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Understanding the use of ecosystem service knowledge in decision making: lessons from international experiences of spatial planning

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Abstract. The limited understanding of how ecosystem service knowledge (ESK) is used in decision making constrains our ability to learn from, replicate, and convey success stories. We explore use of ESK in decision making in three international cases: national coastal planning in Belize; regional marine spatial planning on Vancouver Island, Canada; and regional land-use planning on the island of Oahu, Hawaii. Decision makers, scientists, and stakeholders collaborated in each case to use a standardized ecosystem service accounting tool to inform spatial planning. We evaluate interview, survey, and observation data to assess evidence of 'conceptual', 'strategic', and 'instrumental' use of ESK. We find evidence of all modes: conceptual use dominates early planning, while strategic and instrumental uses occur iteratively in middle and late stages. Conceptual and strategic uses of ESK build understanding and compromise that facilitate instrumental use. We highlight attributes of ESK, characteristics of the process, and general conditions that appear to affect how knowledge is used. Meaningful participation, scenario development, and integration of local and traditional knowledge emerge as important for particular uses.

Keywords: knowledge use, ecosystem services, spatial planning, decision making, science–policy interface

Introduction

Since the publication of the Millennium Ecosystem Assessment (MEA) in 2005, ecosystem service (ES) research has surged (Seppelt et al, 2011; Vihervaara et al, 2010). Studies often aim to inform decisions (Daily et al, 2009; MEA, 2005a; 2005b; NRC, 2004). Politicians, practitioners, and researchers have asserted ambitious claims about the utility of taking an ES approach: that considering the benefits that nature provides to people can transform decisions and thereby improve outcomes for human well-being, biodiversity, and ecosystem condition (TEEB, 2010). Few studies describe and explain the use of science in public policy generally (National Research Council, 2012) or of ES science in particular. It is rare to find systematic evaluations of when and how ES knowledge (ESK) is used, or the conditions that enable use (Ash et al, 2010; Laurans et al, 2013). Examples are often based on personal communications rather than systematic evaluation (McKenzie et al, 2010; Naidoo et al, 2009). Literature, guidelines, and tools describing the value of ESK in decisions are usually hypothetical or based on broad, general principles (eg, Bingham et al, 1995; Daily and Matson, 2008; Hanson et al, 2008; NRC, 2004; TEEB, 2010). The few existing studies evaluating use suggest ES research often has no—or limited—impact on decision making (Daily and Matson, 2008; Kushner et al, 2012; Laurans et al, 2013; Spilsbury and Nasi, 2006). Ruckelshaus et al (in press) make progress by contributing a framework for how ES accounting models are used and have an impact in several interconnected ways, drawing on twenty case studies.

The limited understanding of *how* ESK is used constrains our ability to learn from, replicate, and convey compelling stories of impact. We address this gap by exploring how ESK is used in decision making in three cases of spatial planning. Specifically, we test three established modes of knowledge utilization: instrumental, conceptual, and strategic use (Rich, 1997; Weiss, 1979). To our knowledge, this is the first study that explores evidence of how ES and scenario knowledge is generated and applied to support spatial planning, testing three established modes of use. Filling this gap in understanding is urgent and important, given the growth in natural capital accounting in both the public and private sectors. Commitments to natural capital accounting have been made through, for example, the Natural Capital Declaration in which CEOs from the finance industry committed to integrate natural capital considerations into products and services (http://www.naturalcapitaldeclaration.org). Uptake is encouraged and enabled by recently established efforts, such as the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (http://www.ipbes.net), The TEEB for Business Coalition (http:/www.teebforbusiness.org), and the World Bank Wealth Accounting and Valuation of Ecosystem Services initiative (http://www.wavespartnership.org). Filling the gap in our understanding about how and under what conditions ESK is used is essential for new natural capital accounts to be more than academic exercises. Our research provides a foundation of insights and lessons for researchers and practitioners to learn from as they begin projects that aim to generate and use ESK to inform decisions and achieve better outcomes for biodiversity and people's well-being (Laurans et al, 2013).

Table 1. Modes of knowledge use.

Mode of use	Definition
Instrumental	knowledge flows from scientists to rational decision makers who make observable decisions on technical grounds
Conceptual	knowledge broadens and deepens understanding, shapes thinking, and enables people to develop new beliefs and values
Strategic	knowledge is used to support and promote a specific intervention or policy option, or justify previously held beliefs and values

For each case we use qualitative methods (in-depth informant interviews and observation and survey data) to assess which modes of knowledge utilization (table 1) occur, when they occur, and who uses ESK in these ways (table 2, table 3, and figure 1). We also present preliminary findings about conditions that enable particular modes of use (table 4). In closing, we summarize the main lessons from the cases and recommendations for future research

Modes of use of ecosystem service knowledge

As highlighted in the UK National Ecosystem Assessment (Waylen and Young, 2014), many ES studies expect, assume, or seek 'instrumental' use of ESK (Davoudi, 2006). In this mode of use, knowledge flows linearly from scientists to rational decision makers who make observable decisions on technical grounds (MEA, 2005a; 2005b; NRC, 2004). Instrumental use of ESK is often framed in three contexts of correcting market failure. First, ESK is used within decision-support processes such as cost–benefit or cost-effectiveness analyses to select among alternative options on the basis of a comparison of advantages and disadvantages (Bingham et al, 1995; DeFries et al, 2004; Hockley, 2014; NRC, 2004). Second, ESK is used to revise standard indicators or national accounts frameworks, which are assumed to determine budgetary allocations and policy priorities (Dasgupta et al, 2000; UNU-IHDP and UNEP, 2012). Third, ESK is used to design policy and finance mechanisms, such as payments for ecosystem services, to create new incentives and revenue for ES conservation and restoration, and poverty alleviation (Engel et al, 2008). Decision makers are assumed to apply the results of ES research directly to generate a solution to a particular problem; select among alternative policies, plans, or programs; or design and implement cost-effective policy and finance mechanisms, to achieve agreed goals. When such instrumental use is not observed, a common conclusion is that ESK is not used at all. Recommendations to address this often aim to conduct analyses at more relevant scales (Kremen, 2005; Turner and Daily, 2008), make scientific knowledge more pervasive and accessible through tool development (Daily et al, 2009), or improve the communication of ESK (de Groot et al, 2010).

The focus on instrumental use is not unique to the ES field. It also prevails in health and social policy (Almeida and Báscolo, 2006; Boswell, 2008). However, much can be learned from recent work on knowledge utilization, drawing on political science, public policy, science and technology studies, and evaluation. This work explores interactions between the supply of, and demand for, ESK in different contexts (Ashford and LeCroy, 1991; Bedell et al, 1985; Bogenschneider et al, 2000; Boyer and Langbein, 1991; Dunlop, 2014; Estabrooks, 1999; Jordan and Russel, 2014; Patton et al, 1977; Peterson, 1995). There is extensive theoretical critique of the 'technical–rational' model on which instrumental use is based and empirical evidence that knowledge is rarely used instrumentally (Davoudi, 2006; Hertin et al, 2009; Owens et al, 2004; 2006). Indeed, the policy process is more complex than assumed: policy change occurs over long timescales, through both linear and nonlinear interactions that are sometimes difficult to observe, let alone measure (In't Veld and deWit, 2000; Kingdon, 1995; Kőrnőv and Thissen, 2000; Sabatier, 2007). Research in the policy sciences provides different understandings of how decisions are made. Various theories, such as the advocacy coalition framework, have been tested empirically. Findings indicate that decisions are often developed through strategic interactions between different interest groups as they bargain, negotiate, or alter power relationships (Sabatier, 1988; Sabatier and Jenkins-Smith, 1993).

In this context, two additional modes of knowledge utilization emerge (Almeida and Báscolo, 2006; Owens, 2005; Trostle et al, 1999; Weiss, 1979). First, in the 'conceptual' mode knowledge broadens and deepens understanding of topics and shapes the way people think about policy issues. Decision makers and stakeholders learn about emerging problems and potential solutions, and develop new beliefs and values (Garret and Islam, 1988;

Karl et al, 2007; Olsson et al, 2008; van Kerkhoff and Lebel, 2006; Weiss, 1979). This iterative process gradually redefines the policy agenda over time. It may eventually alter behavior among individuals and organizations and lead to policy change if external events create windows of opportunity (Kingdon, 1995; Sabatier, 1987). In the second 'strategic' mode knowledge is used to support a particular intervention, promote new policy options, or justify previously held beliefs and values (Boswell, 2008; Garret and Islam, 1988). Weiss (1979) proposes that conceptual use is most pervasive, but instrumental and strategic use also occur.

The focus on instrumental use in the ES literature may owe to the field's early intellectual foundations in ecology and economics, with weaker links to political science. Commentators recognize conceptual use insofar as ESK changes discussions about links between conservation and development (de Groot et al, 2010; MEA, 2010) and influences the social psychology of decision making (Daily et al, 2009). Very few studies acknowledge strategic use—perhaps reflecting circumspection that strategic use is political and therefore inappropriate for application of research (Ash et al, 2010; Boswell, 2008).

Introduction to three cases that use ecosystem service knowledge in spatial planning

We seek to assess how, when, and by whom ESK was used in three cases—land-use planning by a private landowner on the North Shore of the island of Oahu, Hawaii; and two instances of marine spatial planning—to develop a national coastal plan for Belize and an integrated regional marine plan on the west coast of Vancouver Island, Canada.

In each case scientists, stakeholders, and policy makers used a set of standardized ES accounting tools called InVEST (Integrated Valuation of Environmental Services and Tradeoffs), developed by the Natural Capital Project,[1] to map, quantify, and, in some cases, value in monetary terms the provision of multiple ES under alternative future scenarios. InVEST is an open-source software platform that includes terrestrial, freshwater, and marine models (Tallis et al, 2012). Each model uses production functions to estimate changes in ES values under different human use and climate scenarios (Guerry et al, 2012; Kareiva et al, 2011; Nelson et al, 2009; Tallis and Polasky, 2009). InVEST models have been applied, tested, and refined in more than twenty decision contexts around the world (Ruckelshaus et al, in press). Here we focus on three of these cases.

We selected these cases for four reasons. First, indications suggested ESK was used in each case, which allowed us to explore patterns of use—how, when, and by whom knowledge was used—rather than whether knowledge was used per se. Second, the three cases had important similarities. Each case entailed participatory spatial planning; involved island and coastal communities working with scientists and decision makers; shared goals to use the land and ocean to balance benefits to people; involved researchers with expertise in spatial planning and ES quantification; and used the same standardized ES accounting tool (InVEST). By selecting three cases that used similar ESK in similar participatory processes and decision contexts with similar goals, we could explore factors that varied across cases and affected how ESK was used. Third, in two of the cases authors were directly involved as scientific researchers which enabled them to gather observation data and access key actors. Finally, each planning process was sufficiently advanced—over a number of years—to assess how ESK use evolved over time. In this section we introduce each case with specific attention to the decision context and ESK outputs.

[1] The Natural Capital Project was formed in 2006 by the World Wildlife Fund (WWF), The Nature Conservancy, Stanford University, and the University of Minnesota, under the premise that information on biodiversity and ES can be used to inform decisions that improve human well-being and the condition of ecosystems (see http://www.naturalcapitalproject.org and Natural Capital Project, 2010).

Belize—developing a national Integrated Coastal Zone Management Plan

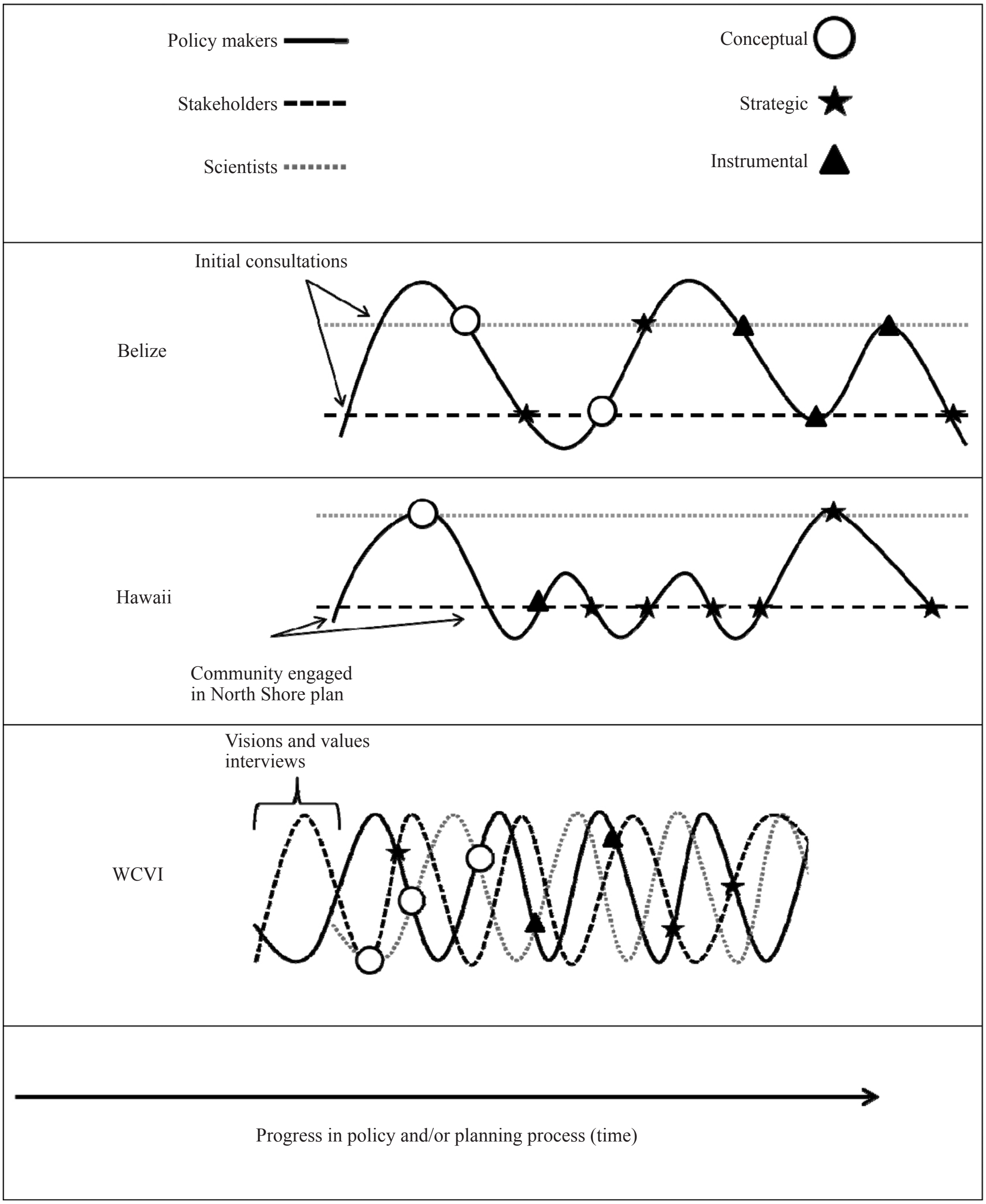
In 2010 Belize's Coastal Zone Management Authority and Institute (CZMAI) began to develop the country's first national Integrated Coastal Zone Management Plan. Established in 1998, CZMAI has a mandate to create a national plan that creates guidelines to develop the coastline sustainably for the long-term benefits of the Belizean people (Government of Belize, 2000). Policy makers at CZMAI formed a partnership with scientists at the Natural Capital Project and the WWF, a global conservation NGO, to create a science-based management plan for the Belize coastal region to designate areas for preservation, restoration, development, and other uses of the coastal and marine environment, on the basis of maps and quantitative ES assessments.

CZMAI developed the plan through an iterative process of stakeholder visioning, scientific research and development, stakeholder review, and policy development (figure 1). Two of the primary venues for engaging with stakeholders were public consultations at the national and regional levels and Coastal Advisory Committees (CACs)—councils of eight to fourteen regional representatives, formed in most of Belize's nine coastal regions. A diverse group of community leaders was invited by CZMAI to participate in each CAC; in most cases representing private industries, such as tourism and fishing, local and national government, and community development and environmental organizations. Many CAC members had participated in previous planning processes with government agencies and/or CZMAI. They voted on a president who facilitated the process; in that person's absence, CZMAI often played a facilitation role. Major roles of the CAC were to review scientific and policy inputs to the plan; offer local knowledge, data, and regional preferences; and review plan components. The CAC process involved exchange of information and open debate, through a series of meetings (typically one to six), workshops, and field trips.

In consultation with government departments, CACs, and others in the private and public sectors, CZMAI and the Natural Capital Project designed three scenarios around contrasting zoning options for the plan. The first scenario prioritizes environmental preservation; the second prioritizes rapid economic development; and the third draws a compromise between the two extremes by means of an informed management approach that incorporates both environmental and development objectives. With the use of InVEST models, CZMAI, scientists from the Natural Capital Project, and stakeholders assessed the impact of these alternative scenarios on three ESs—spiny lobster fisheries, tourism and recreation, and coastal protection from storms and inundation—and on habitat for culturally important species. These ESs were originally selected by CZMAI and confirmed by CAC stakeholders during regional meetings held over a year. Scenarios were presented and refined repeatedly with stakeholders throughout the same period. CZMAI developed zoning and use recommendations that reflect this iterative scenario development and draw on stakeholder input and ES information. The recommendations have been submitted for public comment. In 2014 the plan will be submitted to Belize's national legislature for approval as law.

Hawaii—developing a strategic land-use plan

Kamehameha Schools (KS) is an educational trust and the largest private landowner in Hawaii. KS invited scientists from the Natural Capital Project to map and quantify ESs to inform the design of a strategic land-use plan for a region of their land holdings along the North Shore of the island of Oahu. This plan sought to achieve a balance among environmental, economic, educational, cultural, and community values, as articulated in KS's strategic planning approach. KS engaged stakeholders (those affected by land-use decisions, including representatives from conservation, agricultural, urban, and private business communities) in a community planning process through a series of community meetings. The scientific team, which included scientists from both KS and the Natural Capital Project, conducted their ES



Notes: Following Reid et al (2009), this diagram illustrates the process through which policy makers, stakeholders, and scientists interact to jointly produce and use ESK as they develop a spatial plan. Each line represents a user group. Circles, stars, and triangles represent points where user groups use ESK in a particular way. Parallel tracks indicate no direct interaction between groups; weaving tracks depict use points when both groups are using ESK in the same way or when one group is the knowledge user and another group is the knowledge recipient. WCVI = West Coast Vancouver Island.

Figure 1. Different modes of ecosystem service knowledge (ESK) use as groups interact in iterative spatial planning processes.

analysis after the participatory planning process had begun and completed the analysis before the plan was released.

KS designs plans for how to use its lands, although these must comply with relevant public land-use regulations at both state and county levels. Decision makers at KS worked with scientists from the Natural Capital Project to quantify the likelihood that different plans would achieve their environmental goals under alternative land-use planning scenarios, and to explore the links among environmental, economic, and community values. The perception that this area on the North Shore of Oahu was an 'economically and agriculturally underperforming asset' motivated the decision to embark on a planning process. A pressing management decision framed the scenarios: whether to invest in fixing the region's aging irrigation infrastructure or to pursue alternative uses of the land (Goldstein et al, 2012a). KS drew from the community planning process and conversations with Natural Capital Project scientists to develop scenarios on the basis of two real agricultural land-use options: growing sugarcane for biofuels or establishing diversified agriculture and forestry. A residential development option was also considered because this land conversion had occurred elsewhere, even though it was not supported in this planning process. The scenarios were developed iteratively. An initial set of scenarios that considered a wide set of possible options was presented to KS. Feedback was used to eliminate scenarios that were deemed not useful or plausible and to identify scenarios for which additional options and a finer level of detail should be considered, eventually focusing on seven land-use scenarios (Goldstein et al, 2012b).

The team used InVEST models to quantify and map the ES impacts of these scenarios, including carbon storage, water quality, and financial return from the land (Goldstein et al, 2012a). An iterative feedback process led to strong collaboration between decision makers and scientists in producing the ESK. Staff from KS's Land Assets Division informed the design of the scenarios from the start, and engaged with scientists at the Natural Capital Project in discussions about the intended purpose of their planning efforts. This contributed to an atmosphere in which scientists and decision makers worked together to find answers to KS's land-use management questions.

West Coast of Vancouver Island—developing an integrated regional marine spatial plan

In 2008 decision makers and stakeholders on the West Coast of Vancouver Island (WCVI), Canada began an integrated marine spatial planning process. The process considered the interactions among, and cumulative impacts of, human activities in the marine environment. The objective was to balance a mix of human uses while limiting environmental impacts. On the WCVI the West Coast Aquatic (WCA) Management Board leads the marine spatial planning process. WCA is a regional comanagement agency composed of representatives from federal, provincial, and local government; First Nations; and prominent industries in the region, including aquaculture, commercial fishing, and tourism. The consensus-based WCA Board is guided by the *Nuu-chah-nulth* principle of *Hishukish Tsawalk* (everything is one and all is interconnected). It seeks to foster initiatives that enhance opportunities for coastal communities to benefit from local resources while minimizing conflicts among uses. WCA coordinates and convenes agencies such as First Nations, provincial, federal, and local government who will ultimately implement the plan. WCA partnered with the Natural Capital Project to integrate ES modeling into the planning process. Over the course of several years, Natural Capital Project scientists worked closely with WCA staff and stakeholders to develop, apply, and build capacity to use relevant ES models.

The planning process was characterized by extensive and proactive stakeholder engagement and collaboration over several years. In 2008 WCA hired a group of community liaisons (local community members) in each of the nine traditional territories of the First Nations within the WCA planning region. Over a year, community liaisons arranged community meetings and interviews with local stakeholders who derive benefits from the ocean including employment (fisheries, aquaculture, tourism), recreation opportunities, locally harvested subsistence seafood, and cultural or spiritual traditions. The range of stakeholders was diverse, including fishermen, tourism operators, First Nations' elders, and government scientists. These interviews and community meetings collected local knowledge on the values people associate with the coastal area. Information was collected in a spatially explicit format (ie, important areas for traditional seafood harvest, whale watching, oyster farming, etc). The conversations identified locals' values and visions for the future of their ocean space. WCA then compiled the information to define common goals that apply across the region, such as: vibrant communities and culture, including securing food, social, and ceremonial marine harvesting areas for First Nations; economic development, including promoting renewable energy sources; and maintaining safe and efficient waterways. These common goals, along with a road map and protocol for the planning process, were drafted by WCA in 2011 as part of WCA's Coastal Strategy. They were approved in 2012 by the WCA Board of Directors (representatives from the major industries on the coast, governments, and First Nations) and an open public consultation process (WCA, 2012).

WCA planners then worked with nine First Nations to define a local-scale marine spatial plan for each nation's traditional territory. These local-scale plans represent stakeholders' visions for the future. Most of them include zones for important income-generating activities (eg, shellfish aquaculture), cultural and spiritual activities, and conservation or restoration. Each of the First Nation's plans was stitched together to create a regional spatial plan, to engage larger scale ocean users (eg, the commercial fishing, tourism, and aquaculture industries). WCA acted as a facilitator and engaged the First Nations and industry groups separately at first, and then eventually convened them on issues that needed collaboration to resolve, such as areas with water quality problems.

Over two years, WCA planners, stakeholders, and Natural Capital Project scientists worked together to quantify the flow of benefits from marine ecosystems, identify unanticipated negative environmental consequences of specific configurations of human uses, and find ways to minimize conflicts among ocean users. WCA invited and used local and traditional knowledge at all stages—defining scenarios, collecting data, and interpreting results. For example, WCA collected information on sewage loading points from the Province of British Columbia and several federal government agencies as well as traditional knowledge on the location of highly valued shellfish harvesting beaches from First Nations groups. WCA then ran the InVEST water quality model, which integrated all of this information, and outputs were used as the basis for conversations that WCA convened between stakeholder groups. Through an iterative process involving multiple meetings over two years, each stakeholder group could request changes to the scenarios until a plan was agreed.

Methods and data

It is notoriously difficult to evaluate use of policy-oriented research (CGIAR, 2008). Many impacts are hard to measure quantitatively. Determining causality is challenging given simultaneous, complementary sources of information and other social, economic, and political factors that influence policy change. Moreover, impact evaluation can require a long time frame as policy change often evolves through a chain of events and interactions over years or decades.

Given these challenges, case studies and semistructured interviews are among the best-suited methods for assessing how knowledge is used in decisions (CGIAR, 2008; Hird, 2005; Rich, 2001; Weiss, 1989). We follow this methodology through semistructured interviews with stakeholders, decision makers and policy makers, and scientists. These groups sometimes acted as boundary organizations (Cash et al, 2002). We designed and piloted interview questions to assess use of ESK by each group of respondents, testing the three modes of knowledge use (table 2).

From July to August 2012, in the middle stages of the planning process, we conducted nineteen interviews in Belize: five with policy makers, three with scientists, and eleven with stakeholders. We supplemented interviews with surveys of a broader set of stakeholders to triangulate the interview data. In Hawaii we conducted interviews with three scientists and one decision maker in 2009 during the middle stages of planning, and one scientist and one decision maker in 2012 during implementation. This allowed exploration of how use of ESK—and perceptions about use—evolved. Results from the WCVI are based on interviews with three scientists and six marine planners over 2011, 2012, and 2013. One caveat to highlight is the lack of interviews with stakeholders in either the WCVI or Hawaii cases. In Vancouver Island and Belize we also draw conclusions from direct observation of the process. All findings are also based on analysis of knowledge products, such as ES model outputs and scenarios.

Table 2. Questions used to assess how, when, and by whom ecosystem service knowledge is used.

1 How was knowledge used?	
Conceptual use	Did you use InVEST to bring new information or knowledge to stakeholders, advisors, or policy makers?
	Did InVEST help identify the policy issue or problem in the first place?
	What are the primary things you learned over the course of the planning process?
	How did information about ecosystem services affect how you thought about the planning process?
Strategic use	Did you use InVEST to illustrate the value of particular options?
	Did InVEST help the policy issue gain political traction and momentum?
	Did scientific information about ecosystem services help mediate conflicts?
Instrumental use	Did you use InVEST to help decide among options?
	Did InVEST help design or improve the effectiveness of policy mechanisms?
	Did the use of InVEST influence any policy decisions?
2 By whom was knowledge used?	
Interviewees self-identified as policy maker and/or decision maker, stakeholder, or scientist.	
3 When was knowledge used?	
Framed by stages of the policy process described in Tomich et al (2004).	

Lessons learned: how, when, and by whom is knowledge used? What factors affect use?
In this section we present findings on the modes of ESK use by different groups observed in each case (table 3). We explore the process of iterative interactions among groups over time, highlighting specific points at which strategic, instrumental, and conceptual use occurred (see figure 1). We draw insights into factors affecting the use of ESK (table 4).

Lessons from Belize
All three modes of knowledge utilization were important in Belize. We observed a progression from conceptual to strategic to instrumental, as policy makers gathered information from scientists and stakeholders and then circled back to iterate on various ESK products over two years, with some overlap of use modes (figure 1).

Conceptual use was more common early on. Scientists explained and explored ES model outputs with policy makers and highlighted important quantitative relationships between coastal and marine uses and provision of ES, such as the impact of coastal development on annual spiny lobster catch. Policy makers and stakeholders identified conceptual use as the predominant use of ES modeling outputs, bringing attention to unfamiliar or new issues and in some cases altering stakeholder understanding and preferences. Novel ESK that

Table 3. Modes of knowledge use in the cases.

Mode of knowledge use	Coastal Belize	West Coast Vancouver Island	Oahu, Hawaii
Conceptual	Stakeholders gain new understanding of coastal protection. Policy makers understand relative quantitative impacts on ecosystem services (ESs) of alternative scenarios.	Stakeholders understand fuller range of ESs and connections among, and indirect effects of, human uses. Decision makers identify unanticipated environmental consequences of human uses.	Decision makers understand new issues and broaden perspectives—for example, value of field buffers and the relative ES impacts of different land uses.
Strategic	Scenarios and services provide common language to illustrate benefits of compromise informed management scenario. Policy makers use scenarios to account for stakeholders' interests and feedback.	First Nation portrays its position on float home zoning to a regulatory agency on the basis of water quality benefits. Groups with limited voice empowered to articulate alternative visions.	Kamehameha Schools (KS) use ES results to portray benefits of their preferred plan (to balance agroforestry, irrigated agriculture, and financial return from land) and reduce pressure for residential development.
Instrumental	Stakeholders refine scenarios (which form basis of the plan). Policy makers use ES knowledge (ESK) to improve compromise option.	Limited evidence at larger regional scale, although ESK facilitated comparison of alternative management options. Evidence at smaller scales, for single issues—for example, Town of Tofino used coastal protection model to inform setback for development.	KS implements agroforestry within master plan for North Shore of Oahu on the basis of evidence it will provide a balance of ecosystem services, and contribute to statewide policy initiatives.

surprised users encouraged them to think about their decisions and resources in new ways. For example, in CAC meetings in Punta Gorda in southern Belize, ES model results affected a debate about the construction of a proposed port which was included as a feature in the development scenario. Model results showed how vulnerability of coastal communities to storm surges and inundation would increase where the port required mangrove clearing. This new information influenced stakeholder preferences in later discussions at CAC meetings. Subsequent scenarios either eliminated the port or displayed alternative configurations of coastal uses.

ESK was also used strategically. Policy makers used the scenarios to show stakeholders and government ministers how compromises to achieve sustainable development could provide better outcomes than either development or conservation extremes. As one policy maker noted,

> "It was important because I think people like to be able to know how much or what the science says, that there is a way to actually back up or support what you're saying, instead of just giving blanket statements that thing will occur. The need to have evidence was something that was demanded."

Table 4. Factors that affect how ecosystem service knowledge (ESK) is used in each case.

Mode of ESK use	Attributes of knowledge	Characteristics of process	General conditions
Conceptual use	novelty or surprise of results (B) perceived salience of outputs to important issues and questions (W, B) ES metrics that were previously not quantified (W, B, H) consideration of indirect effects and externalities (W, H) accessible language used (B, W)	depth and frequency of participation in joint knowledge production (H, W) degree and type of participation by different groups (H)	presence of scientists (W, H) early stage of science–policy process (B, W, H)
Strategic use	perceived credibility of outputs (W) use of standard, transparent tool, ie open-source, validated (W) use of boundary objects (H, W, B) knowledge incorporated—ie, use of local, traditional, and expert scientific knowledge (W, B) use of scenarios (B, W, H) multiple ES considered (W)	balance of decision-making power among players (B, W) involvement and capacity building of stakeholders (W) use of local and traditional knowledge (W, B)	level of interest in policy or process (H) authority and accountability of decision makers and scientists (H) expectations/precedent for use of scientific evidence to substantiate positions (B,H)
Instrumental use	method of assessment, including transparency, ease of use and simplicity of ES model or analysis (W) scenarios framed by clear, practical, timely management questions (H) production of comparable metrics (W)	iteration in collecting, analyzing, and using knowledge (W, H, B) degree to which decision makers and stakeholders represented (H, W) use of local and traditional knowledge (B, W) organization acting at the boundary between science and policy (W, B) length of time of engagement (W, B, H)	capacity to measure ES and human uses and monitor impacts (B) credible baseline data about ES (B) established planning or policy process (H, B,W) clear, straightforward decision authority—eg, single landowner (H) clearly defined decision-making protocol (H)

Note: B = evidence from Belize; W = evidence from Vancouver Island; H = evidence from Hawaii.

Another policy maker said, “The scenarios helped us to get the information of what [stakeholders] wanted to see.” Stakeholders commonly felt they had influence and the process was legitimate when their local knowledge, visions, and values were incorporated into the scenarios.

We saw strategic use most often where there was an imbalance of power among actors. Policy makers at CZMAI used their scenarios strategically to earn buy-in from grassroots stakeholders for the scenario that supported their coastal zone planning mandate. CAC members used ESK to illustrate the value of their preferences to the government, such as when Big Creek stakeholders highlighted that proposed port expansion would significantly impact habitat that provides a nursery for spiny lobsters. CZMAI policy makers also reported using ES model results strategically to convince the Belizean Cabinet to approve ICZMP legislation.

Third, local knowledge and ES modeling outputs were used instrumentally. Stakeholders were able to generate solutions to planning issues by providing local knowledge and data about existing and proposed development and conservation projects. Policy makers used local knowledge to ensure that scenarios were feasible, accurate, and fit policy goals. They emphasized that local ESK from stakeholders was critical to improve the accuracy of the model outputs, inform scenarios, and increase stakeholder support.

Policy makers also used ES model outputs instrumentally by modifying the final ‘compromise’ scenario to create a national zoning scheme. The capacity to measure ES was an important prerequisite for using ESK instrumentally throughout the process. Where credible data existed for ES, scientists were able to use models that informed ES policy decisions. As policy makers gained capacity and experience with InVEST, they were able to use the ESK results to refine scenarios and develop a preferred zoning scheme that balanced environmental and development goals. Over several months, scientists and policy makers worked together to use the model results to improve the preferred scenario, to minimize impact on targeted ES, while expanding priority economic development opportunities. The resulting zoning scheme forms the basis of Belize’s coastal management plan.

Lessons from Hawaii

All three modes of knowledge use are evident in Hawaii (figure 1). ESK was used conceptually by decision makers early in discussions with scientists about how to manage the landscape to achieve multiple benefits. One decision maker described how the process “broadened our thinking … and made us think through the role of ecosystems services in land planning. That’s a big contribution.” He also expressed appreciation for how ES models and scenarios gave “a voice to nature in a novel way”. Decision makers felt that ESK helped people to understand the benefits of conservation-oriented land uses. ESK helped KS staff articulate their goals in specific terms, and explore how they fit within the organization’s multivalue land management strategy.

ES model results for different scenarios also helped KS and stakeholders understand new insights. For example, quantitative estimates of how buffers around agricultural fields are likely to affect water quality increased understanding of the value of that land management strategy. For these and other scenarios, decision makers learnt about the likely trade-offs among water quality, carbon storage, and financial revenue of pursuing alternative land-use plans. In this sense, ESK was used instrumentally (to select land-use planning options on the basis of the likelihood of achieving environmental and social goals) and also used conceptually to acquire new insights.

ESK was used strategically in communicating the impacts and trade-offs of preferred land-use scenarios to build support among KS leadership and the local community. The ES maps and analyses were used to show the benefits of land uses that were already desired by KS, such as agroforestry. Once scenarios and models were selected with input from stakeholders, decisions makers used ESK to justify the inclusion of diversified agriculture in the North Shore plan. The residential development scenario, which reflected a land-use strategy implemented elsewhere, was also used strategically, as KS did not consider it a serious option, but wanted to preempt pressure to pursue residential development by illustrating the relative advantages of other land uses. In this way, decision makers used ESK to build support among stakeholders for implementing agroforestry in the regional plan, already a preferred land-use strategy. Interviewees agreed that ES maps served as boundary objects that helped decision makers to clarify among themselves the scenarios under consideration by providing tangible, visual objects to focus discussions.

Instrumental ESK can be observed primarily at the implementation stage of the planning process. It motivated the inclusion of agroforestry and biofuel feedstocks within the diversified agriculture portion of the North Shore plan. While planners and managers used ESK instrumentally to decide which scenarios to pursue, strategic use of the knowledge was predominant, as knowledge was used to mediate stakeholder differences and garner support for KS's preferred planning option.

What conditions enabled different modes of ESK use? First, KS had a clear responsibility for managing their land assets and faced a pressing management question about how to manage agricultural lands. This practical decision context, plus the existence of a decision matrix tool that ESK could feed into and relatively straightforward land ownership, appeared to enable instrumental use. Second, the accountability of KS to community stakeholders made it necessary for KS to demonstrate advantages and disadvantages of particular options, encouraging strategic use. Third, collaboration between stakeholders, decision makers, and scientists from both KS and the Natural Capital Project created an atmosphere ripe for conceptual use of ESK. Collaborative fact finding created an atmosphere in which both decision makers and scientists actively learnt.

Lessons from Vancouver Island, Canada

On the WCVI, all modes of ESK were evident by different user groups at multiple stages of the process (figure 1). ESK was used conceptually in two ways. First, it expanded the benefits from healthy marine ecosystems that stakeholders recognize. As one marine planner noted, "For those who are making initial plans within their backyard … these tools can help them take care of things they already know they care about, but don't realize that they care about it." For example, in the early planning stages, local residents, in interactions with Natural Capital Project scientists and by viewing ES model results, came to appreciate that eelgrass meadows stabilize the shoreline from erosion and prevent flooding. Midway through the planning process, stakeholders requested metrics of shoreline exposure to erosion to help weigh alternative marine plan options. The second example of conceptual use occurred when WCA and stakeholders worked with scientists to use models to illuminate connections among multiple human activities that are often considered in isolation. ESK clarified the ways in which salmon aquaculture and float homes affect traditional shellfish harvesting through indirect effects on water quality. The articulation of these connections enabled WCA to convene discussions among diverse stakeholders, who, though connected through environmental externalities, had not previously worked together.

Marine planners and individual stakeholder groups also used ESK strategically. WCA promoted the legitimacy of the InVEST models with diverse stakeholders—ranging from federal government agencies to industry groups. Because InVEST contains multiple ES models, each relevant to different stakeholders, all groups felt they were equally and fairly represented in the scientific analyses. The credibility of ES models (through peer-review publication and validation) and transparency (through open-source software and guidance) helped WCA convince competing and often polarized stakeholder groups to participate in the marine spatial planning process.

Several First Nations used ESK in strategic, often novel, ways. Most of the First Nations on the WCVI have limited science capacity. By coproducing knowledge with scientists, the Nations increased their capacity and empowered themselves to convene meetings with government authorities and advocate for their preferred planning options. The *Tla-o-qui-aht* First Nation is concerned about the effects of aquaculture and float homes on water and habitat quality in their tribal park in Lemmens Inlet on WCVI. Tla-o-qui-aht used ESK strategically to build support for a marine spatial plan that would protect the ecological integrity of Lemmens Inlet. ES model outputs like water quality maps (expressed in concentrations of fecal coliform bacteria, a standard unit used by regulatory agencies) served as important boundary objects, enabling Tla-o-qui-aht to strengthen their case with credible, relevant scientific information.

ESK was used instrumentally by the WCA and First Nations at small scales and, to some extent, for the entire West Coast region. When crafting local-scale spatial plans, many First Nations used ESK to determine appropriate locations for new income-generating activities such as shellfish aquaculture while minimizing impacts to benthic habitats which support important ESs. At the larger regional scale, ESK facilitated comparison of alternative management options. The Natural Capital Project and WCA team developed 'common metrics' that allowed stakeholders to assess how the proposed plans meet their stated objectives. Example metrics include the number of tourist user days, the percentage of the shoreline in highest categories of risk for coastal hazards, and the percentage of community areas that have compromised visual quality because of development. These metrics will ultimately be used to compare the likely performance of alternative options for the marine spatial plan, which is expected to influence selection and implementation of specific plans.

Several attributes of the ESK product and process appear to affect how knowledge is used. First, relevance of ESK to issues that people care about deeply but are not able to articulate quantitatively (such as water quality or shoreline stabilization) facilitates conceptual use. It allowed scientists and planners to connect with stakeholders, shaping new understanding by discussing issues in new ways. Second, credibility of model outputs enabled strategic use, allowing First Nations to be taken seriously by—and have meaningful conversations with—provincial government. Third, the iterative and transparent process enabled instrumental use by allowing planners and stakeholders to go back and forth to identify a suitable marine spatial plan.

Emerging themes and common lessons

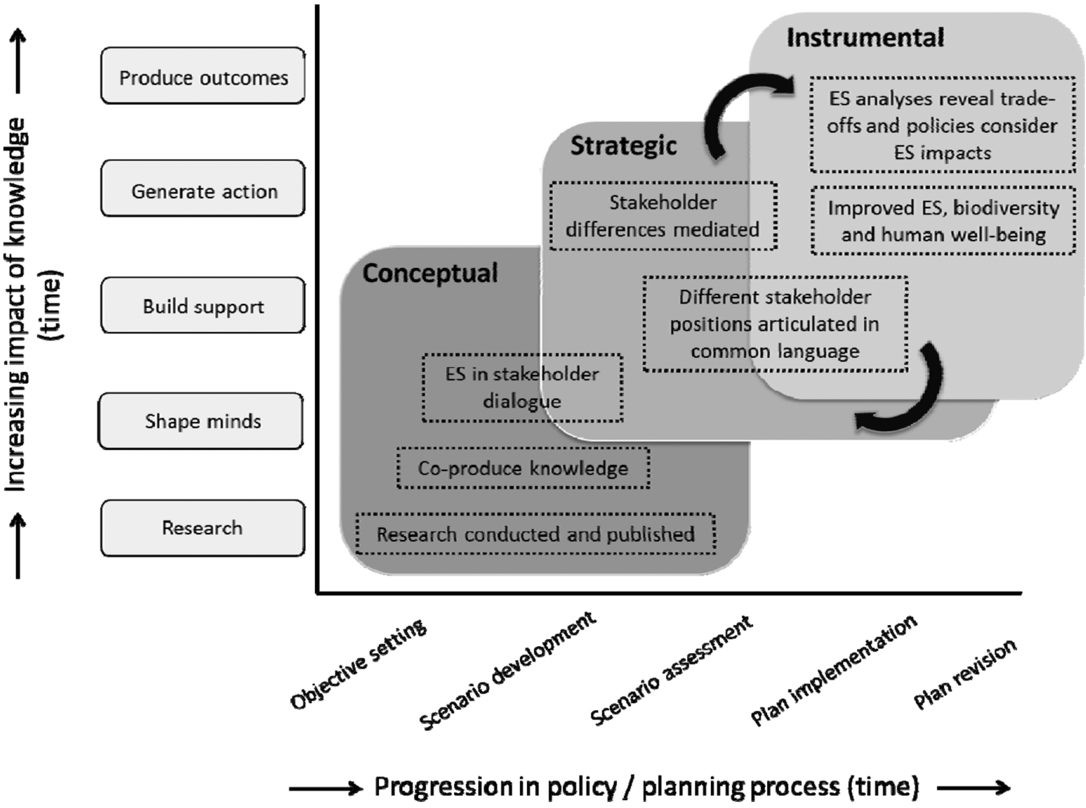
We now discuss common themes and striking lessons from the cases, focusing on two central questions of this special issue: how is ESK used in decisions? What factors affect how ESK is used (see table 4)?

How is ESK used in decisions? Multiple, interacting modes of use

Figures 1 and 2 illustrate how in each case stakeholders, scientists, and policy makers use ESK in different ways at different stages, building cumulatively through iterative engagement.[(2)] Here we highlight remarkable patterns in how knowledge is used.

First, all three modes of knowledge use—conceptual, strategic, and instrumental—are evident in every case. This supports the findings of others in this special issue that ESK is used in diverse and interacting ways (eg, Waylen and Young, 2014). ESK shapes understanding, beliefs, and awareness, analogous to conceptual use, often early in the planning process—for example, new appreciation and prioritization of coastal protection in both Belize and WCVI.

[(2)] Building on figure 1 in Reid et al (2009), who depict how communities and policy makers interact with researchers through bisecting lines representing different user groups.



Notes: Conceptual ESK use is prevalent in early stages of the planning process when interest groups alter beliefs and values as they acquire an understanding of ecosystem services (ES) through coproduction of knowledge on scenarios and ES impacts. Strategic and instrumental use of ESK occurs iteratively in the middle and late stages of the process, as interest groups and decision makers interact with each other and ES information is used to build support and generate action as plans are implemented and adapted.

Figure 2. Iterative progression of conceptual, strategic, and instrumental use of ecosystem service knowledge (ESK) in the policy and planning cycle.

In subsequent stages, instrumental and strategic uses are prevalent, often occurring iteratively. ES information is used to improve the quality of a plan or scenario (instrumental use) and different interest groups portray the ES consequences of implementing their preferred planning options (strategic use). This iterative process helps groups to build understanding and negotiate compromise required to support implementation of specific scenarios or plans.

Second—and strikingly, given how little it is noted in the literature—strategic use is common and plays an important role in gaining buy-in for policies and plans in politicized contexts and mediating power differences. Strategic use is not necessarily ‘bad’: previously held positions are substantiated by robust, credible ES science to communicate how preferred plans or specific land or marine uses could be implemented and why they are beneficial. Strategic use helps stakeholders reflect their values, beliefs, and interests in specific, quantitative ways. Often they were previously ignored because their priority issues or values relate to externalities that are hard to quantify and convey—for example, regulating services. For example, the Tla-o-qui-aht First Nation in WCVI used ESK to convey the water quality impacts of float homes on their tribal park in quantitative, credible ways that added weight to these considerations.

We find that instrumental use takes time to occur, building on growing understanding and support gained through interactive, iterative engagements among stakeholders, decision makers, and scientists. As demonstrated in Hawaii, decision makers and stakeholders use ESK to prioritize choices and select among them; and scientists use local and expert environmental knowledge to improve the credibility, salience, and legitimacy of results (Cash et al, 2002).

What factors affect how ESK is used? Product, process, and general conditions all matter
Table 4 provides detail on factors that appear to affect *how* knowledge was used in each case. Here we highlight striking themes that warrant further investigation.

First, conceptual use requires meaningful participation, engaging diverse groups regularly, to produce ESK products jointly and iteratively (Neβhöver et al, 2013). Such processes are time, resource, and data intensive, and rely on strong institutions and governance. In all three cases, such a process, and the mandates and relationships within them, existed. Furthermore, conceptual use appears to be enhanced by including ES that are affected by externalities and which have not previously been quantified—for example, coastal protection.

Second, strategic use is enabled by scenario development, which stakeholders and decision makers use as a tool to express and achieve their preferences and goals. Through the scenario development process, interest groups can put forward specific positions, values, and preferences that are reflected in the scenarios. In all three cases stakeholders and decision makers were able to provide substantial local knowledge necessary to design scenarios, particularly in terms of current and preferred uses of marine and terrestrial environments.

The integration of local and traditional knowledge improves all modes of knowledge use by making it more understandable, credible, and legitimate. In WCVI, for example, both WCA and stakeholders noted that blending local knowledge with ES models helped increase understanding and advance the planning process by supporting more informed and transparent discussions. This helped to establish: credibility, by ensuring land and ocean uses were accurately represented; salience, by assessing and comparing relevant options and visions for the future; and legitimacy, by creating a platform that reflects diverse knowledge, beliefs, and values.

The pattern of iteration between strategic and instrumental use appears influenced by authority for approving and implementing plans and policies. In Belize, for example, CZMAI enhanced its authority for developing the plan by improving the quality of the plan (instrumental use of ESK) and gaining support from stakeholders (strategic use of ESK). However, final decision-making authority for the national plan lies with the Belizean Cabinet, and CZMAI will use ESK strategically in this final step to encourage the Cabinet to approve.

Finally, instrumental use depends on general conditions, such as capacity to measure ES and an established planning process with clear decision authorities and protocols. For those who want to see research used, the message is clear: be patient and use these factors as criteria to select applications where there is high likelihood of instrumental use.

Implications for future research and policy
The ES field needs more collaboration with political scientists, and experts in evaluation and local and global policy contexts. More research is needed on conditions that enable use of ESK (Cowell and Lennon, 2014; Haines-Young and Potschin, 2014, Turnpenny et al, 2014). This work can usefully build on research into the benefits of stakeholder engagement (Beierle and Konisky, 2001; Young et al, 2013a; 2013b). Promising approaches for empirical work include content analysis of policy documents and meeting minutes to show how dialogue, understanding, preferences, and policy commitments evolve, and semistructured interviews and surveys to elucidate the experience and perspectives of stakeholders, decision makers, and scientists. Early engagement, a long time horizon, and repeated analyses are required to observe change. This work can be extended with a larger sample size to relate characteristics of ESK, process, and context with measures of use. More rigorous impact

evaluation will be challenging to apply due to the many factors influencing change (Pelz and Horsley, 1981).

Although our analysis did not address political factors in depth, other research indicates that the distribution of power between and within groups, especially when mediated by scientific knowledge, can be critical in defining outcomes (Kothari, 2001; Reed, 2008). We encourage future research to explore power distribution as a factor affecting how and by whom knowledge is used.

The pervasiveness of strategic use has implications for both ES science and policy. On the science side, transparent and easy to use ES models allow collaborative and iterative coproduction of knowledge, as local stakeholders and decision makers can repeat analyses and rerun alternative scenarios. This fosters adaptive debate and a common language about the merits of different positions on the basis of the likely ES impacts. In terms of policy, the pervasiveness of strategic use argues for widely inclusive policy and planning processes that promote deliberation through open dialogue and debate about difficult choices that involve trade-offs. This is likely to be particularly important when stakeholders frame issues differently, face conflicting objectives, and have unequal power (Kothari, 2001; Reed, 2008).

Conclusions

We provide new insights into how ESK is used in the context of spatial planning, and factors that appear to enable different modes of use. Our findings indicate the need for a nuanced view of the varied and interacting ways that ESK is used by different groups at different stages of the policy process, including conceptual, strategic, and instrumental use. We also find that both characteristics of ESK and the social process by which ESK is collected and analyzed affect how knowledge is used. The characteristics of ESK that enable use are often connected to their ability to facilitate and support a participatory, transparent process for decision makers, scientists, and stakeholders to jointly produce knowledge—for example, transparent and credible models, use of scenarios, and accessible tools. General conditions also matter, implying it is possible to select applications of ESK that are ripe for particular types of knowledge use.

Given that we purposefully selected our cases, had a limited sample size, and employed exploratory qualitative methods, we emphasize that our case studies serve as illustrations that may not be generalizable. Our questions and findings provide a starting point for researchers to explore further using qualitative methods more rigorously and quantitative methods to triangulate findings.

These findings provide both warning and encouragement for the ES community. A narrow focus on instrumental use is likely to cause frustration. But ES science is, in subtle ways, an important factor informing and influencing decisions—often by altering beliefs and understanding, building support for solutions that balance conservation and development goals, and helping to negotiate compromise. If the ES research community wants to improve decision making, decision makers and stakeholders want to achieve better outcomes for the environment and people, and funders want research to have utility, we must commit to understand the realities of how, when, by whom, and under what conditions knowledge is used.

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