Received: 17 September 2020 | Revised: 12 May 2021 | Accepted: 28 May 2021

DOI: 10.1111/cobi.13784

Conservation Biology

CONTRIBUTED PAPER

Resource users as land-sea links in coastal and marine socioecological systems

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Article Impact Statement: There are multiple ways socioeconomically driven behavior links the land and sea.

Abstract

Coastal zones, which connect terrestrial and aquatic ecosystems, are among the most resource-rich regions globally and home to nearly 40% of the global human population. Because human land-based activities can alter natural processes in ways that affect adjacent aquatic ecosystems, land-sea interactions are increasingly recognized as critical to coastal conservation planning and governance. However, the complex socioeconomic dynamics inherent in coastal and marine socioecological systems (SESs) have received little consideration. Drawing on knowledge generalized from long-term studies in Caribbean Nicaragua, we devised a conceptual framework that clarifies the multiple ways socioeconomically driven behavior can link the land and sea. In addition to other ecosystem effects, the framework illustrates how feedbacks resulting from changes to aquatic resources can influence terrestrial resource management decisions and land uses. We assessed the framework by applying it to empirical studies from a variety of coastal SESs. The results suggest its broad applicability and highlighted the paucity of research that explicitly investigates the effects of human behavior on coastal SES dynamics. We encourage researchers and policy makers to consider direct, indirect, and bidirectional cross-ecosystem links that move beyond traditionally recognized land-to-sea processes.

KEYWORDS

coastal governance, conservation planning, ecosystem management, land-sea processes, natural resource-based livelihoods

Los Usuarios de Recursos como Conexiones entre la Tierra y el Mar dentro de los Sistemas Socioecológicos Marinos y Costeros

Resumen: Las zonas costeras, que conectan los ecosistemas terrestres y acuáticos, se encuentran entre las regiones más ricas en recursos a nivel mundial y además albergan a casi el 40% de la población humana de todo el mundo. Ya que las actividades humanas terrestres pueden alterar los procesos naturales de manera que terminan por afectar a los ecosistemas acuáticos adyacentes, cada vez se reconoce más a las interacciones tierra-mar como críticas para la planeación de la conservación y la gestión costera. Sin embargo, las complejas dinámicas socioeconómicas inherentes a los sistemas socioecológicos (SES) marinos y costeros han recibido poca atención. Con el conocimiento generalizado a partir de los estudios a largo plazo realizados en el Caribe de Nicaragua como punto de partida, diseñamos un marco conceptual que clarifica las múltiples formas en las que el comportamiento con origen socioeconómico puede conectar a la tierra y al mar. Sumado a otros efectos de los ecosistemas, el marco conceptual ilustró cómo los comentarios resultantes de los cambios ocurridos en los recursos acuáticos pueden influir sobre las decisiones de manejo de recursos terrestres y de uso de suelo. Evaluamos el marco conceptual mediante su aplicación a los estudios empíricos de una variedad de SES costeros. Los resultados sugirieron su aplicabilidad generalizada y resaltaron la escasez de investigaciones busquen específicamente los efectos del comportamiento humano sobre las dinámicas de los SES costeros. Alentamos a los investigadores y a los formuladores de políticas a considerar las conexiones directas, indirectas y bidireccionales entre ecosistemas que van más allá de los procesos de tierra a mar reconocidos tradicionalmente.

PALABRAS CLAVE
gestión costera, manejo de ecosistemas, planeación de la conservación, procesos tierra-mar, sustentos basados en los recursos naturales

INTRODUCTION

Approximately 39% of the global population lives within 100 km of a coastline (Millennium Ecosystem Assessment, 2005). The behaviors of these populations have indirect and direct effects on the terrestrial and aquatic ecosystems—including mangrove forests, coral reefs, coastal forests, estuaries, and river deltas—that characterize coastal environments and the processes that link these systems. Coastal environments are among Earth's most resource-rich zones, and changes in these systems can affect terrestrial and marine biodiversity, ecosystem functions, and vital ecosystem services (Stoms et al., 2005). Thus, the complex interactions and feedbacks particular to coastal coupled human and natural systems, or coastal and marine socioecological systems (SES), have garnered increased attention as human pressures on these coastal areas intensifies (Álvarez-Romero et al., 2011; Pittman & Armitage, 2016).

Much of the existing coastal SES research explores the natural (i.e., ecological and hydrological) processes that link terrestrial and aquatic ecosystems and how humans affect these processes in an effort to improve coastal conservation planning (e.g., Stoms et al., 2005; Álvarez-Romero et al., 2011; Makino et al., 2013) and governance (e.g., Lebel, 2012; Reuter et al., 2016; Pittman & Armitage, 2016).While land-sea interactions are typically overlooked in models used to develop conservation policies (e.g., selection of areas for terrestrial or marine reserves [Stoms et al., 2005]), conservation efforts can be enhanced when planners account for the ways in which the direct effects of human activities in one ecosystem can indirectly affect the health and stability of another (Álvarez-Romero et al., 2011; Makino et al., 2013). For example, logging can increase runoff and result in heightened sediment loads and pollution in river systems, which can have significant implications for coral reef ecosystems and fish stocks when the sediment reaches the sea (Hamilton et al., 2017; Delevaux et al., 2018). Therefore, effective sea-based protective measures must also consider land-based activities and processes, and vice versa.

Coupling terrestrial and marine conservation activities can reduce the potential for the effects of human behaviors to cascade across the land-sea boundary of a coastal SES (i.e., "cross-system threats") (Tallis et al., 2008). Integrated coastal zone management (ICZM) or integrated sea-land management (ISLM) approaches to policy making incorporate scientific knowledge on ecological connections and feedbacks between the land and sea (Pittman & Armitage, 2016) and sustainability (Glaser et al., 2012). These management strategies can work to mitigate cross-system threats stemming from distant or diffuse activities that a localized protective measure, such as a conservation easement, may not resolve. Agricultural runoff, for example, carries excess phosphorus and nitrogen fertilizer into waterways and promotes algal blooms, stimulating eutrophication and fueling fish die-offs (Álvarez-Romero et al., 2011; Lebel, 2012). To mitigate this, policy makers using an ICZM or ISLM approach may create policies aiming to improve the timing of fertilizer application and reduce potential runoff throughout a catchment (Lebel, 2012). The underuse of ICZM and ISLM in part reflects challenges in effectively translating science into policy in heterogeneous sociopolitical settings (Lebel, 2012; Reuter et al., 2016); however, these cross-system considerations highlight a growing recognition of how resource users' behaviors may affect the ecosystem health and stability of coastal SESs in novel ways.

Comprehensive knowledge of coastal SES dynamics is, therefore, fundamental to successful conservation planning and governance within these complex systems. While previous research has expanded understanding of the myriad natural processes that connect the land and the sea and how human activities can alter or amplify them (Álvarez-Romero et al., 2011), the socioeconomic dimensions of land-sea interactions have received considerably less attention (see for examples Huang & Smith, 2011; Van Holt et al., 2012, 2017; Cottrell et al., 2019). This deficit exists despite the fact that the livelihoods of 700 million people globally are based on natural resources in coastal SESs (CGIAR Research Program on Aquatic Agricultural Systems, 2012). In their overview of land-sea connections, Álvarez-Romero et al. (2011) identify the importance of socioeconomic processes in coastal SES. They describe how conservation action or policy decisions may alter human behaviors in ways that produce unintended feedbacks within or across ecosystems. They conceive of a hypothetical case whereby the creation of a marine protected area encourages agricultural intensification by coastal populations, which in turn negatively affects the marine system through increased runoff of sediment and pollution. Although this and other scenarios (Cottrell et al., 2018) point to the importance of the socioeconomic dimensions of land-sea interactions, a paucity of empirical research has precluded a nuanced understanding of coastal SES dynamics and inhibits policy makers' abilities to anticipate potential indirect or unintended outcomes of resource management decisions in these systems.

To address this gap, we developed a conceptual framework that describes the multiple ways in which individuals and households can influence land-sea dynamics through their socioeconomic decisions. This framework grew from our evaluation of the drivers and consequences of natural resource use in a central case study in Carribean Nicaragua's Pearl Lagoon basin, a region experiencing changing patterns in natural resource use spurred by globalization pressures. We collected a suite of socioecological data in this area from 2009 to 2014. Our research in the region involved efforts to collect fisheries, agroecological, forestry, ethnographic, and household socioeconomic data. Although we aimed initially to answer questions about the effects of road development and increased access to global markets on natural resource use and ecosystem health (e.g., Stevens et al., 2014; Williams, 2016; Sistla et al., 2016; Kramer et al., 2017; Williams & Kramer, 2019), these separate investigations revealed complex linkages and feedbacks within the system. Through a series of research workshops that included collaboration with local natural resource policy makers, we qualitatively synthesized the findings from our prior work and conceptualized the interrelationships among external drivers, natural resources stocks, ecosystem processes and services, and resource valuation and use dynamics observed in this coastal SES. Ultimately, we found that regional-level processes, which are both endogenous and exogenous to the system, influence key resource-use behaviors that predominate the somewhat stochastic effects of more discrete individual or household behaviors, thereby affecting local land-sea processes and ecosystem functioning.

To assess the generalizability of the framework we developed from our Caribbean Nicaragua case study, we sought comparative examples of empirical research that features resource-use dynamics in coastal SESs in other parts of the world. We queried Web of Science with the topic keyword search (which searches titles, abstracts, author keywords, and keywords algorithmically generated through cited literature) to identify English language articles published from 1900 to 2021 in the following indexes: Science Citation Index Expanded, Social Science Citation Index, Arts and Humanities Citation Index, Book Citation Index-Science, Book Citation Index-Social Sciences & Humanities, and Emerging Sources Citation Index. Our search combining the terms "*coastal* OR *land-sea*," "*livelihood*," "*interaction*," OR (*marine* AND *terrestrial*)," and "*ecosystem* OR *ecological*" yielded 113 potentially relevant articles. We reviewed each of these articles to identify studies that were empirically based, explicitly included socioeconomically driven behaviors, and considered processes directly or indirectly affecting two (or more) distinct ecosystems. We also reviewed studies referenced in synthesis articles focused on land-sea processes (Stoms et al., 2005; Tallis et al., 2008; Álvarez-Romero et al., 2011, 2015; Lebel, 2012; Reuter et al., 2016; Pittman & Armitage, 2016) for additional articles meeting our inclusionary criteria. Ultimately, we identified 22 articles describing the effects of human behavior on processes that link coastal ecosystems around the globe.

For each relevant article, one coauthor developed a short summary of the human behavioral drivers, natural processes and ecosystems affected, and causal connections between human behaviors and ecosystem effects. Individual coauthors then evaluated each study in relation to our framework, determining if and how the processes described fit our framework categories. The classifications were then verified by at least one other coauthor. Although the number of available studies is currently limited, our assessment process did not indicate a need to revise our framework, suggesting that it is generalizable beyond our Caribbean Nicaragua case study.

In addition to considering examples of socioeconomically driven behaviors that affect natural processes both within and across terrestrial and aquatic systems, our case study and supporting examples demonstrate how socioeconomic feedbacks resulting from changes to aquatic resource pools can influence terrestrial resource management decisions, thereby linking the sea to the land through a previously underappreciated process.

We identify three main categories (Figure 1), grouped by the ways in which resource-use decisions affect the larger coastal SES: transecosystem effects (TEE), or the direct ecological effects of resource-use decisions in one ecosystem that cross into and affect one or more other ecosystems; parallel ecosystem effects (PEE), or resource-use decisions that simultaneously and directly affect two or more ecosystems in parallel; and feedback ecosystem effects (FEE), or changes to resources in one ecosystem that feedback to influence decision-making pertaining to one or more other ecosystems.

PEARL LAGOON BASIN CASE STUDY

The Pearl Lagoon basin (Figure 2) is in Nicaragua's Región Autónoma de la Costa Caribe Sur. Moist lowland tropical forest dominates the terrestrial ecosystems of the basin, and the aquatic ecosystem includes an approximately 52,000-ha estuary system that terminates in the Caribbean Sea. The basin is historically home to three main indigenous and Afro-descendant populations: Miskito, Garifuna, and Nicaraguan Kriol. These populations live in 12 communities along the shore of the Lagoon and the Caribbean Sea (Figure 2). These communities have traditionally relied on both the aquatic and terrestrial ecosystems to meet their subsistence needs: fishing freshwater and marine animals along with agroforestry, foraging, and hunting. Despite the episodic exploitation of certain resources (such as rubber and mahogany) driven by foreign interests, the basin's historical inhabitants have and continue to exercise communal management of natural resources and seasonally shift emphasis between livelihood activities to adapt to changing resource availability (Sistla et al., 2016; Kramer et al., 2017; Williams & Kramer, 2019).

Geopolitical factors and globalization have driven recent sociocultural, economic, and political changes throughout the basin. The construction of a transnational road in 2007 established a link between Pearl Lagoon and Nicaragua's highland and Pacific regions, marking an era of increased connectivity (including greater market and technologies access) for the basin. Additionally, mestizo (i.e., Spanish speakers of mixed Amerindian and European descent) migration from Nicaragua's highland regions into the coastal Caribbean region has increased

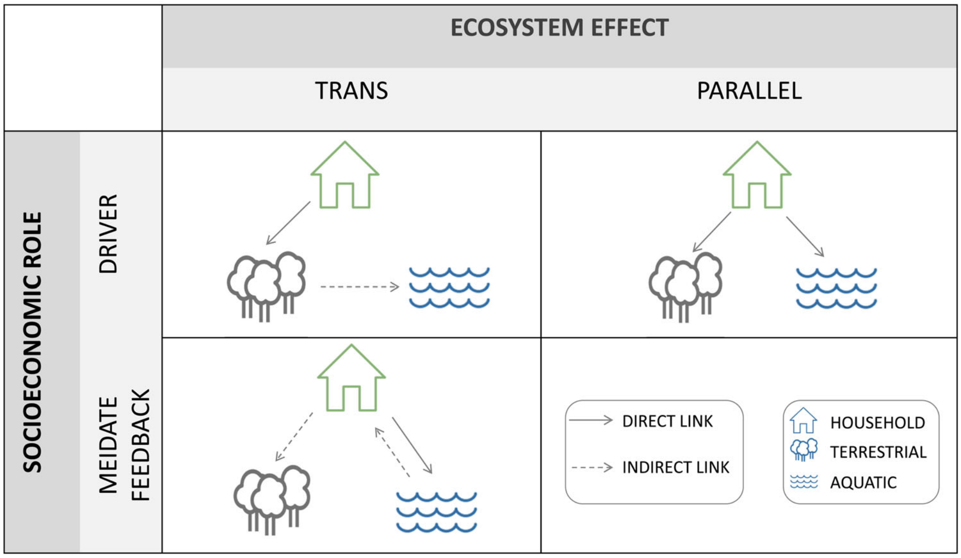

FIGURE 1 The primary ways that resource-use decisions affect coastal socioecological system dynamics classified by socioeconomic role and ecosystem effect (TEE, trans-ecosystem effect; PEE, parallel ecosystem effect; FEE, feedback ecosystem effect). These distinctions depend on the position of the household either as an originating source or as a mediator of ecosystem processes.

following the end of the Nicaraguan civil war (approximately 1990). Migrants have continued to push east over the past decades, clearing and settling areas around the basin's historical communities to develop cattle ranches (Williams, 2016). Ultimately, these exogenous drivers have altered patterns of natural resource use in the basin and profoundly affected this SES (Stevens et al., 2014).

While there are numerous cultural, economic, and ecological changes occurring within the Pearl Lagoon basin, these key, well-characterized regional-level phenomena exemplify the processes driving the three categories of ecosystem effects in this and other coastal SESs. Other drivers of socioeconomic behavioral change in the basin (e.g., a marine turtle conservation program [Lagueux et al., 2014] and climate change [Jameson et al., 2018]) also have implications for local natural resources and land-sea processes. However, similar to processes identified in other coastal SESs, the mechanisms by which any of these individual drivers may affect the Pearl Lagoon basin's SES can be captured by the three categories described here.

TRANSECOSYSTEM EFFECTS (TEE)

The land-use behaviors of the region's mestizo migrants exemplify a TEE, or cross-system threat. Mestizo migrants have moved into the region seeking free or inexpensive forested land to clear for cattle ranching (Williams, 2016). Poorly enforced land-management regulations coupled with this human migration has led to rancher-driven deforestation, increasing sediment loads in local rivers, the estuary, and the Caribbean vis-a-vis runoff (Christie et al., 2000; Fonseca, 2008). Increased sediment loads in the local aquatic ecosystems has negatively affected freshwater species (Christie et al., 2000) and led to algal cover of nearshore coral reefs (Fonseca, 2008). Thus, the effects of human behaviors in one ecosystem that are driven in this case by migration (and beef markets) have unplanned and cascading impacts in a distinct, though ecologically connected, ecosystem.

The TEE linking land use and land-use change to aquatic systems are the most recognized cross-ecosystem effects in coastal SESs. While 10 of the 22 articles we identified exemplified TEE (Table 1), the downstream effects of land use and land-use change have been well-documented globally (Allan, 2004; Álvarez-Romero et al., 2011; Lebel, 2012; Brown et al., 2017). Effects of runoff caused by deforestation and agricultural activities in coastal zones include, but are not limited to, compromising mangroves, degrading wetland vegetation, and affecting water quality (Liu et al., 2008; López-Medellín et al., 2011; Gedan et al., 2011; Zhang et al., 2012; Tulloch et al., 2021), eutrophication that affects coastal food webs (Turner & Rabalais, 1994; Van Holt et al., 2012, 2017; Broadley et al., 2020; Wenger et al., 2020), and damage to coral systems (Fonseca, 2008; Aswani, 2014; Tulloch et al., 2016).

PARALLEL ECOSYSTEM EFFECTS (PEE)

The effects of new markets and technologies on the natural-resource-use decisions of residents of the communities near the terminus of the Pearl Lagoon basin's recently constructed road exemplifies PEE (i.e., resource-use decisions that affect separate ecosystems simultaneously). The road provided access for fish buyers from Nicaragua's capital region to purchase relatively low-cost, traditionally subsistence finfish for export (Stevens et al., 2014). Households in the region that use both fishing and farming for subsistence have responded to new market access by shifting their natural resource use. Some fishers in

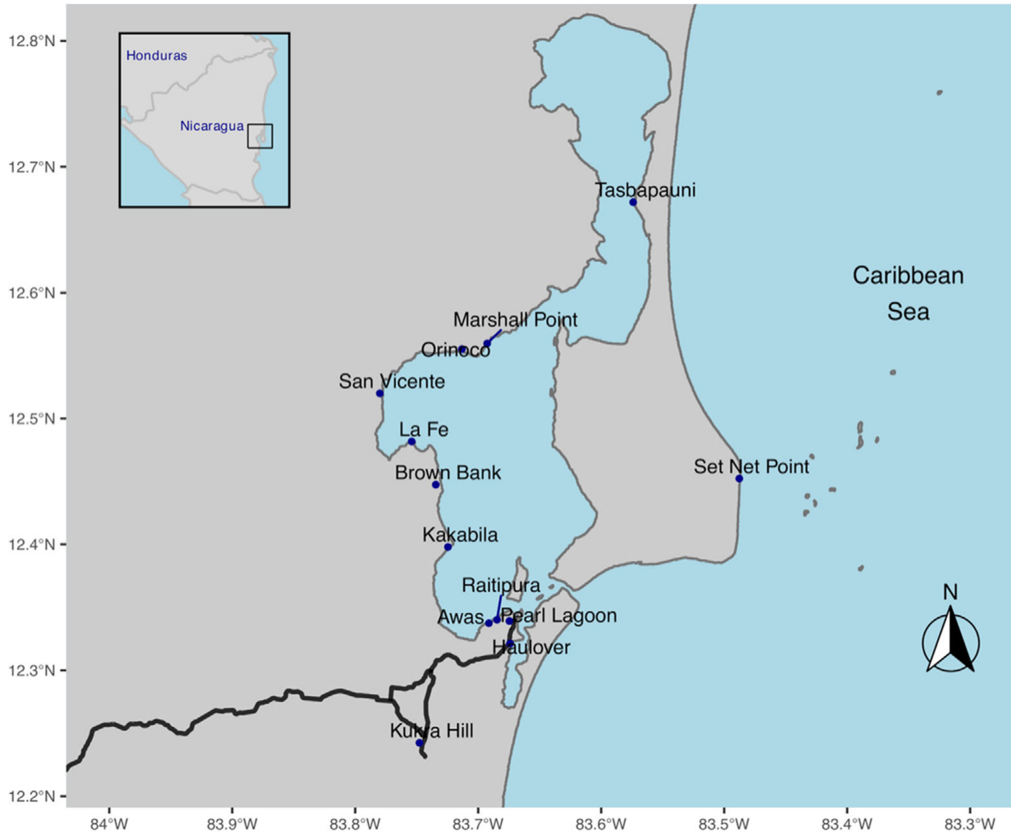

FIGURE 2 Nicaragua's Pearl Lagoon basin, its communities, and road

the communities near the road continue to maintain highly agrobiodiverse farms (Williams & Kramer, 2019), others have abandoned or suspended farming activities—decreasing land-use pressures—to focus their efforts on more financially lucrative fishing activities (Kramer et al., 2017). This shift is partly driven by the concurrent development of newly available goods and services available for purchase such as electricity and mobile phones (Williams, 2015).

Examples of PEE can be identified in a variety of coastal SES (Bunce et al., 2010; Conchedda et al., 2011; Lawson et al., 2012; Hoshino et al., 2017; Fischer, 2018; Kibria et al., 2018; Mirera et al., 2020). Nonfarming Ghanaian fishers reduced or even ceased fishing to focus efforts on small-scale gold mining during a recent boom (Hirons, 2014). In a more inland fishing and farming community, increasingly dry and hot climate patterns reduced water levels and affected fish stocks in Lake Chad and encouraged local populations to shift their focus to agriculture (Sarch & Birkett, 2000). In this way, decisions on resource use directly affect both the terrestrial and aquatic ecosystems and may unexpectedly reduce pressure on one ecosystem at the expense of another.

Notably, socioecological effects generated by PEE may be transient because strategies for natural resource use that simultaneously affect two ecosystems can ultimately affect transecosystem processes, resulting in TEE. For example, inland aquaculture development in fishing-farming communities may simultaneously displace agriculture (Shameem et al., 2014; Islam et al., 2015) and reduce localized coastal fishing pressures (Pomeroy et al., 2006). However, effluent from aquaculture activities can produce algal blooms in waterways and spread disease to wild riverine and marine populations (Páez-Osuna, 2001).

FEEDBACK ECOSYSTEM EFFECTS (FEE)

Socioeconomically driven environmental effects can also produce drivers endogenous to the coastal SES that result in FEE, in which ecological changes in one ecosystem feedback to influence resource use in another ecosystem. In our case study, the market incentives for local finfish drove overfishing, which resulted in significant declines in the Pearl Lagoon's fish stocks and overall fishery health (Stevens et al., 2014). In communities without direct access to fish buyers via the road, reduced catch rates encouraged community members to invest more effort in the agroforestry systems they maintain in communal lands (Kramer et al., 2017; Williams & Kramer, 2019). Thus, spatially heterogeneous resource access in one ecosystem can drive increased human impacts in a separate ecosystem.

A similar FEE process in the basin stems from a marine turtle conservation program, led by an international nongovernmental organization that limits access to a historical food source for local populations. Paralleling the impacts of overfishing of

TABLE 1 Research documenting the effects of resource-use decisions in coastal socioecological systems beyond the Pearl Lagoon basin, Nicaragua

Category	Global example
Transecosystem effects	In China, returning cropland to forest or grassland reduces sedimentation (Liu et al., 2008).
	In the Mississippi River delta (USA), agricultural runoff drives eutrophication (Turner & Rabalais, 1994).
	In Papua New Guinea, models predict effects of future oil-palm development on coral reefs (Tulloch et al., 2016).
	In northwestern Mexico, settlement expansion, agricultural and ranching activities, and inland aquaculture degrade mangrove systems (López-Medellín et al., 2011).
	In Southern Chile, tree-plantation development releases excess nutrients into adjacent coastal waters causing eutrophication that alters the structure and function of coastal ecosystems (Van Holt et al., 2012).
	In the Solomon Islands, local fishers believe logging operations and siltation have damaged coral reefs (Aswani, 2014).
	In the Solomon Islands, land clearing and logging increases sedimentation leading to degradation of coral reefs and reductions of fish abundance and biomass (Wenger et al., 2020).
	In Papua New Guinea, mining, forestry, and palm-oil cultivation reduce forest cover and increase sedimentation and pollution in local rivers (Tulloch et al., 2021).
	In Southern Chile, tree plantations cause high levels of chlorophyll and fishers must fish farther offshore relative to areas where there is native forest (Van Holt et al., 2017).
	In Australia, water extraction for agricultural purposes reduces prawn catch in downstream marine systems (Broadley et al., 2020).
Parallel ecosystem effects	Ghanaian fishes reduce fishing effort to engage in small-scale gold mining on local beaches (Hirons, 2014).
	In the Lake Chad basin, fish stocks affected by low water levels encourage shifting focus to agriculture (Sarch & Birkett, 2000).
	In Tanzania and Mozambique, coordinated marine and terrestrial conservation activities reduce fishing and farming (and undermine local substance strategies) (Bunce et al., 2010).
	In Senegal, seasonal migration for fishing activities and outmigration reduce farming activities (promoting forest regeneration) and relieve pressure on resource extraction in mangrove systems (Conchedda et al., 2011).
	In Ghana, locally caught fish require smoking, which encourages mangrove depletion and inland deforestation (Lawson et al., 2012).
	In Kenya, young trees and shrubs from the surrounding forest are used in seaweed farming. Although current impacts are minimal, the expansion of seaweed farming could lead to greater deforestation (Mirera et al., 2020).
	In the Ganges delta, agricultural land use decreases as shrimp farming expands (Islam et al., 2015).
	In the southwest coastal region of Bangladesh, the decline of the wild shrimp population led to increased inland shrimp farming. Combined with saltwater intrusion, the degradation and displacement of land has negatively affected rice farming (Shameem et al., 2014).
	In Indonesia's Kei Islands, population growth and urbanization are encouraging productivity increases of fisheries. To meet increased demand, fishers require more timber to build traditional lift nets and canoes (Hoshino et al., 2017).
	In Bangladesh, inland pirate strongholds create dangers for deep-water river fishing and timber collection. Thus, most locals prefer collection of fuelwood and shrimp fry as paired livelihoods (Kibria et al., 2018).
Feedback ecosystem effects	In Ontong Java, Solomon Islands, bêche-de-mer trade resulted in fishery decline and thus an export ban. This has driven a renewed focus on horticulture (Christensen, 2011).
	In Ghana, bushmeat demand is driven by a decrease in fish catch (Brashares et al., 2004)

lagoon finfish, these restrictions potentially encourage those who hunt turtle to rely more heavily on other livelihood strategies (Lagueux et al., 2014), including alternate fishing activities and terrestrial activities, such as agroforestry. In the Solomon Islands, foreign markets fostered a sea cucumber harvesting boom. After overharvesting depleted sea cucumber stocks and encouraged a government imposed export ban, local populations intensified taro production because locally produced food once again became vital for subsistence when money to purchase imported goods was scarce (Christensen, 2011). Exogenous drivers can also impel this form of transecosystem effect. In Ghana, foreign (often industrial) fishing fleets significantly reduced fish populations on which locals historically relied as their major protein source. To compensate, local populations shifted effort to bushmeat in reserve areas, affecting wildlife populations and the terrestrial food web (Brashares et al., 2004).

IMPLICATIONS

The Pearl Lagoon basin case study and findings from other coastal systems highlight the various ways that the decision-making of resource users influences the dynamics of coastal SESs. Previous coastal SES research describes the natural processes that connect terrestrial and aquatic ecosystems and the potential for human behaviors to (negatively) affect these processes. Here, we illustrated not only how social and ecological drivers may encourage behaviors that impact natural processes within or across ecosystems, but also how resource users themselves serve as direct links between aquatic and terrestrial ecosystems. Effective conservation policy and governance in coastal SES, therefore, requires a nuanced understanding of the local context, with a particular focus on the relationships between livelihoods and natural resources and acknowledgement of the potential for feedbacks to result in transitions from one type of socioeconomically driven ecosystem effect to another. To better inform policy makers and advance understanding of the processes inherent to coastal SES, our literature review suggests that interdisciplinary research must direct more attention to these dynamics.

The socioeconomic processes that link coastal aquatic and terrestrial ecosystems are typically considered to result only from human activity in a terrestrial ecosystem that then indirectly and negatively affects an aquatic ecosystem due to ecological spillover (Pittman & Armitage, 2016). Because natural processes tend to flow downstream, there are few examples of changes in aquatic ecosystems affecting upstream adjacent terrestrial ecosystems, with the exception of processes involving diadromous fish species (e.g., salmon) (Helfield & Naiman, 2006; Bryan et al., 2013), seabirds (Sanchez-Pinero & Polis, 2000; Ellis, 2005), or saltwater intrusion (Shameem et al., 2014). Our case studies, however, provide evidence that humans can serve as both direct and indirect links between aquatic systems and neighboring terrestrial systems. In fact, among the global studies that examine the roles of socioeconomic decisions in coastal SES dynamics that we identified, more provide examples of humans as mediators between the land and sea (PEE and FEE) than of socioeconomically driven behaviors affecting natural downstream processes (TEE). Because relatively few empirical studies exist, drawing conclusions about spatial patterns or global tendencies is problematic. Published studies may actually reflect more about the types or lack of research being conducted in specific geographic areas, rather than the processes occurring in coastal SESs around the world. For example, identifying FEE requires broad knowledge of cross-system dynamics, and while we found limited global examples, this may merely indicate that more interdisciplinary research that overcomes existing barriers between marine and terrestrial science is needed. However, despite these shortcomings, our findings suggest that socioeonomic processes mediate both downstream and upstream ecosystem effects with potentially equal or greater impact than ecological processes alone in coastal SESs throughout the world.

The diversified livelihood strategies characteristic of coastal populations often are based on resources in multiple ecosystems. The resource-use behaviors of these populations, therefore, directly affect ecological processes in ecosystems and may in turn affect natural land-sea processes. Additionally, a suite of socioeconomic (e.g., increased market access) and natural (e.g., drought) drivers can affect natural resource decision-making and impel coastal populations to shift their resource use from one ecosystem to another. However, this process is not inevitable, and outcomes depend on the specifics of a coastal SES. In the case of the Pearl Lagoon basin, for example, a degraded terrestrial ecosystem or a restrictive land-tenure system not based on communalist cultural norms may have led to migration (or shift to non-natural resource-based livelihoods, if available) following fishery depletion (or a resistance to abandon fishing) rather than a shift in emphasis to agroforestry and ultimately lessening pressure on the system (PEE). Therefore, policy makers aiming to anticipate changing coastal SES dynamics must have a well-developed understanding of local livelihood dynamics, resource governance norms, cultural traditions and valuation of key natural resources, and the current state of natural resources to create effective policies.

It is also vital that policy makers recognize that ecosystem effects rooted in socioeconomically driven behaviors have the potential to produce feedbacks that alter resource-use decision-making. For example, populations like those in the Pearl Lagoon basin (or Solomon Islands) that rely on fishing and farming in parallel (PEE) have been encouraged by foreign markets to target particularly lucrative aquatic resources, resulting in reduced pressure on the terrestrial system. However, overexploitation of these marine resources ultimately resulted in FEE. Once these resource users could no longer benefit from fishing exports, they were incentivized to renew their focus on farming, increasing the local valuation of land and terrestrial resources. The strong potential for transitions from one type of socioeconomically driven ecosystem effect to another must be anticipated by policy makers working to develop sustainable coastal SESs, particularly when considering the potential for rigorous conservation policies to amplify (or instigate) this process.

Global-change processes, including climate change and global development initiatives, are increasingly affecting coastal regions. Successful coastal SES management in the face of these dramatic changes must focus on people, not solely on resources or ecosystems. The estimated 700 million people who rely directly on ecosystem services and functions provided by the biodiversity of coastal ecosystems require that policy makers work to promote natural resource conservation in tandem with supporting the needs of local populations to achieve sustainability goals. This undertaking requires that policy makers consider both direct and indirect cross-ecosystem links that move beyond traditionally recognized land-to-sea processes when designing and implementing conservation policies and recommendations and more fully embrace sea-to-land processes that can be mediated by human behavior. Thus, researchers must work to provide policy makers with holistic understandings of coastal SES dynamics through directed, interdisciplinary, cross-realm research that explicitly examines the drivers and effects of human behavior on and as processes that link coastal ecosystems.

ACKNOWLEDGMENTS

This work was supported by the U.S. National Socio-Environmental Synthesis Center (SESYNC).

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How to cite this article: Williams, N E, Sistla, S A, Kramer, D B, Stevens, K J, Roddy A B. Resource users as land-sea links in coastal and marine socioecological systems. *Conservation Biology*. 2021;1–9. https://doi.org/10.1111/cobi.13784