation program, the development management program, or the coastal management program (Norton, 2008).

A final distinction to note regarding this public coastal management decision-making framework relates to outcomes. Specifically, as illustrated by Fig. 7, a public coastal shoreland management system encompasses two distinct kinds of public actions or outputs, yielding in turn two kinds of outcomes: those that shape shoreland use by influencing the decisions that private actors (or other governmental actors) take in using their shoreland properties; and those that shape shoreland use directly (Norton, 2008). The first kind includes, for example, regulations and tax policies that compel or incentivize property owners to use their shorelands—or not—in particular ways (e.g., in terms of what kinds of structures to build on their shoreland properties and where to place them), which may or may not yield the environmental or social outcomes intended. These outcomes can be characterized as induced or indirect intermediate outcomes. The second kind of action includes, for example, governmental decisions to build roads, dams, or other infrastructure to serve private shoreland owners' or general public needs, which can be characterized as direct outcomes. These 'intermediate' indirect and direct-action outcomes then shape the ultimate environmental and social outcomes observed. They may do so independently, but they also often work synergistically, such as when new road service prompts increased homebuilding on privately owned coastal shorelands zoned for residential development.

Conclusions

Researchers who generate scientific knowledge demonstrating ongoing degradation of coastal resources from various ongoing coastal shoreland uses and activities can easily conclude that scientific knowledge is not adequately informing the public policies that shape those land uses. More broadly, one can easily conclude that science is not adequately informing Great Lakes coastal management policy in general, given those and similar outcomes basin wide. Some researchers in the Great Lakes science community have approached this and related problems from the perspective of reforming public decision-making processes so that they incorporate better the scientific knowledge that is available. Some have focused more on the need to better communicate scientific knowledge to decision-makers in the first place, or perhaps even to collaborate with decision-makers and other stakeholders to produce scientific knowledge that is more policy relevant and useful. All these efforts warrant continued work.

Especially for researchers looking to do the latter, any successes in communicating scientific knowledge through direct engagement with policy decision-makers will likely be enhanced if those researchers have at least a working understanding of the policy system they engage. It is not enough to know the science; it is necessary (or at least helpful) to understand the decision-makers as well, along with the tasks they face and the procedures they will follow in using the science presented to them. The conceptual framework presented here should provide a helpful start toward that end. Having presented that framework, some final considerations might facilitate further its application.

First, hopefully the framework makes clear that 'knowing' something needs to be done to better protect fragile habitats, for example, does not automatically answer the questions of who should act, how they should act, or why they should do so. The decision-making processes societies create to act collectively toward social goals like environmental protection can be just as complex as the natural systems they address, and perhaps even more inscrutable. With the general decision-making framework presented here as a reference, researchers will need to investigate and tailor their understanding of the particulars of the decision-making process they hope to engage. They should contemplate

specifically for that endeavor, for example, who exactly the relevant decision-makers are, what their decision-making responsibilities are, what processes they regularly do (or must) follow in making their decisions, what capacities they have to internalize, digest, and act on that knowledge, what various motivations shape their commitment to doing so, what kinds of decisions their efforts will yield, and what other institutional constraints or mandates they face.

Second, researchers looking to engage with decision-makers and decision-making processes should bear in mind both basic premises regarding individual and collective human behavior and the decision-making structures that influence them. Because decision-makers act through belief systems comprised in part of a heuristic understanding of conditions and causal relationships, providing apt and accurate scientific facts can benefit them, but sometimes their heuristic beliefs about what those facts mean or whether they are accurate matter more. Similarly, public officials may have a mistaken belief that they cannot or should not act on information presented to them because of perceived institutional constraints imposed on them. Local officials, for example, may mistakenly believe their authorities to constrain environmentally damaging land uses through zoning are more limited than they actually are. Or there may in fact be limited technical capacities or legal constraints in a particular setting that prevent desirable decision-maker action, such that providing relevant knowledge may have little effect on the decision to be made. State officials charged with issuing permits, for example, may be required to issue them under applicable rules even though they have compelling evidence that environmental harms will result.

Similarly, researchers looking to engage should always bear in mind that decision-makers themselves are moral agents and the decision-making processes they follow necessarily incorporate values. Often multiple values are at play that can conflict with one another, and sometimes strongly held values can trump every other consideration. Thus, decision-makers' values can sometimes prompt them to disregard the facts, for example. Or a decision-maker may diminish the perceived importance of well-established facts because the implications of those facts do not support, or might even undermine, the advancement of deeply held values. Finally, especially for public policy decisions made collectively, such as by legislative bodies or planning commissions, a host of values and policy goals will almost certainly be in play. Some will be biophilic, others not. To the extent researchers hope to ensure not just that policy decisions are more science-informed but also environmentally respectful, if not protective, they should be prepared to engage both their knowledge and their own values. Or they should at least be prepared to recognize that others' values may properly prevail in a democratic system that must necessarily reconcile and prioritize the pluralistic values of its constituents.

Finally, researchers looking to better inform public policy should recognize that the framework presented here can be used both to engage more effectively within decision-making processes as they currently exist, and to identify reasons for which and ways in which those processes may need to be reformed. If state permitting systems compel state agents to issue permits for coastal shoreland uses and activities that clearly cause environmental harms, for example, perhaps that permitting system should be reformed to change the rules directing the state agents' actions. Appropriate and accurate scientific knowledge can be useful especially for better understanding the key leverage points in complex public coastal shoreland management systems where science is not being adequately considered, as well as for better understanding the full consequences of failing to reform the process accordingly.

In the end, scientists should bring their best available scientific knowledge to the policy table and engage with policy decision-

makers in making their decisions, and scientists should stand ready to help reform those decision-making processes when it becomes clear they are in need of reform. To ensure that the best available science truly informs either and both of those endeavors, scientists should have a good understanding of how best to deploy their scientific knowledge too.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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