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Review

# Restoration of the Golden Horn Estuary (Halic)

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ABSTRACT

Restoration of the iconic Golden Horn Estuary in Istanbul, Turkey was a substantial political, logistical, ecological, and social challenge. Forty years of uncontrolled industrial and urban growth resulted in thick layers of anoxic sediment, toxic bacteria, strong hydrogen sulfide odor, and ecologically unlivable conditions. The major components of restoration, spanning two decades, have included (1) demolition and relocation of industries and homes along the shore, (2) creation of wastewater infrastructure, (3) removal of anoxic sludge from the estuary, (4) removal of a floating bridge that impeded circulation, and (5) creation of cultural and social facilities. Although Turkey is not known as an environmental leader in pollution control, the sum of these efforts was largely successful in revitalizing the area through dramatic water quality improvement. Consequently, the estuary is once again inhabitable for aquatic life as well as amenable to local resource users and foreign visitors, and Istanbul has regained a lost sense of cultural identity. This paper focuses on literature review and personal interviews to discuss the causes of degradation, solutions employed to rehabilitate the estuary, and subsequent physicochemical, ecological, and social changes.



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## 1. Introduction

Water resources around the world are widely impacted by human activity, especially in developing nations due to perverse financial incentives for development and exploitation, as well as inadequate or absent institutions and infrastructure (Peters and Meybeck, 2000; Pirot et al., 2000). This occurs partially because developing countries are able to spend as little as 1–10% of the sum that buys affluent economies more advanced waste management programs (Brunner and Fellner, 2007). According to the World Bank, up to 3% of a country's gross national product (GNP) can be realistically spent on environmental protection. Thus in low GNP countries (<US$3000/capita), the time required to generate capital investments to meet international standards far exceeds the economic life span of treatment plants and infrastructure (Grau, 1994). In addition to financial limitations, mismanagement of resources, ineffective enforcement, poorly prepared personnel, and limited access to scientific information contribute to the widespread practice of wastewater discharge directly into waterbodies (Kennish, 2002; Massoud et al., 2003; Wagener, 2005). As a result, developing countries are often faced with elevated sewage-borne pathogens, heavy metals, trace elements, organic pollutants, their associated bacteria, resultant oxygen deprivation, and toxic byproducts (Islam and Tanaka, 2004).

In recent years, water resources in Turkey have been severely contaminated by urban and industrial pollution (Burak, 2008). However, the restoration of Istanbul's Golden Horn Estuary ("Halic") presents a prime example of a developing country ameliorating environmental problems in spite of inadequate management funds, institutions, policy, and legal infrastructure (OECD, 1999; Burak, 2008). Istanbul is the third largest city in the world with a population of over 11 million people, 70% of who are classified as low income (Altinbilek, 2006). Like many developing metropolises, it became subject to chaotic, unplanned urbanization and industrialization when factories began to dominate the iconic estuarine shores. Mismanagement led to serious environmental problems, health and social impacts, as well as local ecological collapse within and around the estuary. However, reorganizing and strengthening municipal institutions proved critical in reversing the effects of pollution by undertaking one of largest rehabilitation efforts of its kind (Dalan, 2006). Over the past 30 years, numerous monitoring studies were undertaken in the Golden Horn by a wide variety of researchers, but they have lacked thorough integration. In this study, the history, causes, and impacts of contamination and restoration efforts are presented by review and synthesis of this data set and supplementary personal interviews.

### 1.1. *Study area*

Estuaries are transitional zones between rivers and seas, and are important ecosystems typically rich in biodiversity. The Golden Horn Estuary supported thriving fisheries until the latter 20th century. It is a 7.5 km long, 200–900 m wide horn-shaped body of water that connects the Alibeykoy and Kagithane Rivers to the Bosphorus strait. Estuarine surface area covers 2.6 $km^2$ and maximum depth is 36 m at the mouth, sloping to <1 m near tributary inflow. The shallow inner estuary, defined as the area north of the Valide Sultan/Old Galata Bridge (Fig. 1), is more prone to anoxic conditions given that its depth abruptly slopes to <5 m near the bridge. The water column is a highly stratified product of the Mediterranean Sea (~38 psu), Black Sea (~17 psu), and freshwater urban runoff, precipitation, and a small fluvial contribution. Freshwater remains on the surface due to a greater rate of input (300,000 $m^3$ of freshwater enter the estuary annually) than evaporative loss (Ozturk et al., 1998; Alpar et al., 2005). These three layers, separated by strong density gradients, effectively resist mixing of estuarine waters, and movement via tidal mixing or currents is negligible at <10 cm/s (Aksit, 1977). For more oceanographic and related description see Kor (1963), Gunnerson (1974), Saydam et al. (1986), Basturk et al. (1988), and Ozsoy et al. (1988). Low velocity surface winds and stable atmospheric conditions contribute to minimal air ventilation in the surrounding area (Incecik, 1986). Thus, both water and air circulation are severely hampered in and around the Golden Horn, which has led to a local environment extremely prone to lasting pollution problems. These conditions are compounded by steep hills lacking foliage, the presence of stone quarries, and the absence of drainage systems, all encouraging substantial erosion and estuarine sedimentation (Aksit, 1977).

### 1.2. *History of development and environmental degradation*

The Golden Horn lies in the center of the historic city and played a substantial role in Istanbul's culture for thousands of years, particularly for its numerous harbors, abundant fish populations, and recreation grounds. In the mid fifteenth century, it was subject to one of the world's first management policies when Sultan Mehmet the Conqueror limited settlement, encouraged afforestation to combat erosion, banned local agriculture, and encouraged use of alluvial mud by exempting ceramic artisans from taxes (Aksit, 1977; Eroglu, 2001). Similarly, President Mustafa Kemal Atatürk did not allow factories to be built near what was known as the "the

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**Fig. 1 – Location of the Golden Horn and surrounding districts (©Google Earth). The Valide Sultan/Old Galata Bridge between Ayvansaray and Haskoy divides the inner estuary to the north from the outer southeastern section.**

most romantic waterway in Europe" in the 1920–1930s. As a result, the most substantial environmental problems upto this point were shipping discharges and accumulation of silt on the floor of the estuary (Inanc et al., 1998; Ozturk et al., 1998).

The allure of industrialization prevailed after World War II, and rural people relocated to Istanbul when the Marshall Plan provided a means to increase infrastructure (Yalpat, 1984). Formerly prestigious and fashionable areas around the Golden Horn were designated for industrial development by the Municipality according to the Prost plan of 1933 (Yerliyurt and Hamamcioglu, 2005). Subsequently, one-third of the estuarine surface area was filled to accommodate factories and their associated tenements with no provision for stability, industrial or domestic waste disposal, or treatment (Eroglu, 2001; Yerliyurt and Hamamcioglu, 2005). By 1975, 696 industrial plants haphazardly occupied a total of 1.6 $km^2$ along the estuary and nearby river shores (Fig. 2). Metal smelting, electrical, appliance, machinery, textile, wood, food, and meat production facilities comprised 71% of this area, 28% was shipyards and docks, and 8% supported warehouses (Aksit, 1977).

Subsequently, 200,000 tons of liquid (67% chemical waste, 27% wash water, 4% cooling water, and 2% wastewater) were discharged into the Golden Horn daily. Additionally, wastes from shipping and passenger transport contributed 3.1 million tons of industrial materials and coal per year (Aksit, 1977; Samsunlu, 1988). Furthermore, the shores of both streams feeding the estuary were also developed, leading to the local annual release of 1.9 million tons of liquid and 49,000 tons of solid waste from 364 industries (Tezcan and Durgunoglu, 1977). It has been estimated that in 1980 alone all of these industries discharged 24,000 tons of chromium, 300 tons of copper, 130 tons of nickel, and 7500 tons of zinc (Tuncer et al., 2001). Industrial discharges contained upto 370 times more chromium, 290 times more copper, 45 times more lead, 1.5 times more zinc, 10 times more oil and grease, 14 times more suspended solids, and 18 times higher chemical oxygen demand levels than allowed by discharge standards created in 1995, as well as pH values well outside acceptable ranges (Gunnerson, 1974; Aksit, 1977; Sarikaya et al., 1997). The concentration of detergents in estuarine waters was measured at 1.4 mg/L (Aksit, 1977), whereas after 1995 no nonbiodegradable detergent discharge has been allowed (Sarikaya et al., 1997). Contaminants have also entered the Golden Horn through ship transport, operations, ballasting, storage, washings (gas-freeing operations), and accidents, including a 70,000 ton crude oil spill in 1979 just outside the estuary (Akten, 2003, 2004; Guven et al., 2005).

Evidence of industrialization has been found in deep sediments of the Golden Horn, due to poor circulation and massive contaminant absorption. The concentration of anthropogenically-derived elements was relatively constant in sediment dated between 1912 and 1950, but dramatically increased after this time, unlike naturally occurring lithophilic elements. The two major sources of anthropogenic metals, especially zinc, copper, and lead, were discharges from an iron and steel plant beginning in 1948 and metalwork industries commissioned in 1959 (Tuncer et al., 2001). Chromium tended to emanate from textile factories and leather tanneries, while nickel was released from electrometal industries, battery plants, and dockyards. Concentrations of chromium and nickel categorize Golden Horn sediment of the late 1980s as moderately contaminated, while

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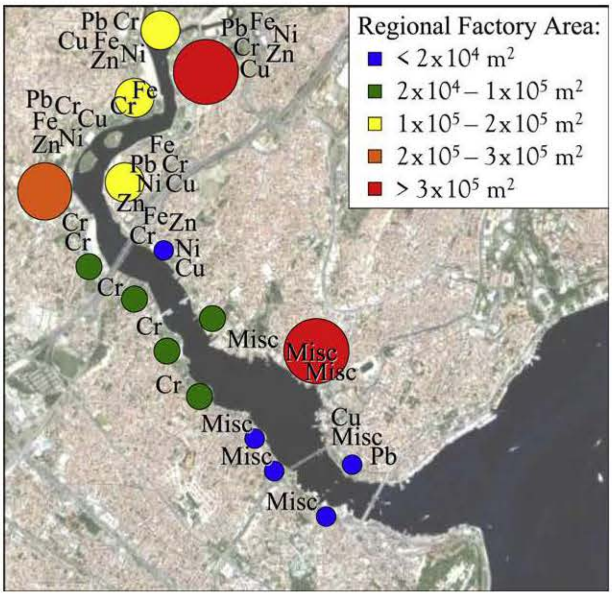


**Fig. 2 – Footprint of regional industrial areas on the banks of the Golden Horn Estuary (Aksit, 1977; ©Google Earth) and major heavy metal discharge points in the 1970s (Cr: chromium, Cu: copper, Fe: iron, Ni: nickel, Pb: lead, Zn: zinc, Misc: miscellaneous other metals; Karpuzcu, 1975; Ergin et al., 1991).**

zinc, copper, and lead levels are classified as moderately to extremely contaminated, compared to sites around the world (Ergin et al., 1991; Saydam and Salihoglu, 1991).

Another major source of pollution, Istanbul's sewer system consisted of drains dating to Roman and Ottoman periods, as well as isolated cesspools and septic tanks, until the 1980s. Crude housing developments discharged 100,000 $m^3$ of raw domestic wastewater per day into 123 major and at least 500 minor sewers that led to the Golden Horn (Gunnerson, 1974; Dalan, 1988). Explosive urbanization in the second half of the twentieth century and a migration rate as high as 14% in the early 1980s forced Istanbul to further expand, although the city lacked infrastructure necessary to treat subsequent domestic wastes, as seen in Fig. 3 (ISKI, 2006). Domestic discharge of heavy metals increased logarithmically between 1950 and 1985, and in 1980 was estimated to include 50 tons of chromium, 90 tons of copper, 13 tons of nickel, and 120 tons of zinc (Tuncer et al., 2001).

Unplanned, uncontrolled urban development around the Golden Horn and its waste production soon gave rise to anoxic sediment buildup, stifling hydrogen sulfide odor, high concentrations of harmful bacteria, mosquitoes, disease, and a lack of formerly abundant biota (Kor, 1963; Gunnerson, 1974; Karpuzcu, 1974; Karpuzcu and San, 1975; Aksit, 1977; Orhon et al., 1980; Kinaci, 1982; Tuncer et al., 2001; Aslan-Yilmaz et al., 2004; Yuksek et al., 2005). Concentrations of fecal coliform were often 2–5 orders of magnitude greater than levels regarded as hazardous by the United Kingdom (Karpuzcu, 1974). These high bacterial counts contributed to incidents of disease, including 2000 times more cases of typhoid per capita than the United States in the 1960s, and a major epidemic in 1970 (Gunnerson, 1974). Rampant factory emissions also led to a rate of lung cancer approximately ten times greater among residents of the Golden Horn than in surrounding areas (Dalan, 2006).

The third major source of pollution was debris entering the creeks and estuary from industrial waste, largely due to slaughterhouse activities, shipbuilding, repairing, and dockyard operations, as well as erosion via chaotic urbanization, deforestation, and livestock grazing (Dalan, 1988; Kanat, 2004). Ten vertical cm was added to the benthos annually by the entry of 260,000 $m^3$ (50,000 tons) of solid waste high inorganic material, nutrients, heavy metals, and hydrocarbons. Estimated alluvial input was 60,000–80,000 $m^3$/year (Karpuzcu and San, 1975; Aksit, 1977; Inanc et al., 1998; Eroglu, 2001; Alpar et al., 2005). In the outer estuary (Fig. 1) sedimentation was estimated as 3.5 cm/year, which is still greater than most globally reported rates for bays and estuaries (Teksoz et al., 1991; Tuncer et al., 2001). This contributed to 76% of inner and 31% of outer estuarine surface sediments being composed of solid matter in 1995, as well as containing up to 50–80 mg/L hydrogen sulfide (Aksit, 1977; Inanc et al., 1998; Kinaci et al., 2004).

Additional trouble with solid debris stemmed from extensive uncontrolled filling of the Golden Horn's shores with gravel, sand, brick, silt, and clay. Fill material and thickness varied by location, and resulted in differential building settlement, uneven compression, lateral movement, displacement, and massive structural problems. In 1957 a building collapsed, and until they were demolished, the Sutluce livestock sale pavilions, Eminonu vegetable market, and Unkapani chamber of commerce were highly unsound as well (Aksit, 1977; Dalan, 2006).

Another significant problem plaguing natural recovery from pollution was the presence of a floating bridge near the mouth of the estuary. Initially built in 1912, the Galata Bridge (now known as the Valide Sultan/Old Galata Bridge) rested on pontoons that dipped 4 m below the surface, making effective circulation of the upper water column impossible (Inanc et al., 1998; Sur et al., 2002; Alpar et al., 2005). While in place, the top 2–3 m of low density water maintained lower dissolved oxygen and salinity as well as higher temperatures. It also retained large concentrations of suspended matter, effectively occluding light from the rest of the water column (Ozsoy et al., 1988; Sur et al., 2002). Furthermore, floating bridges deliver toxins such as lead, rust,

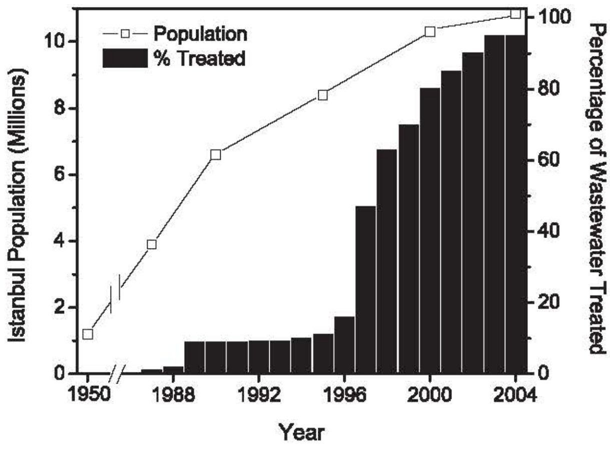


**Fig. 3 – Population of Istanbul and the percentage of residents receiving wastewater treatment over time (Eroglu et al., 2001; ISKI, 2001; Altinbilek, 2006).**

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paint, solvents, abrasives, and cleaning products more readily than normal bridges (Alpar et al., 2005).

As a result of these issues, measured water clarity was consistently low, dissolved oxygen levels were always rated "unusable" (<3.5 mg/L) by US EPA standards (Mitchell and Carson, 1981; Luken et al., 1992), almost all aquatic life was rendered locally extinct causing fishery collapse, and a stench that greatly reduced the quality of life around the Golden Horn pervaded (Aksit, 1977; Kinaci, 1982; Kinaci et al., 2004; Yuksek et al., 2005, 2006). Local residents tended to be poor and unable to relocate to healthier areas, businesses were space and infrastructure-limited, and the city was disgraced by the state of its formerly prestigious center of culture and recreation. These symptoms prompted one of the world's largest estuary cleaning and rehabilitation projects, given the complexity of the situation and need for a multifaceted, staged approach (Altinbilek, 2006; Dalan, 2006). Restoration was undertaken as a series of solutions to contributing problems, with the knowledge that no single approach would resolve the situation without being part of a larger, long-term plan.

## 2. Restoration of the Golden Horn

### 2.1. *Industrial and residential relocation*

The problems caused by industries around the Golden Horn were recognized early, beginning with a meeting in 1953 called to address foul odors in the estuary (Fig. 4). However, the only significant action taken for decades included four localized dredging operations to allow ships to transport coal to Silahtar energy plant, and a 1966 plan to limit construction of large facilities in the vicinity of the estuary (Aksit, 1977; Alpar et al., 2005; Basturk, 2006). The rate of heavy metal discharge began to slow following this restraint, but metal concentrations continued to increase in sediment during the operational period (Tuncer et al., 2001). A poll showed that 68% of business owners were willing to move to an organized industrial zone since twice as much area was actually needed for operations than was available for use without further uncontrolled filling of the shoreline (Aksit, 1977). By the 1980s the situation was dire, as the banks of the Golden Horn housed over one million residents and Istanbul supported approximately 50% of Turkey's industrial activity, mostly around the estuary (Incecik, 1986; Dalan, 1988; Samsunlu, 1988).

The first significant step towards environmental restoration came in 1984, when the government of Istanbul granted more power and funds to local authorities such as the Istanbul Water and Sewerage Administration (ISKI), which worked with the Municipality to resolve problems afflicting the Golden Horn (Eroglu, 2001; Samsunlu, 2006). Stopping untreated waste flow into the estuary was of primary concern, and resulted in the city council's unanimous passage of the mayor's plan to initiate the cleaning process (Fig. 4). The first step of the rehabilitation project involved the purchase (in about 80% of cases) or expropriation, demolition, and relocation of almost all of the 620 industries, 1200 shops, and 5000 shanty homes that lined much of Golden Horn's shore. Approximately 40% of the factories had illegally paid nothing to operate on public land, and were simply destroyed with city council approval (Samsunlu, 1988; Eroglu, 2001; Dalan, 2006). Most shipyards and dry docks that tended to impede estuarine circulation were also destroyed at this time, although three remain (Aydin, 1994). These drastic actions were necessary because creating industrial and domestic wastewater treatment infrastructure would not have been possible under the previous circumstances. As industries were quickly replaced by parkland, public approval rates of the restoration project steadily rose (Samsunlu, 1988; Dalan, 2006).

Relocation also benefited worker safety for more than 400,000 relocated employees, due to both the instability of filled land around the estuary shore and cramped, outdated factory conditions (Aksit 1977; Dalan, 2006). Similarly, public health was enhanced by ceasing factory emissions, given the prevalence of air pollution (especially dangerous levels of $SO_2$, $NO_2$, and CO concentrated near Silahtar and Eyup) in the Golden Horn area (Aksit, 1977; Incecik, 1986). Over 5000 new dwellings and a new organized industrial zone ("Ikitelli") were constructed for the displaced residents and businesses

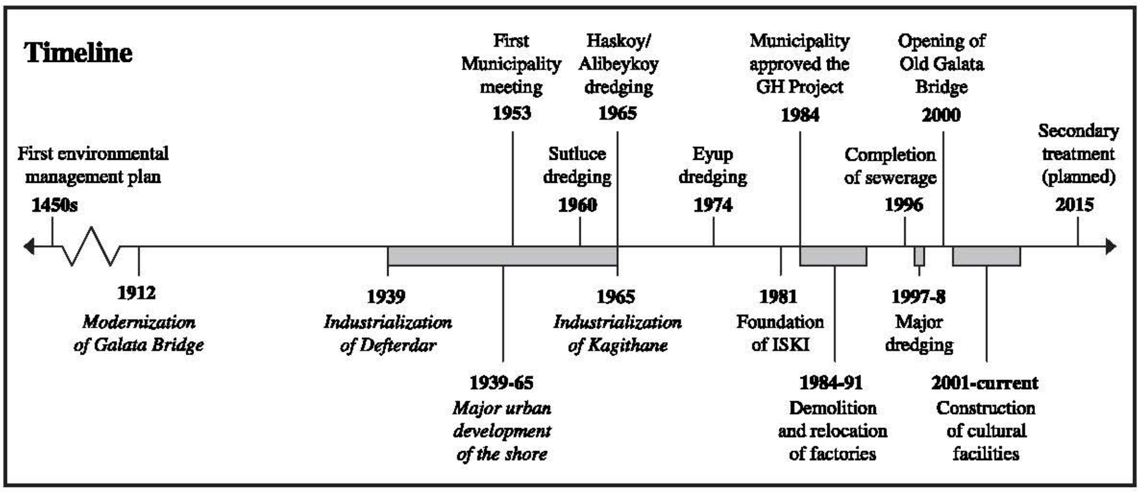


**Fig. 4 – Timeline representing the main causes of environmental degradation (*italics*), and actions (regular font) taken by the Municipality of Istanbul and ISKI (Istanbul Water and Sewerage Administration) to restore the Golden Horn Estuary.**

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approximately 15 km to the west of the Golden Horn on a 6 million $m^2$ area (more than three times larger than the previous area). By 2006 Ikitelli housed 38,000 businesses and employed 2 million workers in significantly safer, healthier, and more productive conditions (Akgun, 2006; Dalan, 2006). In place of much of the old industrial zone, a 1.2 million $m^2$ area was converted into parkland along the shoreline to regain some of its recreational value (Eroglu, 2001).

Upon completion, source destruction was the best solution to industrial and domestic pollution. However, these changes were extreme and unpleasant at the time since many residents and businesses were temporarily displaced. In the end, they were successful largely because strong leadership ensured that new infrastructure was rapidly constructed and the aesthetic result was favorable. The most substantial social problem resulted from suddenly unemployed workers electing to remain in the area. On the logistical side, while estuarine shores were converted from industrial to recreational zones, factories along the Alibeykoy and Kagithane Rivers were not completely removed (Table 1). About 80% of these industries have been destroyed or closed, but currently 17 are suspected to illegally discharge into the rivers, thus continuing to pollute the Golden Horn and undermining the progress made by these efforts (Basturk, 2006).

### 2.2. *Sewerage systems*

A number of sewerage plans were developed for the Golden Horn region of Istanbul within the past century, although it was not until the 1960s that interceptors were proposed along the estuary so that it and the Sea of Marmara would avoid receiving wastewater (Samsunlu, 1988). A large step towards implementing a successful plan was the 1981 creation of ISKI to administer both potable and wastewater. Subsequently, twin sewage transportation systems were constructed north and south of the Golden Horn in the mid 1980s. No formal cost-benefit analysis was conducted but secondary treatment, which did not exist in Istanbul at that point, was deemed too costly. With the city's prestige at stake, research was conducted to determine that primary treatment followed by effluent disposal into the Black Sea, via the deep Bosphorus current, would at least temporarily be the best solution that the city could afford (Basturk, 2006; Dalan, 2006).

By placing outfalls 70 m under the surface of the Bosphorus and 1200 m from the shore, the deep pycnocline contains buoyant effluent plumes. Bottom water, with 1.028 g/mL density, is separated by a 10 m thick boundary layer from 1.011 to 1.014 g/mL surface water. Therefore, sewage of 0.998 g/mL density must only be diluted to half concentration to remain trapped in the lower northward Bosphorus current (Gunnerson, 1974; Dalan, 1988). This procedure sends wastewater towards the depths of the Black Sea, which have been anaerobic for approximately 7000 years. Wastewater resides in this deep anoxic layer, which encompasses 88% of the Black Sea's volume, due to both extreme vertical stratification and organic matter mineralization at depth (Gunnerson, 1974; Ozsoy et al., 1988; Bach et al., 1995; Besiktepe et al., 1995; Hansen et al., 1995; Ozsoy et al., 1995). Large quantities of anaerobic bacteria digest organic material, and estimates predict that phosphorus will diffuse exceeding slowly and heavy metals in wastewater will precipitate, thus posing a negligible threat to recreation and fishing in the Black Sea (Gunnerson, 1974).

Employing a design of concrete pipe and tunnel collectors, primary treatment, and deep Bosphorus current outfalls, the Southern Golden Horn Sewerage Project was completed in 1988, but only operated at 10% capacity for seven years. The project was largely abandoned following a shift in the governing party of Istanbul in 1989. However, the next change of power in 1994 coincided with a major drought, which along with population growth that far exceeded planned water supply, forced the city to reexamine water issues (Patan, 2006; Samsunlu, 2006). Istanbul changed course by appointing Environmental Engineering professors as directors of ISKI and the Secretary General of the Municipality in that period, and by signing the Ramsar Convention for the protection of wetlands in 1994 (Burak, 2008). After modernizing the potable water infrastructure, construction of the northern sewerage component resumed and was finished in 1996, at which point sewage collection and transportation around the estuary was fully operational (Altinbilek, 2006; Patan, 2006; Samsunlu, 2006) and residents with access to treatment increased dramatically (Fig. 3).

Beginning the following year, no domestic wastewater has been discharged into the estuary outside of heavy rain events, as it is collected, transported, and treated at various locations along the Bosphorus and discharged into the deep Black Sea (Inanc et al., 1998). As of 2006, most of the treatment taking place in Istanbul is primary (generally only screening and grit removal), while 28% is secondary, 8% is tertiary, and future plans include increasing the capacity of tertiary treatment to more than 1 million $m^3$ per day (Altinbilek, 2006). With this technology only now on the horizon, the city's implementation of a long-term sewage collection and transportation infrastructure, along with a temporary disposal technique, was wise. Furthermore, this approach was notable in its reliance on academic research to develop the best affordable solution to the sewerage problem.

**Table 1 – Number of specific industries along the Golden Horn, Alibeykoy and Kagithane Rivers in the 1970s (Aksit, 1977), as well as the number remaining along each river in the 1990s, after they were removed from estuary shores (Kanat, 2004). Organic industries include food products and tanning, materials producers make wood, marble, paper, glass, and porcelain products.**

| Time period | 1970s | 1990s | |
|---|---|---|---|
| Area | Entire catchment | Alibeykoy | Kagithane |
| Metal | 200 | 13 | 8 |
| Materials | 52 | 22 | – |
| Chemical | 17 | – | – |
| Organic | 9 | 6 | 4 |
| Textile | 4 | 11 | 16 |
| Auto | – | 3 | – |
| Plastics | – | – | 1 |
| Other | 414 | 16 | 22 |
| Total | 696 | 71 | 51 |

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### 2.3. Anoxic sludge dredging

The suspension of industrial and urban waste inputs to the estuary acted as the first step towards ecological restoration and the return of life to the Golden Horn's waters. The next problem to address was the accumulation of sediment, debris, and wastes in the inner part of the estuary that reached as high as 40 cm above the water level by 1997 (Fig. 5a,b). Even without additional input, the high organic and inorganic pollutant load inhibited ecological function of the estuary, blocked ship travel, and emanated a powerful anoxic stench as the result of anaerobic decomposition (Aksit, 1977; Inanc et al., 1998; Kanat, 2004). The odor caused people living nearby to experience chronic headaches and many could not bear to be outside, especially during summer (Basturk, 2006; Dalan, 2006; Samsunlu, 2006). The situation seemed so hopeless that some researchers and administrators suggested that restoration was infeasible and a better solution might be to fill the inner estuary, leaving a narrow river channel (Yuksek et al., 2006; Basturk, 2006). However, public health concerns, shipping interests, and the Golden Horn's historical and cultural importance convinced the Municipality to launch an extensive improvement project between 1997 and 1998 to dispose of 5 million $m^3$ of anoxic sludge.

Again, the Municipality of Istanbul and ISKI thoroughly examined the situation and options to maximize benefits and minimize ecological, social, and financial impacts (Inanc et al., 1998; Kanat, 2004; Kinaci et al., 2004). Treatment of the estuarine sediment was not affordable. Therefore, the primary options for disposal were transportation via truck or pipeline to abandoned mines or landfills, or via barge to the deep Golden Horn, Marmara or Black Sea (the details of which are described by Inanc et al. (1998)). Not the least expensive, but the best alternative considering environmental impacts, as well as political and public acceptance, was the construction of a unique sludge landfill. Dredged sediment was transferred by an innovative pressure pipeline technique, thus avoiding the odor of dredging, into an abandoned rock quarry 4 km from the Golden Horn (Inanc et al., 1998; Eroglu, 2001; Kanat, 2004; Kinaci et al., 2004).

A novel procedure was developed to siphon sludge from an area of 900,000 $m^2$ at a depth of 0–6 m below sea level via two suction dredgers, six dredging ships from the US, Netherlands, and Turkey, and three large pump stations. Sludge was then diluted to 50% with seawater and pumped to a height of 56 m, flowing through high-density polyethylene pipeline at 4000 $m^3/h$, the equivalent of 400 truckload trips every hour (Inanc et al., 1998; Kanat, 2004). Diluted sediment was dewatered and stored in a former quarry near Kucukkoy Creek, retained by two 20–30 m high impermeable geomembrane-lined holding dams with biogas wells (Kinaci et al., 2004). After sedimentation, the supernatant was discharged into the

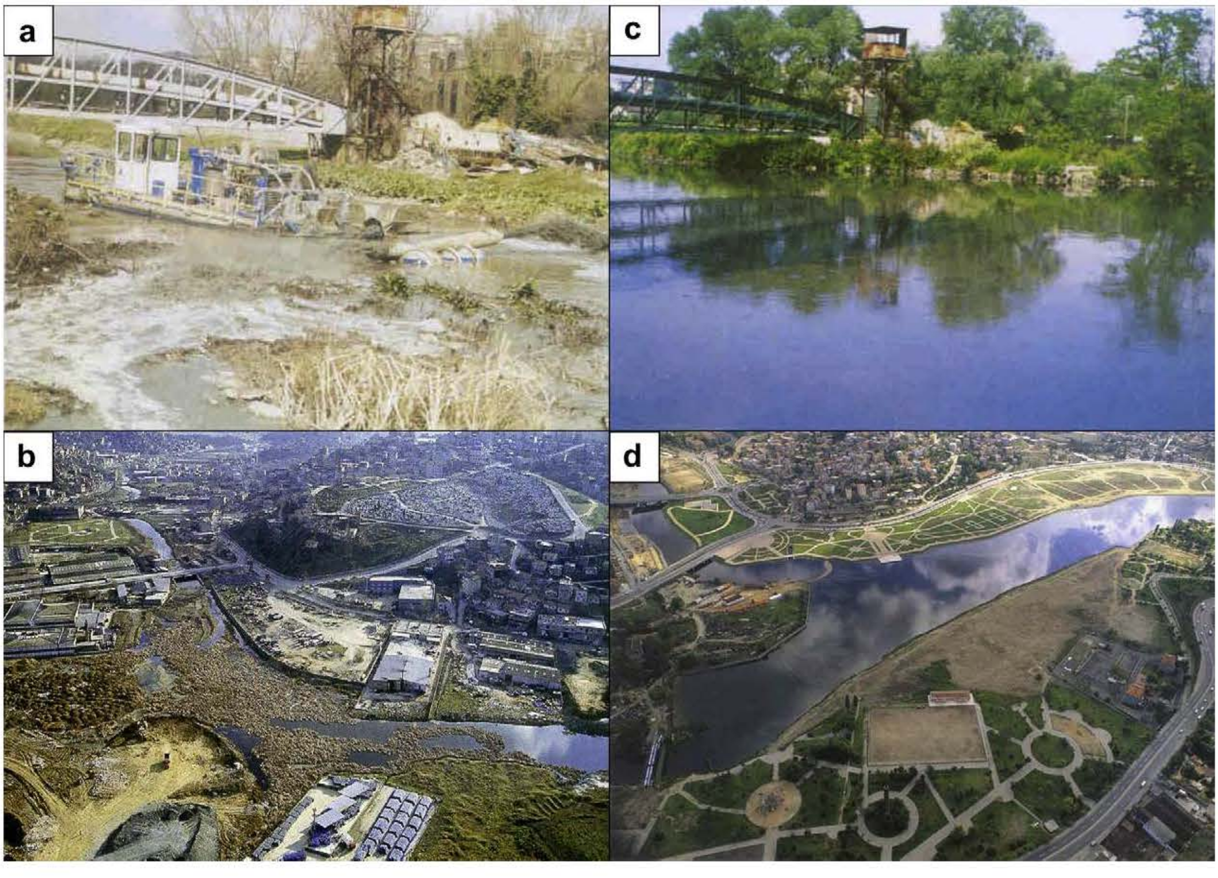


**Fig. 5 – The inner Golden Horn during or just before (photos a and b), and after (corresponding photos c and d) the large-scale dredging operation of 1997–1998 (© ISKI).**

**Fig. 6 – The Kucukkoy dams in 1998 during sludge filling (dams are circled), and post-dredging (inset) when sludge was covered with soil to create a recreational area (© ISKI).**

creek, which flows into the Golden Horn, and the sludge landfill covered with soil to create 200,000 $m^2$ of recreational facilities (Fig. 6).

However, in 2004 the field was uncovered to receive approximately 60,000 $m^3$ of additional sludge per year trucked from the Golden Horn, as well as large quantities from Kucukcekmece lake, another industrially polluted area. Current plans include dredging until anoxic sediment has been removed from the rivers and parts of the inner estuary, then recovering the site (Sahbatoglu, 2008). The Municipality also organizes frequent debris collection, both from the shoreline and via boat (Ciftci, 2006). Approximately 500 $m^3$ of garbage is retrieved monthly from boom nets 150 m across and 1 m deep, acting as solid waste barriers where the creeks join the Golden Horn (Demir, 2006). Direct benefits of the massive dredging operation and frequent debris collection include elimination of the foul odor of anoxic sediment, resumed navigability in the estuary, both for transit and tourism purposes, and the temporary recreational field. Together with the other restoration efforts, dredging played a large role in the return of ecological function and social use of the Golden Horn (Kanat, 2004; Okus, et al., 2008; Sahbatoglu, 2008).

### 2.4. *Opening the floating bridge*

In 2000 the city took its fourth major step to improving water quality in the Golden Horn when the middle section of the Old Galata Bridge was removed (Fig. 1). An architecturally advanced structure when it was built in 1912, the bridge floated at the mouth of the estuary on pontoons 4 m deep. It strongly symbolized the Ottoman Empire's earlier wealth and modernization to its citizens, and was extremely difficult to remove due to nostalgic sentiment. Unfortunately the Galata Bridge had heavily impeded circulation since its construction due to the highly stratified nature of the estuary, effectively retaining low density polluted runoff within the Golden Horn.


**Fig. 7 – Side view from the north (photo a) and aerial view (photo b; ©Google Earth) of the Valide Sultan/Old Galata Bridge after 2000 with the two center sections removed.**

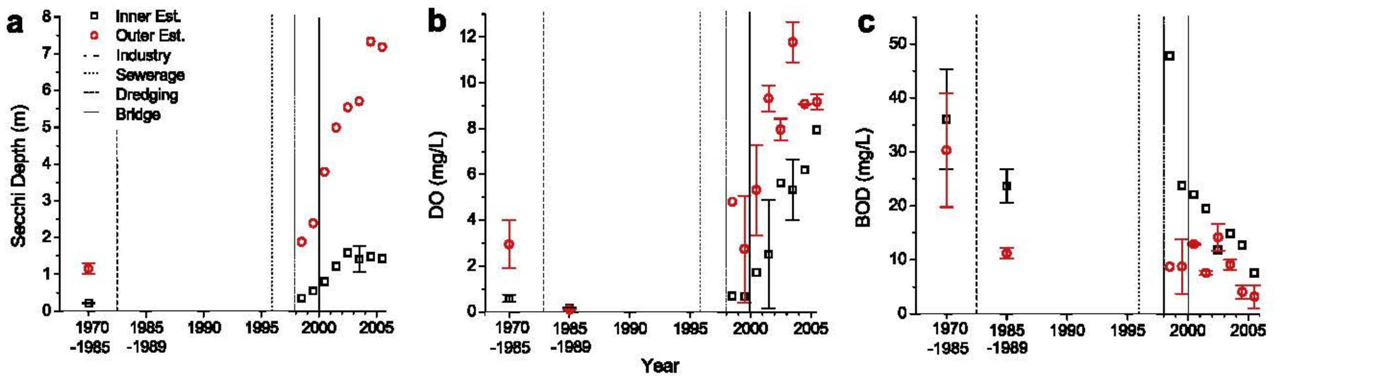


**Fig. 8 – (a) Water clarity (measured via secchi depth), (b) dissolved oxygen (DO) at the surface, and (c) biochemical oxygen demand (BOD) as a function of time measured in both the inner (north of the Valide Sultan Bridge) and outer (southeast of the bridge) Golden Horn (Aksit, 1977; Saydam et al., 1986; Gonullu et al., 2005; Sur, 2006). Vertical lines correspond to significant time periods. Dashed line: industrial relocation, dotted line: sewerage completion, dashed/dotted line: major sludge dredging operation, and solid line: partial removal of the floating bridge. Error bars correspond to standard error values, except where only averaged data are available.**

In 1994 removal was attempted, but the bridge was instead relocated towards the inner estuary and renamed Valide Sultan/Old Galata Bridge. Finally, in 2000 the two center sections of the bridge were disconnected and moved alongside the outer sections, leaving the middle of the channel continuously open to water circulation (Fig. 7). To further improve stagnant water flushing, large quantities of freshwater were released into the Golden Horn from behind a dam 5 km away on the Alibeykoy River. Also in 2000, a fountain was erected near the mouth of the estuary to improve water quality and oxygenation, as well as for its aesthetic value (Eroglu, 2001).

The actions described here encompass the major physical restoration efforts undertaken by the Municipality of Istanbul and ISKI from 1984 to 2000. While they were implemented sequentially due to low funds, remediation inexperience, and political fluctuation, staggering these components afforded the advantage of adaptive management. Thus, the response of estuarine conditions, measured by sporadic but informative research endeavors, informed later plans to successfully rehabilitate the Golden Horn.

### 2.5. *Cultural restoration*

After the physical transformation of the Golden Horn, a second major goal was to revive its culturally iconic status, both as a social service and to reinforce restoration efforts with public support. Rehabilitating the area shifted the economic focus from production towards service, as numerous restaurants and cultural attractions emerged after banishing industrial activities from the shores. For example, the fez factory ("Feshane") built in 1835 was spared destruction to be refurbished into a cultural center and exhibition hall that receives 2 million visitors per year (Bayhan, 2006). Similarly, the 1880 Cibali cigarette company was renovated into a private university. Other historical restorations include the promenade at the north end of the estuary, and conservation of the Eyup, Balat, Fener, Eminonu, and Galata districts (Yerliyurt and Hamamcioglu, 2005). A hill overlooking the estuary that was historically popular ("Pierre Loti Hill") has become fashionable for cafés and restaurants again following the vanished stench. The hill boasts a new hotel and restaurant complex, as well as a tram system for visitors. Where it would have been unbearable to spend more than half an hour in the 1980s due to odor, the area now receives approximately 1000 visitors per day (Bayhan, 2006; Dikkaya, 2006).

New construction was also commissioned on the estuary bank, including museums, one of the largest conference centers in Europe, and a theme park ("Miniaturk") that displays models of Turkish landmarks and hosts 400,000 visitors each year (Bayhan, 2006). In 2003, the Municipality of Istanbul launched a publicity campaign to entice its citizens to look at the Golden Horn in a new light. Popular singers staged

**Table 2 – Characteristics of Golden Horn sediment prior to industrial relocation in 1985 (Karpuzcu and San, 1975; Orhon et al., 1980; Karpuzcu et al., 1996; Gonullu et al., 2001), and 1995 values prior to dredging the top 5 m thick layer (Inanc et al., 1998; Kinaci et al., 2004). Values are averaged with standard errors in parentheses.**

| Parameter | Pre-1985 surface | 1995 Surface | 1995 5 m depth |
|---|---|---|---|
| Organic matter (%) | 22.4 (±2.3) | 13.5 (±0.9) | 5.7 (±1.0) |
| Sulfur (mg/L) | 2276 (±719) | 3172 (±523) | 1161 (±304) |
| Oil/grease (mg/L) | 3054[a] | 8587 (±945) | 3522 (±468) |
| Total nitrogen (mg/L) | 1868[b] | 3141 (±599) | 1370 (±365) |
| Total phosphorus (mg/L) | 0.2 (±0.04) | 506 (±73) | 367 (±48) |
| Total SOD (mg/L)[a] | 56,000 (±19,000) | 26,000 (±7000) | – |

a Total sediment oxygen demand (SOD) is the sum of biological and chemical oxygen demand values.
b Only a single value is available for this time period.

shows on the shore and the mayor made headline news when he swam in the estuary, an action considered unthinkable just a few years before (Basturk, 2006). A number of social events have been scheduled in or near the Golden Horn since restoration, including international air races, a number of fairs on the old Galata Bridge, watersports competitions, and the 2009 World Water Forum (Bayhan, 2006). Finally, the Golden Horn Culture Valley Project was organized to address social problems such as local unemployment following industrial demolition and the need for more recreation and entertainment facilities (Yerliyurt and Hamamcioglu, 2005).

## 3. Results of restoration

Actions taken by the city of Istanbul have measurably improved water quality in the entire Golden Horn, even the formerly condemned inner area. Various physicochemical and biological parameters have been measured sporadically since the 1970s, and a brief overview is provided here. The most abundant data sources were Middle East Technical University's set of 1985–1987 measurements, and monitoring started in 1998 by Istanbul University. Other records compiled from a variety of sources are included where relevant, although a data gap over most of the 1990s prevents thorough comparison of individual restoration technique effectiveness.

### 3.1. *Water quality*

Opening the floating bridge in 2000 was followed by a substantial increase in surface water circulation, and the return to a two layer water column, as in the neighboring Bosphorus (Sur et al., 2002). Furthermore, renewed mixing narrowed the average salinity gradient between the outer and inner estuary to 18.9 vs. 17.2 psu, respectively; half the difference than just before the bridge was opened (Dogan et al., 2001). Fig. 8a shows water clarity increasing dramatically in 2000 and the following years, and Fig. 8b illustrates the positive change in dissolved oxygen experienced at the surface of the Golden Horn. Other notable improvements include declining nutrient concentrations, such as nitrite and inorganic phosphate, and the disappearance of hydrogen sulfide between late 1998 to 2000, where it was formerly prevalent year-round (Yuksek et al., 2005).

Finally, pre-1970 biochemical oxygen demand (BOD) values were measured below 20 mg/L, but ranged from 20 to 70 mg/L, characteristic of dilute untreated wastewater, between 1970 and the beginning of restoration (Inanc et al., 1998). Inner estuary BOD has gradually decreased towards outer estuary BOD values since restoration, and readings in both areas have remained below 20 mg/L since 2001 (Fig. 8c). The latest measurements approximate a moderately polluted river, and would need to fall below 1.5 mg/L to be classified as "swimmable" (Mitchell and Carson, 1981; Luken et al., 1992). Overall, compiled monitoring data show a lack of strong improvement in water quality until the completion of all physical restoration components. An important lesson to derive from this trend is that complicated environmental problems benefit from a variety of mitigation efforts that, when staggered, afford the ability to adaptively manage according to the response.

### 3.2. *Sediment quality*

Sediment in the Golden Horn has been associated with a number of problems, such as contaminant adsorption, obstruction of shipping and sea transportation, foul odors causing great public disturbance, and geotechnical structural issues when used to fill the shoreline (Aksit, 1977; Aydin, 1994; Inanc et al., 1998). Cessation of industrial activity allowed the organic content of sediment to drop significantly (analysis of variance: $F_{1,24} = 11.5$, $p = 0.002$), and the sediment oxygen demand (SOD) to drop marginally between 1977 and 1995 ($F_{1,11} = 3.0$, $p = 0.1$).

However, by the mid 1990s conditions had become worse in a number of metrics (Table 2), and the upper 5 m of sediment was virtually liquid with an average density of 1.1 g/cm$^3$ (Aydin, 1994). Sediment depth gradients in sulfur, oil/grease, and nutrient content largely prompted the decision to dredge the inner estuary. The choice of dredging to 5 m was due to the statistical similarity of 5.7% organic matter content at that depth and 5.0% at 10 m ($F_{1,22} = 0.4$, $p = 0.5$). The choice of receiving location for the dredged sediment was also prompted in part by physicochemical parameters. Even though SOD measurements in the Golden Horn were at their lowest so far by 1995, their extreme values contributed to the decision to store dredged sludge on land, rather than disposal at sea (Inanc et al., 1998; Kinaci et al., 2004).

Heavy metal content of the Golden Horn sediment was also factored into its disposal strategy. Sediment within the inner estuary was deemed appropriate for disposal in an abandoned quarry since concentrations of only one type of metal, lead, exceeded Turkish landfill standards in 1993 (Table 3). Furthermore, sediment-metal binding capacity was found to be unsaturated, and leaching determined negligible (Aydin, 1994; Inanc et al., 1998), especially with the presence of a geomembrane lining. However, to relate heavy metal content to likelihood of negative impacts on biota, universal

**Table 3 – Concentrations of heavy metals in Golden Horn sediment, and their ratios to probable effect levels (PEL-Q). Data are presented from time periods during (Tuncer et al., 2001) and after industrial relocation (Aydin, 1994), and after all major restoration efforts were completed (Gonullu et al., 2001). Turkish standards for landfilling (TSL; Inanc et al., 1998) and PEL values (MacDonald et al., 2000) are included.**

| Category | Year | Cd | Zn | Cr | Ni | Cu | Pb |
|---|---|---|---|---|---|---|---|
| Conc. (mg/L) | 1986 | 6 | 890 | 390 | 90 | 194 | 510 |
| Conc. (mg/L) | 1993 | 11 | 558 | 242 | 115 | 530 | 326 |
| Conc. (mg/L) | 2001 | 66.5 | 726.7 | 300 | 128.3 | 416.7 | 203.3 |
| PEL-Q | 1986 | 1.7 | 2.8 | 4.3 | 2.5 | 1 | 5.6 |
| PEL-Q | 1993 | 3.1 | 1.8 | 2.7 | 3.2 | 2.7 | 3.6 |
| PEL-Q | 2001 | 18.8 | 2.3 | 3.3 | 3.6 | 2.1 | 2.2 |
| TSL (mg/L) | – | 20 | 3000 | 1200 | 200 | 1200 | 120 |
| PEL (mg/L) | – | 3.5 | 315 | 90 | 36 | 197 | 91.3 |

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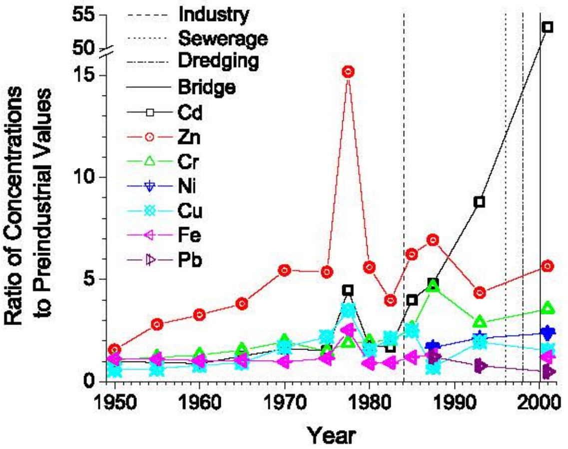


**Fig. 9 – Concentration of heavy metals in Golden Horn sediment relative to levels in 1912, before industrial and significant urban influence (note the axis break for 2001 [Cd]). Values prior to 1990 were obtained from sediment cores in the outer estuary near the Unkapani Bridge (Tuncer et al., 2001), while later measurements are averaged across the estuary (Aydin, 1994; Gonullu et al., 2001). Vertical lines correspond to significant time periods; dashed line: industrial relocation, dotted line: sewerage completion, dashed/dotted line: major sludge dredging operation, and solid line: partial removal of the floating bridge.**

sediment quality guidelines are often used. Metal concentrations in Golden Horn sediment have been standardized via division by probable effect levels (PELs), concentrations above which biotic harm is likely. Table 3 shows that the PEL quotient (PEL-Q) of every contaminant measured was greater than or equal to 1 in 1986 and 1993, before dredging took place. Furthermore, the mean 1993 PEL quotient is 2.8, which exceeds the probable threshold for high toxicity (Long and MacDonald, 1998; MacDonald et al., 2000). Therefore, since treatment was not an option, landfill disposal was indeed preferable to sea dumping, provided the landfill lining retains toxins from entering groundwater.

Fig. 9 illustrates heavy metal concentrations through the latter twentieth century as ratios of the deepest core measurements, attributed to 1912. Lead was the only anthropogenically enhanced trace metal at the beginning of the twentieth century, probably because the Golden Horn was the largest local port at the time (Tuncer et al., 2001). The measured metals tend to remain within five times of pre-industrial levels, except for zinc prior to industrial relocation and cadmium during and after restoration (Aydin, 1994; Gonullu et al., 2001; Tuncer et al., 2001). The latter occurrence is especially noteworthy given its absence on the list of common industrially discharged heavy metals in the 1970s (Fig. 2). While heavy metal concentrations have fluctuated widely in Golden Horn sediment, they do not appear to have been directly correlated with any of the restoration efforts. Both the lack of decline in sediment-metal content after dredging and the recent spike in cadmium concentration are currently unexplained.

### 3.3. *Biological response*

Prior to the completion of restoration efforts, the Golden Horn had remarkably high concentrations of bacteria (Fig. 10a) and toxic dinoflagellates (Tas and Okus, 2003), but supported an extremely low diversity of aquatic life. This was demonstrated by the virtual absence of phytoplankton in the surface layer (Uysal, 1987), and depressed macroalgal representation. Fritsch (1899) described the macroalgae in the Golden Horn more than 100 years ago as making up a eutrophic estuary. However, in the late 1980s and mid 1990s only 3–5 species were found, all in the shallow outer estuary and all from

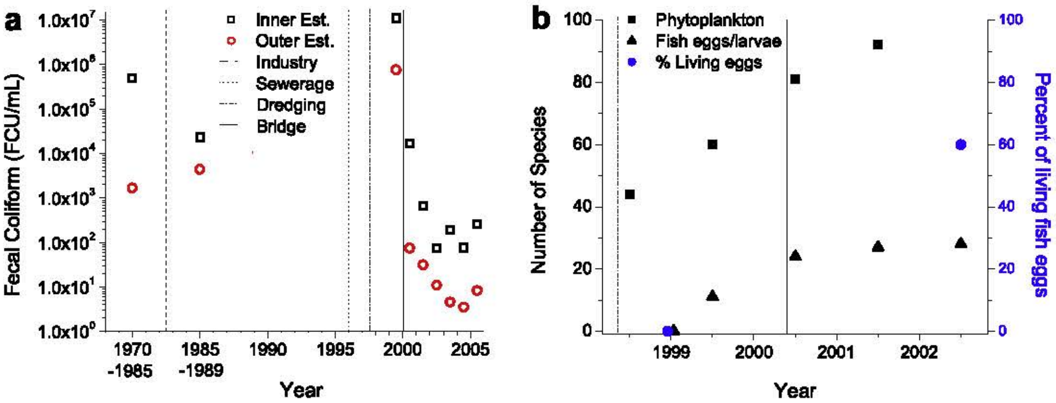


**Fig. 10 – (a) Surface fecal coliform counts (note the log-linear scale) as a function of time measured in both the inner (north of the Valide Sultan Bridge) and outer (southeast of the bridge) Golden Horn (DAMOC, 1971; Saydam et al., 1986; Sur, 2006). (b) Number of species of live phytoplankton (black squares; Tas, 2003) and ichthyoplankton (black triangles) in the estuary, as well as the percentage of fish eggs recovered alive (blue dots; Yuksek et al., 2005). Error bars correspond to standard error values, except where only averaged data are available. Vertical lines correspond to significant time periods; dashed line: industrial relocation, dotted line: sewerage completion, dashed/dotted line: major sludge dredging operation, and solid line: partial removal of the floating bridge. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).**

a single taxonomic class, Chlorophyceae (Aydin and Yuksek, 1990; Okus et al., 1996).

Anaerobic organisms comprised almost all life in the hydrogen sulfide rich inner estuary (Dogan et al., 2001). Furthermore, only the polychaetes *Capitella capitata* and *Scolelepis fuliginosa*, both well-known indicators of organic contamination, dominated benthic abundance and biomass measurements in the 1980s, with a few more species seen just at the estuary mouth (Saydam et al., 1986; Unsal, 1988). In the mid 1990s, fish limited mainly to mackerel, sprat, and mullet inhabited the same area (Okus et al., 1996), although the entire estuary and its tributaries were rich fishing grounds historically (Guvengiris, 1977).

Ecological response quickly followed physicochemical changes in the Golden Horn. After the floating bridge was opened in May 2000, bacterial counts were only half of their April values, and halved again in June. Since 2002 measurements in the outer estuary have been low enough to qualify as "safe for fishing" (Vaughan, 1981). Predictably, correlations between fecal coliform concentrations and salinity, pH, and dissolved oxygen measured at almost all stations during 1998–2002 were negative and strongly significant.

While unrelated to bacteria between January 1998 and April 2000, rainfall represented 36–52% of the factors controlling coliform concentration in the outer estuary from May 2000 to December 2002, after part of the bridge had been removed. Regression of rainfall and bacteria in the inner estuary remained insignificant, however, where fecal coliform counts have remained approximately ten times greater than in the outer estuary (Fig. 10a). Fecal coliform was also unrelated to inorganic phosphate, a principal component of detergent, prior to bridge opening, but significantly positively correlated afterwards (Aslan-Yilmaz et al., 2004). This later association of bacteria with rain and phosphate points to hazardous conditions only during wet weather when wastewater may overflow collectors (Kanat, 2004; Sahbatoglu, 2008).

Additionally, sludge dredging and bridge removal coincided with the decline of toxic cyanobacteria and increase in eukaryotic phytoplankton (Tas et al., 2006; Fig. 10b). In the inner estuary, phytoplankton abundance jumped from consistent zero readings prior to May 2000 to as many as 100 million individuals/L from 11 species in measurements through 2001 (Yuksek et al., 2006). Macroalgal surveys after bridge removal identified 13 species from four classes, growing to at least 30 m depths and occasionally even in the inner estuary, signaling a move from anoxic to eutrophic conditions (Erdal, 2001; Yuksek et al., 2005).

Crustacean, echinoderm, and tunicate larvae were found in the Golden Horn in 1999, and adult populations of these invertebrate taxa observed during scuba surveys in 2002, even in inner waters. Substantial diversity and densities of bivalves, polychaetes, and gastropods were also noted after bridge removal (Erdal 2001; Yuksek et al., 2005, 2006). Ichthyoplankton (pelagic fish eggs and larvae) found in the beginning of 1999 were all dead upon capture, but later that year representatives from 11 out of 16 species caught were alive. By the end of 2002, 60% of individuals sampled were living and the number of species found had leveled off at 28 ichthyoplankters and 35 adult fish (Fig. 10b). Other signs of estuarine recovery include the wide distribution of filter feeding organisms and demersal fish, as well as the presence of top predators and the extremely pollution-sensitive seahorse (Yuksek et al., 2005, 2006). These gains were possible once physicochemical conditions improved and the bridge was removed due to the Golden Horn's link to the Bosphorus as a source of biota.

### 3.4. *Social response*

At the onset of industrial demolition, public opinion of the city's actions was low, unemployment was high, and protests were rampant. However, the following year approval reached 70%, and eventually rose to 96% as parkland replaced factories, temporary housing was supplied, new industries were constructed, and the restoration process was underway (Dalan, 2006). By the end of the 1990s, residents increasingly recreated, fished, and picnicked along the shore and began to change the habit of leaving trash behind since the estuary had become valuable again (Ozturk et al., 1998; Coleman and Kanat, unpublished data). They even resumed recreational boating (Fig. 7), as well as passenger and tourist ferry service from the estuary mouth towards Eyup.

Rapid ecological changes in the Golden Horn attracted public audience and received substantial coverage by the news media, especially due to pre-restoration concerns and expert opinions that rehabilitation was an extremely technically and economically challenging task. For example, the highly publicized swim by the mayor and important figures of society in 2003 encouraged people to view the Golden Horn as a beneficial resource again rather than a cesspool. These measures were critical to restoration success since public support and cooperation are vital to maintaining a healthy ecosystem. Further social benefits that will be discussed in a following paper include increased resident, business, recreation, and tourism valuation of the estuary and shoreline (Coleman and Kanat, unpublished data).

## 4. Conclusion

The case study of the Golden Horn Estuary is an inspiring example of a developing country's success in restoring an important resource without incurring prohibitive expense. A cost-benefit analysis of restoration activities will be published elsewhere, but preliminary analysis indicates that monetized benefit meets the cost only a few years after efforts have been completed (Coleman and Kanat, unpublished data). An important factor in this achievement is strong governance and institutions, including the 1984 mayor and city council who rapidly designed, approved, and accomplished industrial demolition. Also, the well-funded Istanbul Water and Sewerage Administration (ISKI) effectively organized and implemented novel sewerage and dredging plans. These leaders committed to restoration over a long time frame, and maintained this commitment except during a political shift from 1989 to 1994. Engineers and professors serving as the directors of these institutions added to their effectiveness. Furthermore, the Municipality and ISKI funded researchers to examine creative and effective methodologies, as well as to conduct monitoring studies that examined physicochemical and ecological changes over time.

Multiple categories of data gathered from these efforts can be combined into weighted water quality index values (using fecal coliform concentration, DO, BOD, turbidity, and pH from Orhon (1975), Aksit (1977), Saydam (1986), Basturk (1988), Karpuzcu (1996), Kanat (2004), and Sur (2006), categorically describing the overall condition of estuarine waters through time (McClelland, 1974; Vaughan, 1981). The inner estuary remained in the lowest category until 2002, after which it was deemed "boatable" by this metric. Unfortunately, as of 2005 this section of the Golden Horn can barely be classified as suitable for the next determination, "rough fishing." However, the outer estuary became "boatable" in 1998, safe for "rough fishing" in 2002, and for "game fishing" in 2003. As of 2005, it is almost "swimmable" by the index applied here, indicating drastic improvement of water quality in the Golden Horn.

### 4.1. *Future considerations*

Although water and sediment quality in the estuary have dramatically improved and life has returned since restoration, pre-industrial levels have not been restored. One cause for this is urban runoff via rain sewers that are non-operational during wet weather, which can introduce a variety of contaminants including viral, bacterial, and protozoan pathogens, as well as toxins such as organochlorines, organotins, and heavy metals. Also, the shores of both tributaries feeding the Golden Horn still support industrial pursuits (Table 1), and therefore receive wastewater and pollution that flows downstream. These inputs are relatively concentrated considering that the flow rate has been reduced from 300,000 $m^3$/day to 300,000 $m^3$/year (Kor, 1963; Ozturk et al., 1998). Dams on the Alibeykoy River also contribute to the current paucity of fish, which were formerly abundant in the area (Yuksek et al., 2005, 2006). Fish that persist are occasionally subject to large-scale kills in the area where rivers meet the estuary due to low oxygen levels. Many studies have examined pollution issues in the Golden Horn, but problems in the Alibeykoy and Kagithane Rivers have been glaringly ignored, considering the influence that they have over the estuary. To further improve conditions, industries along the rivers must be relocated or regulated and the remainder of the floating bridge removed to augment circulation and aeration.

At the mouth of the Golden Horn, the Bosphorus Strait, Marmara Sea, and Black Sea that supply the estuary also remain polluted and have lost much of their pre-industrial biodiversity, hampering species' re-establishment. Sea traffic of 65,000 vessels per year, 10% of which are petroleum tankers, through the Bosphorus is part of the problem (Akten, 2003, 2004). Shipping effluent and a major spill, combined with discharge from the rivers, contributed to oil levels measured as high as 11 mg/L in the inner Golden Horn in 2002 (Guven et al., 2005). Hundreds of petroleum hydrocarbon compounds have been found in the estuary, including linear and branched varieties, alkenes, cycloalkanes, benzene derivatives, phenols, three-ring compounds, and phthalate esters. Conditions may be improving, however, as the maximum concentration obtained in 2005 was approximately 100 times lower than that of 2002 (Cumali and Guven, 2008). For more complete estuarine recovery, outside threats such as pollution from tributaries, the Bosphorus, and potential contaminant leaching from the sludge dam must be addressed.

Although the Golden Horn is a prime example of restoration success in a developing country, conditions are not being improved everywhere in the region. For example, the city and river of Corlu, 100 km to the west, are currently experiencing similar problems as industries have recently been established with no waste management plan, migrants are settling in large numbers, and pollution controls are lacking. If such places are to be restored rather than become an ecological disaster as the Golden Horn once was, city planners and managers should study the case presented here to create an economically viable, technically feasible, environmentally beneficial, and socially acceptable methodology. It is our hope that the results presented here will inform this and future generations of managers to avoid mistakes of the past and learn from these largely successful efforts.

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