Integrated Land-Sea Conservation Planning: The Missing Links

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Abstract

Spatial management, including setting aside conservation areas, is central to curbing the global decline of biodiversity, but many threats originate from beyond the boundaries of conservation areas. This is a particular problem in marine systems, which are influenced by many activities on land. In addition, connections between land and sea support many species and ecological processes valued for conservation. Integrated land and sea conservation planning is therefore of utmost importance. We review the literature describing connections between land and sea and how they have been incorporated into conservation planning. Land-sea connections include land-sea processes, the natural flows occurring between realms; cross-system threats, which originate in one realm and affect another; and socioeconomic interactions associated with management decisions to maintain or restore land-sea processes and to prevent or mitigate cross-system threats. We highlight the need to explicitly incorporate land-sea connections in conservation planning and suggest ways of doing this through the use of a novel operational framework for integrated land-sea planning. On the basis of expert surveys and a literature review, we also identify those aspects of conservation planning for which improved integration between land and sea is most needed.

INTRODUCTION

Systematic conservation planning: a process to guide the spatial allocation of limited resources to achieve explicit, mostly quantitative, conservation objectives

Conservation areas: places where some form of spatially explicit management (from strict reservation to off-reserve management) is undertaken to contribute to conservation objectives

Stakeholders: people (e.g., resource users, experts) who will affect or be affected by conservation actions or contribute to the planning process

Conservation objectives: statements about how much of each habitat type, species, and/or ecological process of interest should be represented in conservation areas

Costs: socioeconomic and political constraints on setting aside areas for conservation, such as acquisition, management, transaction, and opportunity costs

Continued loss of biodiversity remains a major international concern on land and in the sea (Rands et al. 2010, Stokstad 2010), and many efforts to curb this decline involve spatial protection through systematic conservation planning (Margules & Pressey 2000). The history of protected areas as a formal conservation tool began on land with the establishment of Yellowstone National Park in 1872. The first marine protected area (MPA) was designated in Australia in 1879, but the pace of efforts in the sea has lagged that of those on land by several decades. Because conservation efforts were more prevalent on land, marine conservation science was built on a rich history of terrestrial theory and application (Kirkpatrick 1983, Margules & Pressey 2000). Although there are key differences in marine systems that require adaptation of terrestrial approaches (e.g., different scales and patterns of dispersal as well as different types of threats; Halpern et al. 2008, Kinlan & Gaines 2003), the foundation of planning principles on land has played a pivotal role in the rapid advancement of marine conservation planning.

Despite shared conceptual roots, conservation planning in terrestrial and marine realms has largely proceeded as if the ecological systems were unconnected (Beck 2003, Stoms et al. 2005). This lack of integration is especially problematic in the sea because the physical and ecological connections between land and sea are often highly asymmetrical; marine areas are often more influenced by land than vice versa (Stoms et al. 2005). MPAs designed to protect marine biodiversity (Wood et al. 2008) are vulnerable to both land- and sea-based threats originating outside their boundaries (Boersma & Parrish 1999, Cicin-Sain & Belfiore 2005). Because most MPAs are in coastal waters (Wood et al. 2008), the risks from diverse land-based activities are further accentuated (Halpern et al. 2009). In this review, we examine our understanding of the connections between land and ocean systems as well as how these connections should guide integrated conservation design and implementation of conservation actions.

Conservation planning focuses on the spatial allocation of conservation resources to different actions (e.g., protected areas, restoration sites, managed harvesting, and best-practice land use; Sarkar et al. 2006), which is complemented by non-spatial activities, such as legislation, policy, incentives, capacity building, and education (Pressey & Bottrill 2009). Such complementary efforts strengthen conservation areas and expand the management and sustainable use of natural resources to areas surrounding or linked to focal conservation areas.

Land-sea conservation planning incorporates ecological connections between land and sea and seeks to limit land-based threats to MPAs, but neither a comprehensive review nor an operational framework for land-sea planning exists. Much has been written about integrated coastal zone management and marine ecosystem-based management (see Cicin-Sain & Belfiore 2005, McLeod & Leslie 2009). These approaches often address aspects of land-sea planning such as ecological connections between land and sea, cumulative impacts, multiple objectives, diverse stakeholders, and jurisdictional fragmentation. However, neither addresses the fundamental concepts of systematic conservation planning, namely, complementarity between selected areas, least-cost solutions to achieving objectives, and transparent and repeatable methods for designing configurations of conservation areas (see Margules & Pressey 2000). Ideally, integrated land-sea conservation planning combines systematic principles with aspects of other approaches to delineate conservation areas and to set priorities for action across realms. Beyond the requirements for planning in a single realm (Pressey & Bottrill 2009), land-sea planning should involve explicit conservation objectives for processes that connect the land and the sea as well as explicit ways of accounting for threats that originate in one realm and affect the other. Land-sea planning also addresses the urgent need to effectively integrate conservation investments on land and in the sea to maximize benefits and minimize costs of conservation actions.

Some of the conservation implications of connections between land and sea have been examined previously. Beger et al. (2010) assessed the methods, challenges, and potential for spatial analyses to incorporate processes connecting terrestrial, freshwater, and marine environments. Stoms et al. (2005) outlined a conceptual model and methods to incorporate land-sea linkages that either benefit or threaten marine environments. Tallis et al. (2008) explored potential changes to MPA design to account for threats originating on land. Klein et al. (2010) proposed a method to maximize the return on investment in terrestrial and marine conservation actions to minimize threats to coral reefs originating both on land and in the sea. These studies contributed novel concepts and methods to the quickly evolving and highly complex field of land-sea planning. However, none of these papers integrated all the necessary considerations for comprehensive land-sea planning, which is a primary objective of our review. In addition, nongovernmental organizations (NGOs) and government agencies from around the world have adapted systematic conservation planning to address the practical difficulties of integrating land and sea. Reported mostly in the gray literature, their insights are obscure to the broader conservation community. For the first time, we review their lessons learned and contributions to theory and practice.

Ecological processes: sequences of changes in biological and physical characteristics, including migrations, metapopulation dynamics, dispersal, flows of nonliving materials, and lineage diversification

LAND-SEA CONNECTIONS: ECOLOGICAL PROCESSES, THREATS, AND SOCIOECONOMIC INTERACTIONS

Land-Sea Ecological Processes

Ecological processes are critical, although often neglected, elements in conservation planning (Cowling et al. 1999, Pressey et al. 2007). Some ecological processes link the land and the sea (hereafter referred to as land-sea processes); these are mediated by the flow of water and movements of organisms between terrestrial, freshwater, and marine ecosystems (Beger et al. 2010) and are critical to the persistence of biodiversity across realms. Examples include river inputs of nutrients with effects on the productivity and composition of coastal marine communities (Caddy & Bakun 1994, Humborg et al. 2000, Naiman & Sibert 1978), subsidies to land food webs from marine-derived nutrients (Helfield & Naiman 2001, Naiman et al. 2002, Polis et al. 1997), and ecosystems on the margins of the two realms (e.g., mangroves) that provide protection for vulnerable life stages of terrestrial, freshwater, and marine species (Nagelkerken et al. 2008).

Using the framework of Beger et al. (2010), we classified a range of land-sea processes from the scientific literature and conservation planning studies (**Table 1**). Although not exhaustive, our overview describes processes that are diverse, operate over a wide range of spatial and temporal scales, and include linkages in both directions between land and sea. Even though land-sea processes are relatively well documented, information about them relevant to conservation planning is generally dispersed.

Despite the abundant scientific literature on ecological linkages between realms, our understanding of the spatial and temporal dynamics of many land-sea processes remains limited. Importantly, spatially explicit data to represent these processes in planning are sparse. Examples of land-sea processes that, although incompletely understood, have been incorporated into planning include oceanic foraging by animals breeding on islands and coastal forests (e.g., Hazlitt et al. 2010, Lombard et al. 2007), salmon runs delivering nutrients to freshwater and terrestrial ecosystems (e.g., Ardron et al. 2002), riverine corridors important for downstream nutrient flows, and processes occurring in land-sea interfaces (e.g., Lagabrielle et al. 2009). The limited data on these interactions reflect a poor spatial understanding of processes generally (Pressey et al. 2007). Consequently, most planning exercises have either neglected or only incidentally incorporated these

Table 1 Examples of ecological processes linking land and sea

		Examples of land-sea processes[a]	Conservation features[b]
Connections	Constrained	Movement of euryhaline species, e.g., bull sharks, between freshwater and marine systems (Vasquez-Montoya & Thorson 1982)	Lakes, large river systems, estuaries, marine pelagic
		River input of freshwater and nutrients that influence estuarine and marine systems (Caddy & Bakun 1994, Humborg et al. 2000, Rowell et al. 2008)	Forests, major river and stream systems, estuaries, marine pelagic
		Seasonal spawning migration of aquatic diadromous species, e.g., salmon, and nutrient input to terrestrial and freshwater ecosystems (Ben-David et al. 1998)	Forests, riparian vegetation, river and stream systems, estuaries
	Diffuse	Seasonal spawning migration of animals, e.g., land crabs, to the sea (Green et al. 2008, Hicks 1985) and predators, e.g., terrestrial mammals, feeding in intertidal systems (Carlton & Hodder 2003)	Forests, coastal vegetation, marine intertidal and subtidal
		Island systems subsidized by energy and nutrient inputs through highly mobile animals, e.g., seabirds and pinnipeds (Croll et al. 2005, Lombard et al. 2007, Sanchez-Pinero & Polis 2000)	Roosting, nesting and haul-out islands, marine pelagic (feeding and high productivity areas)
		Movements of animals, e.g., seabirds, between breeding (terrestrial) and feeding (marine) areas (Becker & Beissinger 2006, Burger et al. 2000)	Forests, marine pelagic
Interfaces	Narrow	Input of marine nutrients into terrestrial systems by marine animals, e.g., marine iguanas and sea turtles (Hannan et al. 2007, Okey et al. 2004, Wikelski & Trillmich 1994)	Sand beaches, rocky shores, reefs, marine intertidal and subtidal
		Energy and nutrient inputs via terrestrial animals feeding in the intertidal zone, e.g., invertebrates and reptiles, into low productivity terrestrial ecosystems (Catenazzi & Donnelly 2007)	Coastal vegetation, dunes, intertidal
		Terrestrial-freshwater interface systems, e.g., stream systems and riparian vegetation, that capture sediments, nutrients, and pollutants (Mulholland et al. 2008, Reddy et al. 1999)	Forests, riparian vegetation, river and stream systems
	Broad	Systems, e.g., mangroves, that sustain species aggregations or provide protection for vulnerable life stages of terrestrial, freshwater, and marine species (Nagelkerken et al. 2008)	Forests, river and stream systems, mangroves, estuaries, reefs
		Freshwater-marine interface systems, e.g., seagrass, that trap sediments and organic matter and prevent erosion (de Boer 2007, Hutchings et al. 2005)	Mangroves, seagrass meadows, marine nearshore

(*Continued*)

Table 1 (*Continued*)

		Examples of land-sea processes[a]	Conservation features[b]
		Terrestrial-freshwater interface systems, e.g., floodplains, that capture sediments, organic matter, and nutrients that can enter marine systems (Brunet et al. 1994, Seitzinger et al. 2006)	Terrestrial vegetation, floodplains

[a]Land-sea processes can be mediated by two types of linkages: interfaces and connections. Interfaces are areas where two or more realms and their processes are intermixed. These can be either narrow (e.g., rocky intertidal communities) or broad (e.g., estuaries). Connections are linkages between two end points in different realms that are not adjacent. They can be mediated by well-defined or constrained paths, such as rivers connecting coastal catchments and oceans, but can also be diffuse, without well-defined movement paths of organisms or material (Beger et al. 2010).
[b]The listed conservation features (i.e., elements within terrestrial, freshwater, or marine realms) are the spatial elements that can be targeted in conservation planning. Conservation actions will be most effective if these elements are identified with assistance from local experts.

processes. Cost-effective methods to improve data and models to represent land-sea processes remain a major challenge for planners and scientists (Green et al. 2009).

Cross-System Threats

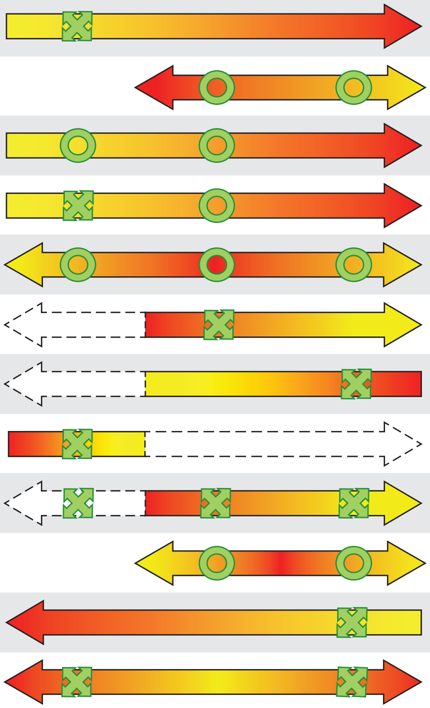
Anthropogenic changes to the land or the sea can disrupt land-sea processes. In conservation planning generally, the crucial role of conservation areas is to mitigate or prevent proximate threats (Wilson et al. 2005). Land-sea planning implies consideration of cross-system threats (Tallis et al. 2008) that can have significant impacts on coastal and marine biodiversity (Halpern et al. 2009, Stoms et al. 2005). Incorporation of cross-system threats involves identifying those that are most critical for coastal and marine conservation and mapping their sources and zones of influence, as well as assessing their magnitude and potential impacts (Allison et al. 1998, Wilson et al. 2005). Previous studies have described and modeled direct threats originating in one realm and affecting others (see Abell et al. 2007, Cicin-Sain & Belfiore 2005, Halpern et al. 2008, Suski & Cooke 2007), but no synthesis of threats relevant to land-sea conservation planning exists.

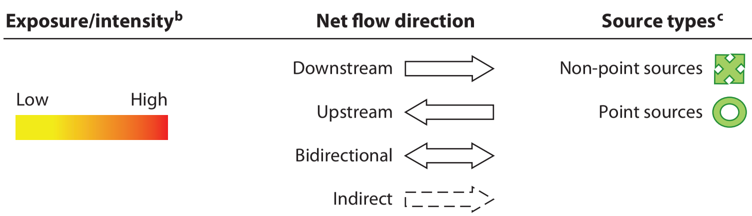
Using the threat classification proposed by Salafsky et al. (2008), we identified 12 major cross-system threats and summarized their key characteristics: sources, affected realms, directions of influence, stressors, and areas to target for intervention (**Figure 1**). Important cross-system threats include: nutrient runoff from agriculture, which can cause severe eutrophication, toxic phytoplankton blooms, and hypoxia in coastal ecosystems (Cloern 1996, Diaz & Rosenberg 2008, Howarth 2008); expansion of agriculture, forestry, and urbanization, which lead to soil loss and increased sediment loads in rivers (Croke & Hairsine 2006, Walling 2006) and alter the structure and function of estuarine and coastal ecosystems (Thrush et al. 2004); and the use of pesticides in agriculture and forestry plantations, which results in dieback in mangroves and coral bleaching (Duke et al. 2005, Haynes et al. 2007, Hutchings et al. 2005).

Cross-system threats most commonly originate on land and affect the sea, mediated by rivers (Stoms et al. 2005), but terrestrial and freshwater systems also can be affected by activities in the marine realm. In addition to direct impacts on salmon spawning, fishing in marine and estuarine areas, for instance, can significantly reduce marine-derived nutrients delivered to rivers (Gresh et al. 2000) and potentially affect populations of terrestrial predators feeding on salmon as well as the delivery of nutrients to riparian forests (Helfield & Naiman 2006). Some threats can have both downstream and upstream impacts, such as damming and other water management practices. Dams can alter the flows of sediments, nutrients, and water, resulting in downstream changes to coastal ecosystems (e.g., changes in phytoplankton species composition; Humborg et al. 2000) and

Cross-system threats: threats to biodiversity that originate in one realm and affect another

Threats	Sources, affected realms, and directions of influence	Stressors with major impacts		Areas to target for intervention
Direct (proximate) threats[a]	*Terrestrial* / *Freshwater* / *Marine*	*Upstream*	*Downstream*	
Agricultural and forestry effluents			P (t), AF (m/n/s/w)	Farms, intensive forestry systems, wood plantations, livestock areas
Marine and freshwater aquaculture		AF (n/o), EX (e/p)	AF (n/o), EX (e/p), P (t)	Fish, invertebrate, and algae farms, ponds, sea cages, and hatcheries
Industrial and military effluents (land-based)			P (t/h/g), AF (s)	Factories, oil/fuel tanks, mining, and other industries
Household sewage and urban wastewater, garbage, and solid waste			P (t/g), AF (n/s/w)	Urban areas, suburbs, villages, municipal treatment plants
Dams and water management/use, other ecosystem modifications		AF (o/s)	AF (m/n/o/s/w)	Dams, levees, dikes, groundwater pumps
Fishing of aquatic resources (freshwater)		AF (n/o)	AF (n/o)	Freshwater fishing areas
Fishing of aquatic resources (marine and estuarine)		AF (n/o)		Marine/estuarine fishing areas
Harvesting of terrestrial plants and animals			AF (n/o)	Natural (terrestrial) habitats
Introduced exotic invasive species (intentional and accidental)		AF (n/o), EX (e/p)	EX (e/p)	Ballast water disposal, aquaculture farming, tourism, biocontrol
Introduced genetic material		EX (e)	EX (e)	Freshwater and marine farms
Climate change: sea level rise		CC (slr)		Terrestrial and freshwater areas potentially affected by sea level rise
Climate change: altered regimes of droughts, storms, flooding			AF (m/n/o/s/w)	Areas potentially affected by increased or decreased runoff





Stressors[d]

AF	Altered flows: increased/reduced	**P**	Pollutants
m	Materials, organic debris	**t**	Toxic chemicals
n	Nutrients	**h**	Heat (thermal pollution)
o	Organisms (e.g., diadromous, highly mobile species)	**g**	Garbage and solid wastes
s	Sediments		
w	Water		
CC	Climate change	**EX**	Exotic species
slr	Sea level rise	**e**	Exotic invasive species
		p	Microbial pathogens

decreased productivity of fishing areas (e.g., as reported for Cuban fisheries; Baisre & Arboleya 2006), but they also affect upstream migration and spawning of anadromous fish, thus potentially also reducing productivity of freshwater and riparian ecosystems (Naiman et al. 2002). Cross-system threats affecting diffuse connections (**Table 1**) can be difficult to identify and measure. For example, reduced reproductive success of the endangered marbled murrelet (*Brachyramphus marmoratus*), a seabird that depends on old-growth coastal forests to breed, has been related to overexploitation of the coastal fish stocks on which it feeds (Becker & Beissinger 2006). In this case, both forest protection and fisheries management are necessary components of a successful conservation plan (Burger et al. 2000, Hazlitt et al. 2010).

Irreplaceability: a measure of the importance of areas in contributing to conservation objectives

An assessment of both single-realm and cross-system threats is needed to determine suitable locations for conservation areas (Stoms et al. 2005, Wilson et al. 2005). In general, including highly vulnerable areas in conservation networks will compromise conservation objectives if the probability of persistence of their valued features is low (Beck 2003, Game et al. 2008, Wilson et al. 2005), especially if conservation of alternative areas can achieve the same objectives. For this reason, planners often aim to avoid imminent threats where possible. Potential replacements for more threatened areas can be identified in several ways, including analysis of irreplaceability (Margules & Pressey 2000), which can provide maps of options for achieving objectives and give scope for participation and negotiation. Depending on circumstances, strategies other than avoidance of current or potential threat might be appropriate, especially if highly irreplaceable marine areas fall within the zone of influence of cross-system threats. **Figure 2** illustrates a decision tree that can be used to evaluate potential conservation areas exposed to cross-system threats. Strategies to manage cross-system threats will depend on irreplaceability, the intensity of threats, and the likely effectiveness and costs of abating them (Klein et al. 2010).

Socioeconomic Interactions

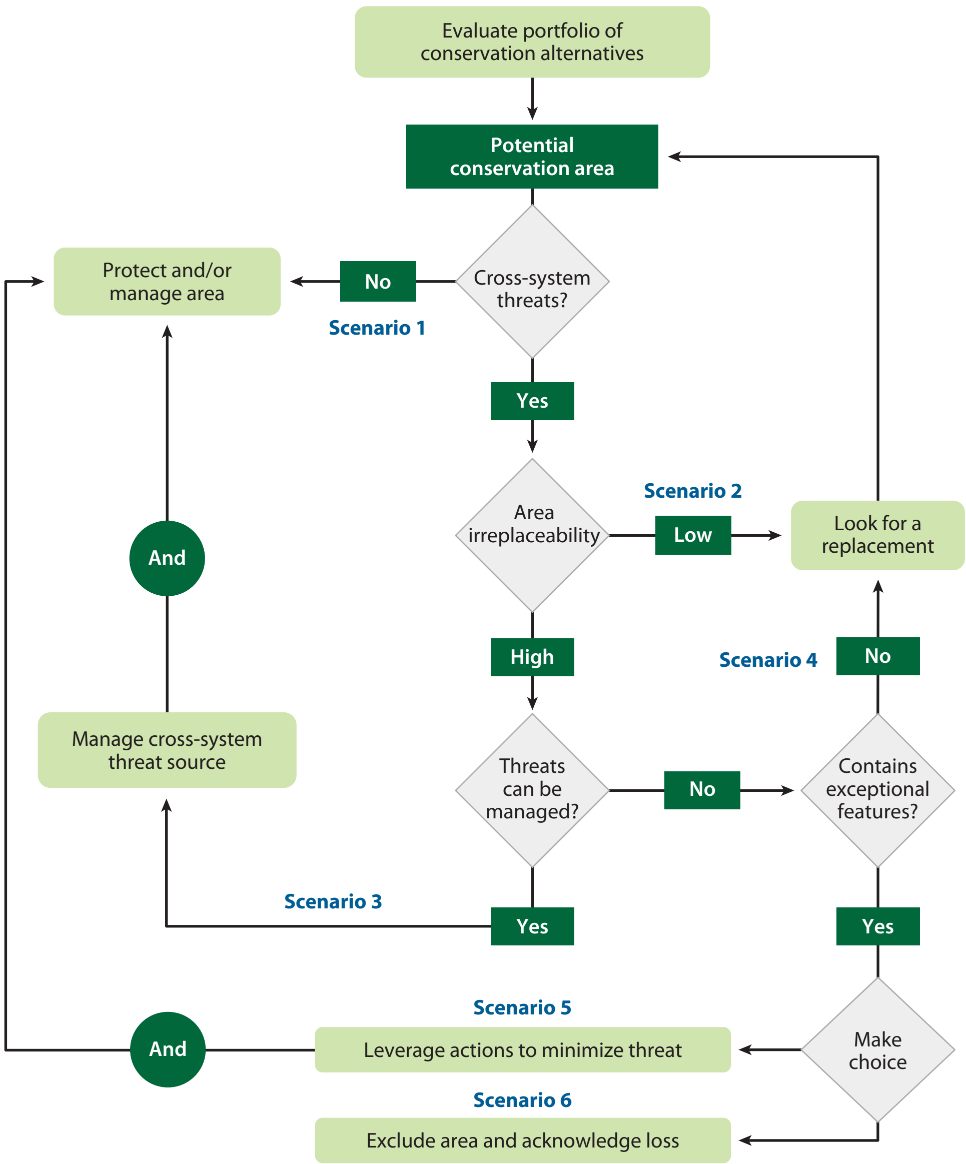
People are an important link between the land and sea, and hence solutions to land-sea planning should consider socioeconomic interactions between realms. Most of the world's population lives in the coastal zone and therefore strongly influences land-sea processes (Cicin-Sain & Belfiore 2005) and drives cross-system threats (**Figure 1**). Curtailing these threats therefore involves managing people's use of the environment across the land-sea continuum, thereby affecting people positively and negatively on land (Carwardine et al. 2008) and in the sea (Klein et al. 2008a). Nonetheless, planning for the socioeconomic benefits and impacts of conservation actions has been undertaken only within single realms.

Conservation actions in one realm can have socioeconomic implications in another (Cruz-Trinidad et al. 2009), particularly in regions where land-sea processes and/or cross-system threats are strongly linked to local livelihoods. Consider the case of a forested catchment that drains into a near-shore coral reef ecosystem. If the coastal forest is converted to an intensive land

Figure 1

Cross-system threats: sources, affected realms, direction, stressors and areas to target for action. Notes: [a]Threat classes are based on Salafsky et al. (2008). [b]On the basis of existing studies (Abell et al. 2007; Halpern et al. 2007, 2008, 2009), we anticipate that cross-system threats will have an array of impacts across the land-sea continuum, but a comprehensive review of these is not yet available. We suggest an initial broad scale of potential exposure to stressors and intensity of impacts associated with cross-system threats (see Wilson et al. 2005). [c]A classification commonly used identifies point and nonpoint sources of pollution, which can be used to classify sources of cross-system threats. Point sources can be addressed directly by managing individual facilities or structures, whereas nonpoint sources require actions associated with areas or regions. [d]Threat agents or stressors are defined as environmental and biotic factors that exceed their natural ranges of variation owing to human activities (Mullan-Crain et al. 2008).

use, such as oil palm production, increased pollutants could negatively affect the reef (Beger & Possingham 2008, Huber 1994) and potentially also damage marine tourism and fisheries. In the Chesapeake Bay, for example, eutrophication derived from agriculture has contributed to declines in demersal fish, resulting in a shift to fishery landings dominated by pelagic species (Kemp et al. 2005). Alternatively, if the coastal forest is protected and contains charismatic wildlife, tourists visiting the marine area might also visit the forest, thus providing additional income to the local economy. In addition to coordination, managing across realms requires social and economic foresight. For example, establishment of an MPA might force fishers to supplement their income by extending land-based activities such as forestry and agriculture, thereby negatively affecting terrestrial biodiversity.



Socioeconomic interactions between land and sea also involve feedbacks at various scales. Locally, displacement of fishers by an MPA leading to intensification of their land-based activities might result in higher sediment and nutrient discharges into the sea. This in turn could negatively affect the MPA, potentially undermining the values that motivated its establishment. Furthermore, pollutants and runoff might negatively affect the remaining fishing grounds, causing more fishers to switch to forestry or agriculture, leading to further negative feedbacks. At broader scales, coral bleaching can be exacerbated by nutrient runoff from coastal catchments (Wooldridge 2009), negatively impacting regional economies through loss of tourism and fishing resources (Hoegh-Guldberg et al. 2007). Thus, the absence of comprehensive land-sea planning can lead to altered socioeconomic interactions between land and sea, often with negative consequences for one or both realms.

ADVANCING LAND-SEA PLANNING: AN OPERATIONAL FRAMEWORK

Given the strong and diverse ecological and socioeconomic couplings between land and sea, how can conservation science inform more effective planning? We developed an operational framework to guide land-sea conservation planning (**Figure 3**) that is informed by expert opinion and case studies that considered land-sea connections. The framework emphasizes the elements that are particularly relevant to land-sea planning and has a loose structural match with the eleven stages of Pressey & Bottrill (2009). We systematically selected 26 case studies (key aspects are summarized in **Supplemental Table 1**; follow the **Supplemental Material link** from the Annual Reviews home page at **http://www.annualreviews.org**) that applied the general principles of systematic conservation planning, identified conservation objectives in both marine and terrestrial realms, and considered cross-system threats and/or land-sea processes. Although each study addressed several components of the framework in **Figure 3**, some components were missing from all studies. This indicates the need for further development of land-sea planning and that different components can be more or less important under different circumstances.

Supplemental Material

Figure 2

Example of a decision tree to evaluate potential conservation areas considering cross-system threats. Scenario 1: Potential conservation areas that are not affected by cross-system threats but contain features of conservation interest that are threatened locally can be considered for inclusion in a marine protected area (MPA) system and protected or managed accordingly. Scenario 2: Potential conservation areas that are affected by cross-system threats and have low irreplaceability values (numerous possible replacements) can be substituted by less affected or unaffected areas. Scenario 3: If irreplaceability is high (spatial options are limited) and threats can be managed or abated (e.g., by improving water quality through better agricultural and forestry practices to reduce nutrient runoff or excessive sedimentation), then actions to manage the source of threats (e.g., in coastal catchments) should be considered along with the local protection of the affected areas. Scenario 4: If cross-system threats cannot be abated, but the area does not include features considered exceptional (e.g., high irreplaceability might be due to one or more features that also occur extensively in neighboring regions), then planners could still try to find replacements to achieve objectives related to features characteristic of the region. However, if a vulnerable area is highly irreplaceable for characteristic features, it could be included in the conservation area system (e.g., MPA network), although the viability of some of its features might be reduced. In these cases, the protection of the area could be used as a strategy to leverage management actions to reduce the impacts of cross-system threats (Scenario 5) and also to increase the resilience of the area to these threats (e.g., by restoring habitat or managing local threats, such as overexploitation). Alternatively, planners might exclude the area from consideration as part of the conservation network and acknowledge the potential loss of the associated biodiversity features (Scenario 6).

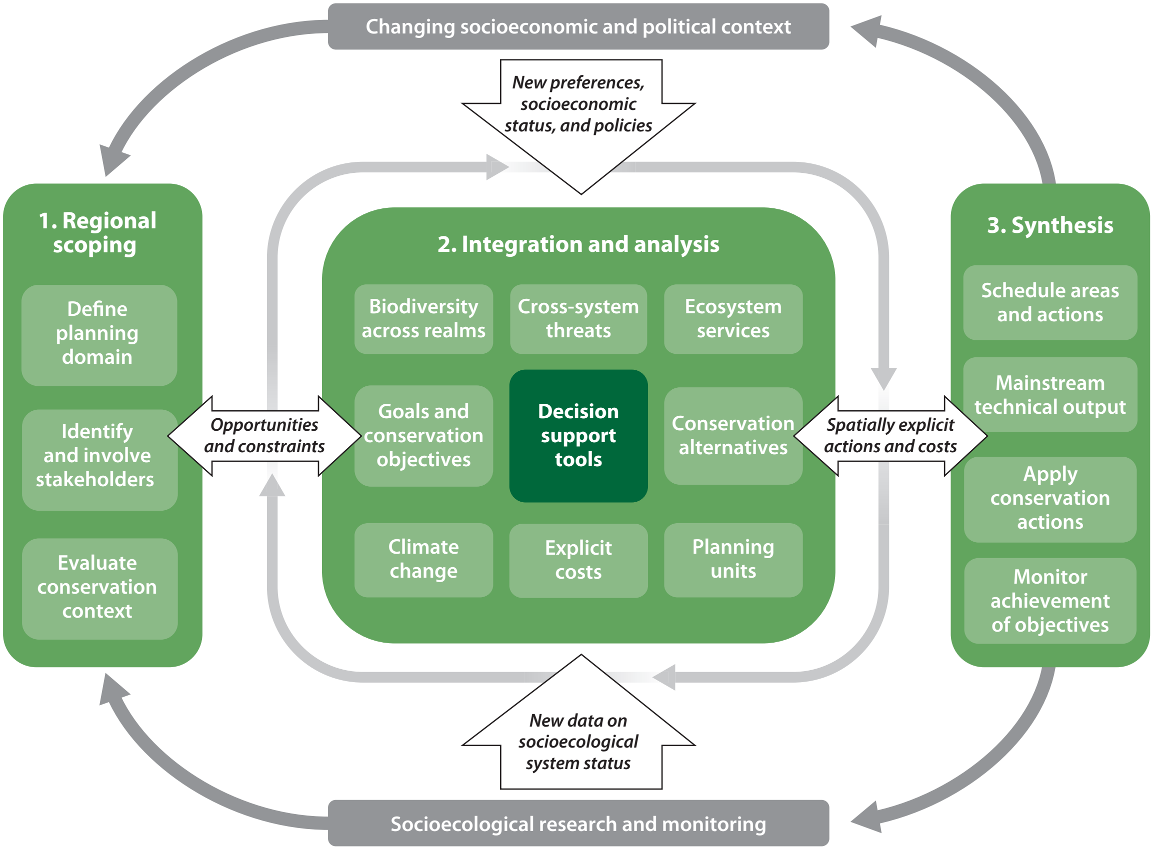


Figure 3

Operational framework for integrated land-sea planning. The framework is composed of three broad phases: regional scoping, integration and analysis, and synthesis. External arrows represent flows of information and feedbacks in the adaptive planning process, and they highlight the need to understand land-sea planning as a continuous and updatable process. Arrows encircling the second phase indicate that planning involves iterative cycles of analysis in which conservation objectives, design criteria, and spatial data and models are adjusted to explore potential solutions under different environmental and socioeconomic scenarios.

The framework has three broad phases: regional scoping, integration and analysis, and synthesis. It includes familiar components of conservation planning adapted to a land-sea approach and some less generic aspects particularly important for land-sea planning. Explicit in the framework is an adaptive approach (see Walters & Hilborn 1978) that is indicated by feedbacks that link the phases and reflect the iterative nature of planning. Feedbacks requiring reconsideration of earlier parts of the process might follow, for example, anthropogenic changes to land/seascapes, altered social and economic conditions, new data sets, and monitoring of the effectiveness of conservation actions (Sarkar et al. 2006). An adaptive approach is particularly relevant for land-sea planning owing to the uncertainty and complexity associated with planning across realms. Among the sources of uncertainty are our limited knowledge of land-sea interactions, lag times between implementation of actions and measurable results, and difficulties in predicting climate change, land-use change, and their potential impacts on water quality and marine ecosystems (Broderick 2008). The phases of the framework and their components are described in the following sections.

Regional Scoping

Land-sea planning involves several additional considerations about aspects of scale and regional scoping. Scoping components lay the foundation for a better understanding of the broad opportunities and constraints that will influence the implementation of conservation actions and set the scene for the following planning phases. Although these issues are critical to conservation planning success, they are less tied to the ecological issues at the core of this review and are not examined in detail here.

Planning domain: region across which conservation areas are assessed and compared for investment in actions to achieve conservation objectives

Conservation context: background about governance, ownership, uses, existing management, and threats in the planning region, including interactions between terrestrial and marine socioecological systems

Goals: a collective vision of aspirations, such as representation and persistence of biodiversity, improved livelihoods, and/or maintenance of ecosystem services

Defining the planning domain. An integrated land-sea approach requires identification of the sources and zones of influence of cross-system threats and spatial representations of land-sea processes (from upland areas to the nearshore and sometimes offshore marine environment), both challenging tasks.

Defining the limits of the planning domain in the terrestrial realm is not always straightforward because land that influences marine areas can extend well inland. For example, waters that discharge into the Gulf of Mexico originate from an area of almost 3 million km^2, or approximately 40% of the United States (Mitsch et al. 2001). A single planning process at this scale is extremely difficult because of the diversity of jurisdictions and stakeholders that would need to be involved as well as the time, expense, and requirements to collect consistent data. Full-catchment approaches have covered small catchments (e.g., the 425-km^2 catchment of Jervis Bay, Australia; Dutton et al. 1994) or larger and multiple catchments, albeit at coarse resolution (e.g., all coastal catchments draining into the Mesoamerican Caribbean Reef; Kramer & Kramer 2002). Other planning exercises have focused on the downstream ends of major rivers draining into the ocean (e.g., Chesapeake Bay Lowlands Ecoregional Plan; TNC 2002) or portions of catchments with major direct impacts on marine ecosystems that are likely to be developed in the near future (e.g., Mission Aransas Estuary, Texas; Dunton 2009).

Stakeholders and conservation context. Identifying and involving stakeholders (Pomeroy & Douvere 2008) and evaluating the conservation context (Pressey & Bottrill 2009) involve critical social and political analyses that bring diverse views and goals into discussion and place the subsequent spatial analyses in the context of multiple social, economic, and political factors operating across terrestrial and marine realms (Cicin-Sain & Belfiore 2005).

Integration and Analysis

The second phase integrates biological and socioeconomic information, which involves adapting several familiar components of conservation planning to a land-sea approach (e.g., planning goals and objectives as well as socioeconomic data and models). Other less typical aspects include incorporating land-sea interactions and adapting decision support systems to address multiple objectives that include land-sea interactions.

Goals and conservation objectives. Goals, framed qualitatively, provide the link between values and the quantitative analyses that characterize systematic conservation planning (Pressey & Bottrill 2009). In addition to goals associated with individual realms (e.g., protection of terrestrial and marine species and habitats), goals for land-sea planning include maintenance and restoration of land/seascape connectivity—defined by natural flows of organisms, water, materials, and energy—to ensure the persistence of biodiversity across realms (Bennett et al. 2006, Talley et al. 2006). Broad goals to maintain marine ecological processes (e.g., Banks et al. 1999, Kramer & Kramer 2002) ideally should be expanded into more explicit statements about specific land-sea linkages, such as maintaining nutrient flows between marine and terrestrial ecosystems (e.g., Lombard et al. 2007). Goals referring to mitigation of cross-system threats also should be specific. Some examples are the identification of areas or catchments to be protected or restored to minimize downstream impacts on marine ecosystems and fisheries in Fiji (Atherton et al. 2005) and the Coral Triangle (Klein et al. 2010). Goals related to integrated land-sea conservation have been rare, or stated but not translated into strategies to achieve them. Reasons include limited resources, lack of information on land-sea interactions, differences in stakeholders' interests, and stakeholders' lack of awareness of the importance of these linkages.

Planning units: natural, administrative, or arbitrary subdivisions of planning domains utilized for assessment and as building blocks for systems of conservation areas

Once stakeholders agree upon goals, they need to be translated into (preferably) quantitative conservation objectives (Pressey & Bottrill 2009). Land-sea planning objectives should include those associated with spatial features that represent land-sea processes and areas to be managed or protected to mitigate cross-system threats. Planning exercises have identified diverse features associated with maintaining land-sea processes. For example, Ardron et al. (2002), in designing a network of MPAs for the Central Coast of British Columbia, mapped and targeted streams that support migrations of anadromous species. Other studies have targeted keystone species that deliver marine-derived nutrients to terrestrial ecosystems (e.g., seabirds and pinnipeds of the Prince Edward Islands, South Africa; Lombard et al. 2007) and freshwater ecosystems (e.g., salmon and steelhead in the Alaska Peninsula and Bristol Bay Basin; TNC 2004). Others have focused on species with life cycles reliant on both terrestrial and marine habitats, such as the land crab, which migrates to coastal waters to spawn (MPO 2003), and the whooping crane, which moves between grasslands and salt marsh (Dunton 2009). Conservation objectives related to land-sea interfaces or linking ecosystems (e.g., estuaries, mangroves, coastal streams) or their associated species (e.g., crocodiles, estuarine turtles and fish, waterbirds) can also contribute to land-sea integration (e.g., Florida's Marine/Estuarine Site Assessment; Geselbracht et al. 2005).

Cross-system threats can be minimized by targeting potential sources of detrimental flows (e.g., areas with a high erosion potential; Atherton et al. 2005), preferably in combination with setting quantitative water quality objectives (e.g., reduction of annual pollutant discharges from catchments in kilograms of nitrogen per hectare per year). Water quality objectives can be based on historic and current discharges as estimated by catchment modeling and monitoring, and ideally on assessment of exposure thresholds or tolerance of marine species or habitats to pollutants as well (Brodie et al. 2009, Queensland 2009).

Biodiversity across realms. Land-sea planning requires spatially explicit data on biodiversity patterns and ecological processes across the land-sea continuum. These include distribution models or occurrences of marine, terrestrial, and freshwater species, communities, and habitat types as well as maps of features associated with land-sea processes. Data and models are commonly focused on a single realm or separate realms, although these might include some species occurring in more than one realm (e.g., diadromous and migratory species of economic and ecological importance; TNC 2003, Vander Schaaf et al. 2006). The types and resolutions of spatial data on biodiversity vary across realms but are generally more diverse and detailed in terrestrial environments (Avery 2003).

Collection of data on and mapping of land-sea processes requires identification of the features that will serve as surrogates to be represented in conservation areas (Cowling et al. 1999). Building on studies that explicitly integrate processes into planning (e.g., Cowling & Pressey 2003, Cowling et al. 1999, Rouget et al. 2003) and methods to incorporate processes across realms proposed by Beger et al. (2010), we identified four potential strategies to plan for land-sea processes: design criteria, variable objectives, planning units, and movable conservation areas (**Table 2**). Few studies have addressed the design needs of land-sea processes in a spatially explicit way.

Table 2 Strategies to incorporate land-sea processes into conservation planning

Design criteria	Spacing: Define a minimum and/or maximum distance between potential conservation areas that contain complementary terrestrial/freshwater and marine habitats to ensure biological or physical connectivity between realms or to reduce the risk of disturbances affecting multiple conservation areas simultaneously.
	Buffers: Define buffers for conservation areas along terrestrial-marine interfaces or around other areas that support land-sea processes. The roles of buffers are to ensure that areas supporting the processes of interest are managed appropriately and that, as far as possible, threatening processes are excluded.
	Replication: Represent terrestrial or marine features associated with land-sea processes in multiple conservation areas to minimize simultaneous exposure to natural or anthropogenic disturbances.
	Adjacency: Place terrestrial/freshwater and marine conservation areas beside each other to maintain connectivity and promote the persistence of land-sea processes.
	Alignment: Include the major movement axes of organisms (e.g., between the foraging and nesting areas of seabirds) or the locations of physical features (e.g., ocean fronts) associated with land-sea processes.
	Connectivity: Select areas for conservation management that promote one or more relevant aspects of connectivity. These could include continuous corridors of suitable aquatic or terrestrial areas, minimum spacing between areas to facilitate movement of organisms, or simultaneous selection of areas that are functionally, even if not spatially, connected (e.g., to allow for organisms inhabiting different realms to move between them to complete their life cycles or to recolonize areas through the movement/transport of planktonic larvae, considering currents and larval biological characteristics and behavior).
Variable objectives	Habitats: Set objectives for both terrestrial/freshwater and marine habitats that are linked through movements of organisms (e.g., wetlands, estuaries, coral reefs) and that need to be protected simultaneously, perhaps with maximum allowable separation distances, to sustain these interactions.
	Species: For organisms that periodically move between realms or that have life stages associated with different realms, set separate objectives for terrestrial/freshwater and marine occurrences to protect their complete life cycles.
	Stratification: To fully represent the internal heterogeneity of narrow land-sea interfaces, a general (larger) objective can be assigned to the interface type of interest as a whole (e.g., 20% of rocky intertidal shores) and specific (progressively smaller) objectives to lower classes or subcategories identified at a finer scale/resolution (e.g., 10% and 5% of exposed and lower exposed rocky intertidal shores, respectively).
Planning units	Special: Delineate planning units (e.g., linear, irregular) that are configured specifically to represent interfaces associated with land-sea processes of interest.
	Smaller: Use smaller planning units in interface habitats to recognize the greater spatial heterogeneity found in and around these areas as well as to increase selection precision and minimize overrepresentation.
Movable areas	Spatial: Apply conservation actions to different areas at different times according to the occurrences of dynamic physical features and associated species' habitats.
	Temporal: Apply conservation actions in the same areas at different times or seasons to protect vulnerable life stages of species moving across realms (e.g., during migration, reproduction, or spawning) or flows (e.g., peak river discharges) that sustain land-sea processes.

Lagabrielle et al. (2009) illustrated for Reunion Island the need to create an inland buffer along the coastline to protect some land-sea processes, including settlement of new species and movements of organisms between land and sea. As part of the design of the Prince Edward Islands' MPA, Lombard et al. (2007) included portions of oceanic foraging areas based on the major movement axes of seabirds and pinnipeds to maintain the input of marine-derived nutrients into terrestrial systems. In British Columbia, Ardron et al. (2002) incorporated the flow of nutrients between oceans, streams, and riparian areas by setting objectives for key salmon-spawning streams, estuaries, and holding sites. Protection of extensive processes, such as the bidirectional nutrient flows mediated by the migration of salmon, could also require the protection of terrestrial features (e.g., riparian vegetation, upland forests) and management of freshwater networks that are currently overlooked in marine planning, but this is yet to be demonstrated.

Ecosystem services: resources and processes supplied by natural ecosystems for the benefit of humans, such as food provisioning, climate regulation, and recreation

Cross-system threats. Understanding the dynamics and potential impacts of cross-system threats is necessary to develop spatial alternatives for conservation areas that can minimize vulnerability and maximize conservation outcomes. Models of cross-system threats can provide planners with four kinds of information: sources, zones of influence, potential impacts, and expected changes in intensity or patterns in response to land/seascape dynamics or to conservation actions. Although planning exercises have modeled and incorporated cross-system threats (e.g., Crist et al. 2009, Green et al. 2009, Tallis et al. 2008), none has addressed them comprehensively through the four types of information above.

Identifying actions to effectively mitigate cross-system threats depends on mapping and modeling of those threats, which can be demanding of time and data. Spatial precision might be infeasible in some circumstances, so coarse-resolution models to identify general patterns at regional scales might be necessary. Models of threats are usually land-based and have generally neglected threats originating in marine and freshwater systems (**Figure 1**). Potential zones of influence of point sources are usually mapped as single or multiple-ringed buffers associated with different levels of impact (Green et al. 2009), but they also can be modeled in more complex ways if directional data on intensity and effects on ecosystems are available. This might be guided by expert opinion (e.g., Halpern et al. 2009, Klein et al. 2008b). Mapping nonpoint sources involves estimating the potential contribution of different areas to the extent or intensity of threats (e.g., pollutant discharge), usually through catchment models, followed by mapping the zone of marine influence using diffusion models (e.g., Dunton 2009, Halpern et al. 2009, TNC 2008), transport models (e.g., Cherubin et al. 2008), or river plume models (e.g., Tallis et al. 2008).

Ecosystem services. Ecosystem services describe what people value from ecosystems and have become prominent components of planning exercises (Chan et al. 2006, Egoh et al. 2007). The importance of land-sea processes in the provision of diverse ecosystem services (e.g., pollution buffering, sediment trapping) is well recognized (Granek et al. 2010, Silvestri & Kershaw 2010), but these generally have been overlooked in setting explicit conservation objectives. Some land-sea processes are critical to sustaining coastal and marine ecosystems and species of economic importance or have been linked to other important processes, such as maintenance of oceanic and terrestrial productivity (**Table 1**). Maintenance of the services provided by coastal and marine ecosystems (e.g., nutrient cycling) and the economic benefits associated with these (e.g., for fisheries and tourism) are commonly recognized as broad planning goals (Beck & Odaya 2001, Green et al. 2009, Hinchley et al. 2007), but seldom have been translated into spatial data and quantitative conservation objectives. A study conducted by The Nature Conservancy (TNC 2007) in Florida's Northwest Coast exemplifies a method to incorporate ecosystem services provided by coastal wetlands, in this case hazard mitigation, into conservation planning. Most studies have not considered ecosystem services or have limited their attention to provisioning services such as sustaining fisheries. Some services supported by land-sea processes might be incorporated incidentally through objectives for other features, but others will remain unprotected, and their persistence will therefore remain at risk. Silvestri & Kershaw (2010) developed a framework to help planners understand, map, and value ecosystem services along the land-sea continuum and to determine the spatial alternatives for their protection or restoration.

Climate change. Of special concern for land-sea planning are the effects of climate change on land-sea processes and cross-system threats. Climate change–associated alterations in land-sea processes, such as migration of fish and nutrient runoff, are anticipated (Nohara et al. 2006, Reist et al. 2006). Projected increases in temperature and altered precipitation regimes will likely result in more intense nutrient and sediment runoff associated with land use change, at least in some regions within the tropics (Nohara et al. 2006, Zhu et al. 2008). Synergistic effects of hypoxia, temperature, and CO_2 levels on the physiology of marine organisms are also expected to intensify with climate change (Harley et al. 2006). The projected sea level rise will probably affect land-sea interface ecosystems (e.g., mangroves; Gilman et al. 2008) as well as terrestrial communities by reducing habitat for species in coastal zones (LaFever et al. 2007). Accordingly, impacts of climate change on biodiversity and threats, and the interactions between them, should be considered for both land and sea.

Although climate change is mentioned as a major concern in most planning exercises, few have explicitly modeled climate-related changes, and most of these are restricted to species and habitats associated with a single realm or separate realms (e.g., shifts in climatic variables across terrestrial ecosystem units to identify potential refuges; TNC 2005). More often, general strategies or design principles are followed with the aim of increasing the resilience of ecosystems to climate change by protecting key habitats and ecosystems. For example, the MPA network designed for Kimbe Bay, Papua New Guinea, considered spreading risks through representation and replication, protection of special sites (e.g., spawning aggregations, nesting areas, and sites more resistant to climate change), connectivity (maximum separation of 15 km), and minimum MPA size (10 km^2) (Green et al. 2009). Similar efforts guided MPA network design along the California coast under the Marine Life Protection Act (Gleason et al. 2010)

Explicit costs. Integration of socioeconomic considerations in land-sea planning is challenging but can be attempted by minimizing the costs of conservation actions to people (Naidoo et al. 2006). A common approach in single-realm planning is to minimize costs of management actions while achieving conservation objectives (Carwardine et al. 2008). In land-sea planning, costs are commonly integrated into cost-suitability indices developed for terrestrial and marine realms independently. Cost-suitability indices integrate economic, sociopolitical, and biological factors to preferentially select areas with higher long-term viability and avoid areas with high conservation costs (Geselbracht et al. 2009, TNC 2005). Ideally, land-sea planning should consider costs in both realms simultaneously. For example, a study in the Coral Triangle region, where coral reef conservation was the main goal, considered the costs of conservation actions on the land (i.e., costs associated with management of terrestrial protected areas and forgone economic return from cropping and grazing to reduce land-based threats) and in the sea (i.e., MPA management costs and associated opportunity costs for fishermen) (Klein et al. 2010). Although the costs were not expressed in economic terms, Tallis et al. (2008) considered costs for marine conservation associated with land-based threats. There might, however, be trade-offs between minimizing cross-system threats and minimizing negative socioeconomic impacts across the land-sea interface. For example, if much land needs to be protected to ensure the persistence of marine biodiversity potentially affected by land-based pollution, but people rely on agriculture for subsistence, the cost of terrestrial protected areas could be unfeasibly high. In these cases, other conservation actions, such as better agricultural practices, may minimize downstream impacts at lower cost (Gordon 2007).

Planning units. The delineation of planning units in land-sea planning is influenced by the same factors considered in terrestrial and marine exercises, including data resolution, size of planning region, and socioeconomic and political factors linked to implementation (Cowling & Pressey 2003, Pressey & Logan 1998). In land-sea planning, another consideration for the choice of planning units is the need to integrate conservation areas across the land-sea interface, which often requires different units for the terrestrial (e.g., subcatchments, ownership parcels), marine (e.g., hexagons), and interface (e.g., linear) parts of the planning domain. Small polygonal units (e.g., Geselbracht et al. 2005) can also be useful to recognize the spatial heterogeneity found in narrow interfaces, to increase selection precision, and to minimize overrepresentation (see **Table 2** and Beger et al. 2010). Banks et al. (2005) used linear units to configure a system of representative intertidal conservation areas on the Queensland (Australia) coast. A study in the U.S. Pacific Northwest used diverse units: Terrestrial and freshwater features were summarized in subcatchments; estuaries were each mapped as single planning units; and square units intersected the coastline, offshore islands, and upstream tidal reaches of major rivers (Vander Schaaf et al. 2006). In contrast, a planning exercise in Alaska's Cook Inlet used a uniform hexagonal grid that covered the land and sea portions of the planning domain (TNC 2003). Until now, most planning exercises have delineated planning units independently for the land and the sea, and their design and configuration have not accounted for linkages between the realms.

Decision support tools: computer programs that provide analytical and graphical capabilities to facilitate negotiation, exploration of scenarios, and involvement of stakeholders in conservation planning

Decision support tools. Major challenges to land-sea planning come with the need to manage data from terrestrial, freshwater, and marine ecosystems, to consider connectivity between realms, and to relate potential conservation areas to sources and impacts of cross-system threats. Decision support tools are therefore key elements in land-sea planning. Incorporation of connectivity between realms can require modification of data or adaptation of existing tools and algorithms (Beger et al. 2010, Mumby 2006, Stoms et al. 2005). Beger et al. (2010) examined existing and new methods to incorporate ecological linkages between realms supported by conservation planning software, but few of these approaches have actually been used. Approaches to integration in decision support systems include design criteria to force the selection of marine conservation areas close to well-protected terrestrial or estuarine areas and away from potential cross-system threats (Fernandes et al. 2005, Green et al. 2009, Tallis et al. 2008). They also include simultaneous prioritization across realms (TNC 2003, 2005) and evaluation of current and projected land-use scenarios to explore alternatives for mitigation of threats (Dunton 2009). Land-sea planning will require the use and adaptation of existing conservation planning software interfaced with other modeling and simulation tools to integrate the diversity of data and models required (e.g., Crist et al. 2009, TNC 2007).

Conservation planners often use numerical optimization tools (e.g., C-Plan, Marxan, Zonation) to help identify priorities for conservation. Two studies demonstrate methods for integrated land-sea planning using Marxan (Ball et al. 2009). Tallis et al. (2008) explored changes in the distribution of threats and the configuration of marine priority areas when cross-system threats were explicitly considered. They incorporated the impact of river-derived threats to identify conservation priorities in the U.S. Pacific Northwest (**Figure 4**). Hazlitt et al. (2010) incorporated a land-sea process to identify priorities for conservation of the marbled murrelet in British Columbia, Canada. For this species, they found that the inclusion of marine objectives (a function of quality of and distance to potential suitable marine foraging habitats) in the planning process influenced the location of priority areas for terrestrial reserves (**Figure 5**), especially when conservation resources only allowed for the protection of a small fraction of available terrestrial habitat.

Conservation alternatives. Systematic conservation planning involves the development and comparison of alternative configurations of areas and alternative actions applied to those areas. Even when designs are presented for public viewing and comment, usually much flexibility exists to reconfigure them and reallocate actions (Cowling et al. 2003).

Approaches to exploring conservation alternatives are diverse, including decision support systems with input from experts and managers (Geselbracht et al. 2009, TNC 2005), successive

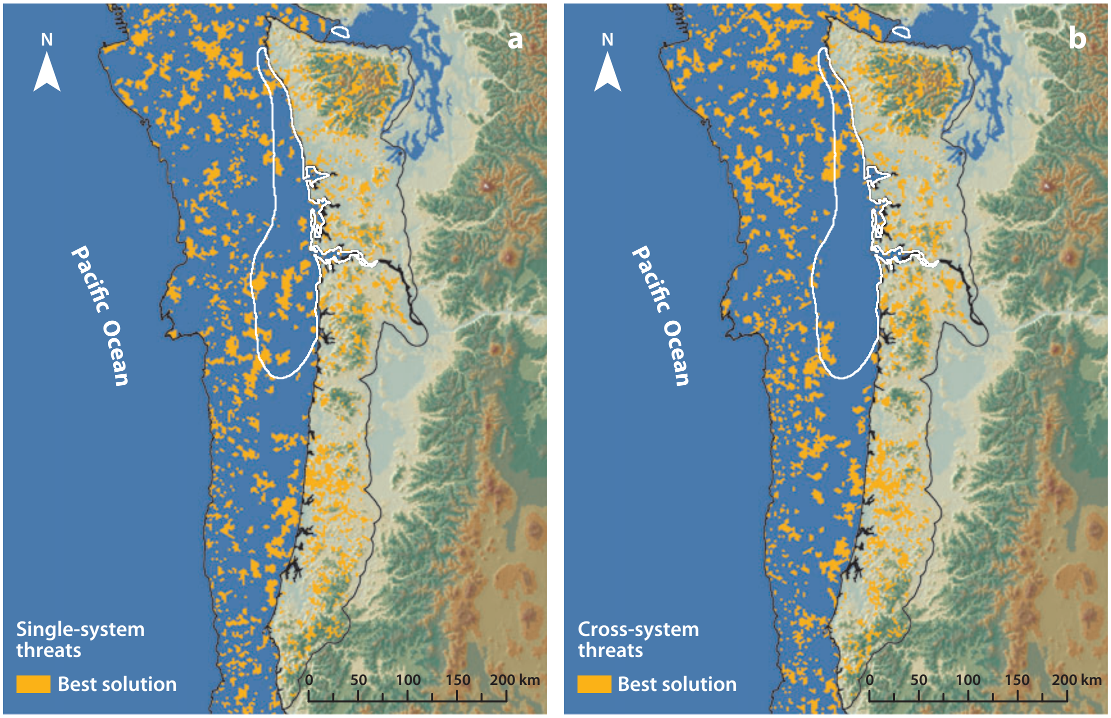


Figure 4

Differences in the spatial location of marine conservation priorities between scenarios that incorporated and ignored cross-system threats. (*a*) Only single-system threats considered. (*b*) Planning units within the plume of the Columbia River (enclosed by the white line) had higher costs for marine conservation. Most coastal marine areas within the zone of influence of the river plume were not selected. Copyright © 2008 Wiley. Figure reproduced and modified from Tallis et al. (2008) with permission from the authors.

designs open for comment and revision (Fernandes et al. 2005), interactive and participatory processes guided by decision support systems (Dunton 2009, Pressey et al. 2009), and expert-driven processes supported by geographic information systems (Banks et al. 1999, Enriquez-Andrade et al. 2005). These approaches can consider land-sea linkages (e.g., Banks et al. 1999, Kramer & Kramer 2002, TNC 2004). Regardless of the approach, developing conservation alternatives usually involves iterative cycles of analysis in which conservation objectives, design criteria, and spatial data and models are modified or adjusted to suit stakeholders' preferences and to explore potential solutions under different environmental, socioeconomic, and protection scenarios (Osmond et al. 2010, Pressey et al. 2009).

Conservation scenarios can reflect variations in objectives (e.g., higher/lower representation), different models of threats (e.g., current/projected, cross-system/single-realm, rapid/moderate change), types of protection and management (e.g., zoning alternatives), and costs, among other factors. Different types and levels of protection and use (e.g., reservation, water management, restoration, land management, fishery regulation) can be linked to specific conservation areas across realms (Banks et al. 1999, Dunton 2009, MPO 2003, TNC 2003). Addressing specific threats, such as high sediment fluxes into coral reefs, might require specific erosion mitigation practices, including reforestation and regulation of logging in catchments (Atherton et al. 2005). Ideally, these strategies should be translated into integrated terrestrial, freshwater, and marine

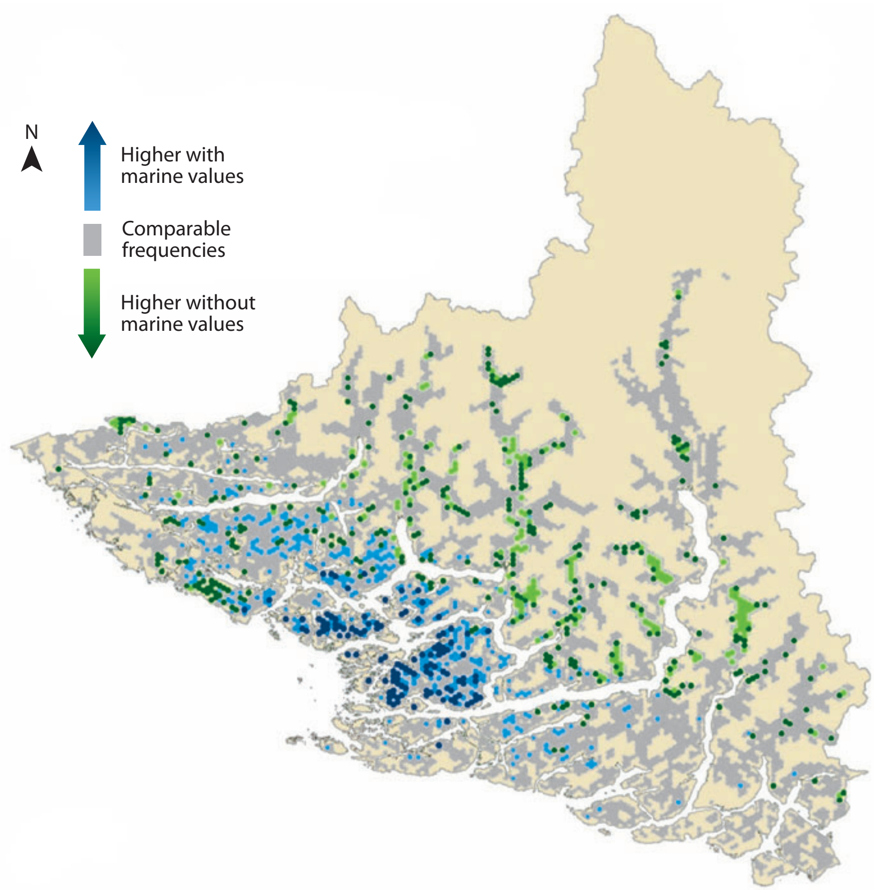


Figure 5

Difference in priority areas for conservation of marbled murrelet terrestrial nesting habitat when marine objectives for this species were incorporated or omitted. This species requires old-growth forest for nesting and high-quality marine habitats for foraging.

multiple-use conservation systems in which different activities are permitted, prohibited, or regulated consistent with ecological and socioeconomic requirements and constraints (Dutton et al. 1994, Fernandes et al. 2005, Vander Schaaf et al. 2006).

Synthesis

The transition from design to implementation involves aspects of particular relevance to land-sea planning, including deciding on the conservation areas that will be protected/managed first, which involves trade-offs between land and sea; adapting and communicating planning outputs to stakeholders associated with different realms and across land-sea jurisdictions; and monitoring the achievement of objectives as conservation actions are implemented.

Schedule areas and actions. Conservation plans are seldom fully implemented over short periods, so scheduling of incremental conservation actions is usually necessary to minimize the extent to which objectives are compromised by ongoing attrition of biodiversity (Pressey et al. 2007). Hence, one of the particular challenges of land-sea planning is the requirement for simultaneous scheduling in terrestrial and marine regions so that threats within and between realms can be addressed comprehensively. Klein et al. (2010) described a protocol to guide planners in scheduling conservation actions simultaneously across realms in the Coral Triangle. The study demonstrated that in any one period, integrated scheduling might require choices between marine areas, between terrestrial areas, or between areas on either side of the shoreline. Deciding between two critical catchments that are equally vulnerable and linked to priority marine areas might require also assessing local values (e.g., terrestrial endangered and rare species and communities). In these cases, experts can play a critical role in determining which areas require immediate attention (e.g., Banks et al. 1999, MPO 2003, TNC 2002), especially when data on the dynamics of local and cross-system threats are limited.

Mainstreaming: translation of technical planning products into forms readily accessible to diverse stakeholders to facilitate the implementation of conservation actions

Mainstream technical outputs. Mainstreaming is a critical, but often overlooked, element in conservation planning (Pierce et al. 2005). In land-sea planning, planners should engage with stakeholders and decision makers with influence on or jurisdiction in the land-sea continuum (e.g., Day et al. 2003, Dunton 2009, MPO 2003), in particular those responsible for land-sea issues, such as catchment-based organizations that consider marine water quality. Mainstreaming for multiple and diverse stakeholders, such as municipal planners, coastal management authorities, and the agricultural and fishing industries, can be complex and requires substantial technical and financial capacity.

Apply conservation actions. Application of actions involves the critical transition from design of conservation areas to implementation of feasible and effective actions on the ground and in the water. Application of actions in land-sea planning will likely require several strategies to address the threats in the land-sea continuum that are implemented via negotiations and arrangements with diverse stakeholders (Baker et al. 2011, Green et al. 2009). Application also requires coordination of administrative arrangements between governmental institutions at different levels (Dutton et al. 1994). Ideally, planning should also deliver a strategy that integrates conservation actions between realms and promotes collaboration of stakeholders from different realms. Existing bodies operating beyond the land-sea boundaries, such as regional catchment management organizations, can significantly contribute to coordination of actions across realms. Inevitably, new data and unexpected constraints and opportunities will be encountered as designs are interpreted and applied. This will likely require extensive adaptation of designs to accommodate these changes (**Figure 3**).

Monitor achievement of objectives. Monitoring is a critical component of an adaptive planning process (Baker et al. 2011). It informs planners about the effectiveness of applied actions in achieving objectives across realms, so that actions, and the areas where they are to be applied, can be adjusted accordingly (Dunton 2009, Dutton et al. 1994, Fernandes et al. 2005). Even though they are a critical component of effective planning, monitoring activities either have not been considered or have been developed for a single realm or separate realms. Rarely has monitoring included species and habitats in different realms as well as sources and impacts of cross-system threats. Notable exceptions are the system-wide monitoring program linked to the Mission-Aransas land-sea planning initiative (**http://cdmo.baruch.sc.edu**; Dunton 2009) and the water quality strategy for the Great Barrier Reef Marine Park (Queensland 2009).

CHALLENGES FOR THE FUTURE

Scientists, managers, and conservation practitioners have called for an integrated approach to managing terrestrial, freshwater, and marine socioecological systems (Dutton et al. 1994, Gordon 2007, Olsson et al. 2008, Stoms et al. 2005). Different approaches to land-sea integration have been followed (for a description of integration levels, see Tallis et al. 2008), including concurrent area prioritization exercises for terrestrial and marine systems that are later assembled to build a single plan (e.g., Floberg et al. 2004); simultaneous planning, in which land and marine features are targeted at the same time and some measure of conservation cost is minimized for both realms simultaneously (e.g., TNC 2005); and explicit incorporation of cross-system threats (e.g., Tallis et al. 2008) and/or land-sea processes (e.g., Lombard et al. 2007) in the prioritization process. Within these approaches, different elements of the framework described above have been incorporated, but no planning exercise has addressed all.

Expert opinion (based on a survey we conducted) indicates that few components of the operational framework we outlined have been incorporated into land-sea planning (**Figure 6**). In addition to the particular needs for improvement illustrated in **Figure 6** and previously discussed, we summarize below three key challenges to land-sea planning based on reviewed studies, expert opinion, and our own experience.

Partial Integration of Cross-System Threats

Although cross-system threats are widely cited as a major concern for marine conservation and often considered in land-sea planning exercises, these have been only partially incorporated into prioritization processes. The impacts of threats with marine origins on upstream ecosystems are poorly studied and not yet incorporated into planning (Green et al. 2009). Data required to model threats originating on land (e.g., pollutant loads and zones of offshore influence) are usually incomplete, available only for short periods, coarse in resolution (Atherton et al. 2005, Kramer & Kramer 2002), or inadequate for planning purposes (TNC 2002). Data limitations can be overcome through the use of simplified models to assess exposure to cross-system threats (Ban et al. 2010, Maughan & Brodie 2009) or expert-based delineation of high-risk areas (Banks et al. 1999). However, simplified data limit the development of adequate conservation actions to mitigate these threats, and they could result in erroneous conclusions and poor management recommendations. More advanced methods of catchment and ocean circulation modeling (e.g., Brodie et al. 2009, Paris & Cherubin 2008) can be employed for land-sea planning if resources, data, and expertise are available. In most cases, however, lack of spatial data to calibrate and validate the models remains a major challenge. Developing and integrating models into a decision support system can be time- and labor-intensive, and trade-offs between quality of results and investment in data and modeling seldom have been assessed (Crist et al. 2009, Dunton 2009).

Competing Objectives

Integrated land-sea planning must address many potentially conflicting objectives. Some studies have found coincidence in the spatial distribution of priorities arising from different objectives, but others have not. Differences in the spatial distribution of conservation priorities for terrestrial biodiversity and ecosystem services (Chan et al. 2006) and of freshwater and terrestrial priorities (Amis et al. 2009) suggest that values within coastal catchments derived from terrestrial conservation objectives (e.g., connectivity between vegetation fragments) will not necessarily be spatially correlated with those for marine conservation (e.g., reducing pollutant loads at river mouths).

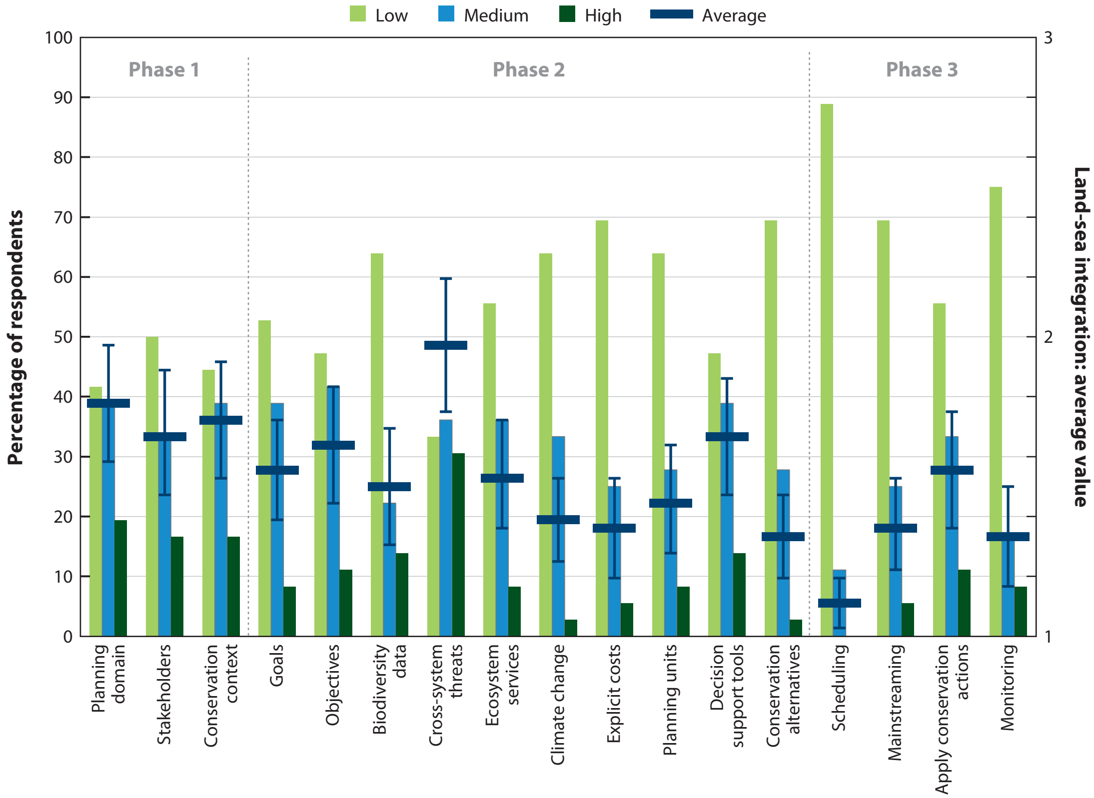


Figure 6

Expert opinion on the level of land-sea integration for each of the components of the operational framework in **Figure 3**. Integration within components of the first planning phase was generally rated between low and medium. In the second planning phase, two components were considered to have achieved relatively good integration: planning for cross-system threats (a common purpose of land-sea planning) and the use of decision support tools. Also within the second phase, incorporation of climate change and explicit costs seem to deserve special attention. Experts generally identified components in the third phase as involving poor integration between land and sea. These included scheduling, which had the lowest rating of all components in the planning process. The horizontal black bars represent the average value of integration assigned by experts ($N = 36$) to each component (1 = low, 2 = medium, and 3 = high integration); error bars denote the 95% confidence interval for the mean ($a = 0.05$, $p < 0.0001$).

However, an integrated study from Florida showed how objectives for both coastal hazard mitigation and biodiversity conservation can be jointly met with little change in the extent of priority areas and with increased spatial efficiency compared with addressing the two sets of objectives separately (TNC 2007). When choices are necessary between objectives, decision makers face complex problems. Some methods have been developed to guide the necessary trade-offs (e.g., Moffett & Sarkar 2006, Stoms et al. 2005), but more tools are needed, especially to work interactively with stakeholders.

Institutional Structures

A fundamental barrier to integrated land-sea planning is the lack of coordination of institutions that support natural resource management. Typically, different institutions, departments, or groups govern marine and terrestrial natural resources (Cicin-Sain & Belfiore 2005). This is also true within a single realm. For example, decisions about fisheries management, marine ecosystem conservation, and mineral extraction have often been made independently by different sectors within a government (Crowder et al. 2006). This segregation is apparent across, and even within, agencies, NGOs, and scientific institutions. In a given region, conservation NGOs often have marine and terrestrial planning teams that work with only limited exchange of information. A similar segregation is common in the scientific community, as different research groups, conferences, journals, and grant schemes exist for marine and terrestrial scientists. The divided nature of natural resource management affects policies, budgets, and goals. Effective land-sea planning will require substantial changes in institutional and organizational structures to allow for more cohesive and integrated planning to occur.

CONCLUSIONS

Incorporation of the missing links in conservation planning presents big challenges but also unique opportunities, especially given the many marine spatial planning initiatives currently underway (e.g., under the Convention on Biological Diversity, United Nations Educational, Scientific and Cultural Organization (UNESCO), World Ocean Council, U.S. National Ocean Council). Gaps in data and knowledge are open niches for theoretical and applied research in multiple disciplines, including ecology, informatics, economics, politics, and sociology. Planning for land-sea processes requires the development of approaches and tools to engage with multiple stakeholders and incorporate their views and values. Conservation practitioners will be required to formulate practical approaches to make best use of available information. Learning by doing and communicating lessons learned from each attempt will advance integrated land-sea planning. Integration of information on different realms can help to bring together scientists, managers, and practitioners from diverse disciplines and sectors who have previously focused on different realms. Bridging interdisciplinary and intersectoral gaps is critical to generating a coordinated response to multiple, interactive, and cumulative threats to biodiversity, which in turn can lead to stronger and more effective conservation initiatives. Making these links will require substantial institutional and policy changes in the management of natural resources. Interdisciplinarity and cross-realm collaboration should therefore continue to be in the core of the programs of international agreements such as the Convention on Biological Diversity. Therefore, further development of the methodological foundations for integrated land-sea conservation and effective communication of these findings to decision makers are important contributions for conservation planners and scientists to make.

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