Embedding ecosystem services in coastal planning leads to better outcomes for people and nature

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Recent calls for ocean planning envision informed management of social and ecological systems to sustain delivery of ecosystem services to people. However, until now, no coastal and marine planning process has applied an ecosystem-services framework to understand how human activities affect the flow of benefits, to create scenarios, and to design a management plan. We developed models that quantify services provided by corals, mangroves, and seagrasses. We used these models within an extensive engagement process to design a national spatial plan for Belize's coastal zone. Through iteration of modeling and stakeholder engagement, we developed a preferred plan, currently under formal consideration by the Belizean government. Our results suggest that the preferred plan will lead to greater returns from coastal protection and tourism than outcomes from scenarios oriented toward achieving either conservation or development goals. The plan will also reduce impacts to coastal habitat and increase revenues from lobster fishing relative to current management. By accounting for spatial variation in the impacts of coastal and ocean activities on benefits that ecosystems provide to people, our models allowed stakeholders and policymakers to refine zones of human use. The final version of the preferred plan improved expected coastal protection by >25% and more than doubled the revenue from fishing, compared with earlier versions based on stakeholder preferences alone. Including outcomes in terms of ecosystem-service supply and value allowed for explicit consideration of multiple benefits from oceans and coasts that typically are evaluated separately in management decisions.

coastal and marine spatial planning | integrated coastal zone management | ecosystem services | Belize | InVEST

Globally, oceans are at increasing risk of habitat degradation, shifts in species distributions, and loss of ecosystem function (1–4). With growth in human populations and in the intensity and diversity of marine activities, more people are demanding more benefits from ocean and coastal ecosystems (1, 5, 6). To meet this challenge, governments and scientists are encouraging innovative approaches to sustainable development. Ocean planning, coastal zone management, and ecosystem-based management, for example, recognize both human impacts and dependencies on ecosystems (7–10). However, integrated approaches to management have been met with some resistance. In the United States and Northern Europe, leaders in more established sectors point to added process complexity with little demonstration that further transaction costs will lead to better outcomes (11–13). Although such resistance is common, it has not hindered efforts in the Central American country of Belize or in >25 other countries around the world, where new ocean plans are on track for implementation by 2025 (14). The Belizean government's pursuit of pioneering coastal management over the past few years illustrates the promise of accounting for multiple benefits in comprehensive planning.

Ecosystem-service approaches can help inform coastal and marine planning by modeling the likely outcomes of management strategies for objectives expressed in terms of value to people (15). If multiple objectives can be considered together from the start of a process—with meaningful metrics that allow people or sector representatives to speak the same language and consider shared values—surprising synergies may occur, and final decisions may reflect open debates about trade-offs (16, 17). Modeling variation in ecosystem services across a landscape or seascape can also illustrate the importance of considering space allocation for impacts of human activities on services. Model outputs show where and how different regions may contribute to the flow of services on a larger scale (18).

Recent studies in terrestrial and freshwater ecosystems demonstrate how estimating ecosystem services can inform spatial planning decisions (19–23). Such success stories require methods for assessing variation in a suite of services and forecasting change under future scenarios. Until recently, these methods were lacking for ocean environments (17, 24–27). Now, research on numerous benefits provided by coastal and marine ecosystems is accumulating (28). Advancements in risk-assessment and cumulative impact mapping have increased our understanding about where habitats and species that provide services are most threatened by anthropogenic stressors (2, 29–31). Novel tools that account for changes in social and economic factors (32, 33) are now available to assess trade-offs among services and to develop the "business case" for ocean planning (5, 25, 26). In this work, we present the next critical advancement: using

Significance

Oceans and coasts provide people with diverse benefits, from fisheries that sustain lives and livelihoods to recreational opportunities that generate tourism. However, translating appreciation of these benefits into changes in management and policy is not trivial. We report on a ground-breaking effort to use ecosystem-service values and models within a coastal planning process. By accounting for spatial variation in the influence of human activities on services, our results allowed stakeholders and policymakers to refine zones of human use, reduce risk to ecosystems, and enhance delivery of multiple ocean and coastal benefits. Application of our approaches and tools will enable planners worldwide to bring ecosystem-service science to bear on real-world decisions, thus directing actions that protect ecosystems and their benefits for people.

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the new science within an actual coastal planning process to test the utility of ecosystem-service values given the reality and complexity of policy-making and stakeholder engagement.

Engaging stakeholders is key to successful ocean planning (34). Coproduction of information maximizes the chances that scientific results will be salient, credible, and legitimate (35, 36). Processes that incorporate active participation, information exchange, transparency, fair decision-making, and positive participant interactions are more likely to be supported by stakeholders, meet management objectives, and fulfill conservation goals (37). Our work in Belize represents the outcome of a unique collaboration between scientists and managers to coproduce ecosystem-service information that effectively integrates stakeholder interests, values, and local knowledge into a comprehensive plan.

Here we describe, to our knowledge, the first effort to apply the largely theoretical science of ecosystem services to design a coastal and marine spatial plan. Our results informed the first Integrated Coastal Zone Management (ICZM) Plan for Belize, to be reviewed by the national legislature in 2015 (38). We used a suite of ecosystem-service models to ask: Where should we site coastal and ocean uses to reduce risk to marine ecosystems and enhance the benefits they provide to people? We quantified ecosystem-service returns now and under three future coastal and marine management scenarios by assessing risk to habitats from a suite of human activities (31), using our risk results to estimate potential change in habitat area, and integrating these results into models that map and value benefits from nature in biophysical and economic metrics (*Materials and Methods* and *SI Appendix*, Fig. S1). We improved candidate plans through iteration of ecosystem-service modeling and stakeholder feedback. Structured feedback from diverse stakeholders explicitly changed the management scenarios, resulting in a fully integrated analysis reflecting coupled human-natural systems in Belize.

Estimating Ecosystem Services to Inform Coastal Zone Management in Belize

Along the coast of Belize stretch hundreds of kilometers of mangrove forests, extensive seagrass beds, the largest unbroken reef in the Western Hemisphere, and >300 cayes. These ecosystems support a diversity of estuarine and marine species and provide numerous benefits to the Belizean people, 35% of whom live along the coast. Renowned snorkeling and diving draw >800,000 tourists to the region annually, and several commercial, recreational, and subsistence fisheries are a source of income and sustenance for local people (39). Although tourism, fisheries, and several other ocean and coastal sectors underpin the economy and support livelihoods, they paradoxically threaten the very ecosystems that make these activities possible. Lack of integrated management has led to conflicts among sectors and recently put the Belize Barrier Reef on the United Nations Educational, Scientific and Cultural Organization's list of World Heritage Sites in Danger (whc.unesco.org/en/danger/).

To minimize ecological degradation, the government passed visionary legislation in 1998 calling for cross-sector, ecosystem-based management of coastal and marine ecosystems (40). It established the Belizean Coastal Zone Management Authority and Institute (CZMAI) and gave it the legal mandate to create a spatial plan. The plan was to integrate scientific expertise and local knowledge to ensure the sustainable use of the environment for the benefit of Belizeans and the global community (38, 40). Despite overwhelming support for the initial legislation, CZMAI faced several challenges: limited capacity, insufficient funding, changing political interests, and the lack of a science-based approach for reducing conflicts among ocean sectors and risk to ecosystems. When a window of opportunity opened in 2010 to renew the planning process, CZMAI partnered with The Natural Capital Project to use an ecosystem-service approach and models to design a spatial plan. It would be national in scope, but support social, economic, and ecosystem differences between nine coastal planning regions (*SI Appendix*, Fig. S2).

We embarked on an extensive stakeholder engagement process that involved scoping objectives, gathering information, and securing feedback through coastal advisory committees, composed of local representatives from diverse sectors and interests, public consultations, and expert reviews. Based on communication with stakeholders and government agencies, we identified eight categories of human activities to include in the zoning scheme (*SI Appendix*, Table S1 and ref. 38). We gathered data on the spatial extent of these activities and conservation areas to create a baseline set of zones for 2010 that we refer to as the Current scenario of coastal and marine use (Fig. 1 and *SI Appendix*, Fig. S3).* Next, we developed three future scenarios for 2025 in which the extent and location of the zones differed based on stakeholder visions, government reports, and existing and pending legislation (Fig. 1; *SI Appendix*, Figs. S4–S6; and ref. 38). The Conservation scenario represents a vision of long-term ecosystem health through investment in conservation and restrictions to coastal development. The Development scenario presents a vision of rapid economic development and urban expansion. The Informed Management scenario blends strong conservation goals with current and future needs for coastal development and marine uses. This scenario was refined over time through iterations of ecosystem-service modeling and stakeholder review (*SI Appendix*).

We identified three ecosystem services for evaluating management goals that stakeholders agreed were of high economic and cultural importance: catch and revenue from the spiny lobster fishery, visits and expenditures by tourists, and land protection and avoided damages from storms. We used a classic risk-assessment approach (30–31 and refs. therein) to identify the location and type of activities that pose the greatest threat to three habitats that deliver these services: coral reefs, mangrove forests, and seagrass beds (*SI Appendix*, Figs. S1 and S7; ref. 31). Next, we estimated expected changes in area and other characteristics of these habitats, based on differences in risk, and input these results into models for quantifying and valuing ecosystem services (*Materials and Methods* and *SI Appendix*, Fig. S1). To inform the design of the ICZM Plan we asked the following three questions. (*i*) What is the delivery of ecosystem services now and under the three future management scenarios? (*ii*) Do ecosystem-service values vary among coastal planning regions? (*iii*) Can we use these results to adjust where human activities occur to reduce risk to habitats and enhance services?

Results

National Returns and Trade-Offs in Ecosystem Services. We estimated annual production of lobster, tourism, and coastal protection for the Current scenario (year 2010) and three future scenarios (year 2025) in both biophysical and economic units. We found that 520,000 pounds (lbs.) of spiny lobster tail are caught from Belizean waters currently for a gross revenue of $16.4 million BZD (Fig. 2). These values are within the range of empirical data on landings and revenue (*SI Appendix*). Coastal habitats currently prevent the erosion of over an estimated 300 km^2 of Belizean mainland, atolls, and cayes, resulting in avoided damages of nearly $5 billion BZD on average per year (Fig. 2). Although empirical data for avoided erosion were not available, the wave evolution and erosion components of our model have been validated extensively in vegetated systems (ref. 41; *SI Appendix*). International visitors spend an estimated two million days in the coastal zone of Belize annually and more than $230 million BZD[†] (Fig. 2; see *SI Appendix* for a description of empirical and modeled data). These three critical services flow, in part, from an estimated 1,500 km^2 of functional seagrass habitat and >300 and 100 km^2 of functional mangrove forest and coral reef, respectively (Fig. 2 and *SI Appendix*, Fig. S7).

To quantify future returns from ecosystem services, we first calculated the expected change in area of functional habitat based on the results of our habitat risk assessment for the three 2025 ICZM scenarios (*SI Appendix*, Fig. S1, *Materials and Methods*, and ref. 31). Our results predict that changes in the extent and location of human activities would lead to a >20% increase in coral, mangrove, and seagrass functional habitat under the Conservation and Informed Management scenarios, relative to the Current scenario. In contrast, the area of functional mangroves

*The ICZM Plan includes two other zones, special development areas and culturally important sites. These are government designations that were already in place and not subject to adjustment during the ICZM planning process.

[†]Belize Tourism Board (2011) National Sustainable Tourism Master Plan for Belize for 2030.

would be halved, and coral and seagrass reduced to 10% of their current area in the Development scenario (Fig. 2).

We used spatially explicit estimates of the areal extent of functional habitat (*SI Appendix*, Fig. S8) and human activities (Fig. 1) to model future changes in services. Modeled catch and revenue from lobster mirror the changes in functional habitat. Compared to 2010, fishery yields rise by 50% in the Conservation scenario and drop nearly 100% in the Development scenario, as a result of increases and decreases in the extent of lobster habitat in these scenarios, respectively (Fig. 2). Results from tourism and coastal protection are more surprising: Avoided storm damages increase by well over 50%, and tourism expenditures are predicted to more than triple with the Informed Management, relative to the Current, scenario of human uses. Increases in the value of these services are comparatively modest under Conservation and Development scenarios (Fig. 2). Our results suggest that the Informed Management scenario is the best option for returns from tourism and avoided damages from storms, and reveal a trade-off with lobster revenue and functional habitat, for which the Conservation scenario is the best option. The Informed Management scenario would lead to increases in the catch and value of lobster, and the extent of functional habitat, relative to today's management practices (Fig. 2).

The higher value of coastal protection and tourism under the Informed Management scenario, compared with the Conservation scenario, serves as a reminder that ecosystem-service values depend on a combination of both biophysical and social variables (32, 33). Relative to a scenario that emphasizes conservation, increases in the extent of activities to support economic development may lead to more cumulative impacts on corals, mangroves, and seagrass; less nursery and adult habitat for lobster; and reduced fisheries returns. However, even a modest increase in coastal development can lead to more land with a higher property value, increases in the value of habitats for protection from storms, and more infrastructure to support tourism (Fig. 2). Limits to benefits provided by coastal development do emerge: habitat degradation and loss under the Development scenario leads to reductions in the values of all three ecosystem services. This combination of biological and socio-economic factors is why, for coastal protection and tourism, the Informed Management scenario is the preferred management option of the three future scenarios we analyzed.

Regional Variation in Habitats and Ecosystem Services. One of the most effective elements of the Belize process is that it sought to be both national in scope and to allow for differences among the roles played by each region in achieving national objectives. The process was designed to understand how the nine planning regions contribute in unique ways to a portfolio of national benefits from ocean ecosystems and to incorporate regional differences in stakeholder preferences for the future. We summed the area of functional habitat and ecosystem-service returns by planning region for the current and three future scenarios (*SI Appendix*, Figs. S8–S11). Our results demonstrate that the coastal planning regions "specialize" in different services and habitats. Five of the nine regions contribute >80% of the catch and revenue from spiny lobster currently, and in the Informed Management scenario, with the greatest contribution from the Central and Southern regions (Fig. 3 and *SI Appendix*, Fig. S12). Revenue from tourism is highest in the South Central and Central regions. However, on a per-area basis, tourism revenues also are substantial from Ambergris Caye and Caye Caulker regions, which are small, but draw significant numbers of visitors. Coastal protection benefits are highest in the Central and South Central regions. In our design of the Informed Management scenario, we strove to maintain and enhance this specialization where it was supported by local stakeholder preferences (e.g., Northern Region for tourism and Southern Region for spiny lobster; Fig. 3).

Spatial variation among regions in the delivery of benefits depends on the distribution and quality of habitats providing the services, other ecological and physical components, and social and economic factors that influence access and the distribution of beneficiaries (32, 33). Planning regions high in lobster catch and revenue tend to have relatively greater coverage of coral or seagrass (adult habitat) and mangroves or seagrass (nursery habitat). Tourism relies on high-quality habitat, but also on supporting infrastructure, such as roads, hotels, and airports.

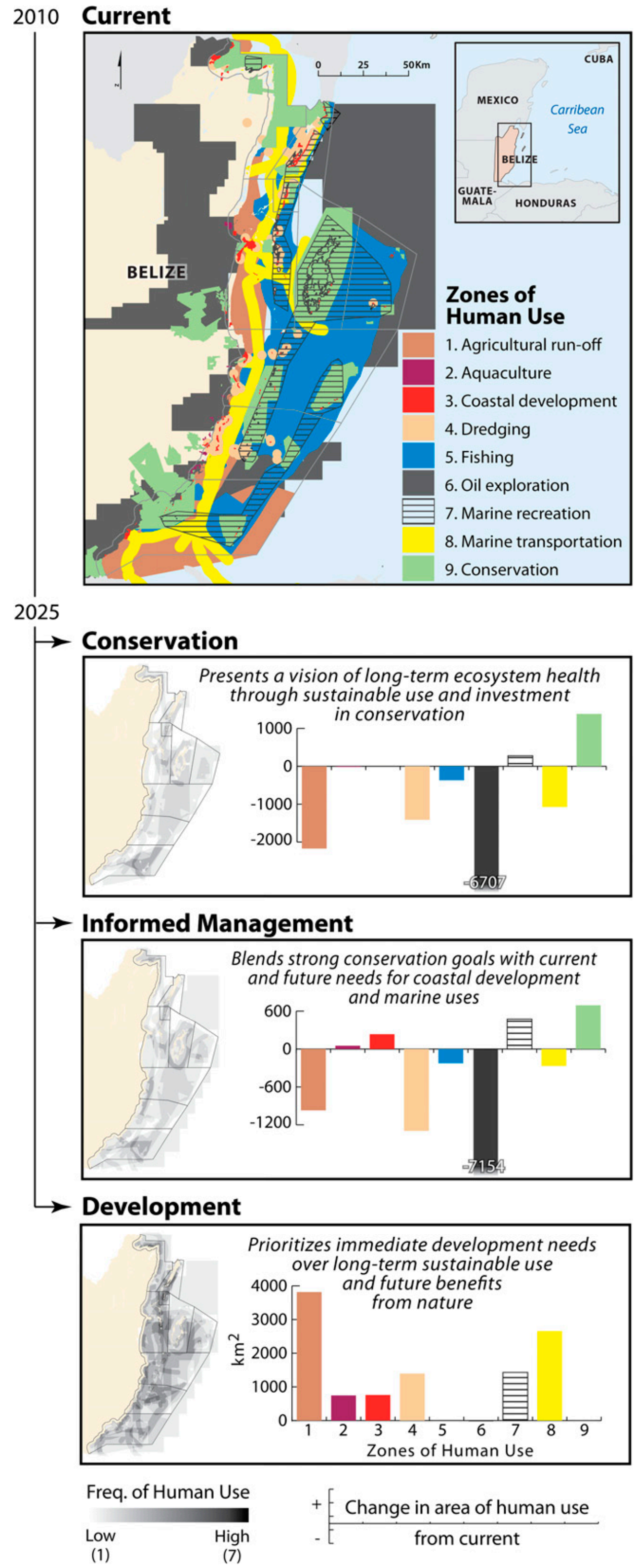

Fig. 1. Map of Current and three future scenarios for eight zones of human activities that may influence habitats and services.

Refining and Making the Case for Informed Management. The ICZM Plan that emerged from our process implements the final version of the Informed Management scenario. Our results suggest that this plan will result in 25–100% better returns from services than

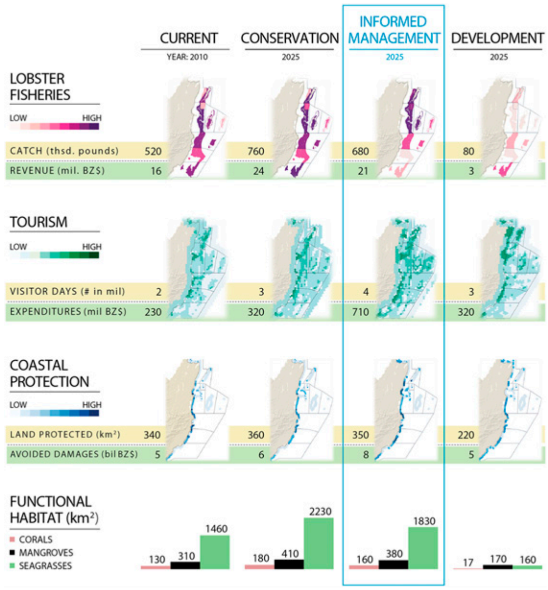

Fig. 2. Biophysical and economic values for three ecosystem services and the area of habitat capable of providing services under the Current and three future scenarios for the ICZM Plan for Belize.

the initial August 2012 version (Fig. 4). The first version was designed to sit between the Conservation and Development scenarios before accounting for changes in ecosystem-service values. Modeling indicated substantial losses for lobster catch and revenue, avoided damages from storms (Fig. 4), and area of functional habitat relative to current conditions (*SI Appendix*, Figs. S8 and S13*A*). In fact, ecosystem services produced in the first iteration of the Informed Management scenario were only marginally higher than in the Development scenario in several regions.

To improve the initial version of the Informed Management scenario, we first identified regions, such as the Central Region, where our models predicted that functional habitat and service delivery would decrease relative to the present scenario (Fig. 4 and *SI Appendix*, Figs. S1*B* and S13*A*). The Central Region is particularly critical to the country's economy because it is where the vast majority of Belizeans live and it is the largest contributor to the three ecosystem services (Fig. 3). In this region, we found large decreases in the area of functioning mangroves due to high-risk activities such as oil exploration, aquaculture, and dredging (*SI Appendix*, Fig. S13). Taking into account the expressed stakeholder priorities for specific uses (e.g., tourism development over oil exploration), we shifted the locations and reduced the extent of these activities (*SI Appendix*, Figs. S1*B* and S13 *B* and *C*).

The second iteration of the Informed Management scenario yielded a dramatic increase in functional habitat relative to the Current, Development, and first iteration of Informed Management scenarios, and concomitant increases in the delivery of almost all services in all regions (Fig. 4). The second version was incorporated into the first draft of the ICZM Plan and reviewed during a 60-d public comment period from May through July 2013. As a result of several expert reviews, public commentary, and changes in national legislation [e.g., Turneffe Atoll officially became a marine reserve and offshore drilling contracts issued by the government of Belize (in 2004 and 2007) were declared null and void], we incorporated new data sources, local knowledge, and local preferences to produce the final Informed Management scenario (Fig. 1 and *SI Appendix*, Fig. S5) and expected returns from services (Fig. 2).

Discussion

Recent policies and high-profile efforts have called for integrating ecosystem services into ocean planning (6, 11), but none have explicitly modeled the benefits of coastal and marine environments to allocate space to various human activities (15, 42). The ICZM Plan for Belize is, to our knowledge, the first national-scale coastal and ocean plan designed using a suite of ecosystem-service models and metrics (38). Through an iterative process of stakeholder engagement, mapping, modeling, and review by scientists and policymakers, we were able to develop and refine a preferred spatial plan that met multiple planning objectives.

Applying what has until now been largely theoretical ecosystem-service science to ocean planning in Belize allowed us to assess risk from multiple human activities and examine trade-offs among several objectives by using a common metric [i.e., Belizean dollars (BZD)] that resonates with diverse stakeholders. We extended recent advancements in risk-assessment and cumulative impact mapping (2, 29–31) beyond habitats to model the influence of multiple activities on services. Making explicit the links between ecosystem structure, function, and services to people are important even in a place like Belize, where many ecological relationships are intuitive for stakeholders. For example, modeling and communicating the relationship between revenue from spiny lobster and change in habitat area revealed the financial importance of corals, mangroves, and seagrass. The analysis also highlighted a trade-off between development and lobster catch that informed conversations over conflicts between government departments overseeing management of fisheries and coastal development.

Quantifying change in services can also help to internalize synergies or trade-offs among multiple objectives that otherwise might be considered separately—even in an integrated management process (5). For example, planners may consider first where habitats are critical for species or fisheries, and then later tourism goals trump conservation because they tend to be more lucrative. Considering multiple objectives from the start of a process in common metrics fosters open discussion about trade-offs and supports diverse stakeholder interests. In a real planning process, services also represent culturally important endpoints that are significant regardless of their economic value. Fisheries are a good example because in some places (e.g., Belize and the

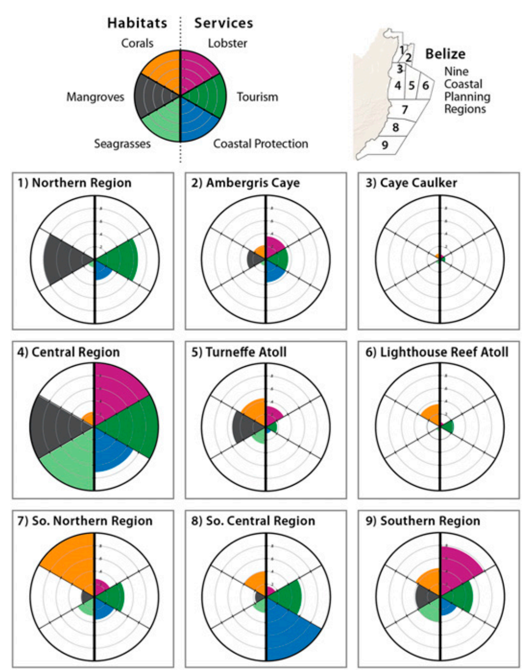

Fig. 3. Relative amount of functional habitat and three services by planning region for the Informed Management scenario. Area of functional habitat, revenue from the spiny lobster fishery, expenditures from tourism, and avoided damages from storms for each planning region are scaled to the maximum planning region value for a particular service. Differences are in part due to variation in planning region size (*SI Appendix*, Fig. S2). Area of functional habitat is based on risk categories such that high = 0%, medium = 50%, and low = 100% of existing habitat, respectively (*SI Appendix*).

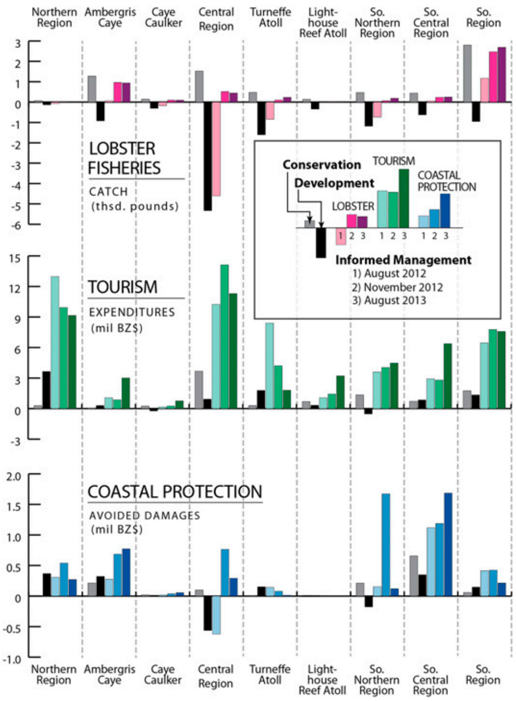

Fig. 4. Change in services for all scenarios and iterations relative to current management. Zones of human activities changed slightly for the Conservation and Development scenarios through the planning process based on revised data layers, but not due to a focused effort of refinement and revision that we used to adjust the Informed Management scenario.

northeast United States), they not only support livelihoods but also are central to the cultural heritage of a place and its people. Thus, a visual depiction like Fig. 2 is much more useful for conversations among policymakers and stakeholders than summing up total service values across current and future scenarios.

The overarching goal for the Belize ICZM Plan is balanced and sustainable use of the coastal and marine environment for the benefit of Belizeans and the global community (38). In practice it is rarely clear how to find such balance. In this planning process, the Development scenario represented a continuation of recent ad-hoc management, whereas the Conservation scenario lacked any future coastal development—a poor strategy for growing an economy based on tourism. The crux of the scientific and management question became: where can we expand coastal development and associated uses, like marine transportation, to enhance economic returns but minimize loss of ecosystems and services? By revealing specific locations where different human activities were putting particular habitats at risk, and whether reducing exposure was a viable management option, the habitat risk assessment (*Materials and Methods*; *SI Appendix*, Fig. S13; and ref. 31) helped to organize and add efficiency to an otherwise unstructured exercise. Advancing the science to model how change in ecosystems (as a result of future scenarios of human use) led to change in service values allowed us to include social and economic factors that influence delivery of nature's benefits to people. Increases in tourism revenue and avoided damages in the Informed Management scenario revealed the importance of coastal development for the economy. Looking beyond coral habitat (often a focus of marine conservation efforts) was essential for adjusting the Informed Management scenario to address the effects of seagrass and mangrove habitats on the decrease in predicted lobster revenue and avoided damages (Fig. 4) in the first iteration of this plan.

Using ecosystem-service values and models helped to develop an ocean plan that a diversity of stakeholders could support, highlighting the benefits of spatial analyses of coupled human–natural systems (20, 26, 35, 36, 43, 44). Studies of linked human–natural systems suggest that spatial heterogeneity emerges not only through variation in nature and economic values, but also through different choices and behaviors (43). Our results point to areas of "specialization" in ecosystem benefits (Fig. 3), such that each planning region contributes to a whole (i.e., delivery of a suite of services on a national level), while meeting threshold objectives of local stakeholder groups. For example, high tourism revenues and coastal protection values in the South Central Region emerged in part from extensive coral coverage, exposure to storms, and high property values, but also from stakeholder preferences for high revenue, low-impact tourism development, and ecosystem-based approaches to climate adaptation and coastal hazard management. Perspectives of stakeholders in other regions differed, thus providing space for different activities, with varying impacts on ecosystems and benefits to people.

The literature overwhelmingly points to the importance of stakeholder participation in the design phase of planning (36, 37). However, a recent case study involving the placement of no-take marine protected areas suggests that scenarios designed solely with stakeholder input will rarely approach optimal solutions (45). Rassweiler et al. (45) propose that managers start with several optimal scenarios based on analysis of trade-off frontiers and then ask stakeholders to modify these. For a more complex, multicriteria problem such as the one we assessed here, our approach was similar—use modeling to highlight unexpected synergies or trade-offs that stakeholders can then incorporate into subsequent iterations of scenarios. Unlike other optimization efforts (e.g., ref. 5), our process was not automated because the feedback from stakeholders was integral to accurately specifying the decision space and reassessing stakeholder preferences based on interim results. Because our models are deterministic, we have little insight into how robust alternative spatial planning scenarios might be to future environmental or human-caused shocks. An interesting next step would be to use a stochastic system model with a management strategy evaluation process designed to select alternatives that are robust to future perturbations outside of management control (26).

Our work in Belize embraces an inherent quality of science-policy processes—that scenarios evolve (44). The Informed Management scenario was originally called "Middle-of-the-Road," and then "Compromise," to reflect concessions between what are often seen as conflicting interests between conservation and development. Eventually, the preferred scenario evolved into a science-based zoning scheme for enhancing economic returns from key coastal resources while minimizing environmental impact. Further analysis can help link how changes in ecosystem services result in changes to human well-being, in terms of health, welfare, and livelihoods. Of course, only continued monitoring will show whether modeled results are borne out in reality. The small subset of potential benefits we estimated may trade off with unmeasured services. Uncertainty also exists in our estimates of the three services, due to measurement error in inputs (e.g., maps of habitats and human uses), scale of the analyses, simplifying assumptions in model formulation, and the relationship between habitat risk and amount of functional habitat which deserves further research (*SI Appendix*). Despite analytical limitations, science made policy more effective by directly addressing the needs and values of people.

The ICZM Plan and our experience in Belize suggest it is worth incorporating ecosystem services into coastal and ocean planning. Our approach and models directly informed the final zoning scheme contained in the Plan now under government review. According to the Belize Coastal Zone Management Act, adaptive management should occur every 4 y. The spatial designation of human activities along the coast and in territorial waters will continue to evolve. Our ecosystem-services approach is extensible so that other benefits can be included in future analyses, and it is sustainable because CZMAI has the tools and skills needed to perform upcoming work. The Belize case demonstrates to governments skeptical of multiobjective planning that considering a suite of human activities and ecosystem services is not only feasible, but can enhance the benefits humans receive from nature relative to what stakeholder preferences alone would have achieved, reduce conflicts and time-consuming legal or community-led protests, and produce an integrated plan with broad stakeholder support essential for its durability.

Materials and Methods

Quantifying Functional Habitat. To estimate spatial variation and change in ecosystem services, we first quantified change in the distribution, abundance, and other characteristics of three habitats: coral reefs, mangrove forests, and seagrass beds. We began with a classic risk-assessment approach (refs. 30 and 31 and *SI Appendix*, Fig. S13*B*) to determine which habitats and where were most at risk for degradation from the cumulative impacts of human activities in the Current and three future scenarios (31). We produced maps of high, medium, and low risk (31) and used them to estimate the area of functional habitat capable of providing ecosystem services in each scenario. In high and medium areas we assumed that 0% and 50%, respectively, of the existing habitat was capable of providing services; in low-risk areas, we considered all habitat to be functional (*SI Appendix*, Figs. S8 and S13*A*).

We used the risk-assessment outputs (i.e., area of each habitat at high, medium, and low risk) and the total area of functional coral, mangrove, and seagrass habitat in each planning region—and nationally—as metrics by which to evaluate conservation goals for the ICZM Plan (Figs. 2–4, this work, and refs. 31 and 38). We used maps of functional habitat (500-m resolution) as input data layers into the ecosystem-service models for each planning scenario.

Modeling Ecosystem Services. We estimated the spatial production and economic value of three ecosystem services as a function of the area of habitat capable of providing the service and the distribution of human activities for each scenario. To estimate catch and revenue from the spiny lobster fishery in Belize, we used an age-structured model with Beverton–Holt recruitment to describe the lobster population as nine subpopulations (one per planning region) connected via immigration as lobster move among habitats (*SI Appendix*, Figs. S14 and S15). For tourism, we used a simple linear regression to estimate the relationships between current visitation (46) and human activities and habitats. We combined our results with Belize Tourism Board data to estimate future visitation rate and tourism expenditures in 5-km grid cells (*SI Appendix*, Fig. S16). For storm protection, we modeled shoreline erosion and wave attenuation in the presence and absence of corals, mangroves, and seagrasses for category 1 and 2 hurricanes (ref. 41 and *SI Appendix*, Fig. S17) and combined these results with property values to estimate avoided damages. We calculated annual values for each service and scenario in current Belize dollars and summed these by planning region and nationally. The scale of our modeling was designed to match the scale of a national planning process that took into account regional variation. Boundaries were 3 km inland and the territorial sea (18,000 km_2; *SI Appendix*, Fig. S2). We projected change in each service by subtracting the model output for the year 2025 from the model output for the current scenario (year 2010). Further details are provided in the *SI Appendix*, Tables S2–S5.

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