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A Biosocial Approach for Analyzing Environmental Conflicts: A Case Study of Horseshoe Crab Allocation

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Ambiguous legislation, insufficient science, jurisdictional disputes, and conflicting values of stakeholders have contributed to the increasing frequency of natural resource conflicts. The allocation of horseshoe crabs in Delaware Bay and Cape Cod Bay can serve as a model system for understanding resource conflicts, because relationships among biophysical and human systems in this example typify many environmental controversies. Herein, we use an interaction web to build a conceptual framework for identifying potential conflicts. Specifically, we identify four subconflicts involving horseshoe crabs, human shellfishers, commercial fishers, the biomedical industry, birdwatchers, and environmental interest groups. Stakeholders hold different attitudes concerning the horseshoe crab and thus advocate competing policy preferences in the political process. An important step in understanding environmental conflicts is to clarify differences in social meanings, attitudes, and values. The integrated approach described here, by depicting and graphically displaying biosocial relationships, can provide a generalized approach for understanding a broad range of environmental conflicts.

Keywords: environmental conflict, conflict resolution, food webs, horseshoe crab, Limulus

Managing natural resources for sustainability (i.e., balancing current human use with opportunities for resource use by future generations) is a priority for managers (Lubchenco et al. 1991, Klare 2001, Palmer et al. 2004). Over the past 40 years, ambiguous legislation, insufficient research, jurisdictional disputes between agencies, and conflicting attitudes, values, and policy preferences of stakeholders have contributed to the increasing frequency, intensity, and intractability of environmental conflicts. Because disputes over natural resources can result in legislative impasse, polarization of stakeholder groups, and diversion of staff time and budgets into time-consuming political, judicial, and administrative processes, sustainable management of resources will require more sophisticated tools to diagnose the causes of these conflicts.

Intricate interactions exist among the components of exploited ecosystems. Resource managers and environmental professionals often fail to examine how humans function within ecological systems. When people are included in these analyses, they are often treated as a monolithic entity; the vast differences in how stakeholder groups perceive and affect the environment are given little regard. One heuristic tool of ecology, the food web, has been used to identify testable hypotheses about consumptive (lethal) interactions (Paine 1980, Link 2002). When elaborated into a broader biosocial framework, this approach can guide our understanding of environmental conflicts and their associated causes, effects, and potential solutions.

The allocation of exploited species by state and federal agencies is often highly contentious. The divisive response of both consumptive and nonconsumptive stakeholders to the allocation of horseshoe crabs (*Limulus polyphemus*) can serve as a model system for the examination of environmental conflicts, because the biological components (the exploited resource and its prey, predators, and competitors) and sociological components (human attitudes, values, management programs, and political actions) of the horseshoe crab system are typical of many natural resource conflicts. For example, horseshoe crab allocation decisions on the northeastern and mid-Atlantic coasts of the United States are characterized by biological and quantitative challenges (e.g., how to estimate population sizes in a highly variable ecosystem with incomplete data, how to transition from traditional single-species management to ecosystem-based approaches) that are common to the management of many exploited resources. In addition, the sociological complexity of the horseshoe crab

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system involves stakeholder groups and other participants common to many natural resource conflicts (e.g., commercial harvesters, outdoor recreationists, environmentalists, scientists, managers, and policymakers; Berkson and Shuster 1999, Walls et al. 2002). Furthermore, the unique role of the biomedical industry in horseshoe crab conflicts allows us to posit some additional hypotheses about socioeconomic motivations and environmental justice. If we can identify and graphically display the relationships among these diverse stakeholders using an interaction web, then this approach may have broad utility for examining a variety of complex natural resource conflicts.

In developing an interaction web that models the horseshoe crab allocation conflict, we address the following sets of questions. First, with what nonhuman coastal taxa does the horseshoe crab interact, and what is the nature of these interrelationships? Second, what are the consumptive and nonconsumptive human uses of horseshoe crabs—that is, who are the principal stakeholders and what do we know about them? Here, we define any use that kills horseshoe crabs as consumptive and any activity that focuses on horseshoe crabs without killing them as nonconsumptive. Third, how do interactions among these competing user groups give rise to social and political conflicts over horseshoe crab allocation? Fourth, do the dynamics of the conflict change when the relative importance of stakeholders is quantified using different demographic metrics? Finally, how useful is the interaction web as a conceptual framework for identifying the range of stakeholders (and their associated attitudes, values, and positions), gaps in the scientific information, research questions, and causes of conflicts in general?

Biosocial background

Much has been written about the biology of horseshoe crabs and their role in coastal ecosystems (Bonaventura et al. 1982, Walls et al. 2002). In this background section, we briefly review relevant aspects of horseshoe crab biology so that the nuances of horseshoe crab allocation conflicts can be understood. To set up our conceptual framework, we also provide an overview of trophic interactions that involve horseshoe crabs. Next, we introduce the human stakeholders. We close this background section with an overview of two conflicts, in Delaware Bay (located between New Jersey, Delaware, and Maryland) and southeastern Massachusetts. In both locations, intense conflicts over the allocation of horseshoe crabs have occurred in the past 15 years. Our abbreviated history introduces the context in which the primary human stakeholders, policy issues, and contested biological science have emerged. Although the account is greatly simplified, we intentionally retain a degree of complexity to illustrate that these conflicts resist simple solutions.

Review of horseshoe crab biology. The Atlantic horseshoe crab, *Limulus polyphemus,* is an arthropod, most closely related to extinct trilobites (Shuster and Anderson 2003). Its closest living relatives are spiders and scorpions. Having changed little in its external appearance over the past 200 million years (Shuster and Anderson 2003), this "living fossil" is found primarily in shallow coastal waters of the North Atlantic, less than 30 meters deep (Botton and Ropes 1987). The largest population occurs in Delaware Bay, although *Limulus* is also found in other locations, including Cape Cod Bay (Shuster 1982). Each spring, during the highest tides of the lunar cycle, horseshoe crabs aggregate in large numbers to mate. Females deposit multiple clutches of up to 4000 eggs, typically on sandy beaches, with about 80,000 eggs laid per female per season (Shuster and Botton 1985). If undisturbed, horseshoe crab eggs remain buried in the sand until they hatch and metamorphose into juvenile horseshoe crabs, which emerge after about 1 month (Shuster 1982). At high spawning densities, some buried eggs and larvae of horseshoe crabs become exposed by wave action and the digging activities of other spawning females. The percentage of eggs disturbed by waves and subsequent spawning cohorts may vary greatly by day, season, and year. Exposed eggs do not develop, and in Delaware Bay they become a critical food source for at least 11 species of shorebirds, including ruddy turnstones (*Arenaria interpres*), sanderlings (*Calidris alba*), semipalmated sandpipers (*Calidris pusilla*), and red knots (*Calidris canutus*) (Castro and Myers 1993). In addition to their role in providing forage for shorebirds, horseshoe crabs may influence benthic community structure and primary productivity in coastal ecosystems. Adult horseshoe crabs rototill the bottom as they move and forage in coastal bays. This agitation and feeding can disturb the benthic community (Kraeuter and Fegley 1994), oxygenate substrates, and potentially resuspend previously unavailable nutrients.

Overview of ecological interactions and human stakeholders. Many human groups interact with horseshoe crabs. Because they consume bivalves (Botton 1984), horseshoe crabs are sometimes viewed as competitors by humans who harvest clams and oysters. In the northeast and mid-Atlantic, horseshoe crabs also have been harvested commercially for use as bait in so-called conch traps (for catching whelk, *Busycon carica, Busycotypus canaliculatus*) and in eel pots (for the common eel, *Anguilla anguilla*). Because the millions of migrating shorebirds that stop in Delaware Bay depend on horseshoe crab eggs to regain as much as 40% of their body weight (Castro and Myers 1993), this unique and spectacular natural phenomenon attracts birdwatchers, ecotourists, and other environmentally interested observers from all over the world. Some conservation groups and resource managers are very concerned over the status of red knot populations and impacts to their forage base (Rist 1997, Hajna 2003). Finally, in 1968, scientists at the Woods Hole Marine Biological Laboratory discovered that Limulus amoebocyte lysate (LAL), refined from the unique copper-based blood of horseshoe crabs, could be used to detect small amounts of endotoxin contaminants in medical products slated for human use (Levin and Bang 1968).

A tale of two horseshoe crab conflicts. Surprisingly, the horseshoe crab—a seemingly headless, furless living fossil—has become a poster child for the conservation community and is at the center of several contentious legal battles. During the 1990s, demand for horseshoe crabs to supply bait for the rapidly expanding whelk fishery led to larger horseshoe crab harvests coastwide, especially in Delaware Bay (ASMFC 1998). As a result, in 1997, New Jersey Governor Christie Whitman, under pressure from environmental groups, issued an emergency ruling that temporarily prohibited commercial harvest of horseshoe crabs in the New Jersey portion of Delaware Bay. These environmental groups were concerned about the decline of migratory shorebird populations that depend on horseshoe crab eggs. In response to an appeal by the Delaware Bay Watermen's Association, a three-judge New Jersey Superior Court panel lifted this ban, thus allowing the commercial harvest of the horseshoe crab to resume. The same day, however, the New Jersey Division of Environmental Protection obtained an injunction against this decision, pending its appeal to the New Jersey Supreme Court. Soon afterward, New Jersey, along with Delaware and Maryland, adopted stricter horseshoe crab harvest regulations that resulted in reduced commercial fishing pressure on horseshoe crabs in these regulated states.

However, harvest increased dramatically in Virginia and in offshore waters (ASMFC 2000). In response, the Atlantic States Marine Fisheries Commission recommended a harvest moratorium in Virginia and the establishment of a 1500-square-mile (3885-square-kilometer) federal horseshoe crab sanctuary in Delaware Bay. Despite vigorous opposition from commercial fishers, both actions, supported by environmental groups, were implemented in 2001 (ASMFC 2001). Throughout the conflict, scientific uncertainty regarding the status of horseshoe crab population trends exacerbated debates over what level of harvest was sustainable. And the conflict continues.

After a short quiet period, the conflict erupted again in 2002 when a coalition of environmental groups announced a new campaign (DNJ 2003). Then in 2004, after considerable public debate, new rules were adopted that reduced harvest and closed Delaware Bay to horseshoe crab harvests during the peak bird migration season (ASMFC 2004).

After the changes in Delaware Bay regulations in 1997, the small, local commercial harvest of horseshoe crabs for whelk bait in Massachusetts increased, partly to meet demand previously supplied by Delaware Bay fishers (ASMFC 2000). In response to pressure from environmental groups, the US Fish and Wildlife Service (USFWS) and National Park Service (NPS) banned horseshoe crab harvest by commercial fishers in the waters of Pleasant Bay adjacent to Monomoy National Wildlife Refuge and the Cape Cod National Seashore. These closures were based on regulatory provisions that prohibit commercial use of resources within USFWS and NPS jurisdictions (Braile 2000). To reverse this closure, a commercial fisherman sued the Department of the Interior in the Massachusetts District Court (civil action 00-10549-RWZ). The Massachusetts Division of Marine Fisheries filed an *amicus curiae* brief, siding with the commercial fisherman. In this brief, the agency argued that (a) no convincing evidence existed that horseshoe crabs were overfished, (b) horseshoe crabs were de facto "shellfish," and, because of this, (c) federal agencies had exceeded their jurisdiction by interceding in the management of state fishery resources. In agreement, the presiding judge in Boston's US District Court lifted the commercial fishing ban in May 2000. However, a year later, this decision was reversed, again prohibiting commercial fishing within Cape Cod National Seashore. In this last decision, the judge ruled that, taxonomically, horseshoe crabs were neither fish nor shellfish and thus were not "grandfathered in" for state management when the National Seashore was established.

The conflicts over allocation of horseshoe crabs in Delaware Bay and along the Massachusetts coast exhibit striking similarities. In both locations, commercial fishers, several environmental groups (including birdwatchers), the biomedical industry, and regulatory and management agencies are the primary adversaries. In both locations, complex social, economic, and political factors are critical. In both locations, biological science is contested. For example, in Delaware Bay, before any of the court battles began, scientists were asked to review data on horseshoe crab population levels. Unfortunately, existing information was inadequate to determine whether populations were stable, increasing, or declining (ASMFC 1998). Similarly, although early evidence existed that horseshoe crabs in at least one Cape Cod location had declined (Widener and Barlow 1999), another study now indicates that some Massachusetts horseshoe crab populations are much larger than previously thought (Carmichael et al. 2003). Although carefully conducted systematic surveys are now being undertaken to help resolve these points of contested biological science, important questions about ecological patterns and population trends remain unresolved. Despite many similarities between the conflicts in Delaware Bay and in Massachusetts, some of the reasons behind these lawsuits differ. In Delaware Bay, the immediate conflict was primarily between birdwatchers' organizations and commercial fishers. In Massachusetts, lawsuits revolved around agency jurisdiction. In both locations, although punctuated by fragile, short-term settlements, these conflicts continue to erupt, suggesting that they resist superficial, short-term solutions.

Development of the interaction web

Our goal was to identify and graphically depict factors underlying horseshoe crab allocation conflicts. To do this, we developed a medium-complexity interaction web that can reveal potentially important policy questions. Although previous research explores a variety of issues related to horseshoe crabs, we synthesize and integrate only the recent literature on their trophic interactions (figure 1). We focus on horseshoe crab adults and eggs in the inshore habitat. Based on organismal references for the years 1954–2004, our conceptual framework illustrates what is known about organisms that eat or use

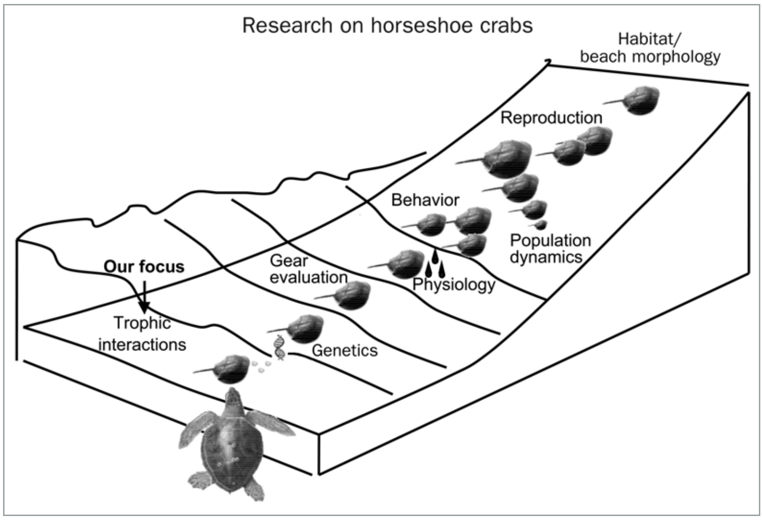

Figure 1. Areas addressed by recent horseshoe crab research. Here we focus only on trophic interactions.

horseshoe crab eggs and adults, and about organisms that are eaten by adult horseshoe crabs. Here we focus on recent peer-reviewed literature on predator–prey interactions (1984–2004).

Based on this review, our interaction web organizes, by approximate trophic level, the interrelationships of humans and nonhuman species directly linked to horseshoe crabs. As in other published food webs (e.g., Link 2002), we aggregated species on the basis of function, particularly at lower trophic levels (e.g., bacteria, small benthic invertebrates, plankton). We retained all groups with direct links to horseshoe crabs and separated out the primary human users. We initially examined interactions between trophic levels (vertical linkages), with the ultimate goal of identifying critical connections within trophic levels (horizontal linkages), as these potential competitive interactions could signal conflicts. In the first interaction webs (figures 2, 3, 4), unshaded rectangles represent nonhuman species that either eat or are eaten by horseshoe crabs or their prey; shaded rectangles represent consumptive human users (those who kill or potentially kill horseshoe crabs); and shaded ovals represent nonconsumptive human users (those who interact with but do not kill horseshoe crabs). Some horseshoe crabs die in biomedical use; we classify this use of horseshoe crabs as a hybrid of consumptive and nonconsumptive functions. Solid arrows represent direct interactions that connect to horseshoe crabs through vertical linkages. Dotted lines show indirect effects or horizontal interactions between two stakeholder groups as mediated by the horseshoe crab. Dashed lines indicate potentially important interactions among human stakeholder groups that are not directly related to horseshoe crabs.

In figure 5, we estimate the relative importance of stakeholder interactions with horseshoe crabs by quantifying each stakeholder group using four demographic metrics (Fermata Inc. 2000, Manion et al. 2000, ASMFC 2004). The differential size of each rectangle reflects (a) the number of horseshoe crabs harvested coastwide; (b) the number of jobs associated with the direct use of horseshoe crabs coastwide (i.e., the approximate number of fishers who harvest horseshoe crabs or who depend on horseshoe crabs for harvesting eel or whelk, and those employed in the biomedical industry); (c) the estimated economic contribution or income generated by the different horseshoe crab–related job categories for commercial fishers and biomedical sectors coastwide and for birders in Delaware Bay; and (d) the number of people potentially affected by the impact of consumptive and nonconsumptive interactions with horseshoe crabs on shorebird migration in Delaware Bay. We use these measures because data on them, albeit limited, were readily available from technical reports. Coastwide estimates provided the most consistent measure for comparing stakeholder sectors for harvest and jobs, but economic data for birdwatchers were available only for Delaware Bay. The number of horse-

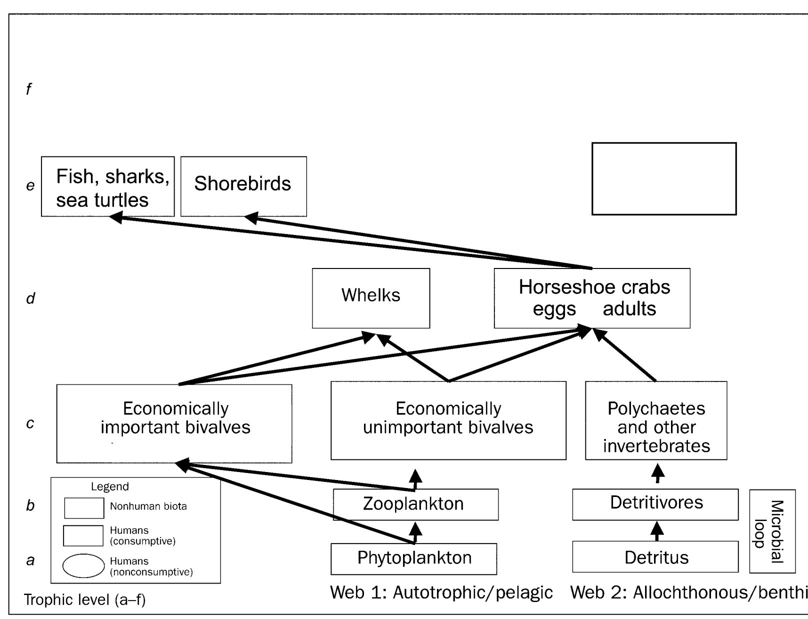

Figure 2. Conceptual framework depicting nonhuman components that interact with horseshoe crabs. Interactions are organized by trophic level, indicated in the left margin (a–f). Both autochthonous (autotrophic) pelagic (web 1) and allochthonous benthic (web 2) pathways are shown. White rectangles depict nonhuman taxa. Economically important molluscan species are quahogs (*Mercenaria*), softshell clams (*Mya*), and other bivalves (*Mytilis *and* Spisula*). Economically unimportant species are dwarf surf clams (*Mulinia*), gem clams (*Gemma*), and other bivalves (*Siliqua, Nucula, Ensis, *and* Tellina*; Botton 1984). In all diagrams, all interactors are in the same positions in the web.

shoe crabs harvested is a 5-year annual average (1999–2004; ASMFC 2004), with the allocation split between whelk (85%) and eel harvesters (15%) (Manion et al. 2000). Number of jobs and job-related income include only jobs that contributed a significant portion of annual income (Manion et al. 2000). The minimum estimate of number of people potentially affected includes jobs, as described above (Manion et al. 2000); the maximum estimate includes jobs plus the number of participating birders and ecotourists in Delaware Bay (Fermata Inc. 2000, Manion et al. 2000). Although sociodemographic information related to human shellfishers is important, we do not include it because existing summaries do not accurately assess the critical contribution of human inshore shellfishing and aquaculture to the Massachusetts and Delaware Bay economies.

The horseshoe crab food web. Horseshoe crabs utilize both autochthonous and allochthonous production from pelagic and benthic food webs (figure 2; Carmichael et al. 2004). Phytoplankton are at the base of the autotrophic pelagic food web in both Cape Cod Bay and Delaware Bay (figure 2). These are consumed by a variety of primary consumers, including zooplankton and bivalves (figure 2). Bivalve shellfish consume both phytoplankton and zooplankton (figure 2). Shellfish that inhabit coastal ecosystems and are preyed on by horseshoe crabs include economically important species harvested by humans (e.g., northern quahogs, *Mercenaria mercenaria;* softshell clams, *Mya arenaria;* blue mussels, *Mytilus edulis;* surf clams, *Spisula* spp.) as well as economically unimportant bivalves (e.g., dwarf surf clams, *Mulinia lateralis;* amethyst gem clams, *Gemma gemma;* jackknife clams, *Ensis* spp.; razor clams, *Siliqua* spp.; nutclams, *Nucula* spp.; macoma clams, *Macoma* spp.; tellins, *Tellina* spp.) (figure 2; Shuster 1982, Botton 1984, Botton and Haskin 1984). As generalist feeders with specialized appendages that can grind hard food, adult horseshoe crabs prey on bivalves (figure 2; Botton 1984, Botton and Haskin 1984, Botton and Ropes 1989), as do other invertebrate predators, such as whelk (figure 2; Flimlin and Beal 1993). A second allochthonous benthic food web, based primarily on salt marsh and eelgrass production, also exists in these coastal systems (figure 2). Deposit feeders such as polychaete worms and other benthic invertebrates, which feed in this web, are important prey for adult horseshoe crabs (figure 2; Shuster 1982).

Many vertebrate predators, including sharks, other fish, and sea turtles, eat horseshoe crabs (figure 2). Benthic fish feed on horseshoe crab eggs and larvae, sharks feed on the smaller juveniles, and sea turtles feed on adults (Botton et al. 2003). Many birds feed on horseshoe crab eggs, with some birds (e.g., gulls) consuming egg clusters and stranded adult horseshoe crabs. Although the role of horseshoe crab eggs in the diet of migratory shorebirds in systems other than Delaware Bay is unknown or uncertain (Berkson and Shuster 1999, Germano 2003), shorebirds migrating through Delaware Bay depend on scavenged horseshoe crab eggs and may require up to 539 metric tons of eggs to fuel the trip to their Arctic summer range (Castro and Myers 1993). The population level of horseshoe crabs required to ensure that the eggs are accessible to shorebirds is in excess of the number required simply to sustain the horseshoe crab population, because horseshoe crab eggs are not available to surface-feeding shorebirds unless they are exposed by wave action or by the digging actions of other horseshoe crabs. Horseshoe crabs thus link an array of prey (bivalves and polychaete worms) and predators (fish, turtles, and birds), utilizing both autochthonous and allochthonous production from pelagic and benthic food webs.

Human stakeholders

Horseshoe crabs are embedded in a web of interactions that involve human stakeholder groups, including clam harvesters, commercial fishers of several kinds (e.g., bait, whelk, eel), the biomedical industry, birdwatchers, ecotourists and ecoresidents, environmental organizations, scientists, and resource managers. These groups, some of which are more formally organized than others, ascribe a variety of often conflicting attitudes, values, and meanings to horseshoe crabs.

Clam harvesters. Humans prey on coastal species in a number of ways. Economically important shellfish are important to many coastal economies, and shellfish-harvesting traditions are firmly embedded in local cultures (Hall-Arber et al. 2001). In both Massachusetts Bay and Delaware Bay, humans who cultivate or harvest economically important shellfish, referred to here as clam harvesters (figure 3a), represent a diverse group of stakeholders. First, many local town residents harvest wild shellfish for their own household use. For example, over 10,000 recreational shellfish permits were sold in Cape Cod townships in 2002 (Damery and Allen 2004). Second, the aquaculture industry, which plants seed clams in order to harvest adults, is economically important in the northeastern United States (e.g., income from cultured quahogs and oysters in the Northeast totals $75.1 million per year; Spatz et al. 1996). Third, commercial fishers harvest wild shellfish either as an exclusive activity or in addition to harvesting finfish. Typical commercial shellfish harvesters use long rakes or dredges to harvest quahogs in the fall and winter, and then dig softshell clams in the spring and summer. Other commercial shellfishers depend on clam harvesting when commercial finfish species are unavailable or less profitable. As a result, shellfish are viewed by some fishers as a socioeconomic safety net (Hall-Arber et al. 2001). These three groups of shellfish harvesters vary in their socioeconomic characteristics, their demographic background, the cultural importance they place on shellfishing, the proportional contribution of shellfish to their household food budgets, and the extent to which income from shellfishing contributes to their household economies.

Commercial fisheries. Adult horseshoe crabs are harvested by commercial horseshoe crab fishers (figure 3b). These crabs, in turn, are used as bait in commercial whelk and eel fisheries, and as a source of blood to make LAL in the biomedical

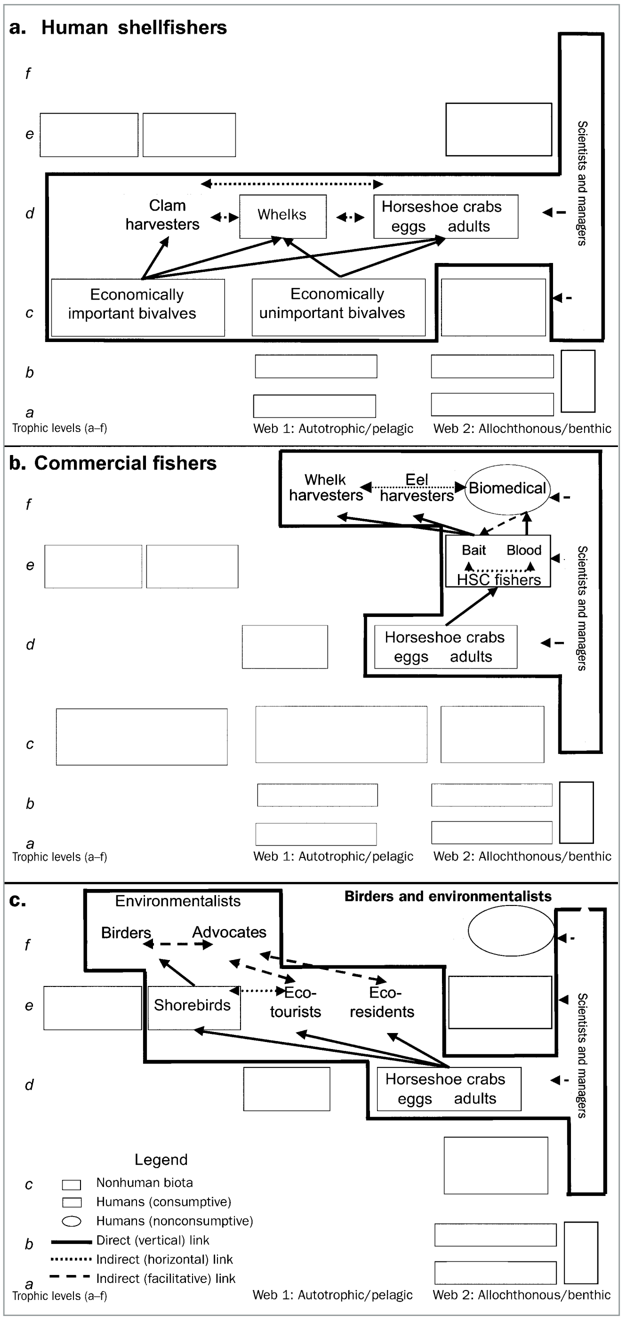

Figure 3. Interactions among nonhumans and humans involved with horseshoe crabs, including human shellfisher interactions (a), commercial fisher interactions (b), and birdwatcher and environmentalist interactions (c). Interactions are organized by trophic level, indicated in the left margin (a–f). Both autochthonous (autotrophic) pelagic (web 1) and allochthonous benthic (web 2) pathways are shown. White rectangles depict nonhuman taxa. Shaded rectangles depict consumptive human users (i.e., stakeholders who kill or potentially kill the horseshoe crab), and shaded ovals depict nonconsumptive human users (stakeholders who do not kill horseshoe crabs). The biomedical industry is considered a hybrid of consumptive and nonconsumptive use. Solid lines represent direct interactions. Horizontal dotted lines reflect potential conflicts and signal nascent conflicts. Dashed lines are interactions among environmental stakeholder groups that are only distantly related to the horseshoe crab.

industry (figure 3b). Although some horseshoe crab fishers sell exclusively to the bait fishery and others to the biomedical industry, many commercial horseshoe crab fishers sell opportunistically to both groups. As harvest restrictions tighten, the links among commercial horseshoe crab harvesters, whelk and eel fishers, and the biomedical industry are shifting. For example, the recently adopted "rent-a-crab" program in Massachusetts allows bait dealers to "rent" horseshoe crabs to the biomedical industry for temporary use. After extracting the blood, the biomedical industry returns the horseshoe crabs to the bait dealers, who can then resell them as bait to whelk or eel fishers. As a result of such practices, and the coastwide adoption of bait bags (developed by a nonprofit group in Delaware), the overall mortality of horseshoe crabs has been sharply reduced (Frank Germano, Massachusetts Division of Marine Fisheries, New Bedford, MA, personal communication, 28 January 2005). However, this innovation in management blurs differences among stakeholders, and when horseshoe crabs are killed and used for bait after bleeding, biomedical use can no longer be characterized as nonlethal.

In the commercial horseshoe crab fisheries in Cape Cod Bay and Delaware Bay, harvesters take horseshoe crabs from spawning beaches by hand, from skiffs using dip nets and dredges, and from offshore habitats using trawls (Berkson and Shuster 1999). Because horseshoe crab reproduction is seasonal, the onshore harvesting takes place during a short period, and much of this harvesting activity is only a minor portion of fishers' income. In addition, many people who participate in this beach harvest are not fishers by vocation, but collect horseshoe crabs as a seasonal odd job to gain extra income. For the full-time fishers in both Delaware Bay and Cape Cod Bay, horseshoe crabs are harvested in addition to a variety of fish species. As foreign demand for whelk has increased, the US commercial whelk fishery, for which horseshoe crabs are effective bait, has also increased in importance. Furthermore, eels are a highly desired bait for a variety of sport fish species, and thus link horseshoe crabs, commercial fishers, and recreational anglers. "Conch" (whelk) traps are baited with either male or female *Limulus* (Shuster and Botton 1985, ASMFC 1998), whereas eel pots are usually baited only with egg-laden females. Some of the same people who fish for horseshoe crabs may also target whelk and eel. As one of the oldest vocations in the United States, commercial fishing helped provide the financial means to launch the American Revolution and, thus, has the enduring status of a heritage activity (Kurlansky 1997). Inshore commercial fishers on Cape Cod and in Delaware Bay (where they are also known locally as "baymen" or "watermen") are overwhelmingly male, white, and working class, and often come from families that have been fishing for several generations. In addition, many have an ethnic heritage long associated with commercial fishing. For example, fishers of Portuguese and Italian descent are concentrated in the fleets of some Massachusetts towns (Hall-Arber et al. 2001).

Biomedical industry. Limulus amoebocyte lysate, made from the blood of horseshoe crabs, is used in testing procedures required by the US Food and Drug Administration to ensure the purity of all injectable drugs and implantable medical devices. The biomedical industry (figure 3b) depends on live horseshoe crabs purchased from commercial horseshoe crab fishers (figure 3b). With proper precautions, withdrawing blood for LAL does not kill horseshoe crabs in the laboratory, but no study has definitively assessed the comprehensive impact of biomedical bleeding on immediate and delayed mortality. Mortality for horseshoe crabs that are bled and returned to the ocean is estimated to be 7.5% to 15% higher than for unbled controls (Walls and Berkson 2003). Results of a behavior study reported by Kurz and James-Pirri (2002) suggest that horseshoe crabs returned alive to the ocean after biomedical bleeding may be disoriented and more vulnerable to other sources of mortality. Furthermore, in 2000, more than 90,000 horseshoe crabs, representing 25% of the total number brought to port for use by the biomedical industry, were rejected because they were injured or too small (ASMFC 2004). Thus, based on these data, overall mortality can be as high as 40% (15% postbleeding + 25% handling = 40%). As noted above, some horseshoe crabs are now killed and used for bait after they are bled, presumably reducing the mortality rate of horseshoe crabs formerly harvested solely for use as bait. Nonetheless, the biomedical use of horseshoe crabs may not be as benign as it is often portrayed. Use of the LAL test has saved many human lives and has obvious benefits to society, but the biomedical industry is also a lucrative business (Manion et al. 2000). The biomedical industry relies on the human harvest of horseshoe crabs, but is generally viewed with less hostility than the bait fishery by the opponents of horseshoe crab harvest, for several possible reasons. First, the biomedical industry kills only a proportion of the total horseshoe crabs harvested. Second, the biomedical industry has been harvesting horseshoe crabs for many years with few scientifically documented adverse effects. Third, the biomedical industry makes a product indispensable for the health and safety of humans. Fourth, industry members and commercial fishers, the other consumptive user group, belong to different socioeconomic classes.

Birdwatchers. The arrival of up to one million migratory birds in Delaware Bay each year during May and June is considered by many to be one of the world's premier birdwatching events. It is said to "rival the caribou migrations as one of the natural world's great spectacles" (Rist 1997). Between 6000 and 10,000 birders travel to the shores of Delaware Bay each spring (figure 3c; Fermata Inc. 2000). Birdwatchers in Delaware Bay are often middle-aged or older (with an average age of 55), comprise equal numbers of men and women, are well educated (with an average of 16 years of formal education), and are relatively wealthy (with a mean annual household income of $80,000). They are committed to birdwatching as a central life interest and have participated in birdwatching for an estimated average of 18 years (with an annual average of 14 trips totaling 46 days; Fermata Inc. 2000). An avid birdwatcher indicated the centrality and depth of his commitment to birding when he said, "When I was a kid, I used to measure the passage of time by Christmases. Now it's the World Series of Birding that marks time" (NJAS 2004). Birdwatchers belong to well-organized, politically sophisticated special interest groups, such as the National Audubon Society, that effectively represent their values and preferences in the policy process.

Horseshoe crab–related ecotourists and ecoresidents. Besides birdwatchers, other environmentally oriented stakeholder groups include ecotourists and ecoresidents (figure 3c). Birders, ecotourists, and ecoresidents can be differentiated using two criteria: (1) the component of the coastal ecosystem (i.e., shorebirds, horseshoe crabs, or the health of the entire coastal ecosystem) on which they place the highest priority, and (2) where they reside. Whereas many birders may feel that providing sufficient nutrients for migratory shorebirds should be the primary consideration in horseshoe crab allocation decisions, other ecotourists and ecoresidents may be more apt to view the horseshoe crab as a cultural icon or a component of the ecosystem deserving of protection for its own sake (figure 3c). Location also differentiates stakeholders; ecoresidents, by definition, reside close to the horseshoe crab environment and may be members of local activist organizations, whereas ecotourists travel from other locations and, by spending money, make additional contributions to the local economy. For example, in Delaware Bay, horseshoe crab–dependent tourism (including birdwatching) may generate up to $10 million a year and provide between 119 and 178 local jobs (Manion et al. 2000). Tourism in general, and horseshoe crab–related ecotourism in particular, has inspired the creation of jewelry, clothing, sculpture, folk art, and children's books (Tate 1991, Dunlop 1999, Horowitz 2004). Annual festivals celebrating horseshoe crabs are held in communities throughout Delaware Bay and coastal Massachusetts. As an example of an ecoresident activity, a popular school curriculum in Delaware Bay called "Green Eggs and Sand" has educated hundreds of local middle- and high-school students about this species. Ecotourists and ecoresidents gather to observe the seasonal spawning aggregations of the horseshoe crab. As a member of a Maine conservation group noted, "It's kind of an honor to have such an ancient being come here and choose this bay" (Edgecomb 2002). (The horseshoe crab is a cultural icon in other countries as well [Chen et al. 2004]. In Kasaoka, Japan, a museum was built in the shape of a horseshoe crab and dedicated to the nearly extirpated Japanese species, *Tachypleus tridentatus,* which is also revered as a living fossil by local residents.) Although horseshoe crab–related ecotourists and ecoresidents appear to be of increasing importance, little systematic information exists about their numbers, attitudes, values, sociodemographic characteristics, or influence on horseshoe crab policy and management.

Other groups with broader interests. Environmental groups that advocate for a broader array of issues may also have a stake in horseshoe crab allocation in both Delaware Bay and Massachusetts (figure 3c). Their interest may be in the preservation of shorebirds, the conservation of horseshoe crabs, the maintenance of the coastal ecosystem, or the use of a conservation crisis to raise general environmental awareness. This broader environmental stakeholder group is composed of environmental organizations of national or international stature, which can affect birders, ecotourists, and ecoresidents through their influence on environmental issues, and specifically on horseshoe crab–related issues. Finally, scientists and managers can also be considered stakeholders (figure 3a, 3b, 3c). Scientists provide research information that guides policy decisions and management actions, while state and federal managers are charged with conserving coastal resources at all trophic levels. Scientists and managers generally support the sustainable harvest of horseshoe crab, although differences in opinion may arise between different agency missions and professional values. Finally, scientists and managers may have personal views that influence their professional behavior. Although quantification of the roles that researchers and managers play in environmental conflicts is beyond the scope of our framework, these interactions need to be examined.

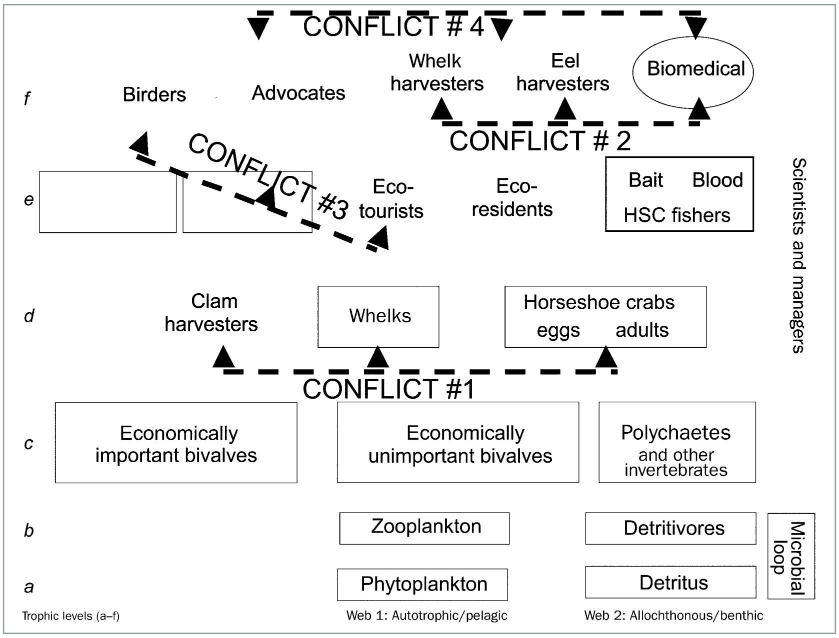

Figure 4. Four interactions that could lead to conflicts involving horseshoe crabs and human stakeholders.

Four interactions that can lead to conflicts

Horseshoe crabs are at the center of four interactions that can lead to conflicts (figure 3a, 3b, 3c, figure 4). The first interaction involves human shellfishers who cultivate and harvest economically important bivalves such as northern quahogs and softshell clams (figure 4). Quahog growers consider predation by horseshoe crabs, whelk, and other carnivorous invertebrates to be one of the three top threats to their clams (figure 3a; Spatz et al. 1996, Walton and Walton 2001). Although most mariculturists now protect young bivalves in mesh bags or nets, predaceous invertebrates such as horseshoe crabs still potentially eat economically important wild shellfish. In the past, some Massachusetts townships have paid a bounty on horseshoe crabs in efforts to reduce impacts on clam resources (Shuster 1950). Bounties are no longer paid, but as recently as 2000, eight Cape Cod townships still had regulations requiring fishers to destroy horseshoe crabs and other predators encountered during harvest activities (Germano 2003). Although some wild shellfish stocks are clearly declining, the impact of horseshoe crab predation, relative to habitat loss, pollution, disease, and overharvest, is poorly understood. However, if horseshoe crabs compete, or are perceived to compete, with human shellfishers, a subconflict exists between horseshoe crabs and human clam harvesters (figure 3a, figure 4).

In the second interaction that may lead to conflict, the whelk fishery, the eel fishery, and the biomedical industry all potentially compete for the limited number of horseshoe crabs allowed to be caught by commercial horseshoe crab fishers. This sows the seeds for an allocation conflict among consumptive users (figure 4). Even though commercial fishers and the biomedical industry agree that sustainable harvest of horseshoe crabs for human use is appropriate, in a common fishery resource, incentives to overfish often exist (Hardin 1969). Thus, as horseshoe crabs become increasingly limited, consumptive stakeholders are likely to find themselves increasingly at odds with each other (figure 3b).

Third, interactions exist among nonconsumptive users as the environmental community continues to grow and diversify (figure 4). These environmental stakeholders have much in common, and the same people may play several different roles as environmental stakeholders (figure 3c). Nevertheless, seemingly subtle differences may have important consequences. For example, birdwatchers are concerned with preserving a spectacular phenomenon that may depend on an extremely high abundance of horseshoe crabs to benefit shorebirds, whereas ecotourists and ecoresidents may seek a sustainable population of horseshoe crabs to preserve the species and protect its ecological role in the coastal ecosystem (figure 3c). Methods to achieve these two environmental goals can differ.

A final potential conflict can occur between these stakeholders who value horseshoe crabs for nonlethal, nonconsumptive uses (e.g., birdwatching, ecotourism) and stakeholders who use them for consumptive or potentially lethal purposes (whelk or eel bait, or blood for LAL; figure 4). Many environmentally oriented (nonconsumptive) stakeholders view the harvesting of horseshoe crabs as one more example of failed fishery management in which poorly controlled harvesting will result in the collapse of yet another vulnerable species. Although the conflict surrounding horseshoe crab harvest is relatively new, conservationists cite the long history of unsustainable harvest in other marine ecosystems as evidence of the need to develop protective, precautionary regulatory regimes and harvest quotas.

How dynamics change with the metrics used to identify human roles

The importance of each human stakeholder group will vary depending on how its role in the policy process is quantified (figure 5). In terms of harvest (figure 5a), the commercial horseshoe crab fishery kills the most horseshoe crabs (a 5-year annual average of 1.9 million; ASMFC 2004). The majority

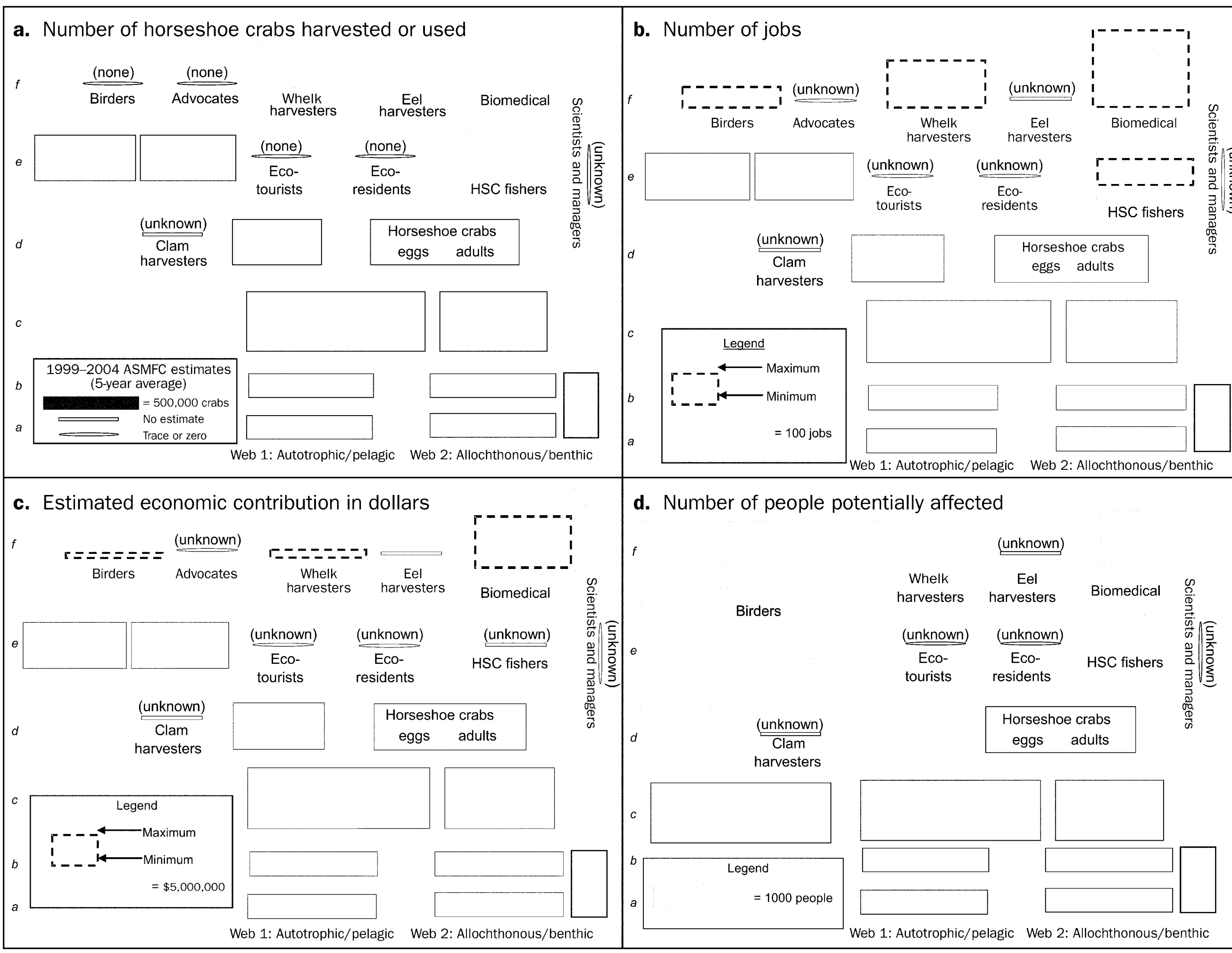

Figure 5. Relative importance of different categories of human stakeholders using the horseshoe crab resource, based on (a) the number of horseshoe crabs harvested or used (× 10,000), (b) the number of jobs directly related to the use of horseshoe crabs, including birdwatching and tourism, (c) the estimated economic contribution from horseshoe crab–related jobs (in millions of dollars), and (d) the number of people potentially affected by horseshoe crab–related activities. All estimates are coastwide except for birdwatchers in (c) and all stakeholders in (d), which are estimated for Delaware Bay only. In (a), not all horseshoe crabs that are harvested by the biomedical industry die. Crabs used by whelk and eel harvesters are obtained from commercial horseshoe crab fishers. Low estimates are indicated by a dashed line; high estimates are indicated by a shaded box. A small empty rectangle indicates that no comparable estimates were available. In all diagrams, nonhuman (white) and human (gray) interactors are in the same positions in each panel and in all webs. Here both consumptive and nonconsumptive human stakeholders are represented by rectangles. Trophic levels are indicated by lowercase italic letters (a–f) at the left of each panel. The size (area) of the gray rectangle reflects the relative importance of each stakeholder group. Estimates are taken from Manion and colleagues (2000), Fermata Inc. (2000), and ASMFC (2004).

of these horseshoe crabs are used in the whelk fishery (1.6 million; figure 5a). Substantially fewer horseshoe crabs are harvested for the biomedical industry (280,000), and less than half of these are killed outright by harvest stress, blood withdrawal, or postbleeding mortality (conservatively estimated at 32.5%, or 91,000 annually [7.5% + 25% = 32.5%]; figure 5a). However, the "rent-a-crab" program is blurring the distinction between these two sources of mortality.

In terms of employment (figure 5b), the biomedical industry provides the most full-time jobs (440 to 540 per year), followed by whelk harvesters (270 to 370 per year) and the commercial horseshoe crab fishing sector (150 to 331 per year) (figure 5b; Manion et al. 2000). Although little systematic information exists regarding the contributions of birdwatching and ecotourism activities to local and regional employment, between 119 and 178 local jobs are added by the seasonal tourism associated with the shorebird migration in Delaware Bay (Manion et al. 2000). In terms of direct job-related income (figure 5c), the highest amount is provided by the biomedical industry ($60 million to $150 million annually), with whelk fishing and birdwatching contributing $11 million to $15 million and $7 million to $16 million, respectively (figure 5c; Manion et. al. 2000).

In terms of the number of people who potentially benefit from interactions with horseshoe crabs (figure 5d), birdwatchers (6000 to 10,000; figure 5d; Fermata Inc. 2000, Manion et al. 2000) greatly outnumber all other stakeholders. However, the number of people in the different stakeholder groups is poorly understood, and their impacts have not been well quantified. More informed policy decisions will result if better data are available on the attitudes, values, socioeconomic backgrounds, and management preferences of all stakeholders, and if, in addition to biological criteria, sociocultural and economic criteria used in decisionmaking are more explicitly clarified and prioritized.

How this interaction web can address environmental conflicts

Currently, natural resource conflicts seriously impede the sustainable management of many exploited resources. For example, as of January 2002, over 110 lawsuits were pending against the National Marine Fisheries Service (NRC 1999, NAPA 2002). Because laws and regulations often require biological standards (e.g., maximum sustainable yield) or economic benchmarks (e.g., providing jobs and harvest-related income) as decision criteria, policymakers and natural resource managers generally view environmental conflicts primarily in terms of these biological and economic metrics. Unfortunately, this focus prevents the examination of more diverse interactions that drive environmental conflicts. For example, examining the horseshoe crab conflict as if it were simply an issue of allocation among harvesters overlooks the relevance of this issue to environmental interest groups. In fact, conflicts over exploited resources are a mosaic of shifting subconflicts that vary in relative importance through time and space. These subconflicts may have their roots in three general areas.

First, environmental conflicts may be based on lack of science or ignorance of basic facts. Using an interaction web approach, we have identified a number of gaps in biological and sociological information related to the horseshoe crab conflict. Critical biological questions that have not been answered include the following: (a) What are the age-specific survival, growth, and fecundity measurements needed to model the population, including the impact of biomedical bleeding? (b) How many horseshoe crabs can be harvested sustainably? (c) What other abiotic and biotic factors (e.g., predation, habitat destruction, climate change) affect the health of the horseshoe crab, shorebird, and wild shellfish populations? (d) How do these patterns and processes change across geographic regions and through time? (e) What is the relevant spatial scale for assessment? Other questions concern the socioeconomic and cultural characteristics of stakeholders: (a) How do we identify and quantify stakeholder importance? (b) How can other aspects of social capital, such as education, environmental advocacy networks, and political influence, be quantified? (c) What are the attitudes and values of different stakeholder groups toward the horseshoe crab resource, toward science, and toward each other? (e) What are the most effective ways to communicate biological, sociological, and economic information to decisionmakers and stakeholders? Research results, communicated effectively through appropriate techniques, may eliminate or partially resolve conflicts that are based on lack of information.

Second, complex environmental conflicts may be less about horseshoe crabs than about different worldviews, especially divergent views concerning the relationship between humans and nature. How a horseshoe crab dies (e.g., being eaten by a shark, harvested by a bait fisherman, or killed by the stress induced by a biomedical technician who withdraws 20% of its blood) doesn't matter to the horseshoe crab, the horseshoe crab population, or the coastal ecosystem. But who or what kills horseshoe crabs may matter to human stakeholders with opposing views on whether environmental policy should focus on providing human benefits or conserving an entire ecosystem. Whether nature should be proactively managed or left alone to "manage itself" is another increasingly contentious issue among many stakeholders. Certain segments of an urbanized, wealthier, better-educated sector of American society increasingly view the killing of fish and wildlife by humans as unnecessary and undesirable (Muth and Jamison 2000). Preferences concerning the conservation and preservation of nature can take on moral and ethical dimensions. A growing body of literature suggests that environmental conflicts reflect social, cultural, emotional, and moral concerns. Components of the natural environment (e.g., fish, whales, old-growth forests) can be symbolic representations of broader sociocultural tensions, aspirations, and fears (Dietrich 1992, Taylor 1999, Muth and Jamison 2000). Thus, although existing laws and regulations often result in natural resource policy debates that focus on quantitative assessments of biological and economic criteria, in reality environmental disputes are also about complex social phenomena that include conflicting cultural constructions of nature (Dizard 1994, Scarce 2000).

Limulus polyphemus, therefore, can take on different meanings for each stakeholder group. For commercial horseshoe crab fishers, fishing for horseshoe crabs may represent not just income but also an occupational identity, a sense of self-sufficiency, and a means of maintaining social and community relationships. For the biomedical industry, horseshoe crabs may, in addition to generating income, represent a critical service to society. For shellfishers, horseshoe crabs may represent threats to self-sufficiency, an impediment to a recreational or central life interest, and a threat to the heritage associated with traditional coastal activities. Birdwatchers may view themselves as caretakers of the environment, and protecting horseshoe crabs may reflect this stewardship value. For others, this living fossil may be viewed as a cultural icon representing a coherence and stability that is absent in the rapidly changing modern world. The subconflict between nonconsumptive users (e.g., birdwatchers, ecotourists, and other environmentalists) and consumptive users (e.g., commercial fishers) may be an example of a conflict in which, because of different values and worldviews, the horseshoe crab does not represent the same resource to all stakeholder groups. Finding a middle ground in this type of conflict may be extremely difficult, but acknowledging that these conflicts involve more than just questions of biology and economics may help policymakers navigate these highly contested waters.

Third, natural resource conflicts may reflect socioeconomic class differences. Conflicts between birdwatchers and commercial horseshoe crab fishers may be grounded to some degree in this sphere. Birdwatchers are overwhelmingly middle class and upper middle class, and often have more formal education than commercial fishers. Although higher income and professional degrees do not signify a better understanding of natural resources, these sociodemographic characteristics may give environmentalists more influence within the policy arena. As another example, socioeconomic differences may affect the way the public evaluates the merits of biomedical versus bait-fishing claims for horseshoe crab harvest. Thus, the horseshoe crab conflict provides an opportunity to test hypotheses related to the role of science, social values, and social class. Although developing and implementing solutions to environmental conflicts can be very challenging, the first step must be to correctly diagnose the underlying causes of the conflicts. Simply developing more and better scientific information will be ineffective in resolving the conflict if the problem is really about a clash of social values.

Larger implications. Our conceptual framework has shown that the horseshoe crab is linked to larger human constituencies such as proponents of endangered species preservation, other commercial and recreational fisheries, and consumers and marketers of seafood (figure 6a). For example, people who have used medical products made safer by LAL tests far outnumber other stakeholders, even though most of them have never seen a horseshoe crab. By casting a wide net in describing horseshoe crab interactions, we have identified several larger issues that may affect this conflict (figure 6b). First, changes in tropical and arctic ecosystems may affect migratory bird populations as much as or more than horseshoe crab harvests. Second, global climate change can affect the entire coastal ecosystem. Third, a decline in other ocean fisheries can affect the profitability of commercial fisheries linked to horseshoe crabs. For example, the closure of Delaware Bay to commercial horseshoe crab fishers in the early 1990s caused the harvest pressure on horseshoe crabs to ripple up the coast. Fourth, changes in the economics or technology of LAL production could change the role of biomedical harvest in horseshoe crab allocation decisions. Fifth, coastal urbanization and alteration of beach habitat for horseshoe crab spawning could undo all of the conservation benefits of reduced harvest. Sixth, overharvest, disease, or eutrophication may have a greater effect on shellfish production than predation by carnivorous invertebrates. Finally, without greater efforts at conservation, human population growth may exacerbate all of these adverse impacts. Using our conceptual interaction model to identify these interconnections and their potential roles in allocation conflicts can help guide the search for policy alternatives and identify ways to track the consequences of different management scenarios.

Biosocial model. Conceptual frameworks of the type presented here can link policy decisions, stakeholder attitudes and values, institutional and regulatory considerations, and biophysical research so that more sophisticated models can be developed (Carpenter and Gunderson 2001). Many of the insights presented here were revealed only through the integration of biological and social scientific perspectives. The interactions between the biological and sociological features of this conflict strongly suggest that social scientists need to understand and appreciate the critical role biological science plays. At the same time, biologists and resource managers need to appreciate more fully that nonscientist stakeholders do not see biological reality as scientists do. Furthermore, intractable management problems can emerge when the legal basis for allocation decisions involves biological and economic criteria but the underlying causes of environmental conflicts are related to conflicting attitudes and values. If the sociological and biological features of a conflict are not concurrently addressed, the contested issues will be perpetually recast, often in the courts. For example, in the horseshoe crab allocation conflict in Massachusetts, the first publicly stated reason for the Massachusetts closures was based on the biological need to reduce horseshoe crab mortality (Kirchofer 2000, Lum 2001). When scientists showed that existing scientific data did not support this position, arguments in favor of closure shifted to the need to avoid lawsuits (Benjamin 2001, Fraser 2003). As this issue was addressed, questions about horseshoe crab taxonomy, interpretation of a colonial ordinance estab-

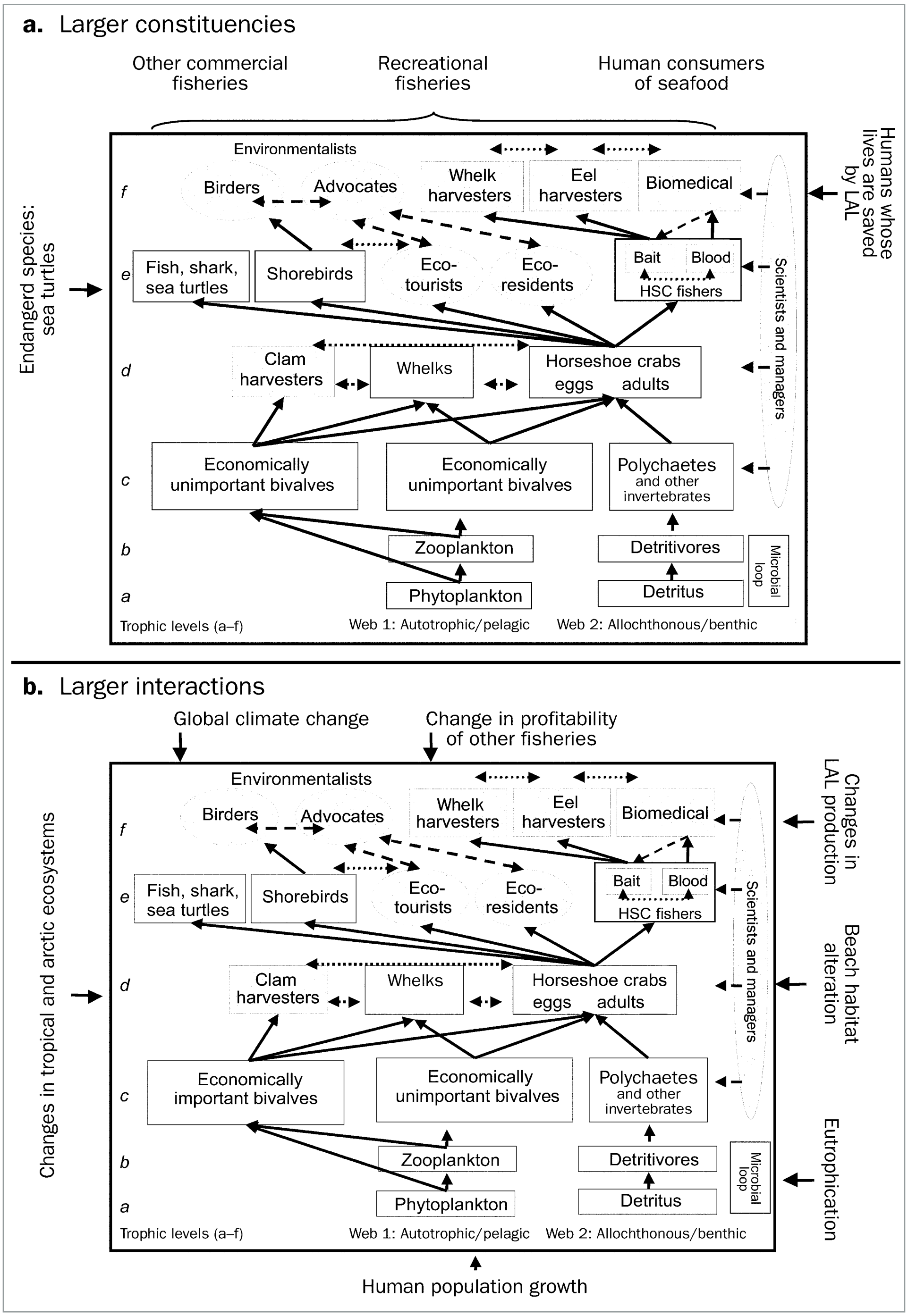

Figure 6. Larger (a) constituencies and (b) interactions related to stakeholders associated with the horseshoe crab allocation conflict. Abbreviation: LAL, Limulus amoebocyte lysate.

What have we learned? The biosocial interaction web approach has identified the major participants of allocation conflicts (i.e., birdwatchers, commercial fishers, the biomedical industry, different agencies), graphically portrayed their interactions, and helped identify the potential for future conflict (e.g., between shellfishers and among environmentalists). Use of this biosocial framework has provided several specific insights. First, the attitudes, values, and policy preferences of human stakeholders are neither monolithic nor static, even within those traditional constituencies often viewed as relatively homogeneous by managers and policymakers. Second, environmental conflicts can be about issues other than the specific resource in question, such as symbolic meanings of nature, socioeconomic class differences, or competing agency jurisdictions. Because tools for dispute resolution have higher probabilities for success when a basic agreement exists among the conflicting parties as to the object or substance of a conflict, a crucial step in understanding and addressing a conflict must be to identify what the resource represents to different stakeholder groups.

Third, additional sociodemographic information is needed. Just as scientists monitor key biological data, social attitudes and values need to be monitored to identify changes in how people perceive the resource, the extent to which they are aware of and understand relevant scientific data, and the values and positions of other stakeholders involved in the conflict. In addition, we need to better quantify the sociological

lishing agency jurisdiction over horseshoe crabs, and the enabling legislation that created Cape Cod National Seashore (Benjamin 2001) became pivotal. To prevent contested issues from forever eluding resolution, integrated interdisciplinary teams need to work continually to understand and reframe both biological and sociological issues as new information becomes available.

characteristics (attitudes, values, and demographics) of stakeholder groups, and better clarify the sociocultural and economic criteria on which allocation decisions are based. For example, if policymakers emphasize the importance of heritage subcultures and economic activities, their decisions will favor commercial fishing. If they instead emphasize the number of people who participate in horseshoe crab–related activities, the preferences of environmental and recreational groups will be considered most important. Fourth, since neither biology nor sociology alone can completely and accurately frame the complex environmental issues facing scientists, managers, and policymakers, an interdisciplinary team needs to evaluate and reframe each new development.

This biosocial analysis of the interactions between humans and the horseshoe crab system provides a generalizable approach for elucidating the underlying causes of a broad variety of environmental conflicts, because many of the biological, quantitative, stakeholder, and socioeconomic issues discussed here are common to other conflicts over exploited species. Although policymakers are fully aware of the complex nature of environmental conflicts and the institutional impediments to resolution, use of an integrated biosocial conceptual framework such as we have presented here, early in an environmental conflict and throughout the course of the conflict, can help identify issues, positions, interests, research questions, and information gaps. The resulting insights can help diagnose the causes of environmental conflicts and assist in designing a road map for their successful resolution.

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