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The conservation of coastal biodiversity

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OVERVIEW

Defined broadly as the place where the land meets the sea, the coast occupies a profound place of importance in society (UNEP, 2006; Martinez *et al.*, 2007). Because of both sea- and land-derived inputs, coastal ecosystems are centers of high biological productivity, and they provide us with an astounding array of goods and services, including commercial products, dietary protein, fisheries nursery grounds, water filtration, and climate regulation (Burke *et al.*, 2001; Barbier *et al.*, 2011). The coastal landscape has consistently been a preferred location for human settlement, and its attractiveness as such has increased substantially over the past several decades (Small & Nichols, 2003; Coverdale *et al.*, 2013), particularly as a recreational destination and outlet for emotional uplift (Granek *et al.*, 2010). Coastal ecosystems also have immense cultural importance that can transcend socioeconomic groups (UNEP, 2006; Duke *et al.*, 2013). From the chic surf cultures in California and Costa Rica to the subsistence fishing villages in southeast Asia, religious, recreational, and economic cultures are deeply rooted in coastal habitats. Despite this importance, and likely because of it, coastal ecosystems are subject to multiple stressors that have combined to degrade the services they provide across most of their worldwide areal extent (Halpern *et al.*, 2008). Common threats across habitats include overexploitation, pollution, invasive species, and the impacts of climate change.

In this book, we focus on characterizing the biodiversity of coastal ecosystems, and the conservation of these species in the face of multiple, often synergistic, environmental impacts. Coastal biodiversity has largely been overlooked within coastal management frameworks and has proven difficult to adequately account for in systematic conservation planning schemes, leaving its protection in doubt (Stoms *et al.*, 2008; Tallis *et al.*,

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2008; Beger *et al.*, 2010). Yet, biodiversity plays a significant role in both the direct and indirect services provided by coastal ecosystems. In this opening chapter, we provide an overview of coastal biodiversity, highlighting its importance in ecosystem function and the complexities in its measurement and management.

THE COASTAL ECOSYSTEM MOSAIC

It is surprisingly difficult to define what constitutes a 'coast' (Barbier *et al.*, 2008). The most obvious feature of coastlines is the physical merging of ocean and land. From this definition, Burke and colleagues (2001) calculated that there are over 1.5 million linear kilometers of coastline worldwide. However, the influence of the ocean on terrestrial ecosystems extends far inland of the high-tide line, while terrestrial dynamics can impact even the deep trenches of the open ocean (Sheaves, 2009). Where, then, do we draw the line in our definition of the coast? Various authors have drawn this line in different places (e.g. Carter, 1998; Martinez *et al.*, 2007). Following Doody (2000), we define *coastal* to include all nearshore marine, shoreline and maritime terrestrial habitats to the extent of the influence of salt spray. This definition includes habitat such as high-relief rocky coastlines, estuarine/deltaic coastal plains, sandy beaches and dunes, and nearshore tidally influenced marine habitats, such as seagrass beds and mangroves. These habitats share the attributes of being highly dynamic in terms of their erosion–accretion patterns. They are also intimately connected to one another via physical and biological processes (Sheaves, 2009), and it is this level of dynamism and connectivity that is a defining feature of coastal ecosystems.

The habitats that encompass coastal ecosystems have fairly distinct physical and biological boundaries dictated to a large extent by the duration and depth of saltwater inundation and the physical action of waves (Carter, 1998). Within any single habitat there is often also distinct zonation of dominant vegetation, which is a consequence of these same forces (Doody, 2000). Therefore, coastal ecosystems are visually striking by virtue of the juxtaposition of distinct habitat types and, taken together, they form a dynamic collage of land and water habitats (Sheaves, 2009; Barbier, 2012). This feature led Sheaves (2009) to use the term *coastal ecosystem mosaic*, and Barbier (2012) the term *seascape*, to broadly describe coastlines, both acknowledging a high degree of synergy between coastal habitats where the boundaries between them are porous and allow organisms and materials to freely flow from one to another. Although (relatively) easy to define in and of themselves, coastal habitats make up a synergistic and irreducible ecosystem whole.

There is a multitude of ways in which coastal habitats are connected to one another (Sheaves, 2009). There is substantial movement of water, sand, and sediment between habitats (e.g. Schlacher *et al.*, 2008); this movement can be steady and gradual (e.g. tidal or aeolian processes; Davis & Fitzgerald, 2004) or highly episodic (e.g. hurricanes or typhoons; Doody, 2000). Biologically, coastal habitats are connected via plant and animal dispersal and the daily foraging movements and migrations of animals (Sheaves, 2009). This high level of biological connectivity plays a leading role in controlling nutrient transport and recycling between habitats, often with some coastal food webs being subsidized by input from others (e.g. sandy beaches; Schlacher & Connolly, 2009; see also Chapter 3). Many species that utilize coastal ecosystems specialize in one habitat type for part of their life history but move on to others (or off the coast entirely) for the rest (Chapters 9 and 10). Such species require the relatively specialized conditions of coastal habitats for breeding or to escape predation when in a vulnerable state (e.g. larvae or juveniles); however, the remainder of their life requires entirely different ecological conditions. The end result is a highly integrated ecosystem mosaic where one habitat cannot function independently of the others (Heck *et al.*, 2008; Beger *et al.*, 2010).

DEFINING COASTAL BIODIVERSITY

This degree of connectivity of coastal ecosystems has a profound impact on how we define and measure coastal biodiversity. Much like the quandary of defining what a coastal ecosystem is in general, we are faced with making a somewhat arbitrary decision as to what species utilize coastal habitats often enough, or long enough, for us to include them in our biodiversity tally. The easy species to include in our count of coastal biodiversity are those that are restricted to one or more coastal habitats, perhaps even being endemic to one (i.e. being found nowhere else). Many coastal habitats do have endemic species that are also the dominant plant species (e.g. mangroves, salt marsh, seagrass beds); however, there are surprisingly few of them (as long as we exclude coral reefs and islands from the definition of *coastal*, as we do here). As far as we are aware, there is no universally understood explanation for the relative paucity of endemic species in coastal ecosystems. Coastal ecosystems do not occupy a large fraction of either the Earth's terrestrial or oceanic extent, and this may naturally limit the number of endemic species found there. Coastal ecosystems are also highly dynamic through space and time, creating a 'moving target' from an evolutionary point of view. There may simply not be enough time for species to evolve specific adaptations to coastal conditions when these conditions are constantly changing. Or, the occurrence of bountiful resources during pulse events (e.g. fish migrations, spawning events) draws species temporarily only to retreat into more sheltered habitats once resources diminish. No matter the mechanism, the relative paucity of coastal endemics means that coastal ecosystems do not often rank highly in global efforts to document and preserve 'diversity hotspots' (e.g. Myers *et al.*, 2000; Orme *et al.*, 2005). Nevertheless, coastal ecosystems provide some of the best examples of how common and dominant species "[s]hape the world around us" and provide key functions and services (Gaston & Fuller, 2007).

The next obvious species to count are those that require coastal habitats to fulfill a key aspect of their life history but that otherwise range broadly into non-coastal ecosystems. There are many more of these species, they are often found in high abundance in coastal habitats for at least some portion of the year, and they figure prominently in calculations of ecosystem services and conservation decisions (Ronnback, 1999; Martinez *et al.*, 2007; Mcleod *et al.*, 2011; Fourqurean *et al.*, 2012). For example, the seven species of marine turtles use sandy beaches for nesting and their International Union for Conservation of Nature (IUCN) Red List status prompted the protection of critical beach breeding ground (http://www.iucnredlist.org; see also Chapter 10). Similarly, coastal species that are harvested in commercial, recreational, or subsistence fisheries provide a hefty economic benefit to society (Ronnback, 1999; UNEP, 2006). These species are (typically) not endemic to coastal ecosystems as they utilize freshwater or marine ecosystems for some portion of their lives, but without one or more coastal habitats these fisheries will decline, often in a dramatic fashion (e.g. Aburto-Oropeza *et al.*, 2008; Hughes *et al.*, 2009).

Finally, there are those species that can regularly be found in coastal ecosystems, but their entire geographical range extends well outside of coasts either landward or seaward (e.g. Chapters 6, 7, 9). For these species, coastal ecosystems represent one of many suitable potential habitats, and coastal habitats may in fact be somewhat marginal in quality relative to the others they utilize. Some biologists may include these species in their counts of coastal biodiversity and others may not; furthermore, they may make such decisions on a species-by-species basis (e.g. Chapters 6 and 7). The value of conserving these species is an open question. Coastal populations of these species may function as sinks within a larger metapopulation context; therefore, they may be given little conservation value (Kauffman *et al.*, 2004; Fodrie *et al.*, 2009; see also Chapter 6). Or, they may represent unique evolutionary units so that, although they are not considered separate species, their persistence is given high conservation value (e.g. Byun *et al.*, 1997; Wenburg *et al.*, 1998; Zink *et al.*, 2000; see also Chapter 7). For many, perhaps most, widespread species whose ranges can incorporate coastal habitats, we simply do not know which situation pertains.

The chapters in this book delve much deeper into the biodiversity and status of coastal habitats than we do here. Together they highlight two salient and non-mutually exclusive themes. First, many coastal habitats appear simple to the casual human observer due largely to the rarity or even absence of primary producers (e.g. sandy beaches) or to the extreme dominance of only one or two species (e.g. salt marshes, seagrass beds, mangroves, and oyster reefs). This simplicity belies a richly complex array of species, most of which go unseen and unnoticed by human residents of coastal habitats. Second, the integration of land and ocean within coastal habitats creates highly unique species assemblages, even if the species themselves are not uniquely assignable to one or more coastal habitats. In other words, coastal ecosystems may harbor few endemic species, but the species they do harbor create quite distinctive food webs.

COASTAL BIODIVERSITY AND ITS IMPACT ON ECOSYSTEM SERVICES

That coastal habitats provide valuable ecosystem goods and services is now well accepted (Barbier *et al.*, 2011), and the protection of these services increasingly is being used as justification in many coastal zone management plans. What is potentially less understood, and certainly more frequently debated, is the role that coastal biodiversity plays in maintaining these benefits. For direct uses of species, such as fisheries commodities and timber, the importance of species abundance is obvious. However, how species richness affects the delivery of ecosystem services is less clear, but understanding it may be vital to our efforts to conserve coastal ecosystem function (e.g. Zedler *et al.*, 2001; Duffy, 2009).

Coastal ecosystems do not seem to fit in well with traditional biodiversity–ecosystem function (BEF) theory, which predicts a strong linear relationship between species richness and ecological processes (Loreau *et al.*, 2001; Balvanera *et al.*, 2006; Schmid *et al.*, 2009). Many coastal habitats are species-poor, relative to inland habitats. In many cases, species assemblages are comprised of one or a few dominant species (e.g. mangroves, seagrass beds) or have distinct zonation patterns of species occurrence (e.g. salt marsh, dunes), with rare species contributing relatively little to overall biomass. Evidence suggests that, particularly in coastal habitats, the contribution of a species to ecosystem processes is directly related to its biomass (Davies *et al.*, 2011). In this case, the loss of dominant species through coastal degradation can have severe consequences on the provisioning of ecosystem goods and services. Further, compensatory effects of remaining species may be inconsequential (Davies *et al.*, 2011).

Some species losses have simple cause-and-effect relationships. For example, the overexploitation of oysters resulted in a significant depreciation of their value as a fished resource (Chapter 5). However, oyster loss has several additional indirect impacts, which are not as easy to quantify. Declines in water quality, shoreline erosion, and the loss of habitat and resources for other commercially valued fish species top the list. In other cases, impacts of species loss may be decoupled from its impacts. Overharvesting of horseshoe crabs (*Limulus polyphemus*), a marine species, along the Atlantic coast of North America triggered the sharp decline of the red knot (*Calidris canutus rufa*), a terrestrial, long-distance migratory shorebird (Chapter 12). In addition, species additions through deliberate or accidental introductions can alter food webs, change biotic composition, and either directly affect ecosystem function or suppress the ability of a native species to do so (Chapter 8).

Finally, we may not know the specific role a species plays in ecosystem functioning, and there is still much uncertainty about how diversity affects ecosystem processes (Hooper *et al.*, 2005). Answering these questions may change how coastal ecosystem functions are valued as ecosystem services (Barbier *et al.*, 2008; Koch *et al.*, 2009; Barbier, 2012).

CONSERVATION OF COASTAL ECOSYSTEMS

Fully 40% of the world's population in 1995 lived within 100 km of a coast, an increase of over 10% from levels recorded in 1990 (Burke *et al.*, 2001). Human density near coastlines is increasing at a rate nearly three times faster than comparable rates of growth inland (UNEP, 2006). By 2020, three-quarters of the global population is predicted to live within 60 km of the coast (UNCED, 1992). Coastal ecosystems represent some of the most urbanized places on Earth, and as expected, this level of urbanization has taken a heavy toll on the ecological integrity of many coastal habitats (Lotze *et al.*, 2006; UNEP, 2006). However, human settlements are not evenly distributed across habitats or coastlines, leaving some coasts heavily impacted and others virtually untouched (Small & Nichols, 2003; UNEP, 2006; Crain *et al.*, 2009; Halpern *et al.*, 2009). For example, over 60% of mangrove forests occur within, or near, major urban centers, and as a result their conservation status is quite dire (UNEP, 2006; see also Chapter 2). Temperate estuaries, particularly those associated with urban centers and ports, are some of the most degraded ecosystems on Earth, suffering significant impacts from marine pollution, biological invasions, and fisheries collapses (Grosholz, 2002; Kennish, 2002; Kirby, 2004). More generally, those coastal habitats that lie near the outlets of large rivers and urban centers tend to be highly degraded (UNEP, 2006; Halpern *et al.*, 2009). Coastlines that are home to less-dense human settlements and are removed from large river systems are relatively unimpacted (Halpern *et al.*, 2008, 2009).

The list of activities that degrade coastal ecosystems is long with an astonishing variety of direct uses, including fishing, salt production, grazing, fuel wood extraction, and mining (Chapters 2, 3, 5, 7, and 12). These same ecosystems are often also subjected to more indirect and sometimes diffuse stressors, such as terrestrial runoff of nitrogen and phosphorus, invasive species, oil spills, and sea level rise (Chapters 4, 5, 8, and 11). Less understood, but potentially as severe, are the emerging impacts of climate change (Chapters 9 and 10), including rising and warming seas, ocean acidification, increased air temperatures, and more frequent severe storms. The chapters of this book emphasize three conservation themes relative to the effect of these stressors on coastal biodiversity.

First, many stressors co-occur and are synergistic in their impacts on the persistence of one or more species. For example, marine turtles dropped to historically low numbers because of overexploitation over the last century. They are now legally protected from direct sources of mortality across their range, but their recovery is limited both by the loss of beach habitat for nesting due to coastal development and from sea level rise (Chapter 10). Similarly, oyster reefs are degraded by several interacting stressors that then create a positive feedback loop whereby the loss of oysters creates further loss of oysters (Chapter 5). In these instances, conservation managers must mount the nearly herculean effort of untangling the influence of each stressor, ranking their influence relative to one another, and acting to reduce each in turn (Lotze *et al.*, 2006). Nevertheless, it is abundantly clear from reading the chapters in this book that such efforts are desperately needed.

Second, there is mounting evidence that these stressors can affect coastal biodiversity in unexpected and often non-linear ways. There are very clear examples where species have declined in the face of an oil spill (Chapter 11), the arrival of invasive species (Chapter 8), or due to overexploitation (Chapters 5 and 9). There are other species that are less affected

(Chapter 11), and sometimes even benefit, from these same disturbances (Chapters 8 and 9). Furthermore, some species show short-term responses to stressors, such as oil spills or beach renourishment, while others evince surprisingly long-lived declines in their abundance or distribution due to the same disturbance event (Chapters 3 and 11). Finally, there can be a multitude of 'knock-on' effects of coastal ecosystem stressors on biodiversity whereby the loss or depletion of one species in the food web precipitates massive changes in another (Unsworth *et al.*, 2008; Hughes *et al.*, 2009; see also Chapters 5 and 12). Together, this array of impacts on coastal species renders predictions about how particular stressors will influence biodiversity uncertain.

Finally, the interconnectedness of coastal ecosystems creates a multitude of challenges when considering the conservation of their biodiversity (Sheaves, 2009). Species that utilize coastal ecosystems for all, or part, of their lives integrate processes that occur across biological realms, which are academically, legally, and administratively considered as independent units (Beger *et al.*, 2010). In other words, in coastal ecosystems, biology and management do not often line up neatly with one another. For example, it is unproductive to create conservation plans for seagrasses that ignore their intimate connection with land- and ocean-based processes (Heck *et al.*, 2008; Unsworth *et al.*, 2008; Waycott *et al.*, 2009; see also Chapter 4). Nevertheless, management actions often proceed based on legal and administrative boundaries that treat habitats, and especially land versus oceans, as independent units (Sheaves, 2009; Beger *et al.*, 2010). In many cases, resultant management actions may inadvertently sever critical biological and physical ties between coastal habitats creating counterproductive impacts on coastal biodiversity (e.g. Aburto-Oropeza *et al.*, 2008; Ewel, 2010). More broadly, coastal ecosystems are not easily considered within conservation decision support tools because the spatial information on biological connectivity that is required to do so is scarce and hard to analyze (Stoms *et al.*, 2008; Tallis *et al.*, 2008; Beger *et al.*, 2010).

THE COASTAL CONSERVATION GESTALT

If there is one overriding theme to this book it is that the factors that make coastal biodiversity so interesting are precisely the things that make it so vulnerable to loss. The dynamism and connectivity of coastal ecosystems support a fascinating and diverse set of species. Some species are rare and found only in local coastal habitats, whereas others only use these habitats for a small but critical part of their lives. These species utilize to their full advantage the often physically harsh interface of ocean and land, and they provide inextricable links between these two biological realms. The chapters that follow provide a tour through the major coastal habitats worldwide, allowing readers to glimpse the full array of species they support. This tour is punctuated by the cold realities of species losses and widespread habitat degradation. While the need to act is clear, the challenges associated with managing a dynamic biological mosaic are substantial. We have no doubt that readers will find their own conservation agenda within these pages. We provide a few of our own in the final chapter.

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