Shallow Water and Shoreline Ecosystems of the Chesapeake Bay Compared to the Northern Adriatic Sea: Transformation of Habitat at the Land-Sea Margin

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Abstract

At first blush, there may seem to be little similarity between Chesapeake Bay (CB) and the Northern Adriatic Sea (NA) -- other than the observation that they are both wet and salty! However, despite the disparate size and marked differences both in climate (Temperate versus Mediterranean) and degree of underlying tectonic activity which drive these systems, it is obvious that there are common trends and problems associated with their habitats along the land-sea margin. Besides the threat of massive eutrophication in both CB and NA, rates of sea-level rise, are surprisingly similar in both systems. The secular trends in tidal records suggest remarkable correspondence over the last one hundred years. The CB is more comparable in this regard to the NA than to the Mississippi Delta or to estuaries on the west coast of the United States (U.S.). The underlying mechanism determining local rates of sea-level rise in both the CB and the NA, land subsidence, is largely due to groundwater withdrawal from underlying aquifers. Not surprisingly, shoreline erosion and the complications associated with long-term armament of sensitive shorelines against erosive forces have been issues that are of increasing concern to managers in both the CB and the NA.

Other common problems involving alterations of shorelines in both CB and the NA include agricultural land-clearing and varying kinds of development. Because both systems are deep enough to have considerable port facilities and ship building has been historically important, the dredging of sediment from channels in the shallows of these systems has had an impact. Despite problems of dredge spoil with possible toxic contamination, nutrient enrichment may be the most significant threat for shallow water communities in both systems. Seagrass and brackish beds of submersed aquatic vegetation (SAV) are very
sensitive to excessive nutrient loadings in both CB and the NA and in both habitat change was evident after the introduction of inorganic fertilizers in surrounding agriculture.

Although there are common problems, the times scales of human impacts in these ecosystems are quite different. The NA has been exposed to civilizations which began to plow and pollute the natural landscape over two thousand years ago. Europeans settled CB in the late sixteenth century, but extensive plowing did not take place until after 1750, and eutrophication in CB began in the mid-nineteenth century after the application of inorganic fertilizer by farmers. In contrast to CB, the great Mediterranean Civilizations were beginning to impact the shoreline of the NA and its watershed as early as the colonization of the Phoenicians (~1200 - 750 B.C.) and Greeks (~750 - 250 B.C.). The most significant impacts in the NA were felt when Imperial Rome with its engineering skills dominated the NA from before the Birth of Christ until its peak in the third century. Not only were they smelting metals on a large scale and building mines, roads, aqueducts, salinas, and harbors, but also Romans were using a wheeled plow in the Po Delta by the first century. There are indications that agricultural erosion was a key factor in the rapid expansion of the Po delta into the NA over the last two millennia. Thus the landscape around the NA was altered many centuries earlier than it was in the CB.

Introduction

Our first working title for this paper was "... Habitat Loss at the Land Sea Margin" (instead of "Habitat Transformation"). After we met in Piran, it became clear that habitat loss was not the most appropriate term for the changes we were able to document in both systems. Although it is in vogue among conservationists to use the term "habitat loss" in the U.S., it does not adequately capture the fact that changing conditions can lead to a variety of new environments and habitats which have considerable ecological value. Furthermore habitat changes are not a one-way process. The word "loss" often conveys a sense of irretrievability. Another consideration is the fact that a mosaic of impacted systems may actually confer more diversity to the larger landscape. In environments which have been dominated by humans for millennia, there is often a spectrum of ecosystems ranging from almost "natural" to very disturbed. Often the goal in restoration ecology involves returning ecosystems to their past condition. While that might be laudatory in one sense, there is an argument that a more effective approach might be to re-engineer environments in order to maximize a diversity of habitats. Some of these might never have existed in the original landscape. In this view, anthropogenically adapted species (i.e., exotic animals and weeds) may even provide help in reinvigorating ecosystems and actually aid in habitat creation. This is an extension of Connell’s argument [1987] that the highest biodiversity in systems often occurs when there is a moderate level of disturbance in the environment. Likewise, in the long run, it may be more desirable to let disturbed communities self-design than to try to return them to a natural state. In order to reflect the concerns above, we chose the phrase "habitat transformation" to describe the anthropomorphic changes in the landscapes of NA and CB.

Another issue involving shoreline communities is that these ecosystems are particularly susceptible to change because they are driven to varying degrees by forcing functions that are complex and sometimes beyond the control of regional managers. Underlying isostatic mechanisms in the earth’s mantle are impossible to control but can cause coastlines to rise and fall over a matter of millennia. In these situations slowly drowning shorelines may
represent habitat transformation rather than loss. Nevertheless, we must be careful not to confuse long-term geological scale changes with shorter term anthropogenic ones. For example global emissions of greenhouse gases now appear to have accelerated global (i.e., eustatic) sea-level rise by a factor of two or three. Although most marshes seem to be able to withstand $-1.0 \text{ mm yr}^{-1}$ by growing vertically, they are now increasingly vulnerable to increasing sea levels [Stevenson et al., 1986]. Since these littoral ecosystems often make direct impacts on dependent marine resources (especially anadromous fish, migratory birds and turtles), it is critical to take stock of what effects the transformation of shoreline habitats will have on the assessment of health of the larger body of water, be it the NA or the CB. Our goal in this essay is to outline some of the major impacts humans have had in terms of increasing population pressure, agriculture and industry at the edges of the NA and CB ecosystems. We have chosen to take a historical approach because it helps to identify which anthropogenic activities have lead to specific changes in the adjacent aquatic systems. The arbitrary boundaries of the coastal zone this essay will explore extend 100 km inland and to the 23 m depth contour in the shallows. Thus, the impacts of rivers arising deep in the hinterland are purposely left out of our discussion since it is covered by Seagle et al. [1998]. First we summarize trends around the NA, and then turn our attention to CB, after which we summarize sea level and policy issues in both systems.

Shoreline Ecosystems at the Interface of the Adriatic Sea

When mapped at equal scales, the NA differs from CB in being much deeper and having much greater water surface area (Figures 1 & 2). Another underlying difference is that, the watershed of the NA is exposed more intensive geological forces. The juncture of two tectonic plates lies along the Apennines Mts. transgressing the spline of Italy. The differential movement of these plates has resulted in considerable volcanism and earthquakes in the region, as well as the elevation of the Alps to the north. Evidence for the importance of volcanism for the NA lies in the interbedded tephra deposits from Mt. Aetna on the seafloor [Calanchi et al., 1998]. In these very geologically active environments, sediment transport is often more prolific and has contributed to the development of the extensive Po Delta. Massive soil erosion in the Po Delta can be traced to the Roman Period where draft animals and wheeled plows were used to cultivate the fields [Jope, 1956]. Due to its distance from the plate boundary, the eastern margin of the NA does not have as robust geology; it has been elevated and submerged several times over the last several million years creating a rugged series of ridges with classic karst topography with distinctive potholes, caverns and underground river systems. Karst topography takes its name from a limestone plateau north of Trieste. Unlike the CB where unconsolidated sands and clay surround the entire embayment, the coastline of the eastern Adriatic has well-lithified rock. The cliff faces around the town of Rovinj in Istria, once provided limestone blocks for constructing many of the finest buildings in Venice.

In contrast to the rest of the NA, south of Trieste there are no large river systems debauching westward, so most of the eroding sediment from hinterland farms of present Croatia and Bosnia moves eastward via the Sava River and ultimately the Danube system to the Black Sea. Although undoubtedly groundwater moves toward the NA from farms located within 100 km of the coast, historical sediment loadings would be expected to be nil from this underground source. Also, lithification of the cliffs makes them resistant to wave erosion. Therefore, this is a rocky "sediment starved" coastline with no parallel in CB.
Figure 1. Map of Northern Adriatic Showing Major Towns Along Northern Adriatic. Split is located on the coast of Dalmatia just off the map (43.30 N, 16.27 E).
Despite low sediment inputs, both nitrogen and phosphorus can be present in groundwater and may be an issue in some traditional agricultural areas along the Istrian and Dalmatian coast (Figure 1). Although there are substantial amounts of nutrients entering the Gulf of Trieste from rivers and point sources in Slovenia and from local coastal towns along the Istrian peninsula, the nutrient loadings decrease south of the town of Split along this coastline. Also, because terrestrial sediment supplies (as opposed to those derived from the...
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Shoreface) are extremely limited along the entire eastern coastline, marshes are poorly developed. Eroding cliff faces are for all practical purposes the only source of "new sediment". Marshes only occur sporadically in this type of topography because of the lack of extensive fine-grained sediments [Stevenson et al., 1988].

Instead of marshy terrain, there are rows of islands (up to four) running southeast of the Istrian peninsula culminating in coast. Dalmatia was subsequently hard fought over by the various barbarian tribes on the interior as well as Greek, Roman, Byzantine, Venetian and Turkish Empires. After 1400, Dalmatia was completely under the control of the Venice until 1797 when Napoleon invaded the NA. Afterward Dalmatia fell under Austria’s control, but following WWI became part of Yugoslavia. It is now an integral region of the Republic of Croatia. This area was at its height of glory when the Emperor Diocletian, in 295-305 A.D., built a port and huge summer palace near his birthplace of Salonae. The reign of Diocletian renewed interest in the building of roads, bridges, and aqueducts in this region. At the time, Dalmatia, as the rest of the NA, fortifications, was intensively cultivated with exotic species of wheat for bread and herds of animals were kept for food. Although the Ancient Romans preferred a meat diet of goat, lamb and pork and placed little value on fish, the Imperial diet was more varied which included a variety of fish dishes; oysters were even imported as far away as Britain packed in snow [Forbes, 1956]. Thus, the Romans increasingly put pressure on harvesting fish and other resources in the Adriatic. One difference between the NA and the CB is the lack of oysters. Particularly along the southern shorelines of the NA, olive growing was as important in Roman times as it had been in Greek, since the oil was an essential ingredient in their cooking and served as a base for cosmetic and toilet preparations. Therefore, natural Mediterranean vegetation was replaced by olive groves during the Roman Period.

The Dalmatian coastline had long been viewed as particularly strategic by the Romans not only for agriculture, but also because it provided access to the many mines they had constructed in the interior of the Balkan region [Bromehead, 1956]. Mining and smelting carried out by the Late Greeks and Romans in such a way that as early as 2500 B.P., massive copper emissions were transported in the atmosphere as far as Greenland, with lesser concentrations of lead [Hong et al., 1996]. This episode of global pollution declined dramatically with the fall of the Roman Empire. When the town of Salonae was ransacked by the Avars in 615 A.D., the Roman townspeople fled first to the islands off Dalmatia, but then returned to live at Diocletian’s old palace (portions of which are still intact) in the town-center of Split (or in Italian, “Spalato”). Split is one of the region’s largest ports and its deep harbor has provided a large shipbuilding industry with attendant pollution problems [Strazicic, 1996]. In recent years it has been a center for production of aluminum, cement, plastics and other chemicals. Of course this has caused a fair share of environmental impact, but good circulation around the islands of Dalmatia provides them with clean water from the Adriatic.

Although it has undoubtedly changed through the centuries, the Dalmatian region today remains one of the more pristine regions in the NA and Mediterranean as well [Chapman et al., 1996]. Since it is still largely “natural” and supports a wide variety of biota it has been a focus of world-wide conservation efforts. Indeed, Dalmatia is famous not only for its distinctive geomorphology but also for its distinctive ecological mix of habitats (e.g., marine lakes, submerged caves and pits, submarine freshwater springs, a highly stratified salt wedge and karst estuaries) with rich fauna and flora [Bakran-Petricioli et al., 1996]. Macro-algae characteristic of low nutrient waters such as Fucus viroides, Cystoseira spp. and Sargassum spp. are still abundant. Further north in Istria, where these were once found in abundance,
the shallows are now dominated by *Padina pavonia*, *Codium bursa* and *C. tomentosum*. This habitat change may be due to natural succession but more likely is associated with increased nutrient loadings from population pressure and a tourist industry which has increased particularly after World War II. *Recent attempts* to curtail raw sewage may be one of the reasons there is recovery of some of the kelp in some areas. However, there are complicating factors. For example, *there was* also an invasion of the Rocky Sea Urchin, *Paracentrotus lividus* which grazes on kelp. More recently there has been progressive disappearance of the sea urchin which has helped in the return of the kelp beds [Ozrelić, pers. obs.].

During the same period that the kelp beds began to disappear along the Croatian coastline, there was also a decline in seagrass meadows. Historically *Posidonia oceanica*, *Zostera marina*, *Zostera noltii* and *Cymodocea nodosa* flourished in the shallows. Unfortunately there is little quantitative data available, but there is every indication that these grass beds have been decimated in recent years. One cause seems to be the increased turbidity in the water column which reduces the amount of light penetrating to the bottom. Another factor may be the past harvesting of the Date Mussel, *Lithophaga sp.*, which embeds itself tightly into limestone rocks. Commercial harvesting was done in such a way as to physically disrupt many types of benthic communities, including adjacent kelp and seagrass beds. Because of the obvious impact on a variety of habitats, there has been legislation passed in Croatia to ban the harvesting of this delicacy. Another problem is the recent introduction into the NA at two sites of an exotic tropical marine alga, *Caulerpa taxifolia*. This introduced species has few natural competitors in the Mediterranean and has often spread very rapidly into areas which were traditionally dominated by seagrass. Although it could be argued that it is better to have an exotic species occupying a niche than no species at all, the introduction of this species, if unchecked, may be problematic for the return of seagrass (as well as kelp) species native to the NA. Despite this overall downward trend, *Cymodoacea nodosa* still persists in several shallow bays along the Croatian coast and more recently has shown some indication of recovering.

In contrast to the Croatian coast, extensive low-lying wetland areas exist in the northern part of Slovenia, where sediment supplies increase because of riverine inputs into the Gulf of Trieste. Many of the wetlands which result from a high sediment supply were reengineered by the Romans as salinas (see below). The runoff from rich alluvial farmland around Trieste provides problems because it stimulates the growth of planktonic algae in receiving waters. Algae attenuate light, causing low light conditions on the shallow sea-floor which diminishes the potential for seagrass growth. The terrain of the eastern NA is dramatically different from that of the western side. North of the heavily industrialized port city of Trieste, the NA coastline increasingly flattens. Progressing westward from there, the steep cliffs near the sea so typical of the eastern NA disappear entirely. They are replaced by barrier island/lagoon systems which extend from the Gulf of Trieste’s Grado-Marano Lagoon, westward to the Caorle Lagoon and culminate with the Venice Lagoon. This series of estuaries lies at the southern edge of the Veneto plain which was formed from sediments emanating from the Austrian-Italian Alps on the northern watershed boundary. The river systems increase in size in a westward direction until the Po which is the largest river system in Italy [Bondesan et al., 1995].

The smaller rivers of the Veneto (Isonzo, Tagliamento, Piave, Brenta, Adige) transgress through gently sloping terrain (<1:1,000) which is now well-fertilized agricultural land [McClennen et al., 1997]. Although these rivers historically conveyed large amounts of sediment to the NA, in recent centuries there has been an extensive network of public works
projects including dams and water diversions to irrigate farmland and reduce spring flooding. The result has been a historical increase in sediment loading followed more recently by a restriction of sediment supplies along this coastline [Stefanon, 1970]. This has shrunk and disrupted the barrier islands at several locations. Long shore transport is generally westward out of the Gulf of Trieste and northward from the Po Delta. Under natural conditions there should be a convergence zone in front of the Venice and Grado-Marano Lagoons where high sediment deposition occurs, but recent reductions in sediment loading to the coast as well as barriers to transport (i.e., jetties and groins) presently deprive these areas from obtaining much needed particulate material [Bondesan et al., 1995]. As a result the barrier islands of the Grado-Marano lagoon appear to be breaking up while the barrier island in front of Venice (i.e., Lido beach) is thinning and migrating inland because of sediment starvation (Figure 3).

The Venice Lagoon originated about 6,000 B.P. when the sea rose during the Holocene transgression to submerge the upper Adriatic Wurmian paleoplain [Gatto and Carbognin, 1981]. The overall area of the Lagoon of Venice is about 551 km² with the bulk (393 km²) comprising open water and canals (including 88 km² of fish ponds), 47 km² comprising salt marshes, and 37 km² being islands [Rusconi, 1987]. Stratigraphic studies [McClennen et al., 1997] have shown that the Venice lagoon has a weathered “caranto” surface (formed during the glacial maximum) overlaid by 4.5 to 6 meters of mudflat deposits formed as a result of the post-marine transgression during the Holocene. The lagoon presently has three inlets connecting it to the NA: Lido, Malamocco and Chioggia. Despite the fact that there is considerable agricultural input to the lagoon [Bendoricchio et al., 1993], the major rivers previously flowing into it were diverted by the Venetians to prevent sedimentation and the inlets tend to be ebb-dominated [Stevenson et al., 1988] creating a net sediment deficit. Thus, there is a net loss of sediment from the lagoon to the NA amounting to as much as 1,000,000 m³ yr⁻¹ [Bettinetti et al., 1995].

Because the wind is the dominant forcing function in determining sea level on the entire northern coastline of Mediterranean [Tsimplis, 1995], Bora winds from the northeast can raise sea levels several meters and drown these low-lying NA coastlines. In winter, winds typically can reach 80-90 km hr⁻¹ [Day et al., 1998]. During these windy periods, called *aqua alta* by the Italians, high tides are especially problematic to developed areas in Venice. On November 4, 1966, a record tide swirled over much of Venice and at one point the height of water in the Piazza Saint Marco was almost 2 meters [Lauritzen, 1986]. The damage to architectural and art treasures of the city drew international concern and UNESCO began the first efforts to identify what could be done to preserve Venice and come up with a strategy to ameliorate the effects of rising tides. Because the configuration of the NA funnels tidal energy toward the north, the Venice Lagoon with its shallow water depth (0.67 m) is especially vulnerable to Bora winds and has been the focus of much concern [Pirazzoli, 1991]. Adding to the problem was the realization that Venice was sinking because of underlying land subsidence.

According to tradition [Norwich, 1989], Venice was founded on the Rialtine Islands in A.D. 421 by Romans fleeing the sacking of mainland towns. The center of the lagoon was a potential refuge for frightened Romans and was as pristine as any area on the Italian peninsula. Until then the Romans had avoided this area because of its swampy conditions [Pirazzoli, 1991]. In contrast the Po Delta was heavily cultivated with an extensive road network. The closest Roman road during the Imperial Period went only as far as Patavium, 30 km from the edge of the Venice Lagoon [Earl, 1968]. Although there is debate about from where settlers actually came from to build a city [Norwich, 1989; Concina, 1998],
carbon dating has verified that remains of wooden fragments beneath modern Venice date to the 5th century [McClennen et al., 1997]. Even after Attila the Hun’s conquest (452 A.D.) of major towns including Ravenna, the islands of the Venetian lagoon remained largely free of barbarian control. This marshy environment allowed the new immigrants a modicum of freedom to engage in trade which eventually brought much wealth to the Rialtine and other islands in the lagoon. The Venetians became adept at sailing in shallow waters and extended their influence as merchant men of the NA.

By 726 Venice elected the first Doge (Orso Ipat) and formed a republic [Norwich, 1989] which lasted over a thousand years, transforming the lagoon into a highly regulated ecosystem. By 1000 A.D., Venetians extended their political control over 75% of the coastline of the NA, in an arc that stretched from Dalmatia, Istria and the Veneto southward.
past the Po Delta almost to Ravenna [Ward-Perkins, 1997]. As Venice grew, particularly after the 13th century, the building projects became monumental in scale, with the present Byzantine-Gothic style Doges Palace constructed at the mouth of the Grand Canal in 1340 [Wolf, 1988]. The Grand Canal is the remains of a channel of an old river which emerged in the Veneto Plain [Franzoi et al., 1993]. The marshes surrounding the mouth of the old river were obliterated under the growing city as the first wooden buildings were built on wooden raft-like underpinnings [McClennen et al., 1997]. As the Venetians switched to stone, piles had to be driven down through the organic sediments to reach underlying strata capable of supporting increased weight. Furthermore, the natural marsh channels became the main thoroughfares for transportation around the City. This accounts for the sinusoidal shape of the Grand Canal (Figure 3) which became the most important transportation corridor within the old city and the location of numerous palaces and houses of the wealthy merchants [Franzoi et al., 1993]. Additional canals were constructed as conveyances and to promote circulation. The latter was necessary to help flush the canal system which received Venice’s sewage.

At first the canal system must have been adequate to process the raw sewage from Venice’s modest population. Although the time period of eutrophication has not apparently been investigated for the Venice lagoon using sediment geochronologies, there is little doubt that by the Renaissance there were extensive odors in summer, reflecting the fact that the canals were overburdened by organic loadings. In addition to organic inputs to the city from humans, the increasing nutrient loadings led to an increasingly productive macrophyte-dominated community in the lagoon [Marcomini et al., 1995]. However, instead of seagrasses, which most likely would have been there before the fifth century (A.D.), there is an assemblage of algal macrophytes characteristic of nutrient rich systems (e.g., Ulva laetevirens and Gracilaria confervides) with Ulva rigida now dominant [Sfriso et al., 1991]. Unlike seagrass, which usually stays in place, the algal macrophytes do not have high tensile strength and break off, often collecting in the deeper portions of the canals. As temperatures warm in summer, decomposition of macrophytic material plus the usual anoxia of primary sewage treatment, results in reduction of sulfate in the seawater of the canals, leading to excessive malodorous conditions (i.e. hydrogen sulfide gas).

The fact that Venetians fled en masse in summers from their city for their sumptuous country villas on the mainland, beginning in the mid-sixteenth century [Wolf, 1988], suggests that eutrophication most likely dates back to that time, and possibly before. One of the reasons for their summer sojourns was that by 1500 Venice had militarily secured most of the Veneto Plain. However, the environmental factor that drove them away from the seacoast (where most people usually like to spend the summer) was associated with their fear of catching malaria (literally meaning bad air in Italian). Although malaria is actually caused by parasitic protozoans carried by several species of mosquitoes (Anopheles spp.) then endemic to marshes of the NA, the Venetians were among the first to make the first connection between the environmental (marshy) conditions and the disease. Thereafter they endeavored to reduce wetlands. Employing skills inherited from the Romans, they diverted major rivers such as the Brenta around the lagoon, helping to dry out much of the landward side. Also they reduce marsh acreage by enclosing the marshes with berms and flooding them to make artificial ponds for aquaculture which still exist. Today the area of ponds is twice that of marshes, which in itself represents a sizeable habitat change. Of course this represents a significant transformation of the Venice Lagoon, but again as on the eastern side of the NA, not all impacts are negative.

In spite of dams, river diversions (Brenta, Piave and Sile) and major sea walls on the barrier islands of the Venice Lagoon, which were all finished by the fall of the Venetian
Republic in 1797, there is still surprising vitality in the lagoon. In the early 1990s, a seagrass survey [Cecconi, 1993] revealed that the most widespread species was Zostera noltii, which covers 4235 ha, followed by Zostera marina (3635 ha) and Cymodocea nodosa (1560 ha). Rismondo et al. [1997] have reported that above ground biomass of Cymosa nodosa can reach 810 g m$^{-2}$ in summer which is much higher than reported at other Mediterranean localities. The high biomass at locations in the Venice Lagoon is reminiscent of Upper Chesapeake Bay where modest levels of nutrients in the vicinity of Washington D.C. can produce macrophytic biomass up to 1 kg m$^{-2}$. Sea grasses are particularly desirable because their root and rhizome systems contribute significantly to stabilizing bottom sediments in the lagoon, especially in winter when 85% of Cymodosia nodosa biomass lies below ground [Rismondo et al., 1997]. Unfortunately, the northern part of the Venice lagoon does not have as much seagrass coverage as the southern part, where multi-species beds can occur. The reason for the difference in distribution may be the inflow of cleaner NA waters in the vicinity of Washington D.C.

However, there is more to the story of this channelization project and it relates to events which unfolded after Napoleon’s demise in 1814. Austria became the next power to control Venice and its former possessions in the NA. Numerous public works projects were carried out by Austrian engineers, such as drilling deep wells in the mid 1800s to obtain clean drinking water and a rail link to the mainland. Venice never regained its status as a trade center. Early in the twentieth century Venice was seen as a dying city and many of its 200,000 citizens were literally poverty stricken. Unlike Rome, Milan, Genoa and Naples, it had stagnated economically. One problem was that modern port facilities and industry had largely bypassed Venice. To help revitalize the economy of the region, a consortium of investors headed by Count Giuseppe Volpi began purchasing large tracts of wetlands on the western side of the Venice lagoon in 1917 [Lauritzen, 1986].

Although the intertidal zone on the western shore of the Venice Lagoon had been altered hydrologically before the 18th century, when the Brenta River was diverted south of the lagoon, the marshes were still clear of development of any kind. In fact the only nearby landmarks, aside from abandoned villas, were an old fortress at Marghera which had been occupied by the Austrian army in the 1800s and a small village called Mestre some distance away [Lauritzen, 1986]. Count Volpi’s idea was to use a formula which had worked so well during the Gilded Age in America (including the building of the steel complex at Sparrows Point near Baltimore on CB discussed below). Raw materials shipped from foreign destinations were manufactured in gigantic self-contained industrial centers (often near a cheap labor supply) where products could be efficiently transported by rail to their ultimate destinations. The result was spectacular in terms of economic production, but much of the natural wetland landscape of the western side of the Venice Lagoon was obliterated. In addition, because there was now a berm around this previously intertidal area (locally known as “barene”), it no longer provided extra capacity for the lagoon to accommodate spillover during high tides [Pirazzoli, 1987]. Flooding is increasingly problematic because the inlets to the lagoon were widened considerably (last during the mid-1960s) to accommodate shipping. Thus during strong aqua alta events, more water can enter the lagoon and the equilibration time is less, causing increased flooding in the lagoon. This prompted the design of elaborately engineered tidal gates for each of the three inlets (Figure 4) which would arise from the bottom when needed. This attempt to hold back the sea was dubbed MOSES and
despite the construction of a full scale prototype gate, full scale construction was never implemented because of environmental concerns. The election of a more environmentally sensitive in Venice has signaled a change in philosophy oriented more toward improved land use planning and ecological restoration of the lagoon than massive engineering projects. This is also reflected in CB where large scale projects are looked upon by the public with increased skepticism.
Another underlying environmental problem posed by the massive Mestre-Marghera industrial complex is that so much water was pumped out of the underlying aquifers that it caused regional subsidence. Gambolati et al. [1974] estimated that the land in the region of the Venice Lagoon subsided almost 4 mm yr\(^{-1}\) from 1930 to the early 1970s because of the Marghera-Mestre pumping. That subsidence coupled with Venice’s own domestic water withdrawal from deep aquifers have acted to accelerate relative sea-level (RSL) rise. The rate of RSL rise, coupled with high wave energy and a loss of sediments from the inlets, has also resulted in an overall decline of marsh habitat in the lagoon [Day et al., 1998]. At one marsh location in the southern lagoon called Punta Cane, Day et al. [1998] documented a shore erosion rate as high as 2.2 m yr\(^{-1}\) (Figure 5). They suggest the only way to prevent further erosion is to deploy permeable breakwaters at the marsh/lagoon edge which could effectively reduce wave energy while permitting enough sediment transport to keep the marsh surface abreast of RSL rise [Boumans and Day, 1984].

Unfortunately other problems which degrade the habitat of the lagoon were created by concentrating industrial operations at Mestre-Marghera. Several studies [Pavoni et al., 1987; Basu and Molinaroli, 1994] have shown a variety pollutants have been released into the water and atmosphere during the past 80 years at Porto Marghera. The immune systems of fish (Gobi) which inhabit waters there have been found to have elevated stress response patterns compared to those of less-contaminated sites in the lagoon (at Crevan, Torcello, Lio Grande). Since the Venice Lagoon is one of the recognized “pollution hotspots” of the Mediterranean Sea in terms of toxics, Italy has agreed, along with other Mediterranean countries participating in the Barcelona Convention, to reduce the inputs of chemicals (particularly organohalogen)s identified as particularly harmful to the environment [Swindlehurst et al., 1995].

South of the Venice Lagoon is the Po Delta where a massive amount of sediment has been carried to the sea in previous centuries. This area provides an excellent sedimentary record. Baramawidjaja et al. [1995] have shown from a sediment core dated using \(^{210}\)Pb and \(^{137}\)Cs, that seagrasses disappeared in this region between 1840 and 1880. This period may be critical because it corresponds to the discovery and the massive worldwide exportation of fertilizers from South America (see discussion of the Chesapeake below for further details). Most likely nutrient loadings took a quantum leap upwards to match the chronic sediment loading in the Po River which had been occurring for centuries due to massive clearing of the watershed. In addition, Baramawidjaja et al. [1995] found that foraminifera associations began to change about 1900 in accordance with further increases in nutrient supplies from the Po. Also since there is evidence of intense anoxia over the last 10 years, Baramawidjaja et al. [1995] concluded that the ecological health of this area was unfortunately still in decline.

Although there is no doubt that development of the Po Delta expanded significantly from the Roman period onwards until the twentieth century, it has now been sharply curtailed by extensive dam construction and diking of major rivers (see Seagle et al., this volume), which cuts off the vital sediment supply. Present sediment inputs are insufficient to sustain the surface of the Po Delta against sea-level rise and underlying compaction and there are now 2,375 km\(^2\) lying below sea level along this coastline [Bondesan et al., 1995]. Steady state conditions of the delta depend on continuous sediment inputs. Unfortunately without continued sustenance, mass erosion may ensue as in the Nile Delta [Smith and Abdul-Kader, 1988; Stanley, 1996]. South of Venice, increasing acreage of farmland is now below sea level (as in the Netherlands), and has to be pumped of water to be cultivated. The increased saturation of fields is one of the reasons that rice, introduced after the Roman
Period, is now a common staple crop in the lower Po Delta. In contrast to CB, intense cropping and natural drainage alterations in areas of the Po Delta, have not combined to produce high phosphorus (P) loadings into the NA. Actually they are comparatively low compared to intensively farmed areas of the CB. Vighi et al., [1991] have estimated nutrient export rates ranging from 0.03 to 0.21 kg P ha\(^{-1}\) yr\(^{-1}\), despite substantial (55-60 kg P ha\(^{-1}\) yr\(^{-1}\)) fertilization rates in the area [Vighi et al., 1991]. However, the deficit between inputs and outputs (including P in the crops) suggests that there must be a huge inventory of P building

Figure 5. Marsh Losses at Punta Cana in the Venice Lagoon [modified from Day et al., 1998].
up in the soils of the Po Delta. Since this area is now in danger of being reflooded and returned to the NA, there could be a massive release of P associated with a major tidal event which could overtop dikes and initiate reconnection with the NA. Thus the consequences in terms of eutrophication of the NA could be staggering if these P-rich sediments are allowed to erode. Given the dire consequences to a P-limited system, it is incumbent to manage this system to prevent this from happening.

Recent Land Use Trends Along the Eastern Margin of the NA

There is a marked contrast between the recent trends in agricultural land use in the Po Delta compared to that in Istria and Dalmatia in the East. One example we will explore in detail involves the complex coastal zone landscape of Northern Istria (Figure 1). Some of this area of Slovenia along the coast is now intensively developed as a port with many associated industrial activities. This has resulted in obviously reduced habitat value for a variety of traditional biota within the area of development. Nevertheless, the changes in the landscape of the broader region are multidimensional. As in other regions of the NA coastline, agriculture was once predominant, but now economics clearly has shifted land use away from farming. The landscape is more distinctive and intensively utilized today than ever before, and there are extensive areas which are reverting there is a reversion to forest (as in CB). Specialized environments have increased, resulting in a more diversified use of space and it can be argued that this complexity may ultimately yield more system diversity than the natural habitat. Not a single area has remained undisturbed by human activity. Can we really expect small countries which have been ravaged by recent political dislocations to spend much of their economic resources restoring the NA coastline to a natural state that occurred in Pre-Roman times? Surprisingly in the case of Slovenia the answer is a qualified -- yes!

In order to understand the dynamics of this terrain one must realize that it has been disturbed by agriculture since the Pre-Roman period. In fact, the overall barrenness of the Karst region is the consequence of agricultural exploitation of land which was highly erodible because of its limestone parent material. Agriculture and grazing (sheep, horses pigs and etc) has transformed the once forest-covered terrain into rocky, barren land. Despite the thin soils, the re-forestation of the Karst in the past century has been quite rapid. Despite the presence of orchids, the scrub forest which results is not as attractive as open green pastures. Some have expressed regret over the recent loss of pastoral landscape [Pertot, 1989]. Often there is a yearning for open landscapes with verdant well-kept fields, in contrast to shrubby secondary succession vegetation which usually replace abandoned fields. Among the concerns is an initiative for the preservation of non-indigenous weed species in wheat (Triticum spp.), which were brought to the NA watershed from Eurasia [Kaligarić, 1993]. Here it seems preservationists have an interest in protecting not only native species, but introduced ones as well. It prompts the question: What constitutes acceptable change in terms of species composition of communities in the coastal zone?

Although details vary throughout the Balkan states, the general picture of land use change is exemplified by an analysis in Slovenia which comprises 40 km of the NA coastline. The NA, the coastal area of Slovenia is intensively developed, but forested areas can be found progressively toward higher elevations in the east. The basic pattern of land use in coastal Slovenia was established by the dense settlement patterns when the primeval forest was cleared for grazing pastures during the Hallstatt period (11th - 5th century B.C.). The
extensive cultivation of terraces on slopes goes back to antiquity, when high points in the terrain were desirable for defensive purposes. From the prehistoric and antique periods onwards, the hinterland of the Northern NA coast was mainly used for agricultural activities to help feed the Roman Empire as well as later invaders. As the land was tilled intensively all over Istria, previously fertile soils eroded from sloping lands leaving only the valley floors with rich organic substrate. Since these were often well manured, they yields were substantial in patchy areas. However, because of the terrain and comparatively low rainfall, there was in all likelihood little impact of agriculture on the NA during this period.

Additional changes in land utilization occurred in the periods of intensified expansion of agricultural and urbanized land and in the periods of human “withdrawal” from the environment. These changes were not only linked to the period of collapse of the antique world, when human presence in the environment was probably most intensive, but also, to a lesser extent, result from changes in political and economic conditions. It is presently difficult to estimate the extent to which natural habitats were preserved within cultivated land. Titl’s map (Figure 6) shows that cultivated terraces covered a relatively substantial part of the coastal area. Thus, agriculture was once a considerable burden on the coastal environment in terms of clearing the natural vegetation. There are still areas where erosion was particularly severe, creating patches of barren land called “badlands” [Natek, 1990]. The flysch rock formations in the region are noted for accelerating surface flow of water, thus causing surface erosion. However, the terracing of slopes in some locations for anti-erosive measures helped retain soils that otherwise would have been lost. Thus, a complex mosaic characterized by a highly diversified relief has resulted.

According to Natek [1990] the Dragonja River basin today covers 486 ha of highly erosive terrain and 279 km of erosive ditches and ravines. Many of these rough areas are habitats for existing plant and bird life. These parts of the environment have escaped human development, and remain refuges in the landscape. In contrast, the living conditions in areas of sedimentation are changing because of erosion. An estimated 43,000 m³ of sediments are released annually in the Dragonja River basin [Natek, 1990]. Local marshes and extensive flat areas along streams and rivers are visible signs of this process.

Alongside erosive ravines and water flows, the land overgrown with trees remains closest to what might have been its natural state. One can hardly speak of the existence of a real forest in the Slovene coastal region; instead foresters refer to it as “bushy growth”. The forest survived in the steepest ravines which were less suitable for agriculture. Even these areas are presently subject to intensive exploitation. Titl [1965] reports that timber cutting for nearby towns also an important source of income for the local inhabitants. In the past, the forest expanded and contracted periodically, depending on the need for its more intensive use. This cyclic process is depicted in three maps of land use in the cadastral district of Izola in the years 1818 (Figure 7), 1876 (Figure 8) and 1963 (Figure 9). The forest gradually expands and the process of spontaneous growth is more intensive in the hinterland and in higher areas with steeper slopes. This cyclic trend appears to be similar for much of the Karst areas of the NA and is comparable in many ways to the CB watershed.

The overall timing of maximum clearing of land in NA is highly dependent on the wine market. Late in the Nineteenth century, the insect Phylloxera vitifoliae infested the roots of grapevines in France and wine prices soared. At the time vineyards in the NA watershed were completely free of this pest. Due to the increased demand for wine, all available land in the cadastral district of Izola was cleared for vineyards. However after World War I, the French had replanted their vineyards with resistant rootstocks and wines from the NA lost market share. In addition they were hit hard by new wine legislation (which was not inclined
KULTURALNE TEREZE NA KOPRIŠČE (1963)
AGRICULTURAL TERRACES IN THE COASTAL REGION OF SLOVENIA (1963)

LEGENDA

- Repopularna mapa
- Drvina mapa
- Unizna leta
- Opedizna leta
- Podravine podzemne
- Opelejne leta
- Opelejne leta
- Cultivated

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Figure 7. Land Use Map of the Cadastral District Izola of Slovenia: 1818.

toward the production of lighter wines). Land use and cultivation practices changed once again. In the 19th century, mixed crops ("Coltura mista" in Italian) had prevailed in the NA which had high change higher to high biological diversity. Til [1965] noted that field crops were mostly grown in vineyards in the direct hinterland of Koper, while grapes and olive trees were grown together in the area of Izola (Figure 1). This resulted in smaller produce, but the higher biological diversity provided more stability. If one crop faltered, another could often offset the loss. When the land was converted to vineyards, it allowed for higher crop yields and easier elimination of fungal diseases. This marked the beginning of the disappearance of traditional "mixed cropping" and, simultaneously, the diversity of habitats.

Present-day land utilization of the area shown in the three maps (Figures 7, 8, & 9) shows continuing changes [Pavlin, 1991]. On one hand the extent of land undergoing ecological succession is increasing, while at the same time the creation of large single-culture plantations is intensifying. These are mostly vineyards and, to a small extent, orchards. After the decline of population in the interior of Istria following World War II, agricultural production began to increase with the introduction of the above-mentioned
changes in the environment and the application of new farming technologies. In the Osp Valley, which was one of the test regions used by Pavlin [1991], changes in land use occurred on one-third of the entire area (54.3 ha) in the period from 1975-1988. The majority of changes (60%) involved the extension of agricultural land, 25% of all changes involved the reforestation of meadows (5.9 ha) and pastures (5.0 ha). But, at the same time, 12 ha of new fields, 3.7 ha of vineyards and 1.5 ha of orchards were created. Nevertheless, the present extent of vineyards cannot be compared to that existing at the beginning of the century, when 53% of all cultivated land in the cadastral district of Osp was used for wine production. By 1988 this figure had fallen to 22%. Pavlin [1991] concluded that changes in land use were caused mainly by social factors (i.e., land ownership), and not by natural factors. It should be stressed that this region lies in the hinterland of the Slovenia at a height of 50 m above sea level where, in the past 80 years the population has decreased from 425 in 1910 to 154 in 1991.
The second study area, Bonini, lies approximately 5 km from Koper, and extends over a ridge 140 m above sea level. In the past eighty years the population of this area has more than doubled from 145 in 1910 to 326 in 1991. This was accompanied by intensified agricultural production, particularly the revival of extensive vineyards. Although almost 1/3 of the entire region is covered with forests (29.7%), only 3 ha (0.6%) of new forests were recorded in the period from 1975 to 1988. The influence of the more developed part of the Slovene coast is evident at Bonini. In addition to the two regions described above, Pavlin [1991] also investigated two regions located further away from the coast at higher altitudes and found that cultivable land became overgrown soon after the departure of the first wave of emigrants in 1947. Later on the abandoned land was repeatedly included in more intensive forms of production. In the opinion of Pavlin [1991], abandonment of agriculture reached a peak in the late 1980s just before the dissolution of Yugoslavian control of the region. Since then, a revival of agricultural activities has resumed in most of the Koper region. The utilization of profitable land is expected to remain unchanged and may even intensify with the introduction of specialized production. In suburbanized areas one may expect a greater
demand for land for recreational farming (orchards and vineyards) by people who earn an income from other sources [Pavlin, 1991].

In terms of land use, what is most unique about the NA was the extensive conversion of natural coastline for the production of salt. Until the last couple centuries this commodity was extremely valuable throughout much of the world. The primitive salt mines in Austria were a mainstay of the Hallstadt culture which pervaded the NA before the Great Civilizations. The conversion of intertidal wetlands and other natural areas to highly-managed salina systems was a major ecological change along the Slovene coastline. Natural salt pans are sometimes found where seawater is trapped and evaporation produces hypersaline conditions culminating in the precipitation of salt. Managed salt pans, i.e., salinas, have been engineered over time by creating a series of evaporative lagoons where evaporation is higher than precipitation. Usually the best locations are under Mediterranean climates (dry summers) or on low lying tropical islands where precipitation is low (e.g., Bahamas). The Romans were especially adept at controlling water flow by draining marshes and lakes, as well as building aqueducts to route water to desired locations. In 41 A.D. the Romans used 30,000 men to construct a six-kilometer tunnel to drain Lacus Fucinus. The tunnel took ten years to build and was 120 meters beneath the surface. The availability of full strength sea-water and low annual rainfall (66 cm) along the NA coast plus easily-worked flysch rock substrate [Savnik, 1951], produces ideal conditions for salina construction. However, because of restrictions to fish and since so few organisms can withstand hypersaline conditions, the traditional nursery value of the previous natural wetland is diminished considerably. It is an open question whether the Romans might have contributed almost two millennia ago, to the decline of some fish species in the NA not only by incorporating them into their regular diet but also by converting wetlands to salinas.

The building of salina systems along the Slovene coast was possible because of the lithological qualities of the so-called “yellow” Istria [Savnik, 1951]. The erosion of soft flysch rock created alluvial plains along the seaside, which enabled the construction of pools for the evaporation of sea water, since clayey mud for the construction of dams and the bottom of the pools was available in large quantities. The salt pans have had a considerable anthropogenic impact on the coast of “yellow” Istria, and have significantly influenced changes in its natural character. In Koper, for example, the salt pans surrounded the old town core in a semi-circle; the town itself, once an island, was accessible from the mainland by means of two bordering dikes of the salt pans [Savnik, 1951]. In addition to these salt pans, larger salt works existed on both sides of the Riàna River. After salt production was abandoned, these facilities provided an excellent habitat for mosquitos, Savnik [1951] noted that 200 cases of malaria were reported in 1926. Subsequently the area was drained in the period from 1932-1939 [Škornik, 1990]. Although of poorer bearing capacity, the ground nevertheless attracted settlers and today is used for port activities and its expansion. The small remainder of the former salt pans is presently a nature reserve, which has been preserved largely through the efforts of environmental interest groups.

It is difficult to estimate the habitat value of the former salt pans, but their environmental impact has undoubtedly been significant. At the height of salt production in the mid 19th century, they covered an area of 360 ha in Koper, 557 ha in Seõvle, 35 ha in St. Lucija and 17 ha in Strunjan [Savnik, 1951]. Although the dikes cut off natural exchange processes from the NA, reducing fish access; they formed a collection of habitats which were unique to the region. Because the salt pans in Koper, Izola and Lucija were transformed into more anthropogenic forms of land use, the endeavors for the preservation of the remaining salt pans is understandable. The diversity of habitats created from former salt pans
is one of the most important reasons for the implementation of an environmental protection regime in the salt pans of Sežovlje. In spite of this, their fate is still uncertain. The development of tourism and the enormous pressures for the further development of the Slovene coast repeatedly give rise to ideas for the utilization of “useless” space. A racetrack and an airport are only two projects which have been proposed.

The salt pans are an example of how abandoned low-lying land can go through succession and develop into functional habitat supporting an abundance of wildlife. There are 45 endangered plants on the “Red List” in Slovenia which thrive in the area of the salt pans. More than 200 bird species use the area during migration, while 80 species nest here permanently [Križan, 1990]. Therefore, even very anthropogenically altered systems can play a significant role in the preservation of biodiversity. Thus, attention should not merely be devoted to the preservation of systems in their original states. This argument could also be made for other extractive sites, although these are rare on the Slovene coast. They are, however, more frequent in the neighboring limestone regions. Abandoned marl pits, clay pits, gravel pits and quarries, even underground mines, can create conditions which spontaneously develop into rich habitats and which may compare favorably with the natural systems they replaced. Perhaps the most well-known example is the freshwater lake in Fiesa. Unfortunately, such abandoned places are often undervalued and used for unregulated dumping of wastes, as in the abandoned marl pit near Miloki.

Today the coastline is the most important focal point for population growth in the NA of Slovenia and Croatia. The principal settlement nuclei on the coast have their origin in antiquity, but their further development was primarily influenced by the changing political situation and administrative boundaries. The most decisive period in the development of the Slovene coast was the period following World War II, when the port of Koper was constructed. This intensified development of residential and tourist facilities on the coast, which was simultaneously reflected in the changed use of the land. The trends in the settlement of Slovenia’s coastal area were predominantly influenced by economic and political considerations. At the end of the past century the population of this region grew relatively quickly - by 42% in the period from 1869-1910. This growth stopped after World War I because of the economic crisis experienced by the nearby city of Trieste [Jakoš, 1990]. In the first years after World War II, the population decreased even more rapidly because of emigrations to Italy. In 1953 the region had 14,000 less inhabitants than in 1910 (in 1910 - 56,189; in 1953 - 42,665). More intensive immigration began soon afterwards, and in 1989 the region increased to 77,471 inhabitants. This general trend has resulted in the intensification of activities in the narrow coastal zone and thinning of the population load in the interior of Slovenia. Jakoš [1990] found that the number of inhabitants living at a height of 0 to 50 m above sea level in the period between 1961 and 1987 increased from 27,349 to 43,323, and at a height of 50-100 m above sea level from 7,939 to 14,493. At heights above 200 m above sea level the total number of inhabitants fell from 7865 to 5747 in the same period.

The rapid concentration of the population in a narrowing coastal strip was also confirmed by Perko [1990], who found that in 1880 60% of the entire population lived in the first hundred-meter zone (height above sea level: 0-99 m). This zone comprises about 1/3 of the entire area of the three coastal municipalities of Slovenia: Izola, Koper and Piran. Fifty years later, in 1931, the distribution of the population in individual zones remained almost unchanged. In 1981 already 80% of the entire population was concentrated near the sea, while the total number of inhabitants doubled. In the next 100-meter zone the population increased by 40%, while in subsequent altitude zones (200-299 m, 300-399 m and 400-499
m) it was reduced by 32%, 54% and 63% respectively (Ibid., p. 92). As is evident from Jakoš's study [1990], the population is increasingly more concentrated in the narrow coastal zone at an altitude of up to 50 m above sea level. In 1987, 58% of the entire population lived in this area, although this zone only encompasses about 20% of the entire coastal region. For this reason one might agree with A. Jakoš when he says that in the coastal zone (0-50 m above sea level) "there is practically no more room for residential construction ..." [Jakoš, 1990]. The situation is quite similar in the zone extending up to 100 m above sea level, and in recent years population growth was even recorded in the next 100-150 m altitude zone. However, these zones are physically closer to the coast. Jakoš [1990] concluded that: "The higher areas in the hinterland of the coast were first abandoned, but due to the lack of space on the very coast, settlement is again moving to ... higher-lying areas that are physically closer to the coastline."

Historical Trends of Human Intervention Along Chesapeake Bay Shorelines

Like the NA, the productive shorelines of CB have long been impacted by human populations. However, the time frames are radically different. The first signs of habitation of CB watershed was about 10,000 - 12,000 years ago, several millennia after the retreat of the Laurentian Ice sheet began (i.e., Holocene Period). The earliest occupation is referred to as Paleo-Indian Period (10,000 to 6,500 B.C.) which was followed by the Archaic Period (6,500 - 3000 B.C.) and thereafter by the Early and Late Woodland Periods [Custer, 1989]. When the first bands of humans invaded the area, they had no pottery or agriculture. However, the exposed terraces (now under Chesapeake Bay) must have been a favorite habitat for large grazing animals, including mammoths, who thrived on the wide-open landscape which was very fertile due to loess deposits associated with maximum glaciation [Foss et al., 1978]. On the arrival of Stone Age hunters, the Laurentian Ice sheet had retreated northward out of the Chesapeake Bay watershed and its leading edge stood approximately at the present location of the Saint Lawrence River [Martin, 1973]. At the time, sea-level was still at least 25 meters below present [Belknap and Kraft, 1977] and the Chesapeake embayment was shifted significantly southeastward of its present position, much nearer the shelf break. Although the present Chesapeake Bay has only existed since the Holocene Period, geologists have traced the origins of the Bay to a 35.5 million-year-old impact crater centered on 37°16.5' N, 76°0.7' W, near the town of Cape Charles, Virginia [Koeberl et al., 1996].

Almost simultaneously with the advent of the hunters from the west, there were over 30 genera of megafauna (including mammoths, horses, saber tooth cats, giant beaver, ground sloths, camels, various pronghorns, dire wolves, peccaries, Asian antelope etc.) which became extinct [Martin, 1973; Bell and Walker, 1992]. There is continuing academic debate about whether quickly-changing climatic conditions or the first wave of humans were responsible for eradicating many of these large "keystone" animals [Fagan, 1991]. Whatever the contribution of humans, the mass extinctions must have created major dislocations in a variety of ecosystems in North America. The removal of these animals early in the Holocene Period undoubtedly helped to transform grassland systems (including marshes) from grazing systems to ones where the primary productivity is shunted into detrital pathways. As such, more primary production ends up being deposited in situ as peat or being exported (via
streams and rivers to the estuaries). Thus it is likely that long before the arrival of Europeans that humans arriving in CB were living in heavily-impacted ecosystems (which they exploited for food and shelter). Indeed the explosive megafaunal extinctions coupled with rising sea-levels and the ensuing effects on ecosystems; led Grove [1979] to argue that this time period was far more destructive in terms of natural resources -- than the modern period.

The impacts of humans in the CB landscape cannot be minimized. There are now indications some groups of very early (perhaps Pre-Clovis) Americans survived by foraging for forest products and hunting small animals and had minimal impact on the ecosystems they inhabited [Roosevelt et al., 1996]. Nevertheless, the invaders from Asia who crossed the Bering Strait land bridge about 11,000 BP were exceptionally skilled big-game hunters who had advanced technology (spears equipped with large fluted points similar to those found at Clovis, New Mexico). Also the fauna was at first totally unadapted to humanoid hunting who used fire for herding of large mammals for mass killing. Later in the Woodland Period (3,000 BC to settlement), Native Americans were forced to adapt to less game and used fire to help clear the forest for cultivation of maize, beans and squash (including agriculture). Most of these crops, including maize, originated further south in Mexico. Thus, the Indians actually began displacing native plant species as well as animals long before the arrival of the Europeans.

Despite clearings around village sites, there appears to have been “old growth forest” along the shoreline of the Chesapeake. Father Andrew White (who came to Maryland in 1634) noted on his arrival [Hall, 1967]: “... the soil is excellent so that we cannot set down a foot, but tread on Strawberries, raspries, fallen mulberrie vines, acorns, walnuts, saxafras etc: and those in the wildest woods. The ground is commonly a blacke mould above, and a foot within the ground of redish colour. All is high woods except where the Indians have cleared for corne. It abounds in delicate springs which are the best drinke. Bird diversity feathered there are infinite, as eagles, swans, geese, bitters, duckes, partridge read, blue, partie coloured, and the like by which will appeare, the place abounds not alone with profit, but also with pleasure.” By the late Woodland era the estimated 22,300 Indians in Virginia and a total of at least 45,000 Indians in the Bay watershed [Denevan, 1992] had a rich diversity of towns and cultures which had already made changes in the virgin landscape, and it would take the Europeans a considerable amount of time to impose an equivalent imprint on CB.

In September of 1570 a small band of Jesuit Priests made the first attempt to settle in Virginia, on the shores of the York River, a tributary of the Chesapeake which was then known on Spanish maps as the “Bahia de Santa Maria” [Gradie, 1988]. However, they would have little impact on the environment of the area -- they were easily exterminated the following February by the local Algonquian inhabitants [McCary, 1957]. The English were slightly luckier than the Spanish and almost failed in their effort to colonize an island 30 nautical miles up the mouth of the James River (Figure 2). Although the 104 of English “adventurers” made it through the long sea-voyage in good health, many became sick within weeks of their arrival in Virginia and a mere 38 were surviving in January of 1608 [Stahle et al., 1998]. Earle [1979] has hypothesized that this mortality was due to typhoid fever “Burning Fevers” and dysentery “Bloodie Fluxes” as well as the annual progression of the salt wedge up the James River which caused their drinking water to go brackish during the summer months. Unfortunately, Jamestown settlers had to cope with the driest 7-year period in 770 years [Stahle et al., 1998]. Thus the Indians had little extra food to spare the Jamestown island settlement. Winter was a time of particular suffering and during the “Starving Time” of 1609-10 most settlers removed to nearby oyster grounds of the James
River and ate oysters for nine weeks with only a bit of corn meal for variety [Wharton, 1973]. Despite John Smith's realization that congregating the colony at Jamestown caused excessive mortality, the Virginia Company repeatedly tried to repopulate Jamestown -- with catastrophic results. Their problems reached crisis proportions when the Pohawtan Indians made a concerted attack on the chain of English settlements along the James in 1622. This eventually led to the demise of the Virginia Company's control over the province and it became a Royal colony in 1624.

Of approximately 6,000 settlers sent to Jamestown beginning in 1607, about 4,800 had died by 1625 [Earle, 1979]. Because of excessive mortality and the lack of an intrinsic rate of increase of the first settlers, the actual transformation of forests along the 10,000 km shoreline of CB to agriculture was very slow during the seventeenth century [Carrier, 1957]. Eradication of native plant species was documented to some extent by the early botanists who came to the colonies [Reveal, 1992]. However, one example of an early coastal fishery which resulted in severe exploitation was the Atlantic Sturgeon (Acipenser oxyrhynchos). The early Virginia colonists were notoriously poor fishermen [Wharton, 1973]. However it didn't take much skill to catch these large (over 3 m long) slow moving bottom dwellers in the shallows as they swam upstream in the tidal rivers to spawn [Hildebrand and Schroeder, 1972]. For a brief period the Virginia Company placed great hope on the sturgeon fishery in the James River. However, the colonists were inept at preserving sturgeon and their eggs (used to make caviar) due in part to a lack of salt. It is not surprising that the Virginia colonists tried to produce salt using "salinas" along the barrier islands at the mouth of the Bay but abandoned efforts when it became apparent that precipitation was too high and they had to use considerable amounts of wood to boil the brine [Wharton, 1973]. This failure gave the sturgeon a reprieve for a while, but during the 19th century fishing pressure increased again. Finally in 1914 Maryland imposed a complete moratorium on harvesting of sturgeon for ten years and thereafter reduced the catch by imposing strict size limits [Hildebrand and Schroeder, 1972]. Despite regulatory efforts, sturgeon are now rare in CB and efforts are underway to restock various tributaries with this species.

Instead of fish as a cash crop, John Rolf pioneered the growing of tobacco which became the obsession of CB planters until the Revolution. Almost at once, Virginians embraced the growing of the "sotweed" to the point where almost every other aspect of the colony was neglected and has prompted Middleton [1984] to call the land surrounding CB "The Tobacco Coast". As early as 1617 Virginia Governor Samuel Argyll complained [Earle, 1979] that even in the capital at Jamestown "he found but five or six houses, the Church downe, the Palazado's broken, the Bridge in pieces, the Well of fresh water spoiled; the Store-house they used for the Church; the market place and streets, and all other places planted with Tobacco: ... the Colonie dispersed all about growing tobacco". Despite the growing of tobacco and over-fishing of sturgeon, most other resources in the CB such as wetlands and shallow water habitat remained little changed in the 17th century. This was due in part to the general avoidance of marshes and the dispersed settlement patterns. Indeed the lack of town development was a continuing source of embarrassment to many colonists [Kelly, 1979].

There were of course early changes in the forest land converted to fields at or near the water's edge. As the cultivation of tobacco became paramount, more forest was cleared for cultivation and surface runoff increased accordingly. However, initial clearing was carried out by simply girdling trees with an axe. Hills were then thrown up with a broad hoe for each tobacco plant. This caused minimal disruption of soil sediment output from these fields. Thus CB differed significantly from the NA because it was spared the ravages of the plow
until the 18th century. Since tobacco could only be cultivated for several years (before fields were depleted of nutrients), the land was allowed to revert to forest between plantings [Carrier, 1957]. Therefore, although all virgin forests were virtually cleared over time, a high percentage of the forest was actually regrowing and sediments were held in place. This helped to buffer impacts on receiving waters. Also, since tobacco removed nutrients from the soil and there was little if any maneuvering by the colonists, eutrophication was at first minimal. It was not until there was a shift away from tobacco after the mid-18th century that wholesale clearing of the land resulted in large amounts of sediment debouching into the tributaries of CB and other rivers along the eastern seaboard [Cronon, 1983].

By the Revolution (1776-1883), tobacco was still the staple crop in much of Virginia and Southern Maryland, but wheat became a popular crop on the upper Eastern Shore of Maryland. At the same time, wheat and corn were increasingly cultivated in the Piedmont of Maryland which provided grain for the mills of the emerging town of Baltimore. Soon Baltimore grew to be the third largest city in the U.S. and the largest on the CB. The period following the Revolution saw the growth of other CB urban centers such as Richmond, Norfolk and Washington, D.C. These new cities required extensive wharf facilities and to facilitate waterfront development, marsh and/or shallow water habitats were increasingly obliterated. There was even a law passed (i.e., “Act to Remove a Nuisance in Baltimore Town”) in 1766 requiring responsible land owners to remove “a large miry marsh giving off noxious vapors and putrid effluvia” [Capper et al., 1983]. In CB as in the NA, malaria was thought to come from “bad air” emanating from marshes in the summer. We now know that mosquitoes brought in open water casks from shrimp fishing ships coming from the Carribean brought malaria to the CB along with the more deadly yellow fever.

As increasing amounts of land were cleared upstream around CB in the late 19th century, soil erosion accelerated and silting of harbors was increasingly a problem for navigation [Gottschalk, 1945] and around piers such as Georgetown, Maryland [Arnebeck, 1994]. Part of the siltation was due to a series of particularly strong spring floods (freshets) which occurred in the latter half of the eighteenth century [Middleton, 1984]. The turbid appearance of streams and rivers after freshets was commented on by various visitors who traveled the Atlantic Seaboard region in the 1700s [Cronon, 1983]. These floods coincided with increasingly large amounts of the Piedmont in the southeastern United States being cleared for agriculture [Trimble, 1974]. The piedmont region, located between the mountains and the coastal plain has comparatively friable fine-grained clay soils. Excessive amounts of fine-grained clay particles were moved downstream to the heads of estuaries during high runoff periods in the spring (i.e., freshets). Especially on the western shore of Chesapeake Bay, excessive sediments changed the bottom configuration, often filling in deep channels to the point where marshes were created [Froomer, 1980]. It appears that in areas in Southern Maryland such as Parker’s Creek, Fisherman’s Creek, St. Clements Bay, and Port Tobacco, marshes accreted considerably due to siltation. Delta emergence has also been documented at Otter Creek northeast of Baltimore and is now becoming substrate for wetland development [Pastemak and Brush, in press].

Because excessive amounts of fertile soil were washing into CB, there was increasing concern in the first quarter of the 19th century that something should be done to improve farm management practices. In 1817, Edward Lloyd, vice president of the Maryland Agricultural Society, urged his contemporaries to try to improve methods of farming since “Lands generally in Maryland are nearly exhausted” and “our agriculture is sinking to its lowest stages of degradation” [Wiser, 1963]. Although there were some attempts in the early 1800s at improving soil fertility by using pulverized oyster shells and exotic additives (e.g.,
plaster of Paris imported from as far away as Nova Scotia), guano from South America was not imported commercially until the 1820's [Cornwell et al., 1996]. After 1850, large amounts of guano were shipped from Peru and applied to fields in the watershed of CB. In addition, animal bones were treated with strong acid and the pulverized end-product was widely sold as "Super-phosphate" fertilizer.

After the Civil War, there were major economic changes throughout the Southern U.S. with some former slaves (i.e., freedmen) staying on the land as sharecroppers [Shlomowitz, 1979]. However, many around CB signed onto the burgeoning fleet of vessels, becoming "Watermen". These were men who fished, crabbéd and oystered for a living. Because of the loss of slave labor in the decades following the Civil War, real estate was cheap on the Eastern Shore and large proprietors were willing to sell their old plantations [Harrison, 1915]. Thereafter, much of the land previously cleared and maintained for agriculture (by slaves) began to revert to forest and/or was converted for less labor-intensive crops (e.g., peach orchards). Although the amount of cropland began to decrease after the Civil War, the amount of fertilizer use increased. Perhaps reflecting incipient eutrophication, Cooper and Brush [1993], detected shifts in species composition of diatoms in parts of CB even before 1900. Increases in nutrient concentrations have been observed in sediment cores in marshes of the Patuxent River beginning about 1850 to 1900 [Kahn and Brush, 1994], and again have been interpreted as signaling eutrophication. However, other studies in mid-CB suggest that excess nutrients in sediments did not occur until mid-20th century [Cornwell et al., 1996].

Another factor which made agriculture more polluting was the introduction steam tractors in the 19th century in the CB. This allowed more frequent and deeper tillage than plowing with oxen or horses. The gasoline-powered tractor was not developed until the 1890s and it was not infrequent in the CB region until the next century. During the 1920s, U.S. farms having tractors increased from 3.6 to 13.5 per cent [Ankli, 1980]. Smaller tractors allowed tillage very close to the convoluted shoreline of CB often exacerbating sediment erosion from agricultural fields. Also during the first decade of the 20th century synthetic nitrogen fertilizers were developed by Fritz Haber in Germany (where NH3 was produced from N2 gas under very high pressure and temperature). Commercial production of this process led to increasing amounts of inorganic N being applied to fields of CB in steadily increasing amounts until the 1980s. At that time it was widely recognized that N-runoff was a problem and farmers began to moderate their applications because of environmental pressures [Cornwell et al., 1996]. In addition, applications of nitrogen ended up not only in surface waters around CB, but also surficial aquifers became increasingly contaminated with high levels of nitrate [Bachman, 1984]. Presently many shallow wells have been contaminated by levels of nitrate exceeding 10 mg l-1, which is the maximum safe limit established by the U.S. Environmental Protection Agency (EPA) for drinking water [Hamilton et al., 1993]. An interesting trend was established by the EPA Bay Program in forest coverage. Although the Chesapeake Bay watershed was once almost totally forested, by the mid-1800s forest land had dropped to 50% with most of the open land being agriculture (Figure 10). Thus, application of fertilizers would begin to have potentially large effects in terms of the overall CB nutrient budget. As in the NA, forested land percentages increased upwards. In CB they exceeded 60% before declining again. However, the recent decline of forested land is due to suburban sprawl associated with increasing population pressures (Table 1).

In addition to agriculture, CB nutrient loadings came from sewage in the 19th Century. Sewage collection systems were constructed as early as the 1820's in Washington, D.C. marking the initiation of "point-source pollution" in the Potomac River. Baltimore was one
Table 1. Comparison of Projected Population Increases (1990-2020) and Shore Erosion Trends in Maryland By County.

<table>
<thead>
<tr>
<th>County</th>
<th>% Pop. Increase</th>
<th>Erosion Rate</th>
</tr>
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<tbody>
<tr>
<td>Eastern Shore</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kent</td>
<td>0-24</td>
<td>Slight to Moderate</td>
</tr>
<tr>
<td>*Queen Annes</td>
<td>25-99</td>
<td>High to Severe</td>
</tr>
<tr>
<td>*Talbot</td>
<td>50-99</td>
<td>Slight to Severe</td>
</tr>
<tr>
<td>Dorchester</td>
<td>0-24</td>
<td>Moderate to High</td>
</tr>
<tr>
<td>Wicomico</td>
<td>0-24</td>
<td>Slight to High</td>
</tr>
<tr>
<td>Somerset</td>
<td>0-24</td>
<td>High</td>
</tr>
<tr>
<td>Western Shore</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cecil</td>
<td>0-24</td>
<td>Slight</td>
</tr>
<tr>
<td>Harford</td>
<td>0-24</td>
<td>Moderate</td>
</tr>
<tr>
<td>Baltimore</td>
<td>0-24</td>
<td>Moderate to Severe</td>
</tr>
<tr>
<td>Anne Arundel</td>
<td>0-24</td>
<td>Moderate to Severe</td>
</tr>
<tr>
<td>*Calvert</td>
<td>50-74</td>
<td>Moderate to Severe</td>
</tr>
<tr>
<td>*St. Marys</td>
<td>25-49</td>
<td>Moderate to Severe</td>
</tr>
</tbody>
</table>

of the last major cities to install a sewage system, which was delayed until 1906 [Capper et al., 1983]. Watermen fought the concept of waste collection and overboard disposal (with no treatment), because they were worried about the health effects of sewage on shellfish. In the 1890s the U.S. Congress was so appalled at the stench in the waters around Washington, D.C. that they ordered a major outfall be placed further downstream in the Potomac River. Also, circa 1900, the first indication of waters of the Potomac being polluted by paper-mill effluent was made public by a representative of a federal agency (U.S. Geological Survey). During most of the 20th century sewage loadings continued to increase and many CB tributaries began to be overloaded with nutrients which prompted the U.S. EPA to initiate a large multi-year program in 1976 to identify key problems and solutions [Malone et al., 1993].

Of course nutrients and sediments are not the only pollution problems in the shallow waters of CB. As in the Venice lagoon there are toxic hot spots. The emergence of Baltimore as the third most populated city in the U.S. in the first half of the 19th century brought considerable industry to the Patapsco River, a tributary on the “Western Shore” of CB. At first, the most important early industry was flour milling which was relatively non-polluting. However, others industries which developed as the century progressed, such as tin, chromium and iron works, proved to be another story. Baltimore became a canning center in the mid-1800s and after the Civil War there was increasing interest in producing steel (using Bessemer’s newly invented process). In 1887, a joint venture between Pennsylvania Steel and Bethlehem Steel created a massive new steelworks at Sparrow’s Point, previously a quiet plantation [Reutter, 1988]. This low lying marshy site quickly developed into a huge industrial complex with its own little town to house the workers. Here iron ore (shipped from Cuba) was refined using coal (delivered by rail from the west) and converted into steel. In 1891, during the first year of operation, Sparrows Point produced 350,000 tons of steel -- more than that of Sweden and Italy combined. [Reutter, 1988]. Some of it was tinned and went into the canning industry but much went into making steel rails and plates. Later, shipbuilding became an important part of the operation. Sparrows Point was viewed as a marvel of the industrial age and by the 1950s it had grown into the largest individually-owned steel center in the free world [Reutter, 1988]. However, the environmental costs of such a large manufacturing operation have been high. In the 1990s, the remaining owner, Bethlehem Steel, had to pay the single largest fine ever imposed in CB for a host of violations to the environment. As with the Mestre/Marghera complex in the Venice Lagoon, much of the pollution history of Sparrows Point is preserved in the surrounding sediments and remains to be elucidated. A dated core recently extracted off Sparrows Point indicates that lead levels ranged up to 4 mg g⁻¹ sediment in the 1940s, or about 40 times higher than typical mainstem CB [J. Cornwell, pers. com.]. Although perhaps not as dramatic, similar “hot spots” in the CB have been identified in the Elizabeth River from Norfolk and near the head of the James River at Hopewell [Helz and Huggett, 1987].

Shoreline Ecosystems at the Interface of Chesapeake Bay

Although toxics may be a problem in isolated areas, most widespread changes in CB have been attributed to increased nutrient loadings which have manifested themselves as eutrophication [D’Elia, 1987]. One prime example is the loss of submersed aquatic vegetation (SAV) throughout the shallows of CB [Stevenson and Confer, 1978; Orth and Moore, 1983]. Although limited declines in eelgrass, Zostera marina, was noted in the 1920s
due to Labyrinthula (wasting disease), the catastrophic SAV decline occurred after Tropical Storm Agnes hit CB in June of 1972. This storm resulted in a massive flush of nutrients, sediments and pesticides (including herbicides) from surrounding farmland [Stevenson and Confer, 1978]. Unfortunately instead of recovering in the 1970s, SAV continued to decline, causing considerable concern among resource managers. A variety of fish and invertebrates (such as blue crabs and clams) inhabit SAV beds and waterfowl feed directly on them during their migration from Canada southward in the autumn [Stevenson, 1988].

A series of studies [Stevenson et al., 1982; Kemp et al., 1983; Cunningham et al., 1984, Twilley et al., 1985] came to the conclusion that although commonly used herbicides such as atrazine can certainly harm SAV, concentrations in CB did not appear to be high enough to cause extensive damage. More problematic were high nutrient and sediment concentrations which interact to limit the light available to leaves. Unfortunately, high sediment loads and high nutrients persist in the oligohaline to mesohaline portions of many CB tributaries are surrounded by agricultural fields [Stevenson et al., 1993]. As in the Venice Lagoon and other impacted areas of the NA, nutrients not only cause dense phytoplankton blooms in the water column but also promote algal growth on leaves (epiphytes) and sediments. A secondary community develops within the epiphytes, consisting of animals such as bryozoans. The mucilaginous secretions of bryozoans can cause suspended sediments from the water column also adhere to leaves, forming a dense matrix. Leaves can be weighted down with more than five times their own mass of material and eventually SAV photosynthesis becomes too small to support the respiratory demand of the system [Staver, 1984].

While the decline of SAV and other resources (oysters, anadromous fish, crabs, turtles, and waterfowl) has been associated with excessive nutrients and with over-fishing (and hunting) there is also an argument that other habitats at the bay margin have been in decline in recent years and have contributed to the diminished harvests. This could be especially true of blue crabs which depend on safe place to molt. With diminished SAV the crabs become increasingly dependent on quiescent marsh embayments for their survival. Unfortunately, at a time when invertebrates like blue crabs depend increasingly on tidal marsh habitats, these too have been decreasing in recent years because of RSL rise. The relationships between marshes, sea-level rise and sediment supplies have many ramifications and needs thorough examination.

CB contains the greatest area of tidal marshes along the middle-Atlantic coast, containing between 120,000 [Stevenson et al., 1985b] and 150,000 hectares [Tiner, 1985]. From a purely ecological standpoint, these marshes play an important habitat role for the traditional species associated with the CB: blue crabs, terrapin turtles, waterfowl of every description, a great variety of fish and muskrats, which were once prized for their fur. Yet, coastal marshes are currently disappearing in the CB at a considerable rate [Stevenson et al., 1985b; Kearney et al., 1988]. Not all marshes in the CB are equally vulnerable, and any prediction on the fate of marshes in this large estuary must be based in an understanding of how the evolution of certain marsh types preconditions them to rapid disappearance if sea level rises sharply, whereas other marsh types may initially remain stable.

Generally, "Estuarine Meander" and "Tidal Fresh" marshes are common in the major tributaries on both the western and eastern shores of CB [Ahnert, 1960] and are able to withstand considerable RSL rise because they receive high sediment inputs [Kearney et al., 1988]. On the other hand, "Submerged Upland" marshes originate from the gradual submergence of low-lying, flat terrain which characterizes much of the CB's Eastern Shore [Darmody and Foss, 1979; Stevenson et al., 1985b]. As these marshes evolve, spreading
across former upland surfaces, interior marsh areas become progressively isolated from major creek systems, mineral sediment influx drops, and vertical accretion becomes increasingly a function of peat accumulation [Stevenson et al., 1985a]. In addition, Stevenson et al. [1988] lengthening reaches of extant tidal creeks in the expanding marshes promote stronger ebb velocities than flood velocities, and more sediment begins to be transported out of the marsh than into it during the tidal cycle. Often, these marshes end up sediment "starved" [Stevenson et al., 1988] and have at least this commonality with many marshes of the NA.

Sea-level Rise in The Chesapeake Compared to The Adriatic

Although global warming and consequential sea-level rise are often viewed as minor consequences for deep water planktonic and benthic communities, it plays a dominant role in structuring littoral ecosystems. One question which was unaddressed before we met in Slovenia and Croatia was: how do these two systems compare in terms of sea level rise? This is not quite so straightforward as might be expected because RSL rise is essentially the secular trend discernable from long-term tide gauge records, uncorrected for land subsidence. Therefore, it comprises processes in two domains, the terrestrial and marine, which may or may not be related. Ideally, tide gage records of 40 years or longer are desirable to determine reliable rates [Douglass, 1991]. In reality, for a detailed picture of sea-level impacts, shorter tide gage records often have to be considered. In CB the longest term data set at Baltimore goes back to 1903 and is about 30 cm per century (Figure 11). Wray et al. [1995] estimation shows a definite flattening in the curve before 1870 using synthesized data form the New York tide gauge. The reliance on synthesized data is often controversial but Wray et al.'s [1995] conclusion of acceleration of RSL rise in CB matches that of Kearney and Stevenson [1991], who used a different approach. Surprisingly, in view of the widespread publicity concerning the sinking of Venice, it appears that RSL rise there and in Trieste are less than in CB (Figure 12). In addition the Venice tide record appears to have leveled off after the early 1970s, apparently due to the cessation of groundwater pumping [Pirazzoli, 1991].

According to Nerem et al. [1998], present rates of sea-level rise in CB range from about -2.4 mm yr\(^{-1}\) at the head to over 7.9 mm yr\(^{-1}\) at Cambridge and 6.7 near the Bay mouth at the Chesapeake Bay Bridge Tunnel. The RSL rise at Cambridge is among the higher estimates along the entire U.S. coastline [Stevenson et al., 1986], but the measurements have been sporadic so interpretation is difficult (Figure 13). Although Nerem's estimates may be somewhat high, they undoubtedly reflect regional, groundwater withdrawal [Rule, 1995]. Also these rates of RSL rise are much greater than Peltier [1985] estimates for the overall rate of sea-level rise for the last thousand years on the basis from theoretical calculations (i.e., about 0.4 mm yr\(^{-1}\)). The classic deceleration in sea-level rise that typifies the late Holocene sea-level curve is associated with a (eustatic) sea-level rise in the CB region of 1.2-1.8 mm yr\(^{-1}\) [Gornitz and Lebedeff, 1987; Douglas, 1991]. The sea-level changes suggest that sea levels in CB have risen as much in 150 years as they have in the preceding 500 years [Kearney, 1996]. That the rate of sea-level rise in the Bay began to accelerate after 1850, was suggested by Kearney and Stevenson [1991] because of changes in historical land loss of the islands in CB. They found that Island abandonment corresponded with an upturn of RSL rise especially after 1920. Braatz and Aubrey [1987] independently concluded from tide-gauge records along the U.S. Atlantic Coast, that most show a sharp inflection in RSL rise after
Forest trends in the Bay watershed

![Forest trends in the Bay watershed](image)

Figure 11. Estimated Percentage of the Forest Coverage in the Chesapeake Bay Watershed 1650-1995 [Courtesy of EPA Chesapeake Bay Program].

1920. However, a very different picture emerges for Bakar on the eastern NA located about 10 km East of Rijeka (Figure 1). Although a linear extrapolation suggests an increase of 8 cm from 1930 to 1990 or about 1.3 mm yr⁻¹ (Figure 14), a more accurate fit might be curvilinear suggesting that this area has actually leveled off after 1970. Even though more data are necessary to resolve this issue, this indicates that there is considerable variability in RSL in the NA as well as the CB. What is surprising is that RSL rise in CB tends to be higher than it is in the NA.

In the decades since WW II, sea-level rise in CB has prompted shore erosion studies [Byrne and Anderson, 1978]. Both shore erosion and the disappearance of marshes are occurring at an alarming rate on the Eastern Shore [Stevenson et al., 1985a; Kearney et al., 1988; Stevenson and Kearney, 1996]. The available data indicate that the onset of the present sea-level trend, when viewed across the span of the last millennium, has been both historically sudden and perhaps unprecedented in magnitude resulting in massive shoreline erosion and retreat in some parts of the Bay [Kearney, 1996]. CB is analogous to a narrow shallow pan and seldom exceeds 8 km in width, with average water depths of only 8.2 m. Average wave heights for most of the Bay average <0.3 m [Ward et al., 1989]. Although wave activity is relatively damped compared to open coasts, wind (and resonant seiche motion) is critical in determining water levels [Chuang and Boicourt, 1989] and erosion potential of storms. During storms, depending on wind direction and speed, however, wave heights can approach 3 m [Ward et al., 1989]. Apocryphal 19th century stories [Shomette, 1982] report waves allegedly reaching heights of 15 m or more. However, the largest...
Figure 12. Relative Sea Level Rise at Venice and Trieste in Italy [Sortino et al., 1985].
Figure 13. Relative Sea Level Rise at Cambridge, Maryland, Determined from Data over Four Time Periods [Data from: NOAA, U.S. Department of Interior].

Figure 14. Relative Sea Level Rise at Bakar, Croatia (Data Courtesy of: B. Douglas, University of Maryland, Department of Geography).
documented waves occurred during Hurricane Connie in 1955, when storm swells reportedly exceeded 8 m off Sharp's Island Light near the mouth of the Choptank River [Shomette, 1982].

Shoreline recession, is pervasive not only along the shores of CB but in the lower tributaries as well, despite generally low wave environment (compared to the Atlantic Coast). This phenomenon often is typical of estuarine shorelines, where shore erosion rates often outpace those of adjacent open coasts [Nordstrom, 1992]. Rosen [1967] pointed out that the most vulnerable shorelines are those with low tidal amplitude because they have lower elevation beaches. One of the more active areas on the mainstem of the Bay is Calvert Cliffs located at mid Bay in Calvert County, Maryland, which consist of 10 to 35 m high bluffs with rates of erosion ranging from 0.1 to over 2 m yr\(^{-1}\) [Wilcock et al., 1998]. This shoreline has less than 0.3 m tidal range. However, this erosion is by no means atypical since 20% of the mainstem CB shoreline is retreating at rates approaching 2 m yr\(^{-1}\) (Figure 15), and most areas are experiencing annual retreat rates of at least 0.5 m (Stevenson and Kearney, 1996). Over the past century, approximately 18,000 have disappeared from shore erosion, an area about the size of the District of Columbia [USACE, 1990]. Moreover in exposed environments, such as Hooper's, James' and Taylor's Islands, in Dorchester County, Maryland, shoreline retreat rates of 10 m have been known to occur in a single year! Byrne and Anderson [1978] found retreat rates on the northwest end of Tangier Island were almost 10 m yr\(^{-1}\). In one stormy three-month period in the 1970s, this part of the island was further diminished by over 5 m of shoreline retreat [Bowes, 1991]. These high rates of shoreline recession are associated with collapsing cliffs on the western shore and the presence of large numbers of trees in the surf on the islands of the eastern Shore [Stevenson and Kearney, 1996]. Equally compelling is the reduction in size or complete loss of Bay islands (e.g., Sharp's Island at the mouth of the Choptank River) which forced most to be abandoned during the twentieth century [Kearney and Stevenson, 1991]. Even in places were erosion in CB has been less than 0.3 m yr\(^{-1}\), such as around Jamestown Island, part of the original fort built in 1607 has been lost to the encroaching James River [Hobbs et al., 1994].

As we have seen in the Venice Lagoon of the NA, shoreline retreat in CB is the result of two distinct processes, lateral erosion and simple submergence, which often operate in tandem. Lateral shore erosion is the principal mechanism in many areas; but until recently, the processes involved have been little studied and mostly extrapolated from studies done on the open coast. One classic example is the appropriation of the Bruun Rule to explain shoreline retreat in the Lower CB, which was only moderately successful even though significantly altered from Bruun's original conception [Rosen, 1981]. Shorelines in the CB after storm events may not reflect onshore transport of eroded sediment at all, but reestablishment of the littoral sediment transport system from an eroding headland. Littoral sediment transport rates in the Bay can be quite high, approaching several hundred thousand cubic meters annually [Downs, 1993].

Although all the factors that determine shoreline configurations have not been elucidated in enough detail to make a quantitative model, stability is related mainly to the amount of RSL, wave energy, and sediment transport at the toe of the eroding bluffs. Shore erosion along the cliffs of CB's western shore is a case in point. In these shorelines, sediment often collapses as whole blocks during winter due to narrowed beaches when storm waves break directly against the base of slopes initiate toe erosion (Figure 16). When critical shear stress thresholds are finally reached, slumping is initiated. In the event that a major slope failure occurs, the new equilibrium profile is often displaced considerably landward of the slope summit. In contrast, the base of the slope where the debris accumulates may
Shoreline Retreat Rates

Figure 15. General Rates of Shoreline Retreat for Chesapeake Bay. For Virginia, Slight = 0-0.3 M Yr⁻¹; Moderate = 0.3-1 M Yr⁻¹; High = 1-2 M Yr⁻¹; Severe = >2 M/yr. For Maryland, Slight = 0-0.6 M Yr⁻¹; Moderate = 0.6->1 M Yr⁻¹; High = >1->2.5 M Yr⁻¹. From: Stevenson and Kearney, 1996).
actually prograde. Sometimes cliff failure is also exacerbated by sapping, especially in the Tertiary age sands and muds composing the Calvert Cliffs of CB. Leatherman [1986] described sapping and failure of Miocene sands where underlying marls impede percolation and form a locally perched water table. Groundwater then seeps at the contact exposed in the cliff face, undermining the stability of capping sands which can contribute to cliff failure. Another mechanism described by Wilcock et al. [1998] suggests the importance of freeze/thaw cycles in recession of coastal bluffs in CB. Many of these features of erosion are not significant in the NA because of the lack of unconsolidated cliffs and it seldom freezes in this Mediterranean climate for significant periods.

Although shore erosion predominates in the western shores of CB, simple coastal submergence is prevalent in many areas of the low-lying Eastern Shore as it is along the Italian coastline of the NA. The wide expanses of submerging marshes along the Delmarva Peninsula and the Venice lagoon amply testify to the power of progressive submergence as a dominant process along this coastline. Even if these areas are relatively wave-protected, marshes can rapidly disappear as sea-level rises. This tendency of loss is especially evident in regions which have microbial diurnal (or diel) tides. When Bora winds of the NA or low pressure NorEasters of CB pile water up over a meter, weak tidal activity does not re-expose marsh surfaces sometimes for days. High water levels can be especially problematic in spring and summer when metabolism creates anaerobic waters which decrease plant productivity. Thus even temporarily submerged marshes can suffer continued physiological stress which may slow down organic production and peat accretion, making them that much more vulnerable to sea-level rise.

In the next century, the escalating changes being wrought by sea-level rise may find the configurations of the CB and NA appreciably different from today. Differential land subsidence accounts for much of the secular trend. It is increasingly a possibility that global sea level rise may eventually outpace present subsidence rates. Over the last 100 years, there
has been a more marked shift than at any time in the last 5000 years. The climatic linkage behind these changes is becoming inescapable, with very little lag between the changes in global climate and the response of sea level [Schneider, 1989]. Given the pressure for the development of the NA and Chesapeake's shores (which can be reasonably expected to continue well into the next century) concerns are increasing that a major disaster may be lurking in the future. Clearer insight into basic land-sea interactions at the shoreline level is critical if any adequate protection measures are to be formulated. Using Schubel and Carter's [1976] estimated input of $1.75 \times 10^6$ tons yr$^{-1}$ into CB, there is a shortfall in the sediment entering CB necessary to offset sea-level rise. If that input were spread over the entire bay bottom it would amount to an accretion rate of about 0.8 mm yr$^{-1}$. This is well short of the 3-5 mm yr$^{-1}$ necessary to keep up with RSL rise. It is no surprise based on shoreline observations that CB is drowning but these calculations indicate it is deepening as well [Stevenson and Kearney, 1996]. Because of the deficits in the overall sediment budget, the sea level future for any particular reach of CB shoreline is particularly ominous.

The NA is about five times deeper and has a tremendous volume compared to the CB. Although we know of no sediment budget for this region to compare inputs with sea-level rise, it would be less instructive than that of the Chesapeake, because the issue of geological aging is so remote in the NA. However, we would argue that sediment supplies are just as critical to the eastern NA as they are in the CB for maintaining shoreline stability. Predictions for changes in the rate of global sea-level rise are highly controversial [Schneider, 1989], and are subject to regional variations such as the elevation of contiguous oceans which modulate sea levels considerably. However, at the local scale, indigenous factors (e.g., subsidence), are often equally poorly understood, and can temper or exacerbate any global trend. Nonetheless, we can present some reasonable shoreline scenarios based on our understanding of present sea-level effects. Indeed, some of these changes may be within our control should we choose to exercise them.

One strategy for marsh stabilization is to use techniques developed in Louisiana for supplementing sediments to marshes. Day et al. [1998] have attempted to stabilize marshes in the Venice Lagoon using sediment fences with varying degrees of success. More promising might be the utilization of dredged materials, as has been tried in Louisiana [Cahoon and Cowan, 1988]. Currently, large amounts of sediment are dredged from the CB and from the harbors of the NA every year. Instead of creating islands and depositing it on uplands or deep water, efforts have been made to use the dredge material to stabilize eroding marshes and low-lying islands which are facing obliteration by sea-level rise. Of course many details need to be worked out before this becomes an acceptable option, but with the advent of new technologies (i.e., global positioning systems, new dredging techniques and etc.) control of the vertical datum is much more feasible than in the past.

The prospect of a quantum leap in the rate of global sea-level rise could produce a transgression of the sea into lagoons and estuaries which have not experienced such water levels in millennia. Only naturally hard shorelines such as that found in Croatia and Slovenia will be somewhat buffered if the NA rises more rapidly. However, there are many port marinas and hotel facilities where a 1 meter sea level rise could pose a potent threat. Although the threat is real enough, the prediction of what may happen will be difficult for any particular shoreline. Along the shores of these bodies of water there are numerous complicating factors of shoreface and slope processes which make any simple linear extrapolation of historical shoreline trends risky. Compounding this may be hidden problems involving enhanced rates of longshore transport from rapidly eroding headlands. As transport rates increase to positions downstream, will retreat rates slow from projected figures as
increasing sediment inputs buffer shoreline response? Currently, there is simply too little known about sediment sources and longshore transport in either the CB or NA to serve as any basis for prediction.

Prediction of future shoreline behavior in response to sea-level is less complex for areas where simple submergence is the major or sole agent of shoreline retreat. In this instance, hypsometric models can provide sea-level predictions. Especially low-lying areas like those of the lower Eastern Shore of Maryland and Venice as well as parts of the Po Delta could be submerged by the 2100. Giese and Aubrey [1989] undertook a hypsometric comparison for the Massachusetts coast, where rocky shores in several areas often limit the straightforward application of shore erosion projections in a rapidly transgressing sea. So far this approach has not been attempted in CB. Bondesan et al. [1995] have made an attempt to assess the effects of flooding on about half of the Italian Coastline of the NA using land contours. Even a rudimentary estimate, extrapolating from present coastal property values around CB (somewhere between $10,000 to $100,000 per acre, depending upon locale) suggests that property losses could exceed $120 million annually if rates of shore erosion were to double. By 2100, these losses could easily exceed $10 billion (present dollars), even without any further increase in the rate of sea-level rise. Escalating property values will almost certainly inflate the absolute dollar figure, perhaps to levels beyond comprehension today.

Possibilities of Increasing Habitat Protection at the Land-Sea Interface

The existing picture of land utilization surrounding the NA and CB shows very complex anthropogenically impacted landscapes. In areas around the major cities where the environment has been especially degraded with toxics as well as nutrients there still remains much work to do. The high spatial concentration of activities often results in ecosystems which are rather unique in themselves but are objectionable to humans. The odors of Baltimore’s Inner Harbor can easily match those of Venice’s canals on warm summer nights when anoxic gases are likely to be emitted. Within even the most impacted of urban areas there ought to be some possibilities for restoration of small patches where preservation is a priority. Although perhaps no where near their natural state, they can offer a wide variety of animals respite from a completely urbanized environment. One can argue that preservation of marshes in both the NA and CB can serve a variety of functions for humans as well as provide habitat for various creatures. One ambitious attempt around Washington, D.C. is the restoration of a system of parks along the Anacostia River which has been heavily impacted by water control projects and numerous pollutants [Schleakat et al., 1994; Velinsky et al., 1994; Wade et al., 1994].

Urbanization of the Slovene coast results in problems similar to those in much of the CB coastal zone where there is a conflict between preserving the environment and developing port, housing and tourist facilities. The dilemma in the development of the Slovene coast involves huge pre-existing monetary investments including the shipyard in Izola and the marinas in Izola and Koper. In addition, development issues surround the salt pans in Seövlgje, the coastal motor way, the extension of the port of Koper into the Bay of Ankaran, the water accumulations and drainage in the Dragonja River basin, the racetrack and airport in Seövlgje, and the construction of holiday cottages in Fiesa. These conflicts have led the Ministry of the Environment and Physical Planning of Slovenia to organize a special planning workshop to guide development in the coastal zone. One of the most recent plans,
the so-called Development Project Koper 2020, proposes relatively moderate development. According to the “green scenario” of this development plan for the municipality of Koper, economic growth will initially be moderate, followed by a gradual increase after the rehabilitation of the economy. The expansion of the port of Koper will be subjected to environmental protection criteria and tourism will develop on a higher quality level and in cooperation with the central part of Slovenia. Another objective of the plan is to reserve land for a University Center. In addition the plan calls for agriculture oriented toward growing crops more suited to the local climate (wine, fruit, olives and vegetables).

The present development program in Slovenia stems from the realization that environmental burdens of the coastal region have reached a very high level. The question is whether the restrained development plans can withstand increasing economic pressures for accelerated development of the coastal zone. For the region as a whole the establishment of two independent states, Croatia and Slovenia, has added to the complexities of governance of the small Istria peninsula, where the tourists flock to isolated coves to sunbathe and holiday cottage industries have been especially lucrative in the 1990s. Two separate governments, along with Italy, now have to weigh environmental choices in the region.

The Gulf of Trieste is also exposed to growing international pressures because its watershed extends deep into the mainland of Central Europe. The construction of relatively large marinas in each of the coastal towns is a visible sign of the increasing popularity of the Gulf of Trieste. The NA is marketed as a destination for foreign tourists from Austria, Germany, and other affluent Central European countries which lie relatively close to this part of the NA. Improvements in the network of highways are making this coastline more accessible from these European Countries which is expected to generate more pressure for hotel and marina facilities. But marinas consume large amounts of space along the littoral zone which is especially problematic for the short coastline of Slovenia. A similar situation exists in plans for the construction of holiday cottages in Fiesa in Slovenia. Because of the expected high demand, individual construction companies anticipate high profits. The market price of apartments and the related profits are expected to be proportional to their closeness to the coastline. Local authorities face serious challenges if they are to implement the “green scenario” (i.e., moderate development), or other strategies to relieve the overburdened coastal environment in Slovenia.

A similar, perhaps more ambitious project aimed at ensuring the preservation of a healthy human environment for the present and future generations is the “Development Project Koper 2020" in Slovenia. This project has a number of components. These range from rehabilitation of existing degradation resulting from pollution of the sea (particularly municipal and industrial sewage), water flows (Riàna River), air (industrial facilities, Port of Koper and individual heating), emissions from motor vehicles and other environmental alterations (such as quarries, buildings and marina and other tourist-related facilities) to regulate the development of the Port of Koper. As in the Anacostia project in the CB, there is high priority placed on creating a green belt and a protective forest system as well as refining land improvement programs. The overall goal is to ensure maximum protection of natural and cultural heritage and implement mechanisms for their maintenance and effective presentation with an effective system of supervision and means of penalizing violators.

These are of course laudable plans but the question remains: Can all these measures be effectively implemented? Needless to say their price will be relatively high, as the authors of the development project have come to realize. A condition for their successful implementation is, therefore, a flourishing economic sector that would be capable of ensuring the necessary resources. But is this a closed circle? The improvement of the
environment seems to be conditioned by its further burdening. Appropriate spatial management should be accompanied by changes in economic activities, which would limit their impact on the environment to the lowest possible and still rational level. The strategy in this case is the same as in any other environmentally-oriented activity: optimal spatial distribution of individual activities, i.e., allocation to places where they cause the least damage to the environment, and the implementation of such activities/technologies as will ensure the least possible damage to the environment.

In Slovenia the existing strategy of statutory protection, which encompasses compulsory compliance with the allowable level of impact on the environment and the creation of natural reserves, may not suffice. It does not ensure the full implementation of the principle of the maximum rationally attainable level of protection. Merely preparing a list of more preserved or high-quality natural habitats in the environment, which is currently one of the priority tasks of services for the protection of natural heritage, is not sufficient. It is also necessary to identify the potentially significant habitats and prioritize their protection. In this case their significance can no longer be defined solely on the basis of the natural state of the environment, but on the role of the natural habitat in a broader sense, for example, with respect to their significance in a broader ecological sense. A ravine or stream whose value was reduced due to the illegal depositing of wastes or the construction of facilities have, despite their poor current condition, a relatively large potential for their restoration to a more natural state. For this reason the governing principle in the rehabilitation of such areas cannot be their further anthropogenization. Or, as in the case of the rehabilitation of the abandoned salt pans in Koper, the potential for malaria cannot be a reason for draining the marshes and changing them into agricultural land. Other possible solutions to the basic problem must be found which are based on environmental as well as purely political criteria.

As we have already seen, land utilization in the coastal zone of Slovenia is being restructured to allow marginal agricultural land to return to a more natural state. At the same time, traditional towns and farms in the hinterland are being depopulated with their inhabitants migrating to the more lucrative coastal zone. This process points to the intensified utilization and burdening of the edge of the NA while agriculture was abandoned in the hinterland. This is viewed by some as negative, primarily because much of the heritage of the cultivated landscape is lost. Several measures have been proposed for the prevention of such processes (e.g., the subsidizing of less profitable agriculture, the implementation of programs for stimulating economic development in demographically endangered areas, etc.). Unfortunately, all these measures have failed to reduce the pressure on more intensively developing regions. In assessing the changing pattern of land utilization, the advantages must also be considered. Although the "restoring of nature" means less "cultivated landscape heritage," it can be viewed, from the standpoint of environmental protection, as positive. This process of restructuring land use must be viewed from many scales and has global implications for other regions including CB where agriculture has been sacrificed to suburban sprawl in many locations. Although there are now economic incentives to maintaining farmland, this may not be best, from an environmental stance, in view of non-point source pollution. Environmental protection may ultimately involve a better way of building suburbs (with more natural areas intact than at present). Consequently, abandonment of farming is not inherently problematic for the environment.

The proposal for the establishment of green systems in other parts of the NA and CB should build on the idea of forested land intermixed with more developed land use types as an integral landscape [Brancelj, 1994]. The existing forest areas, streams and rivers, ravines, coastlines, tidal marshes, smaller marshy patches of land in the mainland (isolated non-tidal
wetlands), and municipal greenery, should be linked into a coherent system. Its objective is to create a more pleasant living environment, recreational areas and to alleviate, to the greatest possible extent, the unfavorable effects of various human activities on the environment. Of course the “green system” is only one of the much needed measures, albeit one of extreme importance, for the preservation of natural habitats. It should be viewed as a form of rehabilitation after the damage has already been done to the environment as well as from a preservation viewpoint.

One long term problem facing both the CB and the NA is the degree to which drowning appears to make appreciable impacts on their shorelines. Because much of the CB shoreline is owned by small property owners, a piecemeal approach is often applied to resisting erosion. Consequently, over very short (< 1 km) spatial scales many types of armament can be found, each having its own degree of effectiveness. Since large boulders needed to build substantial revetments have to be transported long distances, many property owners have not protected their shorelines at all. This can lead to even more jagged shorelines than in natural systems and increase overall failure of structural protection for the entire shoreline. More systematic protection needs to be carried out if shoreline protection is to be effective over the long run. However, the costs of protecting the 9,650 km of shoreline of CB, with high energy absorbing stone revetments (Table 2), is in the range of 12 billion U.S. dollars (about 10x the amount of the present CB clean-up). Moreover, there is also an argument that not every eroding shoreline should be protected. In fact there are strong reasons for maintaining beaches which are critical habitats for estuarine species for part of their life cycle such as sea-turtles (i.e., terrapins in CB) and endangered tiger beetles. However, what is sorely lacking at present is any overall plan for how we will deal with shoreline problems in the future.

Although the Upper CB is supposedly protected by the “Critical Area” legislation which mandates tight control of development within a 1,000-foot buffer area, this is hardly enough to deal with issues involving sea-level rise. As we have seen, many areas around CB have been afflicted by erosion rates of up to 10 feet per year. If erosion proceeds at past rates (much less with any acceleration) the entire critical area of many regions will literally be underwater in a century. Unfortunately, experience of losses at Blackwater National Wildlife Refuge on Maryland’s Eastern Shore and in the Venice Lagoon, suggest that this newly created open water habitat is often not as biologically productive. More long-term planning for the sea-level future could mitigate its consequences for shoreline development, especially for low-lying areas in both the NA and CB.

Any comprehensive plan for shore protection must also take into account sediment longshore transport processes, which if disrupted, could exacerbate shore erosion in many areas. Lack of planning for such effects historically has been the root of litigation on shoreline modification along the open coast (e.g., Long Island). A fuller understanding of sediment transport pathways and budgets of various shorelines is desperately needed in both the CB and NA. The fact that there are so many people with a stake in these shorelines enhances the potential for political friction. However, the ultimate cost to these stakeholders of not taking any action is staggering. One could argue that because a large portion of the coastal problems are due to global increase in CO₂ levels and sea-level rise that it is incumbent on everyone contributing to the problem to pay the costs of planning in coastal areas.

Shoreline protection cannot ultimately stop global sea-level rise. Planning for the increasing risk of this threat from rising sea level will involve employing hypsometric scenarios of future potential flooding from projected rates of sea-level rise, and making
Table 2. Representative Costs of Shore Erosion Measures (Costs Per Linear 0.3 m).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Low Energy</th>
<th>Medium Energy</th>
<th>High Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone Revetments</td>
<td>$125</td>
<td>235</td>
<td>380</td>
</tr>
<tr>
<td>Timber Bulkheads</td>
<td>220</td>
<td>250</td>
<td>275</td>
</tr>
<tr>
<td>Timber Groins</td>
<td>140</td>
<td>160</td>
<td>175</td>
</tr>
<tr>
<td>Headland Breakwaters</td>
<td>135</td>
<td>235</td>
<td>520</td>
</tr>
<tr>
<td>Slope Regrading/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation Planting</td>
<td>105</td>
<td>120</td>
<td>***</td>
</tr>
<tr>
<td>Vegetation</td>
<td>30</td>
<td>30</td>
<td>***</td>
</tr>
</tbody>
</table>

From the USACE (1990). Low = 0.6 m waves, 4 = 1.2 m waves, high = 1.8 m waves

decisions about the course of shoreline development. In Maryland, limitations on shoreline development imposed by the Critical Areas Legislation mentioned above has at least reduced construction in the most affected zone next to the estuary. Nevertheless, the state of Virginia has no equivalent legislation and a more farsighted approach to minimizing the risks of future shoreline development is necessary there.

During the next century, a broad agenda of issues needs to be addressed rather than simply concentrating on the flooding/erosion hazards to the near shore and littoral environment. Complicating matters along the Italian coast, particularly, in the Venice Lagoon, are local nutrient loadings from agriculture, aquaculture, and human populations [Marson, 1996a,b]. If the Venice Lagoon has to be sealed from the sea (with tide gates such as MOSES) temporarily during acqua alta periods, the present nutrient loading rate will create enormous environmental problems. A priority for Venice needs to be comprehensive sewage collection and modern sewage treatment facilities with advanced treatment for nutrients. Boni et al. [1991] found that with highly efficient nutrient removal, the ability of sewage effluent to stimulate dinoflagellate blooms (Prorocentrum micans) was reduced to almost zero and suggested that if applied to treatment plants along the NA, this process could reduce eutrophication problems. To neglect the problem of sewage treatment indefinitely risks increasingly dire consequences for resources in the lagoon -- not to mention the plummeting of image for tourists. In this regard, the existing CB Program appears to be ahead of the NA in attempting to reduce nutrient loadings at major sewage treatment facilities [Malone et al., 1993]. However there are still many tributaries on the eastern shore of CB where nutrient levels continue to be too high and appear to be linked to the Pfiesteria outbreaks in late 1996 and 1997. This dinoflagellate-like organism is found in relatively shallow waters often near marshes and not only kills fish but causes nerve damage to humans.
Another coastal problem, land subsidence (which manifests itself as sea-level rise), can be addressed regionally. Remedies to land subsidence caused by groundwater withdrawal have already been undertaken in the vicinity of Venice. Unfortunately, this is recognition of subsidence as an important environmental problem in CB. In the past it has been difficult to convince the state agencies involved in the planning and permitting process that they should even take marshes into account when allocating water around the shoreline of CB [Stevenson and Kearney, 1996]. Such shortsightedness may be literally lethal to marshes and islands at risk along shorelines. Soon degradation will proceed to the point where these littoral ecosystems can no longer be effective storm buffers when the next large hurricane hits the CB. Thus additional efforts at regional consensus building need to be implemented as soon as possible so that equitable solutions can be reached to curtail groundwater withdrawals.

Although there is considerable complexity in modeling global warming responses [Schimel, 1998] and the path to achieving stability is not yet entirely clear [Wigley et al., 1996], both the CB and the NA would undoubtedly benefit from an international agreement to curtail CO₂ and other greenhouse gas emissions. Some sources of potent greenhouse gases such as nitrous oxide (N₂O), may be more controllable than previously believed. For example, recent research suggests that considerable N₂O could be reduced by changing the configuration of catalytic converters on automobiles and reducing fertilization rates in agriculture. Thus, at least one component of greenhouse gases might be easily dealt with by an international treaty. However, some effort toward reduction of emission of CO₂ is also necessary to avoid long term degradation of both the CB and NA. Indeed, it might be argued that the preservation of the antiquities of Venice alone (much less saving more modest treasures such as James, Smith, Solomons and Tangier Islands in the Chesapeake) would be enough to make such a treaty worthwhile!

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