

Opportunities and Strategies to Incorporate Ecosystem Services Knowledge and Decision Support Tools into Planning and Decision Making in Hawai'i

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Abstract Incorporating ecosystem services into management decisions is a promising means to link conservation and human well-being. Nonetheless, planning and management in Hawai'i, a state with highly valued natural capital, has yet to broadly utilize an ecosystem service approach. We conducted a stakeholder assessment, based on semi-structured interviews, with terrestrial ($n = 26$) and marine ($n = 27$) natural resource managers across the State of Hawai'i to understand the current use of ecosystem services (ES) knowledge and decision support tools and whether, how, and under what contexts, further development would potentially be useful. We found that ES knowledge and tools customized to Hawai'i could be useful for communication and outreach, justifying management decisions, and spatial planning. Greater incorporation of this approach is clearly desired and has a strong potential to contribute to more sustainable decision making and planning in Hawai'i and other oceanic island systems. However, the unique biophysical, socio-economic, and cultural context of Hawai'i, and other island systems, will

require substantial adaptation of existing ES tools. Based on our findings, we identified four key opportunities for the use of ES knowledge and tools in Hawai'i: (1) linking native forest protection to watershed health; (2) supporting sustainable agriculture; (3) facilitating ridge-to-reef management; and (4) supporting statewide terrestrial and marine spatial planning. Given the interest expressed by natural resource managers, we envision broad adoption of ES knowledge and decision support tools if knowledge and tools are tailored to the Hawaiian context and coupled with adequate outreach and training.

Keywords Ecosystem services · Decision support tool · Hawai'i · Modeling · Conservation · Integrated management

Introduction

Natural resource management decisions have a profound influence on affected ecosystems and human welfare (Vitousek et al. 1997; Foley et al. 2005; Cardinale et al. 2012; Farley et al. 2013). Ecosystem goods and services (hereafter ecosystem services, or ES) are the direct and indirect contributions of ecosystems to human well-being (TEEB 2010). They are often classified as provisioning (e.g., fish, food wood), regulating (e.g., water filtration, climate regulation), supporting (e.g., soil formation), and cultural (e.g., recreation, aesthetics) (MA 2005). An ES framework has been advocated as a way to illuminate the linkages between natural resource management/planning, ecosystem structure and function, and human well-being (MA 2005; Daily et al. 2009; Braat and de Groot 2012; Smith et al. 2013). Here we evaluate the potential of ecosystem services knowledge and tools to contribute to

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sustainable natural resource management decisions in Hawai'i, a region where such planning is critical, but where an ecosystem services approach has yet to be used broadly in applied natural resource management. While specifically focused on this biophysically and socio-culturally unique region, findings may provide insights into other regions, particularly island systems across the Pacific and beyond.

Efforts to map and quantify ecosystem service provision under alternate land and marine use and climate change scenarios have proliferated with increasing interest in incorporating ecosystem services and associated benefits into decision-making strategies (Egoh et al. 2008; Naidoo et al. 2008; Peh et al. 2013; Rosenthal et al. 2014; Thomas et al. 2012; Yee et al. 2014). Around the world, multi-lateral organizations, businesses, non-governmental organizations, and national governments increasingly are engaging in ecosystem services quantification, mapping, and economic valuation for terrestrial and marine spatial planning, payment for ecosystem services, permitting and mitigation, and natural capital accounting, among other uses (Guerry et al. 2012; Leh et al. 2013; Maes et al. 2013; Ruckelshaus et al., in press). One proposed benefit of this approach includes enlarging the focus of planning and resource management from a limited number of socio-economic or environmental objectives to a broader analysis of synergies and trade-offs across diverse social, economic, cultural, and ecological outcomes (Nelson et al. 2009; Raymond et al. 2013; Tallis and Polasky 2009).

The demand for greater ES knowledge for decision making has led to the rapid advancement of ES decision support tools (hereafter ES tools), which include a range of end-user products from simple spreadsheet models to highly complex software packages that can quantify ES at numerous spatial scales, each with different resolution, methods, compatibility, and generality (Sharp et al. 2014; Villa et al. 2014; Bagstad et al. 2013; Nemeč and Raudsepp-Hearne 2013). While much of the focus on ES valuation pertains to provisioning and regulating services, a growing body of literature addresses 'cultural' services (MA 2005; Chan et al. 2012; Hernandez-Morcillo et al. 2013; Ruiz-Frau et al. 2013; Gould et al. 2014a). Strategies to fairly and effectively incorporate cultural ecosystem services into decision making continue to grow and remain a dynamic area for future work (Kumar and Kumar 2008; Chan et al. 2012; Hernandez-Morcillo et al. 2013; Ruiz-Frau et al. 2013; Gould et al. 2014b).

At the same time, interest in understanding how, and to what extent, ecosystem services knowledge (ES knowledge)—partly facilitated by ES tools—becomes incorporated into policy and decision making is growing (Gutrich et al. 2005; Daily et al. 2009; Laurans et al. 2013; Ruckelshaus et al., in press; McKenzie et al. 2014). McKenzie et al. (2014) found three uses of ES knowledge:

'instrumental,' 'conceptual,' and 'strategic.' Used 'instrumentally,' knowledge flows from scientist to decision maker, who then acts on acquired ES knowledge to inform decisions. McKenzie et al. (2014) note that while many ES projects expect ES knowledge to be used instrumentally, conceptual and strategic modes of knowledge use are often more common and equally beneficial. 'Conceptual' use promotes awareness, broadens understanding, and changes people's perceptions, which may, depending on the wider context, eventually lead to behavior and policy change. 'Strategic' use involves using ES knowledge to achieve a given end, such as improving community support for a proposed conservation project. McKenzie et al. (2014) conclude that conceptual use is most common in the beginning of projects, where strategic and instrumental use become more prevalent in later stages. Further analysis of actual and potential modes of ES knowledge utilization is critical and timely as efforts to quantify and incorporate ES knowledge into decision-making moves from theory to practice.

The Hawaiian Context

The Hawaiian Islands are the most geographically isolated island archipelago in the world with endemic ecosystems consisting of fragile biophysical interfaces and unique natural processes that are prone to external disruptions. The topography of each island consists of conical high volcanic mountain peaks with extreme topographic relief to the coastline, creating a cascading series of micro-climates and ecosystems (Juvik and Juvik 1998). Due to the diversity of environmental gradients within a small area, the Hawaiian Islands have been proposed as a model system for ecosystem studies as well as for understanding coupled social-ecological systems (Vitousek 1995; Kurashima and Kirch 2011).

Native Hawaiians, as the original inhabitants, valued the diversity of resources accessible across these gradients, subdividing the land into *ahupua'a* (socio-ecological land divisions, often, but not always, stretching from mountaintop to shore) (McGregor McGregor 1996; Derrickson et al. 2002; Gutrich et al. 2005; Jokiel et al. 2011). Western social and economic influence, starting in the 1800s, led to broad shifts in management based on the *ahupua'a* to fragmented land ownership and management. This was driven partly by privatizing land and water for large (monotypic) agricultural export developments (Kelly 1997; Minerbi 1999; Derrickson et al. 2002; Kikiloi 2010). For over two centuries, the structure and function of Hawaiian ecosystems have been severely altered by species introductions, habitat loss, overfishing, and land-based pollution (Carrier et al. 2012; DLNR 2011; Friedlander et al. 2008; Jokiel et al. 2011; Rodgers et al. 2012; SRGI 2012).

Today, a renaissance has brought the *ahupua'a* into a contemporary framework of ecosystem-based management that re-establishes the cohesive links between terrestrial and marine systems of the watershed, encompassing both ecological and social processes integrated from ridge to reef (Derrickson et al. 2002; Higuchi 2008). In part, this renaissance is driven by community recognition that crucial natural resources are increasingly scarce, and that sustainable natural resource management requires integrated land to sea management. Some of the more important moments in Hawaiian watershed protection include the creation of the Forest Reserve System in 1903 and the State Land Use law of 1961 for zoning Conservation Districts. Current efforts include the Department of Land and Natural Resources, Division of Forestry and Wildlife's (DOFAW) Rain Follows the Forest Initiative, and multiple watershed partnerships under the umbrella of the Hawai'i Association of Watershed Partnerships (Gutrich et al. 2005; DLNR 2011). Increasing efforts to protect coastal resources include the Hawai'i State Department of Planning, Coastal Zone Management Program's Ocean Resources Management Plan (ORMP), which seeks to facilitate integrative and sustainable ocean and coastal management (SOP 2012). Moreover, as in other parts of the Pacific (Cinner and Aswani 2007), efforts are on the rise to recognize and strengthen local, community-based land and marine management an equitable and effective conservation and management strategy (Gutrich et al. 2005; Vaughan and Ardoin 2013; Vaughan and Vitousek 2013).

Despite the high value placed on marine and terrestrial resources, management and protection remain under-funded in Hawaii (DLNR 2011; Carrier et al. 2012). Efforts to value key ecosystem services from native forests (Roumasset et al. 1997; Kaiser 2014) and coral reefs (Cesar and van Beukering 2004) in Hawai'i have demonstrated the importance of these systems in terms of monetary value, and/or highlighted the link between land-use or coral reef changes and ecosystem services. Likewise, there are multiple efforts to utilize decision science to guide policies regarding cost-effective invasive species control (Burnett et al. 2008; Kaiser and Burnett 2010). However, these studies did not provide managers or decision makers with spatially explicit information on how land and coastal management and/or climate change may impact multiple ecosystem services. This type of information could complement existing studies to guide cost-effective management and spatial planning decisions.

Several empirical and modeling efforts in Hawai'i and other oceanic islands have evaluated the biophysical supply of ES in a spatially explicit manner. This includes the application of InVEST (Integrated Valuation of Environmental Services and Tradeoffs) carbon and water quality models for spatial planning under differing potential land-

use scenarios in an *ahupua'a* on O'ahu (Goldstein et al. 2012). Other efforts include empirical field observation and modeling of land-based sedimentation impacting coral reefs in Hawai'i and Guam (Stock et al. 2011; Wolanski et al. 2004; DeMartini et al. 2013), mapping of a suite of coral reef ecosystem services in St. Croix; USVI (Yee et al. 2014), and quantification of potential water yield reductions in watersheds with changes in forest cover and composition (MacKenzie 2013; Kaiser 2014). Taking a different approach, the Kohala Center on Hawai'i Island developed a decision support tool integrating Western science with traditional ecological knowledge to understand land-use change effects on groundwater recharge in a single *ahupua'a* (<http://www.spatial.redlands.edu/waipunikahaluu/>). These efforts demonstrate the growing development and application of ES models and decision support tools in Hawai'i and other similar systems and represent a range of approaches and potential applications.

Participation of resource managers—the end users of these tools—can inform tool developers about which metrics are likely to be most helpful in various decision contexts (Bagstad et al. 2013). Here we explore the potential strategies, opportunities, and constraints of ES knowledge and tools to support sustainable natural resource management and planning in Hawai'i. Given that ES models often aim to be decision-making tools, we start from the ground up with a stakeholder needs assessment to ensure that ES tools are chosen and developed by incorporating stakeholder interests, ideas, and concerns. Based on semi-structured interviews with terrestrial and marine natural resource managers, this paper explores the current state of ecosystem services quantification, modeling, and valuation in Hawai'i. It speculates on the future potential of ES knowledge and tools to support local decision-making and conservation efforts, with a focus on factors that make Hawai'i unique. We consider how this approach could support more place-based approach, sustainable land-use planning, and effective coral reefs management, as well as potential lessons learned that could apply to other oceanic island systems and beyond. Lastly, we also explore perceived benefits and risks to furthering this approach and provide recommendations for next steps in tool development. We conclude by identifying key opportunities for ES knowledge and tools in Hawai'i along with considerations and strategies to realize these opportunities.

Specifically, we set out to answer the following:

1. What are the key management objectives and decisions faced by natural resource managers in Hawai'i?
2. Which ecosystem services are most important for land and coastal managers/stakeholders in Hawai'i?

3. How would the knowledge derived from ecosystem services tools likely be used (instrumental, conceptual, strategic)?
4. What aspects of tool design will increase the likelihood of adoption by the end user?

Approach

We conducted semi-structured interviews with land and marine management professionals in Hawai'i. We identified an initial interview list through local, professional networks, and utilized snowball sampling to target natural resource managers who (i) would be most likely to use ES tools, based on management goals focused on producing ecological and social benefits and (ii) could contribute to our broad understanding of the current and potential use of ecosystem services knowledge in natural resource management and planning. To meet these criteria, we selected managers representing a range of government, non-profit, and private landowners and managers in the state. In total, we interviewed managers with a predominantly terrestrial ($N = 26$) and marine ($N = 27$) focus, with 29 focused on multiple island programs, and others focused on island-specific programs on Kaua'i ($n = 1$), O'ahu ($n = 5$), Maui Nui ($n = 12$), and Hawai'i Island ($n = 5$). Terrestrial informants encompassed watershed partnerships ($n = 8$), government agencies (State = 6; Federal = 4; County = 1), private landowners ($n = 5$), and non-profits ($n = 2$). Marine informants were primarily from government organizations ($n = 20$), but also included non-profit organizations ($n = 4$) and multi-stakeholder partnerships ($n = 3$).

Interviews lasted between one and two hours and included a mix of open- and close-ended questions. We designed an initial survey based on the following themes: (1) social and ecological goals and objectives of the organization; (2) key decisions facing the organization; (3) use and familiarity with the concept of ecosystem services and ecosystem services modeling in decision making; (4) perceived utility and opportunities of ecosystem services models for planning, communication, and decision making; (5) characteristics important for tool design and development for uptake; and (6) perceived benefits and risks of pursuing this approach. We piloted the survey with several natural resource managers and experts within the field of natural resource management and revised the survey accordingly.

Analysis

Our analysis combined a quantitative summary of close-ended question responses with contextualized information

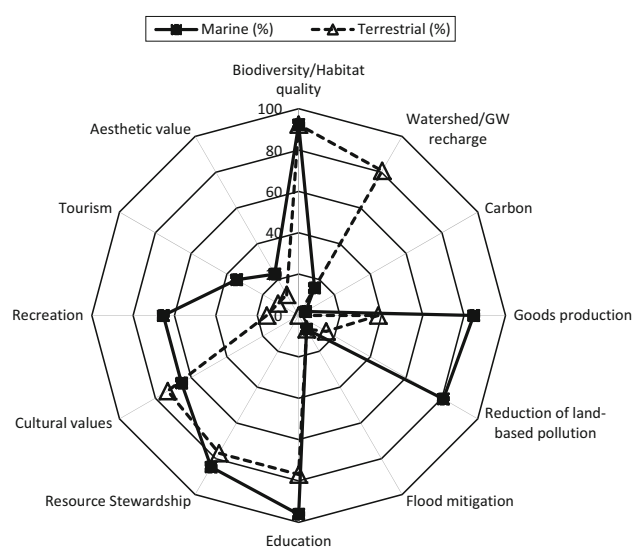


Fig. 1 Marine ($n = 27$) and terrestrial ($n = 25$) informant goals (percentage of interviewees considering the following objectives primary or secondary goals of their organization). Managers were able to respond with multiple primary and secondary goals, if preferred. *Note* Objectives of one terrestrial informant are not included, as she/he framed the objectives very broadly in the interview (to manage terrestrial and coastal areas to protect public welfare through balancing development and environmental protection)

from additional information gathered through open-ended questions and through elaboration upon close-ended questions (see Supplementary Information for the interview questions). Here we provide details on how answers to key questions were analyzed.

We asked managers what their biophysical and socio-economic objectives were and whether they considered each objective primary or secondary. Each participant answered the question in an open-ended manner and then verified the classification of their answer into categories defined during the pilot stage. Categories included biodiversity/habitat quality, watershed health/groundwater recharge, carbon, goods production, reduce land-based pollution, flood mitigation, education, resource stewardship, cultural values, recreation, tourism, and aesthetic values (Fig. 1; Supplementary information). Interviewees were not given a limit on the number of primary or secondary objectives defined. We then calculated the percentage of interviewees who determined each objective as either primary or secondary in order to have an understanding of management priorities in the State (Fig. 1). We aligned the management objective(s) with a provisioning, regulating, or cultural service (MA 2005), noted whether the interviewee discussed the term 'ecosystem service' explicitly, and recorded details of their response to provide contextual information on program objectives.

We also asked about key management decisions made by the organization, including how they decide what types

of land/marine management activities to carry out as well as where to focus management. This was followed by a question regarding what types of tools, if any, were used to make these decisions. These questions were open-ended and common answers synthesized in our analysis (Supplementary Information).

To understand which ecosystem services were considered most useful to evaluate through a modeling platform, we presented interviewees with a list of potential services (Table 1; Supplementary information) and asked them which were of primary or secondary interest. No limit was given to the amount of services selected. We then calculated the percentage of terrestrial and marine informants selecting each service as either of primary or secondary interest (Table 1).

To understand perceptions of the utility of and how an ecosystem services tool would be used, we asked managers how useful they thought such a tool would be. We asked this both in terms of having a tool that would illuminate the spatial distribution of ecosystem services as well as one that would allow for analysis of changes in one or more services with different potential land/coastal use scenarios. We then asked managers to provide one or more examples of how they think this type of tool could be useful for decision making and recorded qualitative answers. We classified these answers into conceptual, strategic, and instrumental uses as defined by McKenzie et al. (2014) and quantified the percentage of interviewees pointing to an example within each category (Table 2; Supplementary information).

Finally, to understand perceptions related to aspects of model design and implementation, we asked managers to rate the importance of the following components: (1) platform simplicity, time requirements, and ease of use; (2) generation of relative versus absolute values in model outputs; (3) monetary valuation of ecosystem services; and (4) the ability to connect ridge to reef or terrestrial and marine ecosystem services (Table 3; Supplementary information). We calculated the number of respondents listing each factor as important or very important. Finally, we asked whether interviewees foresaw any potential risks associated with such a tool and recorded these as open-ended answers. The additional questions asked, which provided contextual information, can be found in the supplementary information.

We then integrated the identified goals and potential uses (instrumental, conceptual, and strategic), alongside current and potential ES knowledge and tools, gaps, and manager needs, to identify sources of impactful opportunities to aid decision making. We selected the four opportunities based on common themes emerging in multiple interviews that fit with both management goals and decision contexts as well as manager-identified potential uses of ES tools and knowledge.

Table 1 Manager prioritization of strategic focus areas for customizing ES tools (ranked as a primary (very useful) or secondary (potentially useful) priority) ($n = 23$ terrestrial managers and $n = 25$ marine managers)

| Ecosystem service | Either primary or secondary (%) | Either primary or secondary (%) |
|---------------------------------------|---------------------------------|---------------------------------|
| | Terrestrial | Marine |
| Provisioning services | | |
| GW recharge (drinking; agriculture) | 78 | 76 ^a |
| Surface water (drinking; agriculture) | 74 | 88 ^a |
| Crop production | 30 | 8 |
| Timber | 39 | 4 |
| Non-timber forest products | 39 | 4 |
| Fisheries | 17 | 80 |
| Aquaculture | 13 | 68 |
| Subsistence fisheries | 22 | 92 |
| Regulating services | | |
| Water quality | 78 | 100 |
| Sediment | 74 | 100 |
| Ground water | NA | 76 |
| Surface water | NA | 88 |
| Carbon sequestration | 35 | 32 |
| Flood mitigation | 43 | 56 |
| Pollination | 13 | 14 |
| Coastal protection | 26 | 76 |
| Cultural services | | |
| Cultural plants | 43 | 32 |
| Pig hunting | 39 | 16 |
| Lo'i kalo | 26 | 28 |
| Fish ponds | 26 | 60 |
| Educational | 35 | 60 |
| Recreational | 30 | 80 |
| Aesthetic | 26 | 52 |
| Tourism | 43 | 72 |

^a Marine managers primarily discussed these services as regulating services (GW recharge and surface water as they affect coastal system processes)

Results and Discussion

Interviews with 53 managers revealed some universal agreements as well as divergent priorities. For some themes, not all respondents answered the questions, and thus we note the sample size for each section.

Management Objectives and Decisions

We found agreement between terrestrial and marine managers on the importance of biodiversity, education, engaging the community in land and resource stewardship,

and restoring or amplifying Native Hawaiian values as project objectives (Fig. 1). However, marine managers more often stressed goods production and reduced land-based source pollution, while terrestrial managers often concentrated on watershed protection and groundwater recharge. This difference likely stems from the fact that water supply (primarily through groundwater recharge) is often considered the current most important provisioning service from upland forests, while fisheries and coastal activities (which are detrimentally impacted by pollution from land) are critical ecosystem services managed by coastal managers.

The vast majority (92 %) of terrestrial organizations interviewed concentrated, at least in part, on protecting and managing native highland ‘*mauka*’ forests within conservation zones, stemming from the idea that this protects threatened and endangered species (noted as biodiversity/habitat quality in Fig. 1.) and enhances groundwater recharge (noted as watershed/GW recharge in Fig. 1). Marine interviewees emphasized links between goods provision (fisheries and aquaculture) and supporting services, such as biodiversity and habitat integrity, analogous to watershed conservation in terrestrial systems. Notably, while both terrestrial and marine informants discussed the importance of connecting ridge-to-reef, marine managers incorporated these links more frequently into management objectives and strategies, particularly in regard to a focus on land-based pollutants (Fig. 1).

While terrestrial and marine managers rarely employed the term “ecosystem services” unprompted during the interviews, they mentioned benefits provided by marine and terrestrial areas under each ecosystem service category (provisioning, regulating, cultural, and supporting) when describing objectives (MA 2005). Provisioning services/benefits indirectly raised by managers included groundwater recharge, surface water flow, fisheries, crop production, non-timber forest products, and timber, with benefits for drinking water, recreation, nutrition, and income. Regulating services included water purification and sediment retention, with benefits for drinking water, irrigation, safety, and coral reefs and fisheries. Most terrestrial and marine managers remarked on the importance of some type of cultural service/value, including those specific to Native Hawaiian cultural values as well as broader cultural services per the Millennium Ecosystem Assessment (MA 2005) classification, such as recreation and aesthetic beauty. Pleasant et al. (2014) found similar emphasis on cultural services by natural resource managers in Hawai‘i, but did not distinguish between the broader concept of cultural services and values specific to Native Hawaiian culture, a distinction that can be critically important (Gould et al. 2014a).

Nearly half (10/21, 48 %) of the terrestrial managers with water-related goals concentrated on general watershed

health, emphasizing co-benefits for biodiversity, cultural values, and human well-being. For example, while several watershed partnerships focused exclusively on groundwater recharge, more often we encountered objectives framed in a similar way to a response from one manager: “sustain[ing] multiple ecosystem benefits... especially watershed areas, native habitat, species, historical and cultural and socio-economic resources for all who benefit from continued health of watersheds.” Cultural and ecological values are often considered inter-connected, supporting the idea that cultural services are often linked with other types of ecosystem services and rarely thought of as individual units (Kumar and Kumar 2008; Hernandez-Morcillo et al. 2013; Gould et al. 2014a). The four terrestrial managers without specific water-related goals focused primarily on endangered species conservation as an ecological objective, but one also emphasized co-benefits for educational, recreational, and cultural values.

Key management decisions highlighted by terrestrial managers included where to invest in invasive species control for forest protection and, for interviewees with agricultural lands ($n = 6$), how to manage agricultural-zoned lands, particularly in a context of a decline of large-scale sugar, pineapple, and cattle ranching. With the exception of state- and county-level planning, where zoning changes are possible, terrestrial management decisions focused on how to manage lands within their designated conservation and agricultural zones.

With the exception of one organization who utilized InVEST as part of a terrestrial spatial planning demonstration case (Goldstein et al. 2012), no manager indicated that they utilized an “ecosystem services tool” such as InVEST (Tallis and Polasky 2009; Sharp et al. 2014), ARIES (Villa et al. 2014), or Envision (Hulse et al. 2009). However, we encountered a number of prioritization mechanisms related to ecosystem services and biodiversity protection. This included two focused on ground water recharge areas: the Department of Forestry and Wildlives’ (DOFAW) Rain Follows the Forest (RFF) initiative (DLNR 2011) and the Honolulu Board of Water Supplies’ (BWS) watershed prioritization (Matsumoto and Tsuneyoshi 2013). The RFF prioritizes areas based on potential changes in recharge based on the threat of land cover change, consisting of a combination of GIS layers of forest type and climate. This methodology places the highest priority on “very wet” and “moderately wet” high elevation native forest areas (DLNR 2011). The BWS prioritization combines metrics of groundwater recharge (soil/rock/vegetation type and rainfall GIS layers) with metrics of groundwater production (amount extracted versus defined sustainable yields and relative chloride concentrations as a measure of how impacted an aquifer is due to extraction) (Matsumoto and Tsuneyoshi 2013).

Beyond watershed protection, the Nature Conservancy (TNC) prioritizes biodiversity value, threat, and feasibility (TNC 2006), while others prioritize based on populations of endangered species and/or areas with high percentage of native vegetation cover. A state manager also discussed the use of the Hawaii Statewide Assessment of Forest Conditions Research Strategy (SWARS) to prioritize areas for conservation or multi-use management (Conry 2010). Finally, several terrestrial managers managing land for goods production and environmental protection pointed to multi-criteria analyses, including a land trust which prioritized sites based on multiple goals of public access, environmental resources, cultural sites/historic value, agricultural sites, and viewscapes.

In general, terrestrial managers expressed confidence in current prioritization mechanisms for biodiversity and *mauka* watershed protection (TNC 2006; Conry 2010; DLNR 2011; Matsumoto and Tsuneyoshi 2013). However, they also suggested that funding, access, and available partners often determined management actions as much as, or more than, ecologically based prioritization efforts. However, many indicated that climate change, new species introductions, and increasing human population will present new challenges in management and planning that may not be well handled by existing prioritization processes.

The most prominent use of existing studies on ecosystem services in Hawai'i include communication materials put out by the Rain Follows the Forest Initiative (DLNR) and watersheds partnerships that point to studies on the economic value of native forest for water supplies (Burnett et al. 2006, DLNR 2011). However, this seems to primarily represent a strategic use of ecosystem services knowledge, rather than to instrumentally prioritize investments. Recent environmental reports from the State Environmental Council used these valuation studies conceptually, evaluating how the cost of environmental changes impacts Hawai'i's "genuine progress" (Ostergaard-Klem and Oleson 2014), while statewide greater attention is being placed on the loss of ecosystem services more broadly (Hawaii Green Growth Initiative—<http://glispa.org/commitments/hawaii-i-green-growth-initiative>).

Marine management decisions focused on balancing multiple interests through identification of synergies and trade-offs among different stakeholder groups. Marine managers in government organizations generally prioritized based on areas they are mandated to manage in combination with ecological and socio-economic criteria including fisheries, habitat, species composition, and community interests. NGOs and marine partnerships worked at different scales ranging from statewide to specific watersheds, and prioritized based on a mixture of ecological and social factors, including community readiness and ecological threat levels. No interviewee indicated

that ecosystem service information was specifically used to inform prioritization of marine management actions. Similar to terrestrial managers, marine managers emphasized the importance of political and socio-economic factors influencing where and how management and conservation is implemented. However, marine managers, even more so than terrestrial managers, pointed to the high expense associated with data collection as well as the difficulty of capturing key ecosystem processes in a three-dimensional and dynamic system as a major challenge to strategic decision making. Accordingly, one informant explained that, "for land, it is simple, we know what area we need to focus on; with the sea we are still figuring it out."

Managers' Strategic Focus Areas for Customizing ES Tools

We asked managers¹ to select from a list of ES those that would be most useful to model, map, and quantify; these specific ES were organized under the MA (2005) categories (Table 1). All terrestrial managers identified hydrologic services as of primary or secondary importance and, to a lesser extent, provisioning services related to goods production (Table 1). Within water-related services, water quality and quantity-related services were of overwhelmingly high interest, including groundwater recharge (78 %), surface water provision (74 %), water quality (78 %), and sediment retention (74 %). With the exception of flood mitigation, which was identified as a management objective by a very few managers, these ES of interest all coincide with terrestrial management goals laid out in "Management Objectives and Decisions" section of this paper. In contrast, the vast majority of marine managers considered food provisioning services important, including fisheries (80 % general and 92 % subsistence) and aquaculture (68 %). Due to the inherent downstream effects, marine informants expressed a much stronger interest in linking land and sea through regulating services, namely water quality and sediment retention (100 %), ground² and surface water (85 %), and flood mitigation (56 %).

The majority of terrestrial and marine managers identified one or more cultural services as very important to capture, but emphasized that these 'services' are often inter-connected to each other as well as with provisional and regulatory services, making them difficult to quantify. The most important 'tangible' cultural services identified by terrestrial managers were cultural plants, subsistence pig

¹ 23 terrestrial and 25 marine interviewees responded to this question.

² Marine managers were asked about groundwater in terms of surface water and groundwater seepage into marine systems (as a regulating service), rather than groundwater recharge or surface water yield (as a provisioning service).

hunting, and tourism, while marine managers pointed most to the importance of including subsistence fisheries, tourism, aesthetic beauty, fish ponds, education, and recreation. As found by previous research on cultural ES (Chan et al. 2012; Gould et al. 2014a), there was clear overlap between cultural ES and other categories of ES, as in the case of subsistence fisheries and pig hunting, which can be classified in multiple ways. Notably, tourism was rarely an explicit management objective because it is the purview of the state Department of Business, Economics, and Tourism. However, managers, nonetheless, wanted it quantified, given the link between natural capital and tourism value.

Because of our focus on modeling, our interviews focused on the ‘tangible’ cultural services potentially amenable to quantification, but terrestrial and marine managers repeatedly referred to other ‘intangible’ services, such as a sense of place, spiritual value, and cultural heritage. One interviewee explained that “cultural resources are part of natural resources—you can’t have one without the other,” and another that “the Hawaiian system is holistic—you can’t really separate things.”

How Would Knowledge Derived from Ecosystem Service Tools be Used?

All but one terrestrial manager and one marine manager (96 % of all informants) thought an ES decision-making tool would be useful or somewhat useful for management, communication, and/or planning. Terrestrial interviewees (85 %) primarily highlighted potential *strategic* use, and to a lesser extent *conceptual* (65 %), and *instrumental* use (50 %) (Table 2). Strategic use was expressed in terms of “communicating what we already know in a more comprehensive way,” and “justifying current management actions.” Similarly, a terrestrial manager suggested that such a tool could help “show the benefits of smart growth,” and could be used to demonstrate the public benefits of planning decisions, which could then facilitate greater generation of government funding (Table 2).

Terrestrial managers (65 %) pointed to potential *conceptual* use to demonstrate links between protecting remaining native forests through invasive species control efforts and freshwater resources, particularly groundwater recharge. This was discussed in terms of education and public outreach as a way to “connect the dots” between conservation and human well-being and “win hearts and mind” through visual representations of benefits humans derive from ecosystems (Table 2).

No terrestrial manager indicated that they would use an ES tool as a central input for planning or decision making. However, half said they would potentially use it instrumentally alongside other decision-making processes. Main constraints to wider *instrumental* use included a lack of

confidence in models and a sentiment that a model would not provide information above and beyond what was already known given field experience or other prioritization tools. Nonetheless, one terrestrial interviewee said that, while they already had their priority areas identified, “any tool that can enhance our ability to identify priority lands would be useful.” He explained that his organization “would use it as a filter first and check and balance outcomes with community input.” Several terrestrial interviewees also indicated that quantification/valuation of ecosystem services could serve as a “tie breaker” between prioritization of several sites, and that an ES tool might be useful for statewide planning and for bringing together disperse planning efforts through greater inter-agency dialog. Likewise, another terrestrial interviewee suggested that an ES tool could be used to understand what areas are most important for ecosystem services to help prioritize critical habitat designations, guide changes in state land-use classifications, and institutionalize ecosystem services in the environmental assessment process.

In contrast, all marine interviewees identified ES tools and knowledge as having a high possibility of *instrumental* use (Table 2). Potential instrumental uses include marine spatial planning, design of marine protected areas and fisheries management areas, prioritization of watershed restoration to reduce land-based pollution, and siting of aquaculture projects. For example, one manager suggested that an ES tool could be used to compare different land and coastal management scenarios to identify important natural buffers, similar to Arkema et al. (2013). Several marine informants also pointed to the potential value of ES tools in participatory planning and conflict management, including, for example, in facilitating stakeholder engagement in MPA and community-based fisheries management area planning representing both *conceptual* and *instrumental* use. Greater expectation of potential *instrumental* use of ES knowledge and tools among marine managers compared with terrestrial managers may, in part, stem from the need for more spatially explicit information to facilitate ecosystem-based marine spatial planning as mandated National Ocean Policy, for example (Guerry et al. 2012).

The majority (69 %) of marine managers also identified potential *conceptual* use of an ES tool. Marine informants desired a tool that facilitates understanding land and sea linkages, thus improving coordination between terrestrial and marine planning to overcome the existing “disconnect” between the two systems. Likewise, a marine interviewee explained “people like visual representations, if we could have a model to show how x population growth or land-use change would affect multiple benefits, that would be really useful.”

Marine managers indicated substantial *strategic* use of ES tools with 92 % thinking such a tool would be very

Table 2 Potential ES tool uses suggested by interviewed managers

| | Terrestrial | Marine |
|--------------|--|---|
| Strategic | Demonstrate benefits and justify actions <ul style="list-style-type: none"> • Demonstrate benefits of ungulate removal • Justify regulatory and permitting procedures • Demonstrate value of protected areas • Communicate what we already know in a more comprehensive way Secure or obtain funding <ul style="list-style-type: none"> • Secure current or obtain new sources of funding • Demonstrate monetary benefits of controlling invasive species | Demonstrate benefits and justify actions <ul style="list-style-type: none"> • Justify coastal and marine planning and marine protected areas Secure or obtain funding <ul style="list-style-type: none"> • Increase funding by providing quantitative data to justify proposed management actions • Demonstrate financial return of aquaculture |
| Conceptual | Communicate knowledge and ideas <ul style="list-style-type: none"> • Visual experience to win hearts and minds • Educational tool • Marketing and outreach Demonstrate links between ecosystems and human well-being <ul style="list-style-type: none"> • Frame to connect dots between conservation and human well-being • Illuminate areas with multiple use values • Understand outcomes of fencing on freshwater resources • Understand impacts of climate change and associated changes in plant distribution on freshwater resources • Understand interactions between land-use change, climate change, population growth, and increased water demand on freshwater supplies • Link Western science and traditional ecological knowledge to promote greater understanding | Communicate knowledge and ideas <ul style="list-style-type: none"> • Promote greater understanding of ecosystem response to changes in land and coastal management • Demonstrate interconnection and linkages between land and sea • Provide visual representation of impacts of population growth and land-use change on marine resources • Communication within participatory, community-based management • Projections of climate change Promote holistic understanding of policies and management <ul style="list-style-type: none"> • Evaluate impacts of policies and development plans • Define tipping points • Evaluate potential outcomes of restoration • Promote holistic, people-centered understanding of management |
| Instrumental | Plan terrestrial management actions <ul style="list-style-type: none"> • Large-scale state planning • Tie breaker to determine conservation prioritization • Offset restricted hunting areas • Optimization of restoration and conservation efforts • EIS, permitting, and regulations Increase funding and capacity for conservation/sustainable management <ul style="list-style-type: none"> • Potential increased funding for conservation • Increase land-use options through quantifying ecosystem benefits | Plan marine management actions <ul style="list-style-type: none"> • Spatial planning for beach restoration and erosion control • Design of marine protected areas and fisheries management areas • Location of aquaculture projects • Prioritization of watershed restoration efforts • Urban and agriculture planning to reduce land-based pollution • Permitting and mitigation • Promote participatory planning and conflict management Inform/create policies for sustainable management <ul style="list-style-type: none"> • Inform fisheries policy, including allocation schemes • Promote payment for ecosystem services programs • Balance alternative energy development • Promote local seafood security • Promote adaptive management |

useful or potentially useful to justify management actions or secure or increase funding. Strategic uses included support for management decisions in face of public, decision makers, and funders and providing justification for

coastal and marine spatial planning. Another pointed to the potential of an ES tool to help provide justification for not building homes adjacent to coastal areas, providing concrete information on potential risks.

What Aspects of Model Design (and Implementation) are Critical to Ensure Tool is Most Useful for Natural Resource Management in Hawai'i?

We asked managers about what aspects of ES tool design would influence the likelihood of adoption by their organization. Managers overwhelmingly (81 % of terrestrial managers and 76 % of marine managers) emphasized the importance of model platform simplicity and low resource and time requirements if they were to be the ones to run the ES tool. While ES tools are often designed to economize resource inputs (Ruckelshaus et al., in press), Bagstad et al. (2013) found that they remain too resource-intensive to gain widespread traction in decision making. Our findings support this, with implications for Hawai'i and beyond; for widespread adoption and use, an ES tool likely needs to be user-friendly, require relatively little staff time, and be available as an open-source platform (or at low cost).

Simplicity must be balanced by model accuracy, validation, and explicit communication of uncertainty, as most managers expressed skepticism of generalized, simplistic models given the complexity of Hawaiian systems, and concerns over data availability. Likewise, an interviewee emphasized the importance of tailoring tool outputs to the State decision-making process and ensuring that results are transparent and useful for public communication. Other informants emphasized the importance of classifying the different scales at which management decisions are made, ranging from statewide planning down to site-level actions. Hence, this may require the adoption of multi-scale decision support tools to accommodate the multiple levels of policy making or identifying the scales for which the tools perform best (Bagstad et al. 2013).

We encountered a mixed response on whether outputs should be in relative or absolute values, with managers expressing that, while ideal if feasible, absolute numbers may be difficult to generate with confidence. More specifically, 41 % terrestrial respondents thought relative values would be sufficient, while 59 % thought it would be much better to have absolute values. Terrestrial managers emphasized the importance of absolute changes, with one manager explaining "it is always good to see a number. A little or a lot people don't get," and another that "funders like numbers." However, others thought, "for the majority of projects, knowing that doing something that is helping is enough." Several emphasized the importance of how the model is used and for what audience in determining the type of information generated and its usefulness. In contrast, marine managers thought both relative values (76 %) and absolute numbers (44 %) would be very useful,³ depending on the ES modeled and the metric used to express it. Marine managers, even more so than terrestrial managers, pointed to the difficulty in accurately generating

absolute values, and, thus, generally were more comfortable with the idea of using relative values in the context of decision making (Table 3).

The majority of managers expressed interest in monetary valuation to justify proposed management actions and secure funding. Terrestrial managers expressed a high level of interest in monetary valuation of services (vs. just a biophysical value) (70 %), particularly for hydrologic services. One manager stated "I would love to know the market value of water. These are little nuggets of gold for us in terms of being able to say that recharge is equal to dollars." Likewise, a terrestrial informant explained that "the legislature is primarily interested in monetary benefits. There is great value in being able to quantify why here and not there." Of note, however, is that studies producing contextualized market values of water in Hawai'i, in the context of ecosystem services, do exist (Kaiser and Roumasset 2002; Kaiser et al. 2008; Kaiser 2014). This points to the need for improved communication of such research to practitioners and decision makers. However, that decision makers are interested in knowing where to focus conservation and restoration efforts, suggests a need for strategies to transfer this type of knowledge to specific and diverse decision contexts. The majority of marine managers (68 %) also thought assigning a monetary value to provisioning and/or regulating services was important. However, while managers were enthusiastic about placing a monetary value on provisioning and regulating ES, they generally opposed any monetary valuation of cultural services.

The ability of the tool to connect ridge-to-reef was considered very important to a majority of terrestrial (73 %) and marine (92 %) managers, who generally expressed that "you can't have a successful model in Hawai'i without this." This finding would likely apply to other island systems (Yee et al. 2014). In addition to modeling ecosystem services under current conditions, a number of managers pointed to the importance of the tool's ability to model scenarios of global climate change and water demand associated with population growth and policy change. One terrestrial informant thought agent-based modeling of land and coastal use would be helpful in developing comprehensive statewide planning efforts. While specifically referred to in the Hawaiian context, concerns over population growth, increasing demand for natural resources, watershed management, and climate change, are applicable to many island systems and beyond (Yee et al. 2014; Jupiter and Egli 2010; Grantham et al. 2011).

³ Marine managers were not asked to determine which would be more useful, and so there was some overlap between the usefulness of absolute and relative values.

Table 3 Model attributes identified as important determinants for adoption

| Model attributes | Terrestrial | Marine |
|---|--------------|--------------|
| Simplicity: ease of use and low resource requirements | 17/21 (81 %) | 19/25 (76 %) |
| Production of relative service values | 7/17 (41 %) | 19/25 (76 %) |
| Production of absolute service values | 10/17 (59 %) | 11/25 (44 %) |
| Monetary valuation | 16/23 (70 %) | 17/25 (68 %) |
| Ridge-to-reef connection | 16/22 (73 %) | 24/26 (92 %) |

We identified several concerns by informants regarding the implementation of ecosystem service models, including model inaccuracy, and the risk of undermining current management strategies. The most commonly noted risk was inaccurate or misleading information, which could “misguide management.” Marine informants, in particular, emphasized the challenge of accurately capturing relevant processes, further noting that the quality of model inputs is limited by a general paucity of data. In order to mitigate this, managers pointed to the importance of model outputs including estimates of uncertainty. Future research should examine how current practices address risk and uncertainty given that decision making with little to no information also presents challenges and drawbacks (Hubbard 2009).

Conclusions: The Path Forward

Our results point to clear interest in further development of ES knowledge and decision support tools for land and marine management in Hawai‘i. Based on interviewee management objectives (Fig. 1) and decision contexts, existing use of ES knowledge and tools in the literature, priority ES (Table 1), and new potential uses (instrumental, conceptual, and strategic) (Table 2), we highlight four potential opportunities for further incorporation of ES tools and knowledge. We then discuss strategies to achieve these in the unique social, cultural, economic, and biophysical context of Hawai‘i.

Opportunity 1: Mauka Conservation—Linking Water and Biodiversity Through Invasive Species Management

First, we see an opportunity for ES knowledge and tools to improve understanding of the impacts of forest management activities, including ungulate removal and weed control, on hydrologic ecosystem services in a spatially explicit manner. This is based on our finding that the majority of terrestrial managers considered watershed health or groundwater recharge a management objective, and that they saw a strong link between these objectives and conserving native forest through invasive species

control. Results could (1) illuminate the links between land management and ecosystem services provision (conceptual); (2) demonstrate the value of invasive species control efforts in biophysical and monetary terms, which could then be used to justify watershed protection and invasive species control efforts (strategic); and (3) leverage funding and, in turn, enhance management capabilities (instrumental).

Realizing this opportunity will require developing simplified biophysical models that adequately capture key processes and controls on water yield, sediment retention, and groundwater recharge in contexts characterized by limited data availability and use, complex biophysical processes, and high environmental heterogeneity (Brauman et al. 2012; SRGI 2012). Highly specified and place-specific models, such as the one developed by the U.S. Forest Service to quantify the effects of strawberry guava on water yield on the Hamakua coast (MacKenzie 2013), could be moved to simpler, manager-accessible platforms. We envision parallel approaches, where complex, place-based models can be used to evaluate biophysical outcomes of given scenarios for areas where precise estimates are required, while a more user-friendly, generic ES platform can provide less precise, but useful and accurate, information on ES to managers broadly. A pending question is the concurrence of management advice generated by the complex biophysical and simplified ES approaches, which is likely highly dependent on the scale of application (Bagstad et al. 2013). For small-scale decisions where localization is more important, we recommend linking locally utilized and validated complex models into ecosystem services model platforms, such as InVEST (Tallis and Polasky 2009; Sharp et al. 2014), ARIES (Villa et al. 2014), or Envision (Hulse et al. 2009) in order to link biophysical and human well-being outcomes (Bagstad et al. 2013). Further, where economic analysis is required, hydrologic models could be complemented by local economic valuation studies (Roumasset and Wada 2013; Burnett and Wada 2014). Monitoring hydrologic services and validating models is a critical complement of the ecosystem service assessment process that can improve the utility and accuracy of modeled results, as well as provide empirical data to increase understanding of links between

land and coastal use and ecosystem services (Rosenthal et al. 2014).

ES knowledge and tools could also uncover biodiversity trade-offs and win-wins posed by prioritizing conservation investments based exclusively on hydrologic services. For example, tropical dry forests have very high conservation value for rare and endangered species, but not as high value for groundwater recharge. Thus, tracking the impacts of ES-based management on broader biodiversity conservation efforts could demonstrate whether a focus on ecosystem services will benefit or detract from biodiversity conservation efforts (Chan et al. 2006; Reyers et al. 2012).

Opportunity 2: Supporting Sustainable Agriculture

Second, we see a clear opportunity to quantify flows of ecosystem services from agricultural lands to underpin the creation of payment for ecosystem services and other policy mechanisms that promote agricultural management with wider societal benefits. As pointed out by some of the interviewees in this study, quantifying and placing a monetary value on the services from sustainable agricultural management, so land owners can justify—and potentially be paid for—keeping agricultural land agricultural and managing it in a sustainable way, would provide important benefits for current and future generations in Hawai‘i. The opportunity to value and compensate landowners for land management strategies that provide ecosystem services to broader society is particularly timely given a wide transition to alternative agricultural systems from large-scale pineapple, sugar, and ranching.

To realize this, policy mechanisms, e.g., carbon credits (Goldstein et al. 2008) or water funds (Goldman-Benner et al. 2012), and detailed processes to quantify the multiple benefits that come from agricultural lands are needed. This will require ES quantification and valuation at multiple scales, including at the site scale, through adaption of methodologies like TESSA (a Toolkit methodology for the assessment of ecosystem services at sites of biodiversity and conservation importance) (Peh et al. 2013), as well as at larger scales, through platforms like InVEST and ARIES. A key challenge for utilizing models like InVEST for this purpose, beyond the need to adapt them to the biophysical context of Hawai‘i, will be to accurately parameterize models to reflect different land management strategies within land use/land cover classes, and to create integrated monitoring programs.

Opportunity 3: Facilitating Ridge-to-Reef Management

The majority of managers, particularly marine informants, emphasized the importance of an ES tool having the ability

to connect ridge to reef in order to enhance understanding of linkages between terrestrial and marine systems and support watershed-based management. Land management decisions can also have downstream impacts on terrestrial, aquatic, and marine environments (Carrier et al. 2012; Tallis et al. 2008; Thomas et al. 2012). Communities relying on coral reef ecosystem services are often vulnerable to downstream impacts of upstream land use (Syrbe and Walz 2012), and a growing number of studies seek to illuminate land-sea linkages (Jokiel et al. 2011; Rodgers et al. 2012; Stock et al. 2011; SOP 2012). An ES tool that links land and sea could (1) *instrumentally* lead to more sustainable land and coastal management and planning; (2) *conceptually* quantify, value, and communicate these linkages and coordinate more affectively across agencies; and (3) *strategically* assist community groups, managers, and planners seeking integrated solutions. This would require linked terrestrial and marine models that forecast how land-use and management changes impact sediment delivery, water quality (e.g., nutrients), and water yield to coastal systems, and how coastal ecosystems in turn respond to changes in these inputs. As with other applications of an ES tool, low time and data requirements will need to be balanced with the challenges of capturing the complexity of land-sea processes (Guerry et al. 2012; Yee et al. 2014).

Opportunity 4: Large-Scale State Terrestrial and Marine Spatial Planning

Interviewees working at multiple scales of management suggested that ES tools could be useful for broader state-level planning. We see an opportunity to utilize ES modeling to guide Hawai‘i’s Land Use Commission in decisions regarding re-designation of lands (between conservation, urban, rural, or agriculture per the State Land Use Law (Chapter 205, Hawai‘i Revised Statutes), based on the potential change in ecosystem services. The Land Use Commission is required to evaluate impacts on the preservation or maintenance of important natural systems or habitats, and the maintenance of valued cultural, historical, or natural resources. An ecosystem services framework that takes into account a suite of natural capital assets and their ES could assist in the county and statewide planning process.

We also see an opportunity for an ES tool to contribute to statewide marine and coastal spatial planning, as well as climate change adaptation. Holistic, integrated, adaptive management can meet the dual goals of mitigating threats to the coastal environment while promoting human well-being and the economy, but this requires understanding the relationships between people and nearshore ecosystems (Wamukota et al. 2012). An ES tool provides a means to

consider multiple ecosystem services and benefits, as well as the trade-offs and win-wins.

Greater incorporation of ES knowledge into statewide planning would be aided through the use of spatially explicit ES tools adapted to the biophysical, social, cultural, and economic context of Hawai'i. This would allow for comprehensive scenario analysis of the cumulative and emergent impacts of multiple land-use and management changes as well as climate change. It would also enable planners to identify beneficiaries of ES, which may facilitate public support of sustainable management policies or uncover vulnerabilities of certain groups to impacts of, e.g., climate change and land/coastal use (Arkema et al. 2013). Balancing benefits of generalizing ES tools is challenging when diverse groups in Hawai'i will value and experience different places in distinct ways (Vaughan and Ardoin 2013). For ecosystem services assessment to benefit people in an equitable way, great attention must be paid to incorporating and integrating values and knowledge across diverse stakeholders and communities (Berbés-Blázquez 2012).

In summary, ES knowledge and tools may contribute to sustainable natural resource management in Hawai'i and other islands experiencing similar issues, particularly through linking *mauka* forest protection for biodiversity and freshwater resources, promoting sustainable agriculture, facilitating ridge-to-reef planning, and statewide, holistic planning. ES tools will need to take into account the island's biophysical, socio-economic, and cultural context. Simplicity and ease of use need to be balanced with accurate display of uncertainty in modeling complex systems and their associated services and benefits. Given the diversity of potential uses and scales of use, decision makers require a toolbox of ES decision support tools and models rather than a one-size-fits-all ES tool. Managers also need to know how and when to use these tools in order to meet the need at hand. It will be extremely important to have communication and extension (training, application demonstration, etc.) to ensure uptake. Several issues that will affect the usefulness of ES tools for island decision makers are presented here and are also useful for understanding "more complex continental systems" (Vitousek 1995; Vitousek 2002).

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