Starlight cannot heat gas to this high temperature, and the power must come from the hypersonic wind emitted by massive stars (*5*).

This wind carries about 10,000 times as much power as the observed x-rays, which means that it is the prime candidate to be the engine driving the x-ray emission. The wind will overtake the escaping low-density gas in the outer nebula, producing shock fronts that immediately reach temperatures of millions of kelvin. This is the same mechanism invoked to explain the hotter x-ray emission in the similar but more populous Omega and Rosette nebulae (*4*), but many questions remain in Orion. Why is the x-ray emission confined to these two areas? Is there a channeling effect of the stellar wind, a rapid cooling of any other shocked gas closer to the star, or does extinction in the veil simply preclude observation of hot gas in the optically brightest part of the nebula?

Researchers can answer these questions by reanalyzing the earlier Chandra Observatory observations and by employing careful subtraction of the instrumental scattered light and mapping the extinction of optical light from the Extended Orion Nebula. Once these observational questions have been resolved, the ball will be in the theoreticians' court; it is they who must then confront the problems of why the Orion gas is at 2 million K and why it is located where it is.

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ECOLOGY

Managing Coastal Wetlands

Ivan Valiela and Sophia E. Fox

Wetland management may be improved by evaluating nonlinear relationships of economic value and ecological services.

About 30 to 50% of the area of Earth's major coastal environments has been degraded during past decades (*1*). The rates of these losses exceed those of the much better publicized losses of tropical forest. Loss of coastal habitat areas reduces key ecological services; for example, fish and shellfish stocks may decline and shorelines may be destabilized (*2*). On page 321 of this issue, Barbier *et al.* (*3*) find that habitat area might not relate linearly to economic value of certain ecological services furnished by coastal wetlands and argue that ecosystem management strategies might benefit from consideration of such nonlinear functions as a basis for coastal preservation.

Previous work has suggested that the more salt marsh area present, the greater the likely harvest of shrimp in adjacent coastal waters (*4*). Such linear results suggest that the best course is to protect as much of these environments as possible; this has largely been the basis for management strategies. Barbier *et al.* show that for at least one ecological service provided by wetlands such as marshes and mangroves—the wave attenuation service that protects coastal areas from storms and tsunamis—the relation between service and wetland area is not linear, but is decidedly curved.

Such nonlinear links have consequences for management. Barbier *et al.* focus on the key management problem in mangroves: conversion of forests to shrimp ponds. Is there some best solution to the dilemma of weighing the value of ecosystem services against the economic value of the shrimp crop? The authors calculated the "economic value" of intact mangrove forests in Thailand, incorporating the nonlinear behavior of wave attenuation as well as the value of shrimp production after mangrove conversion. Economic value peaked at an intermediate level of conversion from mangrove forest to shrimp ponds. Thus, it may be possible to define an economic optimum for conversion of mangrove forest area to shrimp ponds.

The work is based on the premise that an ecological function can be converted into a currency directly equivalent to money (*5*, *6*). We have at least two qualms with regard to this interesting idea. First, given the paucity of available information, practitioners of ecosystem valuation are often forced to make daring (and not always compelling) leaps of faith to convert ecological service to monetary value.

Second, by putting a price on a natural environment, we put it up for sale—and the monetary value of natural services will seldom reach the value accrued by conversion to industrial or commercial use. For instance, some years ago there was a proposal to build an industrial plant on a wetland parcel in the Hackensack Meadowlands of New Jersey. As a counterpoint to the proposal for construction, decision-makers asked for a valuation of the wetland, which came to about $9000 per acre, per year, in perpetuity. The builders offered $200,000 per acre and showed that the added jobs, taxes, etc., would by far exceed wetland "proceeds" in the short and long term. Today a refinery stands on the site.

That said, there are several valuable features of the results reported by Barbier *et al.* They show that consideration of nonlinear aspects of coastal variables improved the ability to incorporate conflicting demands in management strategies. Use of nonlinear relationships could elucidate diminishing ecological returns associated with different amounts of area preserved. This may pro-

Costs and benefits of conversion. Ponds are constructed to raise shrimp in areas previously covered by mangrove forests in northwest Java, Indonesia.

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vide an objective way to decide on the degree of preservation of different environments of the world's coasts.

The results also suggest several fertile areas for further research. First, it is important to determine how general nonlinearities may be; in the Thai mangrove example, the value of coastal protection by wave attenuation was nonlinearly related to the area of mangrove loss, but yields of fishery and wood products were linearly related to habitat area. Second, scientists must establish whether the deviations from linearity are significant in both ecological and management terms to make sure that implementation of policies resulting from use of curved functions leads to detectable differences. Third, more solid evidence is needed that a service is actually being provided; for instance, there has been considerable debate about how much wave protection is provided by mangroves (*7–11*). Fourth, future studies should more comprehensively cover the suite of locally relevant factors influencing economic value. Barbier (*12*) made a good start toward addressing local issues by quantifying the net effects of economic costs and benefits resulting from conversion of mangrove forests to shrimp farming, but the valuation might benefit by addition of a few key terms. In Ecuador, for example, the shrimp industry came to a standstill not because of deficit income, but because the supply of juvenile shrimp in nearby waters (used as the "seed" for shrimp ponds) was depleted by overfishing. In Ecuador and elsewhere, the mangrove conversion rate may be accelerated by the need to abandon ponds that, as a result of high-yield culture methods, have become too chemically altered to be suitable for shrimp growth.

Finally, Barbier *et al.* point to the need to determine ecosystem-based management for coastal areas by weighing and incorporating the interests of several players: shrimp farmers, who will think about the price of shrimp, but are unlikely to consider long-term, regional benefits of coastal protection when deciding whether to dig another pond; outside investors, who might not know or care about mangrove services; and officials, who might be responsible for implementing regional environmental strategies that foster ecological services.

The report by Barbier *et al.* highlights the complexities involved in making the compromises needed for future coastal management. Research from the study areas pointed out above will show whether "bent" relationships make for compromises that are not only ecologically desirable, but also enable compromises for planned management of coastal wetlands that are acceptable to the diverse stakeholders.

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GEOLOGY

Dreams of Natural Streams

Human influences have fundamentally changed river morphologies in temperate regions around the world.

David R. Montgomery

What does a natural river look like? Centuries of human influence can mask historically distinctive river forms in and among regions around the world (see the figure). Results reported by Walter and Merritts on page 299 of this issue (*1*) suggest that human modification of riverscapes has been so extensive that even some fundamental ideas about how rivers work bear the stamp of human influence. The authors show how colonial mill dams and land use changed New England's streams from a marshy multichannel morphology to today's meandering single-channel form.

This transformation is obviously fascinating to students of regional environmental history, but it is not only of academic interest. Understanding how natural streams work is crucial for river restoration, an academically young discipline that is rapidly maturing into a billion-dollar-a-year industry. The classic sinuous form of meandering channels (*2*) has come to represent a natural ideal in channel-restoration design—even for rivers for which such an ideal is historical fiction.

Modern fluvial geomorphology—the study of rivers—evolved out of the studies of Luna Leopold, M. Gordon Wolman, and their colleagues in the 1950s. As the field developed, pioneering studies of streams in the eastern United States contributed to a standard model for how fluvial processes shape rivers and floodplain environments. This model has been elaborated upon and exported around the world. Indeed, these now classic studies provided the basis for the so-called natural channel design central to many river-restoration efforts across the United States (*3*).

Walter and Merritts now show that some of the rivers studied by Leopold, Wolman, and colleagues were not so natural after all. The new study does not challenge their fundamental insights into how the interplay of hydraulics and sediment transport shapes river and stream channels, but in light of the new findings, what constitutes a natural channel form requires reexamination.

The results parallel findings in Europe and the Pacific Northwest of how historical clearing of large wood and logjams altered river morphology. Before European rivers were cleared to promote waterborne commerce, large trees and logjams obstructed many rivers; local blockages split flow into multichannel networks of branching streams (*4*). Similarly, downed wood split channels into branching networks of small channels flowing across slough-rich valley bottoms in the forested floodplains of the Pacific Northwest (*5*, *6*).

Walter and Merritts now present compelling evidence for a similar change that radically altered rivers in the eastern United States. Thus, a comparable transition from

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