Journal of Applied Ecology 2008, **45**, 296–304 doi: 10.1111/j.1365-2664.2007.01355.x

Ecological restoration and estuarine management: placing people in the coastal landscape

Michael P. Weinstein

New Jersey Marine Sciences Consortium, Sandy Hook Field Station, Building No. 22, Fort Hancock, NJ 07732, USA

Summary

1. Amid signs that estuarine ecosystems are increasingly degraded and may reach new thresholds of irreversible decline, restoration ecologists and coastal managers world-wide have joined the debate on how best to reverse the trends of the recent past.
2. Any meaningful effort at reversal must, however, recognize that humans are an integral part of the landscape, particularly in urban estuarine settings, and that natural resource baselines have permanently shifted. Consequently, the human dimensions component of sustainability science has become an integral part of ecological restoration/rehabilitation planning, and new schema evolving out of coastal governance and management are not only increasingly underpinned by transdisciplinary science, but are beginning to address the sacrifices and compromises that will be necessary to achieve a balance between human uses of estuarine resources and biotic integrity.
3. The challenge will be to preserve ecosystem functions and use natural capital at a variety of scales while simultaneously sustaining local communities, social and formal institutions, economies and markets at the highest levels of system organization.
4. How we manage competing uses while at the same time preserving the dynamic properties and resilience of ecosystems will be a significant test. Current ecosystem management and restoration goals appear to be weighted towards returning and/or preserving natural functions decoupled from system reliability. In human-dominated systems, however, they should be redirected towards goals and mandates to rehabilitate the functions associated with service reliability.
5. *Synthesis and applications*. If we are to avoid the harsh lessons of the utilization of terrestrial resources, scientists, practitioners and coastal managers will have to find a middle ground between continued economic growth and preservation/conservation of coastal resources. Success will require broad acceptance that humans are as coastally dependent as any part of the biota, and that future plans for managing, restoring and/or rehabilitating estuarine ecosystems must recognize that humans occupy the highest level of the ecological–cultural landscape.

Key-words: ecological restoration, estuarine types, human density in the shore zone

Introduction

> 'It seems to me that the nature of true tragedy is when something is so badly broken that with the best will in the world, you can't put it back together again and what was broken has to stay broken'
>
> (Salman Rushdie, 29 August 2005).

Amid signs that coastal ecosystems are increasingly 'broken' and may reach new thresholds of irreversible decline, restoration scientists and coastal managers world-wide have joined the debate on how best to reverse the trends of past centuries. But whether in the form of restoration and/or rehabilitation, repair of damaged ecosystems will ultimately require maintenance of ecological functions across regional settings where humans often dominate (Brunckhorst 2002). The challenge is to sustain these functions and use natural capital at a variety of scales while simultaneously sustaining local communities, social and formal institutions, economies and markets at the highest levels of ecological–cultural organization (Brunckhorst 1998, 2002; Naveh 2005).

These are not necessarily new ideas. Restoration practices often include a cultural fabric, so much so that recent emphasis has focused on resolving the 'two-culture' conflict, i.e. distinguishing between the need for scientific rigor and the broader outcomes of restoration based on societal perceptions

Correspondence: Michael P. Weinstein, New Jersey Marine Sciences Consortium, Sandy Hook Field Station, Building No. 22, Fort Hancock, NJ 07732, USA. Fax 732 872 9573; e-mail mweinstein@njmsc.org

and desires (Cairns, Dickson & Herricks 1975; Cairns 1995; Weinstein *et al*. 2001; Gross 2002; Higgs 2005; Swart & van Andel 2007; Van der Windt & Swart 2007). Without sufficient consideration of human needs, along with ecological functions, ecologists will miss an important constituency if the role of humans in ecosystems is ignored or minimized (McDonnell & Pickett 1993). But to achieve this balance the 'paradox of the dual mandate' must be resolved: whereas high levels of complexity, uncertainty and dynamicism, traits that prevent competitive dominance, sustain the biotic integrity of natural ecosystems, human-dominated ecosystems must be predictable and stable in order to buffer core technologies and human safety against the vicissitudes of nature (Roe & van Eeten 2001, 2002; Weinstein *et al*. 2007). The challenge is to reconcile society's desire to conserve, preserve, restore and rehabilitate ecosystems and their concomitant natural variability, complexity, resilience and biodiversity while ensuring the reliable and predictable provision of goods and services from the very same systems.

It has taken time, but there seems to be increasing acceptance that humans are a major force in ecosystem evolution and, for better or worse, we are here to stay (Brunckhorst 2002; McMichael, Butler & Folke 2003; Weinstein & Reed 2005). Thus any realistic attempts to restore/rehabilitate coastal ecosystems at a landscape scale must confront the paradox, and establish goals concomitant with human dominance and the needs of other parts of the biota. Success may rest in partitioning (zoning) these systems into categories weighted towards human uses (the anthropocentric component) and/or towards the conservation and/or preservation of lesser disturbed systems, or parts thereof (the ecocentric component; Weinstein & Reed 2005; Weinstein 2005).

This paper explores the linkages between ecological restoration and emerging tools of ocean governance and conflict resolution as interactive components designed to restore/rehabilitate coastal ecosystems in a human-dominated world. It is suggested that the criteria for restoration/rehabilitation of estuarine habitats rest not only on sound scientific principles and cultural values but are carried out with different goals, depending on the degree of human uses. Attempts have been made to extend earlier work (Weinstein & Reed 2005; Weinstein *et al*. 2007) by (i) defining preliminary boundaries for distinguishing estuarine types that will result in different restoration/rehabilitation goals, and (ii) presenting a conceptual scheme for 'weighting' the restoration/rehabilitation endpoints based upon proportionate combinations of ecocentric and anthropocentric criteria.

COASTAL RESTORATION/REHABILITATION IN AN ECOSYSTEM-BASED MANAGEMENT FRAMEWORK

Ecosystem-based management (EBM) is an approach that reflects the relationships among all ecosystem components, including humans within the biota and the environments in which they live, and it has recently emerged as a guiding principle of new ocean policy in the US and elsewhere (US Commission on Ocean Policy 2004). By placing humans in the landscape within the broader context of the biological and physical environment, EBM ultimately combines ecology and human dimensions into 'society integrated' or transdisciplinary ecosystem management (Wilson 1992; Naveh 2002, 2005; Convention on Biological Diversity 2005). As scientific understanding of ecosystem processes, and the underlying role of variability in maintaining the resilience of ecosystems (that might otherwise descend irreversibly into degraded states; Holling 2000), has improved in the past several decades, emerging management approaches can begin to conform more closely to ecological vs. political constraints.

If we are to embrace EBM or any other management scheme, it will be necessary to address a particularly conscious-raising comment on page 66 of the US Commission on Ocean Policy (2004) report: 'Where multiple desirable but competing objectives exist, it is not possible to maximize each'. This warning is repeated in the seminal paper by Kates *et al*. (2001), 'it will also require fundamental advances in our ability to address such issues [competing interests] ... as the responses, *some irreversible* [emphasis added], of the nature-society system to multiple and interacting stresses'. Thus it is simply not practical, or even rational, to assume that we can maximize all competing uses in a way that will satisfy all stakeholders. Nor can we ignore the differential economic and political powers that enter into the human equation, clearly a substantial obstacle to consensus governance of the coastal zone. I do not pretend to have an answer to this issue, but simply suggest that it must be confronted if true progress is to be made in coastal sustainability.

THE HUMAN DIMENSIONS OF NATURAL RESOURCE MANAGEMENT

While ecological considerations are essential, the ultimate success of restoration/rehabilitation practices will rest on societal values, fundamentally a human endeavour. The political–jurisdictional, economic and social–cultural systems collectively make up what is referred to as the human dimensions of natural resource management. However, natural resource values originate and are endorsed in one system only: the social system (Salz & Loomis 2005). These values are then expressed to natural resource managers and society through the political, economic and judicrary systems. In turn, they are expressed as environmental laws, congressional budgets, volunteerism, voting behaviour, etc., which largely determine the fate of the natural systems that sustain us.

Following norms discussed by Callicott, Crowder & Mumford (1999), I have proposed that estuaries (either in their entirety or in part) be restored/rehabilitated and managed along a spectrum ranging from humans as an integral part of the landscape, no less natural than any other species, in a functionalist approach, to the compositionalist ideal of humans apart from nature in self-sustaining systems that experience few, if any, extractive uses (Weinstein & Reed 2005). Ecosystem-operating principles in the two paradigms are separated along a spectrum that ranges from the compositionalists' (ecocentrists') evolutionary ecology ideal, organisms aggregated into populations whose ecosystem currency takes the form of biotic integrity (Angermeier & Karr 1994) and biodiversity, to the functionalists' (anthropocentrists') ecosystem health, a process-orientated thermodynamic regime where energy flux through a physical system not necessarily limited to the biota governs the well-being of the ecosystem (Odum 1995; Callicott, Crowder & Mumford 1999).

The nuances in DeLeo & Levin (1997) notwithstanding, the terms ecosystem health and biological integrity are also used here to distinguish the desired restoration endpoints in systems, which range from human dominated to those with minimal human intrusion. Similarly, Weinstein (2005) and Weinstein & Reed (2005) used the term restoration to describe practices that attempt to return ecosystems to some optimum level of biological integrity (Angermeier & Karr 1994) or closer to the historic condition (NRC 1992) while the term rehabilitation was applied to human-dominated estuaries where the goal was to return degraded/altered portions of the system to a renewed state of ecosystem health (Callicott, Crowder & Mumford 1999).

Spectrum of estuarine types

Weinstein & Reed (2005) suggested that estuaries should be managed along a continuum determined by human population density, levels of anthropogenic disturbance (the 'human footprint'), reliability in the goods and services provided, and/or by the degree of self-organization and dynamic nature (Van der Windt, Swart & Keulartz 2006). While any estuary may provide benefits to local communities, settlement patterns and industrial and commercial land uses must necessarily constrain the baselines for restoration/rehabilitation or sustainable development goals, as well as identifying the appropriate level of extractive uses that an estuarine environment can support. Clearly, the clock cannot always be set back, and realistic baselines must be established at a post-industrial starting point. On this basis, Weinstein & Reed (2005) have previously categorized estuaries into three distinct types.

URBAN–INDUSTRIAL ESTUARIES

These are systems where physiography and geological setting support intense human uses and populations, principally for living space, navigation, marine transportation and commercial activity related to port commerce, energy production and other water intensive uses. Because ecological baselines have shifted dramatically in urban–industrial estuaries, concomitant losses in habitat and biodiversity are probably irreversible. Consequently, management priorities in urban–industrial systems focus on reliability criteria (Roe & van Eeten 2002) imposed by the need for predictable navigation depths, stable shorelines and berthing areas, cost-effective methods for dredged material management, transportation infrastructure and storage facilities, and managing species adapted to human colonization (Swart, Van der Windt & Keulartz 2001). This approach does not necessarily mean that ecosystem health is sacrificed; rather, contaminant source control, suitable sediment and water quality, and the human endeavours to address them are equally as important to sustaining commercial activity as they are to the well being of extant biota. Concomitant restoration/biotic integrity goals in developing policy for management of urban-industrial estuaries include the conservation and preservation of remnant critical habitat (proximate reservoirs of biodiversity; Callicott, Crowder & Mumford 1999) and rehabilitation of other habitats that support species co-adapted to the presence of humans.

PRODUCTION ESTUARIES

These systems have a dominant ecosocietal service that is vested in sustainable harvest or culture of estuarine-dependent species. These estuaries support, or recently supported, extensive commercial and recreational fisheries and/or aquaculture. Human population density is moderate. In such areas, priority is given to restoration/rehabilitation and fishery optimization approaches that focus on habitat or other factors directly affecting economically and/or culturally important fish and shellfish production. Ecosystem management would incorporate the use of artificial reefs, by-catch reduction methods, turtle excluder devices and crop rotation techniques to allow the live bottom to recover from fishing gear impacts. Other important societal uses include recreation, education, ecotourism and landscape aesthetics.

CONSERVATION ESTUARIES

These are largely undisturbed, self-sustaining systems with minimal human population density and virtually no human extractive uses. Nature and culture are largely separated, and natural processes and high levels of uncertainty dominate (Swart, Van der Windt & Keulartz 2001). Estuarine reserves are an example of conservation estuaries in the USA. Currently small in extent, they support non-consumptive uses on a moderate scale, such as research, education and ecotourism and/or provide aesthetic and cultural benefits to both local communities and society as a whole. In these areas priority is given to conservation and restoration efforts focused on habitats that support finfish and shellfish and wildlife, including endangered and threatened species, migratory birds and resident species of the estuary.

SHORELINE CATEGORIZATION

Using three estuaries in New Jersey, USA, as examples, human activities and density in the landscape were used as the principal metrics for distinguishing estuarine types. A modified version of the US National Oceanographic and Atmospheric Administration's (NOAA) environmental sensitivity index (ESI) maps (NOAA 2000) was applied to the characterization of three New Jersey embayments, New Jersey/New York Harbor, Barnegat Bay and the estuarine portion of Delaware Bay, according to human density in the shore zone and anthropogenic influence in the form of built shoreline (modifications as a result of human activity). ESI maps are useful because they are constructed from digital databases using geographical information system (GIS) layers that are compiled in a

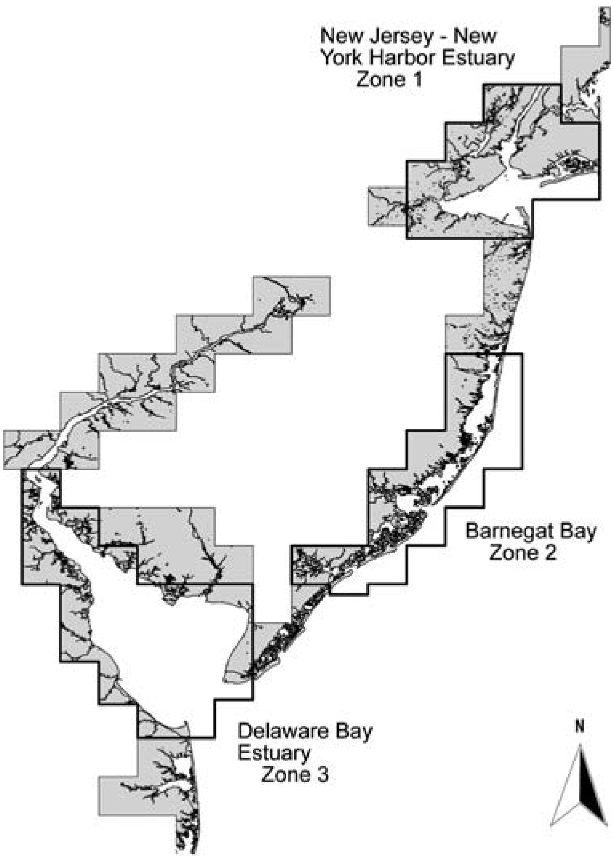

Fig. 1. Environmental sensitivity maps (ESI), outlined in bold, used to categorize the human footprint on New Jersey–New York Harbor, Barnegat Bay and Delaware Bay, USA.

standard format for assessing shoreline sensitivity (to disturbance), biological resources and human-use resources (NOAA 2000). They are also useful for distinguishing the human footprint in the coastal zone, an anthropogenic feature that was chosen as the frame of reference for the broad definitions used in this paper.

ESI base maps were compiled from US Geological Survey (USGS) 7·5-minute quadrangles at a scale of 1 : 24 000. Shoreline classifications contained water and land features depicted as polygons, and narrow rivers and streams displayed as polylines. Forty-seven individual ESI maps (Fig. 1) were used to characterize the shorelines of the three New Jersey estuaries: 14 for the New Jersey/New York Harbor, 16 for Barnegat Bay and 17 for the Delaware Bay estuary. For ease of illustration, the original 28 estuarine shoreline classifications developed for the ESI maps (NOAA 2002) were reduced to three categories to reflect human-made vs. natural physiographic features. In some cases, categories were eliminated that were not relevant to New Jersey, in other instances categories of shoreline types (e.g. beach categories) were combined.

HUMAN DENSITY IN THE SHORE ZONE

Population census data from relevant cities, towns and villages were sorted by watershed known to drain into a particular estuary. In this way population data from counties bordering more than one estuary could be separated, minimizing 'misclassification' of data. Weighted averages of the census data were then calculated for each embayment:

$$\bar{X}_w = \frac{\sum W_i X_i}{\sum W_i}$$

where X_w is the weighted mean, X_i the census data (density km^{-2}) and W_i the incorporated land area; i.e. village, town or city.

ANALYTICAL RESULTS

In an earlier paper, Weinstein & Reed (2005) commented that the three estuarine types are simply punctuations of a continuum, and consciously made the borders between estuarine types appear as diffuse rather than as sharp boundaries. But this does not preclude the need for placing bounds on the three estuarine types for management purposes. Weinstein & Reed (2005) also noted that individual estuaries, such as Chesapeake Bay, might contain elements or significant areas of more than one estuarine type. To begin to capture the scale of the human footprint in each system, we chose to quantify physical structures that were either natural features of the environment (minimally disturbed by humans) or constructed by humans to ensure the stability and reliability of ecosystem goods and services (Table 1). From a management and consensus building perspective (including determining restoration/rehabilitation goals), these results on human construction in the shore zone gave us an initial distinction among estuarine types.

Although much of the fresh portion of the upper Delaware tidal estuary is occupied by two sizeable cities, Wilmington, Delaware, and Philadelphia, Pennsylvania, and their associated industry, including petroleum distribution and port commerce, the physiographic signature of these urban settings is minimally felt in the estuary proper (for purposes of this paper demarcated by Marcus Hook, Pennsylvania, at river kilometre 130). The saline portion of the Delaware Bay estuary remains ringed by a nearly continuous tract of tidal wetlands that occupy more than 88% of the estuary shoreline (Fig. 2). Moreover, < 9% of the total shoreline in the estuary is armoured, and the population density in the coastal zone, 1308 individuals km^{-2}, is only about 9% that of the New York, New York, metropolitan area (Table 1). Not surprisingly, with its largely suburban shoreline, Barnegat Bay falls intermediate between the other two, with more than 57% of the shore occupied by wetlands and armouring occurring on slightly more than one-third of the shore zone. There are also striking anthropogenic influences on subtidal lands of the three estuaries, for example the density of dredged primary channels (not including tributary channels, canals, berthing areas and turning basins) in New Jersey–New York Harbor is about 2·1 and nine times greater, respectively, than in Barnegat Bay and Delaware Bay (Table 1). Although not quantified in this study, the extent of fill (to create fast land) in the Harbor and upper Barnegat Bay

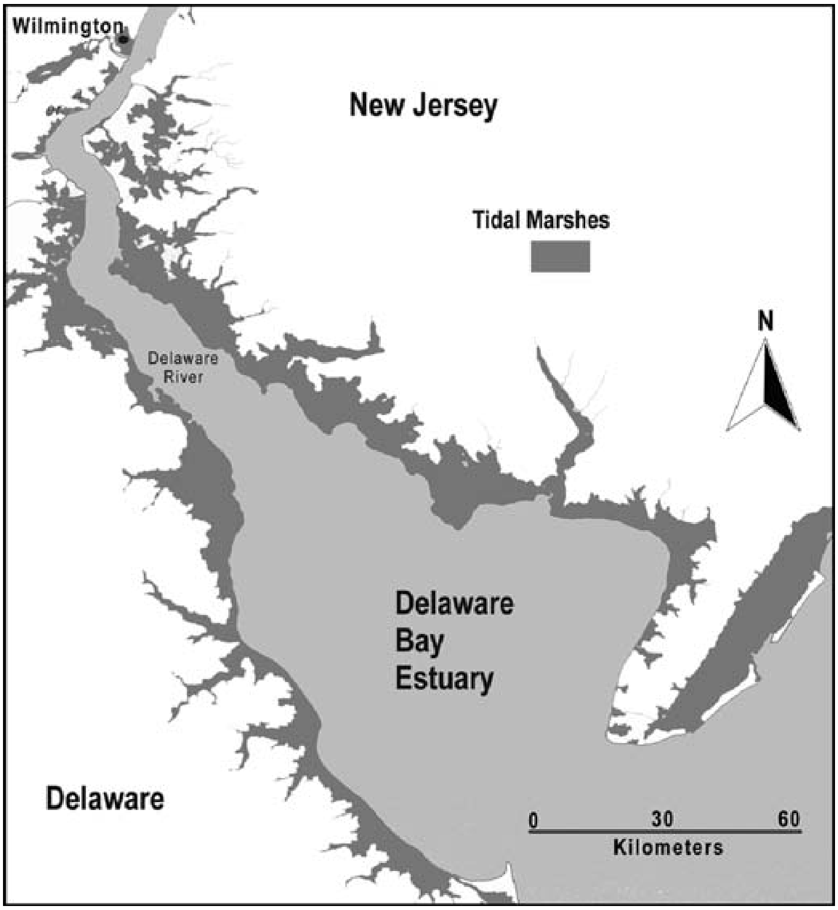

Fig. 2. Tidal salt marshes of the Delaware Bay estuary that form a nearly continuous fringe surrounding the Bay.

Table 1. Comparison of three estuarine types based on natural and human parameter components extracted from environmental sensitivity maps (ESI) (NOAA 2002) and USA population census data

	'Natural' components (% total shoreline)			'Human' components		
Estuary	Tidal marshes	Beaches and other Natural features	Armoured shoreline	Population density (km^{-2})	Area (km^2)	Dredged channels (km km^{-2})
New Jersey–New York Harbor	49·2	5·5	45·3	14 587	570*	0·68
Barnegat Bay	57·3	8·0	35·0	2 562	167	0·33
Delaware Bay	88·2	3·1	8·7	1 308	1600†	0·08

*C. Yuhas, technical co-ordinator, Harbor Estuary Program, personal communication.
†NOAA (1990); Sutton, O'Herron & Zappalorti (1996).

is far more extensive than in Delaware Bay and generally mirrors that of armoured shoreline in the three estuaries (Table 1).

What is not shown in Table 1, however, are influences of human occupation in terms of invasive species, contaminant releases, wastewater loadings and other environmental effects of human activity. In Delaware Bay, for example, approximately 32 000 ha of the brackish wetlands in the upper portion of the Bay have experienced degradation because of an invasive variety of *Phragmites australis*, the M-haplotype (Saltonstall 2002; Weinstein, Litvin & Guida 2005) that has created large areas of monoculture and has negatively affected biodiversity and habitat quality (Weinstein & Balletto 1999; Weinstein *et al.* 2003). The same is true of the New Jersey–New York Harbor, where *P. australis* overwhelms native flora over much of the remaining tidal marsh tracts. In Barnegat Bay, on the other hand, most human occupation occurs in the northern half of the estuary, and while the lower Bay not only contains the majority of tidal wetlands, sufficiently saline to retard the spread of *P. australis*, it is also bordered by the Pinelands National Reserve, which protects more than 445 000 ha of the region from new human development.

The US Environmental Protection Agency's *National Coastal Condition Report* on USA coastal embayments (USEPA 2001) suggests that all three estuaries suffer from varying degrees of contaminant loadings in the form of metals, organics and nutrients. In general, north-east estuaries (Maine to Virginia) are listed as 'border-line poor' (USEPA 2001). While New Jersey–New York Harbor, particularly the Raritan Bay in New Jersey, has demonstrable degradation in the form of contaminant loadings, sediment toxicity and fish tissue contaminant levels, Barnegat Bay, although less subjected to contaminant stressors, is impacted by eutrophication and harmful algal blooms that appear to plague the system, particularly the southern less-populated reaches (Fig. 1). Similarly, fish consumption advisories occur in all three estuaries, partly as a result of movement patterns of highly migratory coastal species. Unlike New Jersey–New York Harbor and Barnegat Bay, much of the contaminant loadings to Delaware Bay originate upstream in the tidal fresh portion of the river (associated with the Wilmington and Philadelphia region), with levels generally much lower in the Bay proper. Thus contaminant levels and distribution in New Jersey–New York Harbor are far higher and more pervasive than in the other two systems.

Discussion and conclusions

A burgeoning literature has developed regarding sustainability science, ecological management, ecological restoration/rehabilitation and ecological economics in response to real and perceived impacts of humans on their environment. Although most can agree that action should be taken, the uncertainties and lack of standard nomenclature have reinforced the 'us vs. them' psyche and has retarded real progress (DeLeo & Levin 1997; Weinstein *et al*. 2007). The problem is not just ecological or economic or social, it is a combination of all three; and although actions to integrate them are currently underway, Holling (2000) suggests that one or more are always short-changed in attempts to build consensus. He rightly calls for an integrated theory that recognizes the synergies and constraints among nature, economy and communities, a theory that at once informs and derives from thoughtful practice.

If we are not to repeat the harsh lessons learnt on land, restoration practitioners will have to find a middle ground between economic growth and the sustainability of coastal resources (Hardin 1968). It will require broad acceptance that humans are as coastally dependent as any other part of the biota (Schubel & Hirschberg 1978) and that future plans for restoring and/or rehabilitating most estuarine ecosystems must recognize that humans occupy the highest level of the ecological–cultural landscape (Naveh 2005). Moreover, the human dimensions of sustainability and restoration science (Kates *et al*. 2001; Salz & Loomis 2005) must become an integral part of the ecological restoration process (vs. restoration ecology as a separate component of it; Higgs 2005).

All of this is reflected in the global call for sound ocean policy that requires managers to simultaneously consider the economic requirements of society, the need to protect the world's oceans and coasts, and the interplay among social cultural, economic and ecological factors. Yet the goal may not be to manage entire ecosystems *per se* (a daunting challenge whatever the current state of knowledge) but to manage people's behaviour as a means of achieving sustainable goals and objectives in coastal restoration and management (NMFS 1999). The desired outcome of any ecosystem approach is not only to restore and rehabilitate the health, productivity and biodiversity of ecosystems but also the overall quality of human life through a resource management approach that is fully integrated with social and economic goals.

Because growing human presence and demands on coastal living space and resources can no longer be met by access to new unexploited resources, consensus building through sacrifice and compromise will become the norm. Today's multiple stresses in the coastal zone require restoration practices that take into account conflicting goals and linkages among the network of environmental issues (Ayensu *et al.* 2003). These authors suggest further that an integrated, predictive and adaptive approach to ecosystem restoration and management will require three categories of information: (i) baseline data and analysis on ecosystem state, and reliable estimates of the amount, economic value and condition of goods and services, provided on a site-specific basis; (ii) data on trends in goods and services that are determined by natural and anthropogenic influences at site-specific locations, made available to decision-makers and the public and private sectors; and (iii) integrated regional models that incorporate these influences and address economic and technological change. Using these tools (and others), scientists, along with representatives from all levels of government, and the stakeholder community will have to find a common voice to advance ecological restoration goals (Weinstein 2005; Weinstein *et al*. 2007).

Baselines have clearly shifted among the three estuaries examined in this study along a gradient New Jersey–New York Harbor > Barnegat Bay > Delaware Bay. Moreover, the ability of these systems to support biotic integrity has been degraded to a greater or lesser extent by habitat loss and alteration in both the intertidal (filling of wetlands and flats and shoreline armouring) and subtidal (deepening doe marinas, berthing areas and turning basins, armouring, channel dredging, artificial reef construction, changing bottom topography, tidal excursion and hydrodynamics and altered sediment composition) zones. Among the three systems investigated, the saline portion of Delaware Bay appears to be the least disturbed and might best be managed as a conservation estuary, or possibly even as a ecology managed area (Weinstein & Reed 2005), using current norms (Table 2) (NRC 2001a). For the port of New Jersey–New York to stay competitive in a global market place that will see waterborne commerce nearly triple by the end of the century (National Ocean Conference 1998), new sacrifices may be required that include navigation channel deepening, in-water expansion (fill) of docking and storage space and the relaxation of environmental windows for dredging (NRC 2001b). On the other hand, attempts must be made to restore and conserve remaining wetlands to serve as source habitats for species adapted to human colonization (Weinstein & Reed 2005).

How we manage competing uses, and make the necessary compromises and sacrifices to achieve consensus, while at the same time preserving, to the extent practical, the dynamic

Table 2. Goals, priorities and trade-offs for restoring/rehabilitating degraded estuarine landscapes based on human density in the shore zone

	Delaware Bay estuary	Barnegat Bay estuary	New Jersey–New York Harbor
Estuarine Type (from Weinstein & Reed 2005)	Conservation–production	Production	Urban–industrial
Restoration/rehabilitation goals	Biotic integrity, biodiversity; populations of finfish and shellfish	Recreational and commercial fish populations	Ecosystem health; rehabilitation and conservation of remnant habitats; reliability of ecosystem goods and services
Management priorities	Oyster restoration; sustainable oyster fishery and aquaculture; sustainable recreational fishery; upstream source control on contaminant influx; source control at local 'hotspots'	Development of hard clam and possibly finfish aquaculture; sustainable recreational fishing; boating and ecotourism; nutrient reduction	Source control for contaminants improving clean water/clean sediments; managing species adapted to human colonization
Ecosystem-based management priorities	Ecology-managed area; marine-protected areas (MPA)?	Ecology/commerce-managed areas	Commerce-managed area
Potential ecosystem-based 'sacrifices and compromises'	Permanent bay-wide ban on horseshoe crab fishery; restrictions on short sea shipping and lightering; restrictions on channel deepening; permanent conservation easements on all wetlands; restoration of degraded wetlands to near historic conditions; wide riparian buffers; mandatory riparian buffers on watershed tributaries; ban on wetland impoundments; limitations on aquaculture, mandatory restrictions on population density and industrialization in the New Jersey CAFRA (Coastal Area Facility Review Act) zone	Expansion of aquaculture and leasing of underwater lands; zoning to protect submerged aquatic vegetation; landward buffer easements to discourage further development	Designated shoreline fill areas for port expansion (loss of benthic habitat); relaxation of environmental windows for dredging; return to ocean disposal of dredged sediments; preservation and conservation of remnant habitats (wetlands, tidal flats); reduced biodiversity and biotic integrity (managing species adapted to human colonization)

properties and resiliency of ecosystems will be the greatest test of our human mettle. There will be no quick or easy fixes, but at least we can strive for better balance in the managing of human-dominated ecosystems. Current ecosystem management and restoration goals appear to be weighted towards returning and/or preserving natural functions (Swart, Van der Windt & Keulartz 2001), decoupled from system reliability. In human-dominated systems, however, they should be redirected towards goals and mandates to rehabilitate the functions associated with service reliability (Roe & van Eeten 2002) or, as Botkin (1990) commented, 'we must focus our attention on the rates at which changes occur, understanding that certain changes are natural, desirable and acceptable, while others are not'. The trick will be to reduce stochasticity and improve reliability while avoiding shifts to a new baseline that pushes the system too far from the natural state (causing fragility and undesirable economic or ecological effects; DeLeo & Levin 1997). A potential scheme for an integrated approach to meeting restoration/rehabilitation goals is shown in Table 2 and Fig. 3. Critical to the paradigm is the realization that restoration/rehabilitation goals should evolve in a framework of both ecology and commerce management proportional to human dominance (Table 2; Weinstein & Reed 2005). This is demonstrated in the overlapping nature of each trapezoid in Fig. 3; there is no instance where both evolving

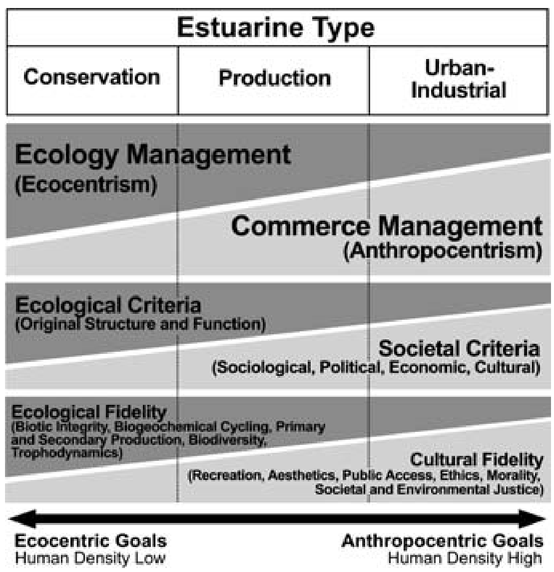

Fig. 3. A conceptual management scheme for restoration/rehabilitation of degraded estuarine ecosystems based upon human domination of the landscape. Defining characteristics of the three estuarine types appear in the text. The proportion of each management criterion applied depends on the type of estuary in question, and a series of drivers defined by ecological and/or societal criteria and the level of ecological and/or cultural fidelity desired.

ecology and commerce management practices and policies are not used to manage an estuary, no matter how pristine or human-dominated each may be. Furthermore, sacrifice and compromises must be accommodated across the spectrum of restoration and maintenance activities whether they favour predictability or far-ranging system dynamics, as suggested in the last row of Table 2.

Managers should also realize that many coastal ecosystems comprise mosaics of ecology and commerce-managed areas, and should be zoned accordingly (Weinstein & Reed 2005). Finally, as noted earlier, I am not suggesting that zoning for commerce and human living space sacrifices ecosystem health or extirpates biotic integrity in urban–industrial estuaries; on the contrary, contaminant source control, suitable sediment and water quality are just as important to sustaining human endeavours as they are to the well-being of extant biota, and the concomitant rehabilitation, conservation and preservation of critical habitat as proximate reservoirs of biodiversity (Callicott, Crowder & Mumford 1999) and as habitats that support species co-adapted to the presence of humans (Swart, Van der Windt & Keulartz 2001). The 'sacrifice' in the latter instance is that restoration and/or rehabilitation practices should not be targeted to the historical condition (NRC 1992; Hildebrand, Watts & Randle 2005) but towards a baseline that is at once practical and realistic given the density of human presence and needs.

Acknowledgements

I thank S. Haag, A. Homsey, J. Gebert, R. Lathrop, J. Pace and J. Peterson for assistance in extracting specific data layers from the ESI base maps and/or for providing other source data to construct Table 1. Comments by S. Levin, J. A. A. Swart, J. Keulartz, H. Van der Windt, M. Gross and anonymous referees improved earlier drafts of the manuscript. I am also grateful to J. A. A. Swart for the invitation to present this paper at the World Conference on Restoration, SER, Zaragosa, Spain. This is contribution No. NJSG-06-623 of the New Jersey Sea Grant College Program. The content and ideas presented herein are solely mine and do not necessarily reflect the opinion of the individuals noted and/or their agencies.

References

Angermeier, P.L. & Karr, J.R. (1994) Biological integrity versus biological diversity as policy directives. *Bioscience*, **44**, 690–697.

Ayensu, E. & 24 co-authors (2003) International ecosystem assessment. *Science*, **286**, 685–689.

Botkin, D.B. (1990) *Discordant Harmonies: A New Ecology for the 21st Century*. Oxford University Press, New York, NY.

Brunckhorst, D.J. (1998) Guest editorial. Creating institutions to ensure sustainable use of resources. *Habitat International*, **22**, 347–354.

Brunckhorst, D.J. (2002) Institutions to sustain ecological and social systems. *Ecological Management and Restoration*, **3**, 108–116.

Cairns, J. Jr (1995) Ecosocietal restoration: re-establishing humanity's relationship with natural systems. *Environment*, **37**, 4–33.

Cairns, J. Jr, Dickson, K.L. & Herricks, E.E. (1975) *Recovery and Restoration of Damaged Ecosystems*. University Press of Virginia, Charlottesville, VA.

Callicott, J.B., Crowder, L.R. & Mumford, K. (1999) Current normative concepts in conservation. *Conservation Biology*, **13**, 22–35.

Convention on Biological Diversity (2005) *Handbook of the Convention on Biological Diversity*, 2nd edn. Secretariat of the Convention on Biological Diversity, Transcontinental Printing, Montreal, Canada.

DeLeo, G.A. & Levin, S. (1997) The multifaceted aspects of ecosystem integrity. *Conservation Ecology*, **1**, 1–12.

Gross, M. (2002) New natures and old science: hands-on practice and academic research in ecological restoration. *Science Studies*, **15**, 17–35.

Hardin, G. (1968) The tragedy of the commons. *Science*, **162**, 1243–1248.

Higgs, E. (2005) The two-culture problem: ecological restoration and the integration of knowledge. *Restoration Ecology*, **13**, 159–164.

Hildebrand, R.H., Watts, A.C. & Randle, A.M. (2005) The myths of restoration ecology. *Ecology and Society*, **10**, 19–29.

Holling, C.S. (2000) Theories for sustainable futures. *Conservation Ecology*, **4**, 7–13.

Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C., Lowe, I., McCarthy, J.J., Schellnhuber, H.J., Bolin, B., Dickson, N.M., Faucheux, S., Gallopin, G.C., Grübler, A., Huntley, B., Jäger, J., Jodha, N.S., Kasperson, R.E., Mabogunje, A., Matson, P., Mooney, H., Moore, B. III, O'Riordan, T. & Svedin, U. (2001) Sustainability science. *Science*, **292**, 641–642.

McDonnell, M.J. & Pickett, S.T.A. (1993) *Humans as Components of Ecosystems. The Ecology of Subtle Human Effects and Populated Areas*. Springer-Verlag, New York, NY.

McMichael, A.J., Butler, C.D. & Folke, C. (2003) New visions for addressing sustainability. *Science*, **302**, 1919–.

National Marine Fisheries Service (NMFS) (1999) *Ecosystem-Based Fisheries Management. A Report to Congress by the Ecosystems Principles Advisory Panel*. US Department of Commerce, Silver Spring, MD.

National Ocean Conference (1998) *Proceedings*. Oceans of Commerce, Oceans of Life Naval Post Graduate School, Monterey, CA.

National Research Council (NRC) (1992) *Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy*. National Academy Press, Washington, DC.

National Research Council (NRC) (2001b) *A Process for Setting, Managing, and Monitoring Environmental Windows for Dredging Projects*. National Academy Press, Washington, DC.

National Research Council (NRC) (2001a) *Marine Protected Areas: Tools for Sustaining Ocean Ecosystems*. National Academy Press, Washington, DC.

Naveh, Z. (2002) A transdisciplinary education program for regional sustainable development. *International Journal of Ecology and Environmental Sciences*, **28**, 167–191.

Naveh, Z. (2005) Epilogue: towards a transdisciplinary science of ecological and cultural landscape restoration. *Restoration Ecology*, **13**, 228–234.

National Oceanic and Atmospheric Administration (NOAA) (1990) *Estuaries of the US, Vital Statistics on a National Resource Base*. US Department of Commerce, NOAA, Washington, DC.

National Oceanic and Atmospheric Administration (NOAA) (2000) *US Delaware, New Jersey and Pennsylvania Environmental Sensitivity Index Files*. National Ocean Service, Office of Response and Restoration, Silver Spring, MD.

National Oceanic and Atmospheric Administration (NOAA) (2002) *Environmental Sensitivity Index Guidelines, Version 3*. NOAA Technical Memorandum Nos OR and R11. Hazardous Materials Response Division, National Ocean Service, Seattle, WA.

Odum, H.T. (1995) *Environmental Accounting, Energy and Environmental Decision Making*. John Wiley & Sons Inc., Hoboken, NJ.

Roe, E. & van Eeten, M. (2001) Threshold-based resource management: a framework for comprehensive ecosystem management. *Ecological Applications*, **27**, 195–214.

Roe, E. & van Eeten, M. (2002) Reconciling ecosystem rehabilitation and service reliability mandate in large technical systems: findings and implications of three major US ecosystem management initiatives for managing human-dominated aquatic-terrestrial ecosystems. *Ecosystems*, **5**, 509–528.

Saltonstall, K. (2002) Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis*, into North America. *Proceedings of the National Academy of Sciences USA*, **99**, 2445–2449.

Salz, R.J. & Loomis, D.K. (2005) Human dimensions. *Science-Based Restoration Monitoring of Coastal Habitats* (eds G.W. Thayer, T.A. McTigue, R.J. Salz, D.H. Merkey, F.M. Burrows & P.F. Gayaldo), pp. 1–67. Decision Analysis Series No. 23, Vol. 2. US Department of Commerce, Coastal Ocean Program, Silver Spring, MD.

Schubel, J.R. & Hirschberg, D.J. (1978) Estuarine graveyards, climate change, and the importance of the estuarine environment. *Estuarine Interactions* (ed. M. Wiley), pp. 285–304. Academic Press, New York, NY.

Sutton, C.C., O'Herron, J.C. & Zappalorti, R.T. (1996) *The Scientific Characterization of the Delaware Estuary*. DRBC Project No. 321. Delaware Estuary Program, West Trenton, NJ.

Swart, J.A.A. & van Andel, J. (2007) Rethinking the interface of ecology and society: the case of the cockle controversy in the Dutch Wadden Sea. *Journal of Applied Ecology*, **44**, in press.

Swart, J.A.A., Van der Windt, H.J. & Keulartz, J. (2001) Valuation of nature in conservation and restoration. *Restoration Ecology*, **9**, 230–238.

US Commission on Ocean Policy (2004) *Preliminary Report*. US Commission on Ocean Policy, Washington, DC.

US Environmental Protection Agency (USEPA) (2001) *National Coastal Condition Report*. EPA-620/R-01/005, ORD. Office of Water, Washington, DC.

Van der Windt, H.J. & Swart, J.A.A. (2007) Ecological corridors, connecting science and politics? The case of the Green River in the Netherlands. *Journal of Applied Ecology*, **44**, in press.

Van der Windt, H.J., Swart, J.A.A. & Keulartz, J. (2006) Nature and landscape planning: exploring the dynamics of valuation, the case of the Netherlands. *Landscape and Urban Planning*, **79**, 218–228.

Weinstein, M.P. (2005) Managing coastal growth in the 21st century: sustainability science and the paradox of the dual mandate. *Urban Dimensions of Environmental Change: Science, Exposures, Policies and Technologies* (ed. H. Feng), pp. 218–226. Chinese Science Press, Shanghai, People's Republic of China.

Weinstein, M.P. & Balletto, J.H. (1999) Does the common reed *Phragmites australis* reduce essential habitat for fishes? *Estuaries*, **22**, 793–802.

Weinstein, M.P. & Reed, D.J. (2005) Sustainable coastal development: the dual mandate and a recommendation for 'commerce managed areas'. *Restoration Ecology*, **13**, 174–182.

Weinstein, M.P., Baird, R.C., Conover, D.O., Gross, M., Keulartz, J., Loomis, D.K., Naveh, Z., Peterson, S.B., Reed, D.J., Roe, E., Swanson, R.L., Swart, J.A.A., Teal, J.M., Turner, R.E. & Van der Windt, H.J. (2007) Managing coastal resources in the 21st century. *Frontiers in Ecology and the Environment*, **5**, 43–48.

Weinstein, M.P., Keough, J.R., Gutenspergen, G.R. & Litvin, S.Y. (2003) *Phragmites australis*: a sheep in wolf's clothing? *Estuaries*, **26**, 397–630.

Weinstein, M.P., Litvin, S.Y. & Guida, V.G. (2005) Consideration of habitat linkages, estuarine landscapes and the trophic spectrum in wetland restoration design. *Journal of Coastal Research*, **40**, 51–63.

Weinstein, M.P., Teal, J.M., Balletto, J.H. & Strait, K.A. (2001) Restoration principles emerging from one of the world's largest tidal marsh restoration projects. *Wetlands Ecology and Management*, **9**, 387–407.

Wilson, E.O. (1992) *The Diversity of Life*. Belknap Press, Cambridge, MA.

Received 20 May 2006; final copy received 9 May 2007
Handling Editor: Paul Giller