Venice and the Environmental Hazards of Coastal Cities

By Carolyn Scearce

Introduction

One of the islands of the city of Venice.
http://europeforvisitors.com/venice/articles/venetian_lagoon.htm
(Durant and Cheryl Imboden, Europe for Visitors)

Over 15 centuries ago a group of refugees from the Italian mainland, fleeing from northern invaders, settled on the islands located in the Venice Lagoon. During the centuries that followed, the lagoon provided for its inhabitants a degree of security that could not easily be found on the Italian mainland. As restless barbarians and ambitious empires sought to build territories, Venice grew in size and autonomy. By the tenth century, the city had become a powerful enough entity to form an independent republic that lasted until the time of Napoleon. The lagoon offered protection and easy access to important trade routes. Its locality helped propel Venice to its place of wealth and political dominance during the late Italian Renaissance. The waters of Venice, however, have not always been trouble free. The very physical features that made Venice so attractive for settlement now may bring the city to its end. The sea may soon lay claim to this historical monument. Due to sea level rise, scientists project that even drastic intervention will only delay the permanent flooding of Venice 100-200 years. Venice, once know as the "Queen of the seas," serves as a stark example of the difficulties that can arise from human settlement too close to the coastal zone.

The distribution of human population forms very uneven patterns over the earth's surface. Coastal zone areas have historically served as important places of settlement providing important resources including water for navigation and human consumption, easy access to fisheries, and productive land. According to UN statistics, currently over 60 percent of the world's population live within 100 km of the coast (Getis et al., 2006), which means that people frequently exert intense, often destructive pressure on coastal habitats. Such pressure can take a variety of forms, including dramatic physical alteration of the landscape, pollution of coastal waters and sediments, and excessive harvesting of local species. Additionally, coastal populations are exposed to a number of hazards associated with close interaction with water, such as loss of life and property due to storms, flooding, and tsunamis.

The city of Venice, whose historical boundaries reside within a lagoon, maintains an unusually intimate relationship with the sea. The city is unusually vulnerable to human alterations of the surrounding environment. Some of the specific problems that Venice's citizens currently struggle with are unique to the city, but the broader issues, of habitat loss, erosion, subsidence, flooding, pollution, and the impact of physical alterations are extremely relevant global issues of human coastal zone interaction. A better understand-

 Released January 2007

ing of the problems facing this city offers insight into how the interaction between the needs of the human and the natural environment must be balanced in order to maintain a sustainable association between man and the sea.

Venice: The city on the lagoon

Image of Venice Lagoon, the three inlets lagoon are circled in red
http://www.salve.it/uk/soluzioni/f_acquealte.htm
(Puntolaguna, Venice - campo Santo Stefano 2949, Italy)

Venice is located on Italy's northeastern coast at the northern terminus of the Adriatic Sea. The Adriatic forms a long, narrow, semi-enclosed section of the Mediterranean Sea between the eastern coast of Italy and the Balkans. Historic Venice rests on a cluster of central islands in the shallow waters of the Venice Lagoon. The Venice Lagoon is an inlet of the Adriatic Sea, with access to sea waters largely restricted by a series of sand bars at the lagoon's entrance. Formerly, substantial freshwater inputs flowed through the lagoon as well, but over the past several centuries most of the freshwater has been diverted to the Adriatic. Today the lagoon's water possesses a salinity level nearly as high as that of the Adriatic. Waters from the Adriatic Sea circulate through the lagoon, currently providing the primary source of lagoon waters. Without continuous exchange with the Adriatic, the lagoon's waters would stagnate and become uninhabitable for many of the organisms now residing within the lagoon.

The city of Venice has expanded beyond its historic boundaries and currently nearly two thirds of the region's inhabitants live on the mainland next to the lagoon. Still, slightly over a third of the city's population are spread over 118 islands within the lagoon. Lagoons, shaped as they are by opposing forces of land and sea, are changeable, geographically ephemeral landscape features. When unhampered, river flows carry sediments to their outlet and fill in lagoon areas. From the ocean side, wave forces tend to carve

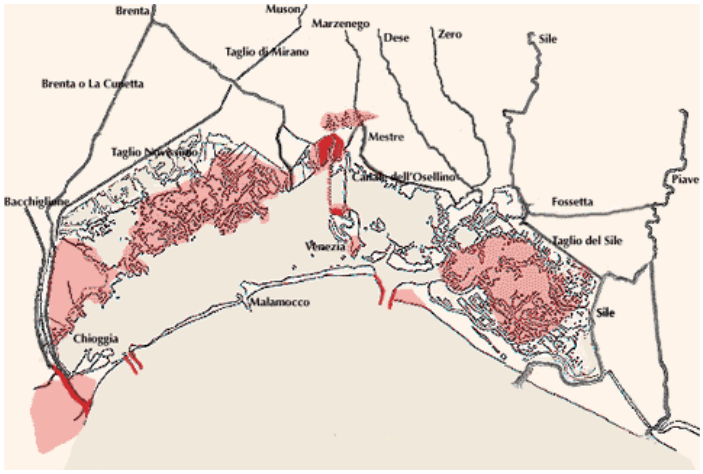


Illustration of human alterations made to the Venice Lagoon c. 1900. Website shows major alterations to the lagoon from approximately 1300-2000
http://www.salve.it/uk/eco/default.htm
(Puntolaguna, Venice - campo Santo Stefano 2949, Italy)

out the sediments and in the process transform lagoons into bays. Only when these two forces can be held in relative equilibrium can the lagoon maintain its form.

For centuries, the inhabitants of Venice have waged war on natural processes of change, in order to shape the city to their needs. Rivers, including the Brenta, Bacchiglione, Muson, Marzenego, Dese, Zero, Plave, and Sile, historically emptied into the lagoon. As early as the twelfth century, technicians diverted the lower course of the Brenta River for strategic reasons (Caniato, 2005). Over the centuries, repeated interventions with a number of the rivers followed. By the 16th and 17th centuries, city planners actively made alterations within the lagoon and surrounding environment, including building canals to help facilitate shipping and further river diversions, and building sea barriers. During the 18th century, work continued in order to improve navigability and a sea wall was built to protect the lagoon. The last couple of centuries have seen work to enhance Venice's port and commercial capacity as well as additional efforts to reduce erosion, enhance industry, reclaim land, and promote aquaculture (VWA, 2006).

The Lagoon habitat

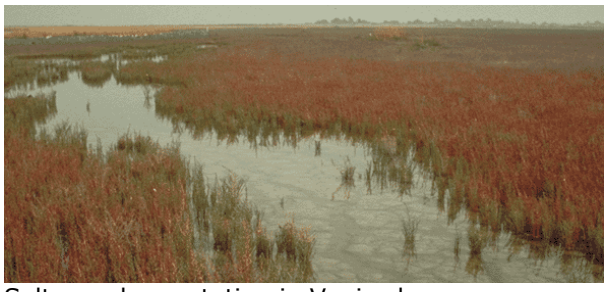
Channels, mud flats, and salt marsh in Venice lagoon
http://www.salve.it/uk/eco/default.htm
(Puntolaguna, Venice - campo Santo Stefano 2949, Italy)

Lagoons exist as transitional environments between land and sea. The Venice Lagoon, Italy's largest lagoon, covers 550 km^2. Sand bars partially isolate the lagoon from the Adriatic, with direct exchange with the sea only occurring at three inlets that individually connect the lagoon's northern, central, and southern portions. The lagoon consists of a number of interrelated habitats. The terrestrial portion includes the lagoon's interior islands and sandbar and the surrounding coastal strip. The aquatic portions, which account for more than 90% of the lagoon's surface area, include channels, shallows, mud flats and salt marshes. These varying habitats host a number of organisms and diverse communities (VWA, 2006).

The average depth of the lagoon is approximately one meter, with the majority of the surface area composed of shallows, mud flats, and saltwater marshes. Channel depths range from 1-15 meters deep. Most of the circulation within the lagoon takes place through the network of channels and tidal creeks. Natural and artificial islands within the lagoon range in size from a few hundred square meters to several square km. The islands of the central portion of the lagoon that comprise the historic site of Venice are densely inhab-

ited. Over 30,000 people inhabit islands in the lagoon outside of the boundaries of the historic city, with other islands remaining uninhabited or abandoned.

The salt marshes and sea grass beds within Venice Lagoon serve important functions, both in maintaining the morphology and ecological integrity of the lagoon environment, and in serving as important habitat for organisms living within the system. The salt marsh area within the lagoon has decreased from 115 km^2 to 33.5 km^2 over the course of the last two centuries. Factors contributing to this decline include land reclamation for human use, erosion, pollution, subsidence, and decreased accretion of sediments (Cecconi, 2005). Sea grass meadows have also been declining over the last several decades (Acri et al., 2005). A study comparing sea grass populations from 1990 and 2002 showed a continued decline; also, the distribution of sea grass species has altered. The northern and southern sections of the lagoon show the greatest overall losses of sea grass; *Zostera noltii*, which used to be the primary species has decreased most dramatically. Only the central lagoon has shown increased sea grass coverage, mostly by *Zostera marina,* the species of sea grass that is becoming dominant in the lagoon as *Zostera noltii* declines (Rismondo et al., 2005). The structure provided by salt marsh and sea grass habitat serves as important substrates, food sources, and refuge for organisms living within the lagoon. As these habitats continue to decline the populations of organism that use these habitats are likely to decline as well.



Salt marsh vegetation in Venice lagoon
http://www.salve.it/uk/eco/default.htm
(Puntolaguna, Venice - campo Santo Stefano 2949, Italy)

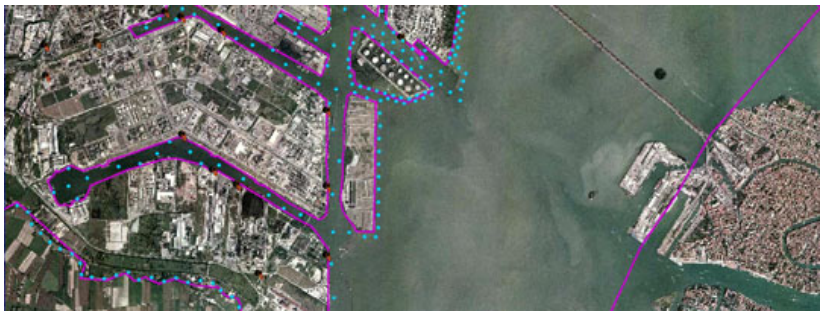
Venice Lagoon hosts the largest population of water birds in Italy. Over 60 species of aquatic birds have been observed in the lagoon. These bird populations make use of salt marsh and island habitats for nesting, over wintering, or as stopover points. In January as many as 130,000 birds make use of the lagoon. 80-90% of Italy's Redshank and Sandwich Terns nest within the lagoon (Scarton, 2005). The lagoon also serves as a productive fish habitat, hosting many euryhaline species, fish that migrate between lagoon and sea environments to complete their lifecycles (Ravera, 2000). Other organisms that make their home in lagoon include bivalve mollusks and gastropods, cephalopods, and crustaceans.

Venice and the Environment

Venice has never maintained a main sewage system (Zonta, et al., 2005). For this reason, a large portion of the wastes generated in the historic center of Venice have always been discharge directly into its channels. Recently, an increasing number of septic systems have been installed. Also, plans are now underway to improve water quality by decreas-

ing sewage flow, improving standards of water treatment, reusing water, and dispersing effluents offshore into the Adriatic Sea (Casarin et al., 2005).

Currently, water quality, particularly near the city, is extremely poor. The lagoon faces eutrophication, chemical pollution, and contamination by endocrine disrupters (Fletcher et al., 2005). During the 1970s and '80s eutrophication frequently lead to large algal blooms and anoxic events (Marcomini et al., 2005). In 1990 phosphates, an important limiting nutrient for algal growth, were banned from use in detergents in Italy (Zirino, 2005). Since that time, algal blooms have declined, though it is uncertain if the cause of decline can be traced to decreased phosphates or increased turbidity within the lagoon.



Arial photograph of dredging and sediment remediation in Venice lagoon
http://www.aecom.com/MarketsAndServices/51/15/index.jsp
(AECOM, 555 South Flower Street, Suite 3700, Los Angeles, California 90071-2300)

More recent concerns have focused on the levels of heavy metals and concentrations of chemical pollutants such as dioxins, PCBs, DDT, aromatic hydrocarbons, herbicides, and pesticides (Zirino, 2005 and Zonta et al., 2005). Both water and sediment pollution is widely distributed within the lagoon. Pollutants not only originate within the city, but from aerosols (Capodaglio et al., 2005) and to a greater extent from the lagoon's watershed (Zonta et al., 2005). About 70% of the drainage basin that empties into the lagoon is used either for agriculture or raising livestock. Substantial pollution from these sources can reach the lagoon, particularly during April and November flooding.

Lagoon sediments can serve as a reservoir for pollutants. If sediments become resuspended during activities such as fishing (Solidoro et al., 2005) or by the wakes caused by motor boats (Dabala et al., 2005) pollution can be reintroduced to the water column. Sediment pollution within the lagoon represents such a significant problem that most of the sediments currently removed during periodic dredging to clear the channels are not considered fit for recycling within the lagoon (Zonta et al., 2005).

Subsidence, sea level rise, and storm surge in the Venice Lagoon

Every year Venice loses a little land. Over the last century, through a combination of natural geological phenomena and anthropogenic influences, Venice lost approximately 25 cm in height relative to sea level (Spencer et al., 2005 and Frassetto, 2005). The geological factors that contribute to the loss of land include subsidence and sea level change.

Additionally, human activities and alterations to the lagoon environment have increased rates of subsidence and erosion.

Venice Lagoon, and the surrounding land, rests on the Adriatic plate in a foreland basin between the Alps and the Apennine mountains. Each year, tectonic processes lead to a loss of about 1.0mm height relative to sea level on the Adriatic plate (Carminati et al., 2005). For millions of years, the Adriatic plate has been subducting under the Apennines, causing the subsidence of the land within and around Venice. The city loses an additional 0.3mm per year due to the gradual rise in sea level associated with the process of deglaciation that has been occurring since the end of the last ice age (Carminati et al., 2005). The combined loss of land due to these natural phenomena averages to about 1.3mm per year.

During 1930-1970, humans substantially accelerated the process of subsidence due to the extraction of deep-well water (Butterfield, 2005). Industries located in the district of Marghera extracted much of the water during this period. Groundwater pumping stopped, once the impact of this activity came to be properly understood, and the ground level rebounded by approximately 20mm. Still the overall impact lead to the loss of 120mm of height, nearly doubling the rate of subsidence for the twentieth century.

Flooding in the streets of San Marco
http://www.agu.org/sci_soc/prrl/prrl0218.html
American Geophysical Union, 2000 Florida Avenue NW, Washington, DC 20009-1277)

A number of alterations over the centuries have decreased the levels of sediments entering the lagoon. The process started with the diversion of rivers around the fifteenth and sixteenth centuries. Further, the jetties built at the lagoon's three inlets from 1850-1920 increased the ratio of sediments lost during ebb tide to those returned during flood tides (Di Silvio, 2005). Other factors, including the loss of salt marsh vegetation and the building of deep navigation channels within the lagoon have lead to increased rates of erosion, subjecting the lagoon more and more to the influence of the marine environment.

Loss of land has made Venice more vulnerable to flooding events. When low atmospheric pressure systems develop around northern Italy, it sets up a pressure gradient that allows storm surges. Since Venice is located at the 'dead end' of the Adriatic Sea, during these storm events water piles up in the lagoon (Tomasin, 2005). The past 50 years have seen an unprecedented increase in the frequency and intensity of flooding (Lionello, 2005). The confining shape of the Adriatic also can cause a phenomenon known as seiche to occur. If the seiche within the Adriatic becomes synchronized with the tidal cycle, flooding can continue for days after the storm event has passed (Tomasin, 2005).

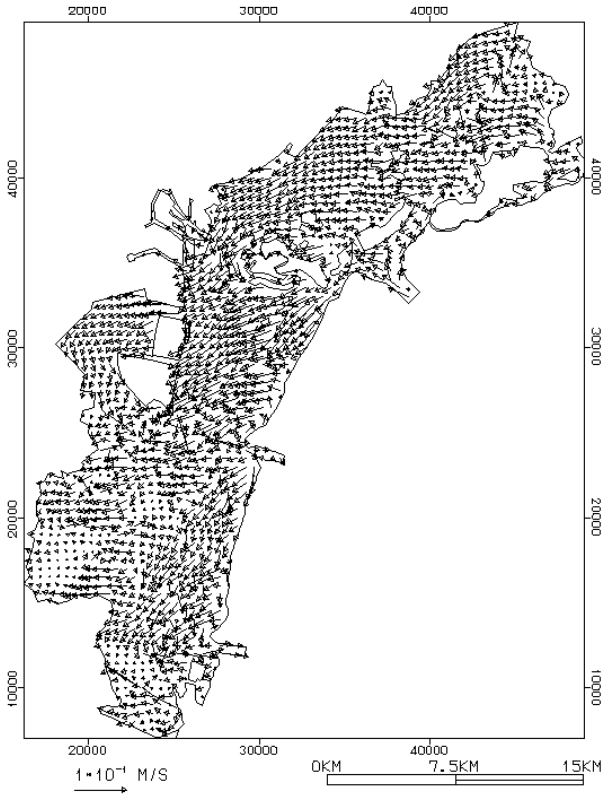
Another factor that may affect subsidence rates within the lagoon is the materials on which the city is built. Only one consolidated strata layer exists within the lagoon, a des-

iccated clay layer known as 'caranto'. The thickness of this naturally occurring geological feature ranges from 10 cm to 10 meters. Scientists speculate that the apparently uneven rates at which the Venetian palaces are sinking may be due to lack of support by this hard clay to hold up the heavy structures (Frassetto, 2005).

When anticipating the future impacts of subsidence and erosion, scientists are concerned as to how climate change may affect the lagoon. A great deal of uncertainty exists about the potential impact of increasing temperatures on glacial melting processes. When calculating the rate of future sea level rise, scientists must not only forecast sea temperature changes in polar regions, but also determine the response time of glacial melting increases associated with such changes. Consequently, extremely wide ranging estimates are offered concerning the rise in Mediterranean waters over the next century. Should deglaciation accelerate over the following decades, the waters around Venice may rise at a faster rate than expected.

Urban maintenance and coastal defense of Venice

The processes of subsidence and erosion, the increasing frequency of flooding, and the ravages of time and the elements have taken their toll on Venice. The Adriatic's encroaching waters do not represent the only threat to the city's integrity. Many of the city's historic buildings and walkways are compromised by factors such as the corrosive effects of sea water, the wearing influences of motor boat wakes, and soil erosion from beneath foundations. In order to address such problems Venice has instituted plans of urban maintenance, established warning systems for extreme weather events, and deliberated on various proposals considered for addressing the impact of rising sea waters.

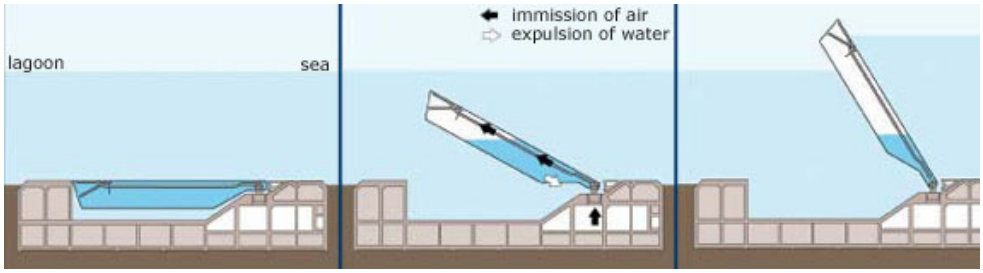


Model showing currents in Venice Lagoon.
http://flux.ve.ismar.cnr.it/~georg/venice/one_year/one_year.html
(ISMAR-Venice, 1364 S. Polo 30125 Venezia, Italy)

For a city like Venice, built as it is in such a potentially changeable environment, failure to conduct regular maintenance represents an acute vulnerability to safety and functionality. During the 1970s and '80s, maintenance regimes were somewhat slack. By the early 1990s, many canals within the city had become choked with sediments, significantly impairing the navigability of the water system. To address this and other problems, plans

were instituted and work began in 1993 to improve the waterways and city infrastructure, with completion scheduled for 2025. The first phase focuses on dredging and improving hydraulic and sanitary conditions within the canals. Other factors the plan addresses include improving structures of buildings and bridges, raising the height of pedestrian walkways, and updating utility services (Dolcetta, 2005). Over the centuries, as sea levels have risen relative to the city, walkways and bridges have traditionally been built up. This may be the last time this approach is feasible as doorways within the city will start to become inaccessible if the pavements are raised more than the projected few centimeters proposed by this project.

A dramatic storm surge experience by the city on November 4, 1966, focused considerable attention on Venice by forecasters and ocean modelers (Tomasin, 2005). Due to Venice's vulnerability to storm surge and unusually high tides, it is crucial for the city to have access to reliable forecasts of sea level conditions (Canestrelli and Zampato, 2005). To fulfill this need, the Centro Previsioni e Segnalazioni Maree (CPSM) provides a forecasting and warning system for Venice. CPSM includes observations of sea level and meteorology, short term sea level forecasts, tide information, and alerts for high water events.



Functioning of the mobile gates, know as MOSE, to be built to protect from flooding
http://www.salve.it/uk/soluzioni/acque/eccalternative.htm
(Puntolaguna, Venice - campo Santo Stefano 2949, Italy)

Since the 1966 event, the increasing frequency of city flooding has demonstrated that warning systems alone will not be enough to protect the city. For this reason, the city has considered more active defensive measures for managing high water events. The proposal that officials have settled on as the most workable is known as (Modulo Sperimentale Elettromeccanico) MOSE. The project consists of a set of mobile gates to be built across the three inlets that provide access to the Adriatic Sea. According to the proposal, the gates would be open the majority of the time, in order to allow free exchange of water between the sea and the lagoon. However, during high water events, the gates would be raised to protect the city from flooding (Ravera, 2000). There has been some debate about the efficacy, impact, and expense involve in the MOSE project. However, it seems likely that the city will go forward with MOSE even though the project is not expected to buy the city more than another 100-200 years of sustainability under current conditions.

Conclusion

Lagoons are spatially complex, temporally changeable environments. Over the course of Venice's history, its inhabitants have attempted to shape the Lagoon environment to their needs. However, human intervention within the lagoon has frequently resulted in unanticipated consequences. Diversion of the rivers to prevent the lagoon from filling in has reduced the levels of sediments necessary for building up salt marsh beds to make up for loss from erosion and subsidence. Attempts to make the water ways within the lagoon more accessible to navigation have also accelerated the rates of erosion. Nor is it possible to simply reverse these effects by trying to return the lagoon to its original state. In the years since the rivers have been diverted, river water has become too polluted to safely be returned to the lagoon. Cutting the lagoon off from sea waters may protect the city from flooding, but if the exchange between the lagoon and the sea is interrupted for more than very short periods of time, the lagoon will suffer. Continuous exchange is necessary to maintain oxygenated conditions within the lagoon and otherwise provide the conditions to allow lagoon species to survive.

No simple solutions can be offered to solve Venice's problems. This city, cradled in the heart of the lagoon, demonstrates humanity's fierce ingenuity to create the world in its own image. At the same time, it tests human limitations to try to invent a sustainable environment inside a habitat whose very nature is instability. Many of the factors that make coastal zone environments attractive places for human settlement also make them vulnerable to human activities. Coastal zone productivity, living resources, and its very waters are vulnerable to pollution, exploitation, and physical alteration. When dealing with complex systems, such as the interface between the land and sea, it can be difficult to anticipate all of the consequences of human action. For this reason, careful consideration should be taken from the lessons learned from coastal cites such as Venice.

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